Independent Evaluation of Recent Flooding in New Hampshire

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FEMA

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AAR	After Action Report
BMP	Best Management Practice
cfs	Cubic Feet Per Second
CN	Curve Number
CRS	Community Rating System
CTP	Cooperating Technical Partner
DAPS	Data Collection System Automatic Processing System
DECODES	Device Conversion and Delivery System
DES	Department of Environmental Services
DFIRM	Digital Flood Insurance Rate Map
EAP	Emergency Action Plan
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
ESF	Emergency Support Function
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HMTAP	Hazard Mitigation Technical Assistance Program
HSEM	Homeland Security and Emergency Management
HWM	High Water Mark
IRP	Independent Review Panel
LID	Low Impact Development
LiDAR	Light Detection and Ranging
NAVD	North American Vertical Datum of 1988
NERFC	North East River Forecast Center
NESDIS	National Environmental Satellite, Data, and Information Service
NFIP	National Flood Insurance Program
NGVD	National Geodetic Vertical Datum of 1929
NHDES	New Hampshire Department of Environmental Service
NHOEM	New Hampshire’s Homeland Security and Emergency Management
NHOEP	New Hampshire Office of Energy and Planning

NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
SITREP	Situation Report
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WFO	Weather Forecast Office

INTRODUCTION AND PURPOSE

In May 2006, and then just 11 months later in April 2007, south central and southeastern New Hampshire were devastated by flooding, leading to presidentially declared disasters after each flooding event. The flooding displaced citizens, destroyed or damaged housing and infrastructure, disrupted transportation and emergency services, and caused severe economic impacts to the region. The Federal Emergency Management Agency (FEMA) requested that URS and its subcontractors, Riverside Technology, Inc. and Watershed Concepts, a division of HSMM-AECOM, under Hazard Mitigation Technical Assistance Program (HMTAP) contract HSFEHQ-06-D-0162, prepare a report to establish how such severe flooding happened, whether the flooding was aggravated by manmade causes, and what can be done in the future to mitigate flooding impacts. The study focuses on the basins and dams within the Salmon Falls, Suncook, Piscataquog, and Souhegan Rivers, but its key findings and recommendations are generally applicable to river basins in south central and southeastern New Hampshire.

The study recommendations are intended to help reduce local flooding. More importantly, the recommendations will help New Hampshire and its citizens plan for future flood events and reduce future flood losses through sound floodplain management and effective emergency response during flood events.

KEY FINDINGS

The May 2006 and April 2007 Floods in Perspective

Both the May 2006 and April 2007 floods were significant natural events that caused high rates of runoff and elevated flood levels in basins throughout south central and southeastern New Hampshire. The reasons for the resulting flooding were different for the two events. The May 2006 event was extraordinary because of the sheer volume of rainfall, which ranged from 6 inches in inland portions of the study area to over 14 inches along the seacoast over a 2-day period. This region normally receives only about 3.5 inches of rainfall in an average spring month. The April 2007 event was extraordinary because of the combination of heavy rainfall, which ranged from 4 to 8 inches in 2 days across the study area, and rapidly melting snow. The heaviest rainfall was over coastal areas during both events.

The runoff produced during these events overwhelmed the region's rivers and streams, and inundated the region's floodplains. At locations with long-term records (starting before 1936), the May 2006 and April 2007 floods set records in the small basins of coastal New Hampshire, the portion of the study area where rainfall was heaviest. The highest flow rate ever recorded on the Lamprey River in Newmarket occurred during the May 2006 flood, and the highest flow rate ever recorded on the Oyster River in Durham occurred during the April 2007 flood. At more inland locations, and in larger basins, the flooding was dramatic but not as large as other historic flood events. The largest floods at these locations generally occurred in 1936 or 1938.

Though relatively rare, floods of this magnitude are regularly occurring natural phenomena that form the floodplains that are one of the characteristics of the region's landscape. Significant flooding has occurred, to a greater or lesser extent, during past flood events in 1936, 1938, 1960, 1987, 1991, and 1998. Severe floods have affected neighboring areas as well, as evidenced by the extensive flooding in southwestern New Hampshire in October 2005 and even more recently in northern Maine in April 2008. There is mounting evidence that the frequency of major flood events is increasing in the United States as a whole. On June 18, 2008, the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center published its report, "Weather and Climate Extremes in a Changing Climate," and concluded: "We are now witnessing and will increasingly experience more extreme weather and climate events" (NOAA 2008).

Dam Operations

There are over 3,000 dams in New Hampshire. This study examined the effect of dam operations during the flood events—whether they reduced or exacerbated flooding impacts. In general, the May 2006 and April 2007 events overwhelmed river channels, lessening the effect of operations performed at dams in the study area. All but the largest lakes in the upper reaches of the rivers filled rapidly and passed all inflows downstream. Flooding occurred upstream and downstream of the dams, similar to the flooding experienced in other locations throughout the study area. Out of the 24 dams in the four basins examined (Salmon Falls, Suncook, Piscataquog, and Souhegan) as part of this study, the operations performed at only one were determined to have aggravated the flooding. During the May 2006 event, operations at the Milton Three Ponds Dam were performed to protect downstream dams in danger of failing. This action aggravated flooding on the lake shore upstream of the dam.

Mitigating Future Flooding Impacts

The study determined that several actions could be taken to mitigate future flood damage. These actions range from improving floodplain management and flood forecasting to using a watershed-based approach to flood operations.

Basis for Recommendations

The recommendations outlined in this study are based on four primary observations:

1. Flood events as large as and larger than the May 2006 and April 2007 floods are likely to happen in the future. Communities and the State should plan accordingly.
2. Many of the floodplains adjacent to the rivers and streams in the study area are still relatively undeveloped. Building in these floodplains will subject the structures to flood risk and will increase flood elevations and flow rates elsewhere, and should be discouraged. Sound floodplain management, based on accurate information about the floodplains, is critical to minimizing the effects of future flood events.
3. Flood forecasting is not yet sufficiently accurate to replace the judgment of experienced professionals, especially on the smaller basins characteristic of the study area. It should be used, however, as a tool to help decisionmakers take appropriate actions during flood events.
4. Storing water in the region's lakes, ponds, and reservoirs, and coordinated dam operations, help reduce flooding. Storage opportunities in south central and southeastern New Hampshire are highly limited, however, and the effect of improved dam operations is relatively minor. Implementing flood management recommendations can reduce local

flooding, but cannot prevent widespread flooding from events like the May 2006 and April 2007 events.

Critical Recommendations

The three most critical recommendations that resulted from this study are to improve floodplain management, to improve flood forecasting, and to take a watershed approach to flood operations, as described below.

Improve Floodplain Management

Improving floodplain management in south central and southeastern New Hampshire involves two key components. The information used to make floodplain management decisions needs to be accurate and effectively communicated to both decisionmakers and the public. The resulting floodplain management decisions should be designed to lessen the impacts of flooding on existing residents and to prevent future flooding.

The basic sources of information used to make floodplain management decisions are the FEMA Flood Insurance Rate Maps (FIRMs). These maps have recently been prepared in digital (electronic) form. However, the information shown on the maps is old, typically dating back to the 1980s, and in many locations is not accurate. Without accurate mapping, establishing the extent of the floodplain, and whether property is subject to flooding, is difficult. New topographic information should be collected and new analyses should be performed in the areas where the mapping is not sufficiently accurate. Updated and more accurate FIRMs would provide the State and its communities with better data to make sound floodplain management decisions.

FEMA uses FIRMs for the purpose of administering its National Flood Insurance Program (NFIP). Although most New Hampshire communities conform to the minimum requirements of the NFIP, the minimum requirements are not sufficient to protect the floodplain from development. To retain the function and value of the floodplain, New Hampshire communities should adopt measures more stringent than the minimum requirements of the NFIP. These measures will prevent buildings from being located in areas with a high risk of flooding and will help keep flow rates and flood elevations from increasing over time.

Improve Flood Forecasting

Two entities can currently provide independent flood forecasts in southern New Hampshire: The National Weather Service (NWS) through the North East River Forecast Center (NERFC) and the New Hampshire Department of Environmental Service (NHDES) Dam Bureau through its data management and streamflow forecasting system.

This study identified deficiencies in the current flood forecasting systems. Some of the existing forecasting products created at the NWS were not readily available to the decisionmakers at the NHDES Dam Bureau and Office of Emergency Management. Forecasting products are not available for all points of interest to the Dam Bureau (in particular the Cocheco, Exeter, Isinglass, Lamprey, and Soucook Rivers). In addition, longer-range forecasts (5 to 6 days) that can enable Dam Bureau decisionmakers to enact preventive dam operations are currently not available at all. The NHDES should engage the NWS to gain timely access to forecasting products at all important locations in southern New Hampshire.

While extensive use is made of the data management capability of the Dam Bureau's system, the forecasting component of the system is not utilized. This component of the system should be revitalized to provide forecasts for locations that the NWS does not serve. In addition, the Dam Bureau should stay informed of new research being conducted at the national level regarding improved flood forecasting.

Take a Watershed Approach to Flood Operations

The NHDES Dam Bureau has procedures in place to collect information on dams. The Dam Bureau should build on that information to develop a plan, including standardized operating rules for each dam capable of flood control operations for each watershed in the study area. The operating rules should be appropriate for each dam, but kept as simple as possible. For each dam, the plan should include a maintenance schedule and rules for operations during flooding events. For those dams where lake elevations are lowered in the winter, the plan should include rules for refilling based on water content of the snowpack in the area draining into the lake, balanced against the need to achieve the summertime target elevation. Each private dam operator should submit information to the NHDES Dam Bureau. The Dam Bureau should ensure that operations at each dam will collectively result in maximum flood control benefits to the watershed as a whole. Each watershed plan should be publically available on the Internet.

This watershed approach will allow for coordinated action by dam operators designed to maximize flood control benefits. The maintenance schedules will help ensure that flood control structures are operable when needed. The rules for operations during flood events will help minimize local and preventable flood damages. The rules for refilling will help ensure that the maximum amount of flood storage is available from the fall through the spring runoff season, while reducing the risk of not refilling the lakes for summer use. Keeping the plans as simple as possible will facilitate their use during flood events. Making the watershed plans publically available will build confidence that everything possible is being done to minimize flooding and will help ensure the plans are implemented.

Other Recommendations

The following summarizes other important recommendations included in this report. Sections 6, 7, and 8 of this report list many additional suggestions.

1. *Apply Vermont's "Fluvial Erosion Hazard Methodology" in New Hampshire.* Vermont has found that much of its flood-related damage is not from inundation, but a result of erosion. The State has implemented a comprehensive "Fluvial Erosion Hazard Methodology" to identify and map these hazards along Vermont streams (Vermont Agency of Natural Resources 2008). Given the similarity between the Vermont landscape and many areas of New Hampshire, a similar methodology should be applied to New Hampshire rivers and streams to identify future erosion hazards.

   In addition, during the May 2006 flood, the Suncook River left its channel and changed its course, returning back to the channel over 0.5 mile downstream (a process termed "avulsion"). The change in course caused, and continues to cause, significant damage. It is unlikely the stream will ever be returned to its previous course. Application of Vermont's "Fluvial Erosion Hazard Methodology" should be used to identify potential future avulsion sites so that appropriate measures can be taken to prevent them.

2. *Determine the benefits and costs of certain potential structural improvements*. Improvements at Kelley's Falls Dam (by increasing its capacity with new gates) and Milton Three Ponds Dam (by installing a second automatic gate) may reduce flood damage. The cost of these improvements should be compared to their potential benefits to assess whether they should be implemented.

3. *Ensure flashboard operations are safe.* Many dams are equipped with flashboards to raise their operating water level. The flashboards can be quickly removed in the event of a flood either by tripping a supporting device or by designing the flashboard supports to fail under specified conditions. When installed, they raise upstream water elevations. When removed, they cause a spike in downstream flows. Dam operators should be required to demonstrate that flashboards can be used safely without contributing to upstream or downstream flooding prior to their use.

SECTION ONE FLOODING IN SOUTH CENTRAL AND SOUTHEASTERN NEW HAMPSHIRE: ITS CAUSE AND RECOMMENDATIONS FOR FUTURE MITIGATION

1.1 INTRODUCTION – THE PURPOSE AND SCOPE OF THIS STUDY

In May 2006, and then again in April 2007, south central and southeastern New Hampshire were devastated by flooding, leading to presidentially declared disasters. The flooding displaced citizens, destroyed or damaged housing and infrastructure, disrupted transportation and emergency services, and caused severe economic impacts to the region. The Federal Emergency Management Agency (FEMA) alone spent $75.6 million in the form of flood insurance claims, Individual Assistance, and Public Assistance in New Hampshire as a result of this flooding.

This study is an independent evaluation seeking answers to these questions:

- What were the major factors causing the flooding?
- Was the flooding aggravated by manmade causes?
- What can be done in the future to reduce flooding impacts?

This study was funded by FEMA in response to concerns voiced to local and State officials, including New Hampshire Governor John Lynch. The scope of work was developed by the New Hampshire Department of Environmental Services (NHDES) and modified by FEMA. The scope may be found on the NHDES Web site at http://www.des.state.nh.us/Dam/floods.htm (FEMA 2007).

URS Corporation conducted this study for FEMA. URS was assisted by two subcontractors: Riverside Technology, inc. (RTi) and HSMM/Watershed Concepts. To ensure the study was performed to the highest standards, URS assembled an Independent Review Panel (IRP), consisting of nationally recognized experts, to review all work performed in this study. The members of the IRP were Brig. General Gerry Galloway (ret), PhD, P.E., Wilbert Thomas, P.H., and Thomas Sullivan, P.E. The conclusions of the report, however, are those of URS Corporation and its subcontractors.

The study area is shown in orange in Figure 1-1, and covers the Piscataquog, Souhegan, Soucook, Suncook, Contoocook, Cocheco, Lamprey, Oyster, Salmon Falls, and Isinglass River basins. The recommendations include remedial, protective, and management measures that will help mitigate the effects of future flooding within the study area.

1.2 ORGANIZATION OF THIS REPORT

This report consists of ten sections. Sections 2 through 10 provide the following information on study investigations:

Section 2 – The May 2006 and April 2007 Events in Perspective. This section explains the similarities and differences between these events, including the hydrologic conditions leading up to the events and the precipitation characteristics during the events. To provide a historical perspective, these events are compared with past flood events in this region of New Hampshire.

This section concludes with information on the comparative severity of these events and whether flooding this severe could happen again.

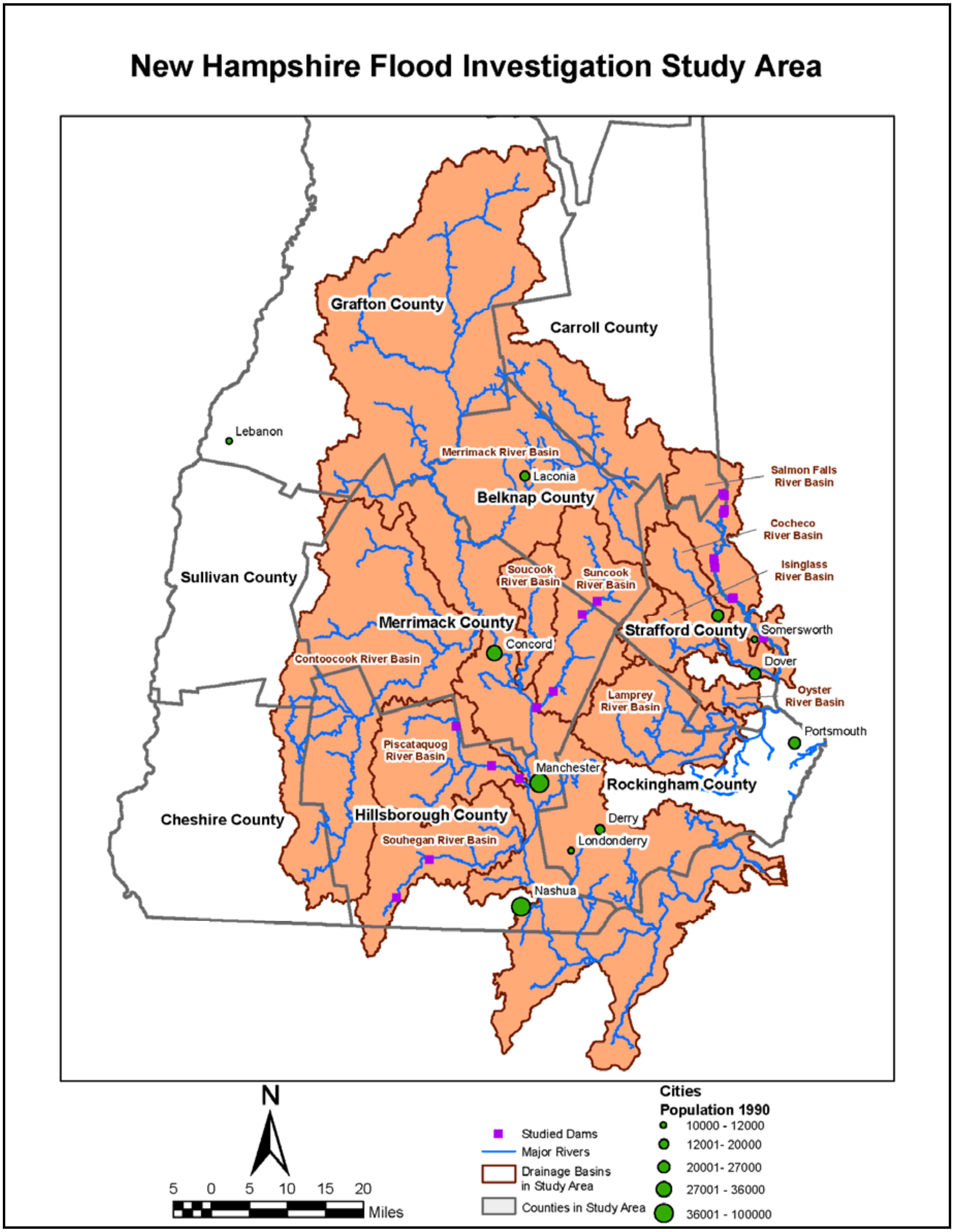


Figure 1-1: NH Flood Investigation Study Area

Section 3 – Dam Operations During the April 2006 and May 2007 Events. Computer simulation techniques were used on four watersheds in the study area to determine whether any logical modifications to gate/dam operations at ten dams specified in the scope of work would result in lower flood levels. These dams include the Otis Falls and Pine Valley dams on the Souhegan River, the Gregg Falls and Kelley Falls Dams on the Piscataquog River, the Webster Mill, Buck Street, and Pittsfield dams on the Suncook River, and the Milton Three Ponds, Spaulding, and Baxter Mill dams on the Salmon Falls River.

Section 4 – Floodplain Management. Sound floodplain management is critical to mitigate flood impacts. This section evaluates the state of floodplain management in the study area and answers questions regarding the following floodplain management issues:

- Land Use – South central and southeastern New Hampshire have undergone extensive development in the recent past. Did this increase in development contribute to higher flood discharges during these events?
- Erosion, Sediment, and Debris – How did erosion contribute to flooding? Has sediment been filling river valleys thus aggravating flooding? Did debris such as fallen trees caught at dams and culverts contribute to flooding?
- National Flood Insurance Program (NFIP) – Are the Flood Insurance Rate Maps (FIRMs) depicting the floodplains in this region of New Hampshire accurate? Do communities in the region conform or exceed the minimum requirements of the NFIP? Have homeowners taken advantage of the protection available to them from the NFIP? Is the State proactively encouraging its communities to practice sound floodplain management and actively participate in the NFIP?
- Dam Safety – How do New Hampshire's dam safety efforts stack up against other States?
- Flood Forecasting – Who is responsible for flood forecasting? Are the forecasts accurate and effective, and used appropriately by the agencies responsible for implementing emergency procedures during flood events?
- Emergency Operations – What are typical emergency operations at the Federal, State, and local level during flood events, and are these operations adequate?

Section 5 – What Can Be Done to Mitigate the Impact of Future Flood Events? Given the conditions experienced in May 2006 and April 2007 (Section 2), specifics regarding dam operations during those storms (Section 3), and the current status of floodplain management in the region (Section 4), this section investigates methods to reduce flood impacts, improve dam operations, and improve floodplain management.

Sections 6, 7, and 8 – Recommendations. These sections present study recommendations for improved floodplain management, improved flood forecasting, and for instituting a watershed-based approach for flood reduction.

Section 9 – References. This is the list of references used during the evaluation and preparation of this report.

Section 10 – Glossary. This section defines some of the more technical terms used in this report.

SECTION TWO THE MAY 2006 AND APRIL 2007 EVENTS IN PERSPECTIVE

Major flooding occurred between May 13 and May 17, 2006 throughout much of central and southern New Hampshire. Record peak flood discharges were recorded at 14 long-term (more than 10 years of record) stream gages. Flood discharges equal or greater than the 50-year flood occurred at 14 stream gages; at 8 of these 14 stream gages the floods were greater than the 100-year flood. Significant property damage, along with numerous road closures and evacuations of residential areas occurred as a result of this widespread flooding. The flood damage was severe and widespread enough to result in the issuance of a Presidential Major Disaster Declaration for seven New Hampshire counties on May 25, 2006.

Less than one year later, from April 16 to April 18, 2007, major flooding again occurred in central and southern New Hampshire. Record peak flood discharges were recorded at six long-term stream gages; at three of these six gage sites, the previous record peak discharge had been set during the May 2006 flood. Peak flood discharges that equaled or exceeded the 50-year flood were recorded at 10 stream gages during this event; at 7 of these 10 stream gages, flood discharges equaled or exceeded the 100-year flood. This severe flood event also resulted in significant property damage, along with numerous road closures and evacuations of residential areas. As a result of the severity and scope of flood-related damages caused by the April 2007 flood, a Presidential Major Disaster Declaration was issued for five New Hampshire counties on April 27, 2007; a sixth county was added to the disaster declaration on May 10, 2007.

The “100-year flood”

The “100-year flood” is more accurately described as a storm that results in flood levels that have a 1-percent chance of being exceeded in a given year. A common misconception is that if an area suffers a 100-year flood, it is safe from having another similar flood for another 100 years. This is not the case. Having a 100-year flood (or worse) in 2009 is just as likely whether or not there was a 100-year flood in 2006 or 2007.

The 100-year flood is a statistical *extrapolation* of a shorter record, typically much shorter than 100-years. In New Hampshire, the longest streamflow records are generally less than 60 years. Many of the records are much less than 60 years, some shorter than 10 years. As the number of years increases, the statistical extrapolation becomes more reliable.

The extrapolation is based on the assumption that climate is not changing. This assumption is the subject of much debate. Most scientists believe that we are currently experiencing global warming. One of the consequences of global warming may be increased frequency and severity of flood events. This is not currently factored into the definition or calculation of the 100-year flood.

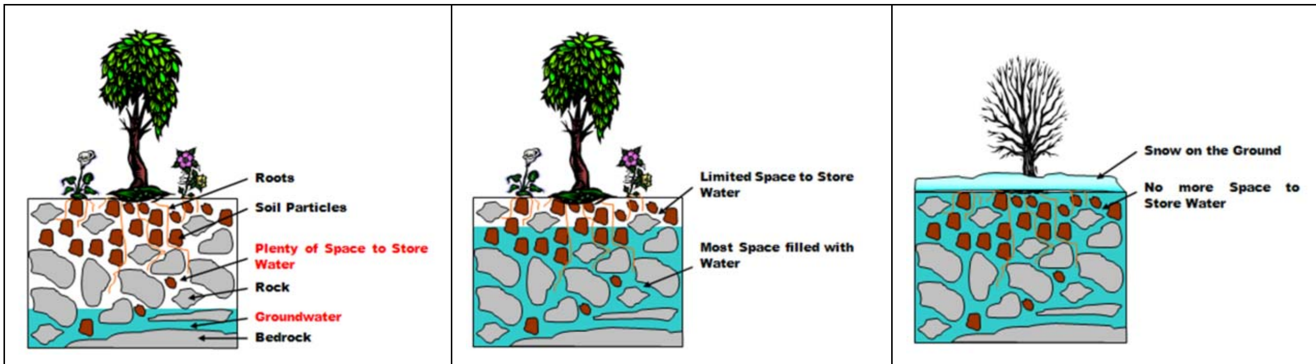
The purpose of this section is to investigate and document the general weather and riverine flow conditions in the affected areas of New Hampshire prior to and during the May 2006 and April 2007 flood events. This includes conditions in the streams prior to the floods (antecedent moisture conditions), characteristics of the precipitation events that resulted in the flood events, and characteristics of the flood discharges. This section takes some of its information from Appendix A, Evaluation of Hydrologic Conditions.

2.1 COMPARING CONDITIONS LEADING UP TO THE EVENTS

Flooding is increased when there is significant rainfall and/or snow prior to the flood event. The amount of water from rainfall or snowmelt that becomes direct runoff and then contributes directly to stream flow and in some cases causes flooding is dependent on several factors. Some portion of the rainfall or snowmelt soaks into the ground and reaches the stream weeks or months later, but does not contribute directly to stream flow during flood events. The amount of rainfall or snowmelt that is absorbed depends for the most part on two factors: the types of land cover and land uses found in the drainage area and the ability and capacity of the soils in the drainage area to absorb water.

Although development and urban growth can change the land cover and land use characteristics of a drainage area with time, these changes are relatively gradual and typically confined to small areas relative to the total drainage area of a large stream. In contrast, the ability and capacity of soils to absorb water from rainfall or snowmelt can vary greatly depending on the moisture and temperature of the soil at the time of the rainfall or snowmelt. *In general terms, the soil can be compared to a sponge that when saturated or full of water can no longer absorb additional water*. As a result, if soil conditions are dry prior to a rainfall or snowmelt event, a larger portion of the total rainfall will be absorbed into the ground and a smaller amount will be available for direct runoff. Conversely, if soil conditions are wet prior to a rainfall or snow melt event, then a smaller portion of the rainfall or snowmelt will be absorbed into the ground and a larger amount of the rainfall or snowmelt will contribute to direct runoff, and the resultant stream flow amounts will be greater. In addition*, if the ground is frozen, then the absorption capacity of the soil is greatly reduced and direct runoff is increased* accordingly.

As such, differences in soil conditions can and often do explain why similar amounts of rainfall or snowmelt can produce different amounts of direct runoff on different streams or rivers. Soil moisture and temperature conditions are a direct result of the rainfall and temperature conditions in the weeks and months leading up to a specific flood event. In general, the climatic and soil conditions leading up to specific flood events are referred to as antecedent conditions. *Variations in the antecedent conditions for a given drainage basin explain the large variations that are observed between rainfall amount and peak stream flows for a given drainage basin*. Differences in typical antecedent conditions, and the conditions observed during the May 2006 and April 2007 event are shown in Figure 2-1.



Typical	May 2006	April 2007

Different soil conditions can affect the amount of flooding that can occur. Typical soil conditions are shown on the left, where there is room in the soil to infiltrate rainfall. Most of the soil prior to the May 2006 event was saturated as shown in the middle, leaving little room for rainfall to infiltrate. The soil was totally saturated prior to the April 2007 event, as shown on the right, when virtually none of the rainfall infiltrated. In addition, the snowpack melted, providing additional runoff to contribute to the flooding.

Figure 2-1: How Antecedent Conditions Can Affect Flooding

2.1.1 Precipitation in the Months and Weeks Leading up to the Events

Moisture conditions in the months leading up to the May 2006 flood can be characterized by examining average precipitation for the period December 2005 through May 2006. Statewide precipitation exceeded the long-term (1971–2000) average for December and January, but was below the long-term average for the months of February, March, and April (Table 2-1). The total rainfall from December 2005 through April 2006 was 15.37 inches, compared to an average for this period of 16.35 inches. Thus, the rainfall for the months leading up to the flood was not extraordinary.

Table 2-1: Statewide Average New Hampshire Precipitation for December 2005 to May 2006

Month	Statewide Average Precipitation (inches)	Average Monthly Precipitation, 1971–2000 (inches)	Percent of Long-Term Average	Rank (1 = wettest, 112 = driest)
Dec-05	4.29	3.44	124	25
Jan-06	4.14	3.42	120	25
Feb-06	2.43	2.62	92	68
Mar-06	1.39	3.37	41	108
Apr-06	3.12	3.50	89	64
May-06	9.30	3.77	247	2

However, in the first 12 days of May 2006, Concord, Manchester, and Portsmouth, New Hampshire received a total of 1.7, 2.2, and 2.3 inches of rain, respectively. No snow was on the ground prior to the May event, and there was no snow during the event. Thus, the ground was not frozen.

As a result of this rainfall in early May, soil moisture conditions for the study area were at higher than average levels, resulting in greater than average runoff response during the May 2006 flood.

A similar examination of the moisture conditions in the months leading up to the April 2007 flood can be characterized by examining average precipitation for the period November 2006 through April 2007. Statewide precipitation was greater than or equal to the long-term (1971–2000) average for each of the 5 months leading up to the April 2007 flood except for February 2007 (Table 2-2). Total rainfall over the period of 16.88 inches slightly exceeded the average of 16.15 inches. Like the May event, the rainfall for the months leading up to the April flood was not extraordinary.

Table 2-2: Statewide Average New Hampshire Precipitation for November 2006 through April 2007

Month	Statewide Average Precipitation (inches)	Average Monthly Precipitation, 1971–2000 (inches)	Percent of Long-Term Average	Rank (1 = wettest, 112 = driest)
Nov-06	4.69	3.44	119	34
Dec-06	3.42	3.42	99	55
Jan-07	3.12	2.62	91	53
Feb-07	2.04	3.37	77	90
Mar-07	3.61	3.50	107	49
Apr-07	7.35	3.50	209	1

In the first 14 days of April 2007 Concord, Manchester, and Portsmouth, New Hampshire received a total of 2.1, 2.2, and 2.2 inches of precipitation, respectively. In addition, a total of 10.5 inches of snow was recorded at Concord during the first 14 days of the month and 1.0 inch of snow remained on the ground as of April 14. Snowfall for the month was greater and remaining snow depths were greater in higher elevation areas of the State than in Concord. As a result of the snow and rain precipitation in early April, soil moisture conditions for the study area were nearly 100 percent saturated and still not thawed out. The melting snow released the water to the soil, resulting in much greater than average runoff response during the April 2007 flood.

Thus, the stage was set for higher than average runoff from the May 2006 precipitation event, and much higher than average runoff for the April 2007 precipitation event.

2.1.2 Streamflow Before the Events

A review of median discharge values for each day of the year measured in cubic feet per second (cfs) for several long-term stream gages (Figure 2-2) shows that, in general, the median flows follow a fairly regular pattern, typically increasing through winter until reaching yearly maximum values in April and then begin a recession that lasts throughout spring and summer. As such, the May 2006 flooding occurred during the typical spring recession while the April 2007 flood occurred near the peak yearly maximum. Discharges in mid-April are typically about twice the discharges in mid-May. Table 2-3 shows the discharges in three of the basins in the study area prior to the beginning of these events. The flow rates trend as expected, with the flow rates prior to the April 2007 flood event more than double the flow rates prior to the May 2006 flood event.

As stated Section 2.1.1, a rainfall in May 2006 would likely result in *higher* runoff than typically expected, and a rain event in April 2007 would likely result in *much higher* runoff than typically expected. This section shows that the flow rates prior to the flood in May 2006 are only half the flow rates prior to the April 2007 flood. Consequently, conditions prior to the April 2007 event were even more conducive to high runoff than conditions prior to the May 2006 event. Thus, a given amount of precipitation would result in significantly more runoff from conditions in April than conditions in May and conditions prior to the April event were even more conducive to high runoff than conditions prior to the May event.

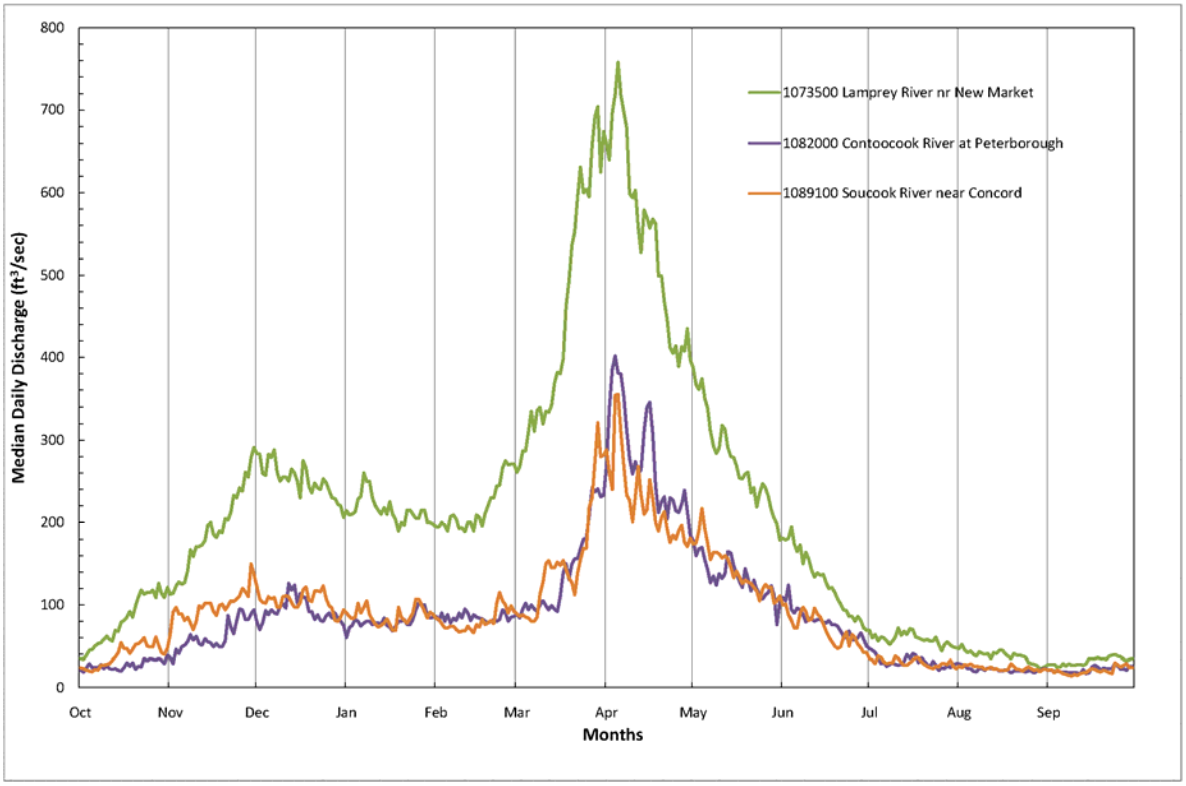


Figure 2-2: Long-Term Median Daily Flows at Selected U.S. Geological Survey (USGS) Gage Stations

Table 2-3: Comparison of Discharges for the May 2006 and April 2007 Events

River (gage)	May 12, 2006 Discharge (cfs)	April 14, 2007 Discharge (cfs)	Difference between flow rates before the events (%)
Lamprey River near Newmarket (1073500)	347	720	207
Contoocook River at Peterborough (1082000)	103	218	211
Soucook River near Concord (1089100)	96	301	313

2.1.3 Comparing Rainfall and Snow during the Events

As shown in Figure 2-3, the rainfall that produced the May 2006 flooding began on May 12 and continued through May 16, 2006, resulting in more than 12 inches of rain in the vicinity of Portsmouth, along the New Hampshire seacoast, and approximately 9 inches of rain in the vicinity of Concord and Manchester, in the south central part of the State. The most intense rainfall occurred from May 13 to May 15, with more than 90 percent of the 5-day storm total falling on these 3 days. In comparison to computed estimates of rainfall frequency (National Oceanic and Atmospheric Administration [NOAA] Technical Paper–40, 2008), the greatest 1-day rainfall (May 13) is roughly equal to the 24-hour, 25-year recurrence interval values, while the 2-day (May 13–14) total rainfall amounts during the storm event exceed the 2-day, 100-year recurrence interval values (Table 2-4). Significant precipitation was also received in the first 12 days of May 2006, making May 2006 the second wettest May since 1895. Precipitation variability in the study area was substantial; precipitation in the Souhegan River Basin was substantially less than in the cities shown in Table 2-4. This caused large variations in the amount of flooding experienced throughout the study area.

Table 2-4: 24-hour and 2-day Rainfall Amounts for the May 2006 Flood

Location	May 13, 2006 Rainfall Total (inches)	24-hour Rainfall (inches)			May 13–14, 2006 Rainfall Total (inches)	2-Day Rainfall (inches)		
		25-year	50-year	100-year		25-year	50-year	100-year
Portsmouth	4.8	5.1	5.5	6.3	9.1	6.0	6.7	7.5
Manchester	4.4				8.2			
Concord	5.0				7.6			

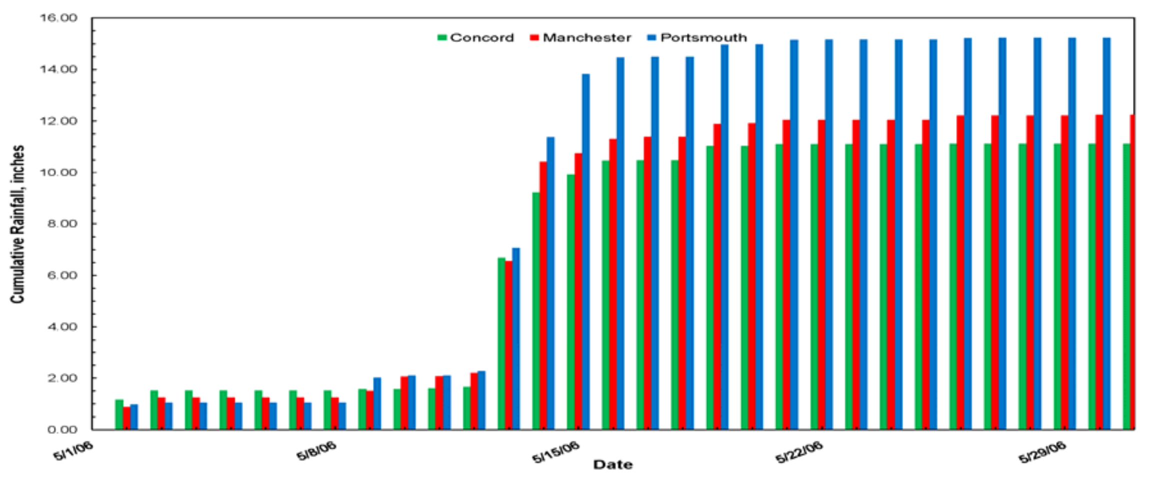


Figure 2-3 Precipitation During and Prior to the May 2006 Event

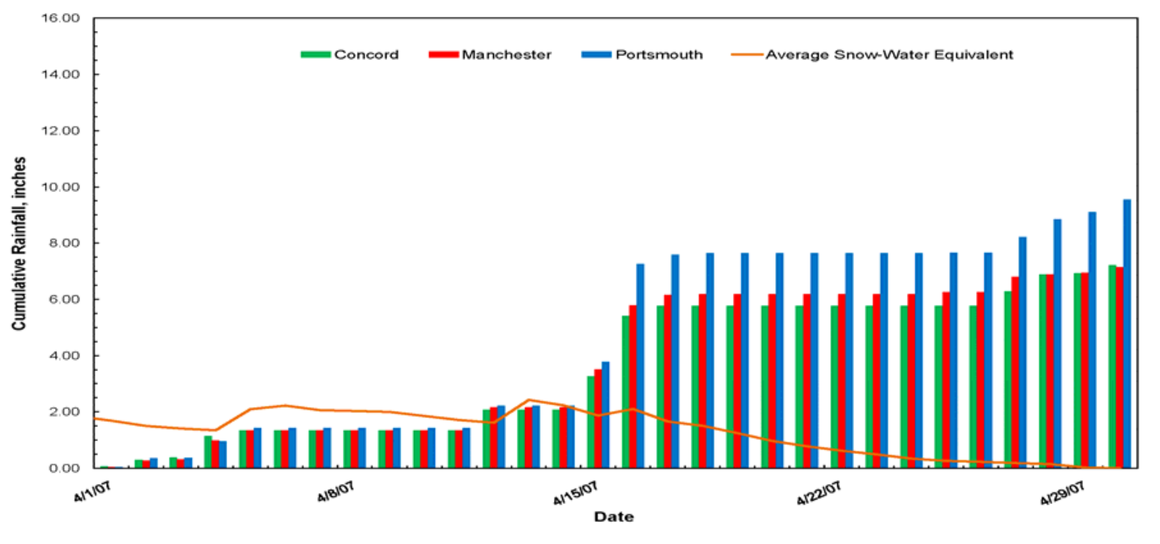


Figure 2-4: Precipitation During and Prior to the April 2007 Event

The precipitation that produced the April 2007 flooding shown in Figure 2-4 began on April 15 as accumulating snow across most of New Hampshire. The snowfall had changed over to heavy rainfall by the afternoon and evening of April 15 and continued as rain throughout April 16 before ending in most areas on the April 17. Total rainfall amounts were more than 5 inches in the vicinity of Portsmouth, along the New Hampshire seacoast, and approximately 4 inches of rain in the vicinity of Concord and Manchester, in the south central part of the State. The most intense rainfall occurred April 15–16, with more than 90 percent of the 3-day storm total falling on those 2 days. In comparison to computed estimates of rainfall frequency (NOAA Technical Paper–40), the April 16 total rainfall amounts for the coastal areas are approximately equal to the

24-hour, 5-year recurrence interval values, while in the south central areas of the State, the rainfall amounts were approximately equal to the 24-hour, 2-year amounts; the 2-day (April 15–16) total rainfall amounts along the seacoast during the storm event exceed the 2-day, 10-year recurrence interval values (Table 2-5). The 12 inches of snow from the first 14 days of April provided as much as 2 inches additional snow-water equivalent during the period of heaviest rainfall. The heavy rain and snowfall received in April 2007 resulted in April 2007 being the second wettest April since 1895 and the ninth snowiest April since 1868.

Table 2-5: 24-hour and 2-day Rainfall Amounts for the April 2007 Flood

Location	April 16, 2007 Rainfall Total (inches)	24-hour Rainfall (inches)			April 15–16, 2007 Rainfall Total (inches)	2-Day Rainfall (inches)		
		2-year	5-year	10-year		2-year	5-year	10-year
Portsmouth	3.5	2.9	3.6	4.3	5.0	3.5	4.5	5.0
Manchester	2.3				3.6			
Concord	2.1				3.3			

Rainfall contour maps for the May 2006 and April 2007 are provided in Figures 2-5 and 2-6, respectively. Total rainfall amounts during both storms varied significantly within short distances. Because of these significant differences in rainfall across relatively short distances, the amount of flooding in adjacent basins often differed significantly.

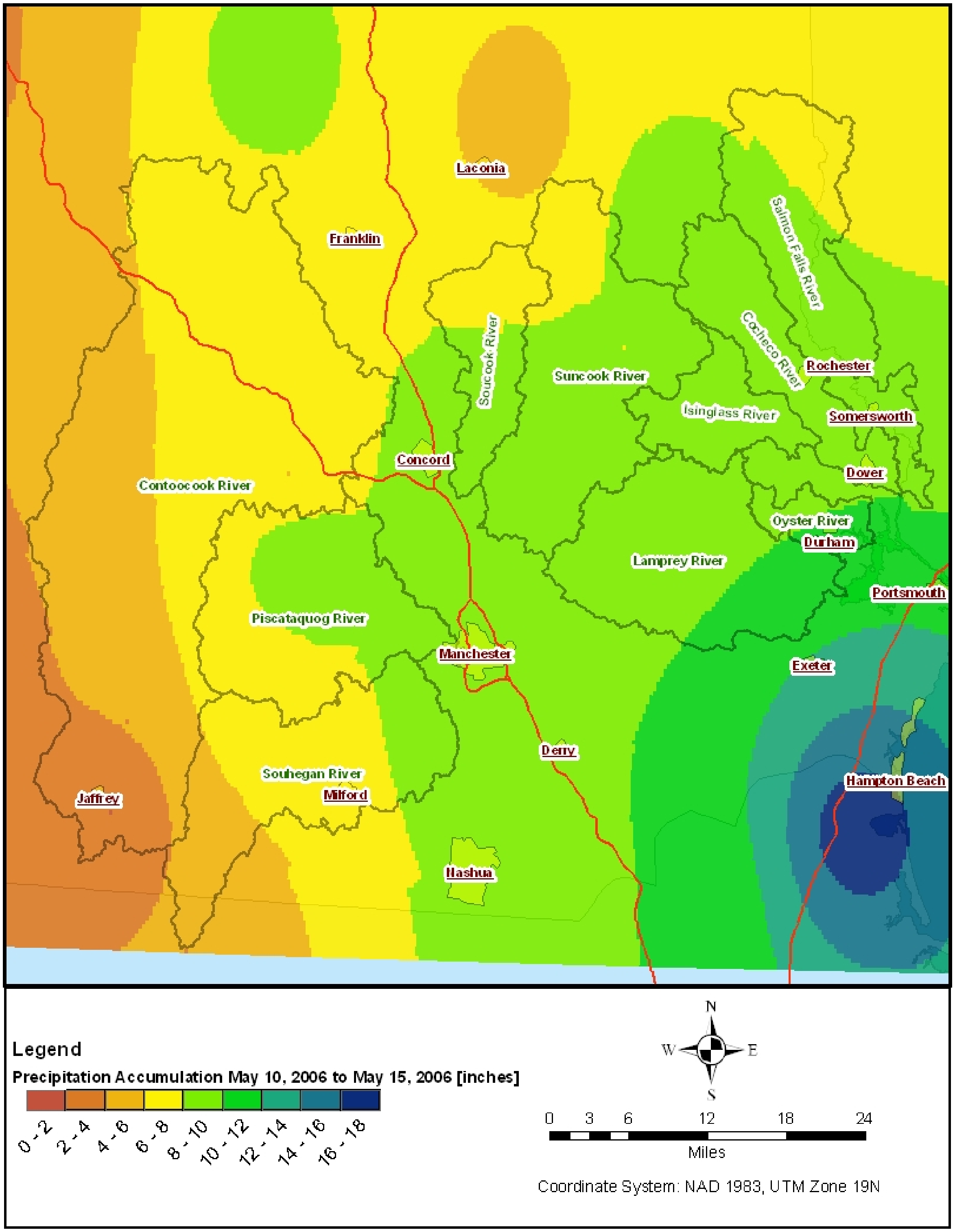


Figure 2-5: Precipitation During the May 2006 Event

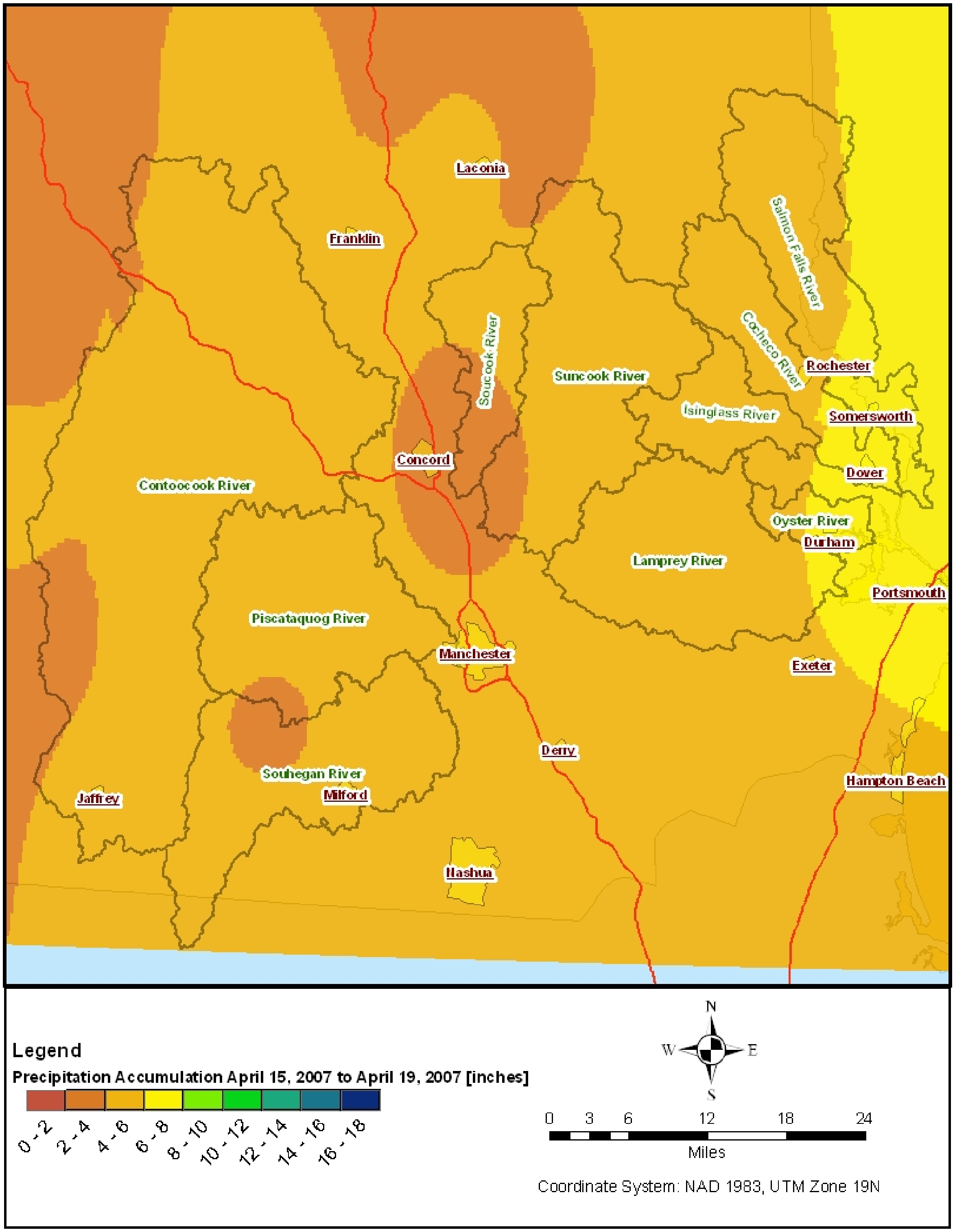


Figure 2-6: Precipitation During the April 2007 Event

The rainfall on April 16, 2007 was greatest in southeastern New Hampshire, along the Atlantic Coast in the coastal drainage basins of the Lamprey, Oyster, and Salmon Falls Rivers. However, rain was heavier in the south central part of the State in the Souhegan River Basin, and upper reaches of the Contoocook and Piscataquog River Basin. These areas of heaviest rainfall coincide with the areas of highest recurrence interval flooding.

Neither of the storms was especially severe for short durations, such as 6 or 12 hours. The important characteristic of both these storms, especially the May 2006 rainfall event, was the total rainfall amount over several days. While the April 2007 storm reached 2-day depths expected every other year or once every 5 years, the May 2006 storm reached 2-day depths expected on average once every 100 years.

2.2 COMPARING RUNOFF AND FLOODING CAUSED BY THE TWO EVENTS

During the May 2006 event, peak discharges with a recurrence interval equal to or in excess of 50 years were observed at 14 stream gages; at 8 of these gages the recurrence interval was equal to or greater than 100 years (Flynn 2008). Record peak discharges were set at 14 stream gages with more than 10 years of record in the Cocheco, Contoocook, Lamprey, Piscataquog, Salmon Falls, and Soucook River basins. The May 2006 peak of record was superseded 11 months later in April 2007 on the Salmon Falls, Cocheco, and South Branch Piscataquog Rivers (Table 2-6).

During the April 2007 event, peak discharges with recurrence intervals equal to or in excess of 50 years were observed at 10 stream gages; at 7 of these gages the recurrence interval of flooding was equal to or greater than 100 years (Flynn 2008). Record peak discharges were set at 6 stream gages with more than 10 years of record on the Cocheco, Contoocook, Oyster, Salmon Falls, South Branch Piscataquog, and Suncook River. Peak discharges on the Cocheco, Salmon Falls, and South Branch Piscataquog Rivers superseded the record peaks set during the May 2006 event.

During the May 2006 event, flooding with a recurrence interval of 500 years or greater was observed in small coastal drainage areas along the New Hampshire seacoast. Recurrence intervals between 100 and 500 years were observed on the main stem of the Soucook River. In addition, 100–500 year flooding was observed on tributaries of the Lamprey, the Piscataquog, and the Contoocook Rivers.

Table 2-6: Peak Discharges, Estimated Return Periods, and Other Characteristics for Flooding

Gage Station Number	Gage Station Name	Return Period Discharge (cfs)				May 2006 Flood			April 2007 Flood			Maximum Peak of Record
		10-year	50-year	100-year	500-year	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	
01072100	Salmon Falls River at Milton, NH	3,190	5,590	6,920	10,900	5,450	10–50	5.0	5,500	10–50	5.5	April 2007
01073000	Oyster River near Durham, NH	633	1,020	1,220	1,750	873	10–50	7.8	1,320	100–500	6.1	April 2007
01073500	Lamprey River near Newmarket, NH	4,660	7,760	9,400	14,100	8,970	50–100	7.3	8,450	50–100	5.7	May 2006
01082000	Contoocook River at Peterborough, NH	2,250	3,130	3,530	4,480	1,470	2–10	3.8	4,110	100–500	5.8	April 2007
01089100	Soucook River at Pembroke Road near Concord, NH	2,730	4,300	5,080	7,200	5,110	100–500	6.7	3,730	10–50	4.4	May 2006
01092000	Merrimack R near Goffs Falls below Manchester, NH	52,900	86,300	105,000	163,000	74,700	10–50	6.8	59,700	10–50	4.9	March 1936
01094000	Souhegan River at Merrimack, NH	6,370	10,400	12,600	18,800	6,140	2–10	5.3	10,500	50–100	6.2	March 1936

During the April 2007 event, flooding with recurrence interval of 500 years or greater was observed on the Taylor River at Old Stage Road near Hampton (01073838) along the seacoast. In addition, the recurrence interval of flooding at South Branch Piscataquog River near Goffstown (1091000) exceeded 500 years at this long term gaging station. Recurrence intervals between 100 and 500 years were observed in several small coastal drainage areas along the New Hampshire seacoast, as well as on the Suncook and Oyster Rivers. Flooding with recurrence intervals between 50 and 100 years was observed on the Souhegan and Lamprey Rivers and on the Warner River, a tributary to the Contoocook River.

During the May 2006 event, runoff, in inches over the upstream drainage area, was computed for seven USGS stream gages (Table 2-6). This value is computed by determining the amount of flow that passes a USGS stream gage over the course of the event and then dividing it by the contributing watershed drainage area for the gage. Computed runoff at these seven gages ranged between a maximum of 7.8 inches to a minimum of 3.8 inches, with an average value of 6.1 inches.

During the April 2007 event, runoff, in inches over the upstream drainage area, was computed at these seven gages and ranged between a maximum of 6.2 inches to a minimum of 4.4 inches, with an average value of 5.5 inches. Despite generally lower total rainfall, the April 2007 event resulted in a comparable amount of runoff.

Maps showing the relative size of the two floods at various locations in south central and southeastern New Hampshire at selected stream gages are provided in Figures 2-7 and 2-8. At some locations, the May 2006 event caused more flooding, while in other locations, the April 2007 event caused more flooding. While the May 2006 event had greater rainfall totals, the April 2007 event was severe because of the combination of rapid snowmelt and saturated ground conditions at a time of already high streamflow.

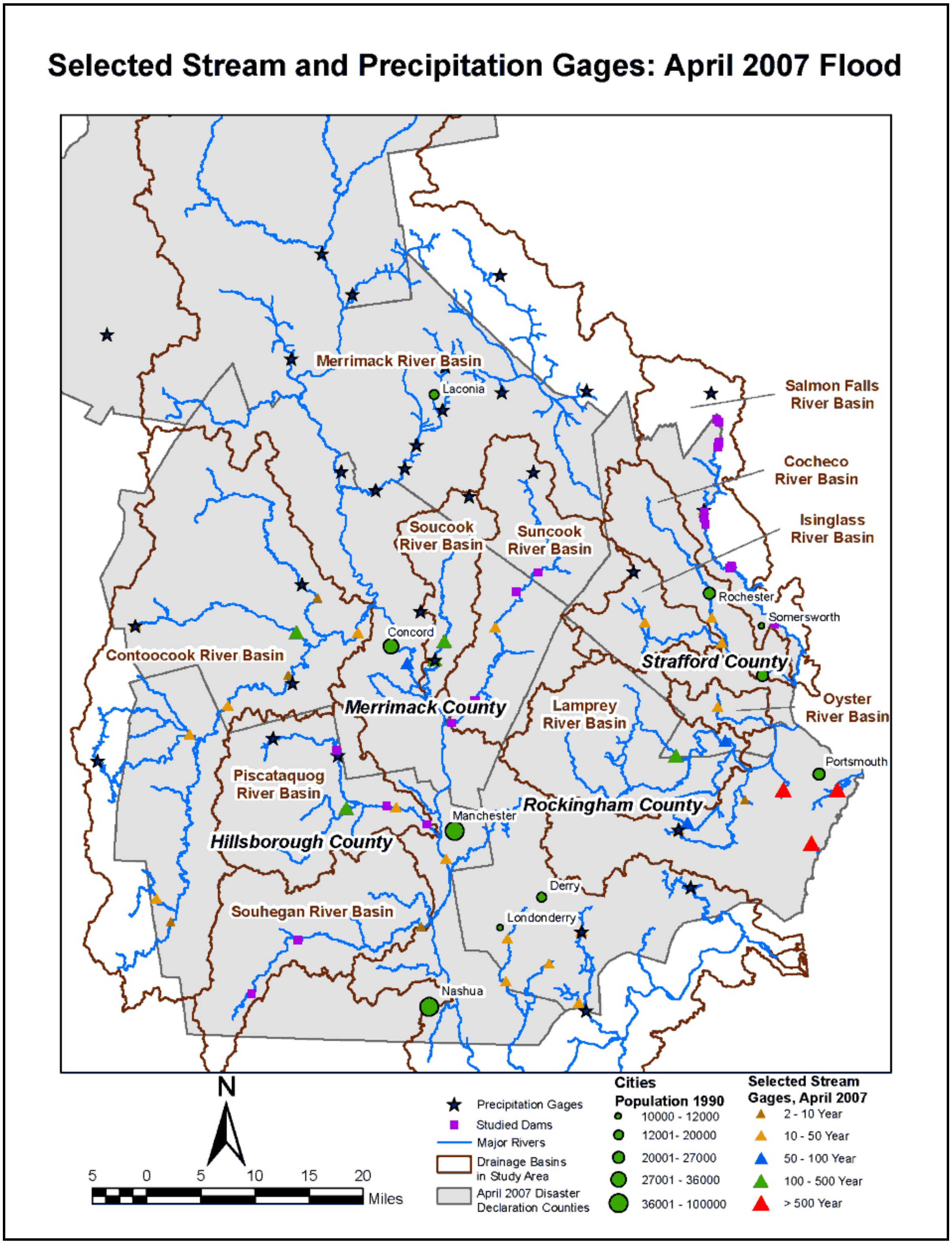


Figure 2-7: May 2006 Flood Event

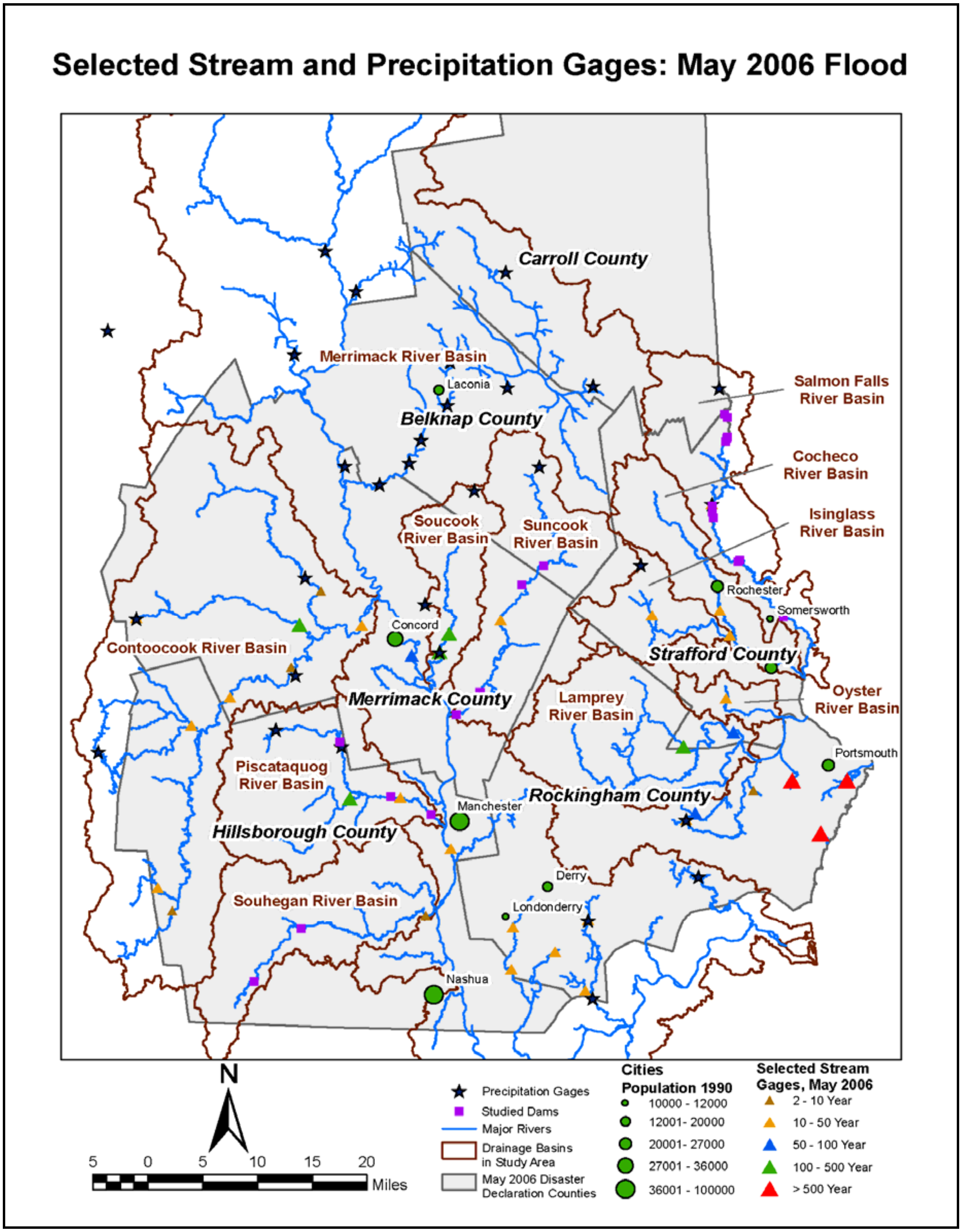


Figure 2-8: April 2007 Flood Event

2.3 COMPARING THESE EVENTS WITH PAST FLOOD EVENTS

New Hampshire has a long history of flooding prior to and including the May 2006 and April 2007 events, as shown in Table 2-7 (University of New Hampshire 2007). Some of the most severe historic floods have occurred in March and April as a result of a combination of heavy spring rains, snowmelt, and ice jams. Coastal storms, in the form of nor'easters throughout the year, or tropical storms or hurricanes in late summer and fall have produced severe flooding. As a result, major flooding events can and have occurred in all seasons, not just in the spring "runoff" season. As indicated in Table 2-7, major flood have occurred in every season of the year, and in every month of the year except January.

Within the time period that gages have measured flows beginning at same locations in the early 1900's, the May 2006 and April 2007 floods were often **not** the floods of record. Other floods that occurred in south central and southeastern New Hampshire have been larger in March 1936, September 1938, June 1984, and April 1987. The March 1936 and September 1938 floods were both extraordinarily large events, and would likely be the record event at many of the gages had the gage record extended back that far.

Perhaps a similar event, still in the memory of many area residents, was the April 1987 flood. This flood resulted from a pair of spring storms in March and April, combined with snowmelt. It remains the flood of record on the Contoocook River below the Hopkinton Dam. The worst flooding from the first storm occurred in Maine, but the storm saturated conditions throughout the region. The second storm, a few days later, resulted in 4–7 inches of precipitation in most of New Hampshire. Because the two storms occurred in such a short time, some of the U.S. Army Corps of Engineers' (USACE's) dams had record high pool levels, including the Edward MacDowell Dam on Nubanusit Brook, a tributary to the Merrimack River located in Peterborough, which discharged over its spillway.

Table 2-7: History of Flooding in New Hampshire

Source: University of New Hampshire Floodplain Learning on Demand, 2007; http://www.nhflooded.org/flood_history.php

Date	Area Affected (River Basins or Region)	Recurrence Interval (yr)	Remarks
December, 1740	Merrimack	Unknown	First recorded flood in New Hampshire
October 23, 1785	Cocheco, Baker, Pemigewasset, Contoocook, and Merrimack Rivers	Unknown	Greatest discharge at Merrimack and at Lowell, MA until 1902
March 24–30, 1826	Pemigewasset, Merrimack, Contoocook, Blackwater, and Ashuelot Rivers	Unknown	
April 21–24, 1852	Pemigewasset, Winnespaukee, Contoocook, Blackwater, and Ashuelot Rivers	Unknown	Merrimack River at Concord – highest stream stage for 70 years Merrimack River at Nashua – 2 feet lower than 1785

Date	Area Affected (River Basins or Region)	Recurrence Interval (yr)	Remarks
April 19–22, 1862	Contoocook, Merrimack, Piscataquog, and Connecticut Rivers	Unknown	Highest stream stages to date on the Connecticut River; due solely to snowmelt
October 3–5, 1869	Androscoggin, Pemigewasset, Baker, Contoocook, Merrimack, Piscataquog, Souhegan, Ammonoosuc, Mascoma, and Connecticut Rivers	Unknown	Tropical storm lasting 36 hours Rainfall, 6–12 inches
November 3–4, 1927	Pemigewasset, Baker, Merrimack, Ammonoosuc and Connecticut Rivers	25 to >50	Upper Pemigewasset River and Baker River – exceeded the 1936 flood Down stream at Plymouth – less severe than the 1936 flood
March 11–21, 1936	Statewide	25 to > 50	Double flood; first due to rains and snowmelt; second, due to large rainfall
September 21, 1938	Statewide	Unknown	Hurricane – stream stages similar to those of March 1936; exceeded 1936 stages in Upper Contoocook River
June 1942	Merrimack River Basin	Unknown	Fourth flood recorded in the lower Merrimack River basin at Manchester, NH
June 15–16, 1943	Upper Connecticut, Diamond, and Androscoggin Rivers	25 to >50	Intense rainfall exceeding 4 inches; highest stream stages of record in parts of the affected area
June 1944	Merrimack River	Unknown	One of the five highest known floods at Manchester on the Merrimack
November 1950	Contoocook River and Nubanusit Brook	Unknown	Localized storm resulted in flooding of this area
March 27, 1953	Lower Androscoggin, Saco, Ossipee, Upper Ammonoosuc, Israel, and Ammonoosuc Rivers	25 to>50	Record peak flow for the Saco and Ossipee Rivers
August 1955	Connecticut River Basin	Unknown	Heavy rains caused extensive damage throughout the basin area
October 25, 1959	White Mountain Area; Saco, Upper Pemigewasset, and Ammonoosuc Rivers	25 to >50	Largest flood of record on Ammonoosuc at Bethlehem Junctions; third largest flood of record on the Pemigewasset and Saco Rivers
December 1959	Piscataquag River, Portsmouth	Unknown	Nor'easter brought tides exceeding maximum tidal flood levels in Portsmouth; damage was heavy along the coast
April 1960	Merrimack and Piscataquog Rivers	Unknown	Flooding resulted from rapid melting of deep snow cover and moderate to heavy rainfall; third highest flood of record on the rivers

Date	Area Affected (River Basins or Region)	Recurrence Interval (yr)	Remarks
April 1969	Merrimack River Basin	Unknown	Record depth of snow cover in the Merrimack River Basin and elsewhere resulted in excessive snowmelt and runoff when combined with sporadic rainfall
February 1972	Coastal Area	Unknown	Coastal area was declared a National Disaster Area as a result of the devastating effects of a severe coastal storm, damage was extensive
June 1972	Pemigewasset River	Unknown	5 days of heavy rain caused some of the worst flooding since 1927 along streams in the upper part of the State; damage was extensive along the Pemigewasset River and smaller streams in northern areas
June 30, 1973	Ammonoosuc River	25 to > 50	Flood event in the Northwestern White Mountains
April 1976	Connecticut River	Unknown	Rain and snowmelt brought the river to 1972 levels, flooding roads and croplands
March 14,1977	South Central and Coastal New Hampshire	25 to 50	Peak flow of record for Soucook River
February 1978 (The Blizzard of '78)	Coastal New Hampshire	Unknown	Nor'easter brought strong winds and precipitation to the entire State; hardest hit area was the coastline, with wave action and floodwaters destroying homes Roads all along the coast were breached by waves flooding over to meet the rising tidal waters in the marshes
July 1986–August 10,1986	Statewide	Unknown	FEMA DR-71I-NH: Severe summer storms with heavy rains, tornadoes, flash floods, and severe winds
March 31–April 2, 1987	Androscoggin, Saco, Ossipee, Piscataquog, Pemigewasset, Merrimack, and Contoocook Rivers	25 to >50	Caused by snowmelt and intense rain Precursor to a significant, subsequent event
April 6–7, 1987	Lamprey River and Beaver Brook	25 to >50	FEMA DR-789-NH: Large rainfall event following the March 31–April 2 storm
August 7–11, 1990	Statewide	Unknown	FEMA DR-876-NH: Series of storm events from August 7–11, 1990 with moderate to heavy rains producing widespread flooding
August 19, 1991	Statewide	Unknown	FEMA DR-917-NH: Hurricane Bob struck New Hampshire causing extensive damage in Rockingham and Strafford Counties, but effects were felt statewide
October–November 1995	Northern and Western Regions	Unknown	FEMA DR-1144-NH: Counties declared: Grafton, Hillsborough, Merrimack, Rockingham, Strafford, and Sullivan

Date	Area Affected (River Basins or Region)	Recurrence Interval (yr)	Remarks
October 1996	Northern and Western Regions	Unknown	FEMA DR-1077-NH: Counties declared: Carroll, Cheshire, Coos, Grafton, Merrimack, and Sullivan
June–July 1998	Central and Southern Regions	Unknown	FEMA DR-1231-NH: Series of rainfall events; counties declared: Belknap, Grafton, Carroll, Merrimack, Rockingham and Sullivan (1 fatality) (Several weeks earlier, significant flooding, due to rain and rapid snowpack melting, occurred in Coos County; heavy damage to secondary roads occurred)
September 18–19, 1999	Central and Southwest Regions	Unknown	FEMA DR-1305-NH: Heavy rains associated with Tropical Storm/Hurricane Floyd; counties declared: Belknap, Cheshire, and Grafton
July 21–August 18, 2003	Southwestern Region	Unknown	FEMA-1489-DR: Severe storms and flooding occurred in Cheshire and Sullivan counties Public Assistance provided for repair of disaster damaged facilities
October 7–16, 2005	Southwestern Region	Exceeded 100 in some areas	FEMA-1610-DR: Heavy rains associated with Tropical Storm Tammy and Subtropical Depression 22 resulted in 6–15 inches of rain
May 13–15, 2006	Central and Southern New Hampshire	Exceeded 100	FEMA-1643-DR: Heavy rainfall of 8–16 inches
April 27, 2007	Statewide	100	FEMA-1695-DR: Severe storms and flooding starting on April 15th

2.4 JUST HOW SEVERE WERE THESE EVENTS?

The May 2006 and April 2007 events were extraordinary. Records were set at many locations in south central and southeastern New Hampshire. Coastal New Hampshire experienced the worst flooding since at least the beginning of the last century during these events. The Oyster River and Lamprey River, which both have gage records extending to before the 1936 flood, set flow records. The Lamprey River record was set during the May 2006 event, while the Oyster River record was set during the April 2007 event, despite the fact that the gages for these rivers are less than 10 miles from one another on different tributaries to Great Bay. The reason that two such severe events occurred just 11 months apart is a matter of speculation. There is some research indicating that weather patterns are cyclical, and that we are at the "high flood" part of a cycle. This is supported by the fact that some of the larger floods occurred in "bunches": 1936–1938, 1942–1944, 1972–1973, 1990–1991, 1995–1996, and 1998–1999. Other research suggests the timing of the two floods is merely coincidental. Finally, global warming and climate change may contribute to the increase in the frequency and severity of flood events.

Much more severe flooding is certainly possible. The rainfall pattern experienced in May 2006 could have been experienced in April 2007, when basin conditions would have led to more severe flooding.

2.5 CAN THEY HAPPEN AGAIN?

As indicated in Table 2-7, many locations within the study area have experienced floods larger than the May 2006 and April 2007 events. These floods occurred in March 1936, September 1938, June 1984, and April 1987.

Rainfalls far exceeding those experienced in the May 2006 and April 2007 events have been recorded at locations throughout the northeastern United States. Table 2-8 compares rainfall statistics from at selected locations in the northeast with rainfall amounts in New Hampshire during May 2006 and April 2007.

Table 2-8: Actual Rainfall Events in the Northeastern United States and Canada

Location	Date	Duration (hours)	Rainfall (inches)
May 2006 Rainfall Depth at Selected NH Locations			
Portsmouth, NH	5/2006	48	9.1
Manchester, NH	5/2006	48	8.2
Concord, NH	5/2006	48	7.6
April 2007 Rainfall Depth at Selected NH Locations			
Portsmouth, NH	4/2007	48	5.0
Manchester, NH	4/2007	48	3.6
Concord, NH	4/2007	48	3.3
Historical Rainfall Depths at Locations in the Northeastern US			
Jefferson, OH	9/1878	72	15
Wellsboro, PA	5/1889	48	9.8
Jewell, MD	7/1887	72	15.8
Cooper, MI	8/1914	6	12.6
Kinsman Notch, NH	11/1927	48	14
Scituate, RI	9/1932	24	12.2
Ewan, NJ	9/1940	12	22.7
Smethport, PA	7/1942	24	29.2
Big Meadow, VA	11/1942	72	18.8
Westfield, MA	8/1955	48	19.4
Tyro, VA	8/1969	12	25.4
Zerbe, PA	6/1972	72	18.5

Source: USGS Water Supply Paper 1887; Crippen and Bue 1887

Similarly, flood discharges far exceeding the discharge rates from the May 2006 and April 2007 events have been recorded at locations throughout the northeast. Table 2-9 compares peak flow rates at selected locations with comparable drainage area size. Despite differences in topography and other characteristics that affect flow rates, the information in Table 2-9 suggests that larger floods are possible in south central and southeastern New Hampshire.

Table 2-9: Peak Flow Rates from the May 2006 and April 2007 Events Compared with Peak Flow Rates from Floods at Other Locations in the Northeast

Location	Drainage Area (square miles)	Date	Flow (cfs)	Flow per square mile (cfs/sq. mi.)
Smaller Drainage Area				
Salem River at Woodstown, NJ	14.6	9/1940	22,000	1,507
Oyster River near Durham, NH	12.1	4/2007	1,320	109
Medium Drainage Area				
Salmon Brook near Granby, CT	66.6	8/1955	40,000	599
Lamprey River near Newmarket, NH	108	5/2006	8,960	83
Larger Drainage Area				
Brodhead Creek at Analomink, PA	124	8/1955	72,200	582
Suncook River at North Chichester, NH	157	3/1936	12,900	104

Flood events that occurred in the last century could be more damaging if they occurred today. Development, often in the floodplain, has grown. Development reduces the ability of flood waters to pass unimpeded and increases flow rates.

South central and southeastern New Hampshire experienced two very large floods in 2006 and 2007. Depending on location, they ranged from 10-year flood events to over 500-year flood events. Southwestern New Hampshire experienced a very large flood (approximately 100-year flood) in 2005. Most recently, northern Maine experienced a large flood in May 2008. Flooding is a natural phenomenon that has occurred quite regularly to form the floodplains that are one of the characteristics of the region's landscape. Although we can't predict the future, planning for flood events as large as and larger than the May 2006 and April 2007 events is prudent.

SECTION THREE DAM OPERATIONS DURING THE APRIL 2006 AND MAY 2007 EVENTS

3.1 OVERVIEW

This section assesses the impacts of actual or alternative dam operations at select dams in the Salmon Falls, Suncook, Piscataquog, and Souhegan River basins on flooding upstream or downstream of the dams.

3.2 TYPES OF DAMS IN SOUTHERN NEW HAMPSHIRE

3.2.1 Flood Control Dams

Flood control dams are specifically built to store flood waters in order to reduce downstream flows. They are typically large structures that are usually nearly empty. In the study area, flood control reservoirs are operated by the USACE according to long established and proven flood operation rules. These rules stipulate that the reservoirs be kept mostly empty throughout the year. During flood events, releases are reduced to capture flood waters that originate upstream. The reservoirs are typically large enough to capture very large flood volumes, which are released after the event in preparation for the next event. The NHDES operates flood control dams built by the Natural Resources Conservation Service (NRCS) in the Souhegan River Basin. These dams are typically much smaller facilities located in the upper reaches of the basin and are designed to reduce flooding in the immediate downstream reaches. Together, the USACE- and NHDES-operated dams reduce basin-wide flood discharges.

3.2.2 Dams that Provide Significant Local Flood Control Benefits

Larger lakes in the study area can store sufficient water during flood events to provide significant *local* flood control benefits. Most of these lakes are located in the upper parts of the basins. They typically have small contributing areas and, therefore, large relative storage capacities.

Many of these larger lakes are drawn down in the winter and refilled in the spring.

During an event, these larger lakes can store some or all the flood waters originating upstream. The dams impounding these lakes are typically operated to release less water than what enters the lake and store the difference. In doing so, they reduce downstream flows and provide flood control benefits. However, once these lakes fill, no more flood waters can be stored and the rising water levels can cause flooding along the shorelines if inflows are not passed downstream.

In this study, lakes are classified as “providing significant local flood control benefits” if they are not flood control dams and have:

- A storage capacity between winter level and maximum pool of 3 or more inches of excess precipitation over the contributing area
- A storage capacity between summer level and maximum pool of 1 or more inches of excess precipitation over the contributing area

3.2.3 Dams that Provide Limited Local Flood Control Benefits

These dams are typically associated with lakes in the middle of the basins. They are located far enough downstream for the upstream contributing area to be large compared to the available storage capacity in the lake.

During an event, these lakes can store limited upstream flood waters and therefore provide limited flood control benefits. They may also cause upstream flooding, as they fill much more rapidly.

In this study, lakes are classified as “providing limited local flood control benefits” if they have:

- A storage capacity between winter level and maximum pool of less than 3 inches of excess precipitation over the contributing area
- A storage capacity between summer level and maximum pool of less than 1 inch of excess precipitation over the contributing area
- A storage capacity between minimum and maximum pool of larger than 0.3 inch of excess precipitation over the contributing area

3.2.4 Run-of-River Dams

These small lakes are typically located in the middle and lower portions of the basins. Their main function is (or was) to provide head for power generation. The storage volumes contained in these impoundments are typically small compared to the upstream contributing area. They fill (and empty) rapidly in response to changes in inflow and operations at the dam site.

During an event, they can only store small amounts of flood waters. They may fill within a few hours and, therefore, cannot reduce downstream flows. They can cause upstream flooding along the reservoir/lake itself if discharge capacity is limited and water levels behind the dams rise excessively.

In this study, impoundments are classified as “Run-of-River” if their storage capacity between minimum and maximum pool is 0.3 inches or less of excess precipitation over the contributing area.

3.3 EVALUATION OF SELECTED DAMS

3.3.1 Dams Evaluated in Detail

While this study provides general recommendations to reduce flooding in all of the areas affected by the May 2006 and April 2007 floods, dams along four of the rivers were investigated in more detail. The evaluation of operations at these dams during the two events is based in part on the dams’ capability to provide flood control benefits. Consequently, the dams were grouped into the four categories discussed in Section 3.2 and are listed along with their classification in Table 3-1.

Table 3-1: Dams Evaluated and Their Classifications

Salmon Falls River

Reservoir	Storage (acre-feet)		Excess Precipitation (in)			Flood Control Capability
	Full Storage	Max Storage	Winter to Full	Full to Max	Winter to Max	
Great East Lake	19600	27700	6.10	9.71	15.81	Significant Local Flood Control
Horn Pond	2751	3318	0.25	0.68	0.93	Some Local Flood Control
Cooks Pond	594	1260	8.5	7.19	15.69	Significant Local Flood Control
Lovell Lake	1750	2400	7.8	2.55	10.35	Significant Local Flood Control
Milton Three Ponds	12500	15000	0.69	0.42	1.11	Some Local Flood Control
Spaulding Pond	325	700	N/A	0.06	0.06	Run-of-River: No Flood Control
Baxter Mill Dam	230	350	N/A	0.02	0.02	Run-of-River: No Flood Control

Suncook River

Reservoir	Storage (acre-feet)		Excess Precipitation (in)			Flood Control Capability
	Full Storage	Max Storage	Winter to Full	Full to Max	Winter to Max	
Sunset Lake	1400	1860	4.90	1.21	6.11	Significant Local Flood Control
Crystal Lake	1400	3500	0.90	1.44	2.34	Some Local Flood Control
Suncook Lake	1617	7917	1.09	2.15	3.24	Significant Local Flood Control
Barnstead Parade	550	1000	N/A	0.08	0.08	Run-of-River: No Flood Control
Pittsfield Mill Dam	112	212	N/A	0.01	0.01	Run-of-River: No Flood Control
Pleasant Lake	552	1200	N/A	3.45	3.45	Significant Local Flood Control
Northwood Lake	2400	3200	2.24	0.75	2.99	Some Local Flood Control
Buck Street Dams	84	413	0.02	0.03	0.05	Run-of-River: No Flood Control
Webster Mill Dam	60	165	N/A	0.01	0.01	Run-of-River: No Flood Control
China Mill Dam	6	14	N/A	0.00	0.00	Run-of-River: No Flood Control

Piscataquog River

Reservoir	Storage (acre-feet)		Excess Precipitation (in)			Flood Control Capability
	Full Storage	Max Storage	Winter to Full	Full to Max	Winter to Max	
Deering Reservoir	3400	4980	5.64	7.06	12.70	Significant Local Flood Control
Horace Lake	6300	8600	1.05	1.49	2.54	Some Local Flood Control
Everett Dam	1000	132800	N/A	25.76	25.76	Regional Flood Control Dam
Gregg Falls	1800	4700	N/A	0.27	0.27	Run-of-River: No Flood Control
Kelley Falls	1000	2290	N/A	0.11	0.11	Run-of-River: No Flood Control

Souhegan River

Reservoir	Storage (acre-feet)		Excess Precipitation (in)			Flood Control Capability
	Full Storage	Max Storage	Winter to Full	Full to Max	Winter to Max	
Otis Falls	75	105	N/A	0.02	0.02	Run-Of-River: No Flood Control
Pine Valley Mill	30	70	N/A	0.01	0.01	Run-Of-River: No Flood Control
Site 28	6	187	N/A	3.08	3.08	Significant Local Flood Control
Site 8	180	2721	N/A	10.14	10.14	Significant Local Flood Control
Site 14	23	885	N/A	7.70	7.70	Significant Local Flood Control
Site 19	85	2072	N/A	3.27	3.27	Significant Local Flood Control
Site 13	12	249	N/A	5.56	5.56	Significant Local Flood Control
Site 35	37	1787	N/A	5.13	5.13	Significant Local Flood Control
Site 26	30	1486	N/A	5.57	5.57	Significant Local Flood Control
Site 12A South	690	3310	N/A	8.77	8.77	Significant Local Flood Control
Site 25B	38	1623	N/A	5.50	5.50	Significant Local Flood Control
Site 15	74	708	N/A	10.81	10.81	Significant Local Flood Control
Site 10A	49	2735	N/A	7.87	7.87	Significant Local Flood Control
Site 33	0	1078	N/A	20.21	20.21	Significant Local Flood Control

Detailed descriptions of the dams and their typical operations are provided in Appendix B, Description of Dams and Typical Operations: Salmon Falls, Suncook, and Piscataquog River Basins, and Appendix C, Description of Dams and Typical Operations: Souhegan River Basin.

The dams were evaluated in three phases to determine whether they were operated to minimize flooding during the May 2006 and April 2007 events:

- Phase 1 – Operations at the selected dams were determined by examining operator records
- Phase 2 – Computer models were run to simulate the operations at the selected dams
- Phase 3 – The computer models were re-run to examine “what-if” scenarios to assess the impacts of alternative operations at the selected dams

3.3.2 Actual Operations

The first phase of the evaluation of dam operations during the May 2006 and April 2007 events focused on collecting relevant information.

Streamflow data were obtained primarily from the USGS, but also from the USACE and the NHDES data collection networks. Lake elevations (“pool elevations”) were supplied by the USACE, the NHDES, and operators of private dams. For most NHDES dams, pool elevations are read only at times when a NHDES dam operator is on site. This is typically once a week, but may be several times a day during flood conditions. Pool elevations are usually recorded by day and do not include the exact hour of the observation. In this study, observations were assumed to occur at noon, unless otherwise noted.

Records of dam operations during the events were also collected during this phase. The NHDES keeps logs of dam operator activities, which provides a history of operations performed. The NHDES dam operation logs typically note the current pool elevation and changes to gates (opening or closing) and stoplogs (adding or removing stoplogs), recorded by date. The dam operators often note special conditions at the dam site, such as debris or ice on the lake. The NHDES provided these dam operation logs for use in this study. Operations at private dams during the May 2006 and April 2007 events were provided by the owners and vary from detailed observations (every 5 minutes) to qualitative descriptions only. Detailed discussions of operating rules and operations at the dams during the May 2006 and April 2007 events are provided in Appendices B and C.

3.3.2.1 Operations at Regional Flood Control Dams

Of the dams investigated, only Everett Dam and the relatively small flood control sites on the Souhegan River are dedicated flood control dams. Everett Dam is operated by the USACE according to long established and proven flood operation rules, which are posted on the USACE New England District Web site at www.reservoircontrol.com (USACE 2008a).

Everett Dam captured all of the upstream runoff and released only minimum flows during the 2006 and 2007 events. The reservoir filled to 58 percent of its capacity in 2006 and 53 percent of its capacity in 2007 before increasing its releases after the events to draw down the pool.

3.3.2.2 Operations at Lakes Providing Significant Local Flood Control Benefits

All lakes that provide significant local flood control benefits along the four rivers are operated by the NHDES. They are typically held at a constant elevation during the summer. Starting in October, lake levels are lowered to a winter elevation, typically 3–7 feet below the summer elevation. This is primarily done by removing stoplogs; however, Sunset Lake has none and is operated using a gate.

The timing of the refill depends on the storage differences of the lakes between the winter and summer pool elevations. Lakes with large storage differences, such as Cooks Pond (also called Kingswood Lake), require more runoff to fill and begin refilling as early as January, when the lakes are typically frozen. Most of these lakes are at the summer pool elevation by May. Other lakes, such as Suncook Lake, require less runoff to reach the summer pool elevation and begin refilling only after the spring runoff season has ended.

During the May 2006 and April 2007 flood events, these lakes in the Salmon Falls, Suncook, and Piscataquog basins captured the majority of the upstream inflows in most cases and thus provided *local* downstream flood control.

The NHDES increased releases from some of the lakes prior to the April 2007 event, but did not operate the dams during the event. Significant overtopping or flooding was reported only at Suncook Lake (which has little storage capacity between winter and summer levels) and Pleasant Lake. NHDES operated the dams more actively in May 2006. Pool elevations at Northwood Lake were lowered in anticipation of the event. Additional operations at the dams were aimed at increasing releases at the onset and also during the event to lower pool elevations and prevent upstream flooding. In spite of these efforts, Pleasant Lake spilled over the street next to the outlet structure. The NHDES reported upstream flooding at the Sunset and Suncook lakes in 2006 and at Suncook Lake in 2007.

The differences in operation during the 2006 and 2007 floods can be attributed to the pool elevations before the events. In April 2007 the lakes (except Pleasant Lake) were still refilling from the winter pool elevations and had ample free storage capacity. In contrast, the lakes were closer to full pool elevation in May 2006 and therefore provided less storage capacity. Consequently, they required more active operations to evacuate water before the event and prevent upstream flooding during the event. Also, the colder weather and ice covered lakes hampered operations in April 2007.

The flood control sites on the Souhegan River basin consist of 12 reservoirs operated by NHDES. These have no substantial gates or operating valves that require operating rules.

During the 2006 and 2007 events, about 65 percent and 75 percent of the storage capacity below the emergency spillway in these reservoirs, respectively, was used to reduce flows. As noted in Appendix C, Description of Dams and Typical Operations: Souhegan River Basin, these reservoirs reduced peak discharges in the Souhegan River basin by more than 25 percent in both the 2006 and 2007 storm events.

3.3.2.3 Operations at Lakes Providing Limited Local Flood Control Benefits

The seasonal operations at NHDES lakes that provide limited local flood control are typically as follows: The pool elevation is held at a constant elevation during the summer. Only Milton Three Ponds is operated to slowly lower its pool elevation from a June 1 target level to a Columbus Day target level. Starting in October, lake levels at all lakes are lowered to a winter elevation typically 1.5 to 5 feet below the summer elevation. This is done primarily by removing stoplogs or flashboards, although gates are operated at Milton Three Ponds.

The lakes generally require little runoff (less than 2.5 inches of excess rainfall) to refill. Refilling operations are therefore typically not started until the lakes are free of ice around mid-April or the beginning of May.

No detailed written flood operation rules exist. During flood conditions, the primary operation objectives are to minimize downstream flooding, to avoid upstream flooding (which can occur below the maximum pool elevation), and to prevent overtopping the dam itself.

Prior to the April 2007 flood event, Milton Three Ponds and Crystal Lake were operated to increase releases in anticipation of the event. During the event, releases at Milton Three Ponds were designed to minimize upstream and downstream flooding. Nevertheless, upstream flooding was reported at Milton Three Ponds and at Crystal Lake in April 2007. The other lakes filled rapidly and in doing so provided downstream flood control, particularly at the beginning of the event. Northwood Lake overtopped at the dam, which was sandbagged to prevent damage.

The dams were operated more actively in May 2006, where the pool elevations at the beginning of the event were higher than in April 2007. Stoplogs were removed in anticipation of the event at Horn Pond, Crystal Lake, and Northwood Lake. All dams, with the exception of Horace Lake, were operated during the event to increase releases.

At least 14 dams provide limited local flood control on the Souhegan River Basin and few, if any, have detailed operating rules.

3.3.2.4 Operations at Run-of-River Dams

Seasonal operations at the Run-of-River dams in the system typically consist of removing the flashboards (where installed) in the fall to prevent damage by ice. Additional drawdowns are performed at the Barnstead Parade and Buck Street Dams.

Private, Federal Energy Regulatory Commission (FERC)-licensed dams (Spaulding Pond, Webster Mill Dam, China Mill Dam, Gregg Falls Dam, and Kelley Falls Dam) are operated according to written flood operation rules. They stipulate operations that increase the discharge capacities of the dams during large events to prevent overtopping of the dam structures. Similar operating criteria exist for the small private dams on Souhegan River Basin where flashboards are required to be maintained at a constant level during normal weather conditions and are required to be removed in flooding conditions.

During the 2006 and 2007 flood events, operations at the private FERC-licensed dams followed the operating rules; however, in 2007 flows through the powerhouse at China Mill Dam were stopped because of damaged equipment. Also, in 2007 power generation was interrupted at Kelley Falls Dam due to debris accumulation. Significant upstream flooding occurred at this site in April 2007, despite the fact that the dam was operated to pass as much flow as possible, and the power interruption had little bearing on flood levels.

Flashboards were installed at Barnstead Parade, and at Kelley Falls Dams in 2006. The flashboards at Barnstead Parade operated during the event. Flashboards installed at Kelley Falls Dams in 2007 operated before and during the event.

Run-of-River dams are not designed to store flood waters and to reduce downstream flows. Operations during flood events typically aim at preventing upstream flooding. The NHDES actively operated its Run-of-River dams to achieve this goal both in 2006 and in 2007, mainly to increase the discharge capacities before and during the event.

Baxter Mill Dam has no structures to control flows. Parts of its wooden spillway were washed away in May of 2006 and another section failed in April 2007. The entire spillway was lowered by 5 feet after the April 2007 event.

At Pittsfield Mill Dam, newly installed gates got stuck during the April 2007 event and could only be operated late in the event and at great effort. The dam overtopped during both events and required sandbagging to prevent damage to the dam.

The gates at the Buck Street Dams were fully open during both events and most of the stoplogs were removed in April 2007. Still, the dam overtopped significantly during both events, with concurrent upstream flood damage.

Flashboard operation generated considerable public concern on the Souhegan River basin, particularly at Otis Falls Dam and Pine Valley Mill Dam, which are located in the upper and middle Souhegan River watershed. The public perceived the timing of the removal of the flashboards on these dams as greatly increasing downstream flooding.

3.3.3 Simulations of What Actually Happened During the Events

The second phase in determining the role of the dams during the May 2006 and April 2007 events was to simulate the operations at the dams and the resulting flows during the events. The goal was to estimate pool elevations, lake inflows, and releases for times when there were no observed records using computer models. The simulation results provided the baseline case against which to evaluate alternative operation scenarios at the dams.

This study utilized two different types of models for the simulations: Computer models already utilized by a forecast system operated by the NHDES were used to simulate pool elevations and flows on the Salmon Falls River, the Suncook River, and the Piscataquog River. A HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) model, a rainfall-runoff hydrologic model developed by the USACE, was created and used to simulate the conditions in the Souhegan Basin, where no NHDES model exists.

The models in the NHDES forecast system are similar to those used by the National Weather Service (NWS) to predict river flows at the NWS River Forecast Centers. Mean areal temperature and precipitation are used as input to a snow model, which simulates the accumulation and melting of snow in the area. The output from this model consists of snow melt (when snow on the ground is melting) and rainfall (when no snow is present), expressed as depth of water in inches over the simulated area. This output is fed into a soil moisture accounting model, which transforms the snowmelt and rainfall into runoff into a lake or river reach. The estimated runoff depends on the amount of snowmelt, rainfall, and the moisture content of the soil (e.g., a wetter soil has higher moisture content and produces more runoff than dry soil). The NHDES forecast system also includes lake simulation models, which estimate lake elevations based on inflow to and releases from the lakes. The releases are determined based on reported opening heights of gates at the dam, the number of stoplogs in the bays, the presence of flashboards, and releases through turbines at hydropower generation sites.

The climate data used for this study are temperatures and precipitation recorded during the May 2006 and April 2007 events, available primarily from the USGS, the USACE, the NWS, and a network operated by the NHDES to monitor climatic conditions. These data are typically recorded every 15 minutes or every hour at climate sites in the region, and provide a good description of the general weather conditions during the May 2006 and April 2007 flood events.

As part of the initial model simulations, mean areal temperature and precipitation were estimated from the available climate observations. In general, there were only a few climate sites reporting in the area and the estimated mean areal temperature and precipitation are questionable at certain points in the simulation. Consequently, these data sets were adjusted as needed to provide adequate and correctly timed snowmelt and rainfall volumes to allow realistic lake inflow computations.

The computer models simulated the observed pool elevations and river flows well, confirming their suitability to model what-if scenarios of alternative dam operations. Figure 3-1 shows the simulation of the pool elevation during the April 2007 event at Horn Pond as an example. Simulation results for all modeled lakes are provided in Appendix B and Appendix C.

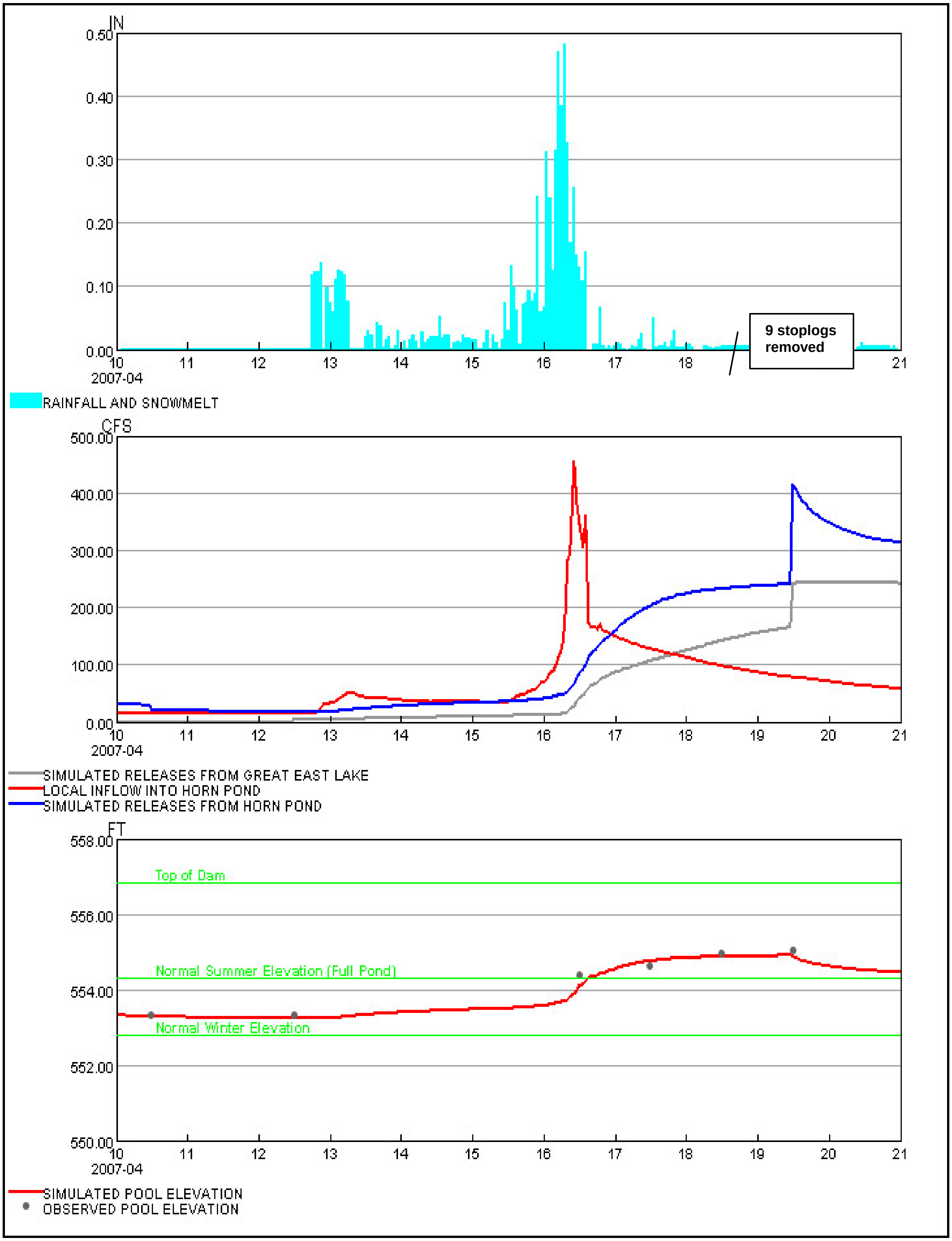


Figure 3-1: Simulation Results for Horn Pond for the April 2007 Event showing the period April 10 2007 to April 21 2007

For the Souhegan River Basin, HEC-HMS was used to examine the storm events of May 2006 and April 2007. The model incorporated data from 59 dams and their corresponding drainage basins, rainfall input provided by NHDES, and USGS runoff data. The May 2006 and April 2007 events were simulated and then alternative operation scenarios were examined focusing on operations at the Otis Fall Dam and Pine Valley Mill Dam.

3.3.4 Alternative Operations Evaluated in What-If Scenario Simulations

In this third phase of the study, the computer models mentioned above were executed using the same temperature and precipitation data, but alternative dam operations. These simulations helped in addressing questions and concerns articulated after the events regarding dam operations.

The following alternative dam operations were investigated:

1. **Would there have been less flooding in April 2007 had all lakes been at the winter pool elevation?**
   During the April 2007 event, many of the NHDES operated dams were in the process of refilling from the lower winter levels to the higher summer levels. A scenario assuming normal winter pool elevations on April 14 for all lakes was evaluated using the models described in Section 3.3.3. Keeping the lakes at normal winter pool elevations would, however, increase the risk of not reaching target summer elevations. The scenario results suggest the following:

   a. Entering the April 2007 event at the lower winter pool elevations would have enabled the lakes that provide significant local flood control benefits to store considerably more flood waters, thereby significantly reducing releases even with no changes to the operations during the event. However, these lakes are located in the upper parts of the basins, and reduced releases would be cancelled out by the large amounts of snowmelt and rainfall occurring downstream. Additional flood control benefits would only have been significant just downstream of the lakes.

   b. Lakes that typically provide limited flood control benefits further downstream would still have received very large inflows and filled very quickly from their winter pool elevations to above the summer pool elevations. Releases from these lakes would have been reduced at the beginning of the event and the maximum pool elevations reached would have been lowered by one foot or less.

   c. Entering the April 2007 event at the lower winter pool elevations would have had no appreciable effect on the run-of-river dams downstream, as most of the runoff would have been generated below the larger lakes that stored more flood waters.

   In summary, entering the April 2007 event at winter pool elevations would have resulted in less flooding only in the upper parts of the basins investigated. The effects further downstream would have been minor.

2. **Could alternative operations at Milton Three Ponds have averted some of the upstream flooding in April 2007?**
   The April 2007 event caused some flooding upstream of Milton Three Ponds Dam. Scenarios assessing whether different operations at the site could have lowered the maximum pool elevation reached during the event were evaluated. The results indicate that, given the actual

pool elevation at the beginning of the event, operation of the gates or the Obermeyer panel during the event would have had little impact on the peak releases or the peak pool elevation. However, significantly lower pool elevations at the beginning of the event would have lowered the maximum pool elevation. Had the lake been at the winter pool elevation, then the maximum pool would have been a third of a foot lower. Very drastic operations (such as opening all gates and removing all stoplogs) 6–8 days before the event would have lowered the maximum pool elevation reached during the event. However, anticipating events and consequently operating dams this far ahead of time is typically not possible.

3. **Could alternative operations at Suncook Lake have averted some of the upstream flooding in April 2007?**
   High pool elevations at Suncook Lake caused damages along the shore in April 2007. Not all gates at the dam were opened completely during the event, thus a scenario assessing whether this contributed to the upstream flooding was evaluated. The results indicate that fully opening gates 1 day or even 3 days before the event would have had negligible impact on the maximum pool elevations reached.

4. **Could alternative operations at Crystal Lake have averted some of the upstream flooding in April 2007?**
   Upstream flooding was reported in April 2007 at Crystal Lake. Scenarios assessing lower pool elevations and more aggressive stoplog removal were evaluated. Results indicate that pool elevations approximately 0.5 foot lower could have been achieved (1) had the lake been at its winter pool elevation at the beginning of the event or (2) had it been possible to remove all 10 stoplogs at the site on April 12.

5. **Did the failure of part of the spillway at Baxter Mill Dam in April 2007 worsen downstream flooding?**
   A scenario designed to simulate the failure of the spillway at Baxter Mill Dams indicates that flows over the wooden spillway at Baxter Mill Dam were so large, that the failure of a small section during the April 2007 event did not significantly alter the pool elevations or downstream flows. An additional scenario assuming that the spillway at Baxter Mill Dam was 5 feet lower during the April 2007 event (which is its current configuration) suggests that flows just downstream of the dam would have been virtually unchanged.

6. **Did the difficulties in opening the gates at Pittsfield Mill Dam in April 2007 cause upstream flooding?**
   New gates installed at Pittsfield Mill Dam before the April 2007 flood event did not operate properly during the event. A scenario assessing proper operation of the gates was evaluated. The scenario results indicate that proper operation of the gates in April 2007 would have only minimally altered the releases or the maximum pool given the large inflows to the dam. Simulations also suggest that the peak flows and maximum pool reached would not have changed considerably even if the lake been completely empty before the event.

7. **Could alternative operations at the Buck Street Dams have prevented some of the upstream flooding that occurred in April 2007?**
   The Buck Street Dams overtopped during the events of May 2006 and April 2007, causing significant upstream flooding. A scenario assessing the operations had the gates been free of debris and all stoplogs removed was evaluated for the April 2007 event. According to the simulation results, the dams would still have overtopped significantly during the April 2007

event, and based on similarities with conditions at the site, would have overtopped significantly during the May 2006 event.

8. **Would earlier operations at Webster and China Mill Dams in April 2007 have changed pool elevations and releases at the sites?**
   Both Webster Mill and China Mill Dams opened all gates and removed stoplogs before the peak of the April 2007 flood. Scenarios assessing whether an earlier increase of discharge capacities at the dams would have changed maximum pool elevations or releases were evaluated. The results suggest that earlier increases of the discharge capacities at the sites would have quickly dropped the pool elevations and caused a short spike in releases only to have the pool elevations rise to levels similar to those before the operation change. Earlier operations would not have noticeably changed peak flows or peak pool elevations.

9. **Did the flashboards and shutting off the turbines at Kelley Falls Dam in April 2007 contribute to the upstream flooding?**
   Flashboards present at Kelley Falls Dam at the onset of the April 2007 event operated during the event. Also, the turbines at the site were shut off during the event because of debris accumulation at the intake and because water elevation differences upstream and downstream of the dam were too small to generate power. Scenarios assessing different timing of flashboard activation and continual operation of the turbines were evaluated. The results indicate that inflows to the lake were so large that neither the presence of flashboards at the beginning of the event, nor the turbine shut-down during the event, significantly affected the releases or the maximum pool reached.

10. **Would lower pool elevations at Gregg Falls or Kelley Falls Dams at the onset of the April 2007 event have averted some of the upstream flooding?**
    Typically, the impoundments upstream of Gregg Falls and Kelley Falls Dams are kept at or above the spillway elevations. Scenarios assessing low pool elevations entering the April 2007 event at both Kelley Falls Dam and the upstream Gregg Falls Dam to reduce upstream flooding were evaluated. The most aggressive scenario assumed that both pools upstream of the dams were completely empty before the event. The results indicate they still would have filled within hours. Once full, the releases and pool elevations would have been defined by the capacities of the dams to pass the inflows, similar to what actually happened. Consequently, peak releases or peak pool elevations would have been virtually unchanged.

11. **Would any basin-wide policy that required lower normal water conditions have reduced flooding conditions on the Souhegan River Basin during either the May 2006 or April 2007 events?**
    To examine the extent of operating flexibility on the Souhegan River basin, a scenario assuming all of the 59 reservoirs within the basin were empty was examined. This situation is not physically or legally possible, but it provided a scenario that maximized the storage capacity of all of the reservoirs within the basin. Because the overall storage within the Souhegan River Basin is so small and the magnitude of the May 2006 and April 2007 events was so severe, the results show no impact on the peak discharge of the Souhegan River, even in this idealized condition.

12. **What impact did the 12 flood control sites on the Souhegan River Basin have on overall basin flooding during the May 2006 and April 2007 events?**
    The impact of these reservoirs was quantified by comparing the actual events with scenarios

in which all of the 12 flood control sites operated by NHDES were removed. The results indicate the removal of these dams would have resulted in an increase in peak discharges of more than 25 percent during both the May 2006 and the April 2007 events at the USGS stream gage near the mouth of the Souhegan River.

13. **Could the operation of the Run-of-River dams in the Souhegan River Basin be improved to reduce flooding conditions?**
Various scenarios were analyzed examining the differing accounts of flashboard operation on both Otis Falls Dam and Pine Valley Mill Dam during the April 2007 event. From an overall basin perspective, simulations showed that operations at these small dams make virtually no difference (<1 percent difference in peak discharge for the entire basin). More noticeable localized effects, within a mile of the dam location, would be observed with the abrupt removal of the flashboards. These effects would be particularly noticeable on Otis Falls Dam (>2 foot increase in water surface elevation immediately downstream of the dam dissipating to no change in elevation 2 miles downstream from the dam) if the flashboards were removed relatively close to the peak of the storm. The results suggest that the localized downstream flooding impact would be less severe the earlier the flashboards are removed relative to a storm event. The increased flooding due to flashboard removal is limited to the first mile below these small dams; any further downstream and the increase in peak flow is attenuated through floodplain storage.

Results of the scenario runs are presented in Appendix B and Appendix C.

3.4 KEY FINDINGS

Based on the operations assessment and the scenario runs:

- None of the actual operations during the events had significant impacts on downstream flooding for the dams evaluated.
- While Everett Dam was able to provide significant flood control benefits along the lower reaches of the Piscataquog River, uncontrolled flood flows from the South Branch Piscataquog River still caused significant flooding in the Manchester area.
- The larger lakes in the upper areas of the basins investigated stored significant amounts of water and thus provided significant local flood control benefits. However, due to heavy rainfall and snowmelt downstream of these lakes, they had little effect on reducing flows in the lower areas of the basins.
- The privately owned dams that were investigated did operate as expected, i.e., they increased their discharge capacities as much as possible at the onset of the event. Releases through turbines were small compared to the overall discharge and did not significantly affect the maximum pool elevation reached.
- Upstream flooding occurred at some of the lakes in 2007. Simulation results indicate that no realistic and reasonable operations at the dams investigated could have prevented flooding at these sites.
- For the dams that provide flood control benefits, the pool elevation at the beginning of an event has a greater impact on releases than operations during the event.

- No realistic operations scenarios could have prevented the Pittsfield Mill and Buck Street Mill Dams from overtopping. Overtopping during events of the size of the May 2006 and April 2007 events could only be averted through structural changes at the sites.
- Operations of flashboards during the events and the failure of parts of the spillway at Baxter Mill Dam had only very localized impacts. They did not contribute to flooding further downstream.
- Any alternative operations at the Run-of-River dams before or during the events would have had little impact on the releases from the sites and thus downstream flooding.

SECTION FOUR FLOODPLAIN MANAGEMENT

4.1 OVERVIEW

The purpose of this section is to evaluate the many components of floodplain management in south central and southeastern New Hampshire. Sound floodplain management helps prevent flooding and helps reduce the impact of flooding when it occurs. This section examines the following topics:

- Land Use – Specifically, did recent land use development exacerbate the flooding that occurred in May 2006 and April 2007?
- Erosion, sediment, and woody material – Do erosion, sedimentation, and woody material aggravate flooding?
- The National Flood Insurance Program – Is the flood plain mapping developed by the NFIP accurate, and is it being used effectively in the study area?
- State Dam Safety Regulations – Are the State's dam safety regulations adequate?
- Flood Forecasting – Are flood forecasts accurate and are they used effectively to anticipate and respond to flooding events?
- Emergency Operations – Is the response at all levels of government during flood emergencies adequate and effective?

The information presented in this section is evaluated in Section 5 to establish potential improvements to floodplain management.

4.2 DID LAND USE DEVELOPMENT MAKE THE FLOODING WORSE?

Development changes the landscape. What were once undeveloped forested or agricultural lands become streets, highways, and parking lots; and industrial, commercial, and residential buildings. Natural drainage is replaced with pipes and channels designed to quickly remove runoff from these areas to nearby streams. The pervious acreage is replaced with impervious surfaces. Rain that once slowly infiltrated into the soil and contributed little to storm runoff can no longer infiltrate the soil. These changes can all contribute to increased flooding.

The impact of development on flooding depends on many circumstances: the intensity and location of the development, the type of rainfall event, and the size of the drainage area among them. In general, (1) more dense development causes greater imperviousness and requires a denser storm drainage system; (2) short severe events that do not saturate the soil result in larger increases in runoff than longer events; and (3) the impacts of development are more obvious for smaller drainage areas. Land use change affects smaller events to a greater extent than events the size of the May 2006 and April 2007 events.

As demonstrated below, land use development made the flooding only slightly worse during the May 2006 and April 2007 events on a watershed-wide basis. These events were long duration events that saturated the soils, thereby providing little opportunity for subsequent rainfall to infiltrate. Thus, the landscape responded as if it was impervious and fully developed.

To quantify the impacts of land use development, the Souhegan River Basin computer simulation model was adjusted to reflect 1986 land use conditions. Then, the April 2007 rainfall event was applied to the model. The results were compared to the most recent land use conditions data (GRANIT, 2001) to model the impact of increased development on flooding.

For both 1986 and 2001, each land use classification was assigned a percent imperviousness, which was used in turn to adjust the "Curve Number" parameter in the computer simulation model. Curve Number (CN) describes the amount of runoff from a rainfall event. The CN used in the model for each land use classification accounted for the imperviousness of that land. The higher the CN, the higher the percentage of rainfall converted to runoff. The estimated percent increase in CN between 1986 and 2001 for sub-basins within the Souhegan River Basin is shown in Figure 4-1. Although development has sometimes been intense on a neighborhood or subdivision basis, increases in CN on a sub-basin and basin basis have been modest, typically ranging from 0 percent to 4 percent. Development also involves channel lining and straightening. Channel lining and straightening are not widespread in the Souhegan River Basin and did not have a significant basin-wide impact.

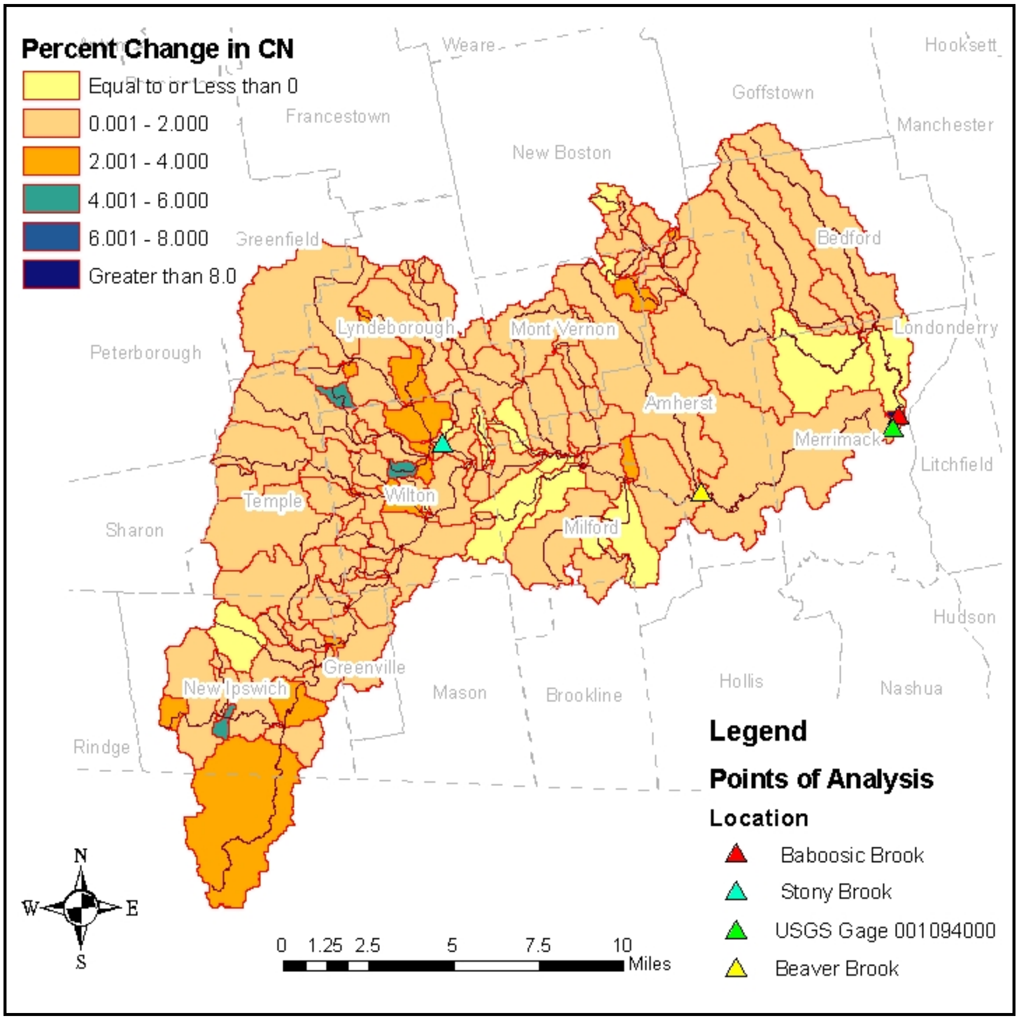


Figure 4-1: Changes in Curve Number in the Souhegan River Basin as a Result of Land Use Changes between 1986 and 2001

The results of the analysis at USGS Gage 001094000 are shown in Figure 4-2. Had the April 2006 event occurred in 1986, the peak discharge would have likely been less than 1 percent lower, a relatively insignificant difference. This minimal change attributable to a long duration rainfall combined with rapid snowmelt on saturated soil. Had rainfall and snowmelt circumstances been different, the increase attributable to development could have been greater.

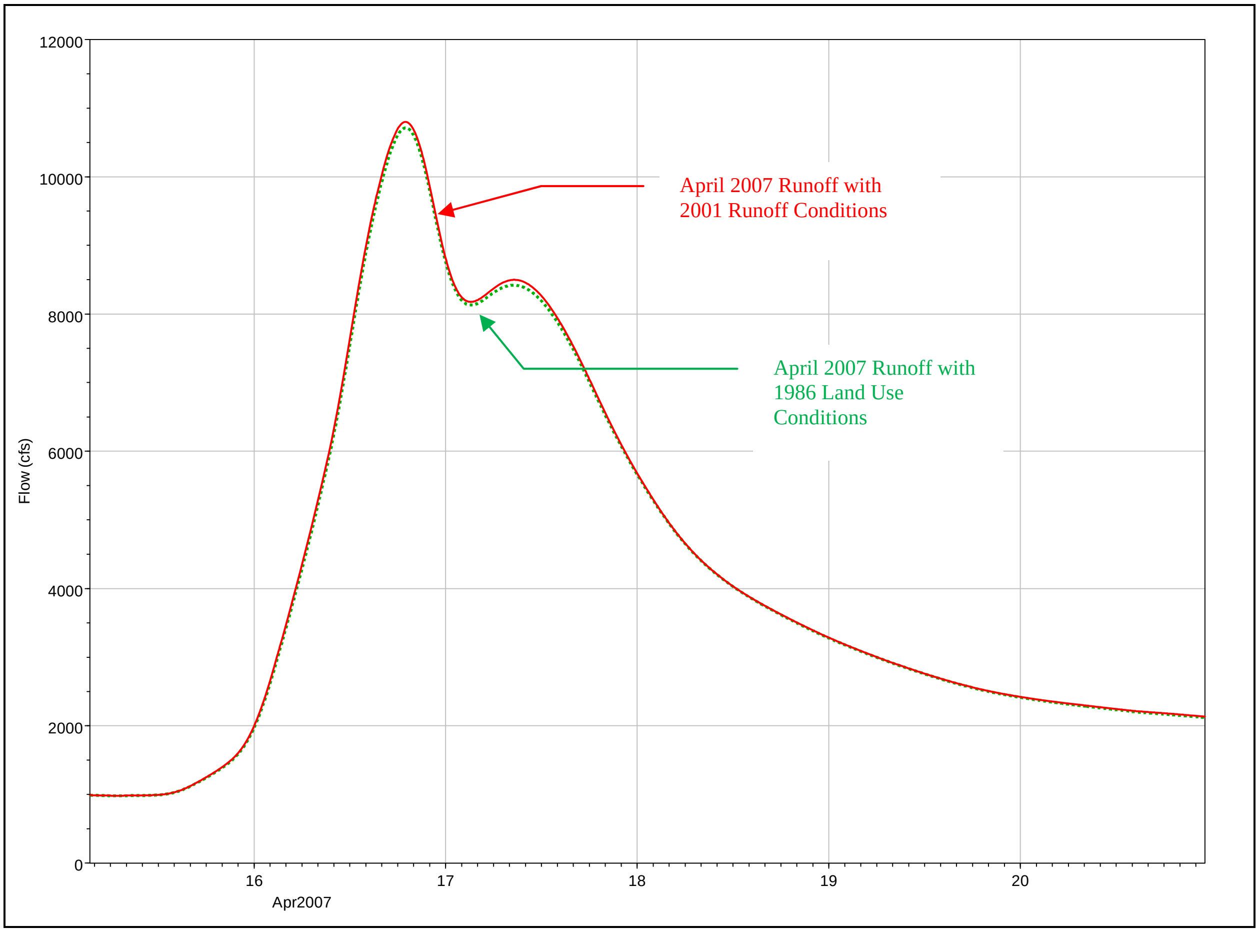


Figure 4-2: Comparison of Runoff from the April 2007 Event under 1986 and 2001 Land Use Conditions at USGS Gage 001094000

Table 4-1 below summarizes the peak flows for both the 1986 and 2001 land use under April 2007 conditions at USGS Gage 001094000, at the mouth of Baboosic Brook in Bedford, and on Stony Brook at the confluence with King Brook in Wilton. Because of the saturated conditions and the contribution of snowmelt during the event, only small differences in peak flow are attributable to land use changes. Had a smaller storm occurred during less saturated conditions, the impact of land use changes (percent increase in peak flow) would have been greater. To illustrate, a 2-year flood event was simulated, and the CNs were adjusted to reflect more normal (unsaturated) soil conditions. Table 4-2 shows the results of this simulation.

Table 4-1: Comparing Peak Flows (cfs) During April 2007 Conditions at Locations in the Souhegan River Basin

	Souhegan River at USGS Gage (171.1 sq. mi.)	Baboosic Brook in Bedford (49.1 sq. mi.)	Stony Brook in Wilton (31.2 sq. mi.)
1986 Land Use	10,710	3,575	2,306
2001 Land Use	10,799	3,611	2,322
Increase	0.8%	1.0%	0.6%

Table 4-2: Comparing Peak Flows (cfs) During 2-Year Flood Event Conditions at Locations in the Souhegan River Basin

	Souhegan River at USGS Gage (171.1 sq. mi.)	Baboosic Brook in Bedford (49.1 sq. mi.)	Stony Brook in Wilton (31.2 sq. mi.)
1986 Land Use	3,080	1,639	810
2001 Land Use	3,176	1,681	852
Increase	3.1%	2.6%	5.2%

Development and urbanization had a minimal impact on the flooding during the May 2006 and April 2007 events. However, the impact of development is not necessarily linear. Some research, such as *USGS Water Supply Paper 2207* (Saur et al. 1983), indicates that at the threshold of 10 percent imperviousness, there are more significant changes to peak flow rates attributable to development. None of the sub-basins in the Souhegan River watershed approach 10 percent impervious overall. However, local areas within sub-basins may approach this threshold, so more significant local impacts may not be captured in this analysis. Also, imperviousness in the seacoast region increased from 4.7 percent in 1990 to 8 percent in 2005. Thus, the seacoast is approaching that threshold and could experience more significant flood impacts as development continues.

4.3 EROSION, SEDIMENT, AND WOODY MATERIAL: DO THEY AGGRAVATE FLOODING?

4.3.1 Erosion and Sediment

Streams naturally convey sediment, in addition to water, as they flow. This conveyance is a natural process of erosion and sedimentation (also called aggradation) that continues perpetually. Where the rate of erosion is approximately equal to the rate of sedimentation, this process is often described as dynamic equilibrium. When this dynamic equilibrium is interrupted, the amount of erosion and aggradation can dramatically increase. Eroded sediment is then deposited at rates exceeding what would have occurred naturally. It is deposited in the slow moving flatter sections of rivers and streams. As it builds up, it fills the stream channels and decreases their capacity. When heavy rainfall occurs, the channel can no longer contain the same flows, resulting in increased flooding and erosion. The resulting erosion and aggradation can directly threaten riverbank and river channel property and infrastructure. In Vermont, the damage done by flowing waters causing erosion during flood events far exceeds the damage from inundation by flood waters, and the State has taken special measures to identify erosion hazards.

The Suncook River downstream from the avulsion that occurred during the May 2006 flood presents a dramatic example of the impact of sedimentation.[1] The river broke through its former bank, and created a new channel before rejoining the old channel 0.5 mile downstream. As a consequence, the river has entirely new characteristics and the riverbanks continue to erode today.

Erosion and aggradation are also associated with construction and winter road sanding operations. Sediment loads in uncontrolled runoff from construction sites are several orders of magnitude greater than from natural landscapes. Winter sanding operations add tons of sediment to rivers and streams annually.

4.3.2 Woody Material

During the initial public meeting on December 12, 2008, meeting participants including town officials, emergency responders, and the general public repeatedly attributed flooding in locations throughout the study area to the accumulation of sediment and the accumulation of woody material consisting of felled vegetation. Woody material was identified as a significant issue in both the May 2006 and April 2007 flood events. Large trees were carried by the flood waters and held back at critical locations such as dams, culverts, and bridges, impeding flow. Specific locations where woody material was observed include the Piscataquog River at the railroad trestle upstream of Kelley Falls Dam, on the Salmon Falls River, and at Bucks Street dams on the Suncook River. Residents in the neighborhood upstream of the railroad trestle reported water was as much as four feet higher on the upstream side of the trestle because of the blockage. Sediment accumulation reportedly caused significantly higher lake levels by clogging outlet channels in lakes in the Contoocook River Basin.

Both sediment and woody material were identified by residents as major factors aggravating flood conditions at locations throughout south central and southeastern New Hampshire. To the extent these are natural processes (not aggravated by manmade conditions), they should be carefully managed to balance protection of natural processes while minimizing human impacts.

4.4 IS THE INFORMATION DEVELOPED BY THE NATIONAL FLOOD INSURANCE PROGRAM ACCURATE?

4.4.1 The Status of FEMA Floodplain Mapping in Southern New Hampshire

Claim payments to New Hampshire residents owning flood insurance surged following the May 2006 and April 2007 events, as shown in Figure 4-3. From 1978 to May 2006, payments totaled approximately $13.3 million. In 2006, payments on 585 claims totaled $13.6 million. Payments in 2007 on 484 claims totaled $10.4 million. Insurance payments for these two events totaled $24 million, almost double the amount paid out for all flooding events since 1978.

[1] An avulsion occurs when a portion of land is suddenly cut off by a flood, current, or change in course of a water body.

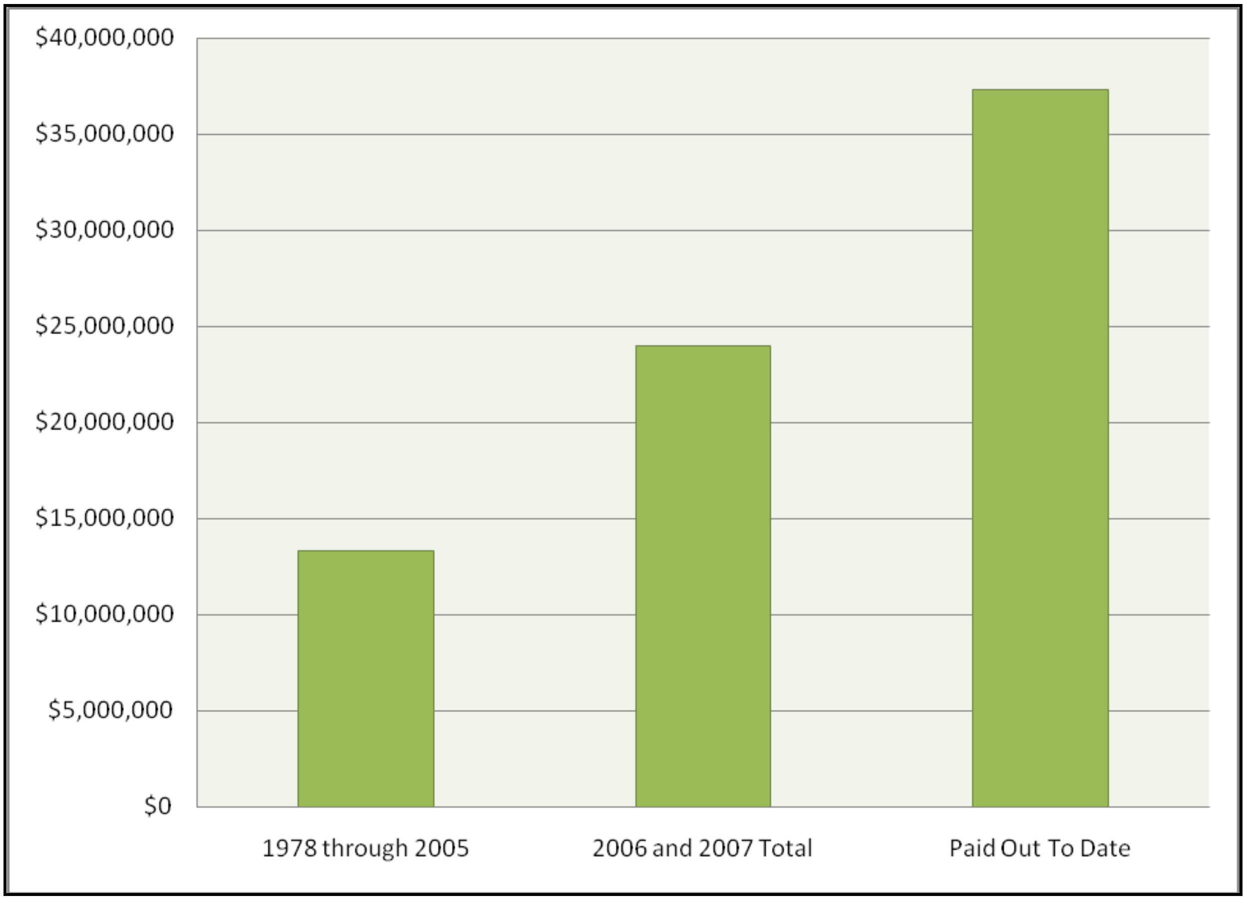


Figure 4-3: Claims Paid to New Hampshire Policyholders (Source: NHOEP)

FEMA is responsible for producing Flood Insurance Studies (FISs) and FIRMs in support of the NFIP. FEMA is currently in the fourth year of a 5-year "Map Modernization" program to improve the quality of the information used in the FIRMs. Most of the original FIS reports in New Hampshire are old, based on information developed in the 1980s. The FEMA Map Modernization efforts in the State have been devoted primarily to making Digital FIRMs (DFIRMs) *without* updating the underlying information developed in the 1980s. These floodplains are mapped onto digital aerial photographs, so that it is easier to tell if a particular point of interest (a building or house, for example) is located inside or outside of the floodplain. However, with few exceptions, the underlying data used to develop the floodplains is unchanged.

New DFIRMs are available for much of the study area, including Rockingham County and Strafford County. New DFIRMs are also available for Grafton, Cheshire, and Sullivan Counties in western New Hampshire. The communities in these counties (that participate in the NFIP) have all gone through a map adoption process and have floodplain management ordinances or bylaws that conform to the minimum standards of the NFIP. Therefore, all participating communities in the study area are in compliance with the NFIP.

DFIRMs (primarily based on digitization of the old FIRMs) for Hillsborough and Merrimack Counties are available in a preliminary form. These counties are currently going through the map adoption process. The communities in these counties that participate in the NFIP are also in compliance with the NFIP but will be required to modify their current ordinances or bylaws to use the new DFIRMs and remain in compliance.

Small portions of Belknap County are in the study area. These maps are not currently slated for revision during the Map Modernization Program. The old FIS and paper FIRMs are the currently effective maps for the communities in Belknap County.

According to the New Hampshire Office of Energy and Planning (NHOEP), for the 8,400 flood insurance policies in the State, forty-five percent are in Rockingham County. For structures located in the 100-year floodplain with a mortgage backed by the Federal government, the purchase of flood insurance policies is mandatory. However, if the property has no mortgage, then the purchase of flood insurance is encouraged but not required. Although 35 percent of flood insurance claims are for property located outside of the 100-year floodplain, the purchase of flood insurance is not required in these areas. Currently, 2,025 policies in the State insure structures located outside the 100-year floodplain.

The percentage of New Hampshire structures in the 100-year floodplain that are covered by flood insurance is not available, though the percentage is presumed to be very low. Thus floodplain managers such as local building inspectors responsible for implementing the NFIP often do not have complete knowledge of the number of floodprone buildings in their communities.

Participation in the NFIP is voluntary. Communities that participate in the program agree to adopt and enforce floodplain regulations that meet the minimum requirements of the NFIP, which involve regulating development in the 100-year floodplain. In return, all residents in participating communities are eligible to purchase insurance protection against losses from flooding. The availability of NFIP flood insurance is one of the biggest benefits to participating in the program. In New Hampshire, 201 of 235 communities participate, though two are suspended. In or near the study area, all communities except Sharon, Temple, Mont Vernon, Kensington, and Madbury participate (FEMA has determined there are no floodplain areas in the towns of Sharon and Temple). Currently, three communities in or near the study area have adopted floodplain ordinances but have not yet applied for participation in the program: Lyndeborough, Newton, and Atkinson. Following the 2006 and 2007 flood events, NHOEP conducted outreach activities to encourage the non-participating communities to join. In May 2006 and July 2007, NHOEP sent letters to the non-participating communities explaining the program. As a result of outreach efforts, NHOEP staff has presented information about the program to 16 communities. Since 2006, seven additional communities (four in or near the study area) now participate in the program. Currently, of the 34 non-participating communities, 8 communities are pursuing enrollment through adoption of the required floodplain regulations, 8 communities have expressed interest but have not yet taken any action, and 18 communities have either expressed no interest or have not responded to NHOEP’s outreach efforts.

Figure 4-4 shows a typical floodplain, and also some types of development that affect the floodplain. The floodplain is any land susceptible to periodic inundation. The 100-year floodplain is the land covered during the 100-year flood. The 100-year flood is more accurately called the 1-percent annual chance flood, a flood having a 1-percent chance of happening in any given year. The floodplain is often divided into a floodway and flood fringe. The floodway is the channel and nearby adjacent land that experiences the highest stream velocities. The flood fringe is the portion of the floodplain that stores water and is often susceptible to development.

As development occurs, the characteristics of the floodplain change. Buildings built too low can be flooded, the area required to pass the floodwaters is reduced, increasing flood elevations (shown as surcharge in Figure 4-4), and the flood waters that would have been stored in the floodplain move more quickly and at higher rates downstream.

For the purposes of the NFIP, no building is allowed in the floodway that would cause a rise in water surface elevation to the 100-year flood elevation. Building is allowed in the flood fringe area, as long as the lowest habitable elevation is above the 100-year flood elevation. If the entire flood fringe is developed, an increase in the 100-year flood elevation of up to 1 foot is allowed.

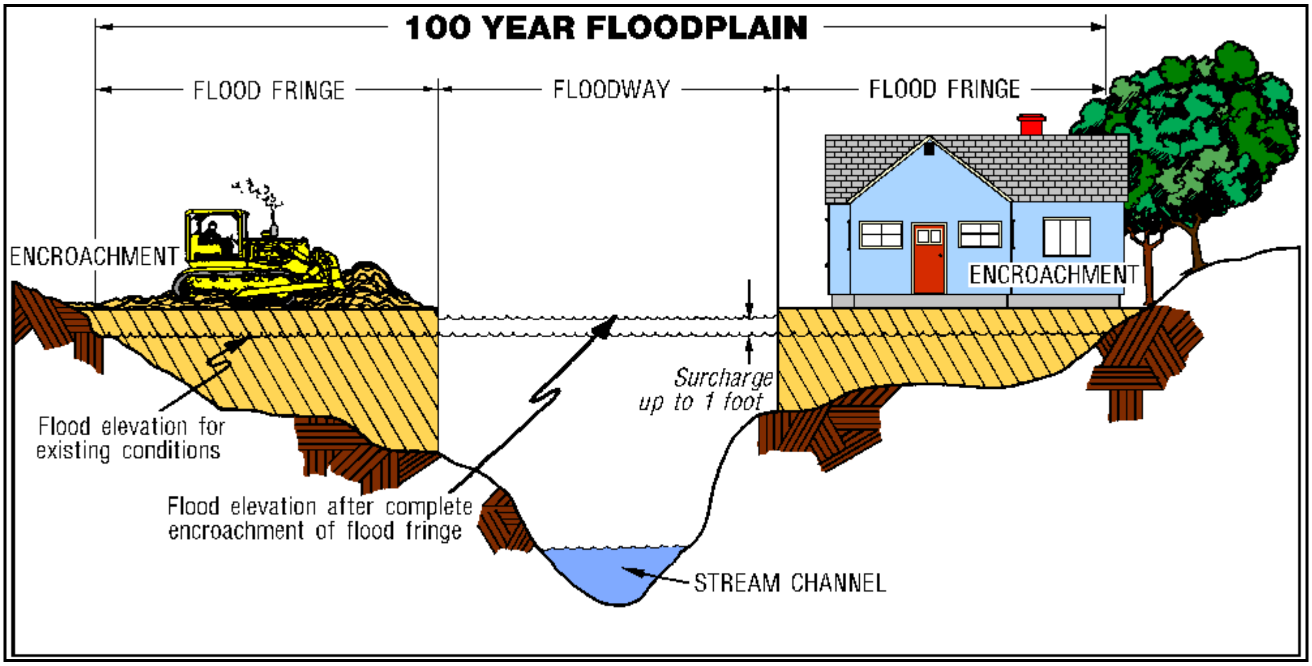


Figure 4-4: The 100-Year Floodplain (Source: USACE 2008b)

Many floodplain managers believe the NFIP minimum requirements are not sufficiently effective and promote the adoption of regulations that exceed the minimum requirements. These range from limiting or prohibiting development in the flood fringe area to building at a higher elevation than the 100-year flood elevation. NHOEP has conducted several outreach activities to encourage and assist communities in adopting regulations that exceed the NFIP minimum requirements. NHOEP also distributes information about communities in the State that have adopted more stringent regulations and reference documents to assist communities with determining which regulations are most suitable for them.

In the study area, some communities have adopted ordinances with standards that exceed the NFIP minimum requirements, including Bedford, Bow, Concord, Epsom, Litchfield, Salem, and Windham.

4.4.2 Is the Floodplain Information Accurate?

When establishing the 100-year floodplain in an FIS, two interdependent analyses are performed. The first is a hydrologic analysis in which the amount of water (discharge) present during the 100-year flood is estimated. The second is a hydraulic analysis in which the estimated discharges are used to estimate the elevation of the water in a river channel and its overbanks. In general, the current maps reflect hydrologic and hydraulic analyses developed during the 1980s. The following sections examine whether that information remains valid.

4.4.2.1 Hydrology

Discharges are generally estimated based on statistical analysis of data collected at stream gaging stations, where continuous records of flow are measured. The statistical analysis involves extrapolation of stream records from periods generally much less than 100 years. In general, the longer the period of stream gage records, the more reliable the estimates. As new data becomes available, the estimates become more reliable. Additional data, especially from large floods, can have a significant impact on these estimates.

The flood events of May 2006 and April 2007 were large flood events. Consequently, the USGS performed new statistical analysis of the gaging station records to increase the reliability of discharge estimates and provided a draft of its report for use in this study (Flynn 2008). Table 4-3 extracts some of this information for basins of interest in the study area and compares these recent estimates to the 100-year flood estimates found in the currently effective FISs.

Table 4-3: Comparing 100-Year Discharge Estimates, Before and After Inclusion of Recent Flood Events

USGS Stream Gage Number	Stream Gage Name	Period of Record	Drainage Area (Square Miles)	Estimate of 100-year discharge in effective FIS (cfs)	USGS estimate of 100-year discharge (cfs)	Percent Change
01072100	Salmon Falls River at Milton	1968–Present	108	5,290	6,920	31
01072700	Cocheco River near Rochester	1995–Present	85.7	6,120	12,500	104
01073000	Oyster River near Durham	1934–Present	12.1	879	1,220	39
01073500	Lamprey River near Newmarket	1934–Present	183	7,300	9,400	29
01073587	Exeter River at Haigh Road, near Brentwood	1996–Present	63.5	3,010	8,530	183
01082000	Contoocook River at Peterborough	1946–Present	68.1	5,700	3,530	-38
01083000	Contoocook River near Henniker	1938, 1940–1977, 1989–Present	368	21,600	16,800	-22
01085500	Contoocook River below Hopkinton Dam	1964–Present	427	9,500	7,150	-25

USGS Stream Gage Number	Stream Gage Name	Period of Record	Drainage Area (Square Miles)	Estimate of 100-year discharge in effective FIS (cfs)	USGS estimate of 100-year discharge (cfs)	Percent Change
01089100	Soucook River at Pembroke Road, near Concord	1989–Present	81.9	5,475	5,080	-7
01089500	Suncook River at North Chichester	1919–1920, 1922–1927, 1929–1970, 2007–Present	157	10,330	9,820	-5
01090800	Piscataquog River below Everett Dam, near East Weare	1963–Present	63.1	2,200	2,010	-9
01091000	South Branch Piscataquog River near Goffstown	1941–1978	104	6,990	6,830	-2
01091500	Piscataquog River near Goffstown	1936, 1938, 1940–1978, 1983–Present	202	12,500	14,300	14
01094000	Souhegan River at Merrimack	1920–1976, 1980, 1982–Present	171	12,500	12,600	1

Hydrology is an inexact science, and considerable variation may occur in flood estimates when new data are added to statistical analyses, particularly for stations with short records. Estimates within +/- 10 or 20 percent indicate the impact of the new events on the estimates of 100-year discharge is relatively minor. However, the two flood events, and all of the other flood events (see Table 2-7) since the initial hydrologic calculations were performed, appear to significantly affect the estimates of 100-year discharges at many locations. The best available estimates for the 100-year discharge in the seacoast are significantly higher than the estimates used to prepare the FIS and DFIRMs, and the best available estimates for the 100-year discharge in the Contoocook River Basin are lower. The higher discharge estimates in the seacoast may be attributable to the comparatively higher rainfall amounts during both the May 2006 and April 2007 events.

4.4.2.2 Hydraulics

The 100-year discharge estimates are used in FISs to compute flood elevations. Water surface profiles are developed along the streams and these elevations are then plotted on maps along the lengths of the streams to create the 100-year floodplain. Water surface profiles are also developed for other flood events, including the 10-year, 50-year, and 500-year floods (the 500-year flood is also mapped). At any given point along a stream, the flood elevation can be estimated from the profiles. During the May 2006 and April 2007 events, the USGS collected high water marks at selected locations throughout the study area. High water marks indicate the highest levels these floods reached. They consist of debris lines, water stains, and similar information marking the highest level of water during the flood events. The USGS also determined the relative magnitude of these flood events compared to the 100-year event. By comparing the high water marks with the flood elevations on the water surface profiles, conclusions can be drawn on how accurate the FISs predict flood levels. Table 4-4 presents this information at selected locations in the study area where both high water mark information was collected and FIS profiles are available. The first column is the USGS identifier for the high water mark. Generally, it includes an abbreviation indicating the town (Epp for Epping, Ray for Raymond, etc.). The second column is the USGS estimate of the recurrence interval for the event, which was updated to include flow rates from both the May 2006 and April 2007 flood events. The third column is the reference point on the flood profile from the effective FIS. The fourth column is the elevation USGS estimated for the high water mark. The fifth column compares the high water mark elevation to the recurrence intervals (10-, 50-, 100-, or 500-year) in the effective FIS. If the recurrence interval in this column matches the USGS-estimated recurrence interval for the event in the second column, the effective FIS information remains valid. The final column shows the difference between the elevation of the high water mark and the elevation on the profile for a flood of the same magnitude as the flood that caused the high water mark. If this difference is large, it means there is a significant difference between the computed floodplain in the FIS and the flood levels experienced during the April 2007 flood event. Sometimes these differences are attributable to debris and sediment in the floodplain. Whereas FISs assume that channels, bridges and culverts, and dams are free of sediment and debris, this is often not the case during actual flood events.

The following discussion summarizes the information in Table 4-4 for the eight rivers included in this analysis:

Salmon Falls River – The table shows poor agreement between high water mark elevations and the effective FIS on the bottom reaches of the Salmon Falls River. The difference between actual and expected elevations sometimes approaches 5 feet. An actual 100-year event would inundate a much wider floodplain than currently shown on the DFIRMs. The predicted flood levels match better in the upper reaches of the river.

Cocheco River – The high water mark information is limited for the Cocheco River, but the table does indicate poor agreement between the effective FIS and the high water mark elevations, with differences in the range of 3–4 feet. If this is representative of conditions throughout the Cocheco River, then the effective FIS underestimates the extent of the floodplain.

Exeter River – The table shows generally good agreement between the effective FIS and the high water mark elevations on the Exeter River.

Lamprey River – The table shows generally poor agreement between high water mark elevations and the effective FIS throughout the length of the Lamprey River. Thus, the actual floodplain is larger than shown in the currently effective FIS.

Suncook River – The table shows good agreement between the high water mark elevations and the effective FIS on the Suncook River, except at Sunhwm7, Sunhwm38, and Sunhwm40. Sunhwm7 is at the Webster Dam. The difference may be attributable to the operation of the Obermeyer gate at that location, which was installed after the effective FIS was prepared. Sunhwm38 and Sunhwm40 are located at U.S. Route 4. There may be a localized problem with the hydraulic analysis at this location. However, because of the avulsion, sedimentation is changing characteristics of the stream and the USGS is re-computing the flood profile in downstream reaches.

Contoocook River – The high water mark information is limited for this large river. Based on the limited information available, the effective FIS information corresponds to the high water mark elevations relatively well. The discrepancy at Contoo1 is likely due to localized effects upstream of a bridge.

Piscataquog River – Except at WSA1, the table shows relatively good agreement between the effective FIS and the high water mark elevations for the Piscataquog River. WSA1 is located just downstream of Kelley’s Falls Dam, and the turbulent conditions there make both hydraulic computations and high water mark determinations difficult.

South Branch Piscataquog River – Unlike other locations, there was a general tendency for the effective FIS to slightly overestimate flood elevations at this location compared to the high water mark elevations, but the differences are generally less than 1 foot.

Souhegan River – The table shows generally poor agreement between the effective FIS and the high water mark elevations, indicating that the effective FIS significantly underestimates the extent of the 100-year floodplain.

FIS information is the basis for almost all floodplain management decisions and its accuracy is essential. Differences up to 5 feet can lead to erroneous assumptions. Buildings believed to be high and dry during a 100-year flood event may in some cases be inundated with floodwaters up to 5 feet deep, and areas that should be treated as floodplains may be developed without adhering to NFIP requirements. This review of the available data suggests the accuracy of the effective FISs vary. For half the rivers investigated (the Salmon Falls, Cocheco, Lamprey, and Souhegan Rivers), the effective FISs underestimate actual flood elevations observed in the field, and suggest a need to update this information.

Table 4-4: Comparing April 2007 High Water Mark Elevations to Flood Elevations in Effective FISs

USGS High Water Mark Identifier	USGS-Estimated Recurrence Interval of Event (years)	Approximate River Station from Effective FIS (feet or miles as noted)	High Water Mark (HWM) Elevation	How HWM Elevation Compares to Effective FIS Recurrence Interval (years)	Approx. Elevation Difference between HWM Recurrence Interval and FIS Elevation (feet)
Salmon Falls River (elevations in National Geodetic Vertical Datum of 1929 [NGVD])					
Rochester SF2	25–50	21,700 feet	181.2	>500	~5 high
Rochester SF3	25–50	22,200	181.4	~500	~5 high
Roches2	25–50	72,700	204.5	~10	~0.5 low
Roches3	25–50	72,800	205.2	~25	-
Roches1	25–50	73,300	207.4	~10	~1 low
Cocheco River (elevations in NGVD)					
FARM9	10–25	103,400 feet	269.1	~500	~4 high
FARM4	10–25	104,100	272.2	100–500 year	~3 high
Exeter River (elevations in NGVD)					
Exeter35	5–10	0.75 miles	28.3	~10	~0.5 high
Exeter36	5–10	0.90	29.2	10–50 year	~1 high
Exeter 33	5–10	19,000 feet	30.2	~10	-
Exeter29	5–10	23,600	30.6	<10	-
Exeter31	5–10	24,200	30.8	<10	-
Exeter25	5–10	35,550	36.1	<<10	-
Exeter22	5–10	39,450	49.9	~10	-
Exeter19	5–10	72,500	93.6	~10	~1 high
Exeter18	5–10	73,300	106.5	50	~2 high
Exeter8	5–10	78,500	113.5	<10	-
Exeter9	5–10	79,000	132.5	~10	-
Exeter12	5–10	80,400	132.8	~10	-
Exeter14	5–10	80,600	133.7	10–50 year	~1 high
Lamprey River (elevations in NGVD)					
New1	50–100	500 feet	33.1	~100	-
Dur1	50–100	14,900	63.3	50–100 year	-
Epp20	50–100	19,200	106.9	>>500	~3 high
Epp18	50–100	36,100	108.9	~100	-
Epp16	50–100	36,600	109.7	50–100 year	-
Epp15	50–100	37,300	111.0	50–100 year	-
Epp14	50–100	38,100	112.6	~100	~0.5 high

USGS High Water Mark Identifier	USGS-Estimated Recurrence Interval of Event (years)	Approximate River Station from Effective FIS (feet or miles as noted)	High Water Mark (HWM) Elevation	How HWM Elevation Compares to Effective FIS Recurrence Interval (years)	Approx. Elevation Difference between HWM Recurrence Interval and FIS Elevation (feet)
Epp13	50–100	54,500	134.3	100–500 year	~0.5 high
Epp9	50–100	57,600	142.8	>500	~4 high
Epp6	50–100	58,200	147.4	50–100 year	-
Epp5	50–100	58,400	148.3	~100	~0.5 high
Epp3	50–100	58,800	150.9	100–500 year	~1 high
Ray16	50–100	71,300	167.4	500	~1 high
Ray14	50–100	71,500	167.7	100–500 year	~1 high
Ray8	50–100	77,300	169.5	100–500 year	~1 high
Ray9	50–100	78,700	184.8	>500 year	~3 high
Ray13	50–100	83,700	187.4	>500 year	~2 high
Ray11	50–100	83,900	188.6	500	~3 high
Ray7	50–100	84,300	189.1	500	~3 high
Ray6	50–100	85,200	190.7	>100	~2 high
Ray3	50–100	89,800	194.9	>500	~5 high
Ray1	50–100	97,100	197.2	>500	~5 high
Suncook River (Elevations in North American Vertical Datum of 1988 [NAVD])					
Sunhwm1	>100	0.10 miles	198.8	~100	-
Sunhwm2	>100	0.36	209.2	>100	-
Sunhwm7	>100	0.85	280.1	~10	~4 low
Sunhwm9	>100	1.19	284.4	50–100	~1 low
Sunhmw12	>100	1.40	288.3	>100	-
Sunhwm20	>100	5.45	296.5	<500	~1 high
Sunhwm26	>100	5.6	299.2	50	~1 low
Sunhwm32	>100	8.98	307.5	~100	-
Sunhwm35	>100	9.54	309.2	>100	-
Sunhwm40	>100	12.94	334.9	~10	~3 low
Sunhwm38	>100	12.98	337.1	10–50	~3 low
Contoocook River (Elevations in NAVD)					
Cont132br1	>100	159 miles	699.9	>100	-
Cont101br1	>100	161.36	721.4	50–100	~1 low
Cont101br3	>100	161.6	724.1	~100	-
Cont001	>100	162.2	735.2	~50	~4 low

USGS High Water Mark Identifier	USGS-Estimated Recurrence Interval of Event (years)	Approximate River Station from Effective FIS (feet or miles as noted)	High Water Mark (HWM) Elevation	How HWM Elevation Compares to Effective FIS Recurrence Interval (years)	Approx. Elevation Difference between HWM Recurrence Interval and FIS Elevation (feet)
Piscataquog River (Elevations in NAVD)					
WSA1	25–50	72.94 miles	147.6	100–500	~3 high
Gof1	25–50	75.05	167.6	~50	-
Glen Lake	25–50	78.49	274.2	~50	-
G1	25–50	79.95	291.9	~50	-
South Branch Piscataquog River (Elevations in NAVD)					
DR2	>500	1.75 miles	319.3	100–500	-
UR2	>500	1.81	322.3	100–500	~1 low
NB6	>500	5.46	386.7	100–500	~1 low
NB3	>500	6.05	411.7	100–500	~2 low
NB5A	>500	6.22	418.8	100–500	-
NB2	>500	6.87	432.2	~100	~1 low
NB1	>500	6.9	432.2	~100	~1 low
Souhegan River (Elevations in NAVD)					
Souh26	50–100	14.4 miles	232.2	100–500	~1 high
Souh24	50–100	14.46	237.0	100–500	~1 high
Souh21	50–100	14.63	239.5	~500	~2.5 high
Souh19	50–100	14.87	246.6	~500	~4 high
Souh18	50–100	14.95	246.8	~500	~4 high
Souh23	50–100	15.61	250.7	>500	~5 high
Souh8	50–100	19.775	248.8	~100	-
Souh10	50–100	19.795	296.0	~100	-
Souh7	50–100	20.4	326.6	~100	-
Souh3	50–100	21.15	346.8	~500	~3 high

4.5 ARE THE STATE'S DAM SAFETY REGULATIONS ADEQUATE?

The purpose of this section is to compare the NHDES Dam Bureau with comparable Dam Bureaus of other States to assess the adequacy of the State's dam safety regulations. In the course of the analysis the New Hampshire Dam Bureau Web site, http://www.des.state.nh.us/Dam/ (NHDES 2008a), was extensively used to gather information on dam safety requirements available to the public and to the engineering profession.

The mission of the Dam Bureau is "to insure all dams in New Hampshire are constructed, maintained and operated in a safe manner. Lake levels, stream flows and the State's surface and groundwater resources are used efficiently and managed to protect environmental quality, enhance public safety and flood protection and to support and balance a variety of social and ecological water needs." The Bureau has divided the mission tasks into three categories: (1) regulatory approaches, which include the permitting of new dams, inspection of existing dams, Emergency Action Plans (EAPs) and compliance with letters of deficiency's and administrative orders; (2) non-regulatory approaches, which include dam owner workshops, drought management, fact sheets, newsletters, training manuals, regional and national associations, and lot leasing; and (3) State dam ownership responsibilities, which include, repair and reconstruction, EAPs, lake level operations, maintenance of dams, and fall lake level draw-downs.

Important publications are readily available on the Web site. One of the more important links is to the Dam Bureau's administrative rules on dam-related programs. The link includes sections on:

1. Definitions
2. Procedures
3. Existing dams
4. Construction or reconstruction of dams
5. EAPs
6. Removal of dams
7. Lake level determinations
8. Administrative fines

The document outlines very specifically the rules that the Bureau will impose for dams within the State. Also, easily accessible on the Web site are the:

1. Laws pertaining to dams
2. Application forms
3. Dam definitions
4. Dam removal and river restoration
5. Drought management
6. Links to publications are referenced in the dam rules
7. EAPs
8. Fact sheets
9. Newsletters
10. Links to other sites

The New Hampshire Dam Bureau regulates approximately 610 dams among 4 hazard classifications; high, significant, low, and non-menace. The hazard classifications among different States are not consistent, but New Hampshire's high and significant hazard categories are similar to most States and are well defined. Owners of all high- and significant-hazard dams that could threaten public safety downstream are required to complete and maintain an EAP, which addresses the area of concern and identifies procedures to be initiated in the case of a dam failure. The procedure for preparing the EAP is readily accessible on the Dam Bureau Web site. EAPs are to be developed for a sunny day failure and also for a hydrologic failure during a 100-year event.

EAPs are not required for flood inundation upstream of a dam resulting from the installation of flash boards. However, a dam owner intending to raise the pool level in a dam must file a permit with the Dam Bureau. Sand bags are sometimes used in an emergency to prevent a dam from overtopping. If the water surface elevation behind a dam may cause additional flooding upstream, letting the dam break, if it does not cause any additional damage downstream, may be more judicious than sand bagging on low hazard dams.

The New Hampshire Dam Bureau regulations are clear and complete, and compare well with comparable regulations in the other States, and are deemed adequate to carry out the Dam Bureau's mission. Recent legislation (New Hampshire Senate Bill 519-FN, New Hampshire General Court 2007) signed by the New Hampshire Governor John Lynch, will further strengthen the Dam Bureau's effectiveness by providing per diem fines on dam owners and operators for failure to repair damage.

4.6 ARE FLOOD FORECASTS ACCURATE AND ARE THEY USED EFFECTIVELY TO ANTICIPATE AND RESPOND TO FLOODING EVENTS?

4.6.1 The Role of NHDES in Forecasting Floods

In 2002, a data management and streamflow forecasting system was installed at NHDES offices in Concord, NH and expanded in the subsequent years. One purpose of the system is to make real-time observations of precipitation, temperature, river stage, and pool elevations available on NHDES's Web site (http://www.des.state.nh.us/rti_home/, NHDES 2008a) and to provide operations information for select NHDES dams to the public. The second purpose is to simulate inflows and releases at many of the NHDES-operated reservoirs in New Hampshire to support operations at the dams.

The system acquires the real-time data from 112 remote sites in New Hampshire, Maine, Vermont, and Massachusetts; the majority via the internet from the NOAA's Data Collection System Automatic Processing System (DAPS). All collected data are made available to the public, and a subset is provided to the RiverTrak® Streamflow Forecasting software developed by Riverside Technology, Inc. Using these data plus precipitation forecasts provided by the Northeast River Forecast Center, RiverTrak® automatically estimates inflows and releases at 30 reservoirs and streamflow at an additional 22 locations, as listed in Table 4-5. These forecasts are intended for internal NHDES use only.

The forecast system is intended to be operated by staff of the NHDES Dam Bureau. These operations include:

- Verifying that data from all monitored sites are imported on a set schedule

- Verifying the accuracy of incoming data and editing suspicious data
- Verifying the reasonableness of the model forecasts
- Updating of rating curves used to convert observed river stage to river flow
- Updating the system to reflect configuration changes at the remote sites

Most of the NHDES dams in the system are not equipped with remote monitoring devices. Dam operators visit the dams on a regular schedule and report the current pool elevation and operations to the NHDES. Similarly, pool elevation and operations at non-NHDES (private) dams are not supplied automatically. This information must be manually entered into the RiverTrak® system, which then estimates current and future releases from the NHDES and private dams.

In past years, the staffing situation at the NHDES Dam Bureau has not allowed intensive operations of the forecast system and missing or incorrect data caused the system's forecast performance to degenerate. Additionally, the data feed from DAPS proved to be unreliable at times, causing observations not to be available for the forecast system in a reasonable time frame. As a result, the NHDES forecast system is no longer actively used, although it continues to operate in an automatic but unattended fashion.

During the 2006 and 2007 events, most of the NHDES Dam Bureau staff with experience in forecasting were either in the field to operate the many NHDES dams or were working at the New Hampshire's Homeland Security and Emergency Management's (HSEM) Emergency Operations Center (EOC). No experienced operator was available to run the NHDES Dam Bureau's forecast system. Consequently, information automatically provided by the forecast system was not utilized during the events.

Table 4-5: Lakes, Reservoirs, and River Points Modeled by the NHDES

Basin	Modeled Lakes or Reservoirs	Other Forecast Points
Exeter		East Exeter at Brentwood
Lamprey		Lamprey near Newmarket
Mascoma	Grafton Pond	Mascoma River at West Canaan
	Crystal Lake	Mascoma River at Rivermill
	Goose Pond	Mascoma River at Glenroad Dam
	Mascoma Lake	
Ossipee	Ossipee Lake	Bearcamp River at South Tamworth
Pemigewasset	Squam Lake	East Branch Pemigewasset River at Lincoln
	Newfound Lake	Pemigewasset River at Woodstock
	Franklin Falls Dam	Baker River at Rumney
		Pemigewasset River at Plymouth
		Cockermouth River
Piscataquog	Deering Reservoir	South Branch Piscataquog River
	Horace Lake	Piscataquog River near Goffstown
	Everett Dam	
	Gregg Falls	
	Kelley Falls Dam	
Powwow	Angel Pond	Tuxbury Pond Inflows
	Country Lake	
	Great Pond	
	Powwow Pond	
Salmon Falls	Great East Lake	Jones Brook at Middleton
	Horn Pond	Salmon Falls River at Union Meadows
	Cooks Pond	Salmon Falls River at Great Upper Falls
	Lovell Lake	
	Milton Three Ponds	
Smith River		Smith River at Bristol
Soucook		Soucook above Pembroke Road, Concord
Suncook	Sunset Lake	Suncook River at North Chichester
	Crystal Lake	
	Suncook Lake	
	Barnstead Parade	
	Northwood Lake	
	Buck Street Dam	
Winnipesaukee	Lake Winnipesaukee	Winnipesaukee River at Tilton
	Winnisquam Lake	Winnipesaukee River at Franklin

4.6.2 The National Weather Service's Role in Forecasting Floods

The NWS is the primary source of weather data, forecasts, and warnings for the United States. The NWS is the Nation's official voice for issuing warnings during life-threatening weather situations. The NWS Northeast River Forecast Center (NERFC), located in Taunton, MA, provides "Significant River Flood Outlook" products and streamflow forecasts for the NWS in the New England area on its Web site at http://www.erh.noaa.gov/nerfc/ (NWS 2008a). The products are updated on a daily basis (at approximately 11 a.m.) and more often during flood events. This and additional information is also distributed by the NWS Weather Forecast Offices (WFOs). The Boston (http://www.erh.noaa.gov/er/box/, NWS 2008b) and Portland/Gray (http://www.erh.noaa.gov/er/gyx/, NWS 2008c) WFOs provide information for New Hampshire.

NERFC's "Significant River Flood Outlook" presents a regional assessment of the potential of river flooding for a 5-day period into the future. While it does not include forecasts for specific points, it provides a general overview of the expected river flows. The "Significant River Flood Outlook" product provides a map identifying areas with a 30 percent probability of exceeding moderate flood levels. It does not account for minor flooding or flash floods. The "Significant River Flood Outlook" product employs a three-tiered prediction scheme, which includes "Significant River Flooding Possible," "Significant River Flooding Likely," and "Significant River Flooding Occurring or is Imminent." The product is accessed on the NERFC Web site by selecting the Flood Outlook tab.

Streamflow forecasts issued by the NERFC are generated using the NWS River Forecast System (NWSRFS), which models many larger rivers in Southern New Hampshire in real-time. The NERFC uses its computer models to simulate snow accumulation, snow melt, and runoff generation on a 6-hour time step, using observations and forecasts of temperature and precipitation as input. The NERFC provides forecasts for basins that can be reasonably modeled with time steps of 6 hours. These are typically larger basins that respond to rainfall and snowmelt within 6 hours or more. Smaller basins and rivers have response times that are too short to allow enough time for data ingestion, forecast generation, and dissemination using traditional implementation of the NWSRFS.

The NERFC provides forecasts to the public for 54 hours (slightly more than 2 days) into the future. Streamflow forecasts further into the future depend on forecasts of precipitation and temperature, which are currently very uncertain for periods more than 24 hours into the future. Thus, long-term streamflow forecasts are not accurate enough to provide useful information to the public.

Overall, streamflow forecasts are provided for more than 100 locations ("forecast points") in New England and New York. The 54-hour forecasts are available as graphs on the NERFC Web site (http://www.erh.noaa.gov/er/nerfc/, NWS 2008a) by selecting the "Forecast River Conditions" tab or as text products at http://www.weather.gov/data/TAR/RVFGYX (for Western Maine and Northern New Hampshire, NWS 2008d) and http://www.weather.gov/data/TAR/RVFBOX (for Southern New England, including Southern New Hampshire, NWS 2008e). Typically, an action level (indicating an impending possibility of flooding), and three flood levels are provided as indicators of flood severity. The NERFC classifies the three flood levels as:

- Flood Stage: This is the lowest of the flood levels, to be reached first during an event. At this level, flooding is likely in lowest lying areas along the river.
- Moderate Stage: Flooding is expected in low lying areas and may force the closure of some roadways along the river. At this level, residents are advised to act quickly and follow the directions of local emergency management officials.
- Major Stage: This is the highest and most dangerous of the flood levels indicating a significant and serious flood. Flooding affects all of the local area. Residents are advised to act quickly and head for higher ground, and to follow possible evacuation orders immediately.

These flood level are established by the NWS based on local conditions. Therefore, the local significance may vary. Descriptions of local flooding occurring at the individual flood levels are available for most forecast points at NERFC's Web site (http://newweb.erh.noaa.gov/ahps2/index.php?wfo=box or http://newweb.erh.noaa.gov/ahps2/index.php?wfo=gyx) by selecting a forecast point and the River at a Glance tab. Descriptions of the local impacts of flooding for the three flood levels, if available, are provided under the Flood Impacts heading.

Table 4-6 lists the locations in Southern New Hampshire for which the NERFC routinely issues streamflow forecasts. Of the river basins investigated for this study, forecasts are available for the Piscataquog, Souhegan, Contoocook, and Soucook Rivers. *Routine streamflow forecasts are not provided for the Suncook, Cocheco, Lamprey, Oyster, Salmon Falls, and Isinglass Rivers.*

Table 4-6: NERFC Forecast Points in the Study Area

Forecast Point Name	Forecast Point Identifier
Merrimack River at Franklin Dam	FFLN3
Warner River at Davisville	DAVN3
Contoocook River at Peterborough	PTRN3
Contoocook River at Henniker	HENN3
Soucook River near Concord	SOUN3
Piscataquog River at Goffstown	GFFN3
Merrimack River near Goffs Falls	GOFN3
Souhegan River at Merrimack	SOHN3
Merrimack River at Nashua	NSHN3

4.6.3 How Well Did the NWS Predict the Flood Events in Southern New Hampshire?

The NERFC issued "Significant River Flood Outlook" products and streamflow forecasts for the May 2006 and April 2007 events. The NERFC provided these forecast data and an internal assessment of the forecast accuracy for the April 2007 event for use in this study.

The assessment of the usefulness of the forecasts focuses on two main indicators:

- Lead Time – This is the time span between the time when a flood warning was issued and the time when flooding actually occurred. Sufficient lead times should be achieved in the forecast of each of the flood levels as well as the flow peak.
- Prediction of the Peak Elevation and Time of Peak – The confidence users of streamflow forecasts have in a forecast is based on the quality of past forecasts in terms of magnitude ("How high will the peak be?") and timing ("When will the peak occur?") for the same locations. While past performance is not necessarily an indicator of future performance, the ability to accurately forecast past floods does lend credibility to forecasting future floods.

The "Significant River Flood Outlook" product can provide forecasts of regional flood conditions with adequate lead time, but it does not include predictive information regarding magnitude of flood peaks. Streamflow forecasts, on the other hand, can provide both lead time and a prediction of the peak magnitude.

4.6.3.1 April 2007 Event

A "Significant River Flood Outlook" product indicating possible flooding was issued by the NERFC on its Web site on April 12, 2007, approximately 4 days before the peak of the event, as depicted in Figure 4-5. The extreme southern portions of New Hampshire are identified as affected areas.

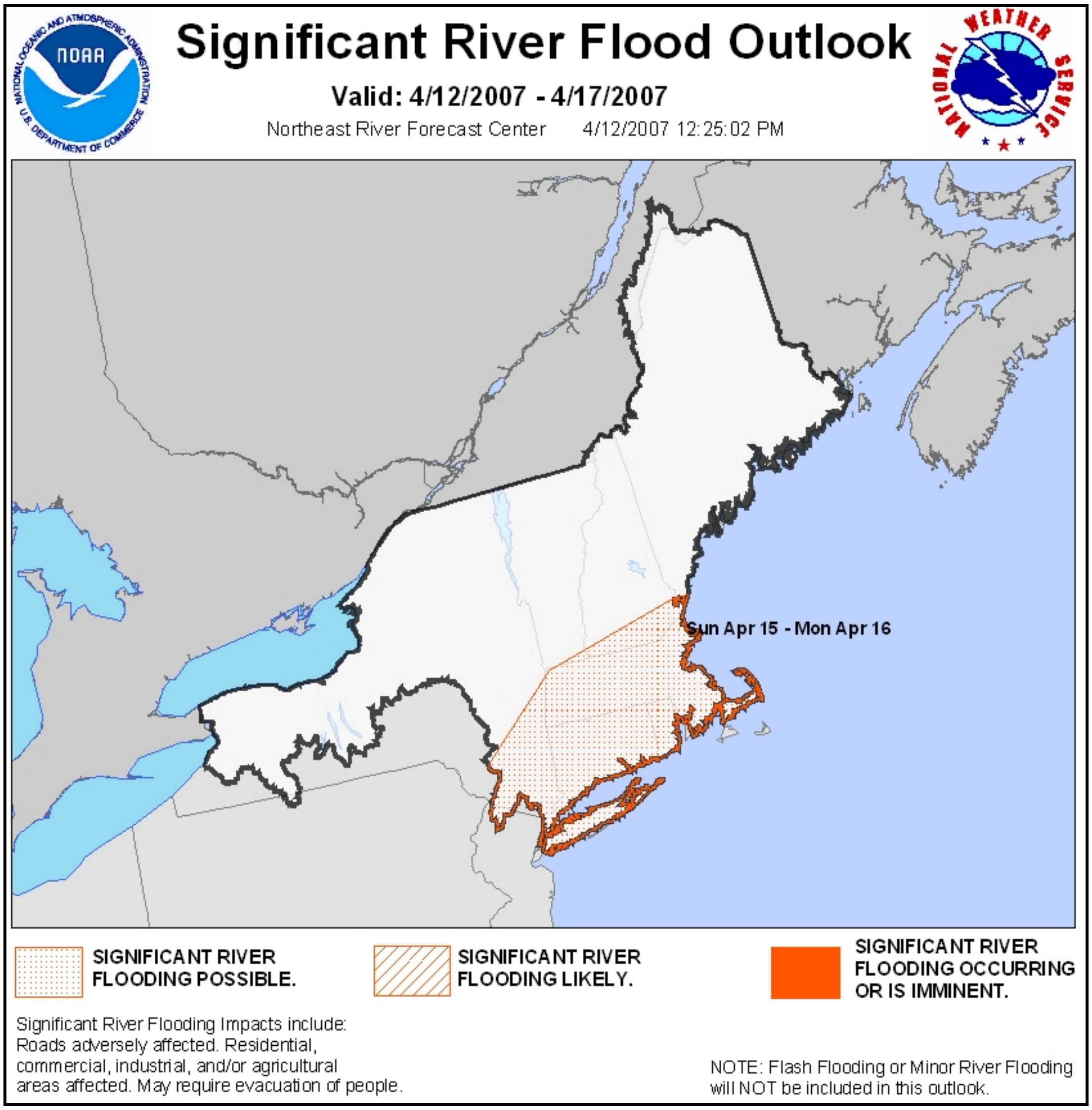


Figure 4-5: NERFC Significant River Flood Outlook from April 12, 2007 (Source: NERFC)

The NERFC updated the "Significant River Flood Outlook" product during the following days and upgraded the potential for river flooding to "likely" at 11:14 a.m. on April 15, as depicted in Figure 4-6. The entire southern half of New Hampshire is identified as susceptible to significant flooding. Given that flood stages in most of the rivers were reached in the afternoon of April 16, the "Significant River Flood Outlook" product provided a lead time of more than 24 hours in advance of the April 2007 event.

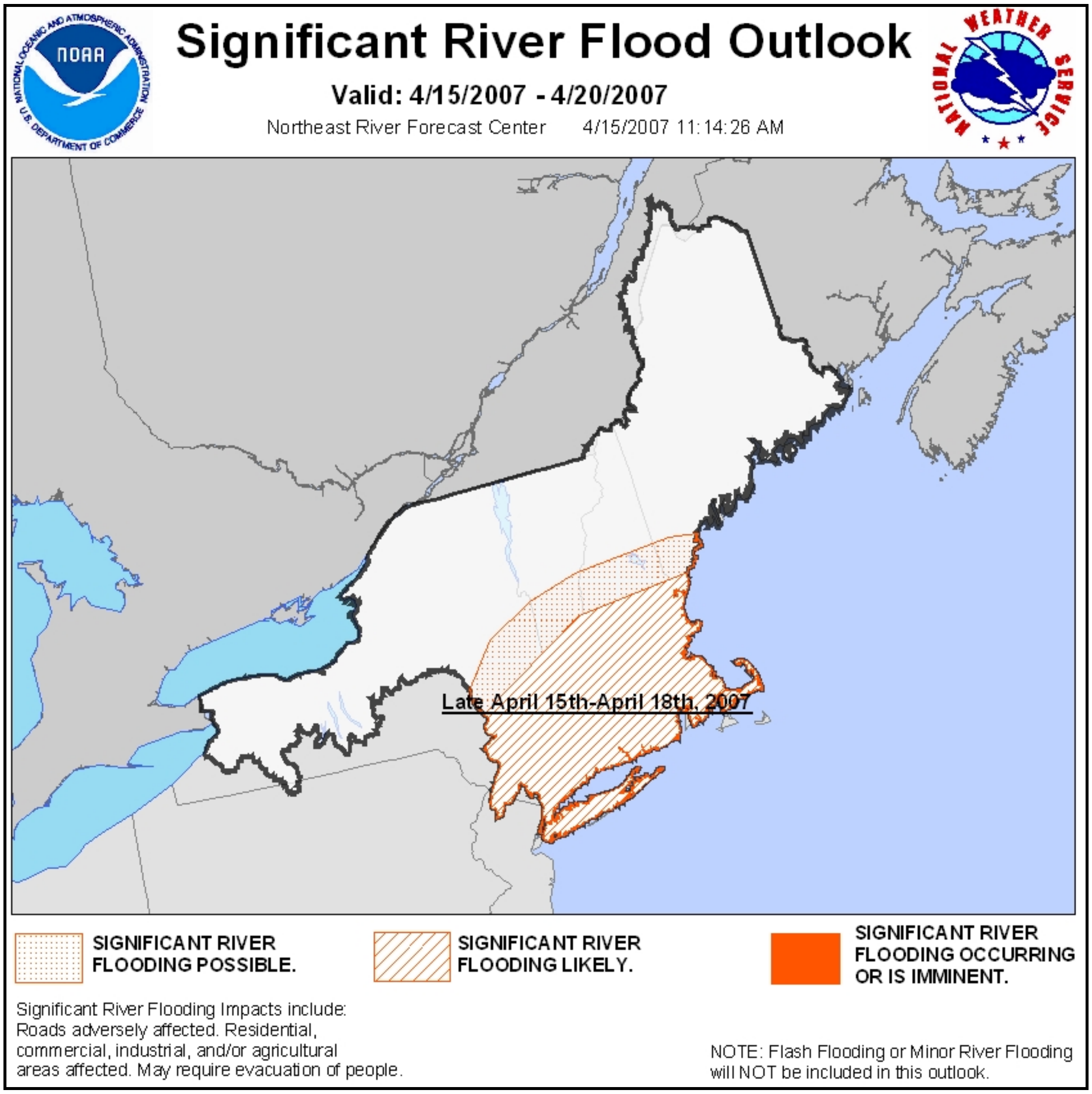


Figure 4-6: NERFC Significant River Flood Outlook from April 15, 2007 (Source: NERFC)

In addition, the NERFC provided more detailed streamflow forecasts for the forecast points, which were available on the Web site on the days leading up to and including the flood event. Streamflow forecast results were available from archived data for the 11 a.m. forecasts and from NERFC's guidance reports. Overall, the NERFC issued 48 such guidance reports for the southern New Hampshire area between April 15, 2007 and April 18, 2007.

Table 4-7 lists lead times and timing for NERFC streamflow forecasts at select forecast points during the event. Item a) is the time when the first forecast was issued that exceeded Flood Stage, Moderate Flood Stage, or Major Flood Stage levels at the specified forecast point. Item b) is the time when the forecast issued at a) predicted the flood level to be exceeded. Item c) is the time when the flood level was actually exceeded. The Lead Time is then computed as the difference between items c) and a). Large positive lead times are the goal of the forecasts, giving emergency personnel and dam operators ample time to prepare for the event. The value of the forecast diminishes with small lead times. Negative lead times indicate that no forecast predicted a flood level to be reached, even though it was reached. The Timing row indicates the difference in the forecasted exceedance time and the actual exceedance time for a flood level. Positive numbers indicate that forecasted flows reached a flood level before it happened in reality, negative values show that the forecasted exceedance time was late. Small positive or negative values for the timing typically indicate a well-timed forecast of flood level exceedance.

Table 4-7: Lead Times and Timing for Select NERFC Forecasts in April 2007

Forecast Point	Warner River at Davisville			Piscataquog River at Goffstown			Merrimack River near Goffs Falls		
	Flood	Mod.	Major	Flood	Mod.	Major	Flood	Mod.	Major
a) Time Flood Warning was issued	4-15 11 PM	4-16 4 PM	n/a	4-15 11 AM	4-15 11 AM	4-16 11 AM	4-16 5 AM	4-16 11 PM	n/a
b) Forecasted Time of Exceedance	4-17 12 PM	4-16 4 PM	n/a	4-16 9 AM	4-16 12 PM	4-16 1 PM	4-16 4 PM	4-17 12 AM	n/a
c) Actual Time of Exceedance	4-16 10 AM	4-16 4 PM	n/a	4-16 5 AM	4-16 7 AM	4-16 11 AM	4-16 2 PM	4-16 10 PM	n/a
Lead Time - c) minus a)	11	0		18	20	0	9	-1	
Timing - c) minus b)	-26	0		-4	-5	-2	-2	-2	
Forecast Point	**Contoocook River at Henniker**			**Souhegan River at Merrimack**			**Soucook River near Concord**		
	Flood	**Mod.**	**Major**	**Flood**	**Mod.**	**Major**	**Flood**	**Mod.**	**Major**
a) Time Flood Warning was issued	4-16 9 AM	n/a	n/a	4-15 11 AM	4-15 11 AM	n/a	4-16 5 AM	4-16 4 PM	n/a
b) Forecasted Time of Exceedance	4-17 4 AM	n/a	n/a	4-16 11 AM	4-16 5 PM	n/a	4-16 5 PM	4-16 8 PM	n/a
c) Actual Time of Exceedance	4-16 6 PM	n/a	n/a	4-16 3 PM	4-16 7 PM	n/a	4-16 11 AM	4-16 11 PM	n/a
Lead Time - c) minus a)	9			28	32		6	7	
Timing - c) minus b)	-10			4	2		-6	3	

Table 4-7 indicates that some NERFC forecasts provided significant value. The Flood Stage was forecasted with lead times between 6 and 28 hours for all investigated forecasts points, providing ample time for emergency response preparation, but often not enough time to evacuate significant amounts of water from NHDES flood control reservoirs. Moderate Flood Stages were predicted more than 7 hours before they were exceeded for all forecast points but the Warner River at Davisville and the Merrimack River near Goffs Falls. No appreciable lead time could be provided for the single occasion where the Major Flood Stage was reached at the Piscataquog River. The forecasted timing of the exceedance of Flood Stages was good, in general; timing predictions were poor only for the Warner River at Davisville and the Contoocook River at Henniker.

Figures 4-7, 4-8, and 4-9 depict archived NERFC forecast hydrographs issued for the Soucook River near Concord, the Piscataquog River at Goffstown, and the Souhegan River at Merrimack. While multiple forecasts were issued by the NERFC during the April 2007 event, hydrographs are only archived for the forecasts issued around 11 a.m. each day. The figures depict the forecasted flow hydrographs (predicted discharges in cfs on given dates prior to and after the peak of the storm.) The times in the figures are presented in Greenwich Mean Time, which is 5 hours ahead of the local time. Red hydrographs represent forecasts issued on April 13 around 11 a.m.; blue hydrographs represent forecasts issued on April 14 at the same time. Green and magenta hydrographs are forecasts issued on the 15 and 16 of April 2007. The pink hydrographs were issued on April 17, at the peak of the event. Ideally, the forecasts issued on April 13 and 14 should have tracked the observed hydrograph (dashed black line); however, this is only achievable if reasonable forecasts of precipitation and temperature are available for input to the computer models. The NERFC notes in its self assessment report that it was difficult to develop reasonable precipitation forecasts before the event. Figure 4-10 depicts the evolution of precipitation forecasts for the entire event in the days leading up to and including the event. The volumes of expected precipitation increased as the event unfolded, leading to increasingly higher forecasted flows. Difficulties were also encountered with forecasted temperatures, which tended to be too low at the onset of the event. Also, the forecasts of snowmelt from April 13 and 14 were low compared to the actual snowmelt. The cumulative effect was that too little moisture (either as precipitation or snowmelt) was input to the computer models, causing simulated peak flows to be low.

The hydrographs for the Soucook and the Piscataquog Rivers (Figure 4-7 and Figure 4-8) clearly show a stair-step effect. The early forecasts (on April 13) were low and subsequent forecasts (April 14–16) predicted increasingly higher peak flows as observed inputs were used instead of predicted ones. The precipitation and temperature forecasts were also updated during the event and produced better, but still low, streamflow forecasts on April 16. Still, the flood stage was not accurately forecasted for the Soucook River until it actually happened, diminishing the value of the forecast.

The early forecast for the Souhegan River (Figure 4-9) on April 14 proved to be very reasonable, accurately predicting the time when flows would reach Flood Stage and Moderate Flood Stage. However, forecasts did not improve during the event as they did for the Piscataquog and Soucook Rivers.

None of the forecasts accurately predicted the crest of the event.

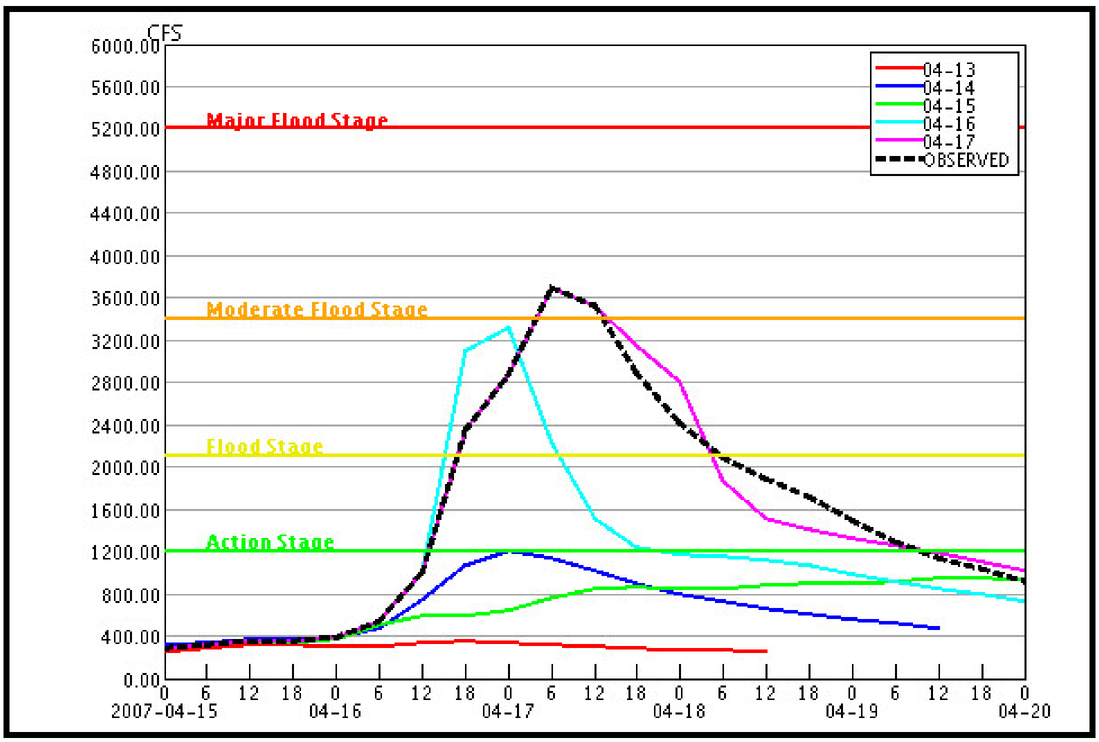


Figure 4-7: NERFC 11 a.m. Forecasts for the Soucook River near Concord (SOUN3) During the April 2007 Event (Source: NERFC)

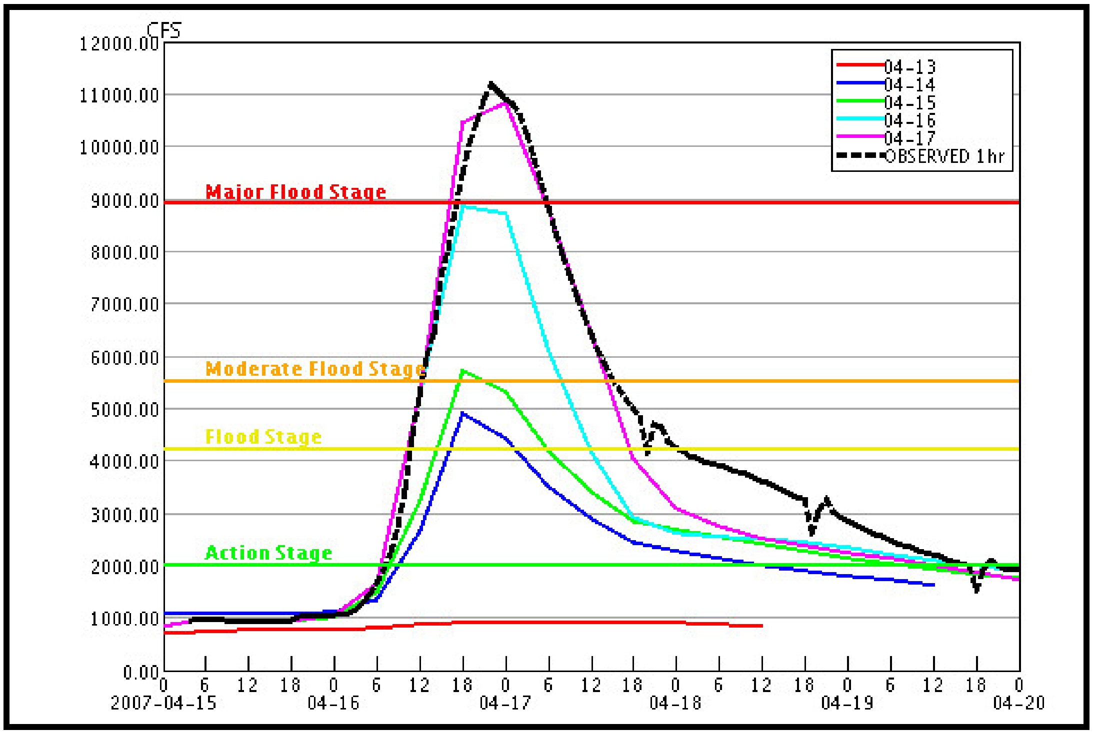


Figure 4-8: NERFC 11 a.m. Forecasts for the Piscataquog River at Goffstown (GFFN3) during the April 2007 Event (Source: NERFC)

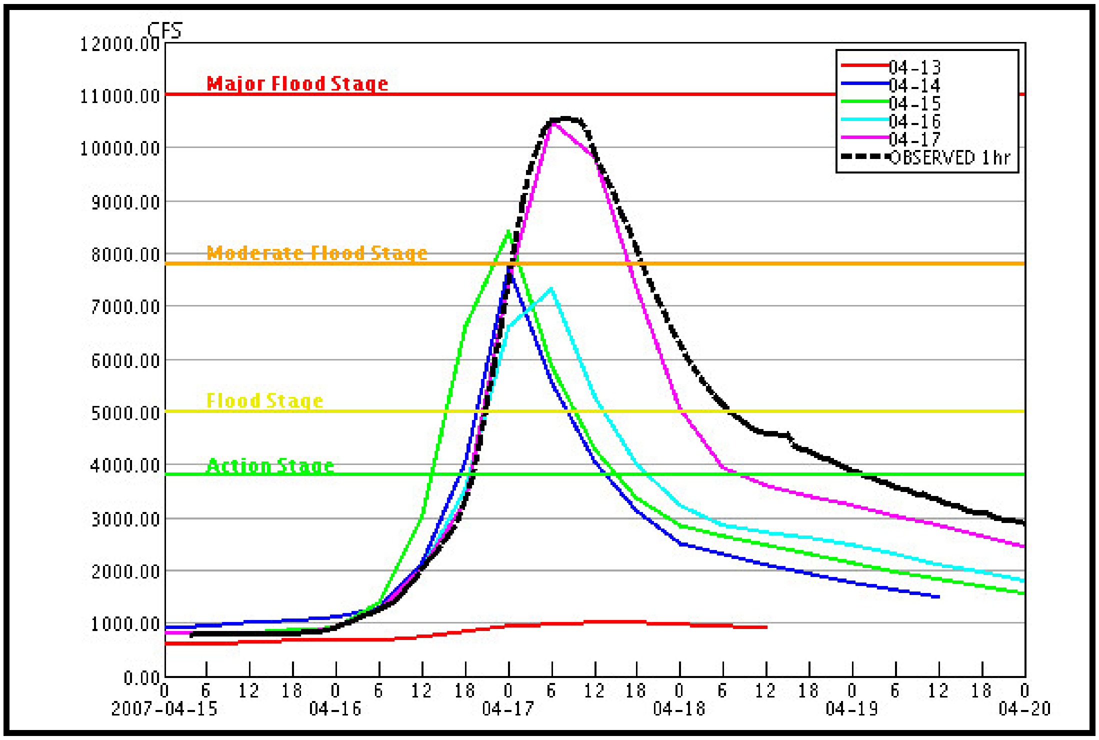


Figure 4-9: NERFC 11 a.m. Forecasts for the Souhegan River at Merrimack (SOHN3) During the April 2007 Event (Source: NERFC)

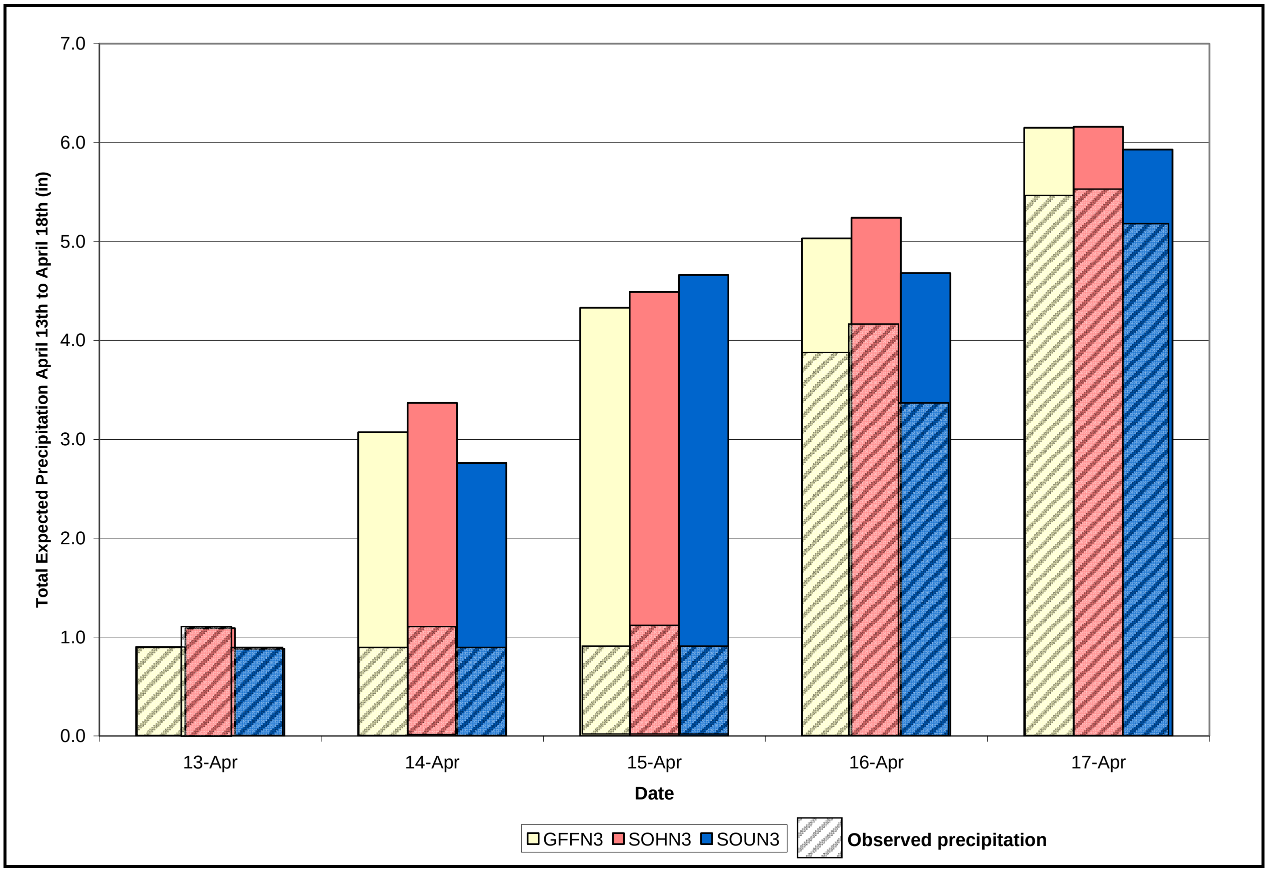


Figure 4-10: Evolution of Total Expected Precipitation from April 13 to April 18, 2007 at Select NERFC Basins

In summary, the NERFC forecasts provided reasonable lead times for Flood Stage during the April 2007 event for some of the sub-basins in Southern New Hampshire. The lead times for Moderate Flood Stage would have allowed for preventative dam operations only at the Piscataquog, Souhegan, and Soucook Rivers. No appreciable lead time was provided for the Major Flood Stage at the Piscataquog River. However, initial forecasts were generally low and peak flows were underestimated for all rivers.

4.6.3.2 May 2006 Event

The NERFC issued "Significant River Flood Outlook" products and streamflow forecasts before and during the May 2006 event on its Web site. These products and archived streamflow forecast data were made available for this study.

Figure 4-11 depicts the "Significant River Flood Outlook" product indicating possible flooding posted by the NERFC on May 12, 2006, roughly 2 days before the peak of the event. The product includes most of southern New Hampshire as affected area. The notable exception is the Salmon Falls River at the New Hampshire-Maine border. However, this area was included in the product for May 13.

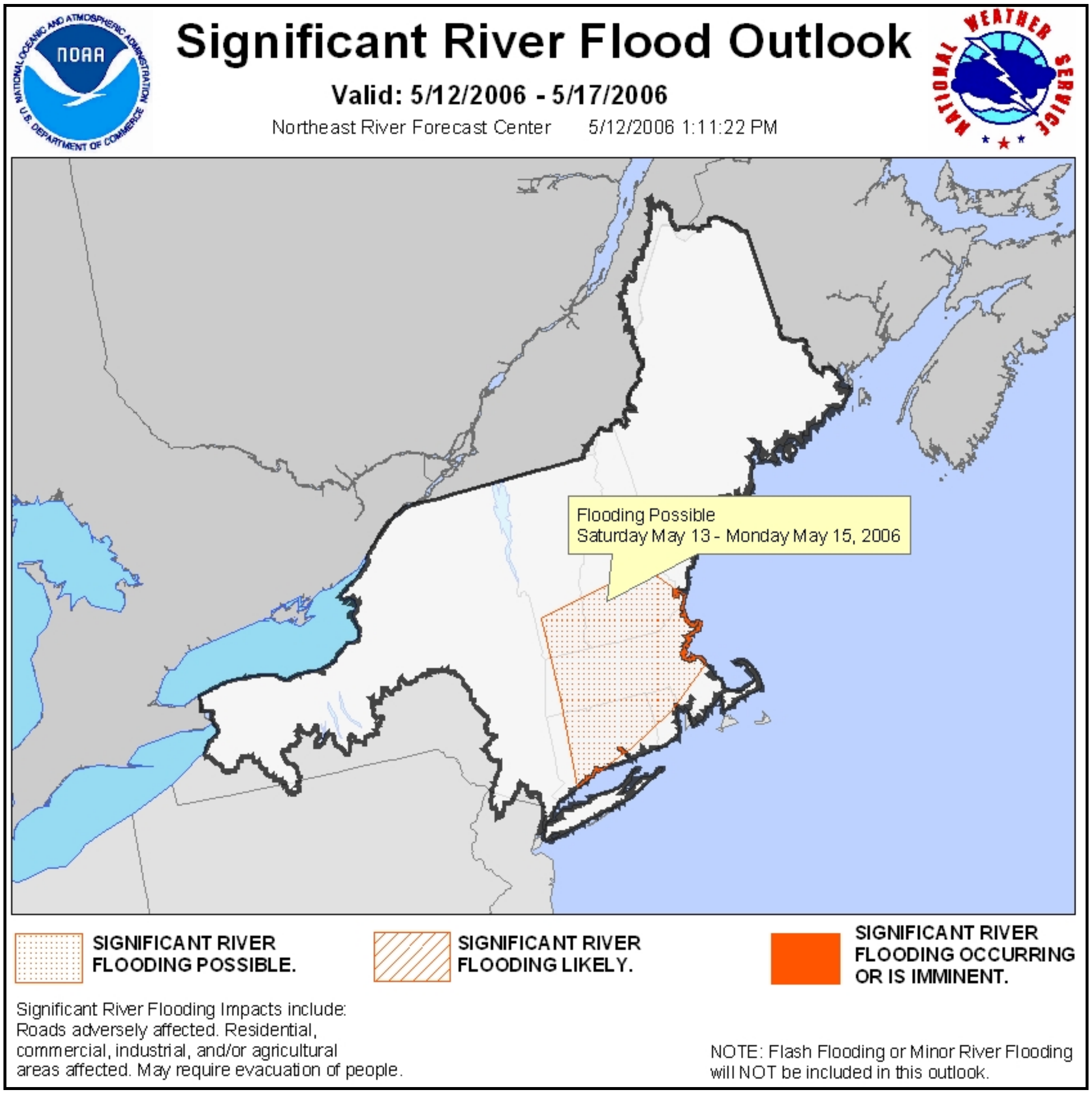


Figure 4-11: NERFC Significant River Flood Outlook from May 12, 2006 (Source: NERFC)

The next “Significant River Flood Outlook” product, issued at noon on May 14, indicated the possibility of significant flooding in the south-eastern corner of New Hampshire and included some areas with “Flooding Occurring or is Imminent” (Figure 4-12). Subsequent products focused on southeast New Hampshire as the hotspot of the May 2006 event.

Overall, the “Significant River Flood Outlook” products indicated “Flooding Possible” 24 to 48 hours before the event. The lead time for “Flooding Likely” conditions was negligible.

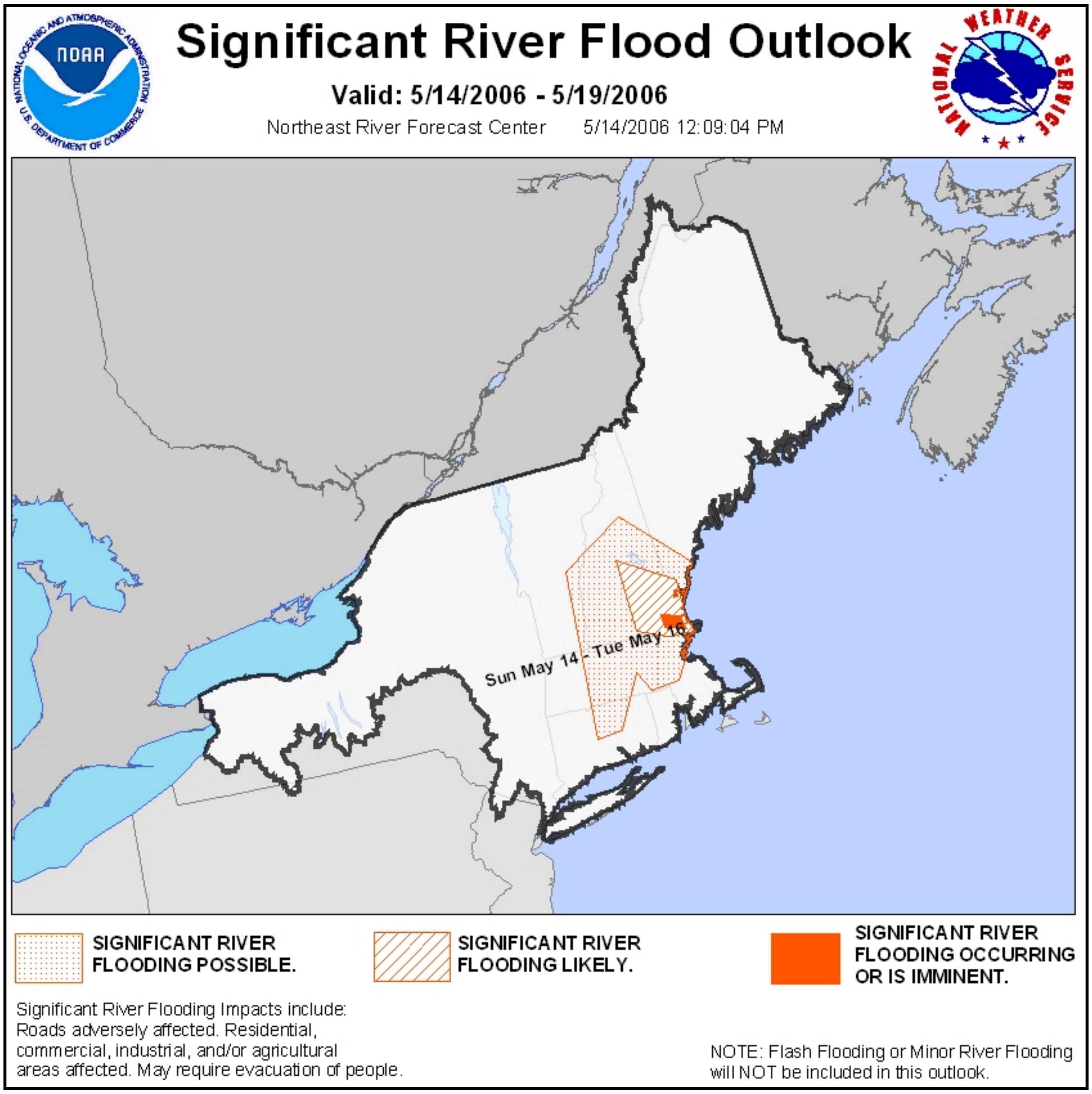


Figure 4-12: NERFC Significant River Flood Outlook from May 12, 2006 (Source: NERFC)

Table 4-8 provides lead time and timing information for NERFC streamflow forecasts at some of its forecast points in southern New Hampshire. The forecasts provided significant lead time for four of the six forecast points, and useful lead times were provided for the Soucook River near Concord. However, the forecasts for the Warner River at Davisville were not accurate enough to provide useful warning information. The timing in the forecast of the flows varied significantly, with the exceedance of flood levels being predicted either considerably early or considerably late.

Table 4-8: Lead Times and Timing for Select NERFC Forecasts in May 2006

Forecast Point	Warner River at Davisville			Piscataquog River at Goffstown			Merrimack River near Goffs Falls		
	Flood	Mod.	Major	Flood	Mod.	Major	Flood	Mod.	Major
a) Time Flood Warning was issued	5-13 9 PM	5-14 4 AM	5-14 4 AM	5-12 11 AM	5-13 11 AM	5-14 4 AM	5-13 11 AM	5-13 10 PM	5-14 4 AM
b) Forecasted Time of Exceedance	5-14 7 AM	5-14 4 PM	5-15 1 AM	5-14 6 AM	5-14 2 PM	5-14 4 PM	5-14 6 PM	5-14 3 PM	5-15 2 AM
c) Actual Time of Exceedance	5-13 11 PM	5-14 3 AM	5-14 9 AM	5-13 9 PM	5-14 3 AM	5-14 4 PM	5-14 6 AM	5-14 3 PM	*5-15 7 AM*
Lead Time - c) minus a)	**2**	**-1**	**5**	**34**	**16**	**12**	**19**	**17**	**27**
Timing - c) minus b)	**-8**	**-13**	**-16**	**-9**	**-11**	**0**	**-12**	**0**	**5**
Forecast Point	**Contoocook River at Henniker**			**Souhegan River at Merrimack**			**Soucook River near Concord**		
	Flood	**Mod.**	**Major**	**Flood**	**Mod.**	**Major**	**Flood**	**Mod.**	**Major**
a) Time Flood Warning was issued	5-13 9 PM	5-14 4 AM	n/a	5-12 11 AM	5-14 4 AM	5-14 4 AM	5-13 9 PM	5-14 4 AM	5-14 4 AM
b) Forecasted Time of Exceedance	5-14 9 AM	5-15 2 AM	n/a	5-14 12 PM	5-15 12 AM	5-15 2 AM	5-14 5 AM	5-14 1 PM	5-14 7 PM
c) Actual Time of Exceedance	5-14 6 PM	**n/a**	n/a	5-15 12 AM	**n/a**	**n/a**	5-14 4 AM	5-14 2 PM	**n/a**
Lead Time - c) minus a)	**21**			**61**			**7**	**10**	
Timing - c) minus b)	**9**			**12**			**-1**	**1**	

Figure 4-13 depicts the progression of NERFC forecast hydrographs for the Soucook River near Concord issued around 11 a.m. each day from May 10 to May 14, 2006. It shows that a large event was not forecasted until May 13, and that even the forecast on May 14 did not predict the flows to reach Moderate Flood Stage. This likely resulted from too little observed and forecasted precipitation on May 13 and May 14 or from inaccurate computer model predictions.

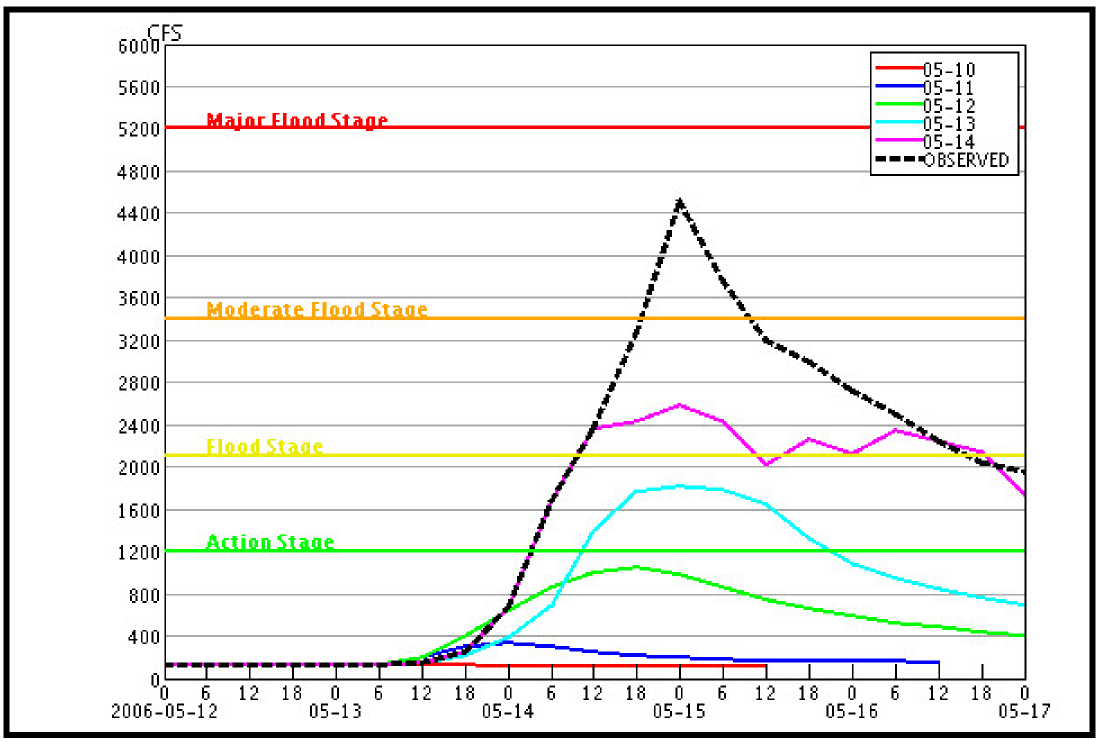


Figure 4-13: NERFC 11 a.m. Forecasts for the Soucook River near Concord (SOUN3) During the May 2006 Event (Source: NERFC)

Figures 4-14 and 4-15 demonstrate that Flood Stages for the Piscataquog River at Goffstown and the Souhegan River at Merrimack were forecasted on May 12, more than 2 days ahead of the peak of the event. The magnitude of the peak at the Souhegan River at Merrimack was estimated accurately on May 13, albeit about 15 hours too early. This indicates that very reasonable precipitation volume forecasts were available for that area on May 13. Figure 4-16 depicts the expected precipitation for the May 2006 event and shows the forecasts predicted increasingly higher volumes as the event unfolded. The sharp increase in expected precipitation from May 13 to May 14 was an overestimation, so that NERFC's hydrologic models exceeded the actual peaks in its May 14 forecast for the Piscataquog and Souhegan Rivers.

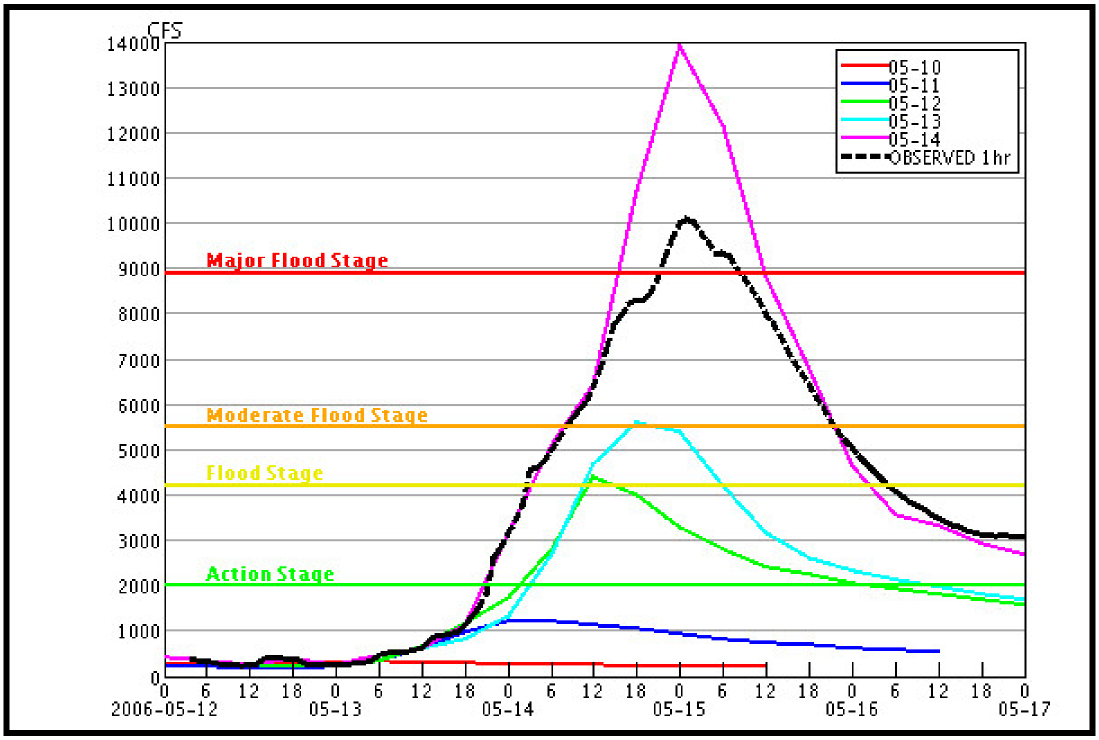


Figure 4-14: NERFC 11 a.m. Forecasts for the Piscataquog River at Goffstown (GFFN3) During the May 2006 Event (Source: NERFC)

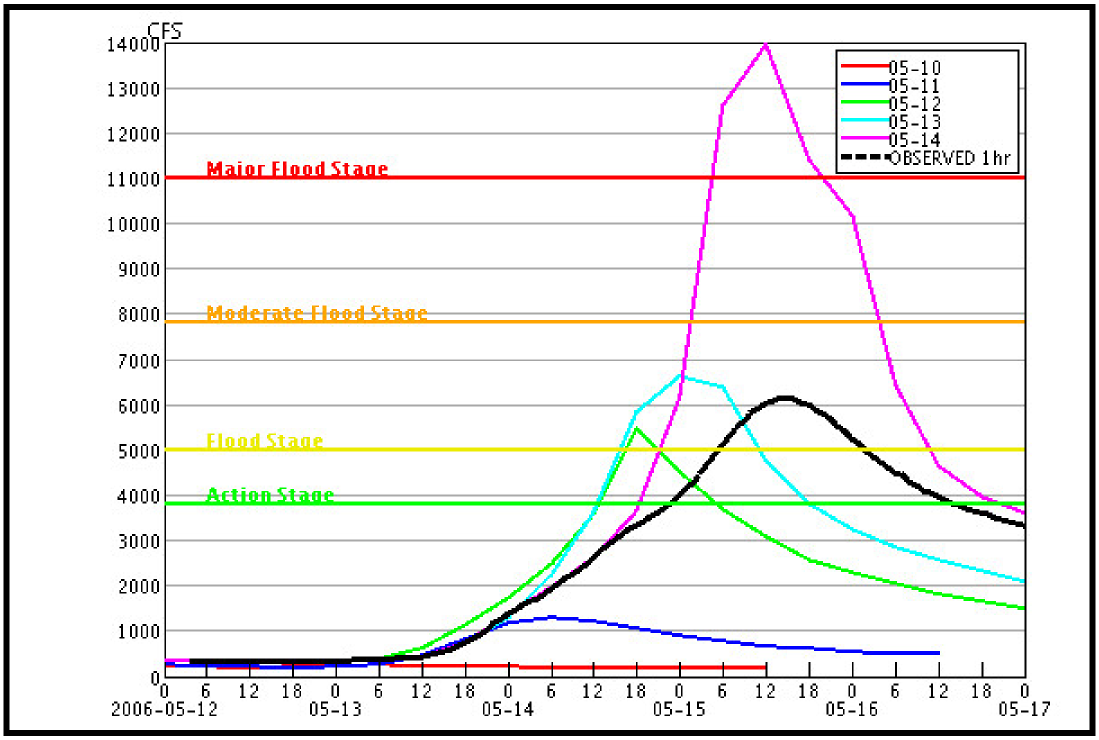


Figure 4-15: NERFC 11 a.m. Forecasts for the Souhegan River at Merrimack (SOHN3) During the May 2006 Event (Source: NERFC)

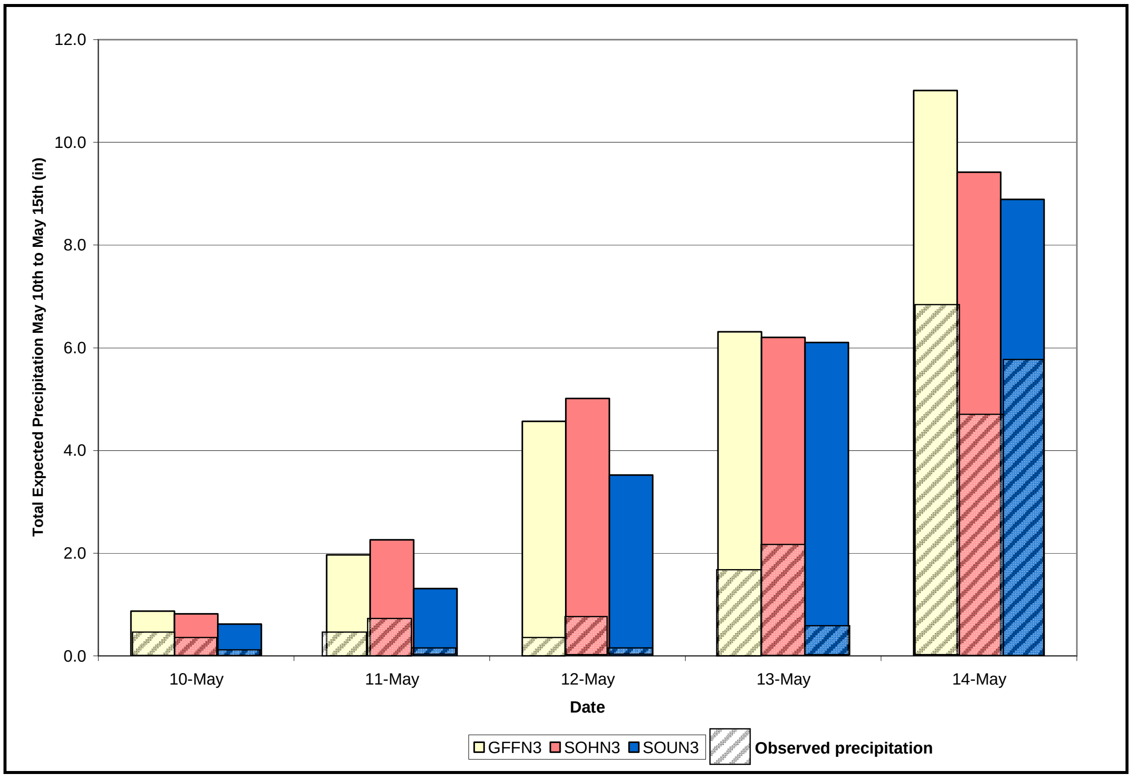


Figure 4-16: Total Expected Precipitation from May 10 to May 15, 2006 at Select NERFC Basins

4.6.4 Value of Forecasts

The following items are important factors affecting the value of streamflow forecasts to the NHDES Dam Bureau during the May 2006 and April 2007 flood events:

1. **Availability at locations of interest**

   NWS streamflow forecast points (Table 4-6) do not include many locations of concern to the NHDES Dam Bureau, in particular the Suncook, Cocheco, Lamprey, Oyster, Salmon Falls, and Isinglass Rivers. While more of these locations can be modeled in NHDES' own forecast system, this system was not utilized during the May 2006 and April 2007 flood events (see Section 3.1). Thus, no forecasts were available for these locations.

2. **Timely availability, including updates of previous forecasts during flood events**

   During the May 2006 and April 2007 flood events, NHDES staff primarily obtained forecast information from the NERFC and local WFOs. Forecasts from these sources were obtained once daily at around 1 p.m., about 2 hours after they were generated by the NERFC. While communications between the NHDES Dam Bureau and the NWS are described as very good, the Dam Bureau was not aware of additional forecasts issued by the NERFC during flood events. So, even though NERFC forecasts were made available, the Dam Bureau did not access them in a timely manner, if at all.

3. **Accuracy of the forecasts**

As discussed in Section 4.6.3, during the May 2006 and April 2007 events the NERFC provided appreciable lead times for Flood Stage for the Piscataquog, Souhegan, and Contoocook Rivers and the Merrimack River at Goffstown. Lead times were smaller for the more northern Soucook and Warner Rivers and also generally smaller for the Moderate Flood Stage. The Major Flood Stage on the Piscataquog River was not forecasted.

The forecasted time of exceedance of the various flood stages varied significantly, from being forecasted 12 hours too early to 26 hours too late. In general, timing was better in 2007 than in 2006. Flow peaks were typically underestimated by a wide margin during the early forecasts, emphasizing that forecasted precipitation volumes were initially too low during both events. Similarly, forecasted temperatures were too low in the lead up to the April 2007 event, resulting in too little modeled snow melt. NERFC's forecasts generally improved closer to the peak of the events, but significantly overestimated the peak flows for some rivers in 2006. These conclusions are consistent with the assessment report provided by the NERFC.

From a dam operator perspective, the NERFC forecasts could have provided more useful predictions of the Flood Stage and Moderate Flood Stage had they been obtained by the NHDES in a more frequent and timely manner. Greater uncertainties would have remained with respect to the timing and magnitude of the higher flows.

Given the lead times provided in the "Significant River Flood Outlook" products for "Flooding Likely" and also in the forecasts of Flood Stage for the Piscataquog, Souhegan, and Contoocook Rivers, preventative operations may have been possible at dams that provide flood control benefits. However, given the current limited discharge capacities at most of the larger NHDES dams, lead times were still too short to significantly lower pool elevations.

The lead times provided by the NERFC for Flood Stage at locations in the area would have been sufficient to increase discharge capacities at the private Run-of-River dams.

4. **Forecast periods ("looking into the future") that are consistent with needs**

According to the NHDES, the currently available forecast period of 54 hours is not sufficient to mobilize and perform flood control operations at its dams. Many of the NHDES reservoirs that provide flood control benefits require several days to lower pool elevations significantly in anticipation of flood events. The NHDES could have benefitted from longer forecast periods, which are currently not available to the public.

5. **Flood levels**

The flood levels currently defined by the NWS for their forecast points are very useful to the NHDES in determining flood-related actions. However, narratives describing the flooding impacts for the flood levels are not published for all forecast points (such as the forecast points on the Contoocook River), making it difficult to assess their overall significance with respect to flooding events.

4.7 IS THE RESPONSE AT ALL LEVELS OF GOVERNMENT DURING FLOOD EMERGENCIES ADEQUATE AND EFFECTIVE?

During flood emergency situations, the NHDES Dam Bureau supports the New Hampshire HSEM agency in providing State resources. If significant flooding is forecasted or is imminent, HSEM mobilizes the EOC, the Incident Planning and Operations Center on the grounds of the State Fire Academy. The EOC is a brand new state-of-the-art facility. To facilitate emergency coordination, the State 911, State Police, and State Department of Transportation dispatch services all share the same location.

During flood events, the EOC coordinates closely with the NWS WFOs in Gray, ME and Taunton, MA, the NERFC, and the NHDES Dam Bureau. Lines of communication are available, when needed, between all relevant parties: the EOC and FEMA; the EOC and the USACE's Reservoir Operations Center; and the EOC and local communities affected by the event. Personnel from the Dam Bureau participate with all parties at the EOC during flood events.

EOC monitors two types of flood events: winter thaw and flash flood. During the winter thaw, EOC monitors local EOCs and opens as needed. Flash flood events are more immediate. For any event requiring EOC response (flood and non-flood), procedures call for core and support functions. The core Emergency Support Function (ESF) includes communications, information and planning, and command structure. Depending on the type of event and needs, other ESF functions are activated as needed. In the case of flood events, the Dam Bureau supports the information and planning section.

In this situation, the NHDES Dam Bureau keeps itself informed of the hydrologic situation by accessing streamflow forecast graphs from the NERFC. Much of the information is Web-based, but it is often collaborated by personal communication. For example, if there are questions regarding a forecast on the NERFC Web site, the NERFC is contacted by regular phone (or secure phone in case of the regular phone system being down) to confirm the information. Conference calls with the local WFOs are held on a regular basis to obtain additional weather information.

The roles of the Dam Bureau during flood events are as follows:

1. Minimize upstream and downstream flood damages at dams by evaluating streamflow forecasts and dispatching dam operators to monitor and operate dams accordingly. Written action plans do not currently exist, as many variables have to be taken into account to reach decisions regarding appropriate dam operations during floods.
2. Ensure the safety of the dams structures themselves.
3. Keep the EOC informed regarding the current and anticipated hydrologic conditions.
4. Provide input to situation reports (SITREP) every 12 hours (or more often as necessary) to update all parties regarding the emergency. If it is a flood event, this would include the status of current flooding, road closures, information on dams, and forecasts for the next period. The SITREPs are disseminated by the EOC.
5. Communicate with the larger private dams (generally hydropower); especially those that have dam operations capability. Each dam owner with a high or significant hazard dam is required to have an EAP. These plans are available on site at the EOC. Each EAP contains a

communications plan, which must be periodically tested to make sure it is effective and accurate. The EOC (and the Dam Bureau) must be notified by the dam operator when an EAP is activated.

- Communications and emergency operations between State agencies supporting the ESFs, FEMA, and the affected communities during the May 2006 and April 2007 floods, and the October 2005 flood that damaged southwestern New Hampshire, were reported to be very responsive by the New Hampshire's Homeland Security and Emergency Management (NHOEM) Chief Planner. After Action Reports (AARs) were developed following these emergencies to document the strengths and weaknesses of the State response.

SECTION FIVE WHAT CAN BE DONE TO MITIGATE THE IMPACT OF FUTURE FLOODS?

This section builds on the information developed in previous sections to investigate approaches to mitigate the impacts of future floods. These will serve as basis for general and site-specific recommendations provided in Section 6.

This section first examines and evaluates physical considerations to reduce flooding, such as improvements at dams and bridges and management of sediment and woody material. Next, the discussion considers improvements to floodplain management in the State to prevent future development from being in harms' way and to enhance the effectiveness of current programs designed to mitigate flood impacts. Lastly, this section discusses approaches to improving forecasting and response to help the people in the study area prepare for future flood events, if and when they occur.

5.1 REDUCING FLOODING

Measures to reduce flooding, which often involve operational changes or construction of flood relief structures, require consideration of costs and benefits, operational performance, and environmental consequences.

- Flood relief structures are constructed to a certain level of performance. In many cases, they are built to prevent flood impacts from the 100-year flood. If floods exceed this level of performance, the damage can be the same as, and in some cases worse than if the structures were not built at all. The level of performance is often a function of the cost of the facility compared with its benefits. Thus, it may be cost effective to build a structure to a certain performance level, but the costs of higher performance levels would often exceed the benefits. For example, replacing a small culvert with a larger culvert may prevent some flood damages from occurring, but the annualized cost of the replacement over the useful life of the project may be greater than the annualized dollar value of the damages prevented.
- Operational changes may improve performance during certain flood events, but may have minimal impact on larger events. For example, improved operations may mitigate some flooding during events similar to the May 2006 and April 2007 events, but in the case of even larger events, the impact may be negligible. If it rains hard enough for long enough, flooding will result despite operational changes.
- Some improvements that will reduce flooding may have other negative consequences. For example, dam removal may lower flood elevations upstream of the site, but also cause serious environmental consequences, such as the movement of contaminated and/or hazardous sediments downstream, invasive species migration, and historical and archeological concerns. Alternatively, dam removal can often have substantial environmental benefits. Removal of some dams can completely change the aesthetic character of the surrounding community.

This section examines these potential flood control measures, but final decisions on implementation need to weigh these and other important considerations.

5.1.1 Operations and Maintenance

What can be done to keep dams ready for a flood?

Routine maintenance tasks can be performed to ensure that all mechanical parts are functioning and operational should a flood occur. In particular, ice can be removed from moving parts in the winter and flood control gates can be tested for proper operation before the flood season.

A very important maintenance task is the removal of woody material, which can clog gates and stoplog bays, preventing water from exiting the reservoir and potentially causing upstream flooding. Cleaning woody material from a stream and river structures on a routine basis and before, during (to the extent possible), and after flood events is good practice for reducing flooding.

Does it make sense to refill more slowly in the spring?

Almost all of the NHDES operated reservoirs that provide significant flood control are currently drawn down in the fall. This helps prevent damage by ice at the dams during the winter, and also makes room for melting snow and rain to be stored in the spring. This storage can be effectively used during spring flood events to store flood waters and reduce downstream flooding. However, the available storage is continually reduced as the reservoirs refill in the spring and early summer to eventually reach the “normal” pool elevation for the summer recreation season. At this point, the available storage in the reservoirs is greatly reduced, so that the dams cannot provide as much downstream flood control as they can during the winter and early spring.

One possibility to increase the flood control benefits of these dams is to refill them more slowly in the spring. By keeping the lakes lower for a longer time, more storage capacity is available should a flood occur and flooding along the lake shores and in downstream areas could be minimized. However, the “normal” pool elevation for the summer would be reached later, or, in dry years, not at all. This would negatively impact habitats in and along the lake, as well as its recreational uses. These considerations must be weighed carefully before a decision is made to keep the lakes/reservoirs lower in the spring to provide better flood control.

The chances of not being able to refill the reservoir in the late spring can be minimized by tying the refill rate to the amount of snow present in the upstream area. This snow contributes a large amount of the water used to refill the reservoirs in the spring. Typically, the snow melt is gradual, filling the lakes slowly. However, quickly melting snow can, as it did in April 2007, contribute to flooding. This is particularly dangerous if there is a significant amount of snow to melt. Slower spring refill can help by ensuring that all, or large parts, of the melting snow can be contained during a flood event. In the absence of a flood event, the slowly melting snow would still refill the reservoir in time for the recreation season.

Slowly refilling the NHDES reservoirs could provide significant local flood control benefits at little risk. Rules for a slower refill can be established on a dam-by-dam basis to ensure successful refill while minimizing the risk of not reaching summer refill elevations.

What can be done just before an event to minimize flooding?

Any dam suitable to provide flood control benefits can be operated to increase these benefits in the days preceding an anticipated flood event. The impoundments can be lowered preemptively to make room for the expected flood waters, by increasing the flow out of the impoundments so that it is greater than the flow into the impoundments. In doing so, the dams can store more water and lower the downstream flows during the flood, thus providing downstream flood control and also minimizing the chance of upstream flooding. However, reliably predicting a large flood event is not easy. Dam operators must closely monitor NWS forecasts before deciding to optimize the flow rates into and out of the reservoirs to drop the pool elevation.

If an anticipated rainfall event does not materialize and a reservoir has been drawn down, refilling it might take many weeks, particularly during a dry summer. This risk can be minimized by only reacting to forecasts that are just a few days out and, therefore, more likely to be accurate. However, this may reduce the time available to draw down the reservoirs and very large releases might be necessary to sufficiently drop the lake level. These releases can in themselves cause flood damages. Still, rules can be established to govern preemptive reservoir releases.

Many of the larger NHDES reservoirs than provide significant local flood control benefits do not currently have the capacity to quickly release the large volumes of water required for preemptive drawdowns. Some capital improvements, as outlined in Section 5.1.3, would be required.

Medium-sized reservoirs that provide some local flood control benefits can be drawn down mainly to prevent upstream flooding, particularly during average flood events. The operating goal is to store some flood waters and to pass additional flood flows at pool elevations that do not cause upstream damages. Again, rules can be established that govern these operations at dams prone to upstream flooding.

Preemptive operations at Run-of-River dams can focus on providing large discharge capacities at pool elevations that do not cause upstream flooding. Woody material at the dam site can be removed to ensure free flow. Rules regarding preemptive woody material removal can be established for affected dams.

What can be done during an event to minimize flooding?

Operations at flood control reservoirs that provide local flood control benefits are typically aimed to ensure that upstream flood waters are stored, particularly at the beginning of an event when enough storage capacity is available. In these cases, gates at the dam can be closed and stoplogs inserted to reduce releases and store flood waters. However, given the typical discharge capacities at the dams, flood waters will likely also be stored if gates are kept open. Some dams are sandbagged during large flood events to store more water than otherwise possible.

Still, once the water in a reservoir reaches an elevation where upstream flooding is likely or where the dam can overtop, then gates, if installed, must be opened to prevent damage to the dam itself or upstream flooding. Rules can be established to govern operations that ensure upstream and downstream flood control.

The NHDES-operated Run-of-River dams, and also all of the private hydropower projects in southern New Hampshire, are too small to store any significant amounts of water during a flood. They typically fill up within a few hours and flow over the spillway. The water backs up if less water can pass over the spillway than enters the reservoir. Backups can be worsened if woody material clogs the spillway, gate openings, or stoplog bays. The more flood waters enter these reservoirs the higher the water will back up and the more likely it will cause upstream flooding.

The only way to prevent upstream flooding is to ensure that inflows to the reservoir can easily pass the dam structure without backing up. This can be done by opening the dam gates and removing its stoplogs and flashboards. Rules can be established to prescribe effective operations.

5.1.2 Security

Some NHDES dams are accessible to the public. In at least one instance, unauthorized personnel operated the gates at a dam. Measures can be taken to secure this and all dams in the State's inventory.

5.1.3 Structural Improvements

Some of the dam structures in southern New Hampshire are not well suited to operations that reduce both upstream and downstream flooding. Structural improvements at the dam sites themselves can remedy this situation.

Some dams lack operational flexibility because they are equipped only, or primarily, with stoplogs, which can be removed only slowly, or not at all when overtopped. Generally, only the top layers of stoplogs can be removed, because the ones below are overtopped by the draining water. The operator must wait (often days) for the water elevation to drop before additional stoplogs can be removed. This lag time prevents dams that would otherwise have flood control potential from being used.

Similarly, stoplogs at Run-of-River type dams may not be removed in a timely manner or at all once they are overtopped at the beginning of an event. In this case, the discharge capacity of the dam cannot be increased sufficiently to prevent backup and potential upstream flooding.

In order to increase the flexibility in dam operations, conventional gates or so-called Obermeyer panels can be installed instead of stoplogs at certain dams. These gates and panels can be opened and closed quickly, even when submerged. These gates and panels can also be equipped with motors or pumps that allow remote operation from a central command center.

Other dam structures are simply too small to pass large flood inflows without backing up and overtopping. If the dam does not pose any upstream flooding danger, then modifications to elevate the dam to prevent overtopping can be considered. Typically, overtopping occurs at a small section of a dam only during very large events, suggesting that raising existing retaining walls by just a few feet could reduce the risk of overtopping in the future. In doing so, emergency personnel can be freed from sandbagging activities.

Unfortunately, raising the dam structures is not feasible at many sites, in particular at Run-of-River dams, without causing upstream flooding problems. Instead, overtopping can be prevented by increasing dam discharge capacities. Many Run-of-River dams are constructed so that most of higher flows run over the spillway and only a small portion of the flows are passed through gates or stoplogs. Lowering the spillway by removing its top section can allow more water to pass without backing up. Of course, any such decision must be weighed against other uses of the dam, and costs and benefits must be evaluated.

5.1.4 Dam Removal

In some instances, removing existing dams to reduce upstream flood levels may be beneficial. For all the dams considered in this study, adding gate capacity can provide similar, though not as substantial, flood level reductions. For this study, select dams were considered for removal. A survey-level assessment was performed to see if dam removal is a sensible alternative for flood reduction benefits in the study area. The dams considered include the dam at the head of the Exeter River in Exeter, the dam in downtown Newmarket on the Lamprey River, and the Bucks Street Dams on the Suncook River.

Exeter River Dam in downtown Exeter – This dam is located on the Exeter River just upstream of tidal influences. The spillway elevation is approximately 22.5 feet NGVD (National Geodetic Vertical Datum). The 100-year flood elevation downstream of the dam is approximately 21.5 feet NGVD, and the 100-year flood elevation upstream is approximately 30.5 feet NGVD, representing a 9-foot rise in the water surface attributable to the dam. The upstream channel is flat. The channel invert is at approximately 16 feet NGVD upstream of the dam (just upstream of High Street) and does not increase until about 3 miles further upstream near Court Street. The flood profile is also relatively flat and reaches 33 NGVD at Court Street, just a 2.5-foot rise in 3 miles. If the dam was removed, lower 100-year water surface elevations would likely be realized this far and further upstream. Aerial photographs of the floodplain in this reach were examined to assess potential benefits. Few structures are located in this floodplain or in the Little River floodplain (a tributary with backwater from the Exeter River). Consequently, this survey-level examination suggests that removal of this structure would provide little flood control benefits, because the floodplain is largely undeveloped.

Lamprey River Dam in downtown Newmarket – This dam separates the tidal portion of the Lamprey River from the non-tidal portion. The tidal reach would extend far upstream without the dam. The tidally influenced 100-year flood elevation is about 10 feet NGVD downstream of the 20-foot-high dam (spillway elevation is approximately 23.5 feet NGVD), while the 100-year elevation upstream of the dam is 30 feet NGVD and quickly rises to 32 feet NGVD as it passes through the State Route 108 bridge less than 400 feet upstream. Thus, the difference in 100-year flood elevation attributable to the dam is over 20 feet. The flood elevation upstream of State Route 108 holds for a considerable distance, and the floodplain caused by the dam and bridge is extensive. However, as was the case for the Exeter River Dam, few structures are in the floodplain; thus, dam removal would have little flood control benefit at this location.

Buck Street Dams upstream of Suncook – Two dams have been constructed (east and west) on the Suncook River using an island in the middle of the river to form part of the flow barrier. The west dam is shown in Figure 5-1. Both are small, Run-of-River dams, less than 10 feet high, with a spillway elevation at about 287.5 feet NAVD. Both dams tend to get clogged by woody material. A foot bridge (not open to large vehicles) is located just upstream of the dams. The 100-year elevation downstream of the dams is 295 feet NAVD, over 8 feet higher than the spillway crests, which are submerged even during 10-year events. The 100-year elevation upstream is 299 NAVD and 301.2 NAVD upstream of the foot bridge. Thus, the dams and bridge elevate the 100-year water surface by just over 6 feet. In addition to the FIS water surface profiles, high water mark data from the April 2007 storm is available for this location. The USGS estimated that the April storm was greater than a 100-year event on the Suncook River. The high water mark data just downstream of the dams and upstream of the foot bridge (Sunhwm20 and Sunhwm26) were 296.5 and 299.2 feet, respectively, a difference of 2.7 feet.

Because of changes since the FIS (including the avulsion upstream), the high water mark data is deemed more accurate.

Figure 5-1: Buck Street – West

The slope of the water surface upstream and downstream of the dams is relatively constant. Though the channel bottom information pre-dates the avulsion, it does indicate a very flat channel. Using pre-avulsion information, the invert in the neighborhood of Route 28 just upstream of the dam is approximately 281 NAVD. The channel does not begin to rise beyond 281 for about 3 miles, just downstream of Short Falls Road. Therefore, the 2.7 foot difference attributable to the dam and footbridge is likely to carry most of the distance to Short Falls Road. Flooding in this reach of river, below the avulsion was significant. From a flood control perspective, the Buck Street Dams and footbridge remain candidates for removal and should be further investigated. The investigation should be done in conjunction with other investigations by USGS ongoing on the river, and with environmental studies to investigate the environmental impact of removal. Quantitative estimates to confirm the benefit attributable to dam removal could be confirmed by the USGS in its ongoing work to re-evaluate the hydrology and hydraulics on this reach of river to develop new flood insurance profiles.

Based on this limited analysis of dam removal in the study area, the relative merits of dam removal are site-specific and need to be weighed against a host of other potentially positive or negative factors, such as the aesthetic and environmental impacts associated with their removal.

5.1.5 Erosion, Sediment, and Woody Material

Wetlands Permitting Issues

Sediment and woody material back up at manmade structures and aggravate flood conditions. A permit from the New Hampshire Wetlands Bureau is not always required to remove this material, as many seem to believe. No permit is required to remove sediment and woody material from manmade structures designed to collect or convey storm water and spring runoff, such as culverts, drainage ditches, catch basins, and ponds in non-tidal areas. As indicated on the New Hampshire Wetland's Bureau Website (http://www.des.state.nh.us/wetlands/):

> "In accordance with RSA 482-A:3 IV (a); man-made nontidal drainage ditches, culverts, catch basins, and ponds that have been legally constructed to collect or convey storm water and spring run-off…may be cleaned out when necessary to preserve their usefulness without a permit from DES with the following conditions:
>
> a. Machinery may be used as long as the machinery is not located within wetlands or surface waters.
>
> b. The drainage facilities may not be enlarged or extended into other wetland areas.
>
> c. All dredge spoils must be placed outside of any wetlands or surface waters.
>
> d. Care should be taken so as to limit water quality degradation to any surface waters."

Fallen trees along stream banks have been major sources of debris during flood events. The Wetlands Bureau has no prohibition against the removal of trees, and no permit is required if removal is done without disturbing wetlands sediments and rivers and without causing erosion. Trees that have fallen along the banks of rivers that have the potential of causing downstream problems can be cut (so the roots remain in place, thereby preventing erosion) and removed, so long as the banks are not disturbed. Thus, the limitations on tree removal are not regulatory, but the practical aspects of access and ownership. Fallen trees should not be removed indiscriminately. They serve useful purposes in nutrient and sediment retention and aquatic habitat. In some instances, they may even reduce the peak flood wave as it moves downstream.

At a minimum, easily accessible fallen trees likely to wash downstream and impede structures should be cut at the roots and removed by the owner or the local department of public works (with the owner's permission). A regularly scheduled program for removal would at least reduce the magnitude of this problem during flood events.

Procedures to expedite the permitting process for activities requiring a permit during emergency situations are already in place. The Wetlands Bureau's Environmental Facts Sheet WB-9 states, in part:

> "In an emergency situation it is possible to obtain authorization from the Department of Environmental Services (DES) to conduct work prior to receiving a wetlands impact permit. The Department will issue authorization in situations which threaten public health and safety or which threaten significant damage to private property provided that the event which caused the emergency has occurred within the last 5 days. Examples of emergencies include: undermining of bridge abutments; weakening of dam structures; or washouts of roadways by flood waters."

When permits are required, they are approved in cases where the permit applicant proves a legitimate need, which can include the return of a water body to historical levels so that existing infrastructure and property can be utilized. Proper planning is critical to submitting a permit application. The Wetlands Bureau recommends applicants contact them early in the process and participate in a pre-application meeting to avoid pitfalls and obstacles during the permitting process. Expedited permitting processes are also available in some cases (for example, for removal of debris in the impoundment above a dam) through permit-by-notification procedures, as explained at http://www.des.state.nh.us/wetlands/PBN/PBN4.pdf (NHDES 2008b).

Stormwater Permitting Issues and Best Management Practices

Two sources of sediment were identified in Section 4: highway sanding operations and construction sites. Wintertime sanding operations on New Hampshire highways are a fact of life. Every effort should be taken to use only the amount of sand required for safe highways. Street sweeping operations should begin as soon as practical in the spring to remove the remaining sand. Catch basins should also be cleaned regularly. Best Management Practices (BMPs) should be considered in the design and construction of new highways and roads to facilitate removal of sediment before it reaches rivers and streams.

Construction sites that disturb more than 1 acre of land require U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) stormwater permits. The permits require erosion controls at construction sites to prevent the eroded material from reaching rivers and streams. The State should ensure that all construction activities disturbing more than 1 acre are permitted and in compliance with the provisions of the permit. The State could also consider its own program for construction sites under EPA's 1-acre threshold.

In order to help mitigate the impact of new development on flooding, BMPs to capture runoff on site and foster infiltration and maintenance of natural flow paths should be used. These practices are also designed to reduce erosion and include implementation of low impact development (LID) principals.

Vermont's Approach to Erosion Hazards

Vermont suffered several flood events in the 1990s, and found that much of the damage was not from flood inundation, but from erosion like that shown below in Figure 5-2, and erosion damage is not necessarily captured on FIRMs. Furthermore, much of this damage was preventable, had the erosion hazard been properly considered. The Vermont Department of Conservation Rivers Management Program (http://www.anr.state.vt.us/dec/waterq/rivers.htm, Vermont Agency of Natural Resources 2008) is establishing fluvial erosion hazard corridors along its streams using a systematic methodology to classify the erosion hazards based on fluvial geomorphology principals. These corridors identify where the erosion hazards are most significant. These corridors can be used as overlay districts for local zoning ordinances.

Given the similarity in the climate and geography of Vermont and New Hampshire, Vermont's program could be used as a template for a similar effort in New Hampshire, so that the erosion hazard could be mapped and preventative measures taken to reduce erosion related damages.

Figure 5-2: Roadside Erosion in Vermont (Source: Vermont Department of Environmental Conservation, River Management Section)

Studies to Prevent Future Avulsions

The Suncook River avulsion has had severe negative impacts on the Suncook River and the adjacent communities. Mitigating the impacts of the avulsion will cost millions of dollars, and restoration of the river to its prior conditions is unlikely.

Learning from the past, preventing future avulsions may be possible. The conditions needed for an avulsion to occur are predictable, and include erodible soil (generally sandy) along a stream bank and high velocities generally along the outside meander of a stream.

A study could be conducted using historical and existing aerial photography and surficial geology maps to identify these conditions. The historical and existing aerial photography would help establish stream movement. The existing aerial photography would be used to locate the high velocity erosive zones along streams. And the surficial geology maps would be used to identify highly erodible soils along these high velocity zones. The most critical areas could be identified through a ranking process. Onsite assessments at the highest ranking sites could be conducted to establish the likelihood of an avulsion. If an avulsion may occur at a particular site, appropriate preventative actions could be taken. Such a study could be undertaken within the context of applying Vermont's erosion hazard methodology.

5.2 IMPROVING FLOODPLAIN MANAGEMENT

5.2.1 FEMA's National Flood Insurance Program

The NFIP is the most widely used program for floodplain management in the nation. Most communities in New Hampshire actively participate in the program. To enhance the effectiveness of the program, the following actions could be considered:

- **Identify structures in the floodplain –** The actual number of structures in the floodplains, with or without flood insurance, in New Hampshire is unknown. Conducting adequate planning under these circumstances, when the magnitude of the problem is not well defined, is difficult. Using floodplain maps, local floodplain administrators could identify the addresses of buildings inside the floodplains. This information could be compared to policy information to establish which buildings do not have flood insurance. An accurate count of structures in the floodplain and the number of flood insurance policies could then form the basis of a public relations campaign to inform building owners of the availability of flood insurance.
- **Improve floodplain mapping –** This can be accomplished using more accurate topography to delineate the floodplains, and by revising the basic hydrologic and hydraulic information, where required. The state-of-the-art method for developing detailed topography is called LiDAR (Light Detection and Ranging). It has been used in many States, including Maryland, North Carolina, and Pennsylvania. As the technology has matured, the price has dropped. Other States have instituted cost sharing among State agencies interested in topography, such as State Departments of Transportation and State Agricultural Agencies, to purchase LiDAR mapping. The uses of LiDAR-based topographic mapping extend far beyond floodplain management objectives.
- **Perform new hydrologic and hydraulic studies –** Section 4.4.2 discussed the inaccuracy of current floodplain mapping on some rivers, including:
  - Salmon Falls River
  - Cocheco River
  - Lamprey River
  - Souhegan River

  Performing new hydrologic and hydraulic studies on these rivers would result in more accurate floodplain mapping.
- **Adopt more stringent floodplain ordinances –** At the local level, communities should consider adopting regulations that exceed the NFIP minimum requirements, such as excluding development in the flood fringe, restricting building construction to elevations higher than the 100-year flood elevation, and/or establishing setback distances from the river channel. Similar ordinances are already in place in a number of New Hampshire communities.
- **Participate in the NFIP –** As discussed in Section 4.4.1, most communities participate in the NFIP. Those communities that do not should consider the benefits of participation.
- **Participate in FEMA's Community Rating System (CRS) –** Finally, NFIP participating communities should consider joining the CRS, which is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements. Communities that participate in the CRS work toward reducing flood losses and improving flood awareness, and earn between a 5 percent and 45 percent discount in flood insurance premiums for their flood policy holders. The following New Hampshire communities currently participate in the

CRS: Keene (10 percent discount), Marlborough (5 percent discount), Peterborough (10 percent discount), Rye (5 percent discount), and Winchester (5 percent discount).

5.2.2 FEMA's Mitigation Planning and Grants Programs

In addition to the NFIP, FEMA has programs to assist communities in their efforts to mitigate flood risk. These programs can be characterized into two broad categories, mitigation planning and grants programs.

Mitigation Planning – One of the best ways for communities to reduce flood losses is to undertake a mitigation planning process to identify policies, activities, and tools to implement mitigation actions. Mitigation is any sustained action taken to reduce or eliminate long-term risk to life and property from a hazard event. This process has four steps:

1. Organizing resources
2. Assessing risks
3. Developing a mitigation plan
4. Implementing the plan and monitoring progress

The adoption of a local mitigation plan is a requirement for receipt of mitigation grant assistance under any of FEMA's grant programs. Compliant mitigation plans have been adopted by 149 New Hampshire communities covering 92 percent of the State's population. Each plan must be reviewed and updated every 5 years.

Grants Programs – Communities and property owners should learn about available FEMA mitigation grants and apply for these grants to undertake measures to reduce losses from flooding and other natural hazards. These activities can include acquisitions of floodprone properties, elevations of buildings above the base flood level, or other activities that reduce losses. These grant programs require a non-Federal cost share of between 10 percent and 25 percent. The programs include:

- Hazard Mitigation Grant Program
- Flood Mitigation Assistance Program
- Pre-Disaster Mitigation Program
- Severe Repetitive Loss Program

Property owners interested in participating in these programs should contact their community officials. The NHOEP administers these programs for the State and can provide additional information.

5.2.3 Emergency Operations and Communications Improvements

With the advent of the Web, cost effective methods have been developed to facilitate communication during emergency operations. The following technologies could assist emergency dam operations.

- Webcams. Webcams could be installed at dams to monitor water levels. This would increase the frequency of response (NHDES personnel visit dams on a periodic basis that can span days, even during emergency situations) and would allow for monitoring and dispatching of personnel where they are needed most. In addition, with dams that already have instrumentation (Milton Three Ponds and Mascoma Lake), the webcams could be used to confirm data fed through the non-visual monitoring systems.

- Reverse 911. This system, which should be available in the near term future, could be set to call residents whose houses are in danger of flooding and issue a warning message.
- New Hampshire Department of Transportation's 511 system. This GIS-based system identifies and maps all State roadways with problems and is currently being updated to automatically generate detour routes. In the future, local roads may be included in the system.
- Satellite communications capabilities. Satellite phones can eliminate communication problems in locations where cell towers are out of order or cell coverage is poor (the more rural areas in the State).
- Mobile internet communications vehicles. These vehicles can be dispatched to damage areas such as dams. They have video and chat room capability allowing effective communications between dam operators and the EOC under adverse conditions.

5.3 IMPROVING FORECASTING AND RESPONSE

This section outlines options to improve streamflow forecasting for the NHDES.

5.3.1 Availability of Forecasts

A critical component defining the value of a streamflow forecast for the end user is its availability, both spatially and temporally.

The NHDES requires streamflow forecasts at critical points of interest, mainly at selected points along rivers with State-owned or other critical dams. These forecasts can be used in the decisionmaking for dam operations in the area. Currently, forecasts from the NWS NERFC are available for some basins in the area but not for all sites of interest to the NHDES. Forecasts from the NHDES system are currently not used.

However, new forecast points can be established at critical dams or at currently un-modeled river systems (such as the Isinglass River) in cooperation with the NERFC, utilizing their expertise, or by revitalizing and expanding the existing NHDES forecast system. In either case, the process of establishing new forecast points requires significant resources to: (1) set up and integrate computer models and (2) operate and maintain the models on a regular basis.

Meaningful and well-described flood levels at each forecast point can aid in decisionmaking during flood events. Useful descriptions of the impact of water levels at defined flood stages can be developed where they are not available.

Streamflow forecasts offer the greatest benefits if they are available well in advance of a potential flood event. To do so, the forecast period must extend a sufficient period out into the future and the forecasts themselves must be issued often enough to take into account the latest developments in local weather. NHDES needs are best met by forecasts that extend out about 5 days into the future to allow for operations at the dams before a flood event occurs. Making these longer-term forecasts available to the NHDES on a regular basis can be achieved by allocating resources to modify existing computer models, either as part of NWSRFS or as part of a revitalized NHDES forecast system.

Streamflow forecasts can only be useful to the NHDES if they are available in a timely manner and if they are updated frequently. A revitalized NHDES forecast system that is rigorously operated can provide both timely and frequent streamflow forecasts. In addition, fully utilizing information available at NWS Web sites and direct communication with the NERFC can help the NHDES to obtain the most up-to-date NWS streamflow forecasts in the area.

5.3.2 Accuracy of Forecasts

The accuracy of streamflow forecasts determines the end user's confidence in their predictive qualities. A dam operator's willingness to make operating decisions based on streamflow forecasts typically depends on the accuracy of these forecasts in the past. Improving this accuracy is a crucial step in increasing the usability of streamflow forecasts in decisionmaking. This can be achieved as follows:

- **Improve forecasts of precipitation and temperature:** The most important factors in accurate streamflow forecasting at longer lead times (more than 1 day) are accurate forecasts of temperature and precipitation. This information is typically obtained from large scale climate (weather forecast) models that are operated by the NWS and other government agencies worldwide. The predictive qualities of these models are steadily improving, but the accuracy of their longer-term temperature and precipitation forecasts, in particular at smaller scales, is still limited. However, improving these climate models is the subject of significant research efforts.
- **Improve observations of precipitation and temperature:** Short-term (less than 1 day) forecasts of streamflow are greatly influenced by the precipitation and temperature conditions during the last few hours. These conditions are typically monitored by weather stations or, more recently, by radar or satellite. Incorporating observations from more weather stations in the area, as well as taking advantage of radar or satellite observations can improve the accuracy of the precipitation and temperature inputs into the hydrologic computer models that compute streamflow forecasts.
- **Improve hydrologic computer models:** The hydrologic computer models used by the current NHDES forecast system and also by NWSRFS have a long and proven history of reasonably simulating river flows. However, these models must be adapted to each individual basin. This process, called calibration, is affected by the input data fed to the models (namely precipitation and temperature), as well as by changing conditions in the river basins themselves (such as land use changes). Many of the models used by the NERFC were originally calibrated in the 1970s and 1980s. Recalibrating hydrologic computer models on a regular basis (every 10 years) can improve the accuracy of the streamflow forecasts they produce.

  In addition, the computation time step within the hydrologic computer models impacts the accuracy of the results at small time scales. While larger basins can be successfully modeled on a 6-hour time step (as currently done in the NWSRFS for most basins), smaller basins that react quickly can be best modeled using a 1-hour time step (as currently employed in the NHDES forecast system).

- **Routine operations and maintenance:** Because streamflow forecasts are so dependent on the observed and forecasted precipitation and temperature data, erroneous or missing data can quickly cause unreliable forecasts. Frequent checks of the input data and adjustments to the soil moisture in the computer models can help prevent such problems.

  Routine use of a forecast system will also increase the confidence of the operators in the capabilities of the models. Experience gained in interpreting streamflow forecasts during non-flood times will be valuable in emergency situations when weather and streamflow conditions must be assessed frequently and rapidly.

5.3.3 Riverine Risk Management Tool

NHDES should coordinate with the NWS to improve flood forecasting within the watershed. Communicating forecasted flood levels to State and local emergency managers so they can carry out emergency actions to protect the floodplain residents and property is critical for a flood warning system. FEMA is currently developing a Riverine Risk Management Tool Web site. The tool will provide emergency managers with vital information for carrying out emergency response activities, such as directing evacuations, setting up shelters, and notifying the public of an in impending flood event. The tool can also be used in other phases of emergency management for mitigation planning and preparedness. FEMA is encouraged to complete and activate the Web site tool and State and local emergency managers should become familiar with its use in advance of future flood events.

SECTION SIX RECOMMENDATIONS TO IMPROVE FLOODPLAIN MANAGEMENT

Sections 6, 7, and 8 present study recommendations. Section 6 presents recommendations for improving floodplain management and associated activities, such as emergency operations and communications and BMPs for the control of erosion and sedimentation. The project team made a separate set of recommendations in March 2008, prior to the 2008 peak runoff season. These recommendations are provided at the end of Section 6. Section 7 presents recommendations associated with improved flood forecasting, and Section 8 presents recommendations for a watershed approach to flood operations.

The recommendations in the executive summary were taken from these three sections. The most critical recommendations are repeated in ***bold italics*** and other important recommendations are shown in *italics* to differentiate them from other project recommendations.

6.1 ACHIEVING ACCURATE FLOODPLAIN MAPPING

The mapping information used to make floodplain management decisions needs to be accurate and effectively communicated to both decisionmakers and the public. The basic sources of information used to make floodplain management decisions are the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRMs). These maps have recently been prepared in digital (electronic) form. The information shown on the maps, however, is old, typically dating back to the 1980s. In many locations the mapping information is not accurate. Without accurate mapping, establishing the extent of the floodplain, and whether property is subject to flooding, is difficult. New topographic information should be collected and new analyses should be performed in the areas where the mapping is not sufficiently accurate. Updated and more accurate FIRMs would provide the State and its communities with better data to make sound floodplain management decisions.

Section 4 discusses the need to update the information presented in the effective FISs in the study area. Without this information, accurately establishing flood risk and the appropriate management measures to mitigate that risk is not possible. The following are recommendations to improve floodplain mapping in the study area:

- A LiDAR mission to develop accurate topography for delineation of the flood hazard in the study area is recommended. The cost of the mission should be shared with other State and local agencies who need and are interested in good topographic data.
- The current floodplain mapping on some rivers is inaccurate. These include:
  - Salmon Falls River
  - Cocheco River
  - Lamprey River
  - Souhegan River

  Performing new hydrologic and hydraulic studies is recommended on these rivers to obtain more accurate floodplain mapping, so that floodplain managers and the affected residents know the true risk of flooding along these rivers.

- Further studies to address the adequacy of the hydrology and hydraulic information in the effective FISs for other streams in the study area should be performed, and new hydrologic and hydraulic studies should be conducted on the streams with inadequate data.
- New studies should consider potential future development and climate change, to the extent possible.
- Areas that have undergone development and are mapped by approximate methods on the current DFIRMs should be mapped using more rigorous methods, such as limited detailed or detailed studies.

FEMA has limited budget to implement these changes. Other States are working on making these changes by contributing a larger share of the costs through FEMA's Cooperating Technical Partner (CTP) program. States that have shared these costs with FEMA have progressed further and have a larger inventory of accurate mapping products. Accurate floodplain mapping and flood insurance information will be available to the State more quickly if it participates more directly in the funding of these recommended improvements.

6.2 IMPROVED FLOODPLAIN MANAGEMENT

FEMA uses the Flood Insurance Rate Maps for the purpose of administering its National Flood ***Insurance Program (NFIP). Although most New Hampshire communities conform to the minimum requirements of the NFIP, the minimum requirements are not sufficient to protect the floodplain from development. To retain the function and value of the floodplain, New Hampshire communities should adopt measures more stringent than the minimum requirements of the NFIP. These measures will prevent buildings from being constructed in areas with a high risk of flooding and will help keep flow rates and flood elevations from increasing over time.***

Specific recommendations for improving floodplain management include:

- Local floodplain administrators should research the floodplain maps in their communities and establish the addresses of the buildings inside the floodplains. By comparing this information to policy information, the buildings without flood insurance should be established. This will result in an accurate count of structures in the floodplain. This information will form the basis of a public relations campaign to inform the owners of the building in the floodplains of the availability of flood insurance if they do not already have it.
- Communities should adopt regulations into their floodplain ordinances that exceed the NFIP minimum requirements, such as excluding development in the flood fringe, requiring building construction at elevations higher than the 100-year flood elevation, and/or setback distances from the river channel.
- Most New Hampshire communities participate in the National Flood Insurance Program. Those that do not should consider joining the program.
- Communities should consider participating in the CRS program, which encourages a comprehensive approach to floodplain management and reduces the cost of flood insurance.

- All communities in New Hampshire (not just the 149 communities that already have them) should adopt local mitigation plans. All plans should be updated every 5 years.
- Communities and property owners should become aware of available FEMA mitigation grants and are encouraged to apply for them to undertake measures to reduce losses from flooding and other natural hazards. These activities include acquiring floodprone properties, elevating buildings above the 100-year flood level and other activities that reduce losses. The grant programs normally require a non-Federal match of between 10 percent and 25 percent and include the following programs:
  - Hazard Mitigation Grant Program
  - Flood Mitigation Assistance Program
  - Pre-Disaster Mitigation Program
  - Severe Repetitive Loss Program
- The New Hampshire Office of Energy and Planning should continue its outreach efforts to encourage and assist communities with promoting sound floodplain management practices including the activities listed above.

6.3 EMERGENCY OPERATIONS AND COMMUNICATIONS IMPROVEMENTS

The following recommendations are designed to improve communications during flood events.

- Install webcams at dams to monitor water levels at NHDES dams with significant flood control potential. Two candidate dams are Milton Three Ponds and Mascoma Lake, where webcams could be used to confirm the accuracy of the information received by NHDES through telemetry. The network could then be expanded to include other critical dams.
- Set up a reverse 911 system to dial up and warn resident's located in flood prone areas of the danger of flooding.
- Set up a reverse 911 system to inform dam operators regarding flood forecasts.
- Use NH Department of Transportation's 511 system to automatically generate detour routes. The system currently focuses on State roads. Include local roads in the system as soon as possible.
- In cooperation with NOAA, provide satellite communications capability, to overcome problems if cell towers are out of order or if cell coverage is poor in the more rural areas in the State.
- Provide a mobile Internet communications vehicle that can be dispatched to damage areas such as dams. Their video and "chat room" capability allows for effective communications with the EOC under adverse conditions.

FEMA Region I is currently developing a Riverine Risk Management Tool Web site for Federal, State, and local emergency responders to use during riverine flood events. The Tool will provide emergency managers with vital information for carrying out emergency response activities such as directing evacuations, setting up shelters and notifying the public of an in impending flood event. The Tool can also be used in other phases of emergency management for mitigation planning, and preparedness. FEMA is encouraged to complete and activate the Web site tool and State and local emergency managers should become familiar with the product so it can be used in advance of future flood events.

6.4 RECOMMENDATIONS TO CONTROL EROSION, SEDIMENT, AND WOODY MATERIAL

Based on the findings from Section 5, the following are the recommended actions for mitigating the impacts of erosion, sediment, and woody material on flooding in the study area:

6.4.1 Sediment and Woody Material Removal

- Ditches, culverts, catch basins, and ponds constructed to collect or convey stormwater and spring runoff should be inspected annually. Excessive sediment and potentially hazardous woody material that threatens to block dams and other structures should be removed. This work can be performed without a permit.
- Where practical and necessary, trees that have fallen along the banks of rivers that are likely to flow downstream and form blockages at dams and other structures should be cut so the roots remain in place (thereby preventing erosion) and removed, as long as this does not disturb the banks. A regularly scheduled program for removal would reduce the magnitude of the problem of blockage during flood events.
- Where sedimentation in excess of natural causes has caused a barrier to flow or has decreased channel capacity, the source of sediment should be identified and appropriate erosion control measures should be taken. In addition, to restore the natural flow paths, a permit for sediment removal should be filed with the NH Wetlands Bureau.

6.4.2 Stormwater Permitting Issues and Best Management Practices

Many of the flood problems during the May 2006 and April 2007 storms were localized, sometimes away from the floodplains in more urbanized areas. The following recommendations will help minimize this kind of flooding.

- During winter sanding operations, every effort should be taken to use only the amount of sand required for safe streets and highways.
- Street sweeping operations should begin as soon as practical in the spring to remove as much of the sand as possible.
- In areas with storm drainage systems, catch basins should be cleaned regularly.
- New highways and roads should be designed to incorporate best management practices for facilitating removal of sediment before it reaches rivers and streams.
- Construction sites that disturb more than one acre of land require EPA NPDES stormwater permits. NHDES should take an active interest in making sure all construction sites disturbing more than one acre have the required permit and are actively conforming to the provisions of the permit.

- NHDES should also consider its own program, for construction sites under EPA's 1-acre threshold.
- BMPs to foster infiltration and maintenance of natural flow paths, such as low impact development, should be encouraged.

6.5 APPLY VERMONT'S "FLUVIAL EROSION HAZARD METHODOLOGY" TO NEW HAMPSHIRE WATERWAYS

Vermont has found that much of its flood-related damage is not from inundation, but is a result of erosion. The State has implemented a comprehensive "Fluvial Erosion Hazard Methodology" to identify and map these hazards along Vermont streams. Given the similarity between the Vermont landscape and many areas of New Hampshire, a similar methodology should be applied to New Hampshire rivers and streams to identify future erosion hazards.

As mentioned in Section 5, Vermont suffered several flood events in the 1990s, and found that much of the damage was not from flood inundation, but from erosion. Furthermore, much of this damage was preventable, had the erosion hazard been properly considered. The Vermont Department of Conservation Rivers Management Program http://www.anr.state.vt.us/dec/waterq/rivers.htm (Vermont Agency of Natural Resources 2008) has undertaken a systematic methodology to classify the erosion hazard along Vermont streams, based on fluvial geomorphology principals. The State is establishing fluvial erosion hazard corridors along its streams. These corridors show where the erosion hazards are most significant. These corridors can be used as overlay districts for local zoning ordinances.

Given the similarity in the climate and geography of Vermont and New Hampshire, Vermont's program should be used as a template for a similar effort in New Hampshire.

During the May 2006 flood, the Suncook River left its channel and changed its course, returning back to the channel over one-half mile downstream (a process termed "avulsion"). The change in course caused, and continues to cause, significant damage. It is unlikely the stream will ever be returned to its previous course. Application of Vermont's "Fluvial Erosion Hazard Methodology" should be used to identify potential future avulsion sites so that appropriate measures can be taken to prevent them.

6.6 RECOMMENDATIONS MADE PREVIOUSLY

The project team provided three recommendations earlier this year, in preparation for the 2008 runoff season. The recommendations were designed to put the emergency community on alert and foster communication within that community, remind dam owners of their responsibilities immediately before the runoff season, and increase the chances that free flow conditions occur at two critical locations in the Piscataquog and Suncook River basins.

6.6.1 Recommendation No. 1 – Reminder letters to dam owners

The project team recommended that NHDES send return-receipt-requested reminder letters to dam owners in the State. The letters were intended to remind the dam owners that:

- The runoff season was approaching.

- They are legally responsible for safe dams and liable for conditions resulting from unsafe dams.
- If drawdown is not at prescribed levels, they should consider further drawdown if it can be safely performed.
- They should review their EAPs and make sure they are up to date. Though they may be under no statutory obligation to do so, they should consider testing the emergency notification procedures as outlined in their plan.

6.6.2 Recommendation No. 2 – Coordination meeting in anticipation of runoff season

The project team recommended that NHDES, in cooperation with other State and Federal agencies, conduct a meeting, modeled after procedures conducted by Maine's River Flow Advisory Commission, in early March, to assess the general susceptibility of the State to flooding, and to foster communication between the various State and local agencies responsible for flood plain management, dam management, and emergency response.

6.6.3 Recommendation No. 3 – Cleaning of debris and woody material from the railroad trestle upstream of the Kelley's Falls Dam on the Piscataquog River and from the Bucks Street Dams on the Suncook River.

Debris, including woody material clogging these locations, significantly aggravates flooding at upstream locations. Therefore, the project team recommended that special consideration be given to ensuring the railroad trestle and the Bocks Street Dams are periodically cleaned of debris.

NHDES took the appropriate actions to ensure these recommendations were implemented.

These recommendations should continue to be implemented in the future.

SECTION SEVEN RECOMMENDATIONS TO IMPROVE FLOOD FORECASTING

This section presents study recommendations for improved flood forecasting. These recommendations are summarized below. Further information regarding these recommendations, and the mechanics of their implementation, are provided in Sections 7.2 through 7.6.

7.1 IMPROVED FLOOD FORECASTING SUMMARY

Two entities can currently provide independent flood forecasts in southern New Hampshire: ***NWS through the NERFC and the NHDES Dam Bureau through its data management and streamflow forecasting system.***

Deficiencies regarding the current flood forecasting systems were identified as part of this study. Some of the existing forecast products created at the NWS were not readily available to the decisionmakers at the NHDES Dam Bureau and Office of Emergency Management. Forecast products are not available for all points of interest to the Dam Bureau (in particular the Cocheco, Exeter, Isinglass, Lamprey, and Soucook Rivers). In addition, longer-range forecasts (5 to 6 days) that can enable Dam Bureau decisionmakers to enact preventive dam operations are currently not available at all. The NHDES should engage the NWS to gain timely access to forecast products at all important locations in southern New Hampshire.

While extensive use is made of the data management capability of the Dam Bureau's system, the forecasting component of the system is not utilized. This component of the system should be revitalized to provide forecasts for locations that the NWS does not serve. In addition, the Dam Bureau should stay informed of new research currently being conducted at the national level for improved flood forecasting.

7.2 ACCESS TO CURRENTLY AVAILABLE NWS FORECASTS

This study indicates that NHDES staff did not have access to all NWS forecasts products during the May 2006 and April 2007 flood events. We recommend that NHDES and the NWS work together to make sure that all pertinent information produced by the NWS is readily available to NHDES in a timely manner during emergency situations.

Currently, important up-to-date information regarding flooding can be found, but is not limited to, the following Web sites:

- http://www.weather.gov/view/states.php?state=NH&map=on (NWS 2008f)

  Provides access to a large number of NWS weather and streamflow forecast products for New Hampshire

- http://water.usgs.gov/nwis/sw (USGS 2008)

  Provides access to real-time streamflow and water level observations at thousands of stream gages in the United States

- http://www.erh.noaa.gov/er/nerfc/ (selecting the "Flood Outlook" tab)

  Provides access to NERFC's "Significant River Flood Outlook" product

- http://www.erh.noaa.gov/er/nerfc/ (select the "Forecast River Conditions", NWS 2008a)

  Provides access to streamflow forecasts at NERFC forecast points

- http://www.weather.gov/data/TAR/RVFGYX (NWS 2008d) and http://www.weather.gov/data/TAR/RVFBOX (NWS 2008e)

  Provide access to NERFC streamflow forecasts in text format. The sites are updated and overwritten whenever the NERFC generates new streamflow forecasts

  http://www.weather.gov/rss/ (NWS 2008g)

  Provides information regarding Really Simple Syndication (RSS) data feeds

  RSS is a family of Web formats used to publish frequently updated digital content. Most commonly used to update news articles and other content that changes quickly, RSS feeds may also include audio files (PodCasts) or even video files (VodCasts). Users can subscribe to RSS feeds to automatically and continuously update the requested information on a browser or RSS feed reader software. With respect to river conditions, the NWS offers RSS feeds for:

  - Observed River Conditions
  - Routine Daily Forecasts of River Conditions
  - "Alert" River Conditions Based on Local Action Settings

7.3 IMPROVE AND EXPAND NWS FORECASTS

We strongly encourage discussions between the NHDES and the NERFC on how to better address NHDES streamflow forecast needs. Costs and benefits should be evaluated for the following items, while minimizing redundant efforts:

7.3.1 Additional Forecast Points

While the NERFC forecasts flows at many rivers in central and southern New Hampshire, none of the coastal basins are modeled. Flows at some coastal rivers, however, are monitored by USGS gages. These locations could serve as additional forecast points with flow observations used to verify simulated flows.

In particular, forecast points might be added at the following locations, where USGS gages are already operated in cooperation with the NHDES:

- Cocheco River near Rochester, NH (USGS gage 01072800, Drainage area: 85.7 square miles)
- Exeter River at Haigh Road near Brentwood, NH (USGS gage 01073587, Drainage area: 63.5 square miles)
- Isinglass River at Rochester Neck Road near Dover, NH (USGS gage 01072870, Drainage area: 73.6 square miles)
- Lamprey River near Newmarket, NH (USGS gage 01073500, Drainage area: 183 square miles)

- Suncook River at North Chichester, NH (USGS gage 01089500, Drainage area: 157 square miles)

Of the basins listed, all but the Cocheco and Isinglass Rivers are currently modeled in the NHDES forecast system.

7.3.2 Smaller Modeling Time Step

The use of a 6-hour time step in modeling basins causes inaccuracies in forecasting streamflow in small, fast responding sub-basins.

The NERFC is currently investigating the implementation of forecast points along the Winnipesaukee River. Given the size of its basins, the NERFC is considering modeling the Winnipesaukee River at a 1-hour time step, using short interval precipitation estimates for input. The basins listed above plus other smaller but already modeled river basins in the area should be modeled at a 1-hour time step in order to account for their small sizes and quick response times.

7.3.3 Longer Forecast Period

NWS streamflow forecasts are currently available to the public 54 hours into the future. The NHDES would greatly benefit from longer-term streamflow forecasts, which would allow more time for the mobilization of dam operations and in particular for lowering pool elevations at certain dams in anticipation of flood events. The NWS is currently considering providing 5 to 6 day forecasts to cooperating agencies. We strongly recommend that the NHDES actively participate in this discussion.

7.4 REVITALIZE AND EXPAND THE NHDES FLOOD FORECASTING SYSTEM

The main obstacles to effective use of the NHDES flood forecasting system are unreliable access to real-time data observations, generally low confidence in modeling results, and more importantly, a lack of resources to dedicate staff to the rigorous operation of the system.

We recommend revitalizing the existing NHDES flood forecasting system, in particular in conjunction with possible improvements to NWS streamflow forecasts in the area.

Benefits of a revitalized NHDES flood forecasting system include:

- More forecast points than the NWS provides, in particular more modeled dams
- Instant access to the latest forecasts
- Longer forecast periods than what the NWS currently provides
- Modeling at a 1-hour time steps
- More control in simulating actual and projected dam releases
- Option to simulate alternative dam operations scenarios and to evaluate their benefits

The revitalization of the system should aim at improving the quality of the forecasts while reducing the required workload in operation. The following items should be part of this effort:

- Update the data import method from the less reliable current system to the more reliable Device Conversion and Delivery System (DECODES) system, which is actively promoted by the National Environmental Satellite, Data, and Information Service (NESDIS).

- Import streamflow data for active USGS gages directly from USGS Web sites instead of NESDIS Web sites where only river stage is available. This removes the need to locally convert imported stage to stream flow and lessens the burden of continually updating rating curves.
- Import streamflow data and dam operation information directly from the USACE for the dams it operates.
- Install additional automated sites to monitor precipitation, temperature, pool elevation, and dam releases at select NHDES dams. These data can be used to better estimate dam inflows and to verify and adjust the hydrologic models in the upstream basin.
- Verify as current all parametric information regarding the NHDES dams and the streamflow rating curves in the forecast system.
- Devise a system that allows the dam operators to send observations and operations at the dams to the NHDES for automated ingestion into the forecast system, thus reducing the workload for the operators. Currently, observations by the dam operators must be manually entered into the system by copying entries from dam operations log books.
- Implement data sharing agreements to allow the automated import of information from private dams into the NHDES forecast system. Operations performed at the non-NHDES operated dams must currently be updated manually.
- Develop standard operating procedures defining:
  - routine tasks required to keep the forecast system operational and accurate
  - operations during flood emergencies
- Assign a minimum of two staff to regularly operate the system. The level of effort for this task is estimated to be a combined 20 hours per week. Operating the system on weekend days is not necessary if no flooding risk is expected and if in-depth data quality control procedures are performed on Mondays.
- Model additional NHDES dams in support of decisionmaking for dam operations.

7.5 INCREASED COOPERATION BETWEEN THE NWS AND THE NHDES

Increased cooperation between the NERFC and the NHDES could greatly improve the accuracy of both the NERFC and the NHDES forecasts. Both entities operate the same hydrologic models using data that can be utilized by either system. Directly exchanging information from one forecast system to another is possible. We recommend that:

- The NHDES provide current and projected releases from its dams to the NERFC and also relay information obtained from the private dams.
- The NERFC support a revitalized NHDES forecast system by providing:
  - Temperature forecasts (precipitation forecasts are already provided).

- Soil moisture information ("model states") for those rivers that are modeled in both forecast systems, albeit with smaller sub-basins in the NHDES forecast system. This would allow the NHDES to take advantage of the expert knowledge of NERFC river forecasters who keep the soil moisture in their models updated and use this information as a guide to adjust its model states.

A more intertwined approach could consist of a joint forecast system, where the NERFC provides inflows to NHDES dams to the NHDES. The NHDES would use the inflows to estimate forecasts of releases from its dams based on current and projected operations. These forecasted releases could then be passed back to the NERFC for further use in NERFC forecasts. This approach has been successfully implemented in the western part of the United States.

7.6 THE USE OF FLOOD FORECASTS DURING EMERGENCIES

We recommend that drawdown operations be considered at NHDES dams that provide some or significant flood benefits once the NERFC issues forecasts exceeding Flood Stage or "Significant River Flood Outlook" products indicating "Flooding Likely." Otherwise, time to significantly lower pool elevations will not likely be available. Discharge increases at the Run-of-River dams, in particular those with gates or Obermeyer panels, could be delayed until Moderate Flood Stage forecasts are issued.

Appropriately trained NHDES personnel should be assigned to operate a revitalized NHDES forecast system in flood situations and perform the following tasks:

- Obtain and interpret the latest streamflow forecasts from the NWS and check for consistency with the NHDES system.
- Provide feedback to the NERFC and resolve issues should the forecasts between the two systems be inconsistent.
- Keep information regarding actual dam operations current in the system.
- Identify dams likely to pose upstream and/or downstream flooding danger.
- Simulate scenarios to identify which operations would be most effective in minimizing flooding at these sites.

Provide decisionmakers at the EOC with streamflow and reservoir pool forecasts and discuss possible operations at dams. Coordination with the NWS will improve flood forecasting within the watershed. Communicating forecasted flood levels to State and local emergency managers so they can carry out emergency actions to protect the floodplain residents and properties is critical for a flood warning system.

SECTION EIGHT RECOMMENDATIONS FOR A WATERSHED-BASED APPROACH FOR FLOOD REDUCTION

This section presents study recommendations designed to implement a watershed-based approach, for each of the ten watersheds in the study area, to flood control operations. The section begins with a summary of the watershed approach. As was the case in Sections 6 and 7, the critical recommendations found in the executive summary are presented here in ***bold italics*** and other important recommendations in the executive summary are presented in *italics*.

Section 3 presented four types of dams in the study area: flood control dams, dams that provide significant local flood control benefits, dams that provide limited local flood control benefits, and Run-of-River dams. Recognizing that a typical watershed in the study area has a combination of many of these types of dams, Section 8.2 provides information on how best to operate each of these dam types. These general recommendations apply to all dams in the study area, including those not specifically analyzed in this study. These recommendations can be used as guides to help assemble a watershed plan for each watershed.

Recommendations specific to individual dams are presented for the sites investigated in the Salmon Falls, Suncook, Piscataquog, and Souhegan River watersheds in Section 8.3. Section 8.4 provides background information on some of the operational considerations that were used to develop the recommendations for the different types of dams.

The purpose of this watershed approach is to operate the dams systematically and efficiently, taking into account what is happening watershed-wide. While these recommendations will minimize flooding at locations near the dams, they will not prevent flooding.

8.1 TAKE A WATERSHED APPROACH TO FLOOD OPERATIONS

The NHDES Dam Bureau has procedures in place to collect information on dams. The Dam Bureau should build on that information to develop a plan including standardized operating rules for each dam capable of flood control operations for each watershed in the study area. The operating rules should be appropriate for each dam, but kept as simple as possible. For each dam, the plan should include a maintenance schedule and rules for operations during flooding events. For those dams where lake elevations are lowered in the winter, the plan should include rules for refilling based on water content of the snowpack in the area draining into the lake, balanced against the need to achieve the summertime target elevation. Each private dam operator should submit information to the NHDES Dam Bureau. The Dam Bureau should ensure that operations at each dam will collectively result in maximum flood control benefits to the watershed as a whole. Each watershed plan should be publically available on the Internet.

This watershed approach will allow for coordinated action by dam operators designed to maximize flood control benefits. The maintenance schedules will help ensure that flood control structures are operable when needed. The rules for operations during flood events will help minimize local and preventable flood damages. The rules for refilling will help ensure that the maximum amount of flood storage is available from the fall through the spring runoff season, while reducing the risk of not refilling the lakes for summer use. Keeping the plans as simple as possible will facilitate their use during flood events. Making the watershed plans

***publically available will build public confidence that everything possible is being done to minimize flooding, and will help ensure the plans are implemented*.**

To implement the watershed plan, operating rules should be developed or updated by the NHDES for all State-owned dams. Guidelines for operating rules covering the topics shown in Table 8-1, should be provided to private dam operators and (updated) operating procedures based on these guidelines should be required from dam operators of all dams that can contribute to flooding in each watershed. These dams include, but are not limited to, dams than can store significant amounts of water and Run-of-River dams.

Table 8-1: Operating Rules for Flood Control at New Hampshire Dams

Maintenance Schedule and Tasks
Seasonal Operations (if applicable)
o Target pool elevations and applicable dates (based on upstream snowpack for dams that provide flood control benefits)
o Dates when flashboards are installed or removed
o Factors that can cause deviations from the standard rules
Flood Operations
o Factors that trigger flood operations
o Actions taken in anticipation of a flood event
o Actions taken during the event
o Actions taken after the event
o For sites equipped with flashboards:
▪ Pool elevation triggering flashboard operation
▪ Volumes released during the operation and an assessment whether those will contribute to downstream flooding

The rules should be commensurate with the expected flood control benefits at the site. Typical Run-of-River dams, where upstream flood control can only be achieved through release capacity increases, will likely require very simple rules. Rules will be more complicated for dams that can provide flood control benefits and might require additional analysis to develop rule curves.

NHDES should compile these operations rules on a watershed basis and institute a policy for periodic updates and review, avoiding nonessential bureaucracy. The NHDES should ensure that operations at each dam will collectively result in maximum flood control benefits to the watershed as a whole, and make appropriate adjustments as necessary to achieve this goal.

Up-to-date dam operating rules for each watershed should be made public and outreach efforts should be conducted to promote the distribution of this information. This will allow affected residents to become familiar with the operating rules, ultimately leading to more transparent dam operations and a better understanding of flood control measures.

8.2 GENERAL RECOMMENDATIONS FOR FLOOD CONTROL AT DAMS IN THE STUDY AREA

The recommendations below are based on an analysis of NHDES and private dam operations during the May 2006 and April 2007 flood events. The analysis included an inventory of dam infrastructure, operating rules, actual operations during the two events, and computer model simulations to assess alternative operation scenarios. These recommendations should be used as guidelines for establishing each watershed plan.

General recommendations regarding dam operations and structural improvements are presented for:

1. All dams in the NHDES jurisdiction
2. Non-NHDES dams in the NHDES jurisdiction
3. Dams equipped with flashboards
4. Dams classified as providing significant local flood control benefits and dams classified as providing some local flood control benefits, where operations are a blend of those for "large" and "small" dams (see Section 3)
5. Dams classified as Run-of-River, providing no flood control benefits (see Section 3)

The development of dam operating rules based on these recommendations is suggested. Dam operating rules should be incorporated into the watershed plans and made available to the public.

8.2.1 All Dams

This section presents general operating recommendations for all dams investigated, regardless of size, location, or ownership.

Regular performance of the tasks shown in Table 8-2 is recommended.

Table 8-2: General Recommendation for All Dams

• Before the snowmelt and storm seasons (i.e., the spring and the fall), ensure that mechanical control structures that are intended to be operated during flood events, such as release gates or Obermeyer panels, are operational.
• Closely follow streamflow and precipitation forecasts provided by the NERFC and WFOs.
• Remove debris from the gate area and upstream reaches before freezing.
• If possible, remove debris from the gate area and upstream reaches when a large rainfall event is anticipated.
• Ensure that mechanical control structures that are intended to be operated during flood events are kept ice free.
• Continue to review and inspect affected dams after major flood events to assess damage. The NHDES inspects its own dams, while requesting inspection reports from private dam owners.

8.2.2 Non-NHDES Dams

A number of privately operated dams exist along the reaches of the investigated rivers. While not under the direct jurisdiction of the NHDES, operations at these dams can affect the risks of flooding in the area. An additional flood control project, Everett Dam, is located in the northern part of the Piscataquog Watershed and is operated by the USACE. This dam provides significant flood protection for the downstream area, and its operations should always be monitored during flood events.

Close communication between NHDES and private and USACE dam operators is important to exchange information regarding (1) the current state (pool elevations, releases) of NHDES and private dams; (2) current operating objectives at NHDES and private dams; and (3) planned operations at NHDES and private dams.

The actions shown in Table 8-3 are recommended to achieve these objectives.

Table 8-3: Recommendations for Non-NHDES Dams

Clarify flood operating rules with the private dam operators.
Ensure that all dam operators have established and tested procedures for regular communication during non-flood-event times.
Ensure that all dam operators have established and tested procedures for additional communication during flood events.

8.2.3 Dams Equipped with Flashboards

Many dams in New Hampshire are equipped with flashboards, which raise the water level behind the dam above the spillway crest. This is typically done to increase the elevation of the water for hydropower generation. Flashboards can be used safely without causing upstream or downstream flooding, but only if designed properly. Therefore, our recommendations for flashboard use are summarized below and in Table 8-4.

Make sure flashboard operations are safe. Many dams are equipped with flashboards to raise their operating water level. They are quickly removed in the event of a flood either by tripping a supporting device or by designing the flashboard supports to fail under specified conditions. When installed, they raise upstream water elevations. When removed, they cause a spike in downstream flows. Operators of dams should be required to demonstrate that flashboards can be used safely without contributing to upstream or downstream flooding before using them.

Table 8-4: Recommendations for Dams with Flashboards

Flashboards can be used only if the operators demonstrate that:
• Before operating they do not cause flooding upstream
• When operating they do not cause flooding downstream

The NHDES should develop guidelines for operators to use to demonstrate that flashboard operations do not cause upstream or downstream flooding. NHDES should work with the FERC to ensure that operators of FERC-licensed dams provide this information. We strongly encourage FERC to cooperate and dam owners to comply.

8.2.4 Dams Providing Significant Local Flood Control Benefits and Dams Providing Limited Flood Control Benefit

In this study, dams are considered to providing significant local flood control benefits if their storage is large in comparison to the drainage area they control. Dams that provide some local flood control benefit have a storage capacity in between the ones providing significant flood control benefits and the Run-of-River dams that provide no flood control benefits.

The benefit of lowering the target pool elevations should always be weighed against the risk of not being able to fill the lake to the target summer pool elevation. The evaluation of seasonal climate forecasts and outlooks can help in this decisionmaking. Damages caused by ice on the lake should also be considered.

Flood Operations – Most of these dams do not provide mechanisms for rapid and significant operations during floods. Also, since these dams must be operated manually, NHDES dam operators will not be able to visit them all in time to make all desired adjustments. However, some operations are recommended that can potentially minimize downstream flood risks, as shown in Table 8-5.

Given the uncertainties associated with streamflow and regional forecasts, lowering pool elevations as recommended in Table 8-5 will only be suitable for the largest forecasted events. Flood operations in anticipation of events are risk-based decisions aimed at balancing the risk of not providing flood control with the risk of lower lake levels should the anticipated event not materialize. These factors should be carefully weighed and operation procedures should be evaluated individually for each dam and watershed, always taking into account the expected flood control benefits.

- When possible, discharges from dams should be increased to prevent upstream flooding along the shoreline of the impoundment. These actions should, however, be weighed against the increased potential for downstream flooding.
- For each dam, upstream and downstream flood control benefits should be assessed and rules should be established to balance the prevention of upstream flooding with the prevention of downstream flooding.
- After an event, operations at the dam should aim at reaching the current target pool elevation rapidly and safely.

Structural Improvements – In addition, we recommend that NHDES consider the structural improvements shown in Table 8-5.

Table 8-5: Recommendations at Dams Providing Significant or Limited Local Flood Control Benefits

Seasonal Operations Seasonal operations are currently performed to lower the reservoirs to fixed target pool elevations starting in October. Refill begins between January and May, depending on the storage capacity of the lake. The reservoirs typically reach their summer pool elevation in May or June. Currently these operations do not regularly take potential flood inducing conditions such as snowpack into account. The following actions are recommended for seasonal operations:
• Continue to lower pool elevations to the current target levels on the currently specified dates using the stoplogs for operation (except Suncook Lake where the gate must be used).
• Starting in January, re-evaluate the target pool elevations based on the snowpack in the watershed upstream of the dam. No changes to the target pool will be necessary for years with little snow cover. Rule curves of target pool elevation as a function of snowpack and date can be established based on an investigation of historical patterns. The target pool elevation may then be adjusted over the course of the snowmelt season according to the rule curves. In particular, adjustments should be performed when significant changes occur in the snowpack above the dam. Releases from the dam should be adjusted based on the changes in pool elevation targets.
Operations During Flood Events
• Pool elevations should be lowered in anticipation of large flood events, based on streamflow forecasts and regional flood outlook products. These operations would be performed using gates at sites where they exist; where gates do not exist, stoplogs should be removed if conditions permit.
• In considering lowering pool levels, rules should be established to define: o Which anticipated events should trigger additional lake drawdowns o The flood event target pool elevations o The maximum allowed releases • If not already open, gates should be opened at the onset of the actual event. This can help reduce upstream flooding. • In some instances during an event, if downstream flooding is imminent and the probability of upstream flooding is low, consider closing the gates to maximize the use of available storage in the impoundment. • In each watershed, sequence the lowering of lakes to prevent excessively high flows downstream.
Potential Structural Improvements
• Consider installing gates at sites where significantly changing the discharge capacity under flood conditions is not currently possible (i.e., at sites where only stoplogs are currently used).
• Consider the installation of remote cameras (webcams) to quickly assess the situation during flood events without the need to dispatch a dam operator. Pictures from the remote cameras should be made available to the public.

8.2.5 Run-of-River Dams

In this study, dams are considered Run-of-River if their storage is insignificant in comparison to the drainage area they control. Recommendations at these dams are shown in Table 8-6.

Table 8-6: Recommendations for Run-of-River Dams

Flood Operations – Flood operations at the Run-of-River dams should strive to prevent upstream flooding. We recommend increasing the discharge capacities at the dams, as follows:
• At non-hydropower facilities, open all gates and, if possible, remove stoplogs early before large anticipated events. • At hydropower facilities, open gates just before the actual anticipated event, when it is certain that the event will happen. This approach should prevent unnecessary reduction in power generation should the event not materialize, while increasing the discharge capacity if the event occurs.
In considering whether to open gates, rules should be established to define:
o Which anticipated events should trigger gate operations to increase discharge capacity.
o The maximum allowed releases (to prevent scouring at the dam site or at downstream reaches/dam sites).
o The sequence of flow increases to prevent excessively high flows downstream.
Given the uncertainties involved with forecasting precipitation and temperature, these operations will only be suitable for the largest anticipated events. Depending on the discharge capacity of the dam, opening gates, etc. may only have a minor effect. However, it signals to the public that the dam operators do the best they can. Also, given the very small storage capacities of these dams, refilling them after a false forecast should not be problematic.
• Close gates, Obermeyer panels, and stoplogs only when the peak of the event is clearly over and the expected remaining flows will not raise the pool elevation enough to cause upstream flooding.
Structural Improvements – In addition, we recommend that dam owners:
• Consider installing gates at sites where significantly increasing the discharge capacity under flood conditions is not currently possible (i.e., at sites where stoplogs are currently used as primary means to control releases).
• Consider the installation of remote cameras (webcams) at NHDES dams to quickly assess the situation during flood events without the need to dispatch a dam operator. Pictures from the remote cameras should be made available to the public.
• For dams that currently do not serve any appreciable purpose but cause upstream flooding, consider removal.

8.3 DAM-SPECIFIC CONSIDERATIONS

In addition to devising rules for seasonal and emergency operations for all dams as discussed in Section 8.2, the actions shown in Table 8-7 are recommended for consideration at specific dams based on the investigations performed in this study. These recommendations require further study and engineering analysis before implementation:

Table 8-7: Dam-Specific Considerations

Salmon Falls River Watershed
• **Horn Pond** – Given that Horn Pond Dam is currently operated with stoplogs only, consider installing one or more gates at some stoplog bays to increase the operational flexibility.
• **Cooks Pond:** o Downstream flooding is a concern at this site. Consider installing one or more gates at some stoplog bays to increase operational flexibility. o Lock down the existing stoplogs to prevent unauthorized operations at this dam.
• **Lovell Lake:** o Given that the lake typically starts spilling to the left side of the control structure at 1 foot above the full lake elevation, consider installing a small retaining wall to prevent flows over the road and the need for sandbagging. o Consider installing one or more gates at some stoplog bays to increase operational flexibility.
• **Milton Three Ponds –** *Determine the benefits and costs at Milton Three Ponds Dam by installing a second automatic gate that may lead to reduced flood damages.* When using only the gates and the Obermeyer panel to increase releases, more than 4 days of lead time are required to appreciably lower the pool elevation. Reliable forecasts will not generally be available this early. With the current configuration at the dam, the removal of stoplogs is required to draw down the lake faster, which might be impossible or dangerous at times. Computer simulations suggest that installing an Obermeyer type panel in the four stoplog bays next to the gate house would enable the NHDES to significantly lower the pool at Milton Three Ponds just 2 days before the event. For example, lowering the suggested panel on April 15, 2007 at 12 p.m., the time when significant river flooding in the area was predicted by the NERFC, would have lowered the maximum pool reached during the event by almost 0.5 foot.
• **Spaulding Pond:** o Ensure established and tested procedures for communication during flood events. o The NHDES indicates that this dam has safety issues. These should be corrected immediately.
Suncook River Watershed
• **Crystal Lake** – Upstream flooding was reported at this lake in April 2007. The dam currently has one stoplog bay available for operations. For added flexibility in operations, consider replacing the bay with a gate that can be opened quickly to release flows. A computer simulation shows that had the proposed gate been in place in April 2007, and had it been fully opened on April 12 at 1 p.m., just after the NERFC predicted likely flooding in the area, the maximum pool reached during the event would have been about 0.5 foot lower.
• **Pittsfield Mill –** This structure overtopped in both 2006 and 2007. Simulations suggest that the dam would have overtopped even if it had been empty at the beginning of the April 2007 event and all gates were open and stoplogs were removed. This indicates that a general increase in discharge capacity would reduce the risk of overtopping during very large events. Preliminary discharge calculations suggest that lowering the spillway could remedy this situation.
• **Pleasant Lake:** o Consider building a new or raising the existing retaining wall where the lake overtopped. o Quickly increasing discharges at the lake is limited by the fact that only stoplogs are available for operation and that the capacity of the culvert at the outlet structure limits releases at times. Modifying the outlet structure should be considered in order to increase operational flexibility.

- **Northwood Lake** – The lower core wall of the dam required sandbagging during both the 2006 and 2007 events. Consider structural changes to this part of the dam to mitigate the need for sandbagging.
- **Bucks Street Dams –** As described in Section 4, the removal of the Bucks Street Dams (and upstream abandoned bridge) will likely reduce flood elevations for a considerable distance upstream on the Suncook River, and since this area is subject to flooding, further investigations are recommended to assess the benefits of removing (or otherwise increasing the discharge capacity) of these dams and bridges. These investigations can be incorporated into current studies being performed by the USGS to establish the impact of the avulsion on the Suncook River water surface elevations during flood events.
- **Webster Mill** – Ensure established and tested procedures for communication during flood events.
- **China Mill** – Ensure established and tested procedures for communication during flood events.

Piscataquog Watershed

- **Crystal Lake** – Given that Crystal Lake is currently operated with stoplogs only, consider installing one or more gates at some stoplog bays to increase the operational flexibility.
- **Everett Dam** – Ensure established and tested procedures for communication during flood events.
- **Gregg Falls:**
  - Ensure established and tested procedures for communication during flood events.
  - Ensure that the flashboards meet the design criteria.
- **Kelley Falls:**
  - Ensure established and tested procedures for communication during flood events.
  - Ensure that the flashboards meet the design criteria.
  - Flooding in the reservoir was reported in 2006 and 2007. This is caused in part by an abandoned trestle bridge just upstream of the dams, which accumulated debris and woody material. Consider establishing an accord between the City of Manchester, local residents, and the dam operators to efficiently and cost-effectively prevent debris accumulation and perform debris removal.
  - *Consider the benefits and costs of certain potential structural improvements at Kelley's Falls Dam (by increasing its capacity with new gates). The cost of these improvements should be compared to their potential benefits to assess whether these improvements should be implemented.* Consider increasing the discharge capacity of the dam in order to lower peak pool elevations during large floods. A University of New Hampshire student report titled ""Kelley Falls Dam Rehabilitation" (Balbo et al. 2007) suggests constructing a bypass channel on the west side or lowering the spillway and installing Obermeyer panels to accomplish this increased discharge capacity.

Souhegan Watershed

- **Otis Falls** – Evaluate and establish rules regarding the installation and removal of flashboards to protect downstream areas. The use and removal of these devices should be carefully coordinated with FERC permitting.
- **Pine Valley Mill:**
  - Evaluate and establish rules regarding the installation and removal of flashboards to protect downstream areas. The use and removal of these devices should be carefully coordinated with FERC permitting.
  - The operator opened the waste gates early during the April 2007 flood event. This likely reduced the effect of localized flooding and should be considered as an established operating rule.

8.4 OPERATIONAL CONSIDERATIONS

Different factors were important in establishing the recommendations for each specific dam type. These operational considerations are explained in this section.

8.4.1 Dams that Provide Significant Local Flood Control Benefits

In this study, dams are considered to provide significant local flood control benefits if their storage is large in comparison to the drainage area they control.

The following describes important operational considerations for these dams:

- These dams can provide limited flood control at the summer pool elevations.
- The flood control capacities are significantly larger when the lakes are at the winter pool elevations.
- Ice on the lakes and at the dam sites can seriously hamper operations.
- At NHDES dams, operations are typically performed by a dam operator who has to travel to the site.
- Stoplogs control most of the release capacities and are therefore the primary means to control lake elevation (with Suncook Lake being the exception). Stoplogs are typically removed or added manually, which can be difficult and dangerous when they are submerged. This can prevent operations of stoplogs during flood events.
- Gates, if installed, can only provide a small portion of the total release capacity. They are often inoperable during the winter because of icing. Typically, stoplogs are used to control winter pool elevations.
- Gates, if not frozen, can be operated rapidly during flood events.
- The total discharge capacities at the dams are typically smaller than inflows during large events. Pool elevations will therefore rise during large events even if all gates are open and all stoplogs are removed. This will provide for the storage of some flood waters even if no operations are performed to close gates and/or set stoplogs.

Given these findings, operating objectives may include:

- Providing some flood control benefits during the summer months.
- Providing increased flood control benefits when flooding potential is the greatest (fall and spring) through seasonal operations to increase storage capacity.

The recommendations based on these considerations were provided in Table 8-5.

8.4.2 Dams that Provide Limited Local Flood Control Benefits

The following describes important operational considerations at dams that provide some limited flood control benefits:

- When at winter drawdown levels, most of the dams provide appreciable flood control storage.

- Flood control storage is significantly smaller when the impoundments are at their summer pool elevations. Summer storage capacities are especially small for Horn Pond, Milton Three Ponds, and Northwood Lake.
- Lake levels increase rapidly during large events.
- Operations are typically performed by a dam operator who has to travel to the site (Milton Three Ponds can be operated remotely).
- Discharge capacities can be rapidly increased using gates or Obermeyer panels (Milton Three Ponds).

Given these findings, the main operating objectives during flood events should be:

- During the spring (before the refill period) provide storage capacity to control both upstream and downstream flooding.
- When at summer pool elevation, lower pool elevations in anticipation of large events.
- During an event, provide sufficient discharge capacity in order to prevent upstream flooding.

Table 8-5 presents recommended seasonal operations, flood control operations, and potential structural improvements to these dams, which are the same as for the dams that provide significant local flood control benefits.

8.4.3 Run-of-River Dams

The following describes important operational considerations at the Run-of-River dams:

- The storage capacities of the impoundments behind the dams are very small compared to the upstream controlled areas. They fill rapidly during high flow events, even from their lowest possible pool elevation. They cannot provide any appreciable downstream flood control.
- During flood events, the reservoir pool is determined by the ratio of inflows to outflows, not the pool elevation before the event. Outflows that are smaller than the inflows cause rapidly rising pool elevations and possibly upstream flooding.
- Outflow capacities are typically controlled by gates and/or turbines, which can operate rapidly, even during events.
- Debris in the powerhouse intake area might require a shutdown of the turbines to prevent damage. Turbines must also be shut down if the net head (the difference in water elevation above and below the dam) is too low. This results in a loss of discharge capacity.
- At NHDES dams, operations are typically performed by a dam operator who has to travel to the site. Dam operators are often present at the private dams during flood events.

The seasonal operations at Run-of-River dams, if any, currently consist of removing flashboards in the fall and re-installing them in the late spring. Some impoundments are also lowered using gates and stoplogs to prevent ice damage in the winter.

Seasonal operations at Run-of-River dams have no effects on their capability to provide flood control benefits. If applicable, winter drawdowns should continue as presently performed. No specific recommendations are required to modify seasonal operations at Run-of-River dams.

Given these operational considerations, the main operating objectives for Run-of-River dams during flood events should be:

- Provide sufficient discharge capacity in order to prevent upstream flooding.
- Prevent downstream flooding caused by the operation of flashboards, if installed.

Run-of-River dams are not suitable to provide downstream flood control. However, structural improvements can be designed to reduce upstream flood impacts.

The recommendations based on these operational considerations are provided in Table 8-6.

SECTION NINE REFERENCES

Balbo, Gagnon, Medaglia, Rosencrans, Sherman, and Welch. 2007. *Kelly Falls Dam Goffstown, NH*, A University of New Hampshire Senior Project Investigation.

Crippen, J.R. and C.D. Bue. 1887. *Maximum Floodflows in the Conterminous United States,* USGS Water Supply Paper 1887, 1977.

Federal Emergency Management Agency (FEMA). 2007. Task Order HSFEHQ-08-J-0007 Statement of Work, October 2007, http://www.des.state.nh.us/Dam/documents/FEMAwork2007fldstdy.pdf, Accessed July 2008.

Flynn, R.H. 2008. *Flood of April 2007 in New Hampshire: USGS Open-File Report,* 2008, Draft.

GRANIT (2008). New Hampshire's Statewide GIS Clearing House, http://www.granit.unh.edu/, accessed July 2008.

MassGIS (2008). Massachusetts Geographic Information System, http://www.mass.gov/mgis/massgis.htm, Accessed July 2008.

National Oceanographic and Atmospheric Administration (NOAA). 2008. Technical Paer Number 40, *Rainfall Frequency Atlas of the United States, May 1961,* http://www.nws.noaa.gov/oh/hdsc/PF_documents/TechnicalPaper_No40.pdf, Accessed July 2008.

National Oceanographic and Atmospheric Administration (NOAA). 2008. Weather and Climate Extremes in a Changing Climate, http://www.noaanews.noaa.gov/stories2008/20080619_climatereport.html, Accessed July 2008.

National Weather Service (NWS). 2008a. Northeast River Forecast Center, 2008. http://www.erh.noaa.gov/nerfc/. Accessed July 2008.

National Weather Service (NWS). 2008b. Advanced Hydrologic Prediction Service, Weather Forecast Office Boston, MA, July 2008. http://newweb.erh.noaa.gov/ahps2/index.php?wfo=box. Accessed July 2008

National Weather Service (NWS). 2008c. Advanced Hydrologic Prediction Service, Weather Forecast Office Gray, ME, July 2008. http://newweb.erh.noaa.gov/ahps2/index.php?wfo=gyx. Accessed July 2008.

National Weather Service (NWS). 2008d. River Stage Forecast Western Maine & Northern New Hampshire, July 2008. http://www.weather.gov/data/TAR/RVFGYX . Accessed July 2008.

National Weather Service (NWS). 2008e. River Stage Forecast Southern New England, July 2008. http://www.weather.gov/data/TAR/RVFBOX . Accessed July 2008

National Weather Service (NWS). 2008f. New Hampshire State Information, July 2008. http://www.weather.gov/view/states.php?state=NH&map=on. Accessed July 2008.

National Weather Service (NWS). 2008g NOAA's NWS RSS Library, July 2008. http://www.weather.gov/rss/. Accessed July 2008.

National Weather Service Precipitation Analysis. 2008. http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php?location=tar&overlay=1100101)6, Accessed July 2008.

New Hampshire Department of Environmental Services (NHDES), Dam Bureau. 2008a. Real-Time Data & Information for Watersheds in New Hampshire, http://www.des.state.nh.us/rti_home/. Accessed July 2008.

New Hampshire Department of Environmental Services (NHDES), Wetlands Bureau. 2008b. http://www.des.state.nh.us/wetlands/, Accessed July 2008.

New Hampshire General Court. 2007. Senate Bill 519-FN, http://www.gencourt.state.nh.us/legislation/2008/sb0519.html, Accessed July 2007.

Olsen, S.A. 2007. Flood of May 2006 in New Hampshire: U.S. Geological Survey Open-File Report 2007-1122, 32 p.

Sauer, Vernon B.; Thomas, W. O., Jr.; Stricker, V. A.; Wilson, K. V. 1983. Flood characteristics of urban watersheds in the United States, 1983, http://pubs.er.usgs.gov/usgspubs/wsp/wsp2207, Accessed July 2008.

University of New Hampshire. 2007. Floodplain Learning on Demand, http://www.nhflooded.org/flood_history.php, Accessed July 2008.

U.S. Army Corps of Engineers (USACE). 2008a. New England District, NAE Reservoir Regulation Section, http://www.reservoricontrol.com, Accessed July 2008.

U.S. Army Corps of Engineers (USACE). 2008b, https://www.nwo.usace.army.mil/hydro/floodplain/definitions.html, Accessed July 2008.

U.S. Geological Survey (USGS). 2008. Surface-Water Data for the Nation, July 2008. http://waterdata.usgs.gov/nwis/sw. Accessed July 2008.

Vermont Agency of Natural Resources. 2008. http://www.anr.state.vt.us/dec/waterq/rivers.htm, Accessed July 2008.

SECTION TEN GLOSSARY

100-year flood: A storm that results in flood levels that have a 1-percent chance of being exceeded in any given year. The 100-year flood is usually developed from a statistical distribution that is based on historical floods.

Acre-feet: Unit to express large water volumes. The amount of water required to cover 1 acre to a depth of 1 foot. One acre-foot equals 326,851 gallons, or 43,560 cubic feet.

Aggradation: The process by which streams and other waterways naturally convey sediment, in addition to water, as they flow.

Avulsion: The process by which a river leaves its normal channel and changes course, possibly returning to its original channel downstream.

Contributing Area (or Drainage Area): Area above a reservoir, lake, or stream gage from which runoff drains.

Curve Number: A measure that describes the amount of runoff from a rainfall event. The higher the Curve Number, the higher the percentage of rainfall converted to runoff.

Downstream flooding: Flooding occurring along the river downstream of a dam.

Excess precipitation: Rain or snowmelt that is not intercepted by plants, does not infiltrate into the soil, and immediately causes runoff.

Flashboards: Bulkheads placed on the crest or top of a channel wall or control structure to provide additional storage. Flashboards are designed to break and wash away under high flow conditions ("to operate") and while permitting large flows to pass a dam at lower elevations. In contrast, stoplogs are intended to be reused.

Flood fringe: The portion of the floodplain located between the floodway and floodplain boundaries. The flood fringe stores water and is often developed.

Floodway: The channel of a river or stream and those parts of the floodplains adjoining the channel, which are reasonably required to carry and discharge the floodwater or floodflow of any river or stream. The floodway experiences the highest stream velocities. The floodway must remain open (i.e., free of development) to allow conveyance of the 100-year flood.

Maximum Pool: Water level of a reservoir or lake just before it overtops its shore or dam.

Obermeyer Gate: A row of steel gate panels supported on their downstream side by inflatable air bladders. The pond elevation maintained by the gates can be adjusted by controlling the pressure in the bladders.

Pool elevation: The elevation of the surface of a body of water such as a lake. Specifically, the pool at a lock and dam or a reservoir is the elevation of the water surface immediately upstream from the dam.

Spillway: A structure used to provide for the release of flood flows from a dam into a river. Spillways pass flood flows so water does not overtop and damage or destroy a dam.

Stoplogs: A hydraulic engineering control element used in floodgates to adjust the water level and/or flow rate in a river, canal, or reservoir. Stoplogs are typically long rectangular timber beams or boards that are placed on top of each other and dropped into premade slots inside a dam weir (the "stoplog bay"). Placing more stoplogs in a stoplog bay increases the elevation of the lake or reservoir and decreases the releases.

Storage Capacity: Space available in reservoirs or lakes to store water; often expressed in acre-feet or in inches of excess precipitation falling over the contributing area.

Summer Level or "Full Pond": Typical planned water elevation of a reservoir or lake in the summer recreation season, obtained if meteorological conditions permit.

Upstream flooding: Flooding occurring along the lake or reservoir shore above a dam.

Winter level: Typical planned water elevation of a reservoir or lake in the winter, obtained if meteorological conditions permit.

Appendix A

Evaluation of Hydrologic Conditions

Tables

Figures

A-1.0 INTRODUCTION

A-1.1 Overview

Major flooding occurred between May 13 and May 17, 2006, throughout much of central and southern New Hampshire. Record peak flood discharges were recorded at 14 stream gages that have at least 10 years of record. Peak discharges with recurrence intervals equal to or in excess of 50 years were observed at 14 stream gages; at 8 of these 14 stream gages the recurrence intervals exceeded 100 years (see Table A-1). Significant property damage, along with numerous road closures and evacuations of residential areas occurred as a result of this widespread flooding. The flood damage was severe and widespread enough to result in the issuance of a Presidential Major Disaster Declaration for seven New Hampshire Counties on May 25, 2006.

Less than one year later, from April 16–18, 2007, major flooding again occurred in central and southern New Hampshire. Record peak flood discharges were recorded at six stream gages that have at least 10 years of record; at three of these six gage sites, the previous record peak discharge had been set during the May 2006 flood. Peak flood discharges with recurrence intervals equal to or in excess of 50 years were recorded at 10 stream gages during this event; at 7 of these 10 stream gages the recurrence intervals exceeded 100 years (see Table A-1). This severe flood event resulted in significant property damage, along with numerous road closures and evacuations of residential areas. As a result of the severity and scope of flood-related damages caused by the April 2007 flood a Presidential Major Disaster Declaration was issued for five New Hampshire counties on April 27, 2007; a sixth County was added to the disaster Declaration on May 10, 2007.

As a result of these recent severe floods in New Hampshire the Federal Emergency Management Agency (FEMA), initiated an independent evaluation to characterize the meteorologic and hydrologic conditions prior to and during the May 2006 and the April 2007 flooding in New Hampshire and to compare and contrast the conditions associated with the two flood events. In addition, this study will provide recommendations for improving water management procedures and dam operations to reduce the impacts from future flooding. Numerical hydrologic and hydraulic models of the affected river basins were developed or adapted from existing models and used to evaluate the effects of various alternative procedures and policies. The results of the investigation will be presented in two parts: the initial characterization and description of the hydrologic and meteorologic conditions, and the description of the development and use of the hydrologic models to evaluate various scenarios.

The purpose of this appendix is to investigate and document the general meteorologic and hydrologic conditions in the affected areas of New Hampshire prior to and during the May 2006 and April 2007 flood events. The general hydrologic conditions considered include antecedent conditions, characteristics of the precipitation events that resulted in the flood events, and characteristics of the flood discharges. In addition, the general hydrologic conditions for the April 2007 and May 2006 flood events will compared and contrasted.

A-1.2 Effect of Antecedent Conditions on Flood Peaks

Stream flow, in general, can be thought of as being composed of two components: base flow and direct runoff. Base flow is the water that flows in a stream between rainfall or snowmelt events and consists primarily of water from shallow groundwater sources. Direct runoff is the water that flows over (or ‘runs off’ of) the surface of the land during and right after a rainfall event and is eventually collected in streams and rivers.

The base flow contribution to stream flow typically results from rainfall or snowmelt that soaks into the ground and then travels through porous shallow soil or fractured rock (depending on the specific geographic setting) to the stream. The time it takes for water to soak into the ground and then travel through the shallow soil or fractured rock is on the order of weeks and months and is dependent on the characteristics of the soil and fractured rock as well as the general topographic setting of the drainage area of the stream. This slow release of water from the water table sustains flow in streams during periods between rainfall events.

As noted above, direct runoff is the water from rainfall or snowmelt that flows over land or through small ditches directly into streams and rivers. The time it takes for direct runoff to reach a stream or river is on the order of hours and days and depends on the land cover, land use, and steepness of the land over which the runoff travels. This rapid contribution to stream flow leads to the rapid rises in streams during and after rainfall events and is the component of stream flow most responsible for flooding.

The amount of water from rainfall or snowmelt that becomes direct runoff and then contributes directly to stream flow, and in some cases flooding, is dependent on several factors. As discussed above, some portion of the rainfall or snowmelt soaks into the ground and reaches the stream weeks or months later as base flow, but does not contribute directly to stream flow during flood events. The amount of rainfall or snowmelt that is absorbed from a rainfall or snowmelt event depends for the most part on two factors: the types of land cover and land uses found in the drainage area and the ability and capacity of the soils in the drainage area to absorb water.

Although development and urban growth can change the land cover and land use characteristics of a drainage area with time, these changes are relatively gradual and typically confined to small areas relative to the total drainage area of a large stream. In contrast, the ability and capacity of soils to absorb water from rainfall or snowmelt can vary greatly depending on the moisture and temperature of the soil at the time of the rainfall or snowmelt. In general terms, the soil can be compared to a sponge that when saturated or full of water can no longer absorb additional water. As a result, if the general soil conditions are dry prior to a rainfall or snowmelt event, a larger portion of the total rainfall will be absorbed into the ground and a smaller amount will be available for direct runoff. Conversely, if general soil conditions are wet prior to a rainfall or snow melt event, then a smaller portion of the rainfall or snowmelt will be absorbed into the ground and a larger amount of the rainfall or snowmelt will contribute to direct runoff and the resultant stream flow amounts will be greater. In addition, if the ground is frozen, then the absorption capacity of the soil is greatly reduced and direct runoff is increased accordingly.

As such, differences in land cover and land use can and often do explain why similar amounts of rainfall or snowmelt can produce difference amounts of direct runoff on different stream or rivers. However, in many cases, storms with similar amounts of rainfall or snowmelt will result in significantly different amounts of direct runoff on the same stream or river. These differences in the direct runoff response for similar storms on a particular stream or river are the result of differences in the soil moisture and temperature conditions at the beginning of the rainfall or snowmelt event. Soil moisture and temperature conditions are a direct result of the rainfall and temperature conditions in the weeks and months leading up to a specific storm event. In general, the climatic and soil conditions leading up to specific storm events are referred to as antecedent conditions. Variations in the antecedent conditions for a given drainage basin explain the large variations that are observed in the relation between rainfall amount and peak stream flows for a given drainage basin.

A-1.3 Study Area

The study area for this investigation includes the areas in central and southern New Hampshire affected by the May 2006 and April 2007 flood events. This area includes the Cocheco, Contoocook, Isinglass, Lamprey, Oyster, Piscataquog, Salmon Falls, Soucook, Souhegan, and Suncook River basins. The Contoocook, Piscataquog, Soucook, Souhegan, and Suncook River basins are all tributary to the Merrimack River, while the Cocheco, Isinglass, Lamprey, Oyster, and Salmon Falls River basins are all part of the Piscataqua-Salmon Falls River basin, which drains directly to the Atlantic Ocean (see Figure A-1).

The river basins included in the study area drain all or parts of Belknap, Carroll, Cheshire, Hillsborough, Merrimack, Rockingham, Strafford, and Sullivan Counties. The terrain elevation in this part of New Hampshire ranges from sea level along the Atlantic Coast to more than 2,000 feet North American Vertical Datum of 1988 (NAVD 88) in the more mountainous areas in the north-central part of the study area. The climate in New Hampshire is generally humid, with an average annual precipitation of about 43 inches. The total precipitation is distributed fairly evenly across the State, except in areas of high elevation (above 4000 feet) which typically receive as much as 10 inches more than the average precipitation. In addition there is little seasonal variation in precipitation, with winter and spring months (December–May) receiving slightly less than half (46 percent) of the average annual precipitation.

The following table and figures show the streams and major tributaries and the towns in each of the ten study basins. The upper portions of most of the watersheds are relatively rural and highly forested with slightly increasing densities of population and urban land use in the downstream portions. The severity of storm events varied by basin and sometimes within basin depending on rainfall patterns and antecedent conditions.

Table A-1: Data for Individual Watersheds

Watershed Name	Tributary to:	Drainage Area (square miles)	Recurrence Interval for May 2006 Flood	Recurrence Interval for April 2007 Flood
Cocheco	Great Bay	111	50-100	10-50
Contoocook	Merrimack River	764	10-50	2-10
Isinglass	Great Bay	74	10-50	10-50
Lamprey	Great Bay	214	50-100	50-100
Oyster	Great Bay	31	10-50	100-500
Piscataquog	Merrimack River	217	10-50	10-50
Salmon Falls	Great Bay	188	10-50	10-50
Soucook	Merrimack River	91	100-500	10-50
Souhegan	Merrimack River	220	2-10	50-100
Suncook	Merrimack River	256	10-50	100-500

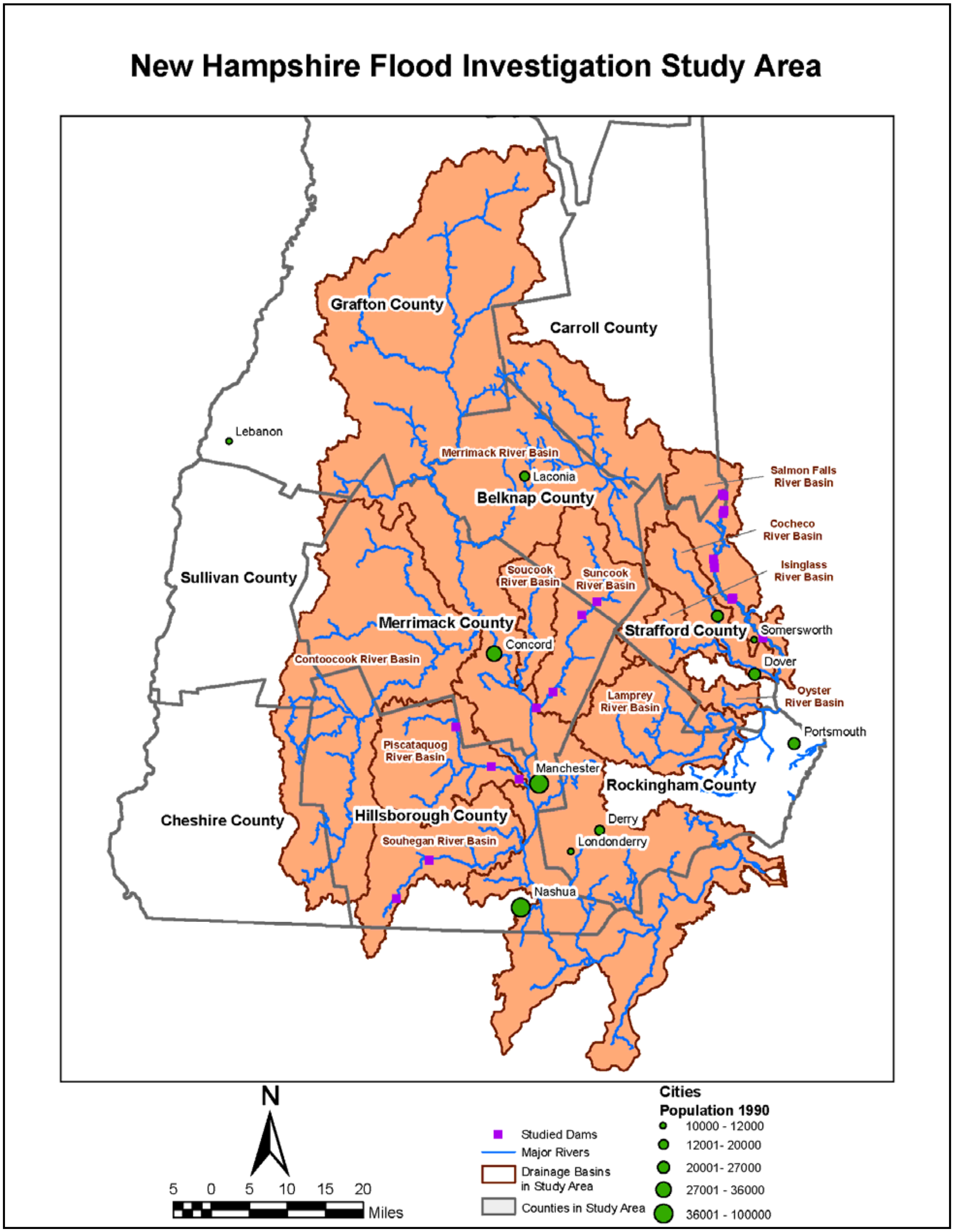


Figure A-1: New Hampshire Flood Investigation Study Area

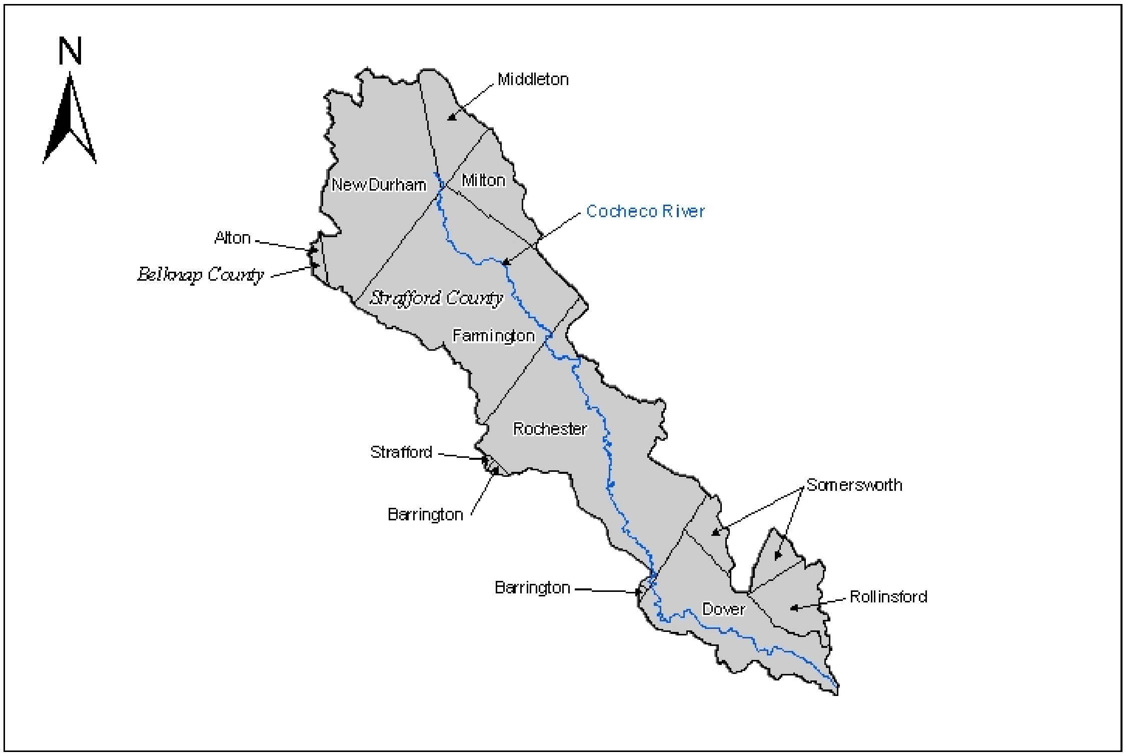


Figure A-1a: Cocheco River Watershed

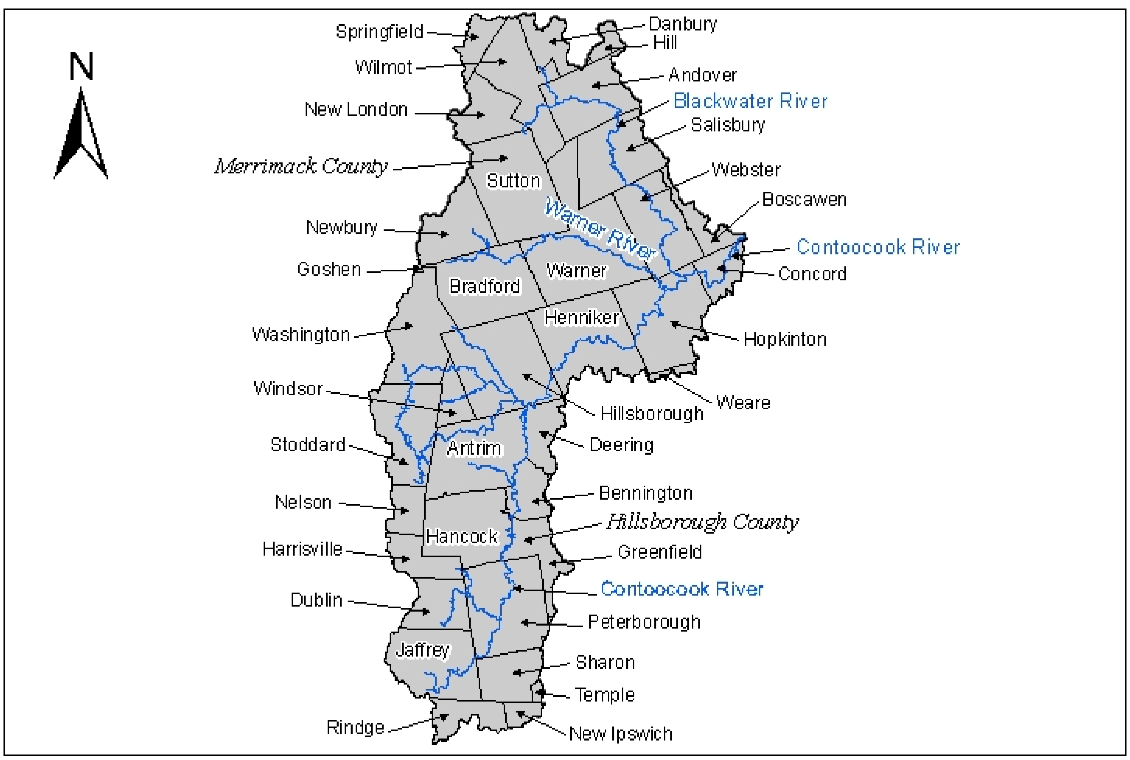


Figure A-1b: Contoocook River Watershed

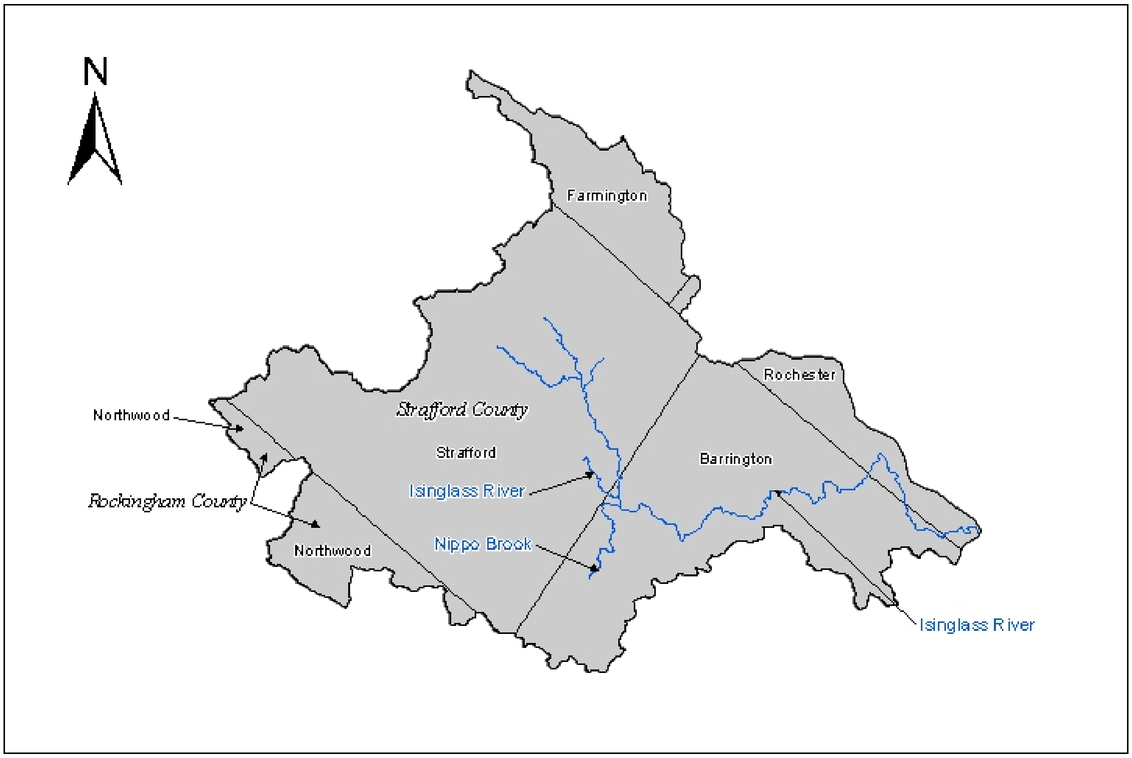


Figure A-1c: Isinglass River Watershed

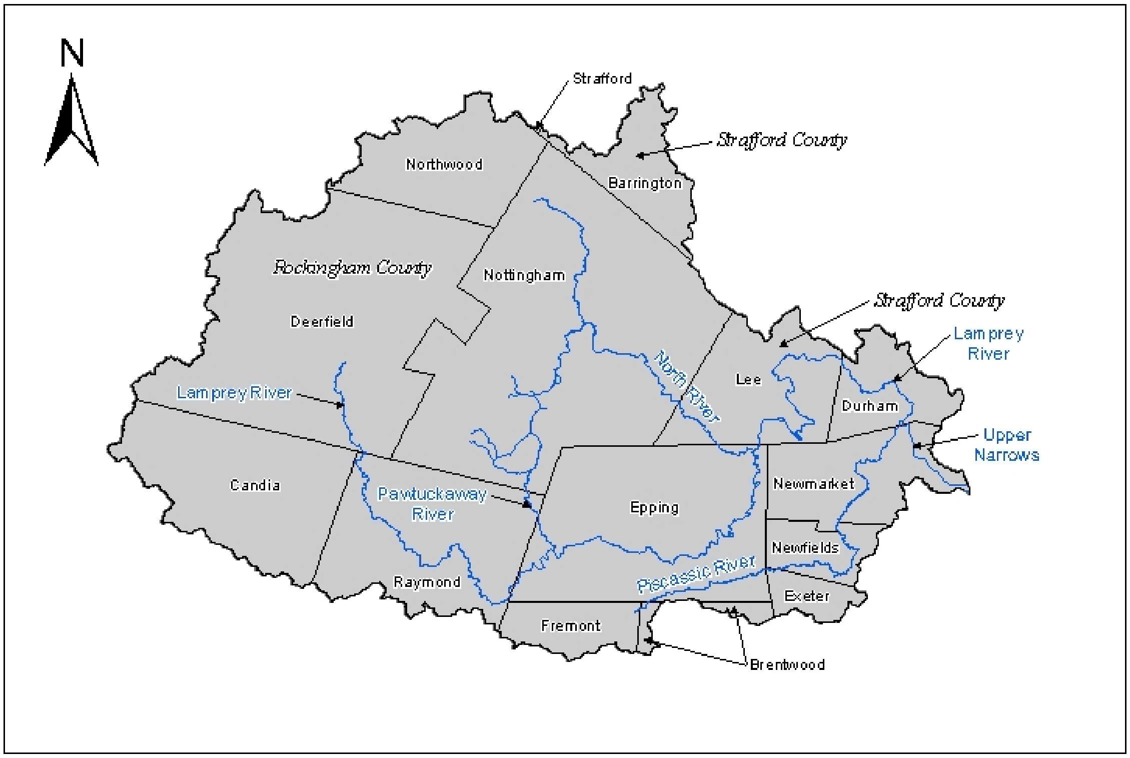


Figure A-1d: Lamprey River Watershed

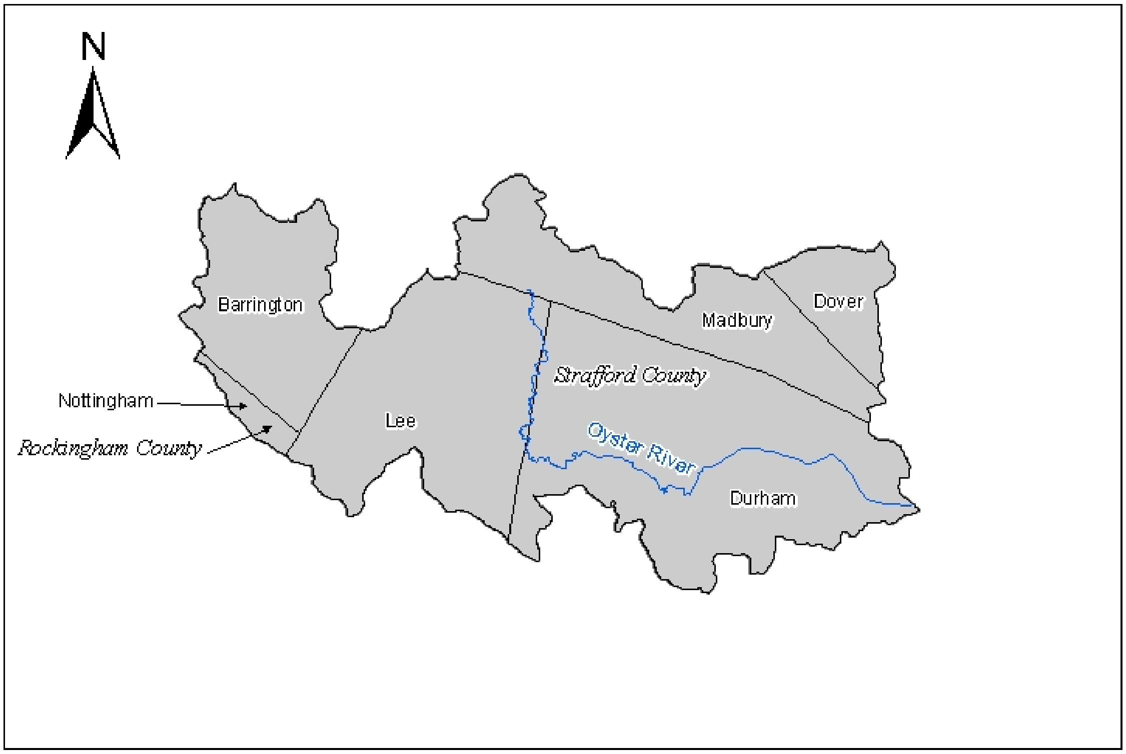


Figure A-1e: Oyster River Watershed

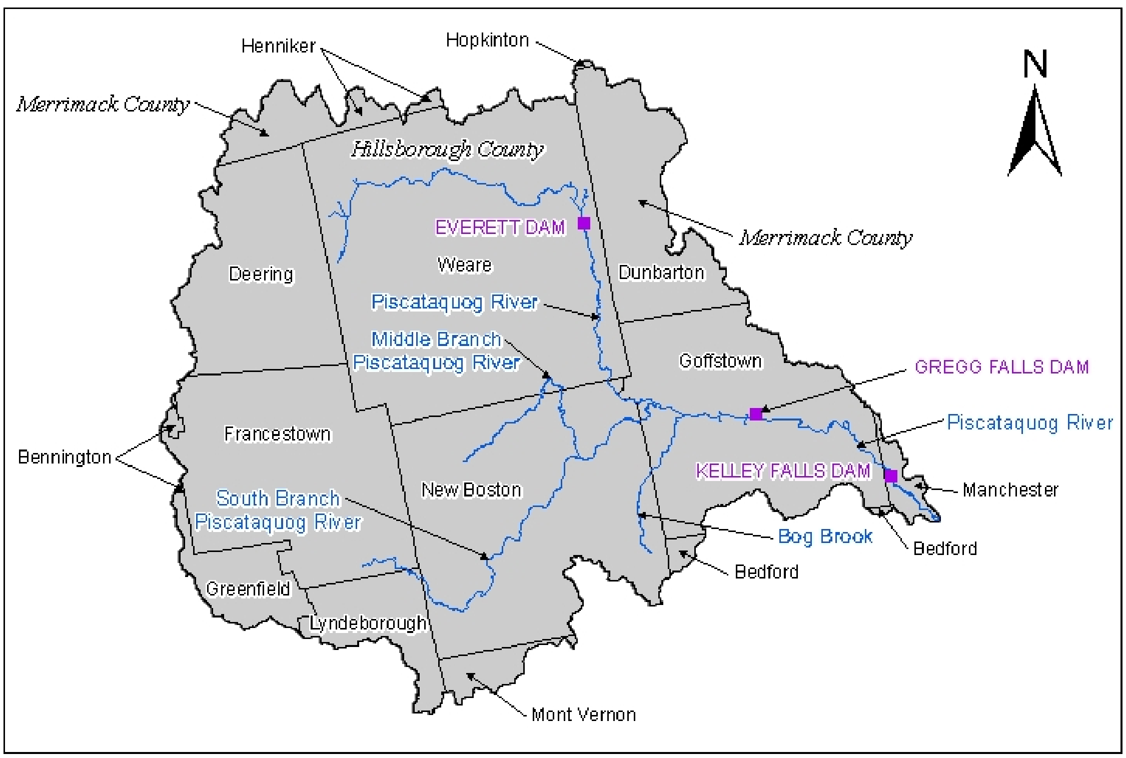


Figure A-1f: Piscataquog River Watershed

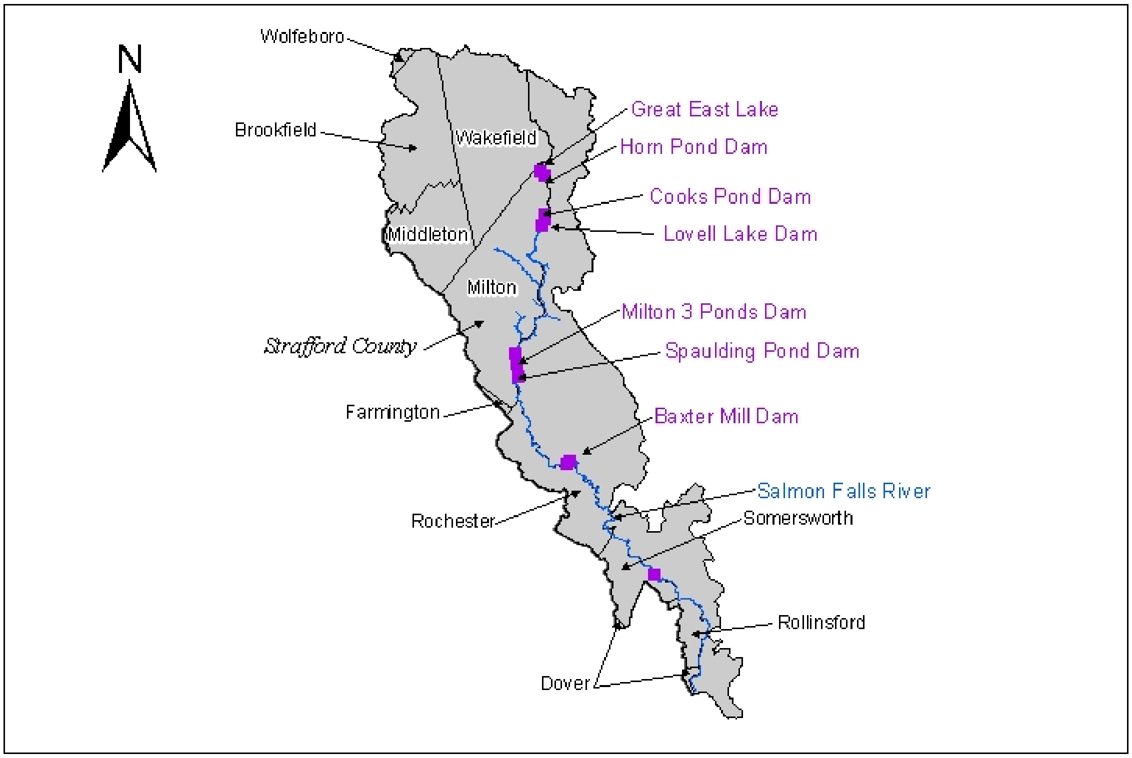


Figure A-1g: Salmon Falls River Watershed

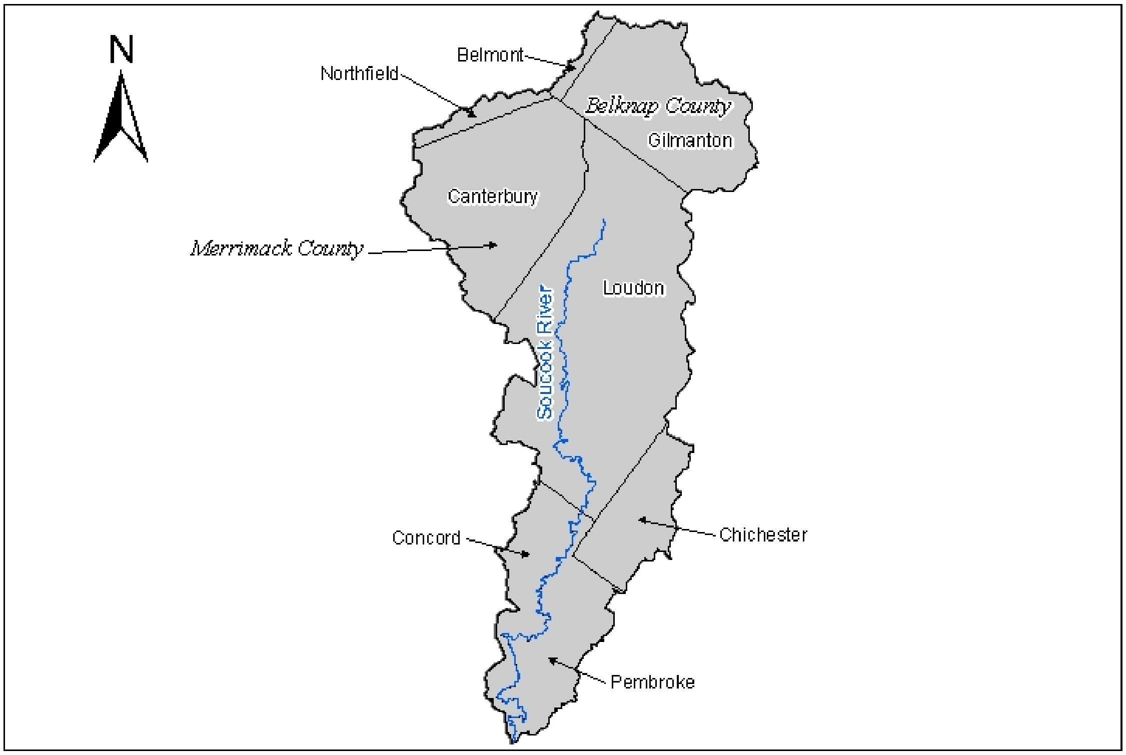


Figure A-1h: Soucook River Watershed

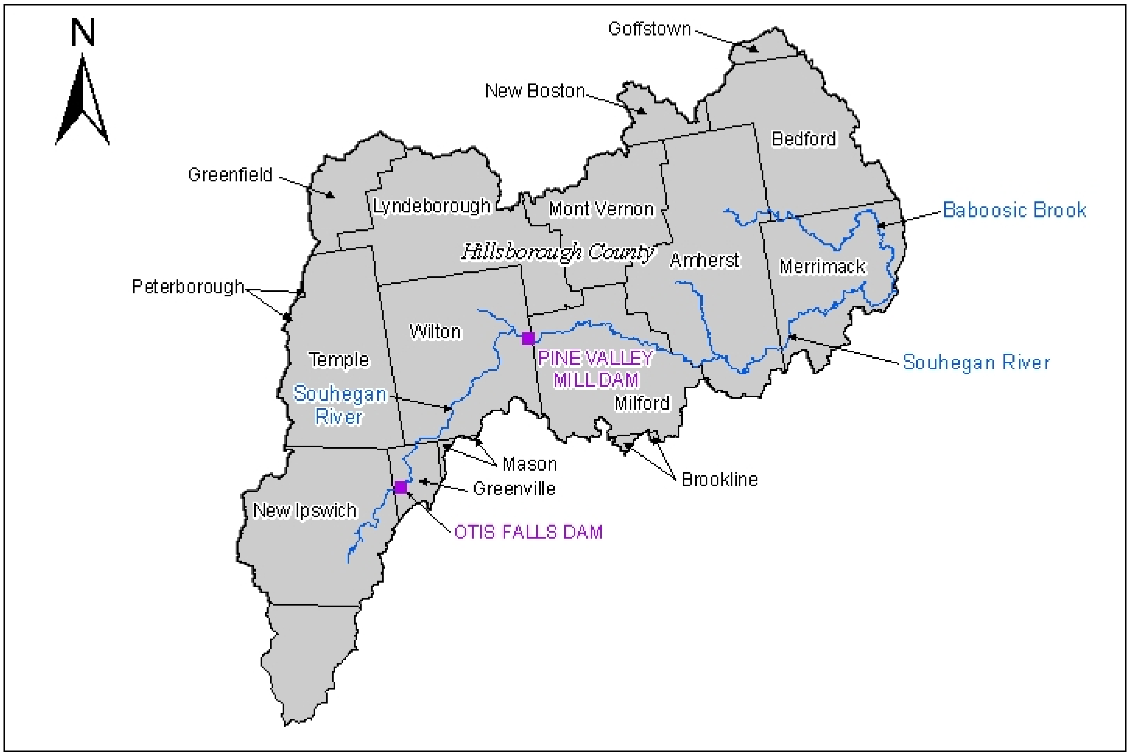


Figure A-1i: Souhegan River Watershed

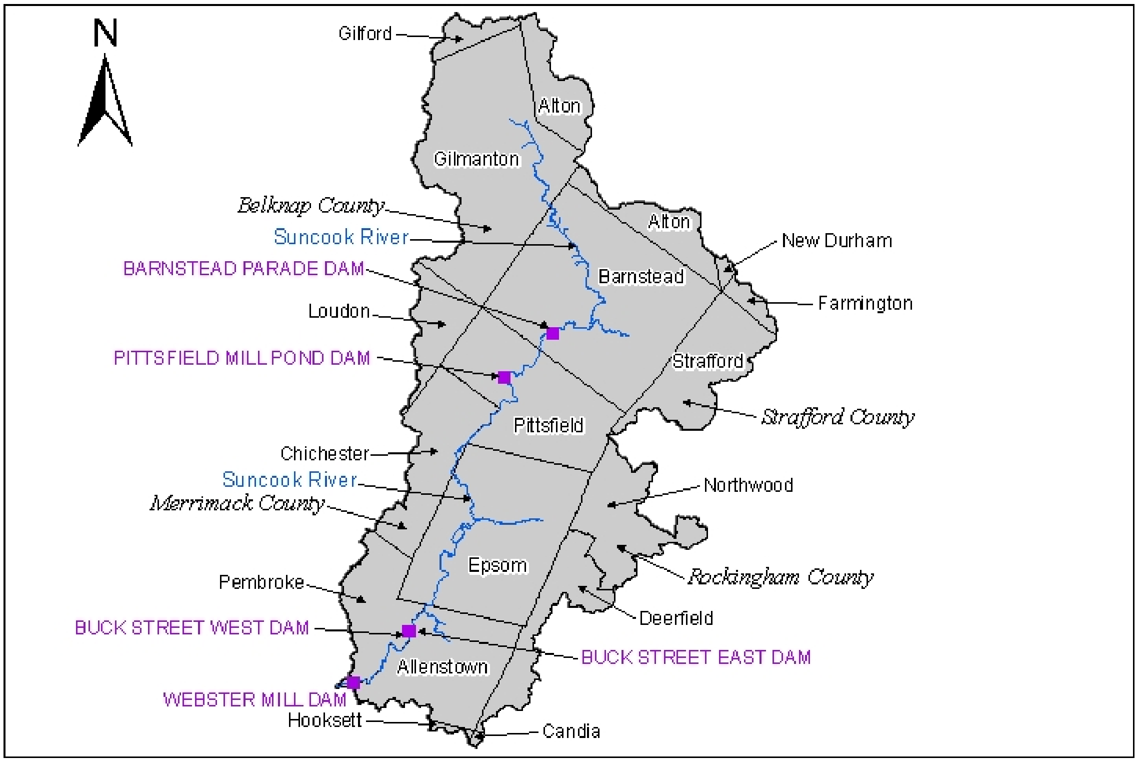


Figure A-1j: Suncook River Watershed

Previous Historical Flooding

New Hampshire has a long history of severe flooding prior to and including the May 2006 and April 2007 floods, as shown in Table A-1. Some of the most severe historic floods have occurred in March and April as a result of a combination of heavy spring rains, snowmelt, and ice jams. Coastal storms, in the form of nor'easters throughout the year, or tropical storms or hurricanes in late summer and fall have produced severe flooding occurs either in early spring or autumn. As a result major flooding events can and have occurred in all seasons, not just in the spring "runoff" season.

Table A-2: History of Flooding in New Hampshire (University of New Hampshire 2007)

Date	Area Affected (River Basins or Region)	Recurrence Interval (year)	Remarks
December 1740	Merrimack	Unknown	*First recorded flood in New Hampshire*
October 23, 1785	Cocheco, Baker, Pemigewasset, Contoocook and Merrimack	Unknown	*Greatest discharge at Merrimack and at Lowell, MA until 1902*
March 24–30, 1826	Pemigewasset, Merrimack, Contoocook, Blackwater and Ashuelot	Unknown	
April 21–24, 1852	Pemigewasset, Winnespaukee, Contoocook, Blackwater, and Ashuelot	Unknown	*Merrimack River at Concord - highest stream stage for 70 years. Merrimack River at Nashua - 2 feet lower than 1785*
April 19–22, 1862	Contoocook, Merrimack, Piscataquog, and Connecticut	Unknown	*Highest stream stages to date on the Connecticut River; due solely to snowmelt*
October 3–5, 1869	Androscoggin, Pemigewasset, Baker, Contoocook, Merrimack, Piscataquog, Souhegan, Ammonoosuc, Mascoma, and Connecticut	Unknown	*Tropical storm lasting 36 hours. Rainfall, 6–12 inches*
November 3–4, 1927	Pemigewasset, Baker, Merrimack, Ammonoosuc and Connecticut	25 to >5O	*Upper Pemigewasset River and Baker River - exceeded the 1936 flood. Down stream at Plymouth - less severe than the 1936 flood*
March 11–21, 1936	Statewide	25 to > 50	*Double flood; first due to rains and snowmelt; second, due to large rainfall*
September 21, 1938	Statewide	Unknown	*Hurricane. Stream stages similar to those of March 1936 and exceeded 1936 stages in Upper Contoocook River*

Date	Area Affected (River Basins or Region)	Recurrence Interval (year)	Remarks
June 1942	Merrimack River Basin	Unknown	*Fourth flood recorded in the lower Merrimack River basin at Manchester, NH*
June 15–16, 1943	Upper Connecticut, Diamond and Androscoggin	25 to >50	*Intense rainfall exceeding 4 inches; highest stream stages of record in parts of the affected area*
June 1944	Merrimack River	Unknown	*One of the five highest known floods at Manchester on the Merrimack*
November 1950	Contoocook River and Nubanusit Brook	Unknown	*Localized storm resulted in flooding of this area*
March 27, 1953	Lower Androscoggin, Saco, Ossipee, Upper Ammonoosuc, Israel, and Ammonoosuc	25 to>50	*Peak of record for the Saco and Ossipee Rivers*
August 1955	Connecticut River Basin	Unknown	*Heavy rains caused extensive damage throughout the basin area*
October 25, 1959	White Mountain Area; Saco, Upper Pemigewasset and Ammonoosuc Rivers	25 to >50	*Largest of record on Ammonoosuc at Bethlehem Junctions; third largest of record on the Pemigewasset and Saco Rivers*
December 1959	Piscataqua - Portsmouth	Unknown	*Northeaster brought tides exceeding maximum tidal flood levels in Portsmouth. Damage was heavy along the coast*
April 1960	Merrimack and Piscataquog	Unknown	*Flooding resulted from rapid melting of deep snow cover and the moderate to heavy rainfall. Third highest flood of record on the rivers*
April 1969	Merrimack River Basin	Unknown	*Record depth of snow cover in the Merrimack River Basin and elsewhere resulted in excessive snowmelt and runoff when combined with sporadic rainfall*
February 1972	Coastal Area	Unknown	*Coastal area was declared a National Disaster Area as a result of the devastating effects of a severe coastal storm, damage was extensive*
June 1972	Pemigewasset River	Unknown	*Five days of heavy rain caused some of the worst flooding since 1927 along streams in the upper part of the State, damage was extensive along the Pemigewasset River and smaller streams in northern areas*
June 30, 1973	Ammonoosuc River	25 to > 50	*Northwestern White Mountains*

Date	Area Affected (River Basins or Region)	Recurrence Interval (year)	Remarks
April 1976	Connecticut River	Unknown	*Rain and snowmelt brought the river to 1972 levels, flooding roads and croplands*
March 14,1977	South-central and Coastal New Hampshire	25 to 50	*Peak of record for Soucook River*
February 1978 (“The Blizzard of ‘78”)	Coastal New Hampshire	Unknown	*Nor’easter brought strong winds and precipitation to the entire State. Hardest hit area was the coastline, with wave action and floodwaters destroying homes. Roads all along the coast were breached by waves flooding over to meet the rising tidal waters in the marshes*
July, 1986–August 10,1986	Statewide	Unknown	*FEMA DR-71I-NH: Severe summer storms with heavy rains, tornadoes; flash flood and severe winds*
March 31–April 2, 1987	Androscoggin, Saco, Ossipee, Piscataquog, Pemigewasset, Merrimack and Contoocook River	25 to >50	*Caused by snowmelt and Sense rain Precursor to a significant, following event*
April 6–7, 1987	Lamprey River and Beaver Brook	25 to >50	*FEMA DR-789-NH: Large rainfall event following the March 31– April 2 storm*
August 7–11, 1990	Statewide	Unknown	*FEMA DR-876-NH: Series of storm events from August 7–11, 1990 with moderate to heavy rains during this period produced widespread flooding*
August 19, 1991	Statewide	Unknown	*FEMA DR-917-NH: Hurricane Bob struck New Hampshire causing extensive damage in Rockingham and Strafford counties, but the effects were felt statewide*
October–November 1995	Northern and Western Regions	Unknown	*FEMA DR-1144-NH: Counties declared: Grafton, Hillsborough, Merrimack, Rockingham, Strafford, and Sullivan*
October 1996	Northern and Western Regions	Unknown	*FEMA DR-1077-NH: Counties declared: Carroll, Cheshire, Coos, Grafton, Merrimack, and Sullivan*

Date	Area Affected (River Basins or Region)	Recurrence Interval (year)	Remarks
June–July, 1998	Central and Southern Regions	Unknown	*FEMA DR-1231-NH: Series of rainfall events. Counties declared: Belknap, Grafton, Carroll, Merrimack, Rockingham, and Sullivan (1 fatality). (Several weeks earlier, significant flooding, due to rain and rapid snowpack melting, occurred in Coos County, undeclared in this event. Heavy damage to secondary roads occurred)*
September 18–19, 1999	Central and Southwest Regions	Unknown	*FEMA DR-1305-NH: Heavy rains associated with Tropical Storm/Hurricane Floyd. Counties declared: Belknap, Cheshire, and Grafton*
July 21–August 18, 2003	Southwestern Region	Unknown	*FEMA-1489-DR: Severe storms and flooding occurred in Cheshire and Sullivan counties. Public Assistance provided for repair of disaster damaged facilities*
October 7–16, 2005	Southwestern Region	Exceeded 100 in some areas	*FEMA-1610-DR: Heavy rains associated with Tropical Storm Tammy and Subtropical Depression 22 resulted in 6–15 inches of rain*
May 13–15, 2006	Central and Southern NH	Exceeded 100	*FEMA-1643-DR: Heavy rainfall 8–16 inches*
April 27, 2007	Statewide	100	*FEMA-1695-DR: Severe storms and flooding, starting on April 15th*

A-2.0 MAY 2006 FLOOD

Major flooding occurred in several river basins in central and southern New Hampshire from May 13 through May 17, 2006. Widespread, significant property damage, along with road closures and evacuations of residential areas resulted in the issuance of a Presidential Major Disaster Declaration on May 25, 2006, for Belknap, Carroll, Grafton, Hillsborough, Merrimack, Rockingham, and Strafford Counties. The most severe flooding, with peak discharge recurrence intervals in excess of 50 years, occurred in coastal areas of the Piscataqua-Salmon Falls River basin, including the Cocheco, Lamprey, and Salmon Falls River basins, and in south-central New Hampshire in the Contoocook, Piscataquog, Soucook, and Suncook River basins (see Figure A-2). According to published U.S. Geologic Service (USGS) records, record peak flood discharges were recorded at 14 stream gages with more than 10 years of record in New Hampshire; although at three of these gage locations the May 2006 peak of record would be superseded in April 2007 (see Table A-1). Peak discharges with recurrence interval of flooding equal to or in excess of 50 years were observed at 14 stream gages; at 8 of these gages the recurrence interval of flooding was equal to or greater than 100 years (Olsen 2007).

A-2.1 Antecedent Conditions

A-2.2 Antecedent Meteorological Conditions

Moisture conditions in the months leading up to the May 2006 flood can be characterized by examining average precipitation for the period December 2005 through May 2006 (see Figure A-3). Statewide precipitation exceeded the long-term (1971–2000) average for December and January, but was below the long-term average for the months of February, March, and April (see Table A-1).

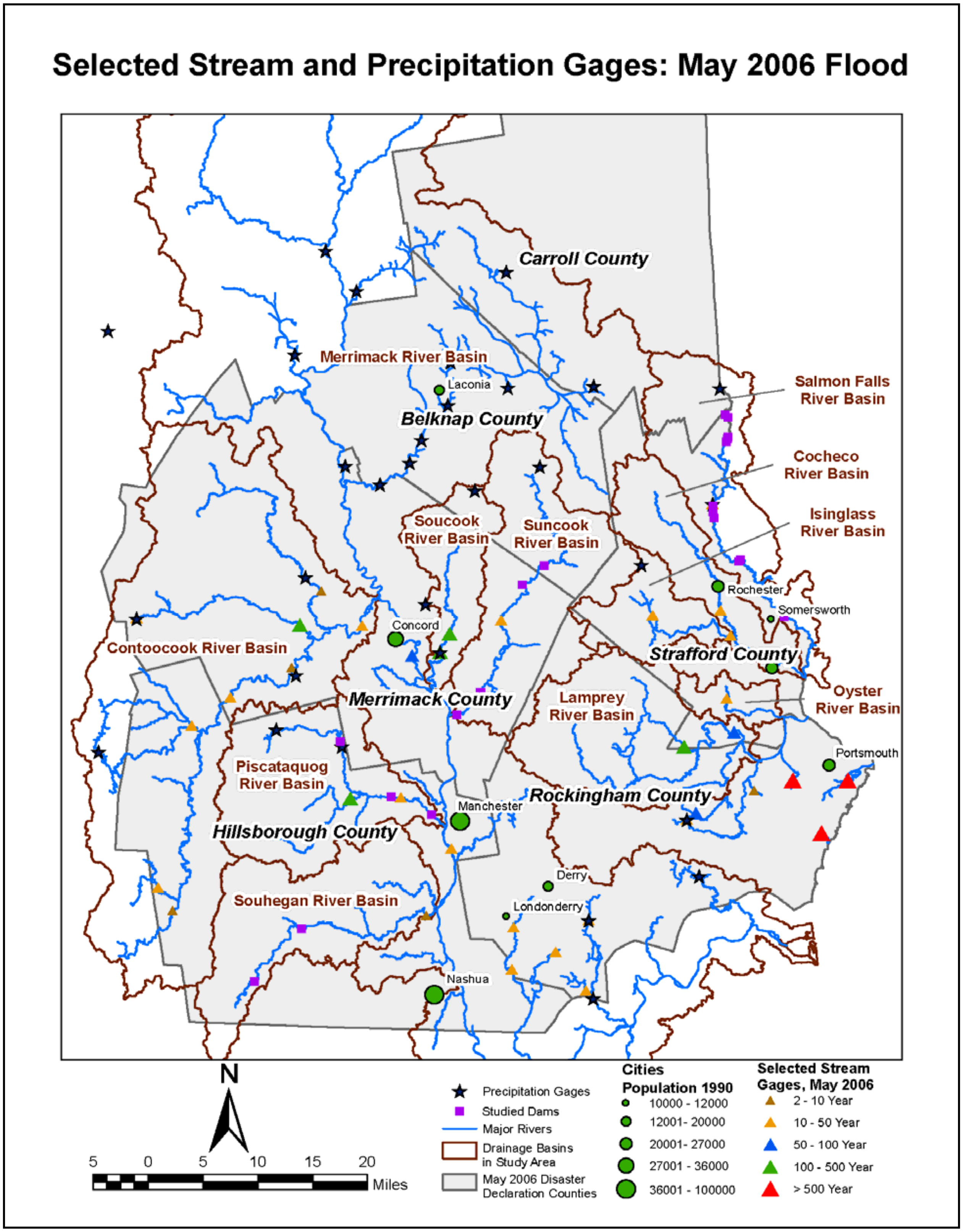


Figure A-2: May 2006 Study Area Map, Showing Selected Streams, Gages, and Dams

Table A-3: Statewide Average New Hampshire Precipitation for December 2005 Through May 2006

Month	Statewide Average Precipitation (inches)	Average Monthly Precipitation, 1971–2000 (inches)	Percent of Long-Term Average	Rank (1 = wettest, 112 = driest)
December 2005	4.29	3.44	124%	25
January 2006	4.14	3.42	120%	25
February 2006	2.43	2.62	92%	68
March 2006	1.39	3.37	41%	108
April 2006	3.12	3.50	89%	64
May 2006	9.30	3.77	247%	2

In the first 12 days of May 2006, Concord, Manchester, and Portsmouth, New Hampshire received a total of 1.7, 2.2, and 2.3 inches of rain, respectively (see Figure A-4). As a result of this rainfall in early May, soil moisture conditions for the study area were at higher than average levels, resulting in greater than average runoff response during the May 2006 flood.

A-2.2.1 Antecedent Stream Flow Conditions

In order to characterize the stream flow conditions prior to the May 2006 flood event, daily mean discharges for April and May 2006 were compared to long-term median (or 50th percentile) daily discharges at USGS stream gages on the Salmon Falls, Oyster, Lamprey, Contoocook, Soucook, and Souhegan Rivers (see Figure A-5). In general, this comparison indicates that daily discharges on the Salmon Falls and Contoocook Rivers were less than the long-term median daily discharges for all of April and early May 2006; although small rises were noted, the daily discharges on these rivers did not exceed the median discharge values until the onset of major flooding on May 13, 2006. Daily discharges on the Soucook and Souhegan Rivers were generally less than median discharge values throughout the period prior to the onset of major flooding; however for these two streams the three relatively small rises on April 5, April 25, and May 4, resulted in daily discharges that were nearly equal to or slightly greater than the median discharges values. Daily discharges on the Oyster and Lamprey Rivers were generally nearly equal to slightly greater than the median discharge values for most of the period from early April through May 12; in addition the daily discharges for these two rivers remained greater than the median discharge values for the week between the small rise on May 4 and the onset of major flooding on May 13.

A further review of median discharge values for several long-term stream gages (see Figure A-6) show that, in general, median flow values follow a fairly regular flow pattern typically increasing through winter until reaching yearly maximum values in April and then begin a recession that lasts throughout spring-and summer. As such, the May 2006 flooding occurred during the typical spring recession.

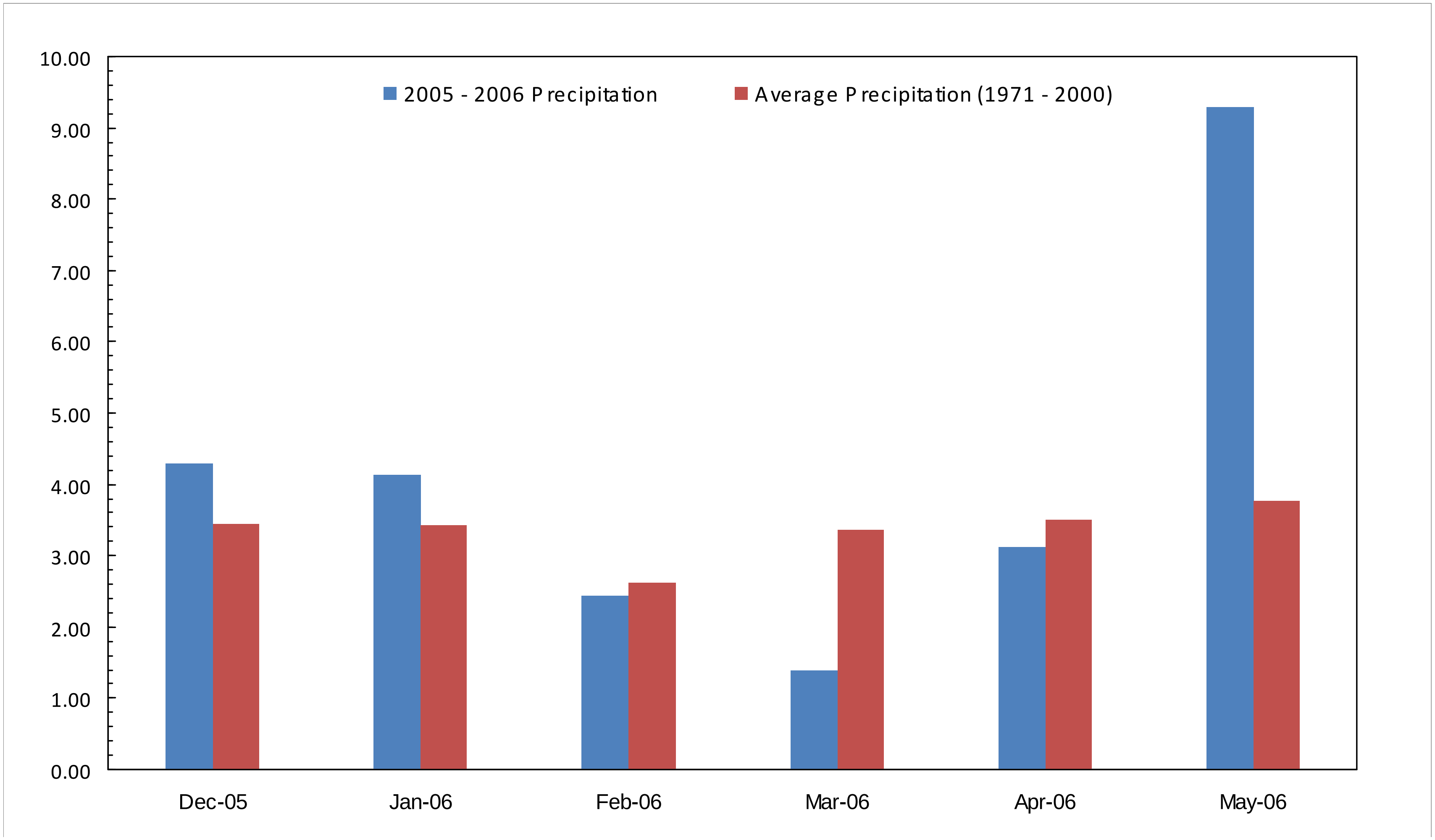


Figure A-3: New Hampshire Monthly Precipitation for Winter and Spring 2005-2006

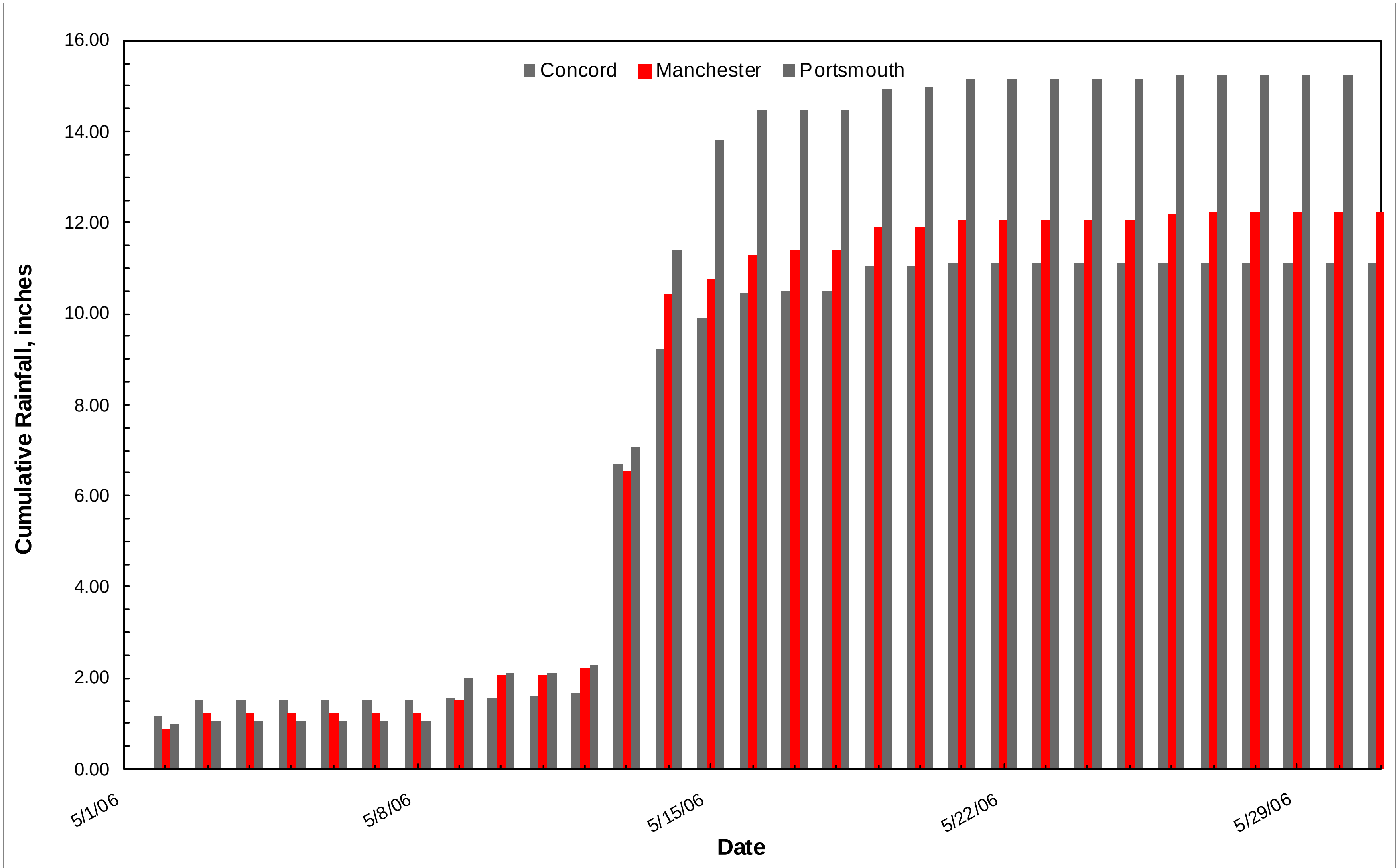


Figure A-4: Cumulative Daily Rainfall Totals, May 2006

Figure A-5: Daily and Long-Term Median Discharges

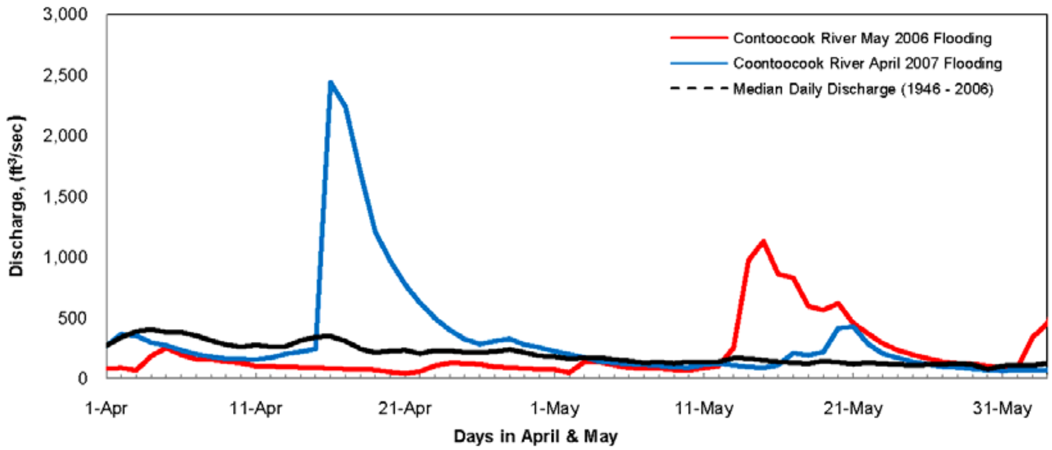


Figure 5a. Contoocook River Daily and long-term Median Discharges

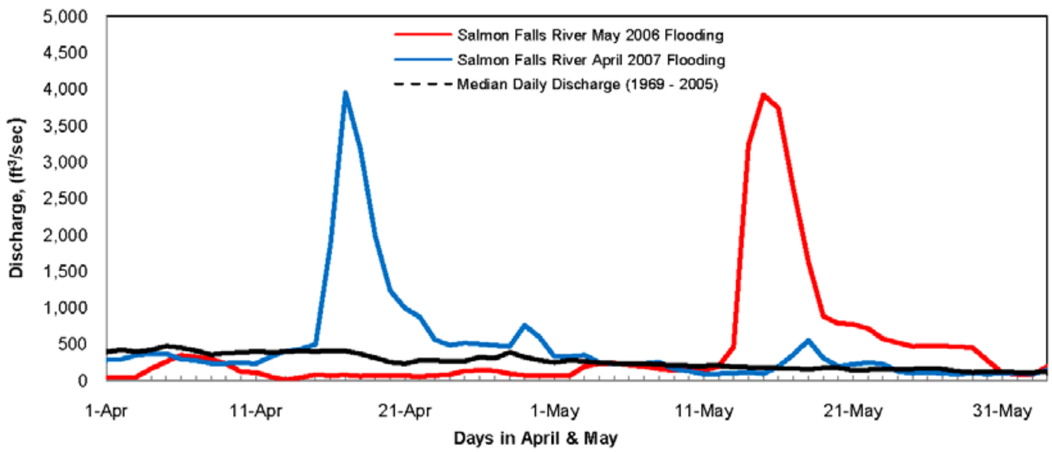


Figure 5b. Salmon Falls River Daily and long-term Median Discharges

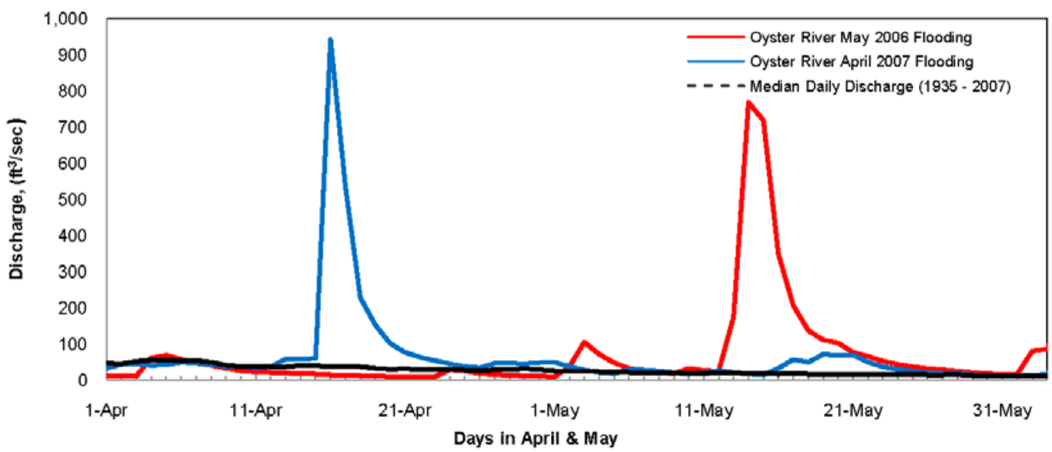


Figure 5c. Oyster River Daily and long-term Median Discharges

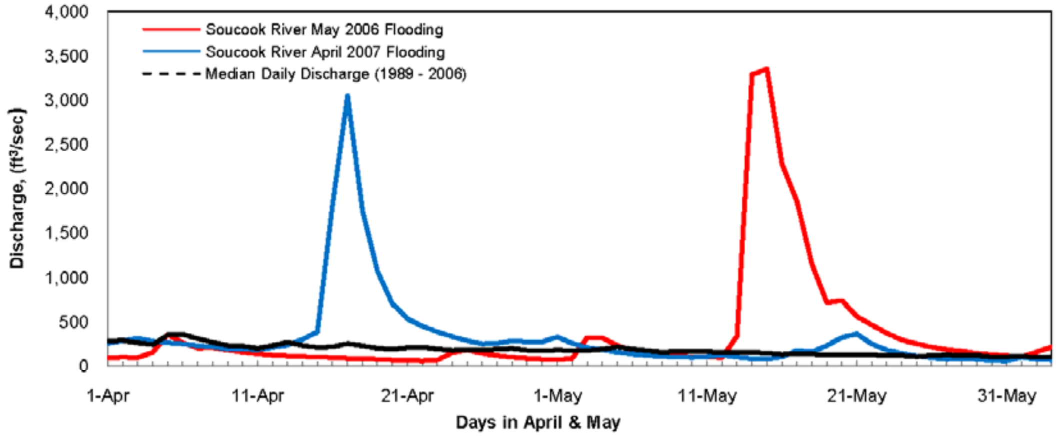


Figure 5d. Soucook River Daily and long-term Median Discharges

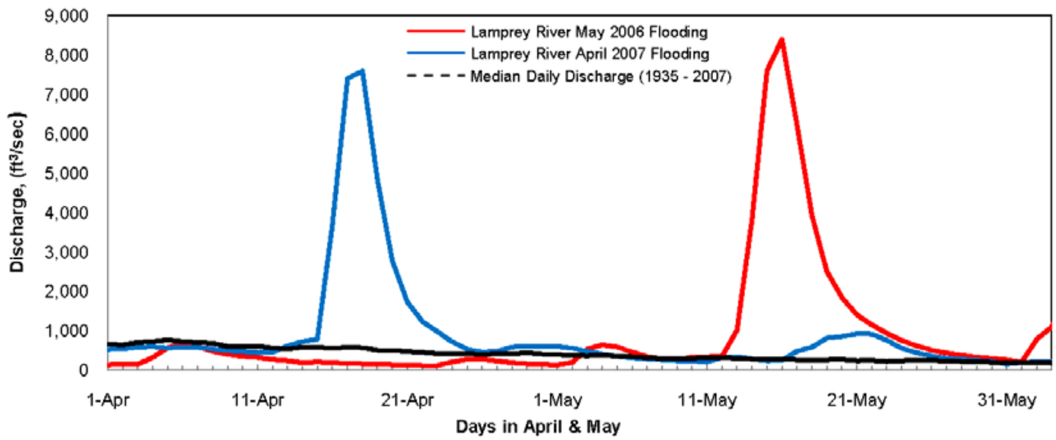


Figure 5e. Lamprey River Daily and long-term Median Discharges

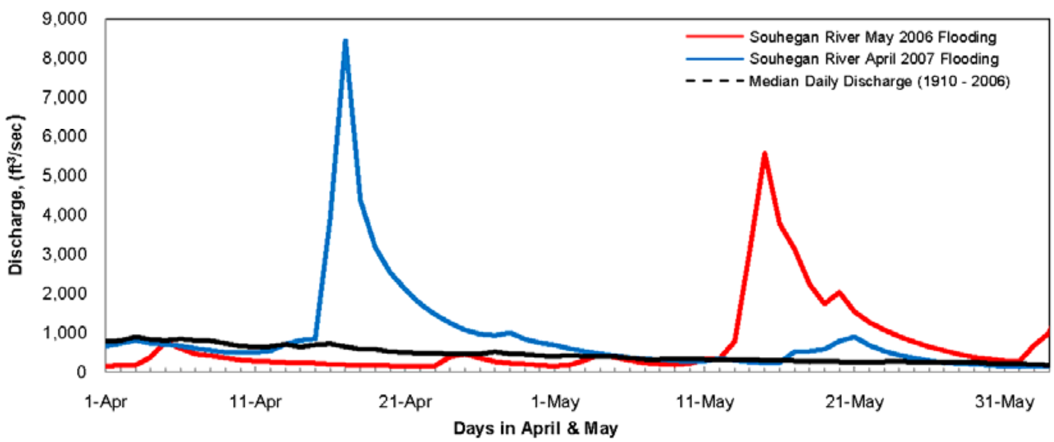


Figure 5f. Souhegan River Daily and long-term Median Discharges

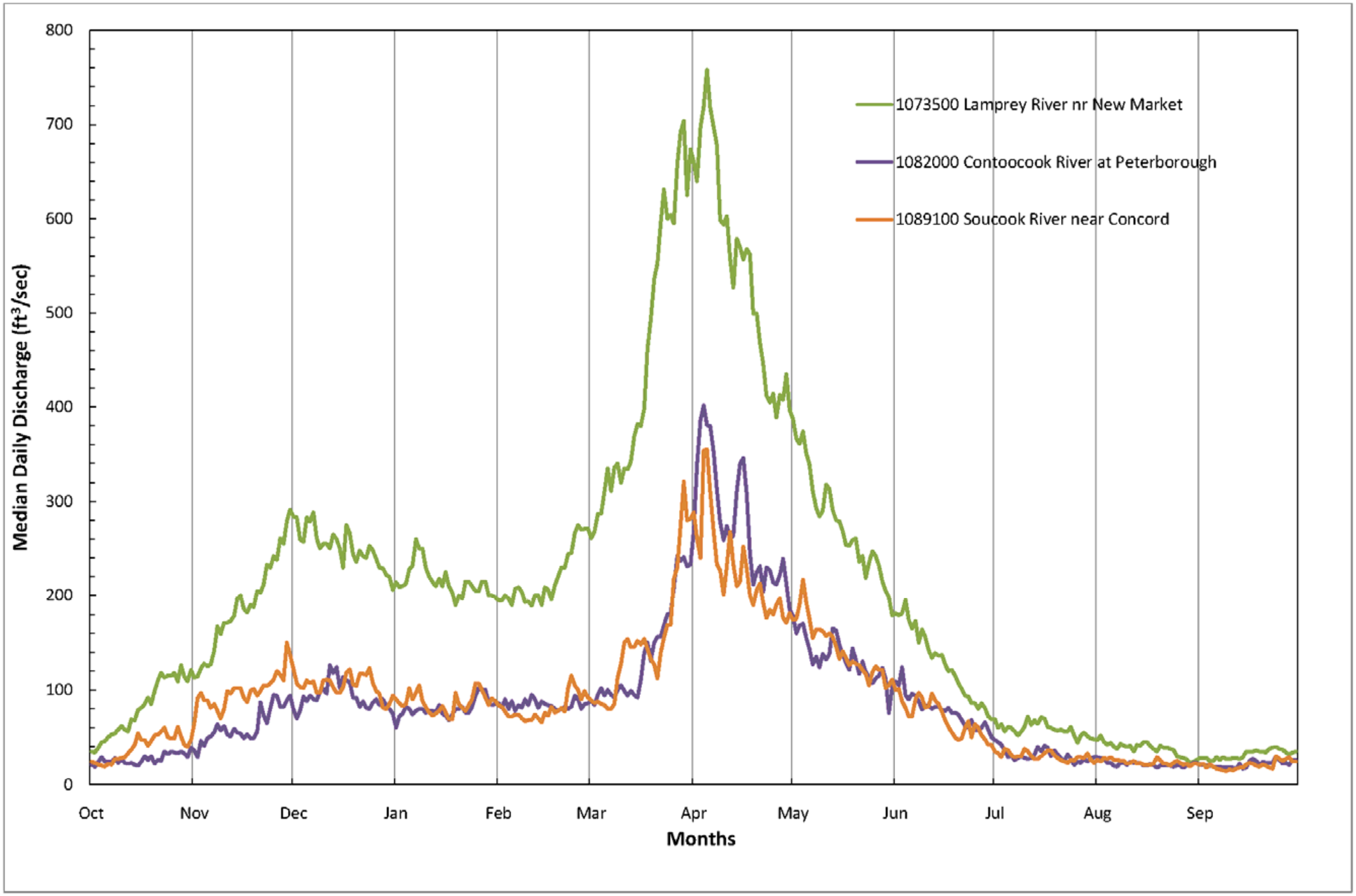


Figure A-6: Long-Term Median Daily Flow Values at Selected Gage Locations

A-2.3 Precipitation

The rainfall that produced the May 2006 flooding began on May 12 and continued through May 16, 2006, resulting in more than 12 inches of rain in the vicinity of Portsmouth, along the New Hampshire seacoast, and approximately 9 inches of rain in the vicinity of Concord and Manchester, in the south-central part of the State. The most intense rainfall occurred from May 13 through and May 15, with more than 90 percent of the 5-day storm total falling on these 3 days. The rainfall distribution and amount for May 15th, at the height of the storm, is shown in Figure A-7. In comparison to computed estimates of rainfall frequency presented in the National Oceanic and Atmospheric Administration's Technical Paper 40, *Rainfall Frequency Atlas of the United States* (NOAA TP-40), the greatest 1-day rainfall (May 13) is roughly equal to the 24-hour, 25-year recurrence interval values, while the 2-day (May 13–14) total rainfall amounts during the storm event exceed the 2-day, 100-year recurrence interval values (see Table A-3). As noted in previous section, significant precipitation was also received in the first 12 days of May 2006 as well; making May 2006 the second wettest May since 1895. There was substantial precipitation variability in the study area; precipitation in the Souhegan River Basin was substantially less than in the cities shown in Table A-3.

Table A-4: 24-Hour and 2-Day Rainfall Amounts for May 2006 Flood (National Weather Service Precipitation Analysis 2008)

Location	May 13, 2006 Rainfall Total (inches)	24-Hour Rainfall			May 13–14, 2006 Rainfall Total (inches)	2-Day Rainfall		
		25-year	50-year	100-year		25-year	50-year	100-year
Portsmouth	4.8	5.1	5.5	6.3	9.1	6.0	6.7	7.5
Manchester	4.4				8.2			
Concord	5.0				7.6			

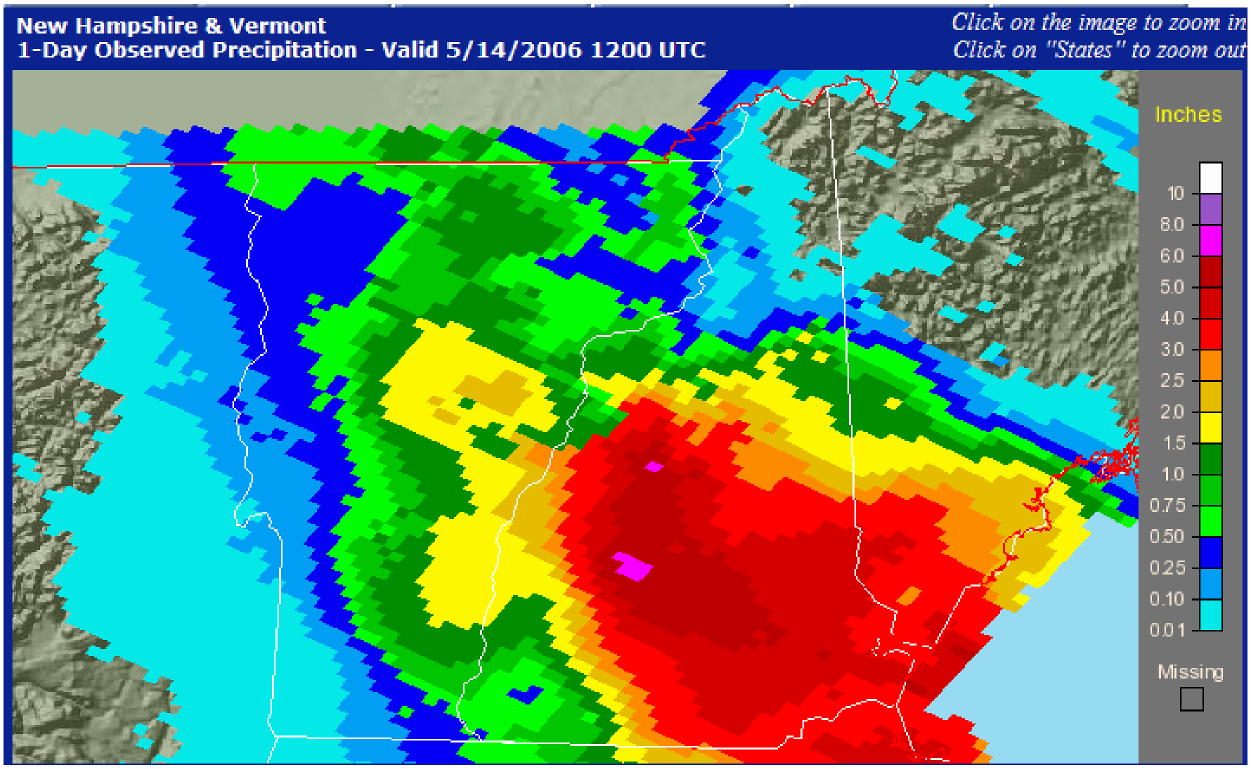


Figure A-7: Radar Rainfall Estimates for May 15, 2006 (NWS 2008h)

A-2.4 Flood Discharges

Peak discharges with a recurrence interval of flooding equal to or in excess of 50 years were observed at 14 stream gages; at 8 of these gages the recurrence interval of flooding was equal to or greater than 100 years (USGS, 2007). Record peak discharges were set at 14 long-term stream gages in the Cocheco, Contoocook, Lamprey, Piscataquog, Salmon Falls, and Soucook river basins; although the May 2006 peak of record would be superseded in April 2007 on the Salmon Falls, Cocheco, and South Branch Piscataquog Rivers (see Table A-1).

Flooding with recurrence interval of 500 years or greater was observed in small coastal drainage areas along the New Hampshire seacoast. Recurrence intervals between 100 and 500 years were observed on the main stem of the Soucook River. In addition, 100–500-year flooding was observed on tributaries of the Lamprey, the Piscataquog, and the Contoocook Rivers.

Runoff, in inches over the upstream drainage area, was computed for seven USGS stream gages (see Table A-1). Computed runoff at these seven gages ranged between a maximum of 7.8 inches to a minimum of 3.8 inches, with an average values of 6.1 inches.

Hydrographs (or plots of river gage height versus time), along with rainfall vs. time plots of the May 2006 and April 2007 flooding on the Piscataquog and Souhegan are presented for comparison (see Figure A-8). In general, comparison of the observed rainfall patterns at the two locations indicate that although the May 2006 rain event was longer in duration and resulted in more total rainfall, the rainfall for the April 2007 was more intense. This comparison is evident in the more rapid initial rise observed in the April 2007 hydrographs for both the Piscataquog and Souhegan Rivers. In addition, the May 2006 hydrographs are somewhat wider than those observed for the April 2007 event, indicating an overall larger amount of direct runoff.

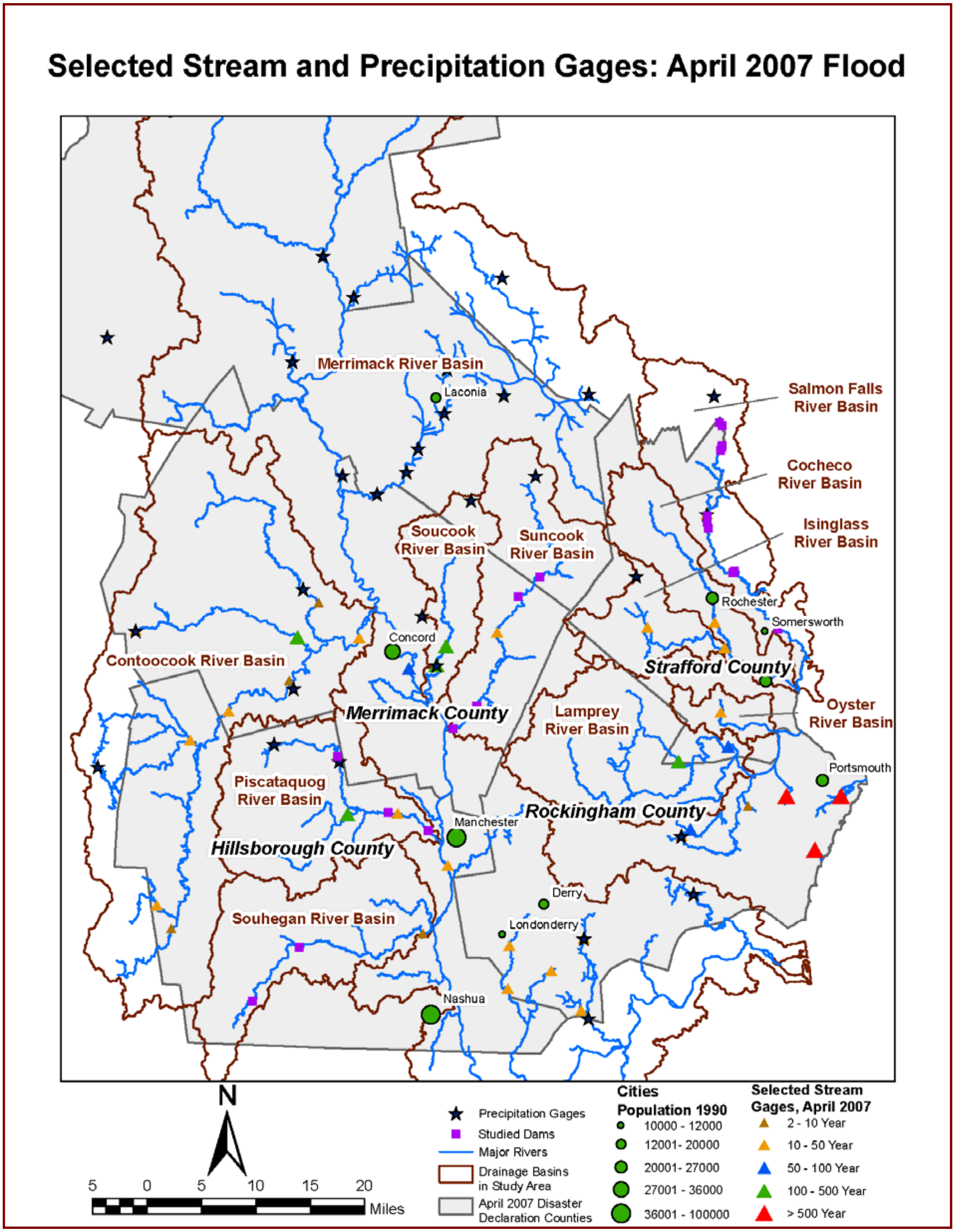


Figure A-8: April 2007 Study Area Map, Showing Selected Streams, Gages, and Dams

A-3.0 APRIL 2007 EVENT

Major flooding again occurred in central and southern New Hampshire from April 15 through 19, 2007. Widespread damage across the area resulting in the second Presidential Major Disaster Declaration in less than a year on April 27, 2007, for five counties: Grafton, Hillsborough, Merrimack, Rockingham, and Strafford; Belknap County was added to the Disaster Declaration on May 10, 2007. The most severe flooding, with peak discharge recurrence intervals in excess of 50 years, occurred in the coastal areas of the Piscataqua-Salmon Falls River basin, including the Lamprey and Oyster River basins, and in south-central New Hampshire in the Contoocook, the Piscataquog, the Souhegan, and the Suncook River basins (see Figure A-9). According to published USGS records, record peak flood discharges were recorded at six stream gages in New Hampshire (see Table A-1). Peak discharges with recurrence intervals of flooding equal to or in excess of 50 years were observed at 10 stream gages; at 7 of these gages the recurrence interval of flooding was equal to or greater than 100 years (USGS, 2008).

A-3.1 Antecedent Conditions

A-3.1.1 Antecedent Meteorological Conditions

Moisture conditions in the months leading up to the April 2007 flood can be characterized by examining average precipitation for the period November 2006 through April 2007 (see Figure A-9). Statewide precipitation was greater than or equal to the long-term (1971–2000) average for each of the 5 months leading up to the April 2007 flood except for February 2007 (see Table A-4).

Table A-5: Statewide Average New Hampshire Precipitation for November 2006 Through April 2007

Month	Statewide Average Precipitation (inches)	Average Monthly Precipitation, 1971–2000 (inches)	Percent of Long-Term Average	Rank (1 = wettest, 112 = driest)
November 2006	4.69	3.44	119%	34
December 2006	3.42	3.42	99%	55
January 2007	3.12	2.62	91%	53
February 2007	2.04	3.37	77%	90
March 2007	3.61	3.50	107%	49
April 2007	7.35	3.50	209%	1

In the first 14 days of April 2007, Concord, Manchester, and Portsmouth, NH, received a total of 2.1, 2.2, and 2.2 inches of precipitation, respectively (see Figure A-10). In addition, a total of 10.5 inches of snow was recorded at Concord during the first 14 days of the month and 1.0 inch of snow remained on the ground as of April 14. Snowfall for the month was greater and remaining snow depths were greater in higher elevation areas of the State. As a result of the snow and rain precipitation in early April, soil moisture conditions for the study area were nearly 100 percent saturated. The melting snow released the water to the soil, resulting in much greater than average runoff response during the April 2007 flood.

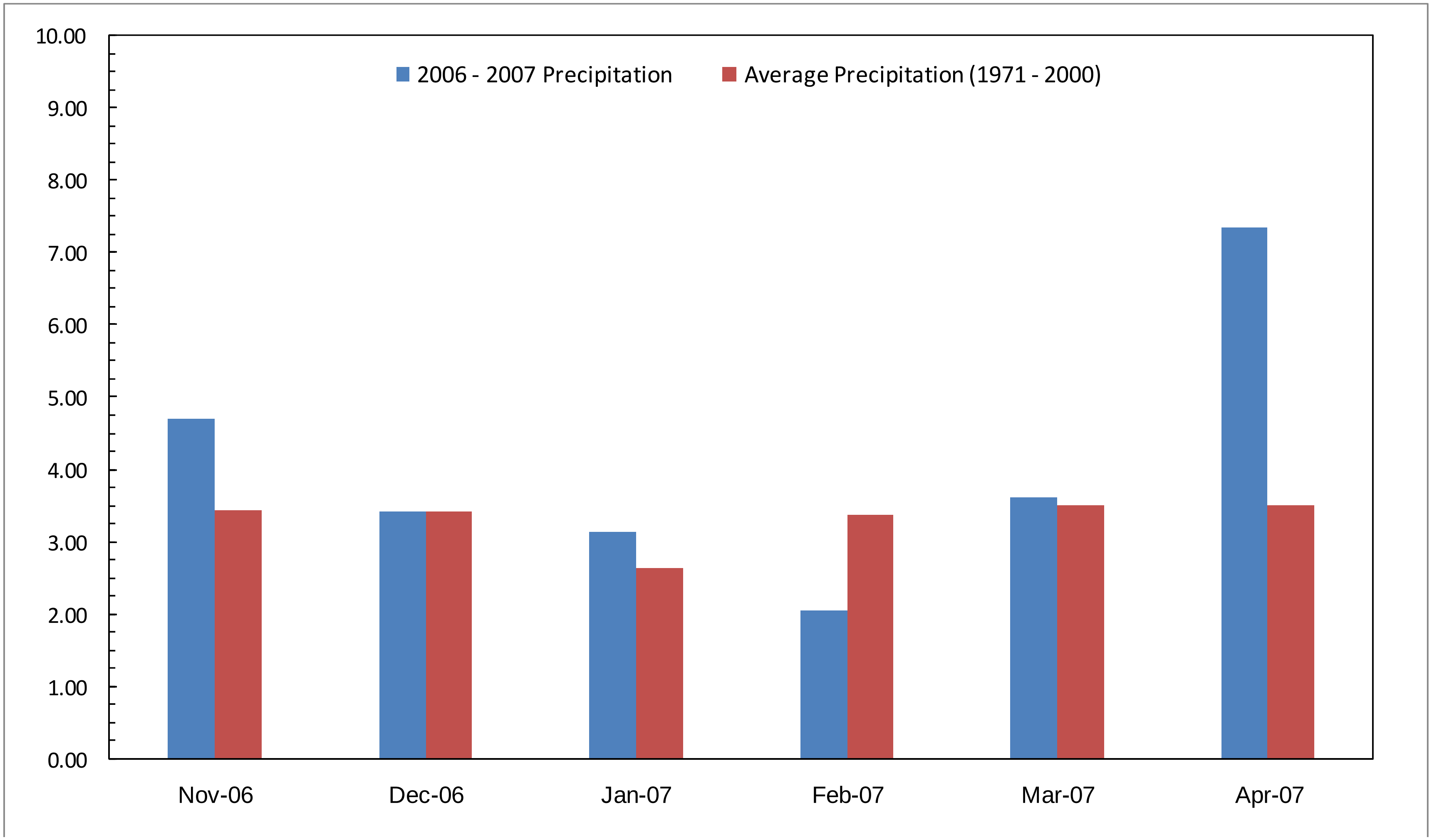


Figure A-9: New Hampshire Monthly Precipitation for Winter and Spring 2006–2007

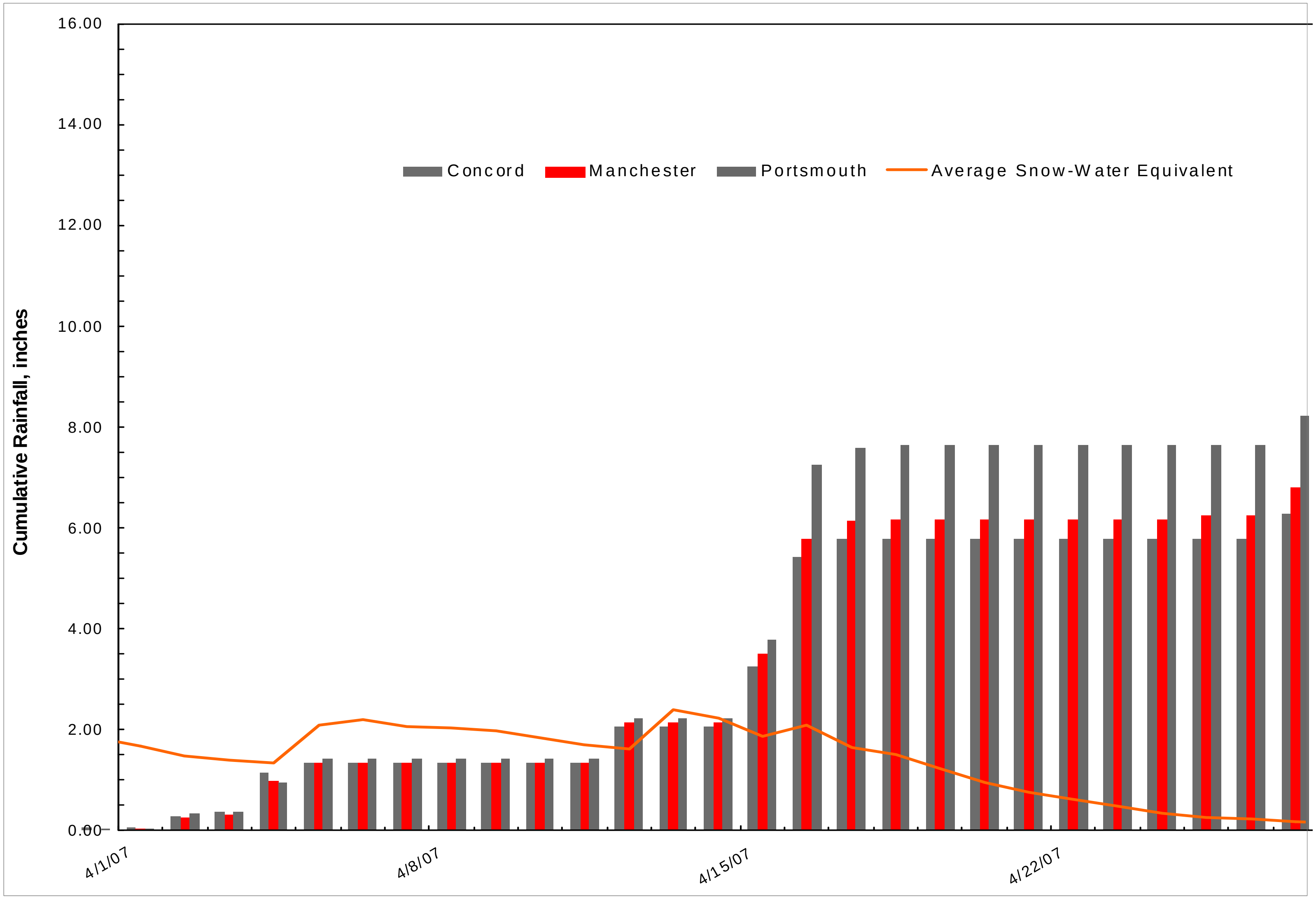


Figure A-10: Cumulative Daily Rainfall Totals, April 2007

A-3.1.2 Antecedent Stream Flow Conditions

In order to characterize the stream flow conditions prior to the April 2007 flood event, daily mean discharges for March and April 2007 were compared to long-term median (or 50th percentile) daily discharges at USGS stream gages on the Salmon Falls, Oyster, Lamprey, Contoocook, Soucook, and Souhegan Rivers (see Figure A-5). In general, this comparison indicates that daily discharges on the Salmon Falls River were less than the long-term median daily discharges for all of March and early April 2007; although small rises were noted, the daily discharges on the Salmon Falls River did not exceed the median discharge values until the onset of major flooding on April 15, 2007. Daily discharges on the Oyster, Lamprey, Contoocook, Soucook, and Souhegan Rivers were for the most part equal to or in excess of the median discharge values throughout the period prior to the onset of major flooding, with the exception of a few short periods of recession following some small rises.

A further review of median discharge values for several long-term stream gages (see Figure A-6) show that, in general, median flow values follow a fairly regular flow pattern such that median flow values typically increase through winter until reaching yearly maximum values in April and then begin a recession that lasts throughout spring and summer. As such, the April 2007 flooding occurred during the typical peak period of maximum flows.

A-3.2 Precipitation

The precipitation that produced the April 2007 flooding began on April 15 as accumulating snow across most of New Hampshire. The snowfall had changed over to heavy rainfall by the afternoon and evening of April 15 and continued as rain throughout the 16th before ending in most areas on the April 17. Rainfall distribution and total amounts for April 16th, the heaviest day of rainfall, are shown in Figure A-11. Total rainfall amounts of more than 5 inches in the vicinity of Portsmouth, along the New Hampshire seacoast, and approximately 4 inches of rain in the vicinity of Concord and Manchester, in the south-central part of the State. The most intense rainfall occurred on April 15-16, with more than 90 percent of the 3-day storm total falling on those 2 days. In comparison to computed estimates of rainfall frequency (NOAA TP-40), the April 16 total rainfall amounts for the coastal areas are approximately equal to the 24-hour, 5-year recurrence interval values, while in the south central areas of the State, the rainfall amounts were approximately equal to the 24-hour, 2-year amounts; the 2-day (April 15–16) total rainfall amounts along the seacoast during the storm event exceed the 2-day, 10-year recurrence interval values (see Table A-5). As noted in previous section, significant precipitation in the form of 12 inches of snow fell during the first 14 days of April. This snowfall provided as much as 2 inches additional snow-water equivalent during the period of heaviest rainfall. The heavy rain and snowfall received in April 2007 resulted in April 2007 being the second wettest April in since 1895 and the ninth snowiest April since 1868.

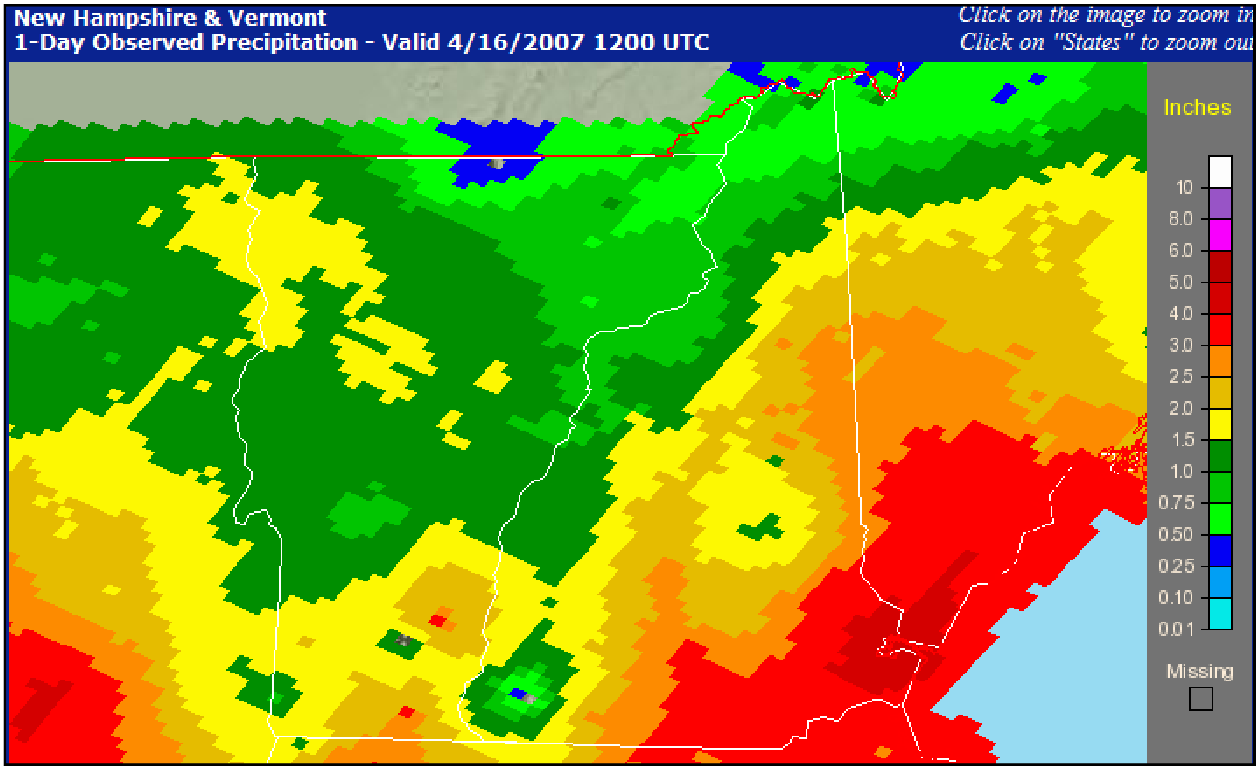


Figure A-11: Radar Rainfall Estimates for April 16, 2007 (NWS 2008i)

The rainfall on April 16 was greatest in southeastern New Hampshire, along the Atlantic Coast (see Figure A-11); in the coastal drainage basins of the Lamprey, Oyster, and Salmon Falls River. However, there were areas of heavier rain in the south-central part of the State in the Souhegan River Basin, and upper reaches of the Contoocook and Piscataquog River Basin. These areas of heaviest rainfall coincide with the areas of highest recurrence interval flooding (see Figure A-11).

Table A-6: 24-Hour and 2-Day Rainfall Amounts for April 2007 Flood (National Weather Service Precipitation Analysis 2008)

Location	April 16, 2007 Rainfall Total (inches)	24-hour Rainfall			April 15–16, 2007 Rainfall Total (inches)	2-Day Rainfall		
		2-year	5-year	10-year		2-year	5-year	10-year
Portsmouth	3.5	2.9	3.6	4.3	5.0	3.5	4.5	5.0
Manchester	2.3				3.6			
Concord	2.1				3.3			

A-3.3 Flood Discharges

Peak discharges with recurrence intervals of flooding equal to or in excess of 50 years were observed at 10 stream gages; at 7 of these gages the recurrence interval of flooding was equal to or greater than 100 years (USGS, 2007). Record peak discharges were set at six stream gages with more than 10 years of record on the Cocheco, Contoocook, Oyster, Salmon Falls, South Branch Piscataquog, and Suncook River; on the Cocheco, Salmon Falls, and South Branch Piscataquog Rivers, the record peak discharge superseded a record peak set during the May 2006 flood (see Table A-1).

Flooding with recurrence interval of 500 years or greater was observed at the Taylor River at Old Stage Road near Hampton (01073838) along the seacoast. In addition, the recurrence interval of flooding at South Branch Piscataquog River near Goffstown (1091000) exceeded 500 years at this long term gaging station. Recurrence intervals between 100 and 500 years were observed in several small coastal drainage areas along the New Hampshire seacoast as well as on the Suncook River and the Oyster River. Flooding with recurrence intervals between 50 and 100 years was observed on the Souhegan and Lamprey rivers and on the Warner River, a tributary to the Contoocook River.

Runoff, in inches over the upstream drainage area, was computed for seven USGS stream gages (see Table A-6). Computed runoff at these seven gages ranged between a maximum of 6.2 inches to a minimum of 4.4 inches, with an average values of 5.5 inches.

Hydrographs (or plots of river gage height versus time), along with rainfall vs. time plots of the May 2006 and April 2007 flooding on the Piscataquog and Souhegan were examined). In general, comparison of the observed rainfall patterns at the two locations indicate that although the May 2006 rain event was longer in duration and resulted in more total rainfall, the rainfall for the April 2007 was more intense. This comparison is evident in the more rapid initial rise observed in the April 2007 hydrographs for both the Piscataquog and Souhegan Rivers. In addition, the May 2006 hydrographs are somewhat wider than those observed for the April 2007 event, indicated an overall larger amount of direct runoff.

Table A-7: Peak Discharges, Estimated Return Periods, and Other Characteristics for Selected Stream Gages Affected by May 2006 and April 2007 Flooding

n.d., not determined n/a, not available

Gage Station Number	Gage Station Name	Period of Record	Return Period Discharge (cfs)				May 2006 Flood			April 2007 Flood			Maximum Peak of Record
			10-year	50-year	100-year	500-year	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	
01072100	Salmon Falls River at Milton, NH	1968–2007	3,190	5,590	6,920	10,900	5,450	10–50	5.0	5,500	10–50	5.5	April 2007
01072800	Cocheco River near Rochester, NH	1995–2007	5,350	9,920	12,500	20,300	5,550	10–50	n.d.	7,240	10–50	n.d.	April 2007
01072870	Isinglass R at Rochester Neck Rd near Dover, NH (see note 1)	2003–2007	2,920	4,680	5,620	8,230	4,370	10–50	n.d.	4,540	10–50	n.d.	n/a
01072880	Cocheco River at Spaulding Turnpike at Dover, NH (see note 1)	1992–1996	6,040	9,300	11,100	15,800	10,800	50–100	n.d.	n.d.	n.d.	n.d.	n/a
01073000	Oyster River near Durham, NH	1934–2007	633	1,020	1,220	1,750	873	10–50	7.8	1,320	100–500	6.1	April 2007
01073460	North River above NH125 near Lee, NH (see note 1)	2004–2006	1,520	2,500	3,020	4,520	3,790	100–500	n.d.	n.d.	n.d.	n.d.	n/a
01073500	Lamprey River near Newmarket, NH	1934–2007	4,660	7,760	9,400	14,100	8,970	50–100	7.3	8,450	50–100	5.7	May 2006
01073587	Exeter River at Haigh Road near Brentwood, NH	1996–2007	3,450	6,690	8,530	14,100	3,450	10–50	n.d.	2,840	2–10	n.d.	May 2006
01073600	Dudley Brook near Exeter, NH	1962–1985	379	646	791	1,210	660	50–100	n.d.	470	10–50	n.d.	May 2006

Gage Station Number	Gage Station Name	Period of Record	Return Period Discharge (cfs)				May 2006 Flood			April 2007 Flood			Maximum Peak of Record
			10-year	50-year	100-year	500-year	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	
01073785	Winnicut River at Greenland near Portsmouth, NH (see note 1)	2002–2007	406	637	758	1,100	1,450	> 500	n.d.	1,030	100–500	n.d.	n/a
01073810	Berrys Brook at Sagamore Road near Portsmouth, NH (see note 1)	2003–2004	136	213	253	368	505	> 500	n.d.	278	100–500	n.d.	n/a
01073822	Little River at Woodland Road near Hampton, NH (see note 1)	2003–2006	202	329	395	590	774	> 500	n.d.	n.d.	n.d.	n.d.	n/a
01073838	Taylor River at Old Stage Road near Hampton, NH (see note 1)	2004	172	257	302	424	n.d.	n.d.	n.d.	436	> 500	n.d.	n.d.
01077510	Newfound River below Newfound Lake near Bristol, NH	1994–2007	2,720	3,500	3,780	4,350	3,500	10–50	n.d.	1,690	2–10	n.d.	May 2006
01082000	Contoocook River at Peterborough, NH	1946–2007	2,250	3,130	3,530	4,480	1,470	2–10	3.8	4,110	100–500	5.8	April 2007
01085000	Contoocook R near Henniker, NH	1938, 1940–1977, 1989–2007	9,240	14,300	16,800	23,900	10,400	10–50	n.d.	13,000	10–50	n.d.	September 1938
01085500	Contoocook R Below Hopkinton Dam at W Hopkinton, NH (see note 2)	1964–2007	6,070	6,880	7,150	7,630	5,460	2–10	n.d.	5,370	2–10	n.d.	April 1987
01086000	Warner River at Davisville, NH	1940–1978, 1999–2007	4,260	6,550	7,660	10,700	8,640	100–500	n.d.	6,910	50–100	n.d.	May 2006
01089000	Soucook River near Concord, NH	1952–1987	2,560	4,030	4,760	6,750	4,790	100–500	n.d.	3,500	10–50	n.d.	May 2006

Gage Station Number	Gage Station Name	Period of Record	Return Period Discharge (cfs)				May 2006 Flood			April 2007 Flood			Maximum Peak of Record
			10-year	50-year	100-year	500-year	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	Peak Flow (cfs)	Return Period (years)	Runoff (inches)	
01089100	Soucook River at Pembroke Road near Concord, NH	1989–2007	2,730	4,300	5,080	7,200	5,110	100–500	6.7	3,730	10–50	4.4	May 2006
01089500	Suncook River at North Chichester, NH	1919–1920, 1922–1927, 1929–1970, 2007	5,300	9,930	12,700	21,700	7,600	10–50	n.d.	10,600	100–500	n.d.	April 2007
01090800	Piscataquog River below Everett Dam near East Weare, NH (see note 2)	1963–2007	1,580	1,910	2,010	2,220	1,540	2–10	n.d.	1,600	10–50	n.d.	June 1984
01091000	South Branch Piscataquog River near Goffstown	1941–1978	3,990	5,930	6,830	9,100	7,180	100–500	n.d.	9,700	> 500	n.d.	April 2007
01091500	Piscataquog River near Goffstown (see note 2)	1936, 1938, 1940–1978, 1983–2007	7,090	11,800	14,300	21,100	10,100	10–50	n.d.	11,200	10–50	n.d.	September 1938
01092000	Merrimack R near Goffs Falls Below Manchester, NH (see note 2)	1936–2007	52,900	86,300	105,000	163,000	74,700	10–50	6.8	59,700	10–50	4.9	March 1936
01094000	Souhegan River at Merrimack, NH	1910–1976, 1980, 1982–2007	6,370	10,400	12,600	18,800	6,140	2–10	5.3	10,500	50–100	6.2	March 1936
01141800	Mink Brook near Etna, NH	1963–1988	486	810	973	1,420	870	50–100	n.d.	n.d.	n.d.	n.d.	May 2006

Notes: (1) Some of the gages in this table have relatively short records. The peak discharge estimates for these gages with short records were computed based on regional regression equations, not statistical analysis of the gage data.

(2) Flood discharges are affected by upstream flood control works.

Appendix B

Description of Dams and Typical Operations: Salmon Falls, Suncook, and Piscataquog River Basins

Figures

Tables

Channel Capacity: Maximum flow through a river or man made channel without reaching damaging stages. Often expressed as 'cfs' (cubic feet per second).

Storage Capacity: Volume of water a lake or reservoir holds at a certain elevation.

Normal Pool Elevation: Typical water elevation of a lake or reservoir. This value might change seasonally.

Winter Drawdown: Difference between the summer normal pool elevation and the winter normal pool elevation.

Spillway: A structure used to provide for the release of flood flows from a dam into a river. Spillways pass flood flows so water does not overtop and damage or destroy a dam.

Stoplog: A hydraulic engineering control element used in floodgates to adjust the water level and/or flow rate in a river, canal, or reservoir. Stoplogs are typically long, rectangular timber beams or boards that are placed on top of each other and dropped into premade slots inside a dam weir (the "stoplog bay"). Placing more stoplogs in a stoplog bay increases the pool elevation of the lake or reservoir and decreases the releases.

Flashboards: Bulkheads placed on the crest or top of a channel wall or control structure. Flashboards are designed to break and wash away under high flow conditions ("to operate") and thus to provide additional storage while permitting large flows to pass a dam at lower elevations. In contrast, stoplogs are intended to be reused.

Obermeyer Gate: The OBERMEYER Spillway Gate system is most simply described as a row of steel gate panels supported on their downstream side by inflatable air bladders. By controlling the pressure in the bladders, the pond elevation maintained by the gates can be adjusted within the system control range (full inflation to full deflation) and accurately maintained at user-selected set-points. [from http://www.obermeyerhydro.com/info.htm].

Upstream Flooding: Flooding occurring upstream of a dam site due to high reservoir or lake pool elevation.

Downstream Flooding: Flooding occurring downstream of a dam site. Releases from the dam in certain cases can contribute to downstream flooding.

Sub-basin: Area draining into a lake or river above a certain point.

Precipitation: Rainfall or snowfall onto an area, typical expressed as depth of water over an area.

Excess Precipitation: Precipitation not infiltrating into the ground.

Mean Areal Precipitation (MAP): Assumed mean precipitation over an area, typically a river sub-basin. It is typically estimated from observation at climate sites in the area.

Mean Areal Temperature (MAT): Assumed mean temperature over an area, typically a river sub-basin. It is typically estimated from observation at climate sites in the area.

Snow Water Equivalent: Volume of water (expressed as depth of water over an area) that is stored in snow.

Runoff: Flow of water on or just below the ground caused by excess precipitation.

Snow Model: A computer model simulating the accumulation and melting of snow over an area. The most important inputs to a snow model are typically MAT and MAP.

Rainfall-Runoff Model: A computer model simulating the effects of rainfall (or snowmelt) onto an area and estimates the resulting runoff into a river or lake.

B-1.0 INTRODUCTION

This section describes the lakes and reservoirs that were investigated as part of this study in the Piscataquog, Salmon Falls, and Suncook river basins. It introduces the observed data available for the May 2006 and April 2007 flood events, presents the results of computer model simulations of these events, and explains the dam operations as provided by Hampshire’s Department of Environmental Services New Hampshire Department of Environmental Service (NHDES) Dam Bureau staff. Subsequently, the effects of alternative dam operations are assessed.

B-1.1 Available Data

The climate data used in this study are temperature and precipitation, available primarily from the Unites States Geological Survey (USGS), the United States Army Corps of Engineers (USACE), the National Weather Service (NWS), and a network of climate sites operated by the NHDES. These data are typically recorded every 15 minutes or every hour at climate sites in the region, and provide a good representation of the weather development during the May 2006 and April 2007 flood events.

Additional precipitation data were estimated through radar observations and provided by the NWS.

Observations of streamflow data were obtained primarily from the USGS, but also from the USACE and the NHDES data collection network. Observations of lake elevations (“pool elevation”) were supplied by the USACE, the NHDES, and operators of private dams. For most NHDES dams, pool elevations are read manually when a NHDES dam operator is on site. This is typically performed once a week, but might occur several times a day during flood conditions. These pool observations are usually recorded by day, and do not indicate the exact hour of the observation. In this study, it assumed these observations occurred at noon, if not noted otherwise.

The NHDES keeps a log of the activities of its dam operators at its dams and thus provides a history of performed operations. The NHDES dam operation logs typically note the current pool elevation, and changes to gates (opening or closing) and stoplogs (adding or removing), recorded by date. The dam operators often note special conditions at the dam site, such as debris or ice on the lake. The NHDES provided these dam operation logs for use in this study. Operations at private dams were provided by the owners and vary from detailed observations (every 5 minutes) to qualitative descriptions only.

B-1.2 Model Simulations

The initial model simulations presented in this section aim at reproducing the dam operations and the resulting pool elevations as they actually happened during the May 2006 and April 2007 flood events. As such, the simulated pool elevations, reservoir releases, and streamflow try to match observations where available.

In doing so, the simulations provide an estimate of inflows into the lakes and rivers investigated. These inflows can be used to simulate effects of alternative dam operations.

This study employs two different types of models for the simulations. Computer models employed in NHDES’ forecast system were used to simulate the conditions on the Salmon Falls River, the Suncook River, and the Piscataquog River. The Hydrologic Engineering Center’s Hydrologic Modeling System (HEC-HMS) was used to simulate the conditions in the Souhegan basin, where no NHDES model exists. This appendix presents results for those dams modeled with the NHDES system. Appendix C presents results for the dams in the Souhegan basin.

The models in the NHDES forecast system are similar to those used by the NWS to predict river flows at the NWS River Forecast Centers (RFCs). Mean areal temperature and precipitation are used as input to the “SNOW-17” snow model, which simulates the accumulation and the melt of snow in the area. The output from this model consists of snow melt (when snow on the ground is melting) and rainfall (when no snow is present), expressed as depth of water in inches over the simulated area. This output is fed into the Sacramento Soil Moisture Accounting Model (SAC-SMA), which transforms the snowmelt and rainfall into runoff into a lake or river reach. The estimated runoff depends on the amount of snowmelt and rainfall and the moisture content of the soil (e.g., a wetter soil has higher moisture content and produces more runoff than dry soil). The NHDES forecast system also includes reservoir simulation models, which estimate lake elevations based on inflow to the lake and releases from the lake. The releases are determined using reported opening heights of gates at the dam, number of stoplogs in the bays, the existence of flashboards, and releases through turbines for hydropower generation.

As part of the initial model simulations, mean areal temperature and precipitation were estimated from climate observations in the area. In general, there were only few climate sites reporting in the area and the estimated mean areal temperature and precipitation are at times questionable. These data sets were therefore adjusted as needed to provide adequate and correctly timed snowmelt and rainfall volumes to compute realistic inflows into the reservoir models.

Once the computer models were configured to simulate the actual dam operations and observed pool elevations sufficiently, alternative dam operations were modeled to assess their impact. These ‘scenarios’ also will be described in this Appendix.

B-2.0 SALMON FALLS RIVER

The return period of the April 2007 flood event on the Salmon Falls River was about 75 years, according to observations at Milton Three Ponds. The flows downstream of Milton Three Ponds for the May 2006 and April 2007 event are shown in Figure 2-1. The figure includes the FEMA 10, 50, 100, and 500 year flood flows.

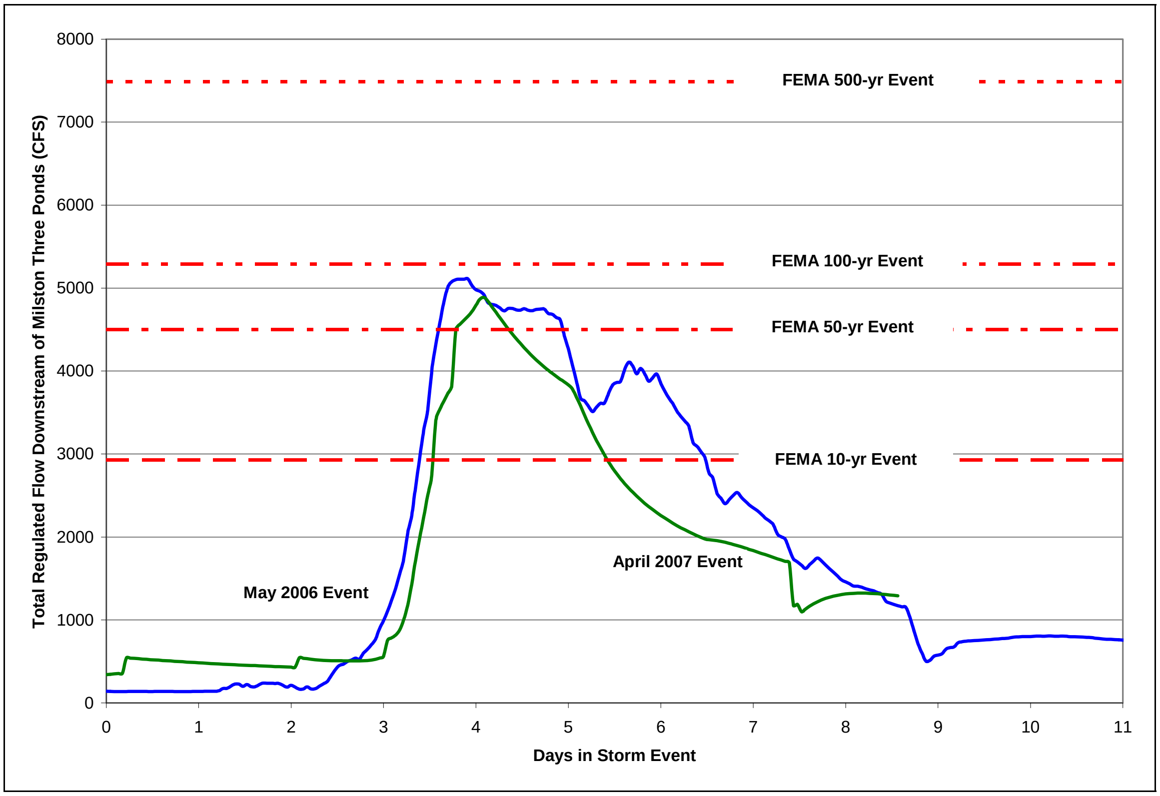


Figure 2-1: Salmon Falls - Comparison of May 2006 and April 2007 Events and FEMA Flood Levels

Figure 2-2 depicts the dams investigated in the Salmon Falls River basin.

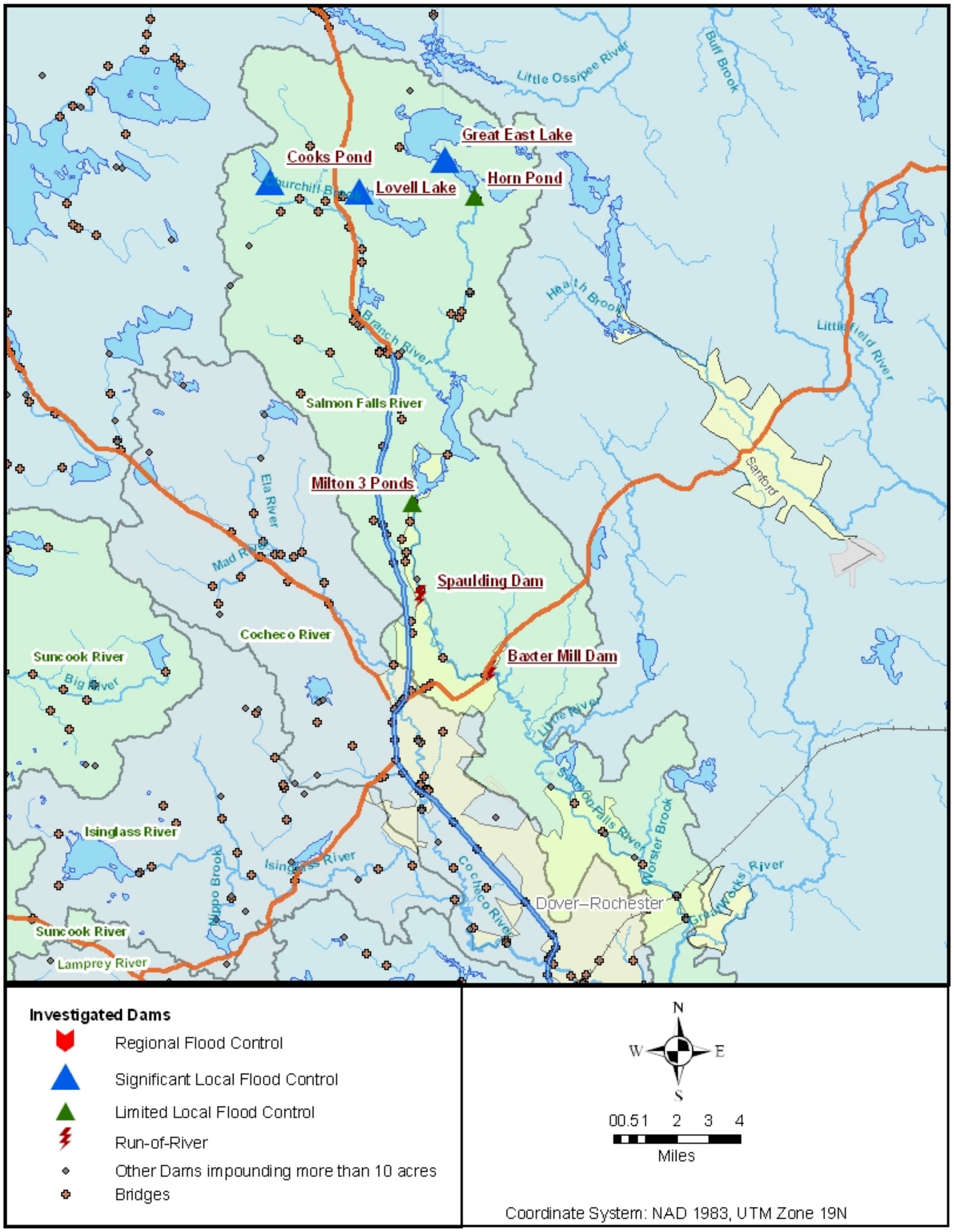


Figure 2-2: Dams Investigated in the Salmon Falls River Basin

B-2.1 Great East Lake (NHDES# 241.14)

B-2.1.1 General Description

Great East Lake is located in the headwaters of the Salmon Falls River, to the east of the town of Wakefield at the New Hampshire-Maine border. Most of the lakeshore is developed. The lake has a storage capacity of about 19,600 acre-feet at normal levels, and up to 27,700 acre-feet at its maximum elevation. Between those levels, Great East Lake can store about 9.7 inches of runoff into the lake, providing significant storage capacity and local flood control capabilities.

The pool elevation can be controlled by NHDES staff at a small dam structure at the southeastern edge of the lake near Canal Road. This is typically done by manual operation of a gate, or, during the winter months, by using stoplogs located just upstream of the gate.

The typical summer lake elevation is 574.25 feet, which corresponds to the elevation of the spillway. The lake is usually drawn down by 3 feet starting in October. Refill occurs in general during the spring with a goal of reaching the summer lake elevation once ice is melted. It requires approximately 6.1 inches of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view of Great East Lake Dam is shown in Figure 2-3.

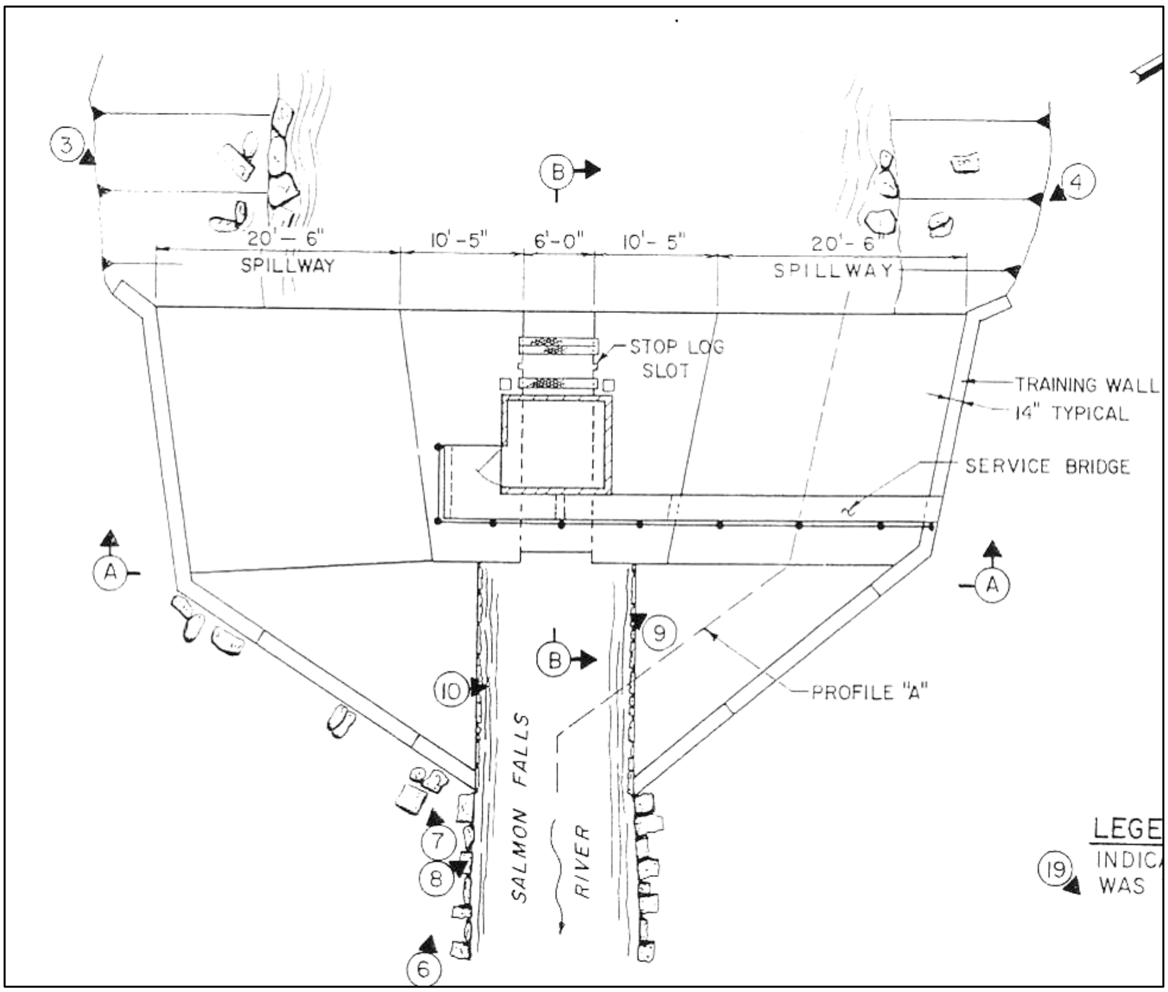


Figure 2-3: Plan View of Great East Lake

B-2.1.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. They consist of observations of the pool elevations as well as stoplog and gate settings as noted by dam operators during visits to the site. The pool elevation is recorded relative to the summer lake elevation of 574.25 feet. Table 2-1 and Table 2-2 list the pool elevation and the dam operations performed by the NHDES at Great East Lake.

Table 2-1: Great East Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY	GATE	COMMENTS	DAM OPERATOR
5/4/2006	-0.80	15 LOGS IN	30" OPEN	MINUS ONE FOOT ON LOGS IN	CT
5/13/2006	-0.5	14 LOGS IN	30" OPEN	PULLED ONE LOG	CT
5/14/2006	0.6	10 LOGS IN	30" OPEN	PULLED FOUR LOGS	CT/CL
5/15/2006	0.85	10 LOGS IN	30" OPEN		CL
5/16/2006	0.9	10 LOGS IN	30" OPEN		CL
5/17/2006	1	10 LOGS IN	30" OPEN		CL
5/22/2006	0.7	10 LOGS IN	36" OPEN	OPENED GATE TO 36"	CT/BH

Table 2-2: Great East Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY	GATE	COMMENTS	DAM OPERATOR
4/3/2007	-1.35	17 LOGS IN	48" OPEN	SET ONE LOG/ICE STILL ON LAKE	AS
4/10/2007	-0.9	17 LOGS IN	48" OPEN	LET RUN AS IS/ICE SOLID ON LAKE	CT
4/12/2007	-0.8	16 LOGS IN	48" OPEN	PULL ONE LOG .18 FLOW	CT
4/16/2007	0.2	16 LOGS IN	48" OPEN	LET RUN AS IS	CT
4/17/2007	1	16 LOGS IN	48" OPEN	LET RUN AS IS	CT
4/19/2007	1.1	13 LOGS IN	48" OPEN	PULLED THREE LOGS	CT
4/23/2007	0.7	13 LOGS IN	48" OPEN	LET RUN AS IS	PA

Ten days before the May 2006 storm, on May 4, the pool elevation was 0.8 foot below the spillway crest. At the onset of the storm, on May 13, the pool was 0.5 foot below the spillway crest. One stoplog was removed, increasing releases and slowing the rise in pool elevation during the event. The pool elevation overtopped the spillway crest by 0.6 foot on May 14, 2006, and remained high despite the removal of 4 additional stoplogs. The maximum recorded depth over the spillway was 1.0 foot on May 17, which corresponds to 2.0 feet below the top of the dam.

The lake was still refilling from the winter drawdown at the beginning of April 2007. The pool was 1.35 feet below the spillway on April 4, and 0.9 foot below on April 10. Snowmelt induced by the high temperatures and the rain event on April 12 filled the lake, which crested the spillway by 0.2 foot on April 16. The pool rose rapidly in response to the April 16 event, reaching a maximum of 1.1 feet over the spillway crest on April 19, at which time three stoplogs were removed to increase the releases and lower the pool elevation.

The simulation for April 2007 is depicted in Figure 2-4 and tracks the observed pool elevations reasonably well. This is shown by the red line for simulated pool elevations and the gray dots for observations.

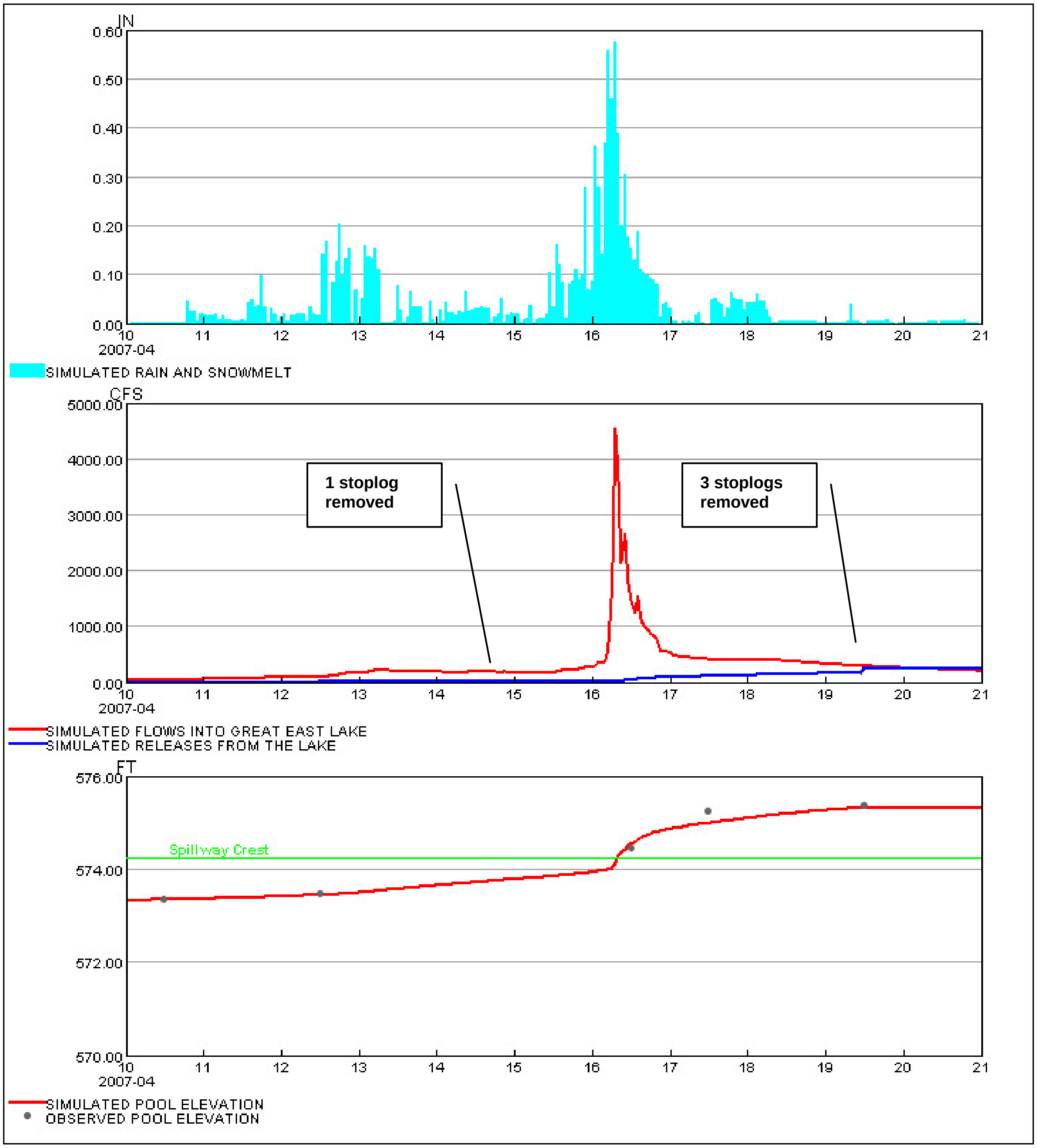


Figure 2-4: Great East Lake Simulation Results for the April 2007 Flood Event

Great East Lake has a large storage capacity beyond its full pool elevation and stored most of the runoff from the 2006 and 2007 events. As a result, the releases from the lake were significantly smaller in magnitude than the inflows, providing considerable downstream flood control.

In 2007, the increase of releases on April 19 was primarily aimed at preventing a further rise of lake levels and possible upstream flooding. At the same time, the releases were modulated as not to exceed the limited capacity of the downstream channel.

Even though the lake filled significantly above the normal pool elevation in April 2007, no complaints regarding upstream flooding were received by the NHDES.

B-2.1.3 Alternative Operations

A simulation of Great East Lake with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 2-5. All other operations were assumed to be unchanged. Holding the winter pool elevation into April would have caused more water to be captured during the event, allowing Great East Lake to release lower flows (less than 100 versus more than 300 cfs of peak flow).

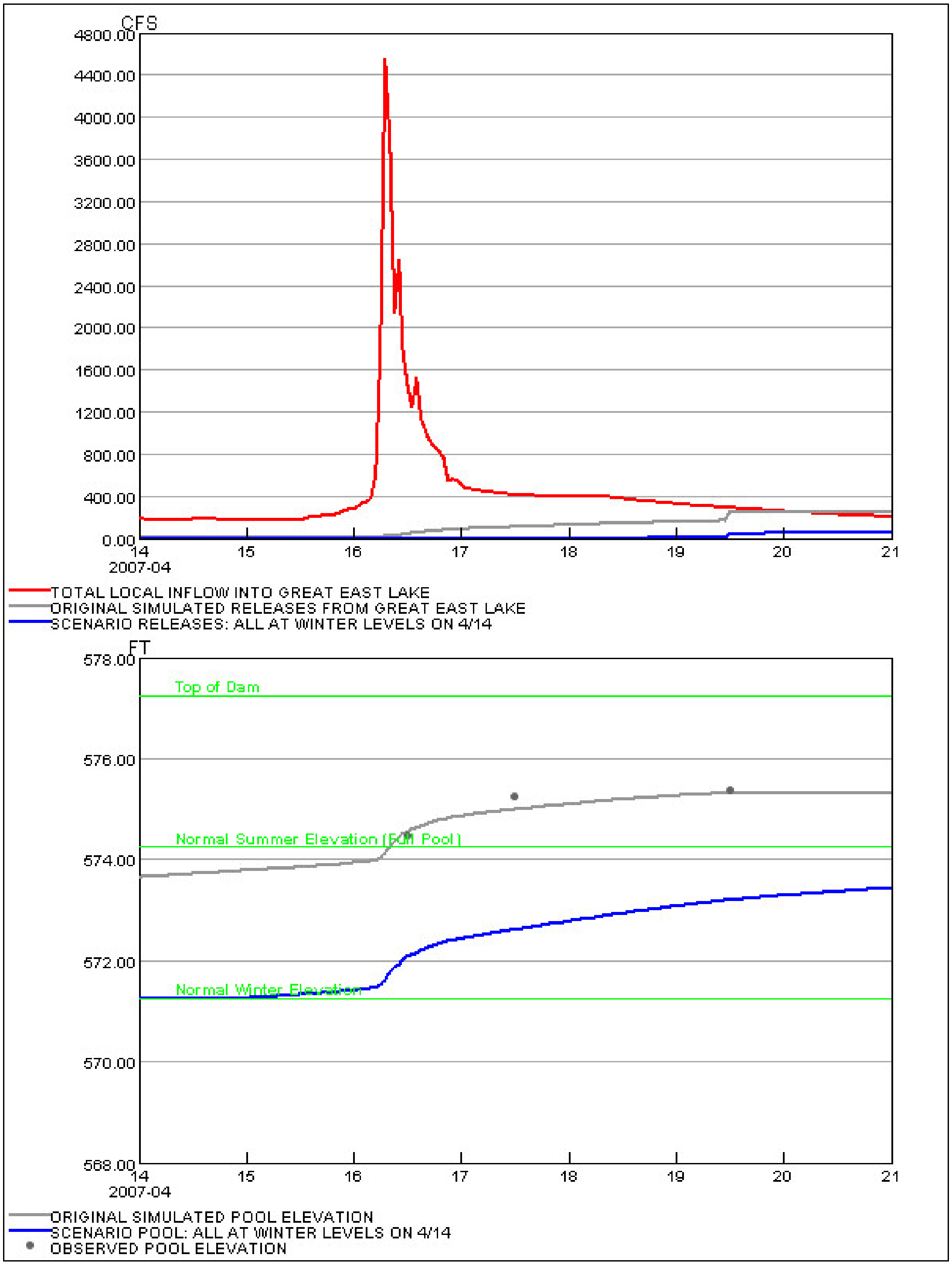


Figure 2-5: Great East Lake Alternative Operations - Starting at Minimum Pool on April 14th

B-2.2 Horn Pond (NHDES# 241.15)

B-2.2.1 General Description

Horn Pond is located on the Salmon Falls River just downstream of Great East Lake. Development seems concentrated along Camp Road and New Bridge Road on the eastern and western shore.

Inflows into Horn Pond are greatly affected by the upstream operations at Great East Lake Dam. Horn Pond is significantly smaller than Great East Lake, with a storage capacity of about 2,750 acre-feet at normal levels, and up to 3,300 acre-feet at its maximum elevation. Between those levels, Horn Pond can store about 0.5 inch of runoff into the lake, providing by itself little storage capacity and limited flood control capabilities.

Pool elevation at Horn Pond can be controlled by NHDES staff at a dam structure at the southern end of the lake near Route 109 / Lovell Lake Road. This is typically done by adding or removing stoplogs from 11 bays. The dam has no spillway.

The typical summer lake elevation is 554.32 feet, which corresponds to the elevation of the topmost stoplogs. The lake is usually drawn down by 1.5 feet after Columbus Day. Refill occurs in general during the spring after all ice is melted. It requires only 0.25 inch of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view of Horn Pond Dam is shown in Figure 2-6.

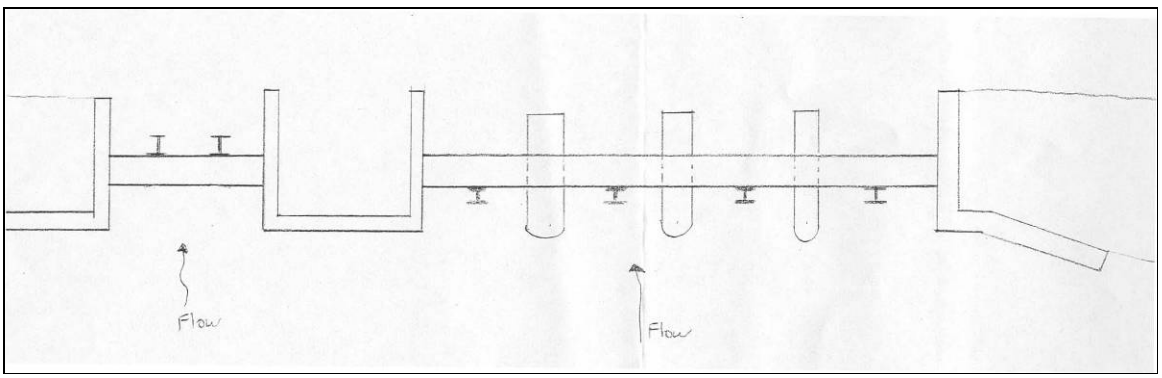


Figure 2-6: Plan View of Horn Pond Dam

B-2.2.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. They consist of observations of the lake pool as well as stoplog settings as noted by dam operators during visits to the site. The pool elevation is recorded relative to the ‘normal’ summer lake elevation of 554.32 feet, the elevation of the topmost stoplog when all stoplogs are in place. Table 2-3 and Table 2-4 list the pool elevation and the dam operations performed by the NHDES at Horn Pond. Stoplog bays not listed are filled with logs and no operation occurred during the event.

Table 2-3: Horn Pond Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 7	LOG BAY 8	COMMENTS	INT
5/4/2006	-0.60			2 OUT	1 OUT			NOT MUCH RAIN	CT
5/13/2006	0	1 OUT	1OUT	3 OUT	3 OUT	2 OUT	1 OUT	PULLED 8 LOGS	CT
5/14/2006	0.45	1 OUT	4 OUT	3 OUT	3 OUT	2 OUT	1 OUT	PULLED 3 LOGS	CT/CL
5/15/2006	0.6	1 OUT	4 OUT	3 OUT	3 OUT	2 OUT	1 OUT		CL
5/16/2006	0.8	1 OUT	4 OUT	3 OUT	3 OUT	2 OUT	1 OUT		CL
5/17/2006	0.7	4 OUT	4 OUT	3 OUT	3 OUT	2 OUT	1 OUT	11 LOGS OUT ME. SIDE	CL
5/22/2006	0.5	4 OUT	4 OUT	3 OUT	3 OUT	2 OUT	1 OUT	LET RUN AS IS	CT/BH

Table 2-4: Horn Pond Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 5	COMMENTS	INT
4/3/2007	-1.1	2 OUT	3 OUT	2 OUT	3 OUT	2 OUT	LET RUN/ICE STILL ON POND	AS
4/10/2007	-1	2 OUT	2 OUT	2 OUT	3 OUT	2 OUT	SET ONE LOG ME. SIDE	CT
4/12/2007	-1	2 OUT	2 OUT	2 OUT	3 OUT	2 OUT	NO CHANGE	CT
4/16/2007	0.05	2 OUT	2 OUT	2 OUT	3 OUT	2 OUT	LET RUN	CT
4/17/2007	0.3	2 OUT	2 OUT	2 OUT	3 OUT	2 OUT	LET RUN	CT
4/18/2007	0.62	2 OUT	2 OUT	2 OUT	3 OUT	2 OUT	LET RUN	CT
4/19/2007	0.7	4 OUT	4 OUT	4 OUT	5 OUT	3 OUT	PULLED 9 LOGS	CT
4/23/2007	-0.05	4 OUT	4 OUT	4 OUT	5 OUT	3 OUT	LET RUN	PA

The pool was 0.6 foot below the normal pool elevation on May 4, 2006 rising to the normal pool elevation at the onset of the storm event on May 13. At this time, 11 stoplogs were removed. Releases increased, but the pool elevation continued to rise and overtopped all stoplogs on May 14. The maximum recorded depth over the stoplogs was 0.8 foot on May 16, which was 1.7 feet below the top of the dam. Three additional stoplogs were removed on May 17, and the pool elevation dropped.

The pool was 1.1 feet below the normal pool elevation on April 3, 2007, refilling from the winter drawdown level. Despite setting one stoplog in place, the pool remained steady and was 1.0 foot below normal pool elevation on April 12, just before the storm. The April 16 event rapidly raised the pool elevation, which increased the release and therefore prevented a significant rise above the normal pool elevation. The maximum of 0.7 foot over the normal pool elevation was reached on April 19, which was 1.8 feet below the top of the dam. At this time, nine stoplogs were removed and the pool began to fall.

The simulation for April 2007 is depicted in Figure 2-7 and tracks the observed pool elevations very well as shown by the red line for simulated pool elevations and the gray dots for observations.

In May 2006, the dam was operated to increase discharges by removing stoplogs just as the event started. The lake was still able to store large amounts of flood waters, but did neither overtop nor cause (reported) upstream flooding.

Even though Horn Pond has only limited storage capacity, it was operated successfully to store most of the inflow on April 15 and the early hours of April 16, 2007. This eased the potential for downstream flooding. The stored waters were released after the flood event on April 19, when 9 stoplogs were removed. During the event, the lake filled to 0.7 foot above the normal pool elevation—however, no upstream flooding was reported to the NHDES.

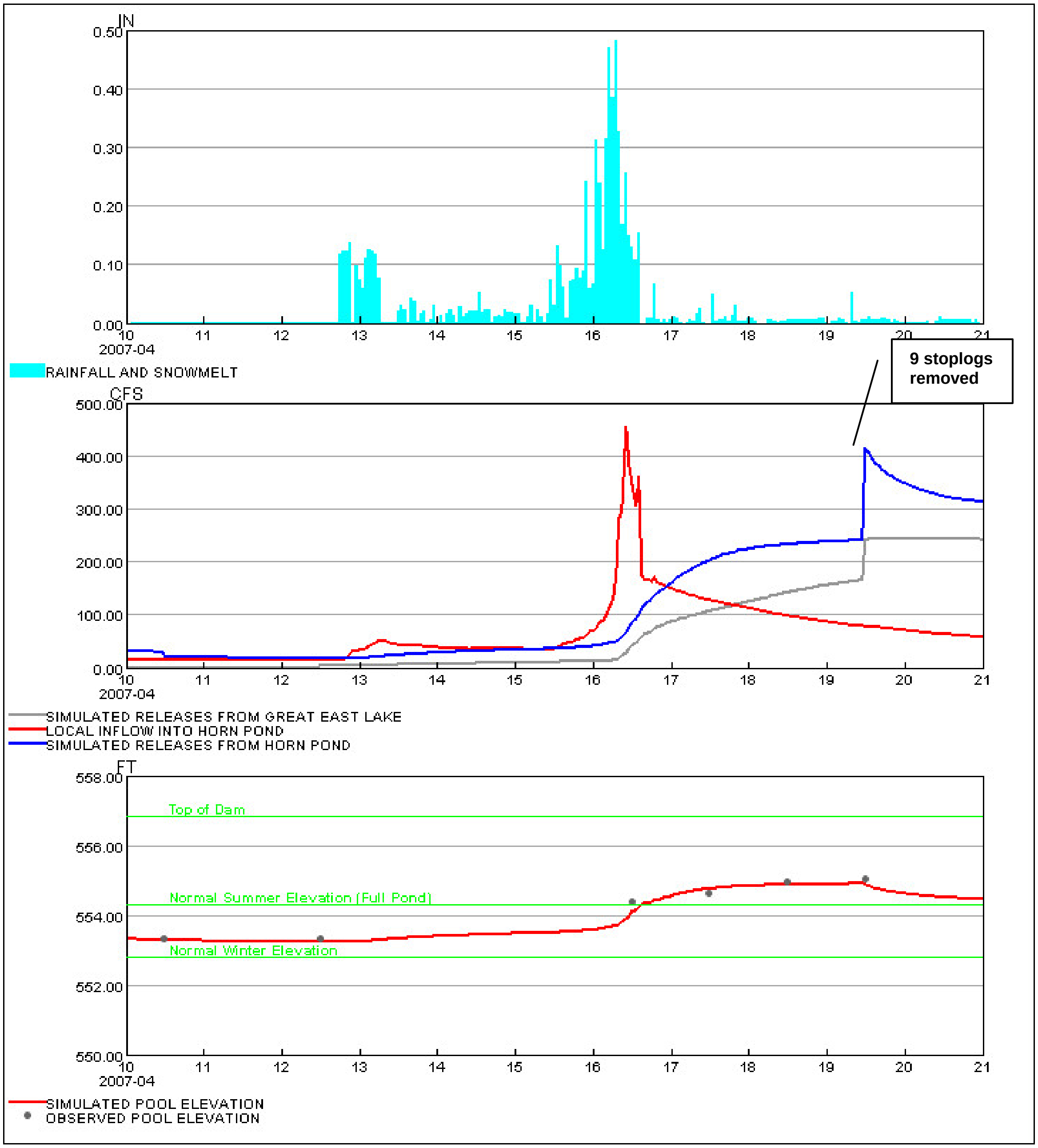


Figure 2-7: Horn Pond Simulation Results for the April 2007 Flood Event

B-2.2.3 Alternative Operations

A simulation of Horn Pond with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 2-8. All other operations were assumed to be unchanged. This scenario was designed assuming that the pool elevation at Great East Lake was also at the winter drawdown level on April 14.

Similarly to Great East Lake, holding the winter pool elevation into April would have caused more water to be captured during the event. With the initial pool at the winter level on April 14, the water level in the pond did not rise above the normal summer elevation during the flood event. Peak releases on April 16 were reduced from 160 cfs to 80 cfs.

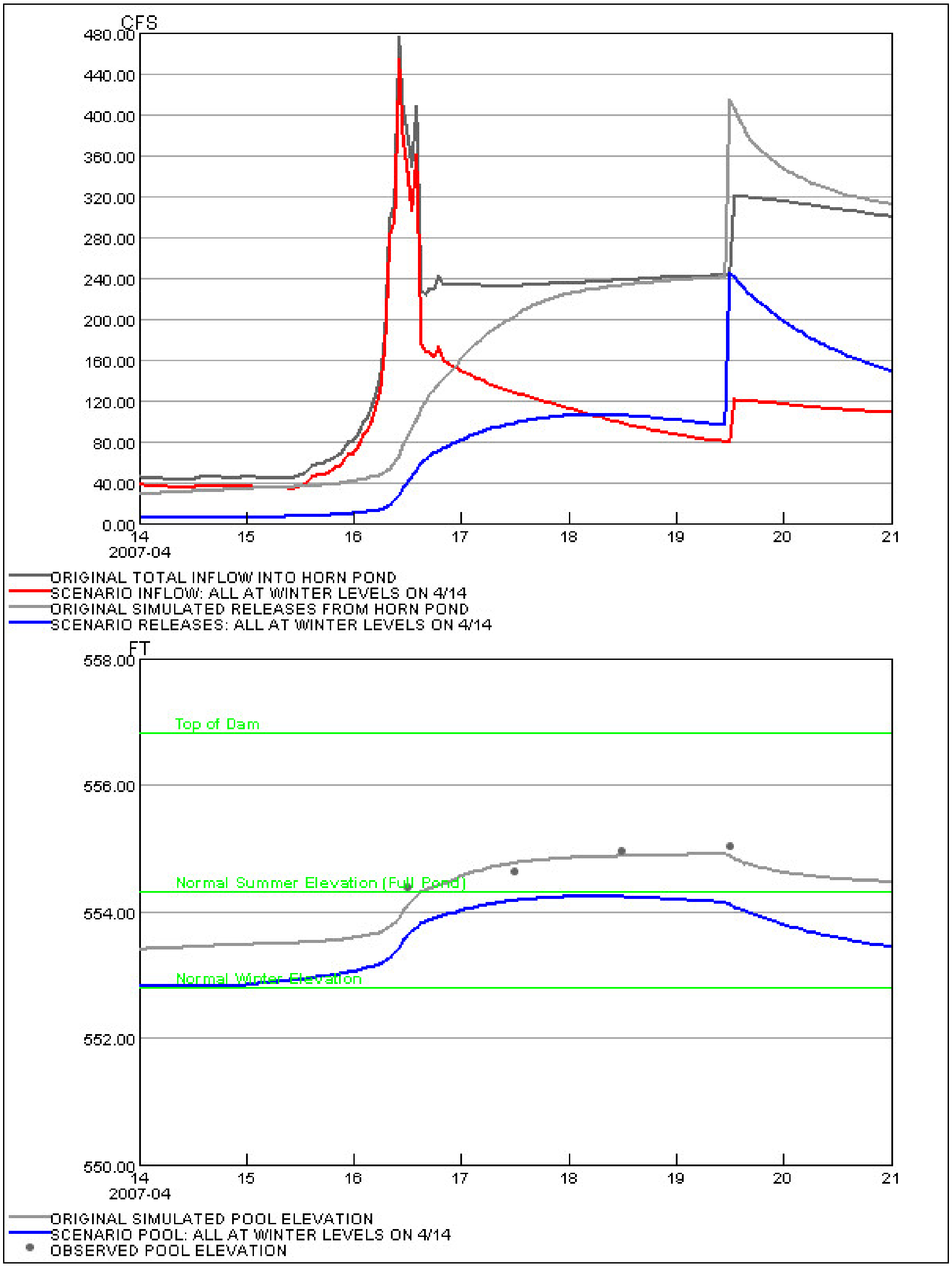


Figure 2-8: Horn Pond Alternative Operations - Starting at Minimum Pool on April 14th

B-2.3 Cooks Pond (AKA Kingswood Lake, NHDES# 032.02)

B-2.3.1 General Description

Cooks Pond, also called Kingswood Lake, is located off of the Salmon Falls River on Churchill Brook. Development is concentrated along the north-east shore off of Gov John Wentworth Highway. There is also some development on the opposite shore.

Cooks Pond has a relatively small amount of storage, with a capacity of about 594 acre-feet at its normal elevation, and 1,260 acre-feet at its maximum elevation. Between those levels, Cooks Pond can store approximately 7.2 inches of runoff into the lake. Although the storage is small, Cooks Pond can provide significant local flood control due to a small contributing area.

Pool elevations at Cooks Pond are controlled by NHDES staff at a dam structure at the southern end with three stoplog bays with ten stoplogs in each bay. The dam has no spillway.

The typical summer lake elevation is 654.0 feet, which corresponds to the elevation of the topmost stoplogs. The drawdown for the lake begins around Columbus Day. Stoplogs are slowly removed from the dam to try and achieve a four foot drawdown. In most years the full four foot drawdown is not met. Three to three and a half feet drawdown is the usual target level. Most of the stoplogs are replaced at the beginning of the year. The lake will slowly refill over the remaining winter months to reach full pond. It requires approximately 8.5 inches of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view of Cooks Pond Dam is shown in Figure 2-9.

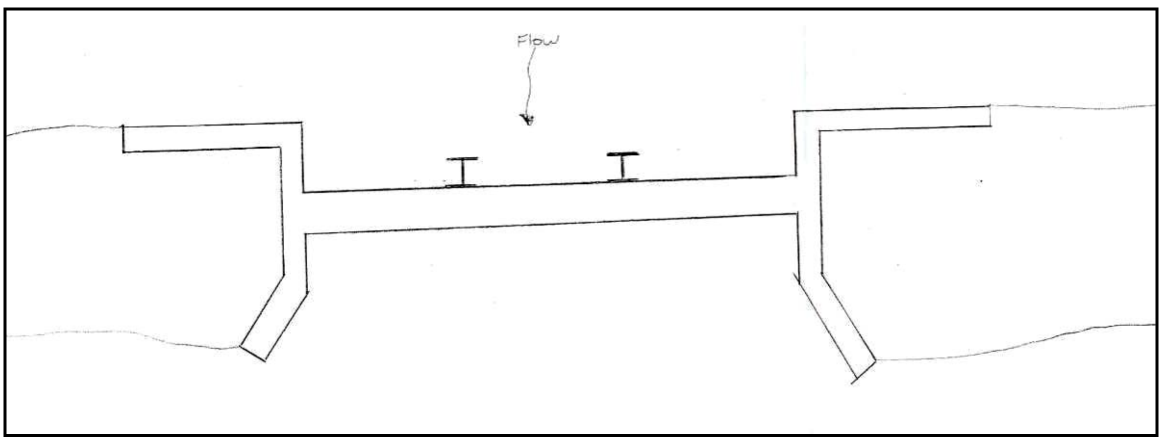


Figure 2-9: Plan View of Cooks Pond Dam

B-2.3.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 654.0 feet. Table 2-5 and Table 2-6 list the pool elevation and the dam operations performed by the NHDES at Cooks Pond.

Table 2-5: Cooks Pond Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	COMMENTS	INT
5/4/2006	0.15	0 OUT	0 OUT	0 OUT		CT
5/13/2006	0.45	1 OUT	1 OUT	0 OUT	PULLED 2 LOGS/FULL CULVERT	CT
5/14/2006	1.5	1 OUT	1 OUT	0 OUT	ROAD FLOODED D/S	CT/CL
5/15/2006	1.25	1 OUT	1 OUT	0 OUT		CL
5/22/2006	0.45	1 OUT	1 OUT	1 OUT	PULLED ONE LOG	CT/BH

Table 2-6: Cooks Pond Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	COMMENTS	INT
4/3/2007	-0.55	0 OUT	0 OUT	0 OUT	ALL LOGS IN/ICE TURNING BLACK	AS
4/10/2007	-0.25	0 OUT	0 OUT	0 OUT		CT
4/12/2007	1	1 OUT	1 OUT	0 OUT	PULLED 2 LOGS /CULVERT OK	CT
4/30/2007	0.1	0 OUT	0 OUT	0 OUT	SOMEONE PUT ALL LOGS BACK IN	AS

Ten days before the May 2006 event, all the stoplogs were in place and the pool was 0.15 foot above the top of the stoplogs. On May 13, as inflows increased, the pool elevation was 0.45 foot above the top of stoplog elevation and two stoplogs were removed. The maximum recorded pool elevation was 1.5 feet above the stoplog elevation and occurred on May 14. This was 1.25 feet below the top of the dam. One additional stoplog was removed on May 22. The pool was 0.45 foot below the top of stoplog elevation at this time.

As evident in Table 2-6, the NHDES did not operate this dam during the April 2007 flood event. All stoplogs were in place and the lake was 0.55 foot below the top of the stoplogs on April 3, and 0.25 below on April 10. The lake was slowly filling at the time and the pool elevation reached 1.0 over the top of stoplogs by April 17. This was the maximum recorded pool elevation, 1.75 feet below the top of the dam. Two stoplogs were pulled at this time. The next observed pool elevation was 0.1 foot above the top of stoplog elevation on April 30.

According to the NHDES, downstream flooding at a camp site and a private road is a concern during large rainfall events—therefore, no more stoplogs were removed during the April event. No upstream flooding was reported to the NHDES and the lake provided significant local flood control during both events.

Note that the dam operators noticed on April 30, 2007, that someone had replaced some stoplogs to keep the lake from draining faster. According to the NHDES local residents have in the past added or removed stoplogs themselves. The NHDES plans to lock down the stoplogs in the future.

The simulation for April 2007 is depicted in Figure 2-10 and tracks the observed pool elevations very well.

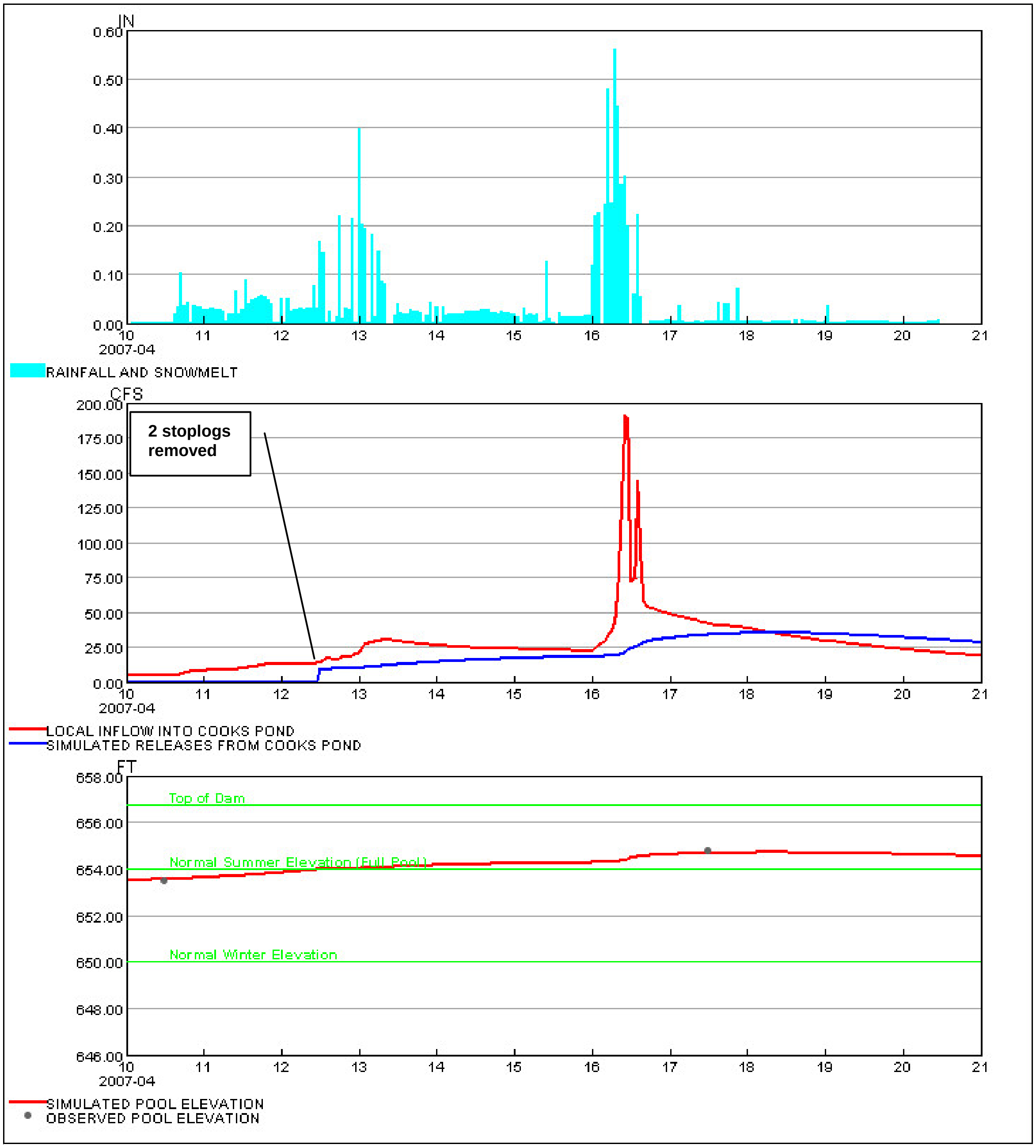


Figure 2-10: Cooks Pond Simulation Results for the April 2007 Flood Event

B-2.3.3 Alternative Operations

A simulation of Cooks Pond with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 2-11. All other operations were assumed to be unchanged. As in many of the headwater reservoirs with smaller catchment areas, Cooks Pond provided flood storage during the April 2007 event. Maintaining the winter drawdown longer would increase the flood control storage capability, allowing Cooks Pond to reduce the releases from a maximum of 30 cfs on April 16 to almost zero.

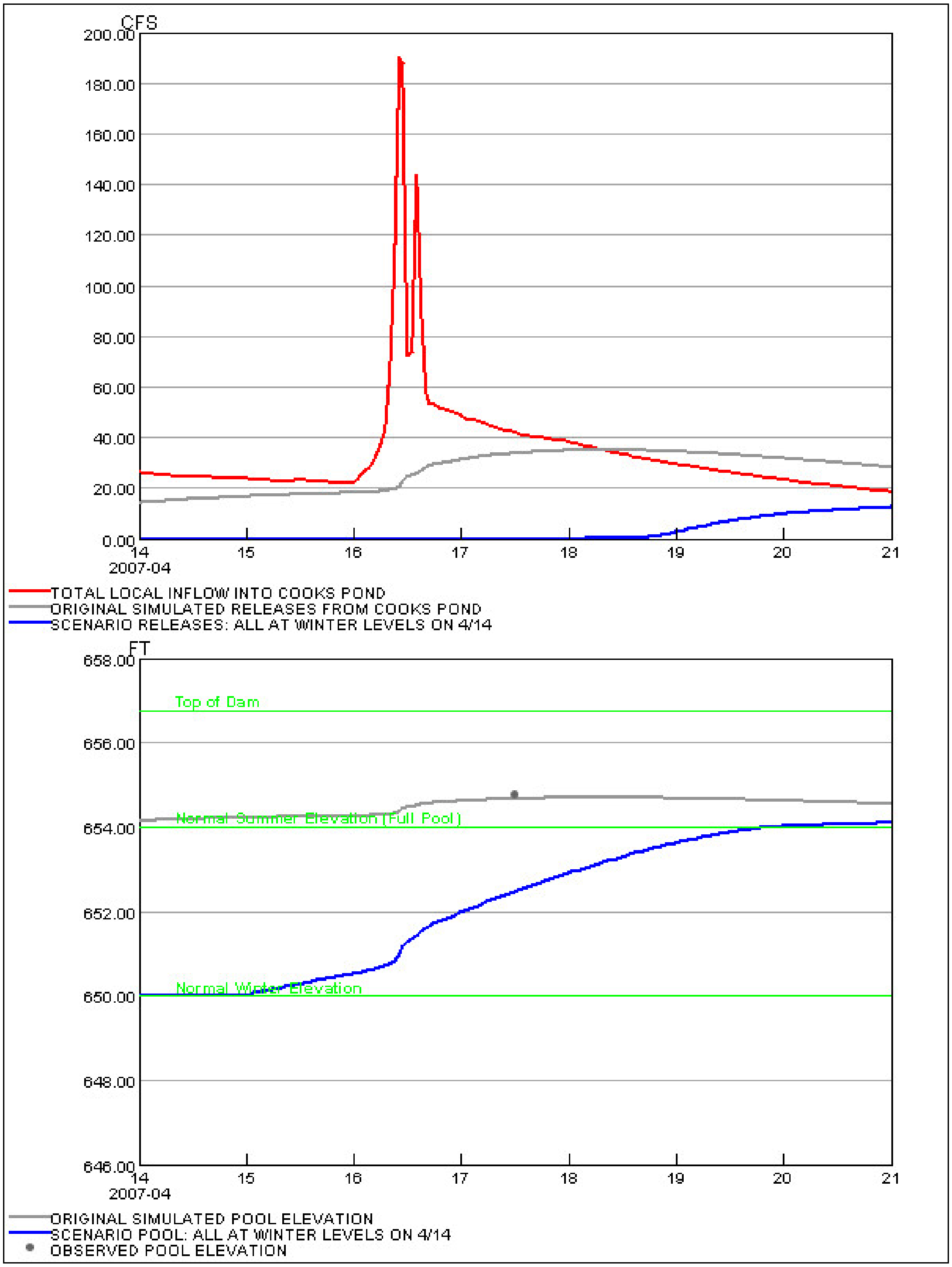


Figure 2-11: Cooks Pond Alternative Operations - Starting at Minimum Pool on April 14th

B-2.4 Lovell Lake (NHDES# 241.06)

B-2.4.1 General Description

Lovell Lake is a headwater located off of the Churchill Brook, a tributary to Salmon Falls River. Sanbornville is located off of the North-West corner of the lake. Development along the lake is concentrated near the town.

Lovell Lake has a capacity of 1750 acre-feet at its normal elevation, and 2400 acre-feet at its maximum elevation. Between those levels, Lovell Lake can store approximately 2.55 inches of runoff.

Pool elevations on Lovell Lake are controlled by NHDES staff at a dam structure at the North-West end of the lake. Water levels can be controlled through eight stoplog bays with six stoplogs in each bay, except for one deep bay which contains eleven stoplogs. A culvert under a road, located just downstream of the stoplog bays, can potentially restrict releases from the lake.

The typical summer lake elevation is 572.39 feet, which corresponds to the elevation of the topmost stoplogs and the normal elevation. Water level is drawn down three feet below full pool starting after Columbus Day. Every 4th year, the drawdown is increased to four feet (2003, 2007, 2011, 2015, etc.). It requires approximately 7.8 inches of runoff to refill the lake from the lower winter pool to the normal summer pool, providing for significant local flood control.

A plan view of Lovell Lake Dam is shown in Figure 2-12.

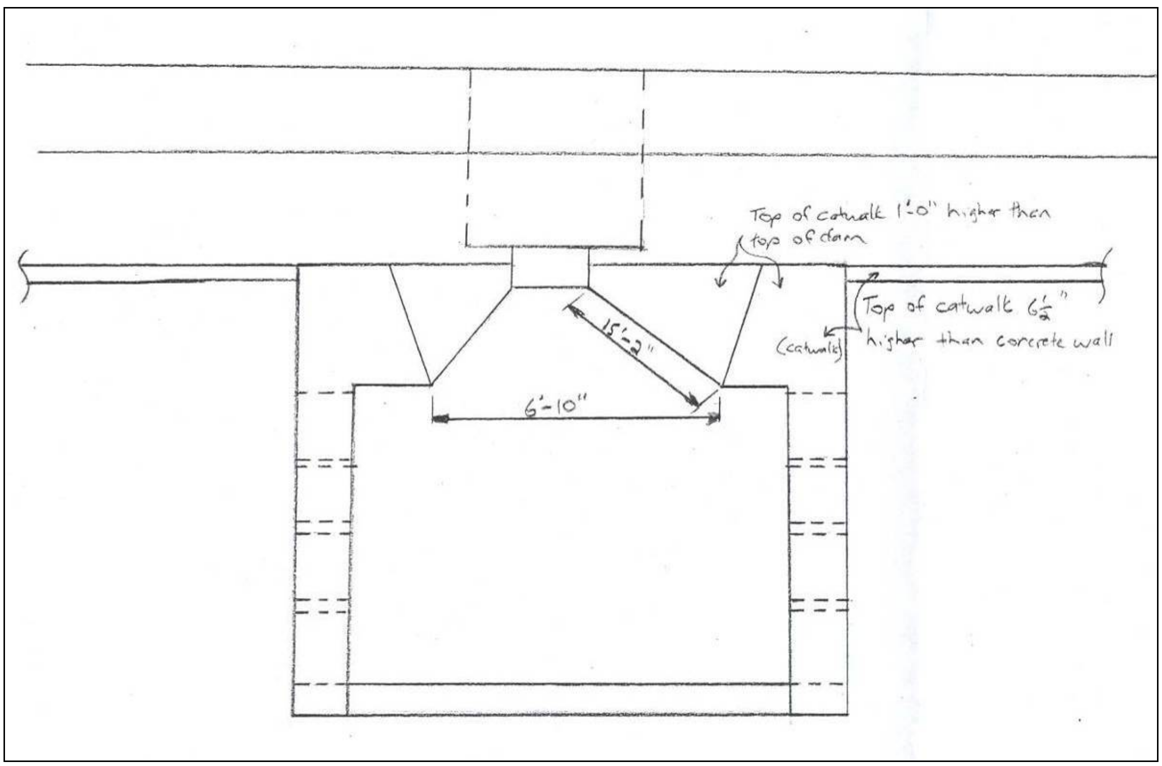


Figure 2-12: Plan View of Lovell Lake Dam

B-2.4.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 572.39 feet. Table 2-7 and Table 2-8 list the pool elevation and the dam operations performed by the NHDES at Lovell Lake.

Table 2-7: Lovell Lake Pool Elevation and Dam Operations during the May 2006 Flood

	POOL		LEFT SIDE				RIGHT SIDE		DEEP BAY		
DATE	ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	COMMENTS	INT
5/4/2006	-0.60	0 OUT	0 OUT	0 OUT	0 OUT	0 OUT	0 OUT	0 OUT	0 OUT	ALL IN	CT
5/13/2006	0.1	0 OUT	0 OUT	1 OUT	1 OUT	0 OUT	0 OUT	0 OUT	0 OUT	PULLED 2 LOGS	CT
5/14/2006	1	0 OUT	0 OUT	1 OUT	4 OUT	0 OUT	0 OUT	0 OUT	3 OUT	PULLED 3 LEFT/3 RIGHT	CT/CL
5/15/2006	0.3	0 OUT	0 OUT	1 OUT	4 OUT	0 OUT	0 OUT	0 OUT	3 OUT		CL
5/16/2006	0.4	0 OUT	0 OUT	1 OUT	4 OUT	0 OUT	0 OUT	0 OUT	3 OUT		CL
5/17/2006	0	0 OUT	0 OUT	0 OUT	2 OUT	0 OUT	0 OUT	0 OUT	2 OUT	SET SOME LOGS	CL

Table 2-8: Lovell Lake Pool Elevation and Dam Operations during the April 2007 Flood

	POOL										
DATE	ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	COMMENTS	INT
4/3/2007	-1.1	1 OUT	1 OUT	1 OUT	2 OUT	1 OUT	1 OUT	1 OUT	2 OUT	LET RUN /ICE STILL ON POND	AS
4/10/2007	-1.1	1 OUT	1 OUT	1 OUT	2 OUT	1 OUT	1 OUT	1 OUT	2 OUT	LET RUN /SOLID ICE STILL ON POND	CT
4/12/2007	-0.9	1 OUT	1 OUT	1 OUT	3 OUT	1 OUT	1 OUT	1 OUT	2 OUT	PULLED ONE LOG	CT
4/16/2007	0.2	1 OUT	1 OUT	1 OUT	3 OUT	1 OUT	1 OUT	1 OUT	2 OUT	LET RUN	CT
4/18/2007	0.25	1 OUT	1 OUT	1 OUT	3 OUT	1 OUT	1 OUT	1 OUT	2 OUT	LET RUN	CT
4/23/2007	-0.65	1 OUT	1 OUT	1 OUT	2 OUT	1 OUT	1 OUT	1 OUT	1 OUT	SET LOGS	PA

All stoplogs were in place on May 4, 2006 and the pool was 0.60 foot below the spillway crest. Inflows to the lake began to increase on May 13 and two stoplogs were removed. Pool elevation overtopped the spillway crest by 0.1 foot on May 13. The pool continued to rise, and reached the maximum recorded height of 1.0 foot over the spillway on May 14. This was 0.8 foot below the top of the dam. Six more stoplogs were removed on May 14, effectively lowering the pool. The pool elevation gradually decreased over the next three days, and dropped below the spillway crest on May 17.

Lovell Lake was filling when the April 2007 event occurred, and was 1.1 feet below the spillway crest on April 3. Ice was still on the pond and the pool elevation changed slowly until April 12, when it rose 0.2 foot in response to rain and snow melt. One stoplog was removed on April 12, but no other operations were performed during the storm. The spillway was overtopped by 0.2 foot on April 16. The pool reached a maximum recorded height on April 18, 0.25 ft over the spillway crest, corresponding to 1.6 feet below the top of the dam. One stoplog was set on April 23 and the pool had dropped to 0.65 foot below the spillway.

According the NHDES, action is taken when the pool elevation reaches 0.5 ft over full pond (spillway crest) to prevent upstream flooding. Also, the lake typically spills to the left side of the control structure at one foot above the spillway. Stoplogs were therefore removed on May 14, 2006. Pool elevations were lower April 2007 and no action was required during this event. No reports of upstream flooding were reported by the NHDES.

The simulation for April 2007 is depicted in Figure 2-13 and tracks the observed pool elevations well.

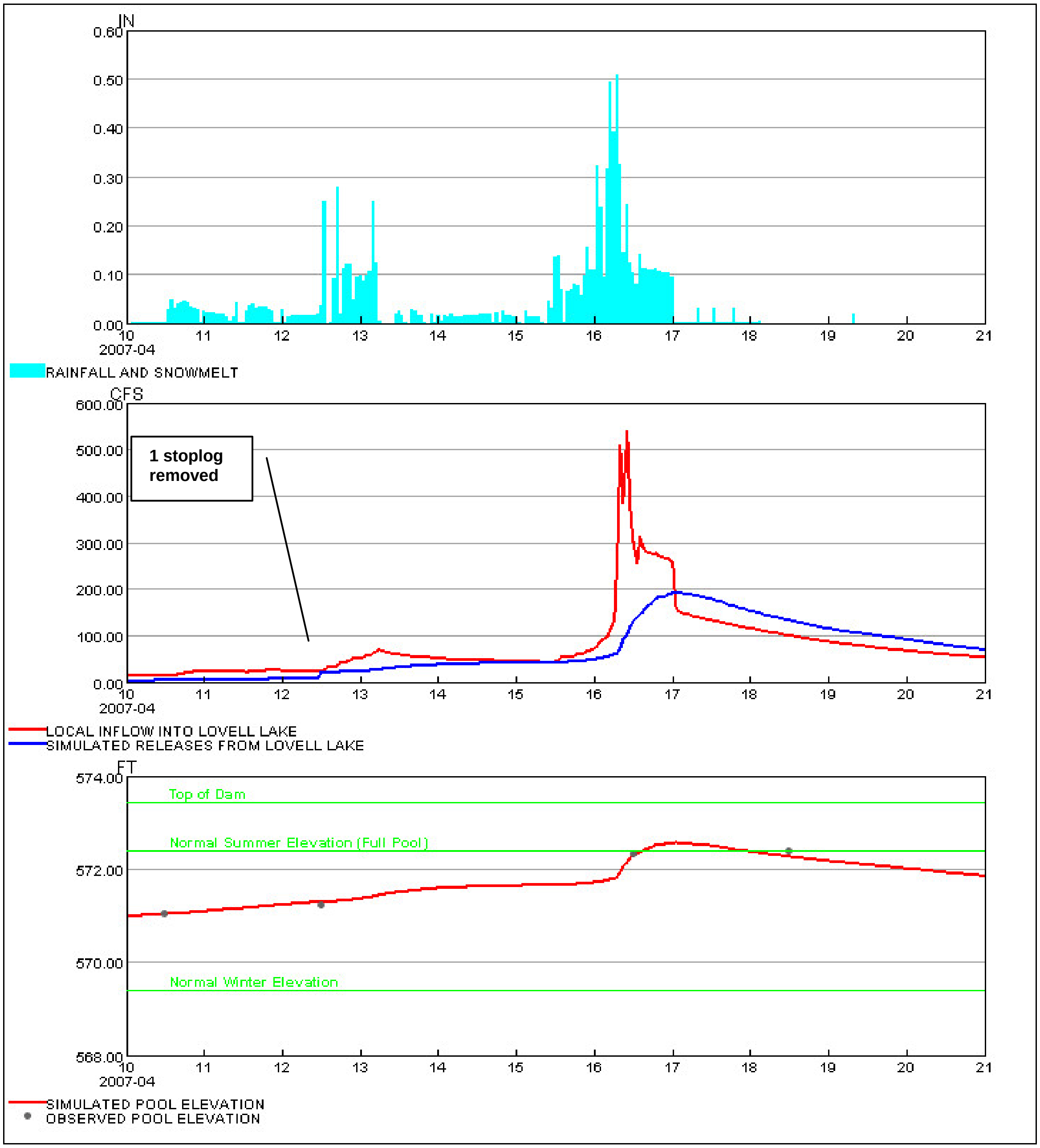


Figure 2-13: Lovell Lake Simulation Results for the April 2007 Flood Event

B-2.4.3 Alternative Operations

A simulation of Lovell Lake with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 2-14. All other operations were assumed to be unchanged. With a fairly small catchment area, Lovell Lake was able to significantly reduce the peak of the April 2007 event.

Maintaining the winter drawdown level into April would further increase the flood control storage capabilities of Lovell Lake. Lovell Lake was approximately three-quarters of the way to its normal summer elevation on April 14. If the lake where maintained at the normal winter elevation in April then it would not have filled to the summer pool elevation during this storm event. The maximum releases on April 16 could have been reduced from approximately 200 cfs to approximately 70 cfs.

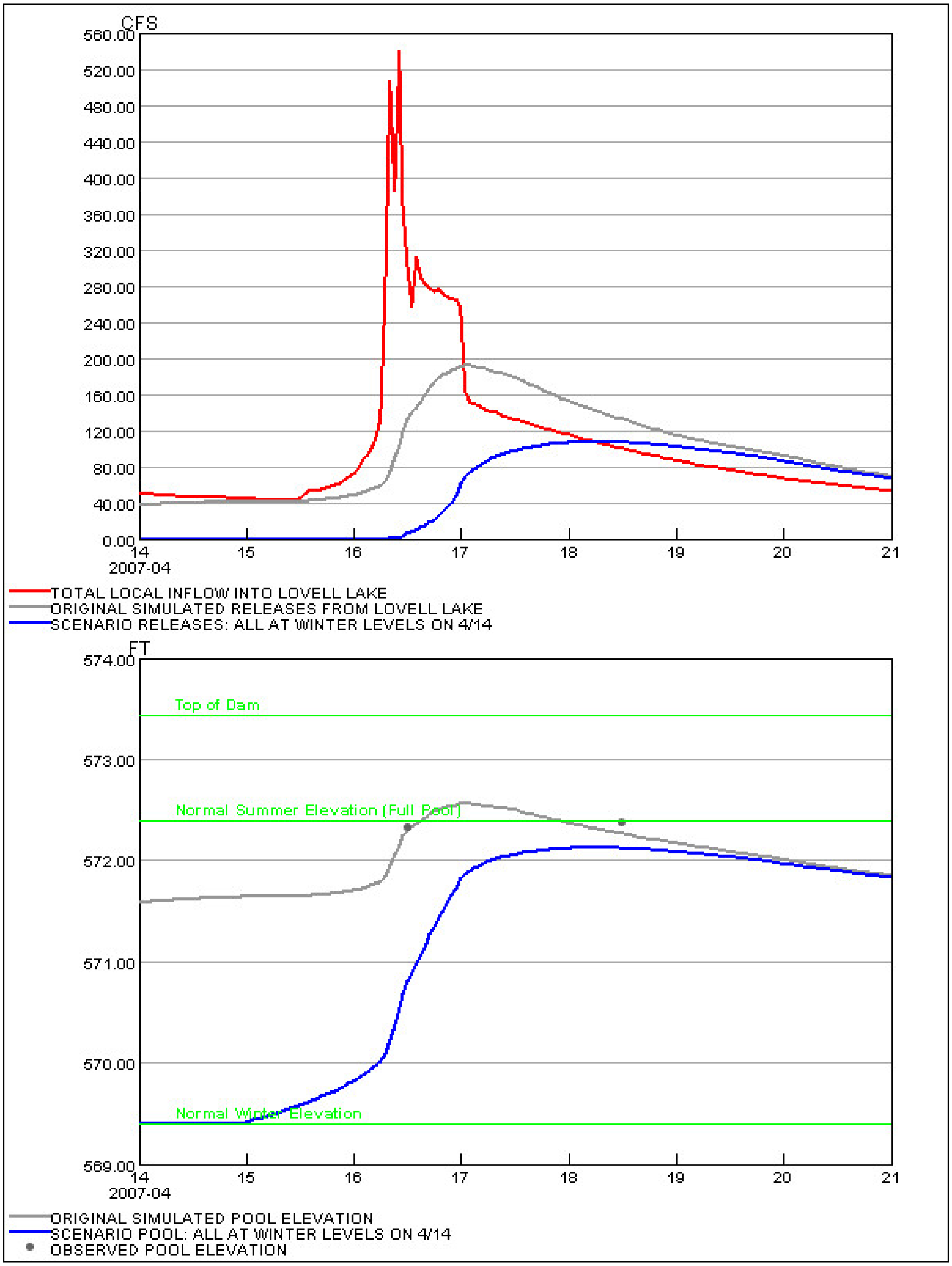


Figure 2-14: Lovell Lake Alternative Operations - Starting at Minimum Pool on April 14th

B-2.5 Milton Three Ponds (NHDES# 161.06)

B-2.5.1 General Description

Milton Three Ponds Dam is located on the Salmon Falls River downstream of where Churchill Brook/Branch River enters the Salmon Falls River. Milton Pond consists of several connected ponds, which is where it gets its name. Housing developments are present along the majority of the shoreline around the ponds.

The Milton Ponds are larger then all the upstream ponds but Great East Lake. The ponds have a storage capacity of about 12,500 acre-feet at normal levels, and 15,000 acre-feet at its maximum elevation. This allows for the storage of 0.42 inch of runoff (assuming no other regulation upstream).

Pool elevations at Milton Ponds are controlled by the NHDES at a dam structure at the southern end of the lakes. This is typically done by adding or removing stoplogs from twenty bays and by controlling one automated Obermeyer gate and two deep gates (referred to as the 'New Hampshire- NH' gate and the 'Maine-ME' gate). The dam itself has no spillway—at high pool water flows over the stoplog bays.

The typical summer lake elevation is 414.67 feet, expected to be reached by June 1. The pond level slowly decreases over the summer months, leaving the level six to twelve inches below full by Columbus Day. After Columbus Day, the lake level is slowly lowered to a target of 3.25 feet below the June 1 target. This allows for shorefront maintenance and prepares for spring runoff. This information was obtained from the NHDES Dam Bureau website. Other information sent by NHDES shows an annual drawdown of three feet. It requires 0.69 inch of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view and photograph of Milton Three Ponds Dam are shown in Figure 2-15 and Figure 2-16.

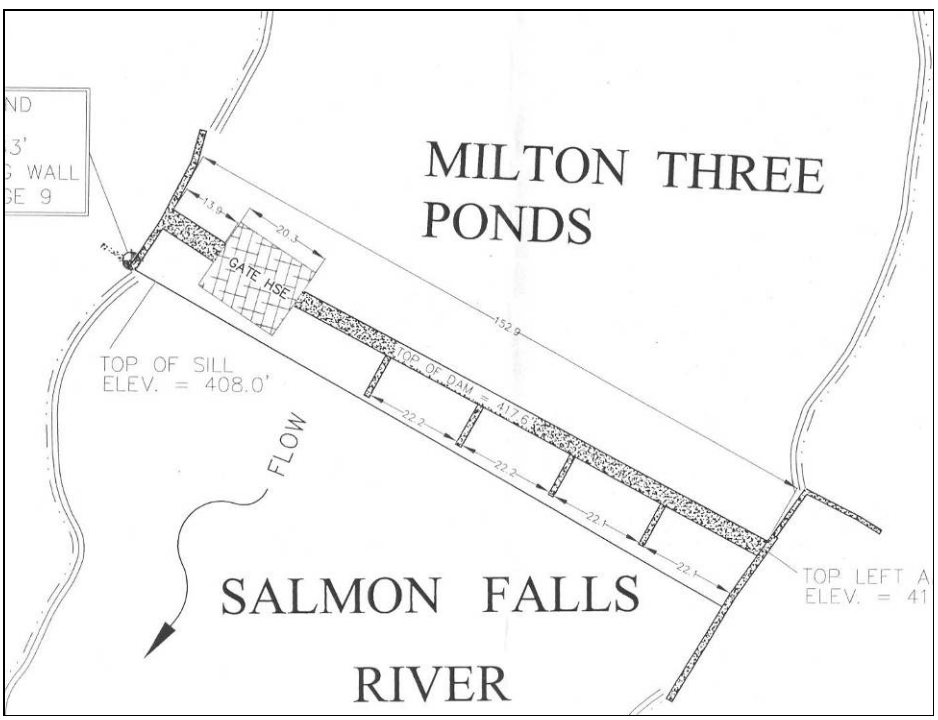


Figure 2-15: Plan View of Milton Three Ponds Dam

Figure 2-16: Photograph of Milton Three Ponds Dam

B-2.5.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 414.67 feet. Table 2-9 and Table 2-10 list the pool elevation and the dam operations

Table 2-9: Milton Ponds Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	NH GATE	ME GATE	OBIE PANEL	LOG BAYS	COMMENTS	INT
5/12/2006	-1.13	OPEN 6"	OPEN 25"	OPEN 14"	2 OUT		SND
5/13/2006	-1.14	OPEN 48"	CLOSED	OPEN 11"	2 OUT		SND
5/14/2006	0.95	OPEN 48"	CLOSED	OPEN 11"	3 OUT	1 LOG BAY STRING PULLED	SND
5/16/2006	0.45	OPEN 48"	CLOSED	OPEN 11"	5 OUT	23 LOGS OUT TOTAL	SND
5/18/2006	-1.10	OPEN 48"	OPEN 48"	OPEN 15"	5 OUT		SND
5/19/2006	-1.45	OPEN 40"	OPEN 28"	OPEN 14.6"	3 OUT		SND
5/20/2006	-0.96	OPEN 40"	OPEN 48"	OPEN 14.6"	3 OUT		SND
5/21/2006	-0.92	OPEN 40"	OPEN 48"	OPEN 14.6"	3 OUT		SND
5/22/2006	-1.05	OPEN 40"	OPEN 48"	OPEN 14.6"	3 OUT		SND
5/23/2006	-1.13	OPEN 40"	OPEN 48"	OPEN 14.6"	3 OUT		SND
5/24/2006	-1.30	OPEN 40"	OPEN 48"	OPEN 14.6"	3 OUT		SND
5/25/2006	-1.51	OPEN 40"	OPEN 1"	OPEN 14"	3 OUT		SND
5/26/2006	-1.37	OPEN 40"	OPEN 13"	OPEN 12"	2 OUT		SND

Table 2-10: Milton Ponds Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	NH GATE	ME GATE	OBIE PANEL	LOG BAYS	COMMENTS	INT
4/1/2006	-1.78	OPEN 36"	OPEN 1"	OPEN 14.1"	logs @ 14.0'		SND
4/2/2006	-1.77	OPEN 36"	OPEN 1"	OPEN 14.1"	logs @ 14.0'		SND
4/3/2006	-1.64	OPEN 36"	OPEN 1"	OPEN 14.1"	logs @ 14.0'		SND
4/4/2006	-1.59	OPEN 36"	OPEN 1"	OPEN 14.1"	logs @ 14.0'		SND
4/5/2006	-1.58	OPEN 36"	OPEN 1"	OPEN 14.1"	logs @ 14.0'		SND
4/6/2006	-1.67	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/7/2006	-1.61	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/8/2006	-1.63	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/9/2006	-1.63	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/10/2006	-1.66	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/11/2006	-1.68	OPEN 12"	OPEN 4"	OPEN 14.1"	logs @ 14.0'		SND
4/12/2006	-1.69	CLOSED	CLOSED	OPEN 14.5"	logs @ 13.4'		SND
4/13/2006	-1.72	CLOSED	OPEN 36"	OPEN 14.5"	logs @ 13.4'		SND
4/14/2006	-1.91	CLOSED	OPEN 36"	OPEN 14.5"	logs @ 13.4'		SND
4/15/2006	-2.00	OPEN 12"	OPEN 48"	OPEN 9.8"	logs @ 13.4'		SND
4/16/2006	-1.71	OPEN 12"	OPEN 48"	OPEN 9.8"	Between the morning of the 16th and the morning of the 20th the NH gate was opened to "full" and two adiitional rows of stroplogs were removed. At the time I was at the state's EOC in full statewide response mode. You may be able approximate the timing of some of these ops from the rating curve.		SND
4/17/2006	1.09	OPEN 12"	OPEN 48"	OPEN 9.8"			SND
4/18/2006	0.09	OPEN 12"	OPEN 48"	OPEN 9.8"			SND
4/19/2006	-1.04	OPEN 12"	OPEN 48"	OPEN 9.8"			SND
4/20/2006	-1.79	OPEN 48"	CLOSED	OPEN 9.8"	logs @ 12.2'		SND
4/21/2006	-1.59	OPEN 22"	OPEN 48"	OPEN 14.5"	logs - 7@13.5' & 13@12.9'		SND
4/22/2006	-1.84	OPEN 22"	OPEN 48"	OPEN 14.5"	logs - 7@13.5' & 13@12.9'		SND
4/23/2006	-2.07	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/24/2006	-1.61	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/25/2006	-1.49	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/26/2006	-1.52	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/27/2006	-1.60	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/28/2006	-1.61	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/29/2006	-1.63	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND
4/30/2006	-1.63	CLOSED	OPEN 48"	OPEN 14.5"	logs @ 14.0'		SND

On May 12 2006, the Milton Dam pool was 1.13 feet below full pool elevation. At this time the NH gate was open 6”, the ME gate was open 25”, the top of the Obermeyer panel set to 14”, and two log were out from all bays. When inflows to Milton Dam peaked on May 14, the NH gate was opened 48”, the ME gate was closed, the Obermeyer panels were lowered to 11”, and 3 log were out from all bays. At this time the pool elevation topped out at 0.95 foot above full pool elevation, about 2 feet below the top of the dam.

The Milton Dam was actively operated before and during the April 2007 event. On April 3, the pool was 1.64 feet below the spillway as the reservoir was refilling from winter drawdown. Until the 16th, the pool was dropped slightly by removing stoplogs, opening gates, and lowering the Obermeyer panels as the inflows increased. Some of the inflows were stored during the event by not opening the NH gate all the way, and by not lowering the Obermeyer gate completely. This provided relief for the downstream Milton Hydro project, which incurred damage early in the event and was in danger of failing. On the other hand, it caused the water level at Milton Three Ponds to rise and, according to accounts from residents, contributed to considerable upstream flood damages. Some stoplogs were removed during the event; removing stoplogs when water is overtopping them is, however, dangerous and often impossible, as water pressure keeps them lodged in the bay. The maximum recorded pool elevation was 1.09 feet above the spillway on April 17. This was 1.87 feet below the top of the dam, slightly higher than in 2006.

Pool elevation and release data are automatically collected at Milton Dam and are available at an hourly time interval. This allows for an in-depth calibration of the simulation models. As seen in Figure 2-17, it was possible to simulate the observed pool elevations well. Observed releases are not matched as well, indicating a possible inaccuracy in the elevation-storage relationship for the three ponds.

During the April 2007 flood event, the inflows at Milton Dam were at least one magnitude larger than releases at the dams studied upstream. The peak inflow at Milton Dam was more than 6000 cfs, compared to peak releases of 200 cfs each from Lovell Lake and Horn Pond and 40 cfs from Cooks Pond. This illustrates that most of the inflows were generated downstream of those dams. The operations at Milton Dam demonstrate how competing objectives regarding the prevention of upstream and downstream damages complicates the operation of a dam during a serious flood event. Another small dam, Union Meadows Dam, is located between Cooks Pond, Lovell Lake, and Milton Three Ponds, but the flood control potential of that dam is minor as well. Union Meadows Dam is not modeled in this study.

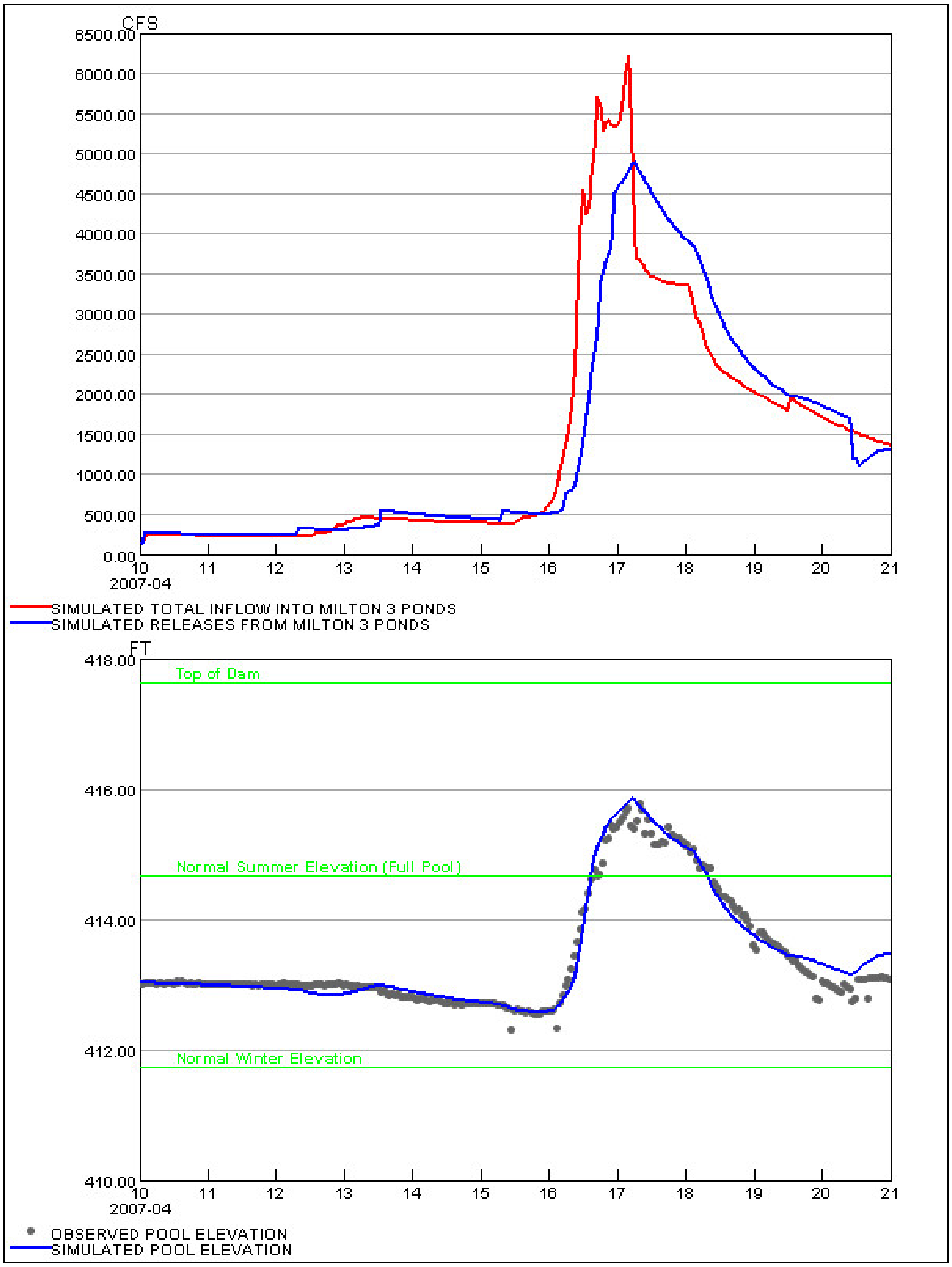


Figure 2-17: Milton Three Ponds Simulation Results for the April 2007 Flood Event

B-2.5.3 Alternative Operations

Several different scenarios were tested for Milton Three Ponds, considering it is a point where upstream flooding occurred. Figure 2-18 and Figure 2-19 show the three different scenarios in terms of the releases and pool elevations respectively. The scenarios tested include the following operations for Milton Three Ponds: all gates are open and stoplogs removed on April 10; winter drawdown maintained until April 10; and all gates fully open on April 10. Maintaining the winter drawdown until April 10 and holding all other operations had very little effect on the maximum pool elevation and no effect on the maximum releases during the event.

Opening all the gates and removing the stoplogs or only opening all the gates several days before the event drew down the pool elevation very far below the normal winter elevation and significantly affected the maximum pool elevation and releases. These operations provide the maximum possible flood control benefits given the current infrastructure at the site.

A possible improvement at the Milton Three Ponds dam site is to replace the four stoplog bays next to the gate house with an Obermeyer panel. These panels can be lowered much faster than stoplogs can be removed. They can therefore be used to lower pool elevations in anticipation of an event and pass larger flows at lower pool elevations during an event. Figure 2-20 illustrates the effect of lowering this new Obermeyer gate in addition to the existing gates on April 15, 2007 at noon, the time when the NWS predicted likely flooding in the area: Significant water volumes can be released in a short time, lowering the maximum pool elevation reached by about half a foot for the April 2007 event. The effect on peak releases would be insignificant.

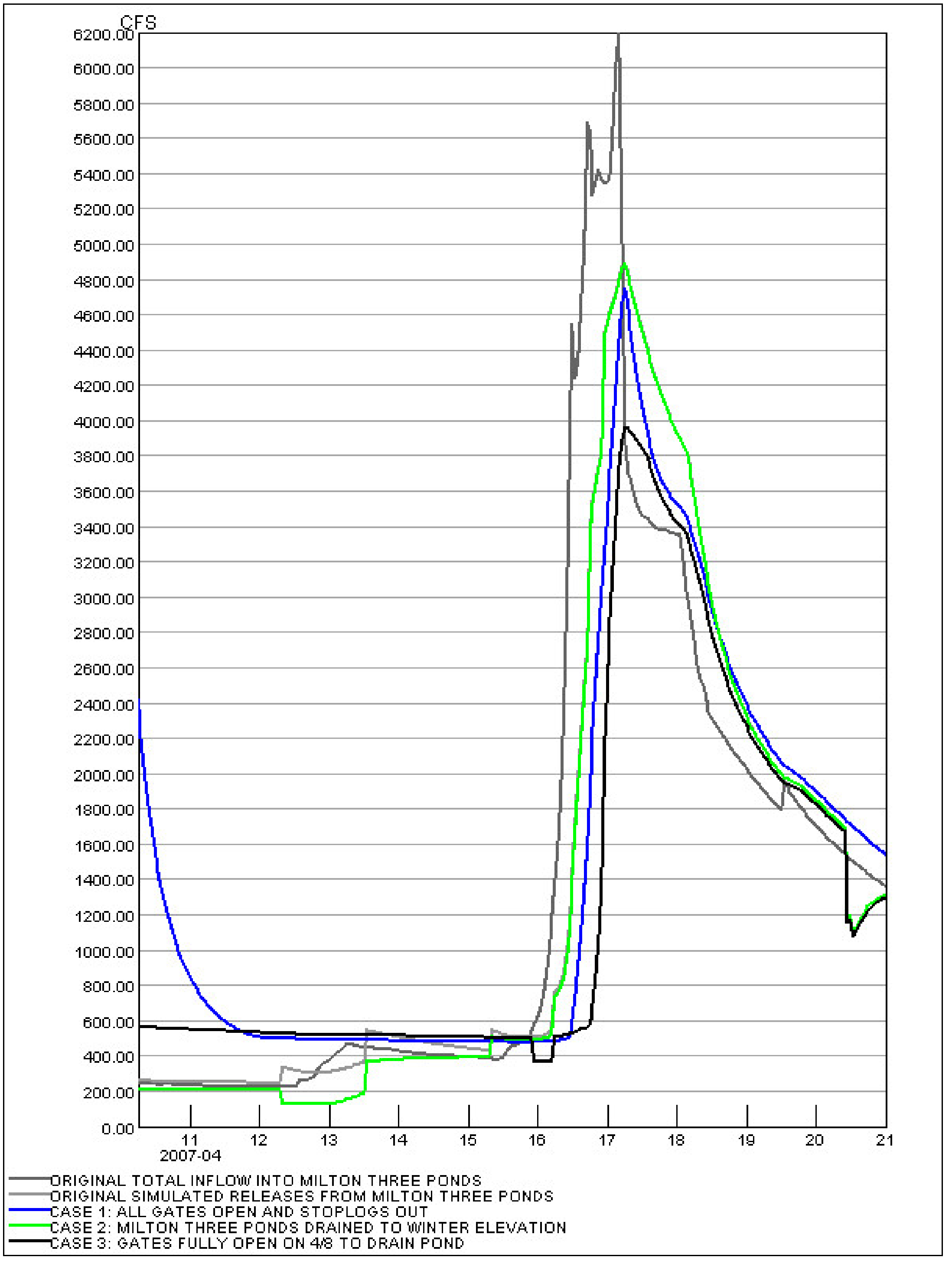


Figure 2-18: Milton Three Ponds Alternative Operations - Various Scenarios (Flow)

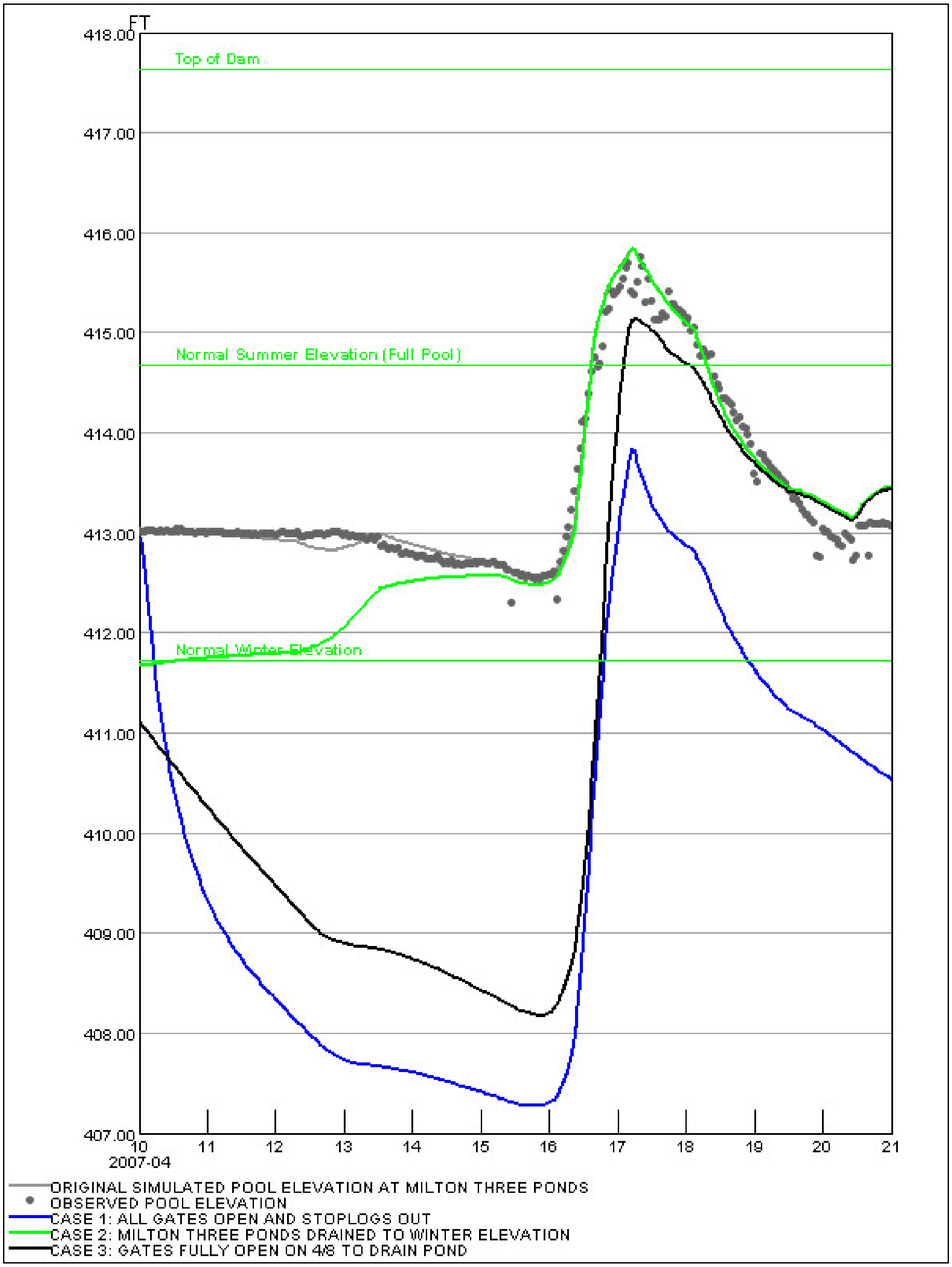


Figure 2-19: Milton Three Ponds Alternative Operations - Various Scenarios (Pool)

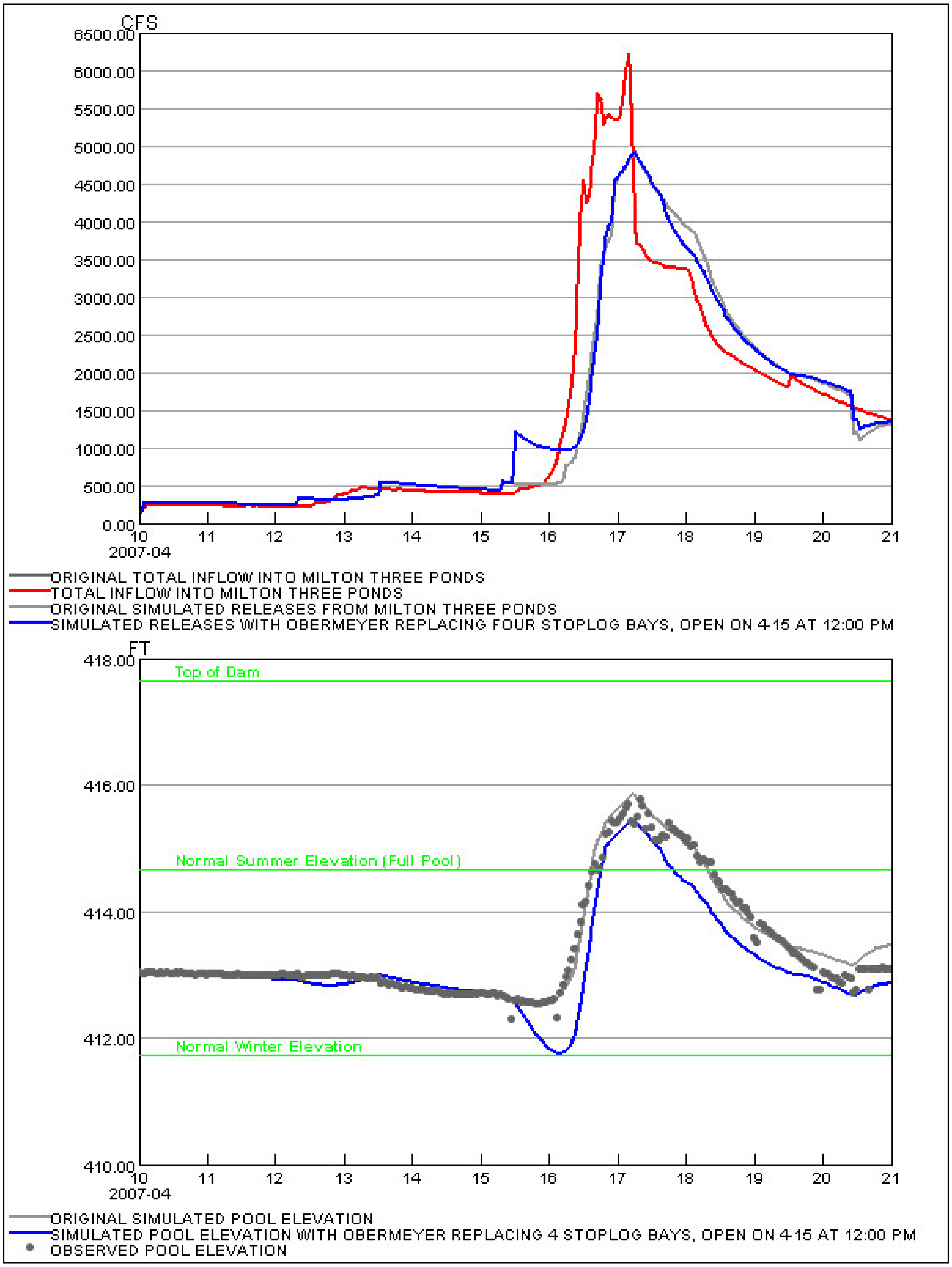


Figure 2-20: Milton Three Ponds Alternative Operations – Open New Gate on April 15th

B-2.6 Spaulding Pond (NHDES# 204.08)

B-2.6.1 General Description

The run-of-river Spaulding Dam is owned by the Spaulding Ave Industrial Complex, LLC and serves as a hydro power project. It is located downstream of Milton Ponds. Housing and other developments are located around the pond. Spaulding Pond is very small, with a capacity of approximately 325 acre-feet at normal pool elevation, and 700 acre-feet at its maximum elevation. This provides for a storage capacity of only 0.06 inch between these pool elevations.

The normal elevation of the pond is 247.0 feet. The water levels at Spaulding Pond are controlled by nine stoplog bays, three gates at the dam, and three gates at a mill where the powerhouse is located.

A plan view and photograph of Spaulding Pond Dam are shown in Figure 2-21 and Figure 2-22 respectively.

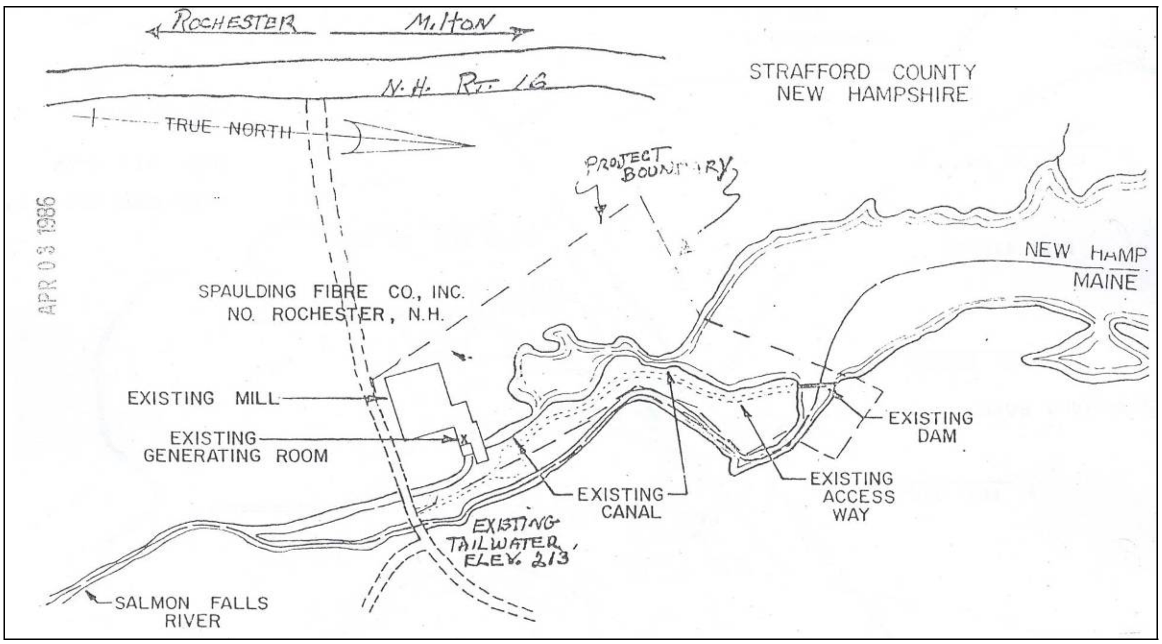


Figure 2-21: Plan View of Spaulding Pond Dam

B-2.6.2 Actual Operations

On May 12, 2006 the pool was 3" above normal pool, and as a precaution one gate was set to a half open position. The pool rose rapidly in response to the storm and by the evening of May 13 the pool had reached 20" above full pond. At this time all three operational gates were fully opened, effectively dropping the pool elevation at a rate of 1" per hour. However, five hours later, early in the morning on May 14, the pool had risen to 30" above full pond. Accumulating debris was removed and 12 stoplogs were pulled, which maintained the pool at 12" below the top of the dam.

Spaulding Pond Dam was not overtopped during the April 2007 storm. The dam was monitored hourly while the pool was rising and every 2 to 3 hours while declining. The maximum pond elevation at the dam was 26 inches over the spillway boards at '2:00 p.m. on 4-17-07'. The dam was operated during the storm, but the specifics are not known. No portion of the dam structure was damaged and the plant manager was not aware of any downstream damages.

As evident in Figure 2-23, it is hard to thoroughly simulate and evaluate this project for the April 2007 event, given the limited availability of observed data. It was therefore assumed that the pool was kept roughly constant until the onset of the event, and that the gates were fully opened in the morning of April 16 to prevent possible overtopping. These operations cause the pool elevation to rise close to the single observed elevation.

Note that opening the gates does dramatically drop the pool for a short period of time and cause a small spike in releases in the morning hours of the 16th. However, the large inflows and the small storage capacity of the lake cause the Spaulding Pond to rise quickly again. Inflows then pass through the pond almost unchanged, demonstrating that the project has no appreciable flood control effect.

Figure 2-22: Photograph of Spaulding Pond Dam

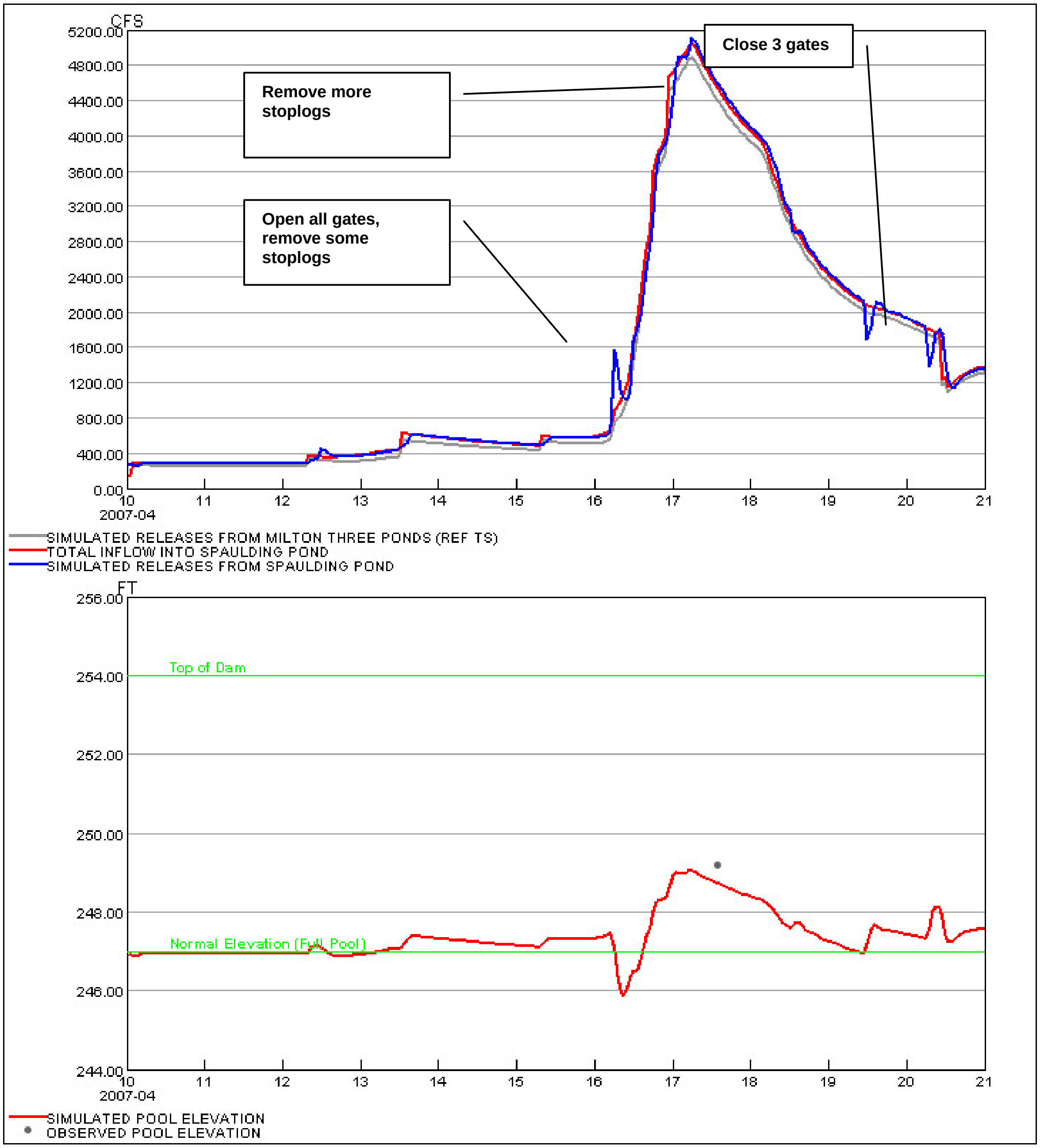


Figure 2-23: Spaulding Pond Simulation Results for the April 2007 Flood Event

B-2.6.3 Alternative Operations

Two scenarios were tested for Spaulding Pond. The first (Figure 2-24), shows the pool elevation at the winter level on April 14. All other operations were assumed to be unchanged. This scenario assumes that all upstream reservoirs were also drawdown to the winter level. The second scenario (Figure 2-25) shows the simulation results if all the gates were open and stoplogs removed on April 10. Because Spaulding Pond has very little storage, maintaining the pool elevation at its winter level in April would have had little effect on the flows or pool elevations. However, if Spaulding Pond had opened all its gates and removed all its stoplogs, the pool elevation could have been maintained below the summer elevation.

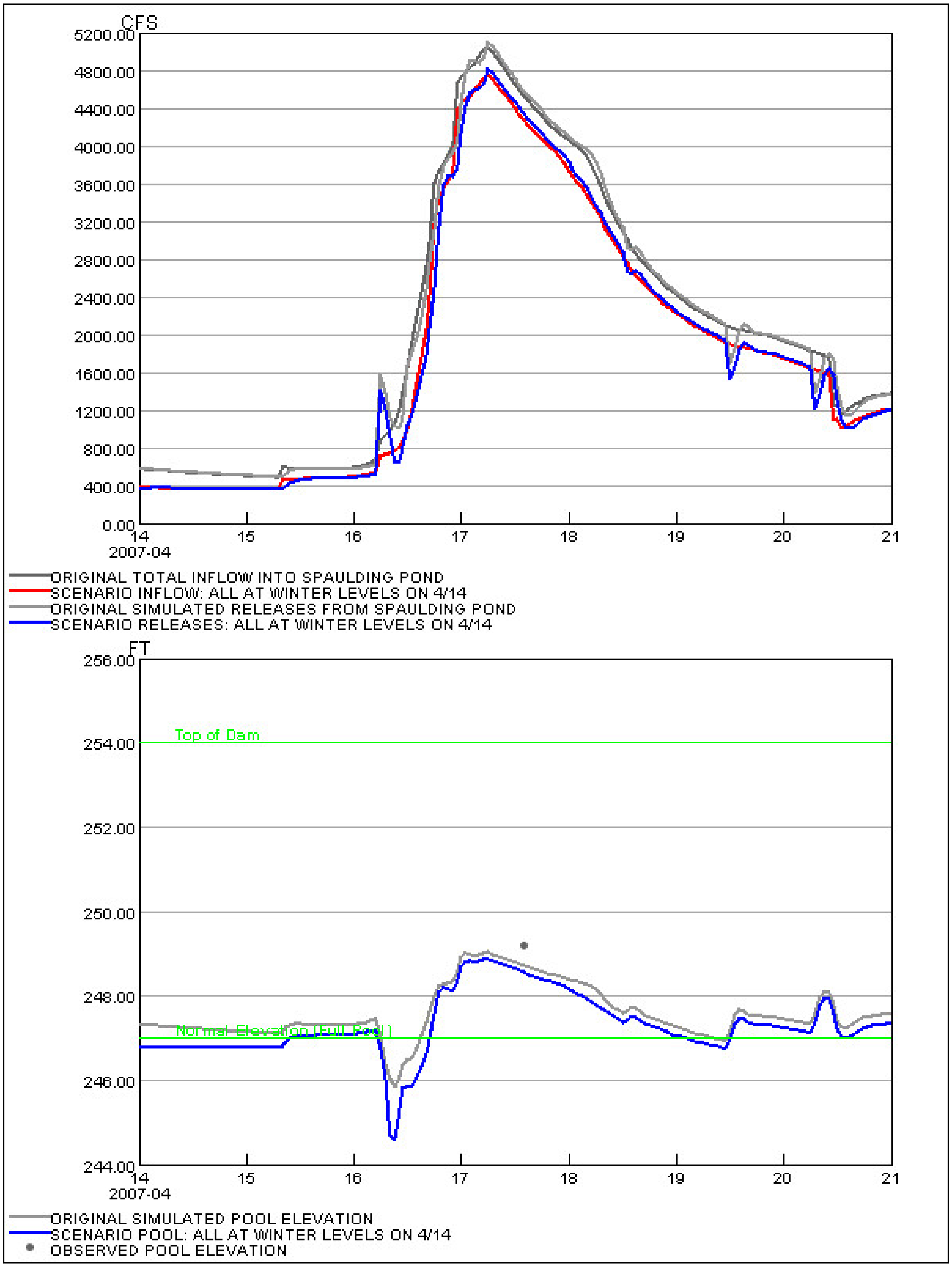


Figure 2-24: Spaulding Pond Alternative Operations - Starting at Minimum Pool on April 14th

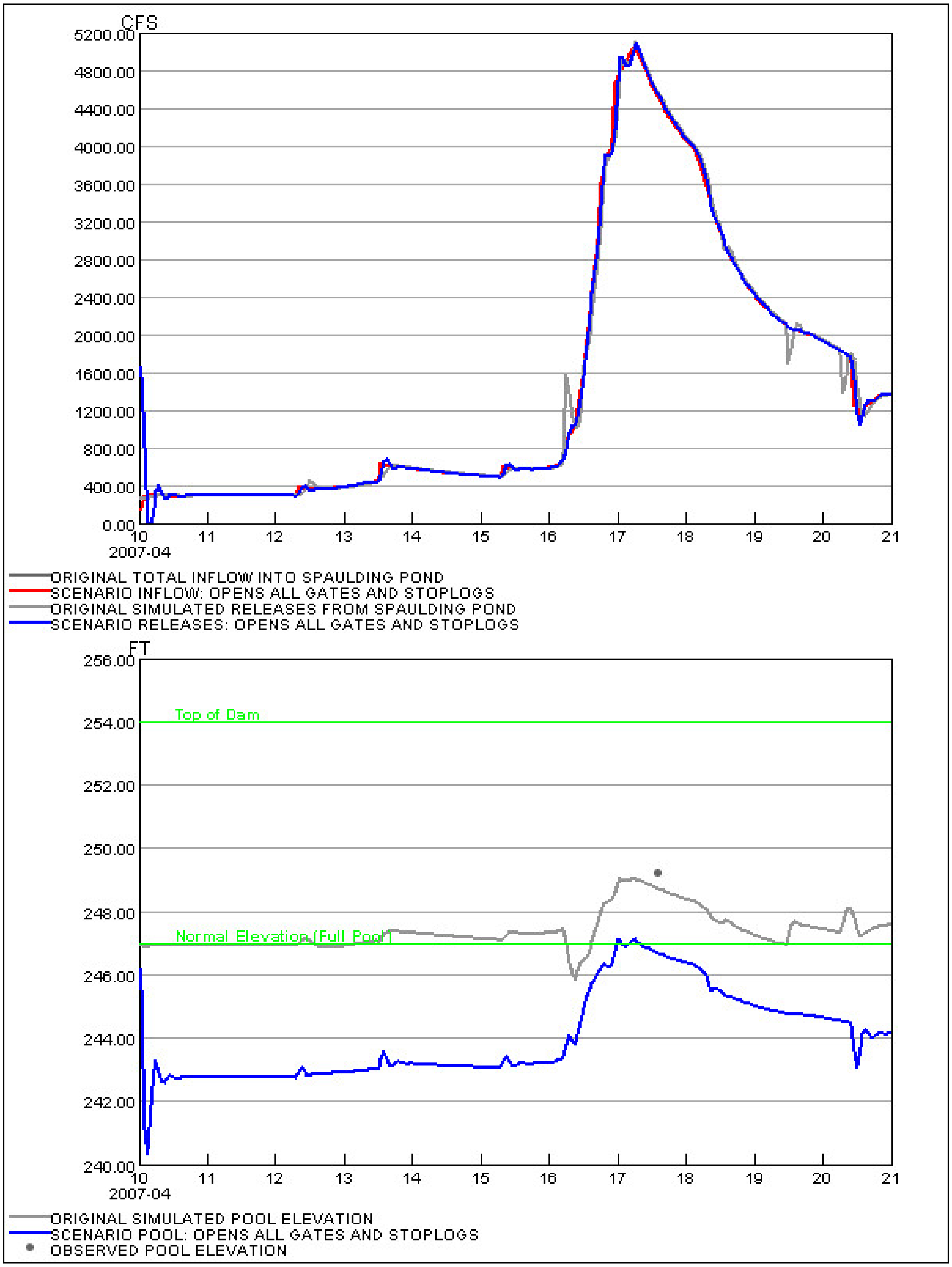


Figure 2-25: Spaulding Pond Alternative Operations - All Gates Open and Stoplogs Removed on 4-10

B-2.7 Baxter Mill Dam (NHDES #204.06)

B-2.7.1 General Description

Baxter Mill Dam is a run-of-river structure located downstream of Spaulding Pond. The pond behind Baxter Mill Dam is very small and is surrounded by developments on almost all sides. It has a capacity of about 230 acre-feet at normal its elevation, and 350 acre-feet at its maximum elevation. Baxter Mill Dam originally consisted of an uncontrolled wooden spillway with a height of 9.8 feet. According to the NHDES, a drainpipe next to this spillway is inoperable. The weir was damaged during the May 2006 event when approximately 37 ft of the 103 feet wide section failed. An additional nine feet of the spillway was lost during the April 2007 flood. Since then, the structure was rebuilt to a height of approximately 5 feet, as shown in the photograph in Figure 2-26.

Figure 2-26: Photograph of Baxter Mill Dam

A plan view of Baxter Mill Dam is shown in Figure 2-27.

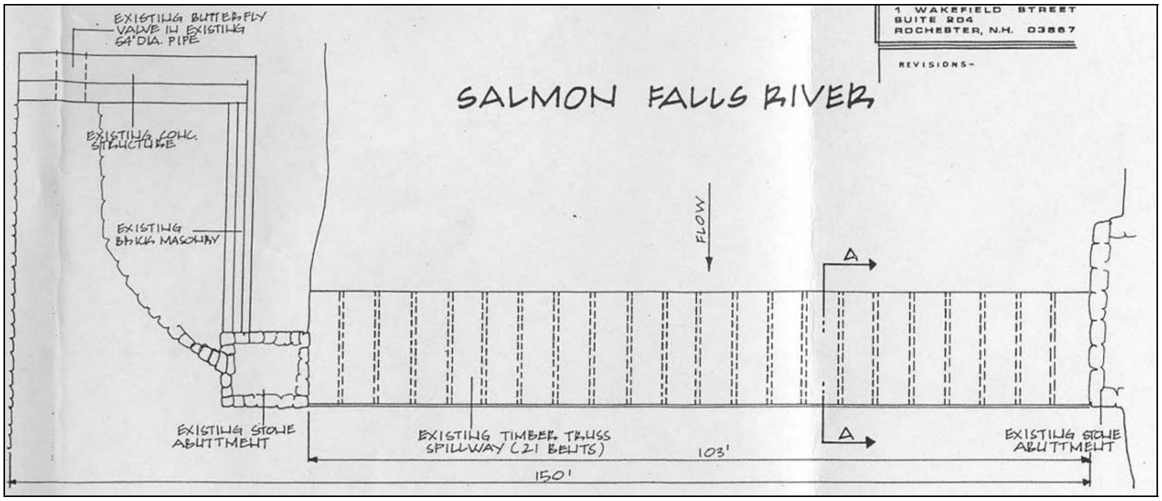


Figure 2-27: Plan View of Baxter Mill Dam

B-2.7.2 Actual Operations

No observed pool elevation data are available for either the May 2006 or the April 2007 events. No operations can be performed at the site.

The model for Baxter Mill Dam was set up to simulate the failure of part of the spillway during the April 2007 event. The exact time of the failure is unknown. For simulation purposes it was assumed that the failure happened at 2 p.m. on April 16, shortly after a small flow peak caused by the opening of gates at Spaulding Dam passed. The failure of the spillway caused only a temporary drop in pool elevation and an almost unnoticeable increase in releases, as shown in Figure 2-28.

B-2.7.3 Alternative Operations

Several scenarios were run for Baxter Mill Dam, including: winter drawdown held until 4-10 (Figure 2-29); failure of spillway at the peak flow, before the event, and no failure (Figure 2-30 and Figure 2-31); and simulation of the new spillway (Figure 2-32). When holding the winter drawdown for all reservoirs until April 10, the flow and pool elevation for Baxter Mill Dam are reduced slightly. This cannot be attributed to increases in storage capacity of Baxter Mill Dam, but due to the combined effect of all the upstream reservoirs. Different failures of the Baxter Mill spillway changed the shape of the hydrograph slightly, but had little effect on the peak flow or pool elevation. Finally, the new and lower spillway at Baxter Mill Dam would have maintained the pool elevation significantly lower (thus preventing overtopping), but would have had little effect on the peak flow.

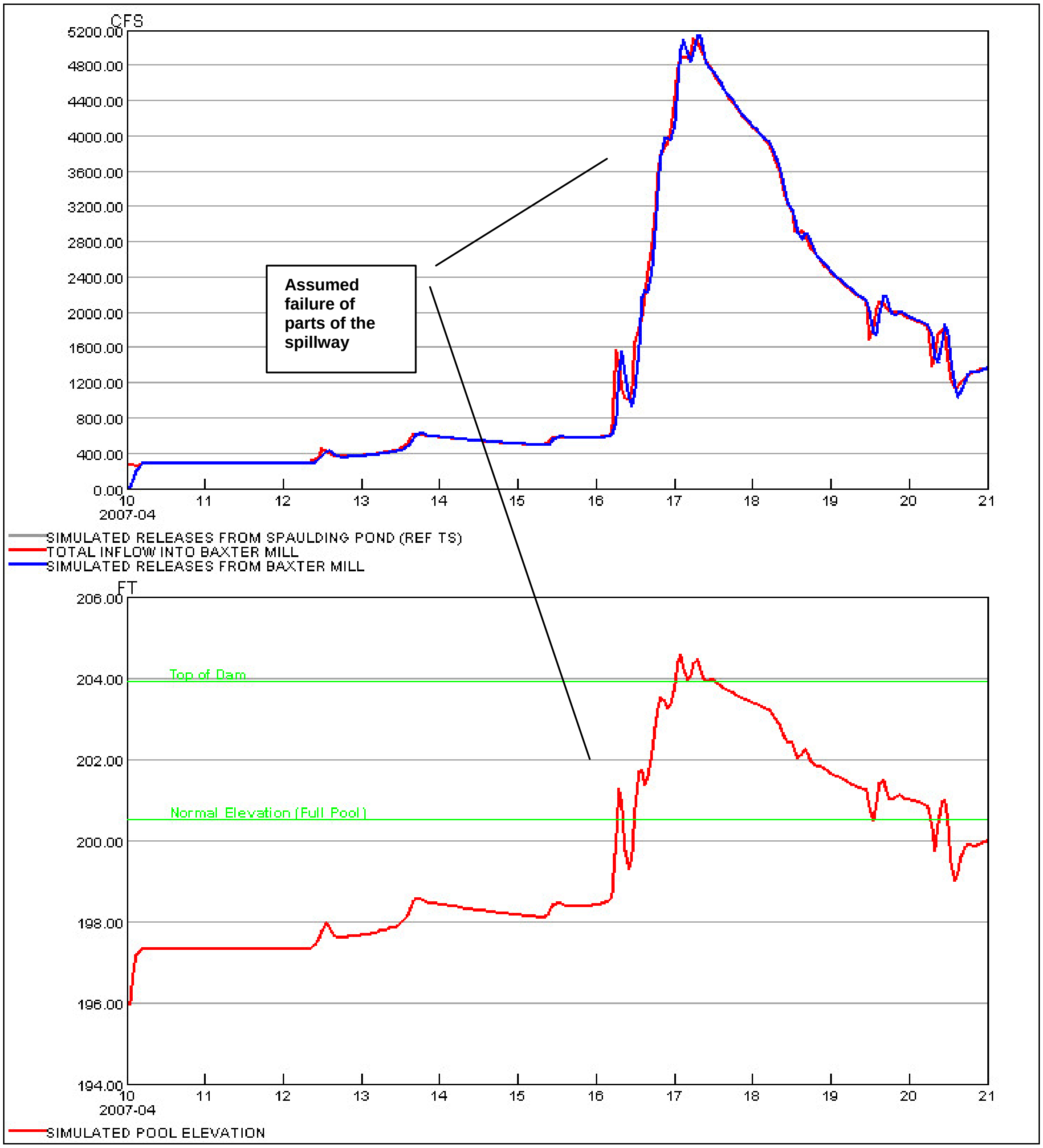


Figure 2-28: Baxter Mill Dam Simulation Results for the April 2007 Flood Event

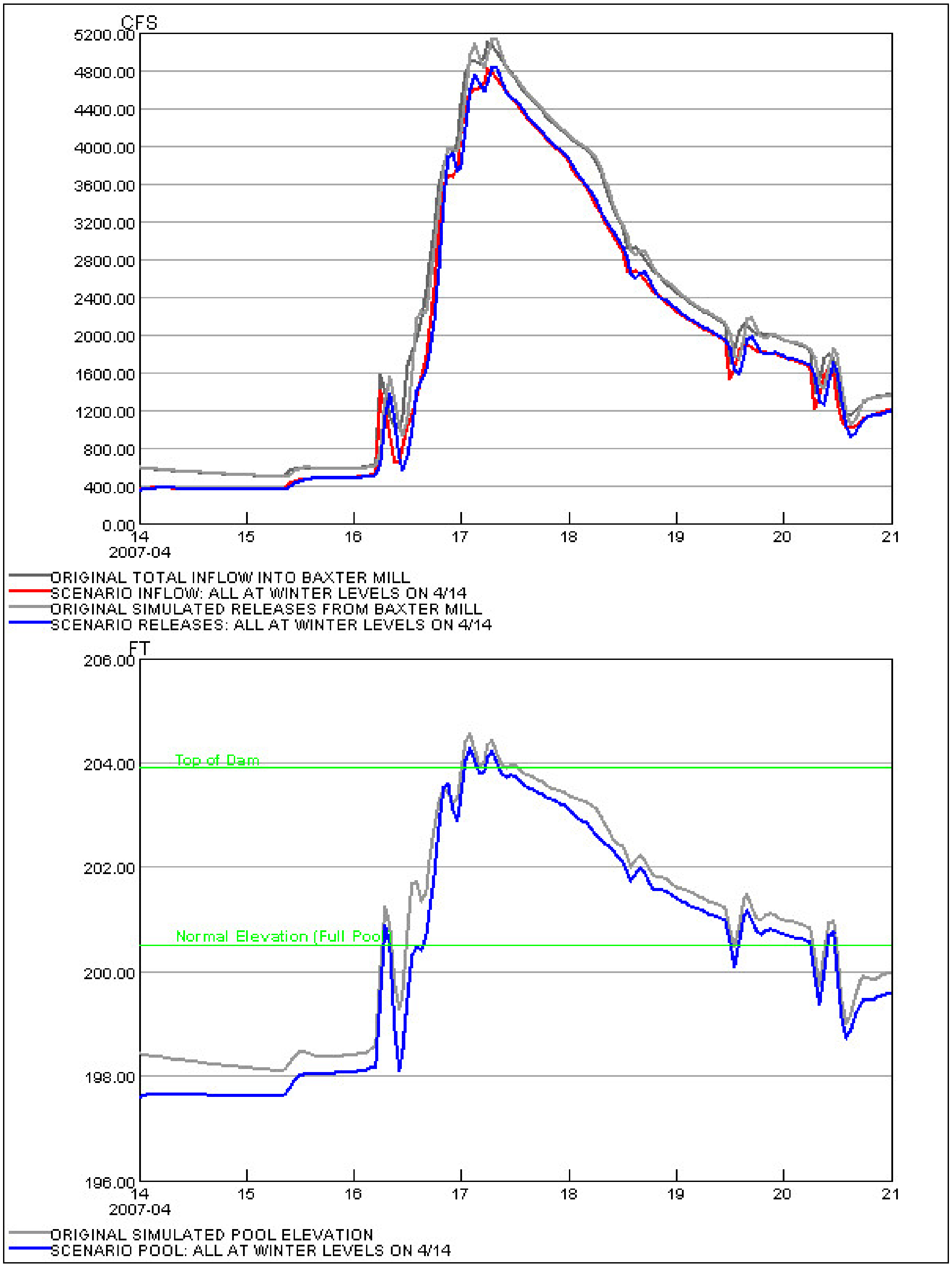


Figure 2-29: Baxter Mill Dam Alternative Operations - Starting at Minimum Pool on April 14

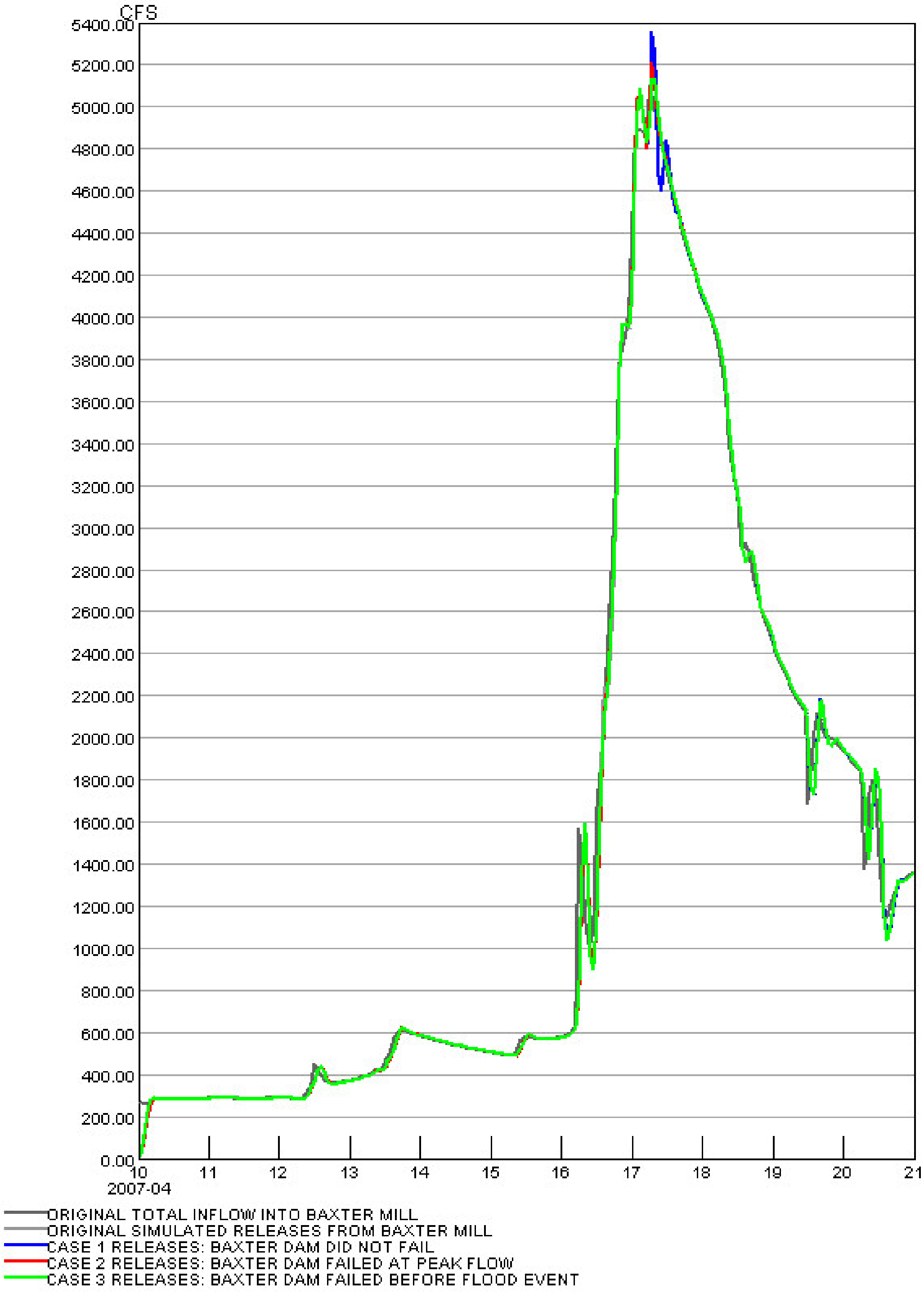


Figure 2-30: Baxter Mill Dam Alternative Operations - Spillway Failure (Flow)

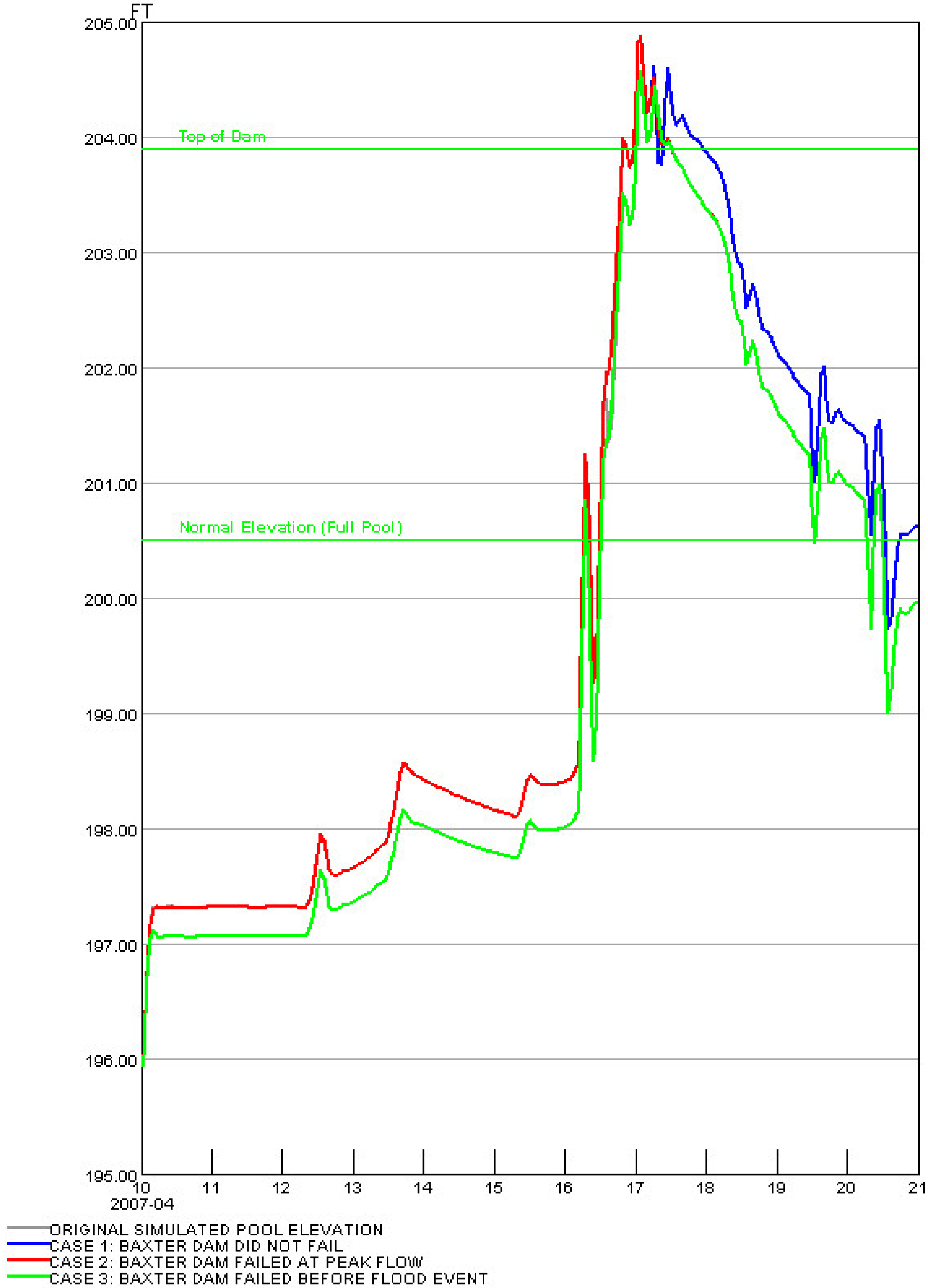


Figure 2-31: Baxter Mill Dam Alternative Operations - Spillway Failure (Pool)

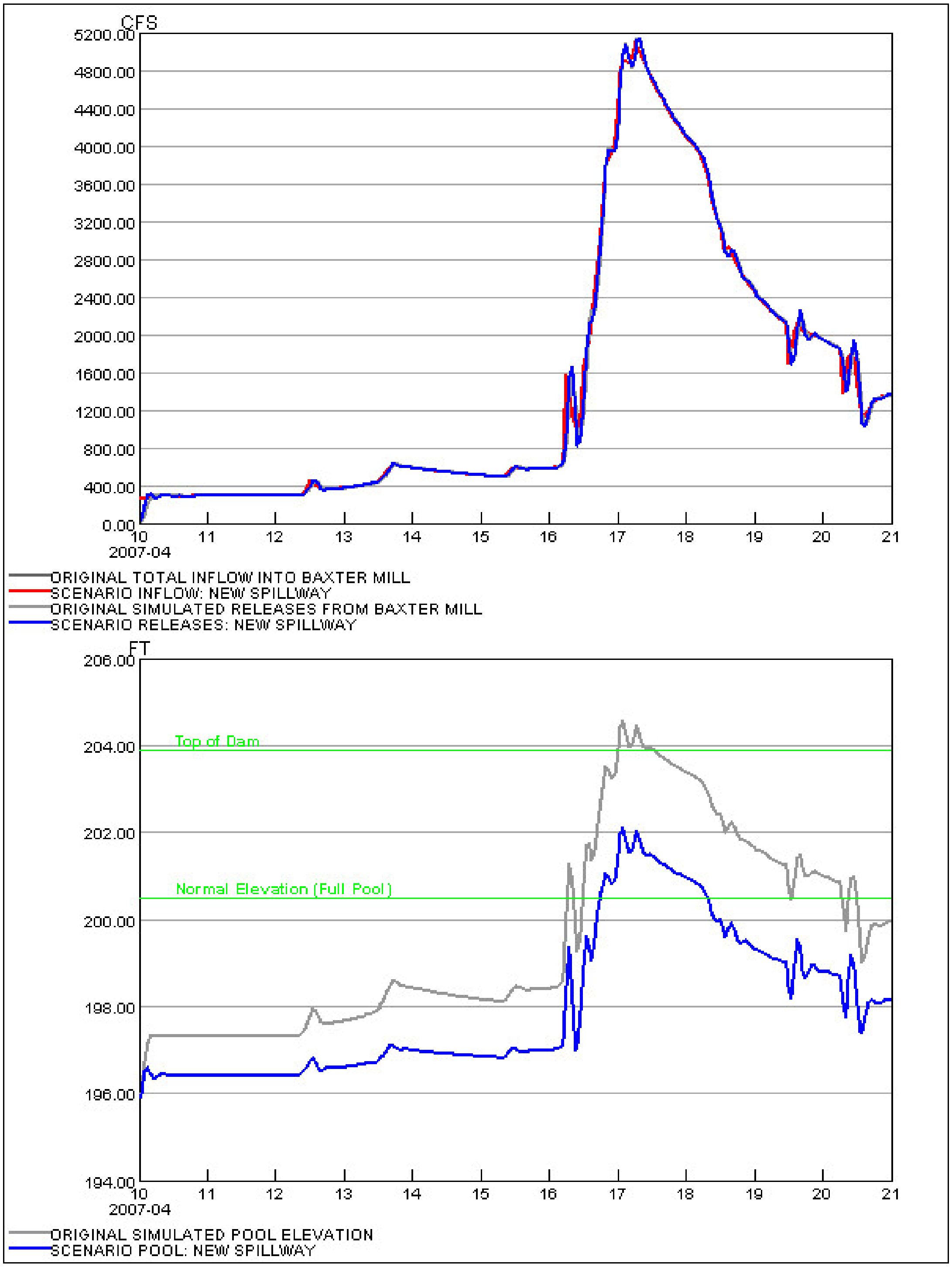


Figure 2-32: Baxter Mill Dam Alternative Operations - New Spillway

B-3.0 SUNCOOK RIVER

The return period of the April 2007 flood event on the Suncook River was close to 50 years, according flow observations near North Chichester. These are shown for the May 2006 and April 2007 events in Figure 3-1, including the FEMA 10, 50, 100, and 500 year flood flows.

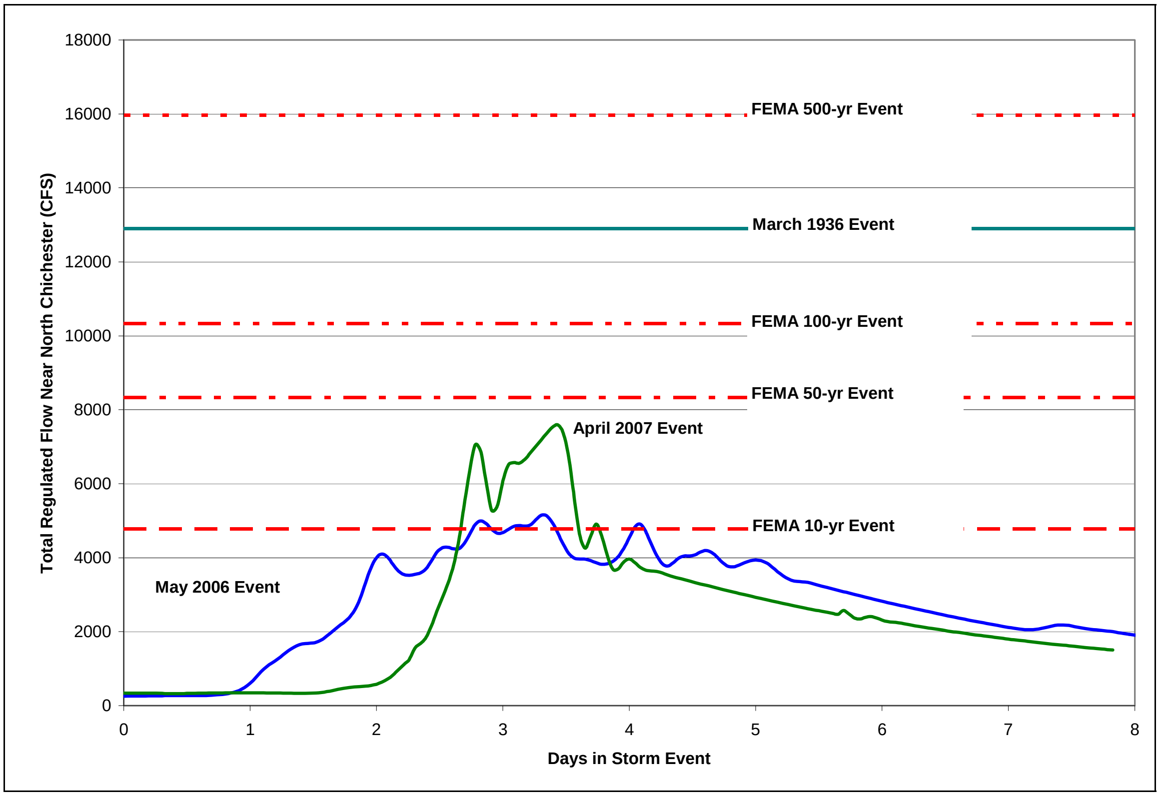


Figure 3-1: Suncook River - Comparison of May 2006 and April 2007 Events and FEMA Flood Levels

Figure 3-2 depicts the dams investigated in the Suncook River basin.

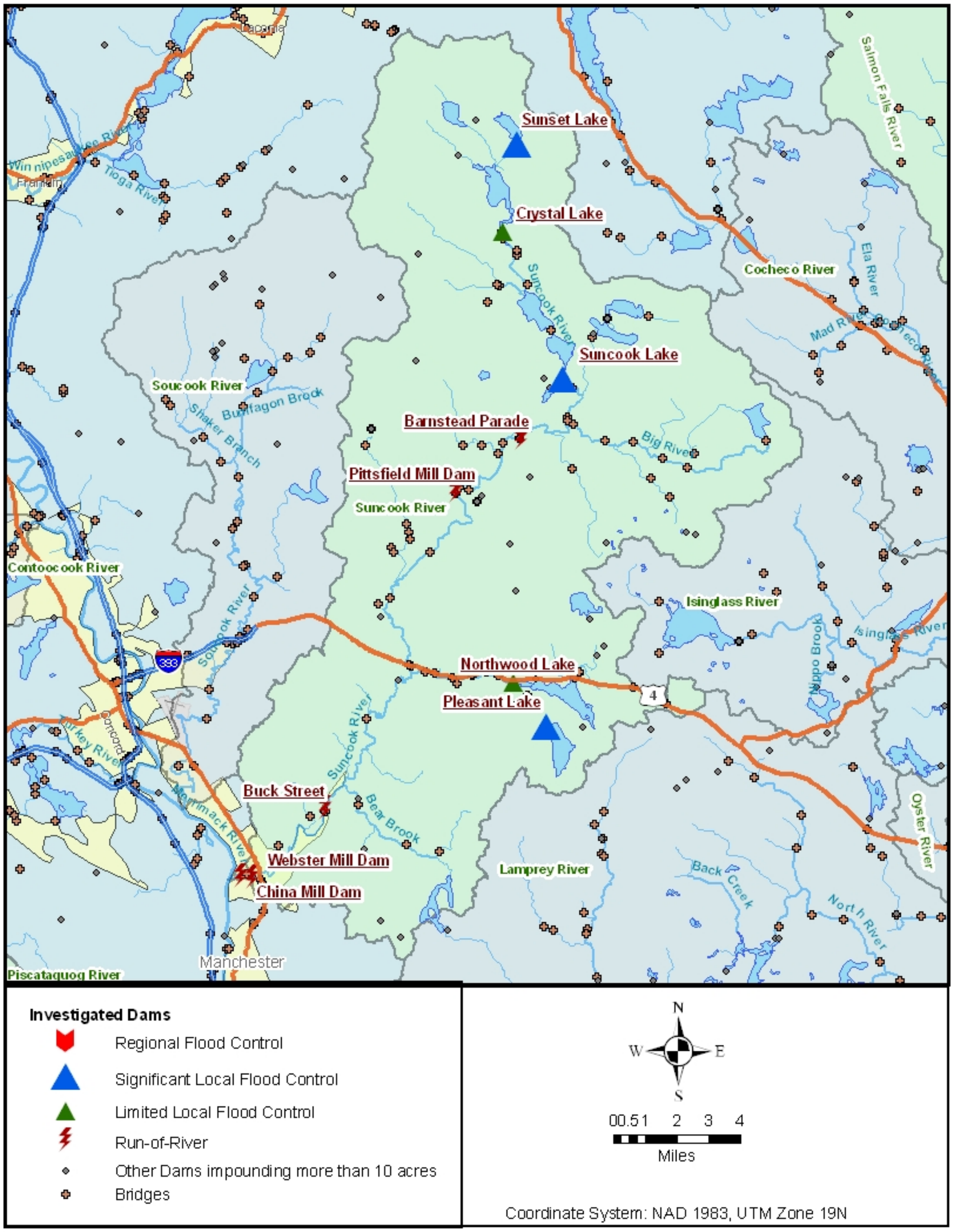


Figure 3-2: Dams Investigated in the Suncook River Basin

B-3.1 Sunset Lake (NHDES# 006.01)

B-3.1.1 General Description

Sunset Lake is located in the headwaters of the Suncook River. The lake shoreline is mostly undeveloped; the only major housing development is off the northeast shore of the lake.

Sunset Lake has a capacity of about 1,400 acre-feet at its normal elevation, and 1,860 acre-feet at its maximum elevation. Between those levels, Sunset Lake can store approximately 1.21 inches of runoff into the lake.

Pool elevations at Sunset Lake are controlled by NHDES staff at a dam structure at the southern end. Water levels can be controlled through two winter stoplog bays and two gates (made from stoplogs bolted together).

The typical summer lake elevation is 807.0 feet, which corresponds to the top of the spillway. After Columbus Day, the lake is drawn down seven feet from the full level. It requires approximately 4.9 inches of runoff to refill the lake from the lower winter pool to the normal summer pool. Given this, Sunset Lake can provide significant local flood control.

A plan view of Sunset Lake Dam is shown in Figure 3-3.

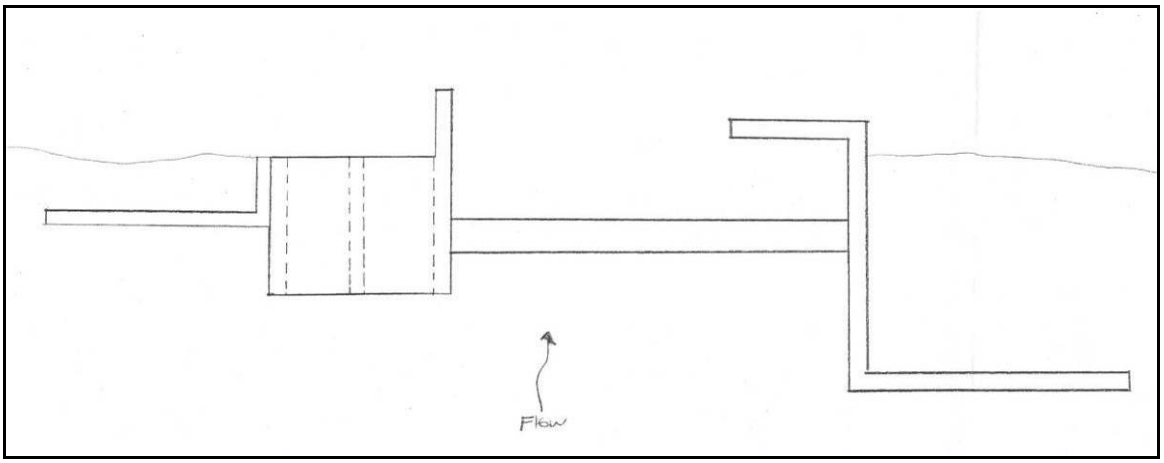


Figure 3-3: Plan View of Sunset Lake Dam

B-3.1.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 807.0 feet. Table 3-1 and Table 3-2 list the pool elevation and the dam operations performed by the NHDES at Sunset Lake.

Table 3-1: Sunset Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
5/1/2006	-2.10	CLOSED	CLOSED		PA
5/14/2006	1.75	CLOSED	CLOSED	LET RUN AS IS PER JG	PA
5/15/2006	1.9	CLOSED	CLOSED	LET RUN AS IS	PA
5/16/2006	1.6	CLOSED	CLOSED	LET RUN AS IS	PA
5/17/2006	0.85	CLOSED	CLOSED	WATER LEVEL COMING DOWN GOOD	PA

Table 3-2: Sunset Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
4/3/2007	-2.85	CLOSED	CLOSED		PA
4/13/2007	-1.15	OPEN 5"	CLOSED	ICE LOCKED BACK ONTO SHORELINE	PA
4/16/2007	1.2	OPEN 5"	CLOSED	RAIN EVENT/DAM CLEAR OF DEBRIS	PA
4/19/2007	0.75	OPEN 5"	CLOSED	WATER LEVEL COMING DOWN/ICE ON LAKE	PA
4/24/2007	0.4	OPEN 5"	CLOSED	ICE OUT	PA

For the duration of the May 2006 storm event, both gates remained closed. On May 1, the pool was 2.1 feet below the spillway crest. Inflows increased rapidly in response to the storm, and the spillway crest was overtopped by 1.75 feet on May 14. The maximum recorded height over the spillway was 1.9 feet, and occurred on May 15. This corresponds to 2.0 feet below the top of the dam. Upstream flooding was reported at this pool elevation. The pool was still 0.85 foot over the spillway on May 17.

Given the data available, opening the gates at the onset of the event might have helped minimizing upstream flooding; however, it might have worsened downstream flooding.

Sunset Lake was filling at the beginning of April 2007. Both gates were closed and the pool was 2.85 feet below the spillway on April 3. By April 13 the pool had risen to 1.15 feet below the spillway and the left gate was opened to 5 inches to release flows in anticipation of the event. The gates were not operated further during the event in order to provide downstream flood control for seriously endangered areas. This caused the pool to rise to a maximum recorded depth of 1.2 feet above the normal pool, which, according to the NHDES, does not cause upstream flooding problems. This elevation was 2.7 feet below the top of the dam. The pool elevation remained above the spillway crest, and was 0.4 foot over on April 24. The lake was not ice free until April 24.

The simulation for April 2007 is depicted in Figure 3-4 and tracks the observed pool elevations very well.

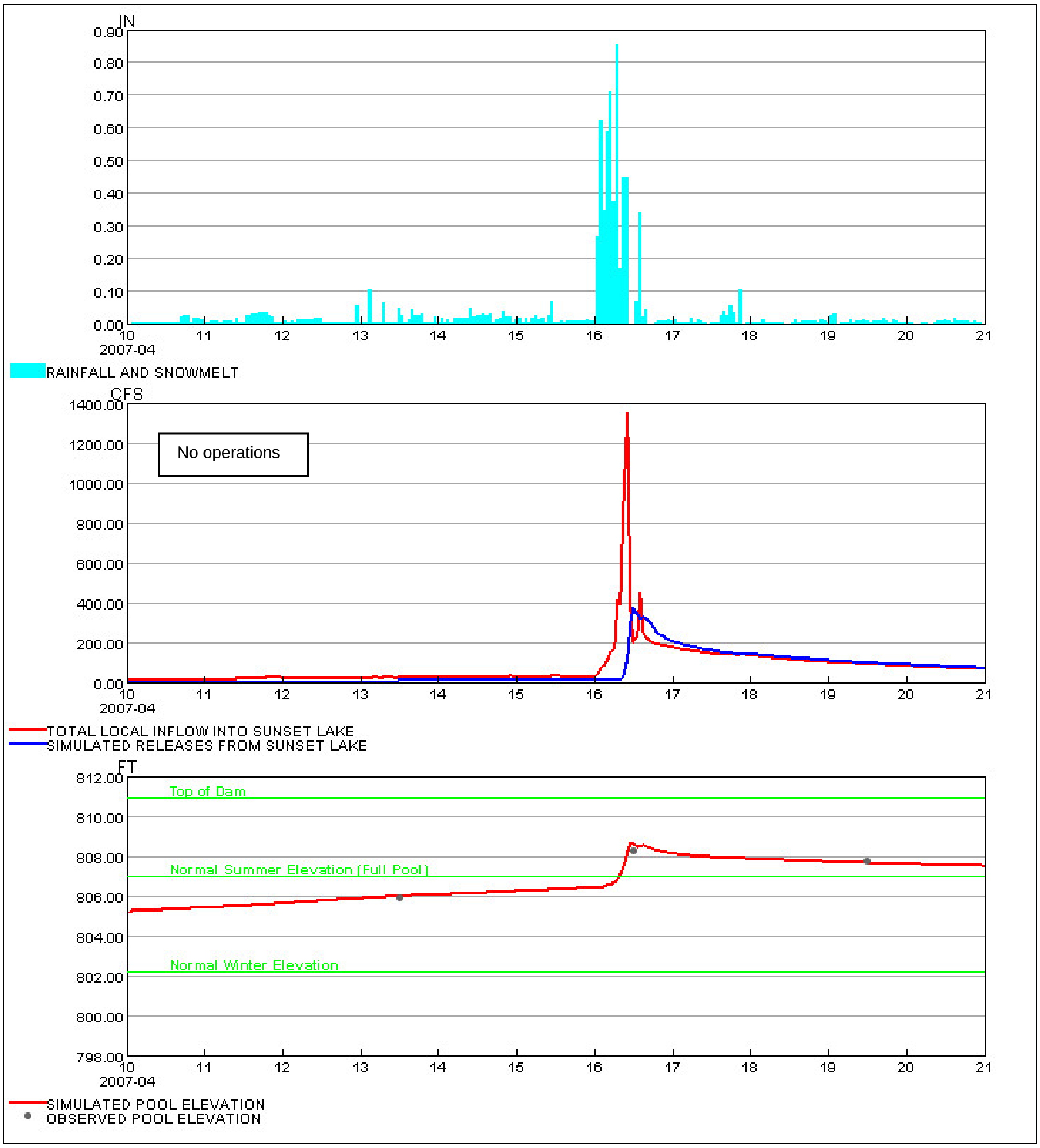


Figure 3-4: Sunset Lake Simulation Results for the April 2007 Flood Event

B-3.1.3 Alternative Operations

A simulation of Sunset Lake with the pool elevation at the winter drawdown level on April 14 was run and is shown in Figure 3-5. All other operations were assumed to be unchanged. Given these alternative operations, Sunset Lake would have been able to significantly reduce the April 16, 2007, peak release from approximately 370 cfs to 20 cfs.

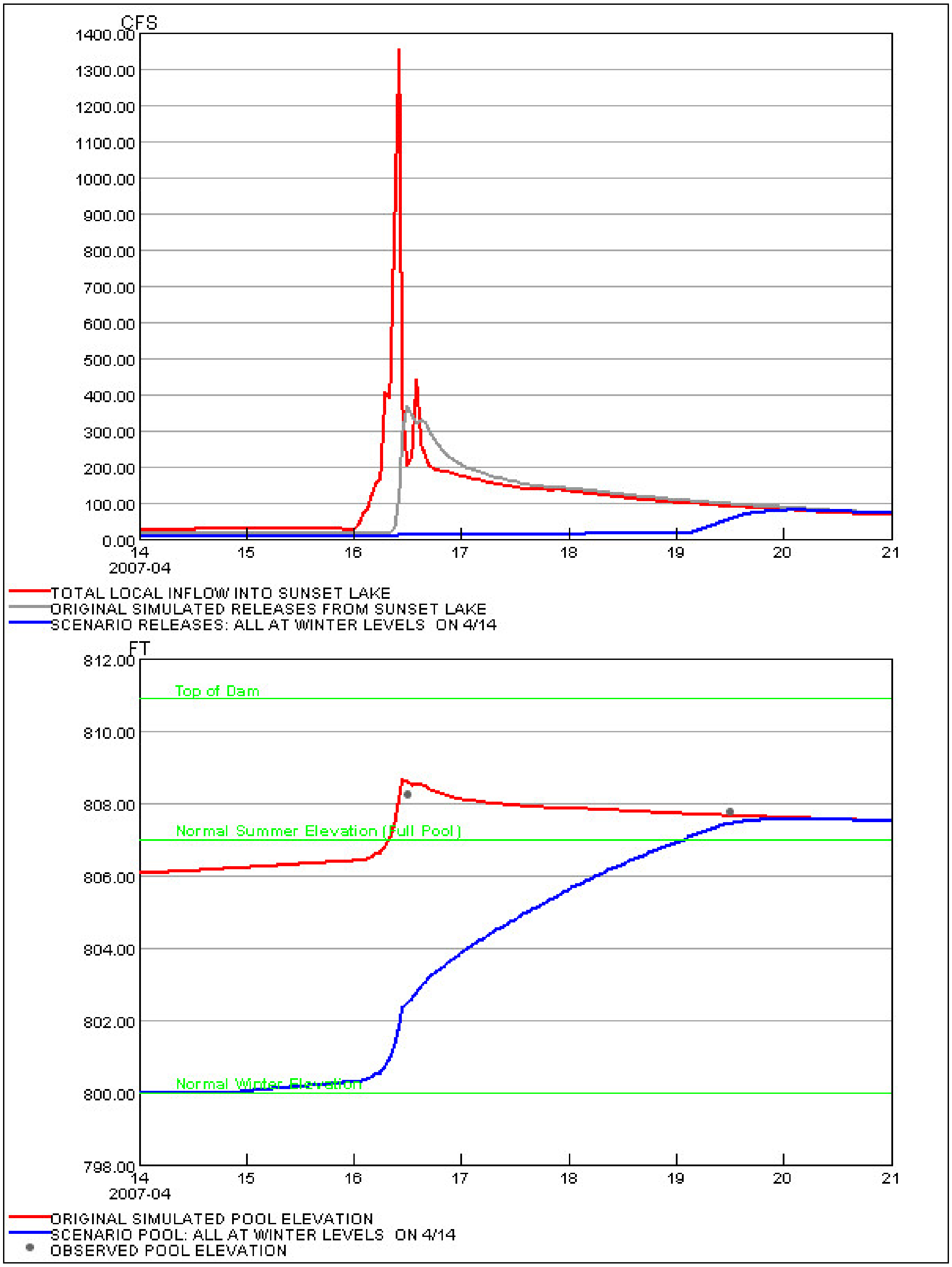


Figure 3-5: Sunset Lake Alternative Operations - Starting at Minimum Pool on April 14

B-3.2 Crystal Lake (NHDES# 091.11)

B-3.2.1 General Description

Crystal Lake is located on the Suncook River, downstream of Sunset Lake, to the west of Alton. There are well-spaced housing developments around the majority of the lake.

Crystal Lake has a capacity of about 1,400 acre-feet at its normal elevation, and 3,500 acre-feet at its maximum elevation. Between the normal and maximum levels, Crystal Lake can store approximately 1.44 inches of runoff. Pool elevations at Crystal Lake are controlled by NHDES staff using one stoplog bay at the dam structure.

The typical summer lake elevation is 623.19 feet, which corresponds to the top of the spillway. After Columbus Day, the lake is drawn down towards a target of three feet; however, this target is not met in most years. It requires approximately 2.24 inches of runoff to refill the lake from the lower winter pool to the normal summer pool. Given this, Crystal Lake can provide limited local flood control.

A plan view and photograph of Crystal Lake Dam are shown in Figure 3-6 and Figure 3-7.

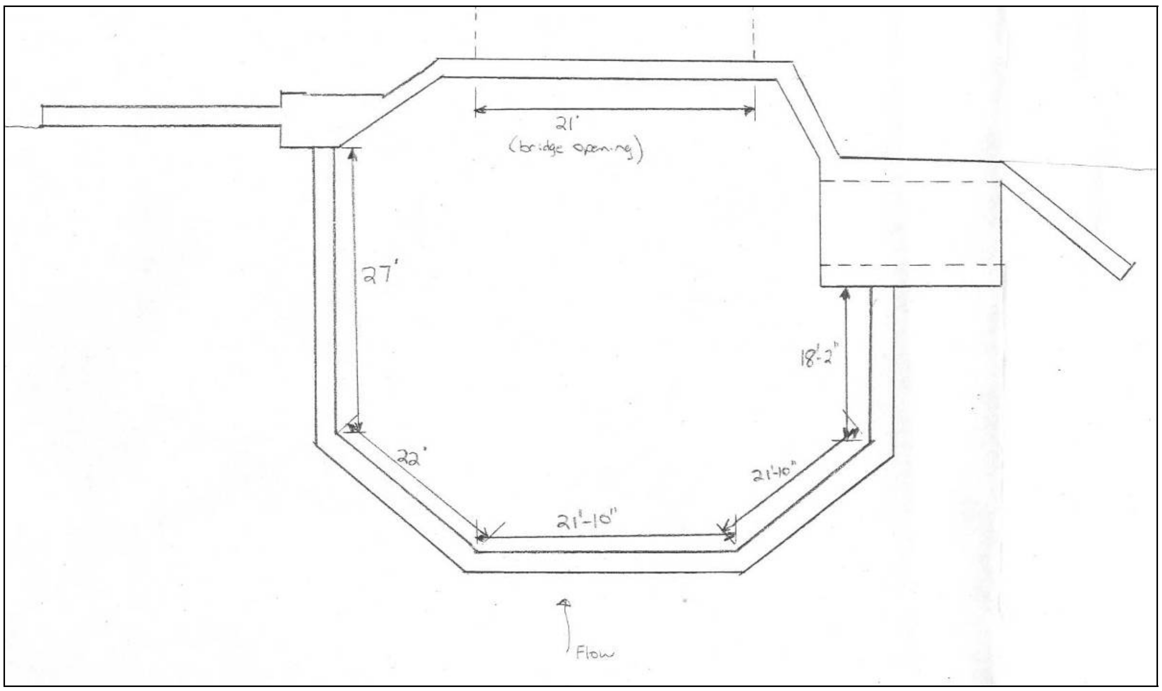


Figure 3-6: Plan View of Crystal Lake Dam

B-3.2.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 623.19 feet. Table 3-3 and Table 3-4 list the pool elevation and the dam operations performed by the NHDES at Crystal Lake.

All stoplogs were in place on May 1, 2006 and the pool was 0.10 foot below the spillway crest. On May 12, two days before peak runoff occurred, the pool was 0.12 foot below the spillway and two stoplogs were removed. During peak runoff on May 14 a total of three stoplogs were out. At this time the pool elevation reached its maximum recorded height of 3.0 feet over the spillway crest, 1.7 feet below the top of the dam. At this time the flows over the stoplogs inhibited any additional operations. As the storm abated the pool elevation dropped 1.0 foot and on May 16 three more stoplogs could be removed. Pool elevation continued to drop and on May 20 four stoplogs were set in place with the pool elevation 0.4 foot above the spillway crest.

Figure 3-7: Photograph of the Crystal Lake Dam Spillway

Table 3-3: Crystal Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY	COMMENTS	INT
5/1/2006	0.10	ALL IN	CLEAR	PA
5/12/2006	0.12	2 OUT	PULLED 2 LOGS/CLEAR	PA
5/14/2006	3	3 OUT	RAIN EVENT/PULLED ONE LOG	PA
5/15/2006	2.5	3 OUT	CLEAR	PA
5/16/2006	2	3 OUT	WATER LEVEL DROPPED .50 OVER NIGHT	PA
5/17/2006	1.1	6 OUT	PULLED 3 MORE LOGS	PA
5/20/2006	0.4	2 OUT	SET 4 LOGS	PA

Table 3-4: Crystal Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY	COMMENTS	INT
4/3/2007	-1	5 OUT	LET RUN FOR NOW/KEEP EYE ON LEVEL	PA
4/13/2007	-1.15	6 OUT	PULLED ONE LOG/ICE STILL TIGHT	PA
4/16/2007	2.6	6 OUT	RAIN EVENT/DAM CLEAR	PA
4/19/2007	0.9	6 OUT	CLEAR/ICE STILL ON LAKE	PA

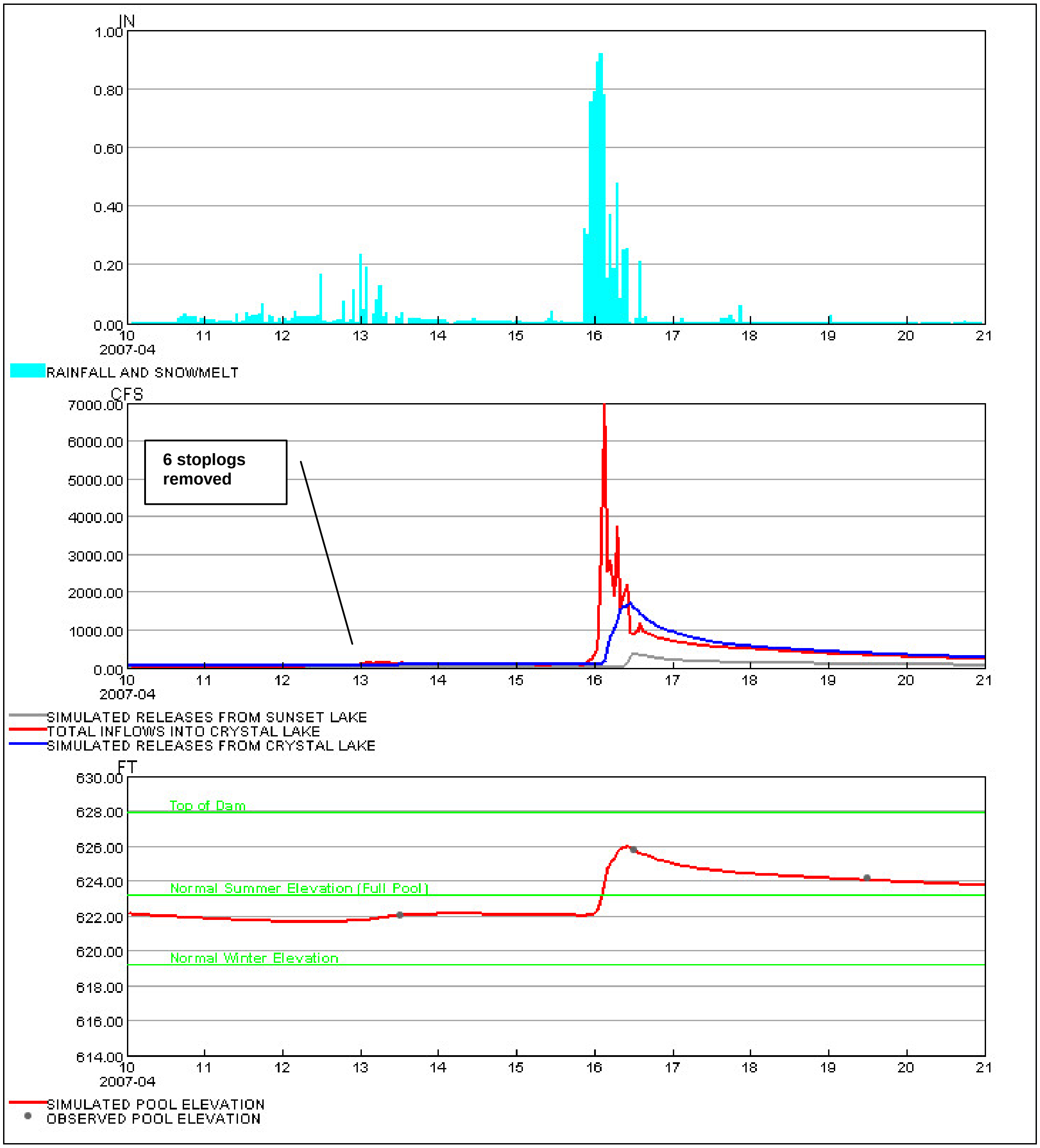


Figure 3-8: Crystal Lake Simulation Results for the April 2007 Flood Event

Prior to the April 2007 event, the NHDES tried to keep the pool of Crystal Lake constant to prevent the ice on the lake to cause damage to the shores. On April 3 the pool was 1.0 foot below the spillway crest, and on April 13 the pool was 1.15 feet below. NHDES operators were able to remove six of ten stoplogs on April 13 in anticipation of the event. This kept the pool elevation constant until April 16, when heavy precipitation and snowmelt quickly filled the lake to its maximum recorded height of 2.6 feet above the spillway. This was 2.10 feet below the top of the dam. At this time, however, no more operations were possible, as the remaining stoplogs were submerged by about 6 feet of water. This caused flooding at an upstream road and residences. However, Crystal Lake provided appreciable downstream flood control as the peak of the inflows (most of which were generated below Sunset Lake) was stored.

The simulation for April 2007 is depicted in Figure 3-8 and tracks the observed pool elevations very well.

B-3.2.3 Alternative Operations

A simulation of Crystal Lake with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 3-9. All other operations were assumed to be unchanged. All upstream reservoirs were also maintained at the winter level until April 14 for this simulation. Starting at the minimum pool on April 14, another 2.3 feet below the original starting pool, would have reduced the maximum pool elevation reached by approximately 0.25 ft. The maximum releases on April 16 could have been reduced by almost 25 percent (from an actual 1700 cfs to 1300 cfs).

An alternative scenario investigated assumed that the existing stoplogs were replaced with a gate of similar dimensions. The simulation included dam operations that opened the gate at 1 p.m. on April 12 2007, just when a regional flood outlook implying possible flooding within the next five days was issued by the NWS. Figure 3-10 demonstrates that this would have significantly lowered the pool elevation by the start of the event and would have lowered the peak pool elevation reached by more than half a foot. Peak releases on April 16 would have been reduced from approximately 1700 cfs to approximately 1400 cfs.

Since upstream flooding is a concern at this site, a small reduction in the pool elevation could have an impact on the local residences.

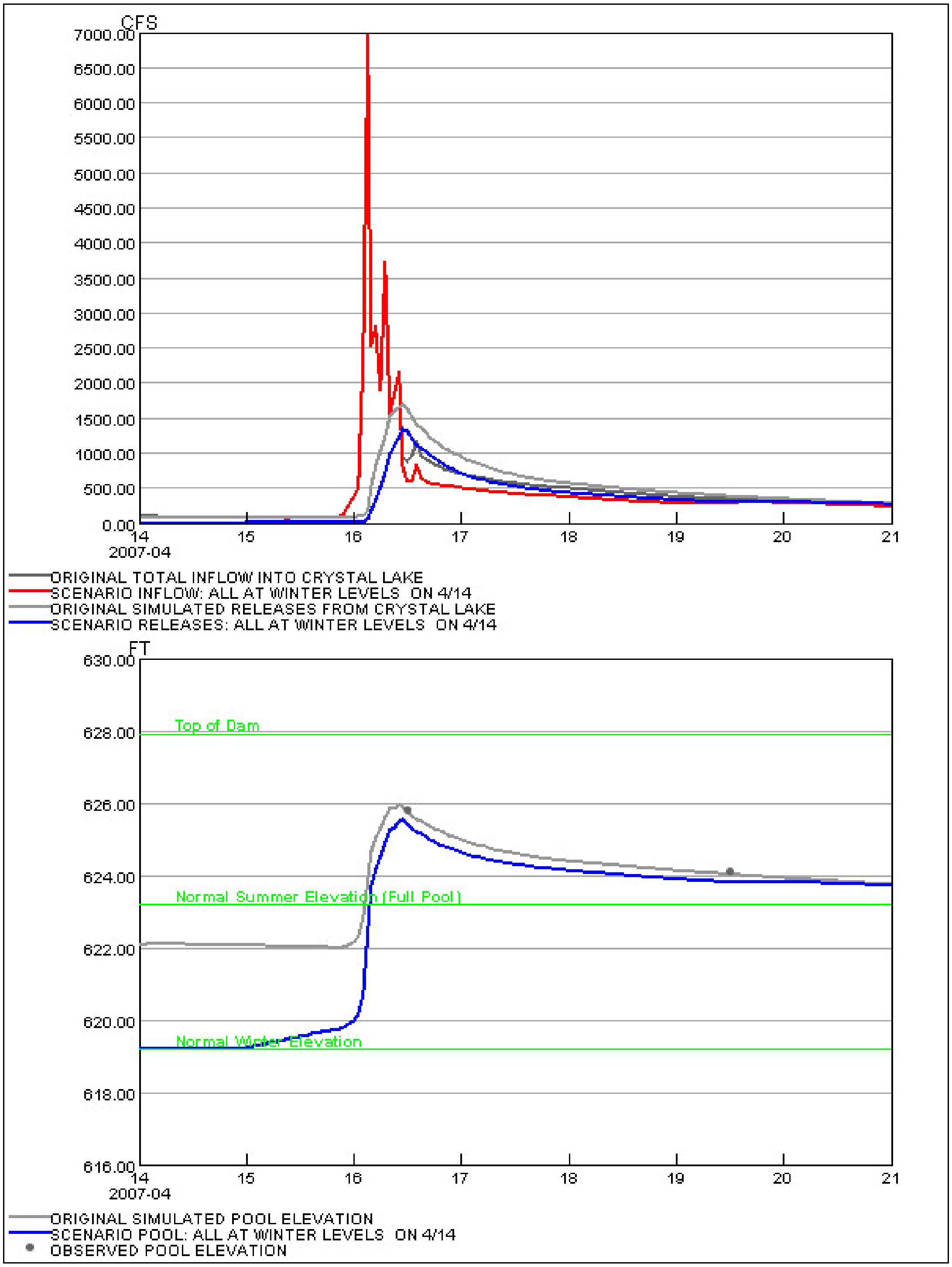


Figure 3-9: Crystal Lake Alternative Operations - Starting at Minimum Pool on April 14, 2007

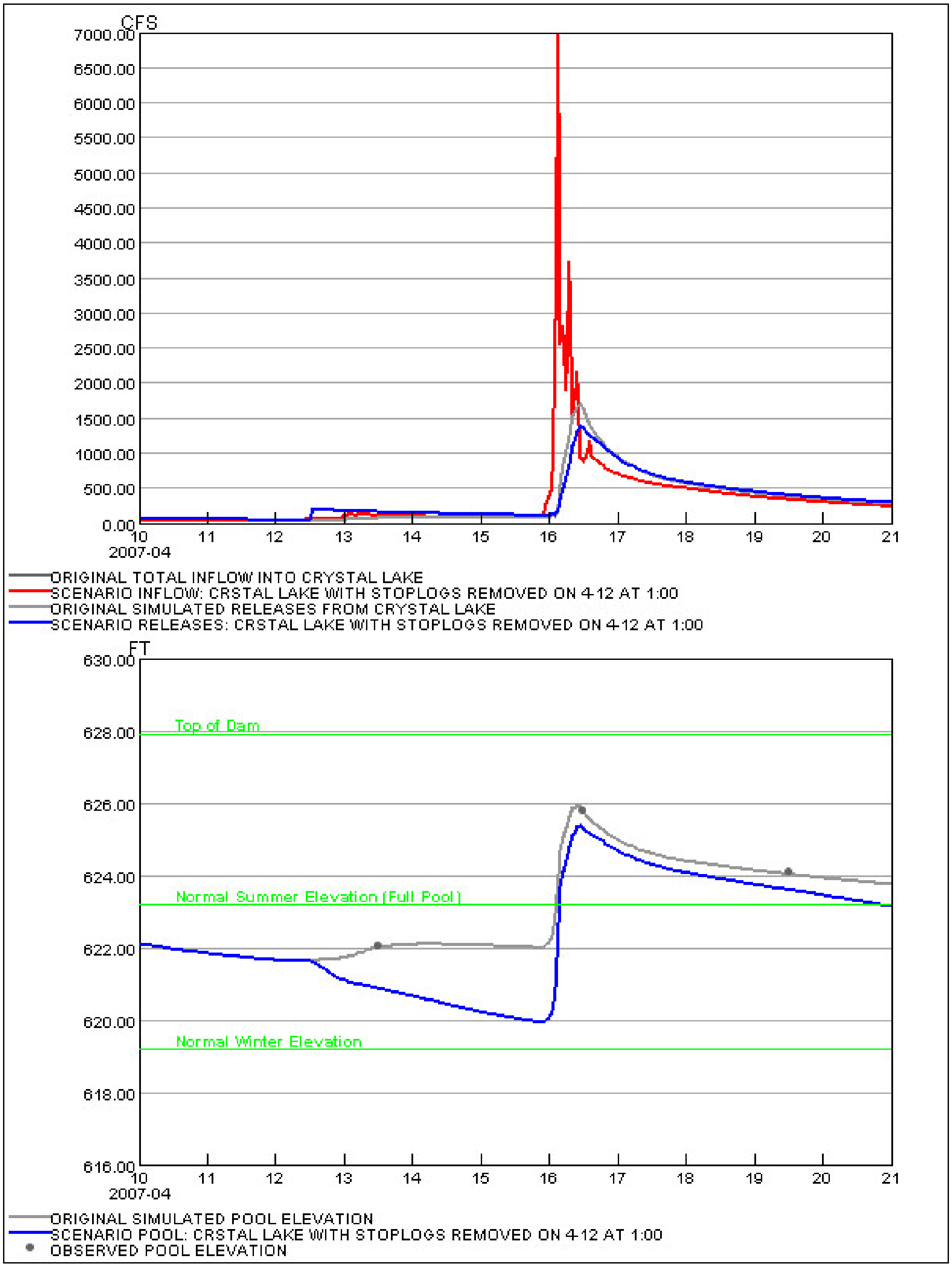


Figure 3-10: Crystal Lake Alternative Operations - New Gate (in place of stoplogs) opened April 12, 2007

B-3.3 Suncook Lake (NHDES# 014.03)

B-3.3.1 General Description

Suncook Lake is split into an upper and lower portion. Most of the shoreline is developed on the lower lake, and about half on the upper lake. The lake has a storage capacity of about 1,617 acre-feet at normal levels, and up to 7,917 acre-feet at its maximum elevation. Between those levels, Suncook Lake can store about 2.15 inches of runoff.

The pool elevation can be controlled by NHDES staff at a small dam structure at the southeastern edge of the lower lake in Gilmanton. The water level is controlled by opening the gates at the dam.

Typically, the lake level is maintained full (its 'normal level'), during the summer months. This elevation is 550.75 feet. Drawdown for Suncook Lake generally begins around October 1. The full drawdown of five feet is reached by Columbus Day in most years.

A narrow canal and a bridge divide the upper and lower portions of Suncook Lake. This can cause lake elevations to differ in the upper and lower parts. The water level in the lower portion of the lake is therefore two to three feet lower then the lake level in the upper portion during winter operations. It requires 1.09 inches of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view of Suncook Lake Dam is shown in Figure 3-11.

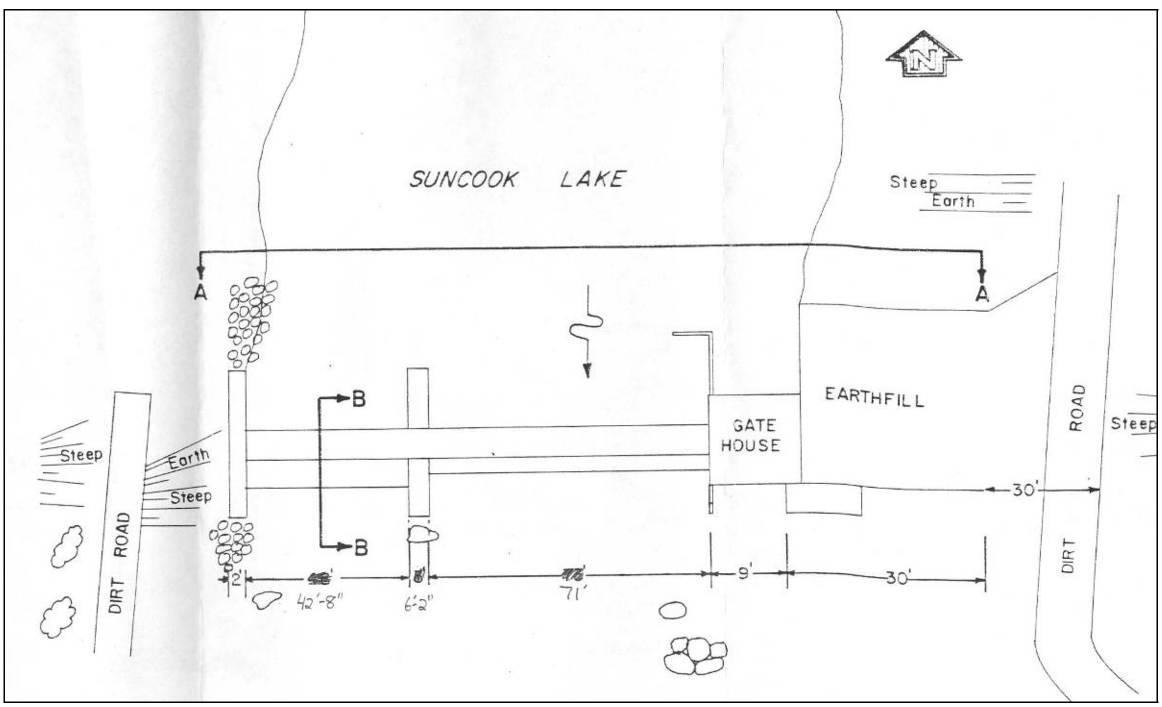


Figure 3-11: Plan View of Suncook Lake Dam

B-3.3.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevations are recorded relative to the summer lake elevation of 550.75 feet. Table 3-5 and Table 3-6 list the pool elevation and the dam operations performed by the NHDES at Suncook Lake.

Table 3-5: Suncook Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	TIME	DAM POOL ELEVATION	LAKE POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
5/1/2006		0.08	-0.10	CLOSED	CLOSED		PA
5/8/2006		0.25		CLOSED	CLOSED		AS
5/12/2006			-0.15	CLOSED	CLOSED		PA
5/14/2006		2.1	HIGH	FULL OPEN	FULL OPEN	RAIN EVENT/DAM CLEAR	PA
5/15/2006		2.35		FULL OPEN	FULL OPEN	FREE BOARD ON LEFT SIDE= 1.80	PA
5/16/2006	AM	2	1.8	FULL OPEN	FULL OPEN	DAM CLEAR/COMING DOWN SLOW	PA
5/16/2006	PM	1.9		FULL OPEN	FULL OPEN	MINUS 19"OFF OF CONCRETE	CL
5/17/2006		1.7	1.5	FULL OPEN	FULL OPEN	DROPPING GOOD	PA
5/20/2006		0.5	0.8	2 FEET OPEN	2 FEET OPEN	CLOSED BOTH GATES TO 2 FEET OPEN	PA
5/22/2006		0.4		2 FEET OPEN	2 FEET OPEN	LET RUN	PA

Table 3-6: Suncook Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	TIME	DAM POOL ELEVATION	LAKE POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
3/27/2007		-5.5	-2.85	2 FEET OPEN	OPEN FULL	CLOSED ONE GATE TO 2 FEET OPEN	AS
						ICE STILL ON UPPER AND LOWER PONDS TURNING GRAY IN COLOR	
4/3/2007		-3.25	-2.4	2 FEET OPEN	OPEN FULL	LET RUN/ICE PULLING AWAY FROM SHORE	PA
4/13/2007		-4.6	-3.2	2 FEET OPEN	OPEN FULL	CHOPPY/WINDY	PA
4/16/2007	6PM	0.3	0	2 FEET OPEN	OPEN FULL	RAIN EVENT	PA
4/16/2007	9PM	2		2 FEET OPEN	OPEN FULL		PA
4/17/2007		1.9		2 FEET OPEN	OPEN FULL	COMING DOWN	PA
4/19/2007		1.3	2	OPEN FULL	OPEN FULL	SOME DEBRIS IN GATES/CLEAR OUT WHEN WATER LEVEL IS DOWN	PA

Both the left and right gates were closed on May 1, 2006 and the pool was 0.08 foot above the spillway. Pool elevation had risen to 0.25 foot above the spillway on May 8. Lake inflows peaked on May 14, at which time both gates were fully opened. The pool elevation reached a maximum of 2.35 feet over the spillway crest on May 15. This was 0.82 foot below the top of the dam. The gates remained fully open until May 20, when the openings were reduced to 2 feet. At this time the pool was 0.5 foot over the spillway crest. Some damage was reported at an upstream campground during the storm event.

The Lower Suncook Lake was close to its maximum winter drawdown during the first half of April 2007. The pool was 3.25 feet below the spillway on April 3. The pool had dropped to 4.6 feet below the spillway on April 13. The dam was not operated until April 19 to provide some flood control downstream while not causing upstream flooding at the same time. Not fully opening all the gates caused Sunset Lake to rise to about 2 feet above normal pool on April 16, which was 1.17 feet below the top of the dam. Some upstream flooding occurred according to verbal complaints received by the NHDES. However, large portions of the inflows were stored and thus Sunset Lake provided significant downstream flood control.

The constriction between the upper and the lower lake often minimizes the impact of operations at the dam (at the lower portion) on the upper lake. Thus, flooding might occur along the shore of the upper lake even though the dam is discharging at its maximum capacity.

This complicates modeling the Suncook Lakes. The observed pool elevations could not be exactly reproduced—however, the general trend is captured as shown in Figure 3-12.

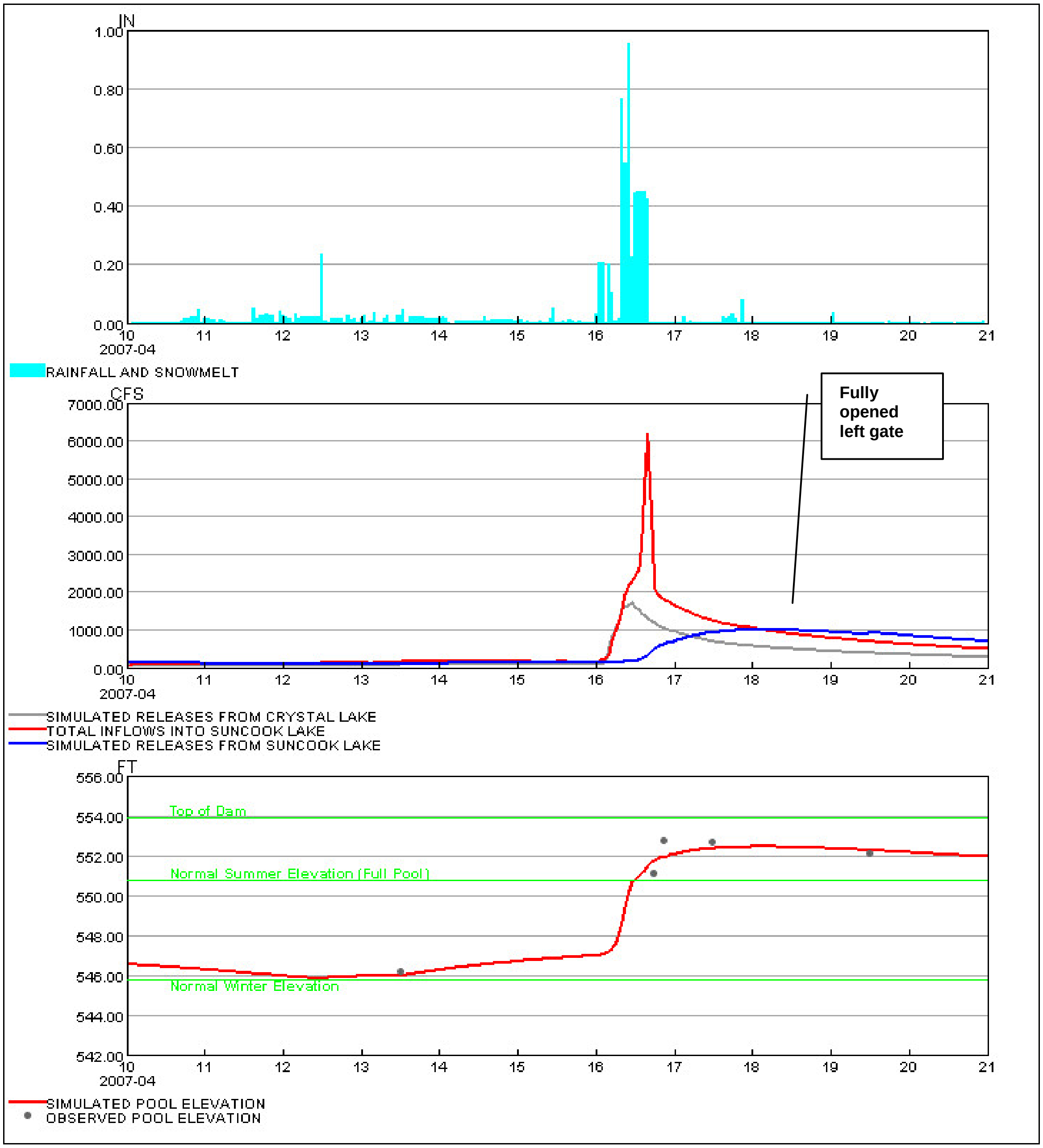


Figure 3-12: Suncook Lake Simulation Results for the April 2007 Flood Event

B-3.3.3 Alternative Operations

A simulation of Suncook Lake with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 3-13. All other operations were assumed to be unchanged. All upstream reservoirs were also maintained at the winter level until April 14 for this simulation.

Before the April 2007 event, Suncook Lake was already near the winter drawdown. Therefore little additional flood control was gained by maintaining the winter drawdown longer. The maximum pool elevation would have been slightly reduced by starting at the winter pool elevation. Similarly, the maximum releases between April 16 and April 17 would have been reduced from approximately 1000 cfs to approximately 750 cfs. Considering that upstream flooding was a problem, this small reduction could be significant.

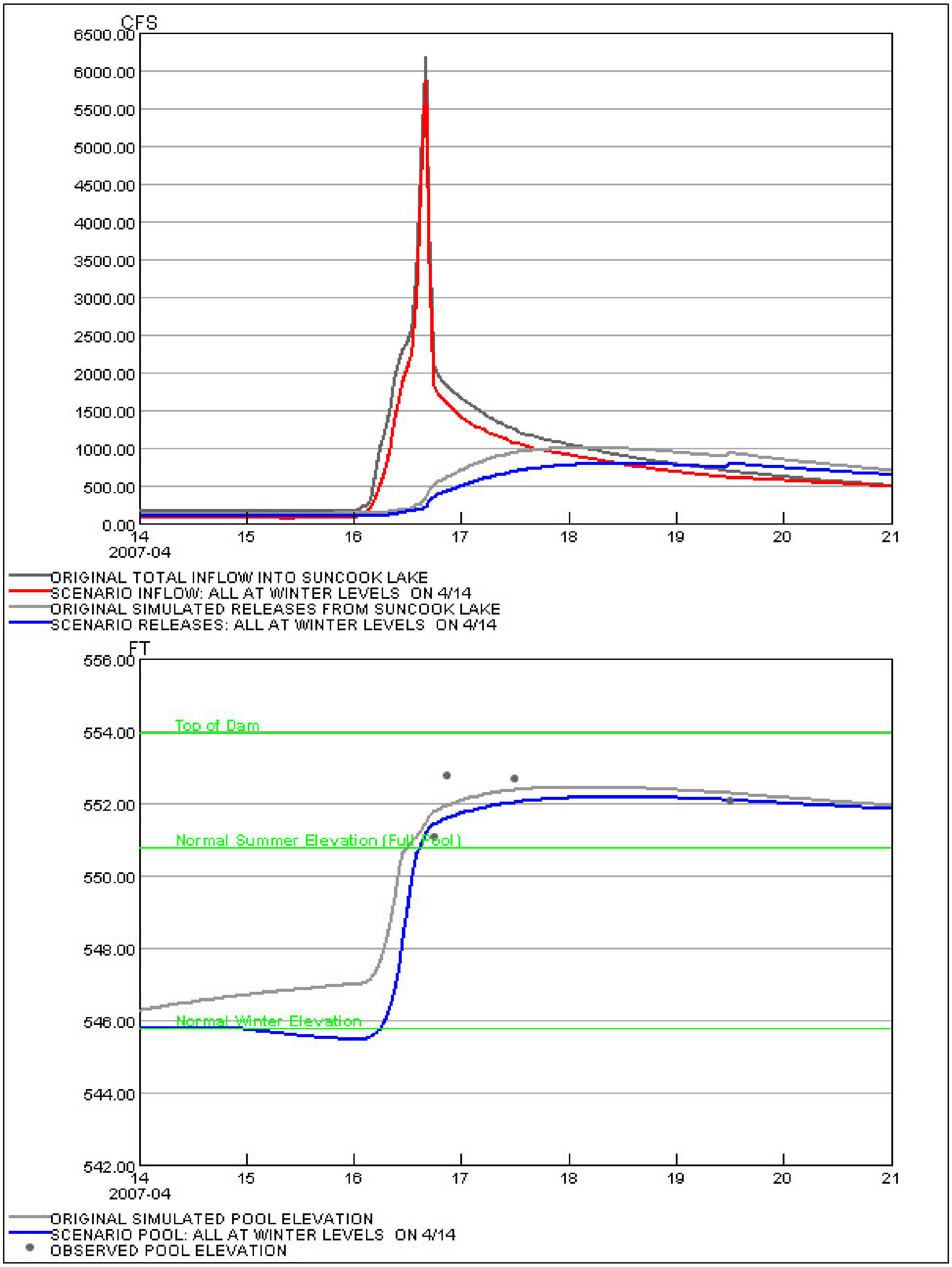


Figure 3-13: Suncook Lake Alternative Operations - Starting at Minimum Pool on April 14

B-3.4 Barnstead Parade (NHDES# 014.08)

B-3.4.1 General Description

Barnstead Parade is a run-of-river project located directly upstream of the town of Barnstead. The lakeshore on the northern side, along Parade Hill Road, is mostly developed. The impounded area is a small pond, located directly on the Suncook River. It has a storage capacity of 550 acre-feet at normal levels, and up to 1,000 acre-feet at its maximum elevation. Between those levels, Barnstead Parade can store about 0.08 inch of runoff.

The pool elevations are controlled by NHDES staff at a dam structure located in the town of Barnstead. This is typically done by manual operation of a gate, a stoplog bay, and flashboards. The normal lake elevation is 494.36 feet, which corresponds to the top of the flashboards at the dam. After Columbus Day, drawdown begins and the lake level is lowered by 1.5 feet.

A plan view and photograph of Barnstead Parade Dam are shown in Figure 3-14 and Figure 3-15, respectively.

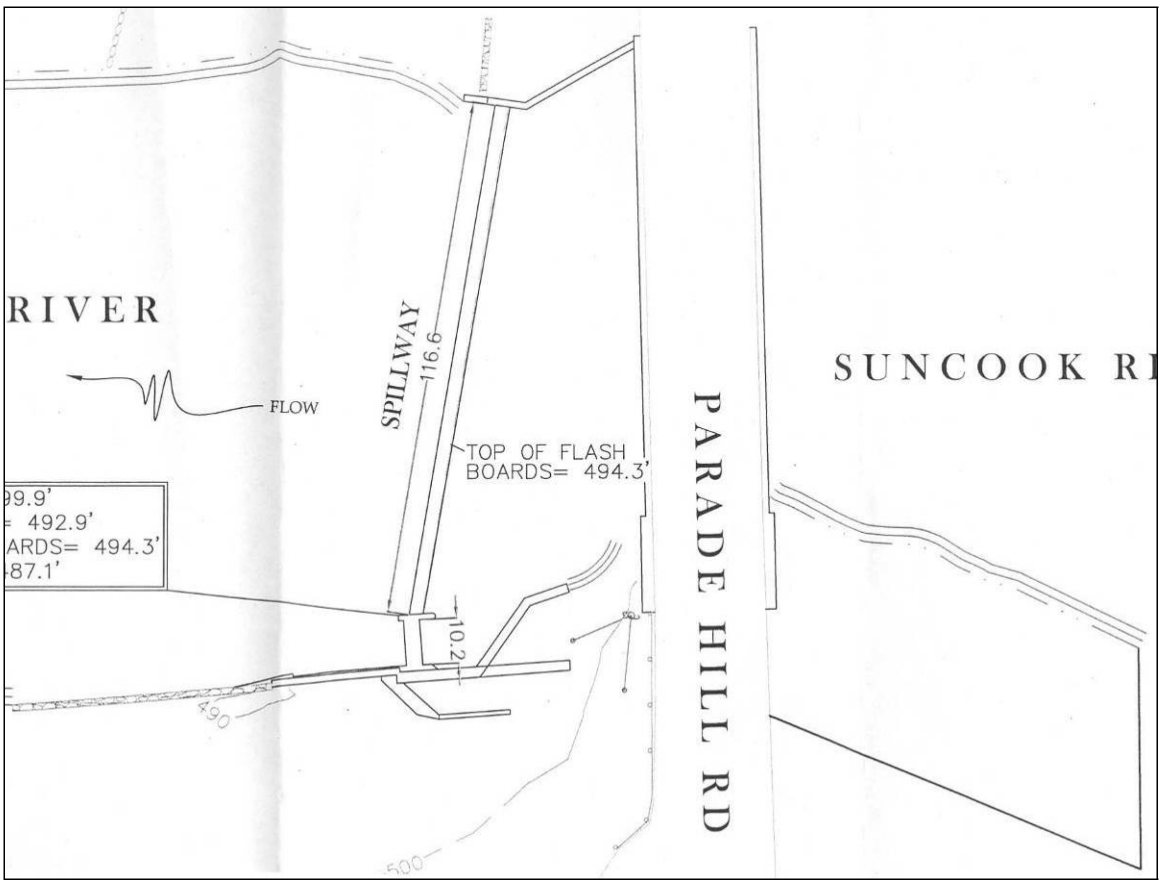


Figure 3-14: Plan View of Barnstead Parade Dam

Figure 3-15: Photograph of Barnstead Parade Dam

B-3.4.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 494.36 feet. Table 3-7 and Table 3-8 list the pool elevation and the dam operations performed by the NHDES at Barnstead Parade.

Table 3-7: Barnstead Parade Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	GATE	LOG BAY	SPILLWAY/FLASHBOARD CONDITION	COMMENTS	INT
5/1/2006	0.38	GATE CLOSED	ALL IN	FLASH BOARDS UP		PA
5/8/2006	0.45	GATE CLOSED	ALL IN			AS
5/12/2006	0.45		3 OUT		PULLED 3 LOGS/CLEARED DEBRIS	PA
5/14/2006	3	GATE FULL OPEN	3 OUT	FLASH BOARDS OPERATED IN		
				MIDDLE SECTION APROX. 40 FEET	RAIN EVENT	PA
5/15/2006	3	GATE FULL OPEN	3 OUT		RIGHT WALL=2.00' OF FREEBOARD	PA
5/16/2006	3.25	GATE FULL OPEN	3 OUT		COMING DOWN	PA
5/17/2006	2.75	GATE FULL OPEN	3 OUT	ALL OF F/B'S OPERATED OVERNIGHT	COMING DOWN	PA
5/20/2006	1.75	GATE FULL OPEN	3 OUT		CLEAR/LET RUN	PA
5/22/2006	-1.2	GATE FULL OPEN	3 OUT		LET RUN	PA

Table 3-8: Barnstead Parade Pool Elevation and Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	GATE	LOG BAY	SPILLWAY/FLASHBOARD CONDITION	COMMENTS	INT
4/3/2007		-0.3	GATE CLOSED	4 OUT	FLASH BOARDS NOT ON SPILLWAY	CLEAR	PA
4/13/2007		-0.6	GATE CLOSED	4 OUT		LET RUN/CLEAR	PA
4/16/2007		4.5	GATE CLOSED	4 OUT		RAIN EVENT	PA
4/17/2007	AM	3.75	GATE CLOSED	4 OUT		CLEAR	PA
4/17/2007	5:30 PM	2.3	GATE CLOSED	4 OUT		CLEAR	PA
4/19/2007		1.25	GATE CLOSED	4 OUT			PA

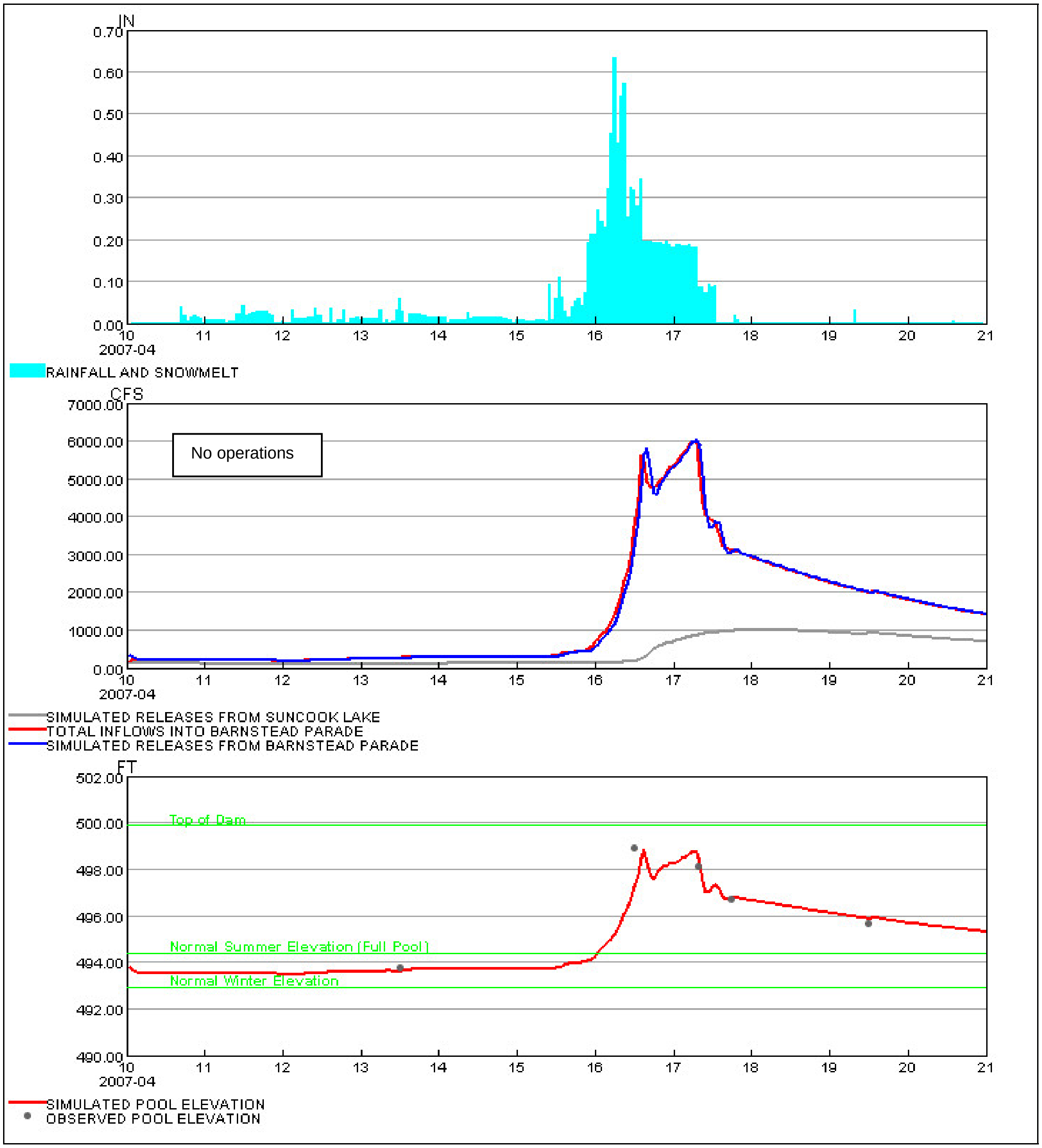


Figure 3-16: Barnstead Parade Simulation Results for the April 2007 Flood Event

At the beginning of May 2006, the gate at the dam was closed, all stoplogs were in place, and the flash boards were installed. The pool was 0.38 foot above the flashboards on May 1, and rose to 0.45 foot over on May 8. The pool was still 0.45 foot over on May 12. Three stoplogs were removed at this time in anticipation of the storm event. Inflows started to increase on May 13, raising the pool to 3 feet above the flashboards on May 14. On this day the gate was fully opened, in addition 40 feet of flashboards operated. On May 16 the pool elevation reached its maximum recorded height of 3.25 feet above the flashboards. This was 3.75 feet below the top of the dam. During the following night the remaining flashboards operated and the pool elevation started to drop. On May 22, with all flashboards out, the gates still fully open and three stoplogs out, the pool elevation had dropped to 0.3 foot above the spillway crest.

For the April 2007 event, the observed pool elevations at Barnstead parade suggest that most of its inflows originated in the area downstream of Suncook Lake. According to the NHDES, high pool at Barnstead Parade does typically not cause upstream damage. Flashboards were not installed at the time of the April 2007 event and the dam itself was not operated during the event. The pool was 1.20 feet above the spillway on April 3, and had dropped to 0.9 foot above the spillway on April 13. Without intervention, Barnstead Parade rose to a maximum recorded height of 6.0 feet above the spillway on April 16. This was 1.0 feet below the top of the dam. No flood damage was reported to the NHDES. The pool dropped after the storm event and was 2.75 feet above the spillway crest on April 19. Downstream flooding is a concern at this location, but the simulation results suggest that the releases very closely mirror the inflows into Barnstead Parade and that the project does not provide any appreciable flood control.

The area contributing runoff to Barnstead Parade includes the Big River and is about twice the size of the area contributing to Suncook Lake. Most of the inflows into Barnstead Parade during the April 2007 event (peaking at approximately 6000 cfs) were therefore generated below Suncook Lake, which released a maximum of approximately 1800 cfs on April 16. The simulation for April 2007 is depicted in Figure 3-16 and tracks the observed pool elevations reasonably well.

B-3.4.3 Alternative Operations

Figure 3-17 shows a simulation of Barnstead Parade with the pool elevation at the winter drawdown level on April 14. The upstream reservoirs were also simulated to be at the winter drawdown level on April 14. All other operations were unchanged. Barnstead Parade is a very small reservoir and the alternative operations would not have significantly reduced the maximum pool elevation. The peak flows at the site would have been reduced by approximately 250 cfs (from a total of 6000 cfs) on April 17, caused by lower releases from Suncook Lake.

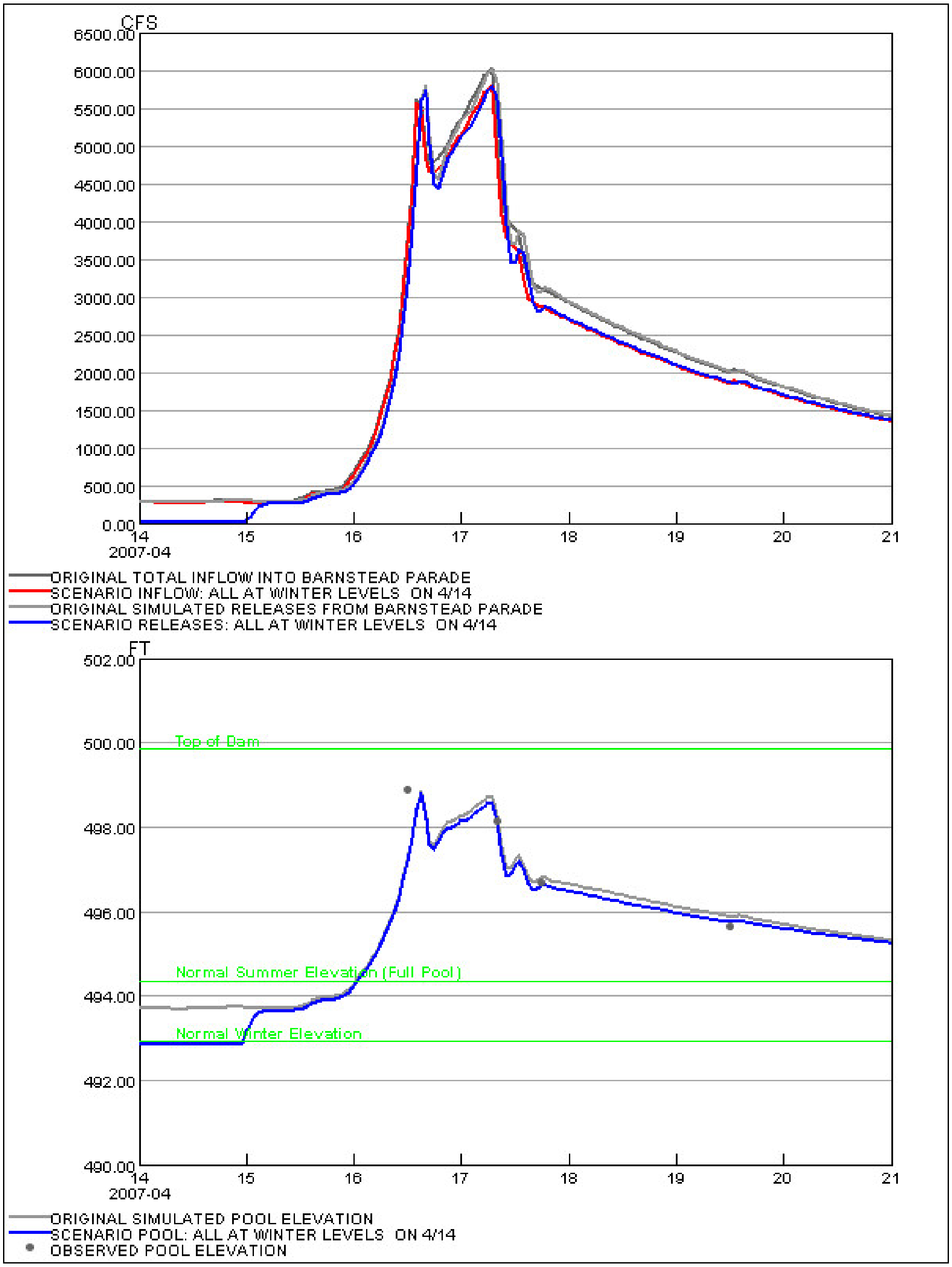


Figure 3-17: Barnstead Parade Alternative Operations - Starting at Minimum Pool on April 14

B-3.5 Pittsfield Mill Dam (NHDES# 195.11)

B-3.5.1 General Description

Pittsfield Mill Dam is run-of-river project located below Barnstead Parade in the town of Pittsfield. As the pond is located in the town, most of the shoreline is developed. The pond has a very small storage capacity of about 112 acre-feet at normal levels, and up to 212 acre-feet at its maximum elevation. 0.01 inch of runoff can be stored between those elevations.

The pool elevation can be controlled at a small dam structure at the western edge of the pond. This is typically done by manual operation of two gates and two log bays.

A photograph of Pittsfield Mill Dam is shown in Figure 3-18.

Figure 3-18: Photograph of Pittsfield Mill Dam

B-3.5.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 474.6 feet. Table 3-9 and Table 3-10 list the pool elevation and the dam operations.

Table 3-9: Pittsfield Mill Dam Pool Elevation and Dam Operations during the May 2006 Flood

DATE	TIME	POOL ELEVATION	LEFT GATE	RIGHT GATE	LOG BAY	LOG BAY	SPILLWAY/FLASHBOARD CONDITION	COMMENTS	INT
5/3/2006		0.80	CLOSED	CLOSED	ALL IN	ALL IN			AS
5/12/2006		0.35	CLOSED	CLOSED	3 OUT	3 OUT		PULLED 3,3	PA
5/14/2006		3	1.50 OPEN	7" OPEN	3 OUT	3 OUT	SANDBAGGED RIGHT AND LEFT SIDE	RAIN EVENT/TEETH ON GATE	PA/BH/MC
								MECH. BROKE/ FIRE DEPT. SANDBAGGING	
5/15/2006	8:30AM	4.1	1.50 OPEN	7" OPEN	3 OUT	3 OUT		CUT CABLE/HOLDING DEBRIS/.10 OVER GATE SIDE	PA
5/15/2006	12:00PM	4.1	1.50 OPEN	7" OPEN	3 OUT	3 OUT			PA
5/15/2006	2:30PM	4.15	1.50 OPEN	7" OPEN	3 OUT	3 OUT			PA
5/16/2006		3.35	1.50 OPEN	7" OPEN	3 OUT	3 OUT		MINUS 0.65 FROM TOP OF CONCRETE/GATE SIDE	PA
5/16/2006	PM	3	1.50 OPEN	7" OPEN	3 OUT	3 OUT		MINUS 12" OFF CONCRETE/GATE SIDE	CL
5/17/2006		2.85	1.50 OPEN	7" OPEN	3 OUT	3 OUT		MINUS 1.15 FROM TOP DECK/GATE SIDE	PA
5/20/2006		1.2	1.50 OPEN	7" OPEN	3 OUT	3 OUT		CLEAR/LET RUN	PA

Table 3-10: Pittsfield Mill Dam Pool Elevation and Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	LEFT GATE	RIGHT GATE	LOG BAY	LOG BAY	COMMENTS	INT
4/3/2007		1	CLOSED	CLOSED	ALL IN	ALL IN	CLEAR	PA
4/13/2007		0.75	CLOSED	CLOSED	ALL IN	ALL IN	CLEANED OUT LOG BAYS	PA
4/16/2007		3.5 ALSO SEE COMMENTS	CLOSED	OPEN 6 FEET	ALL IN	ALL IN	AM= 6" OF FREEBOARD/FIRE DEPT. SAND BAGGING/ AT 1:00 PM PLUS .50 OVER CONCRETE, BOTH SIDES SANDBAGGED/ START OPENING GATE TO 15" AT 3:00PM AND WATER IS PLUS 1.0' OVER TOP/GOT GATE OPEN TO 6.0'/ 10:00PM POND STARTING TO COME DOWN	PA
4/17/2007	PM	-1.5	CLOSED	OPEN 6 FEET	ALL IN	ALL IN	MINUS 5.5 OF FREEBOARD/GATE= 6.0'	PA
4/19/2007		1.6	OPEN	OPEN	ALL IN	ALL IN	CREW WORKING D/S	PA
4/23/2007		0.6	1 FOOT OPEN	1 FOOT OPEN	ALL IN	ALL IN	CLOSED BOTH GATES TO 1 FOOT EACH	PA/CL

On May 3, 2006 the pool elevation was 0.80 foot above the spillway crest. Six stoplogs were removed on May 12, effectively dropping the pool elevation to 0.35 foot over the spillway. At this time both the right and left sides of the spillway were sandbagged. Inflows to the dam started to increase on May 13. On May 14 the left gate was opened 1.5 feet and the right gate was opened 0.6 foot. No more operations were performed. The maximum recorded pool elevation was 4.15 feet over the spillway crest on May 15, exceeding the top of dam elevation by 0.15 foot.

Pittsfield Mill Pond was 1.0 foot over the spillway crest on April 3, 2007. Ten days later, on April 13, the pool had dropped slightly to 0.75 foot over the spillway. On April 16, one gate was opened amidst rising pool elevations. A second gate could initially not be operated and was only opened 6 feet in the afternoon of the 16th. By this time the water levels at Pittsfield Mill Pond had risen above the top of the dam, which was sandbagged to prevent overtopping and associated damage. At that time it was already impossible to remove stoplogs. The maximum recorded height was 2.5 feet over the spillway on April 16, exceeding the dam height by 0.5 foot.

The simulation model (see Figure 3-19) implements some documented operations at the gates in the afternoon of April 17, 2007, however, it seems impossible to recreate the sudden drop in pool suggested by a pool observation at 7 p.m. that day.

The vast majority of inflows into Pittsfield Mill Pond are releases from Barnstead Parade, which itself cannot provide significant flood control. Note that the operations at Pittsfield Mill Dam had only minor impact on the releases from this dam, which greatly resemble the inflows. This demonstrates the limited flood control capacity of the Pittsfield Mill project.

The USGS estimated peak flow at a gage downstream of Pittsfield Mill, “Suncook River at North Chichester,” to be 10, 600 cfs. This is very close to the 10,554 cfs estimated by the simulation for the gage at 7 a.m. on April 17.

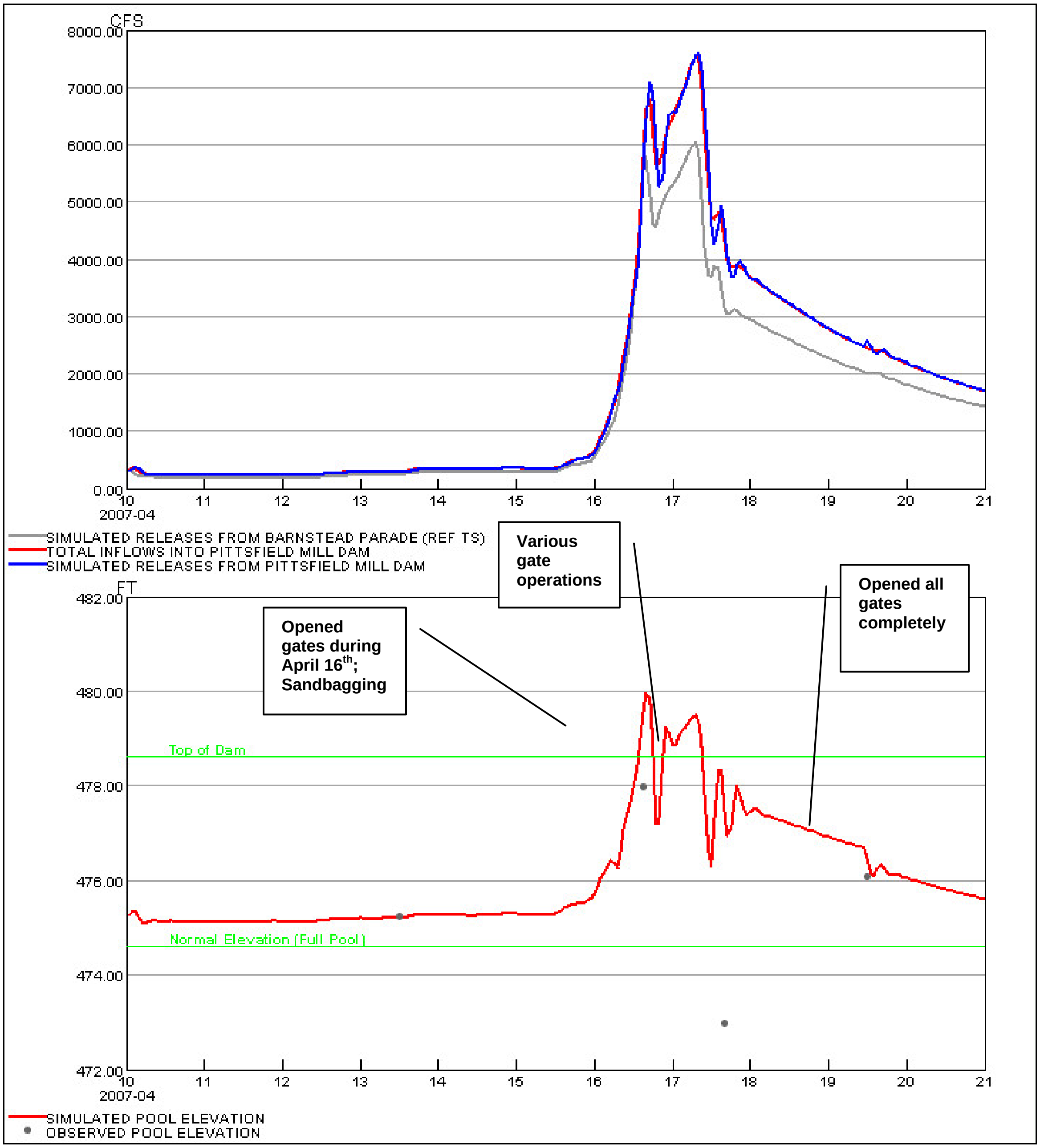


Figure 3-19: Pittsfield Mill Dam Simulation Results for the April 2007 Flood Event

B-3.5.3 Alternative Operations

Figure 3-20 shows a simulation of Pittsfield Mill Dam with the pool elevation at the winter drawdown level on April 14. The upstream reservoirs were also at the winter drawdown for this simulation. All other operations were unchanged. The results of additional alternative operations are shown in Figure 3-21, addressing concerns regarding the effects of the inoperable gate at the dam. The investigated scenarios include: (1) approaching the event with a completely drained reservoir (‘minimum pool’) on April 14; (2) starting at minimum pool, with all gates open and all stoplogs removed, thus providing maximum discharge capacity, (3) starting at minimum pool with all gates closed and all stoplogs in, thus storing the maximum flood volume in the reservoir. These scenarios employ very extreme operations, but illustrate the maximum achievable flood control benefits.

Neither scenario resulted in significant drops in peak pool elevation, indicating that Pittsfield Mill Dam can provide no appreciable flood control through the storage of flood waters.

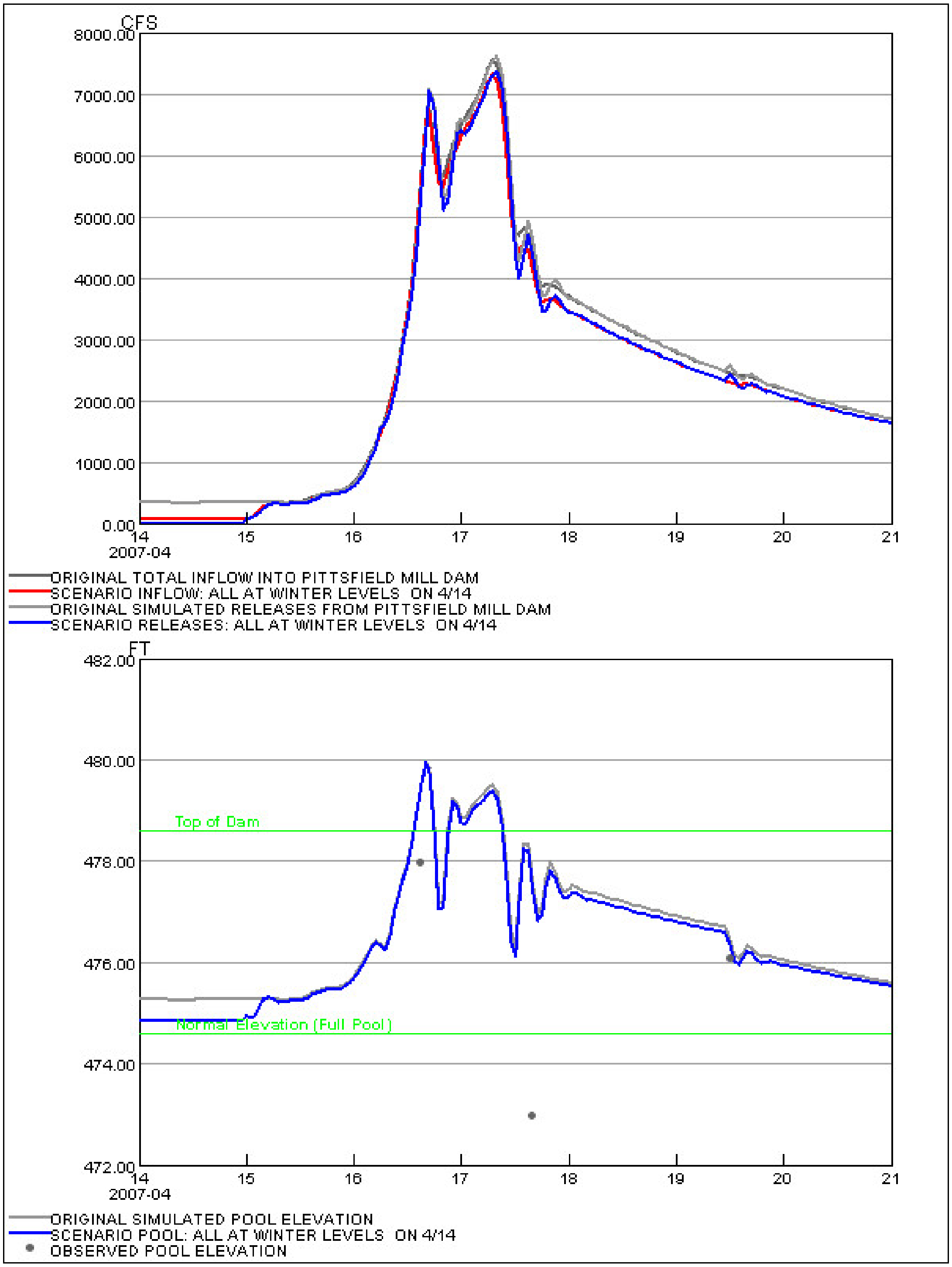


Figure 3-20: Pittsfield Mill Dam Alternative Operations - Starting at Winter Pool on April 14

Figure 3-21: Pittsfield Mill Dam Alternative Operations - Various Scenarios

B-3.6 Pleasant Lake (NHDES# 061.01)

B-3.6.1 General Description

Pleasant Lake is located on the Little Suncook River, upstream of Northwood Lake. The majority of the shoreline is developed. The lake has a storage capacity of 552 acre-feet and 1,200 acre-feet at its normal and maximum elevations respectively. Between those levels, Pleasant Lake can store about 3.45 inches of runoff, providing significant local flood control. The normal pool elevation is 578.7 feet. Operations at Pleasant Lake are limited to setting or removing stoplogs in front of the culvert at the dam site.

A plan view of Pleasant Lake Dam is shown in Figure 3-22.

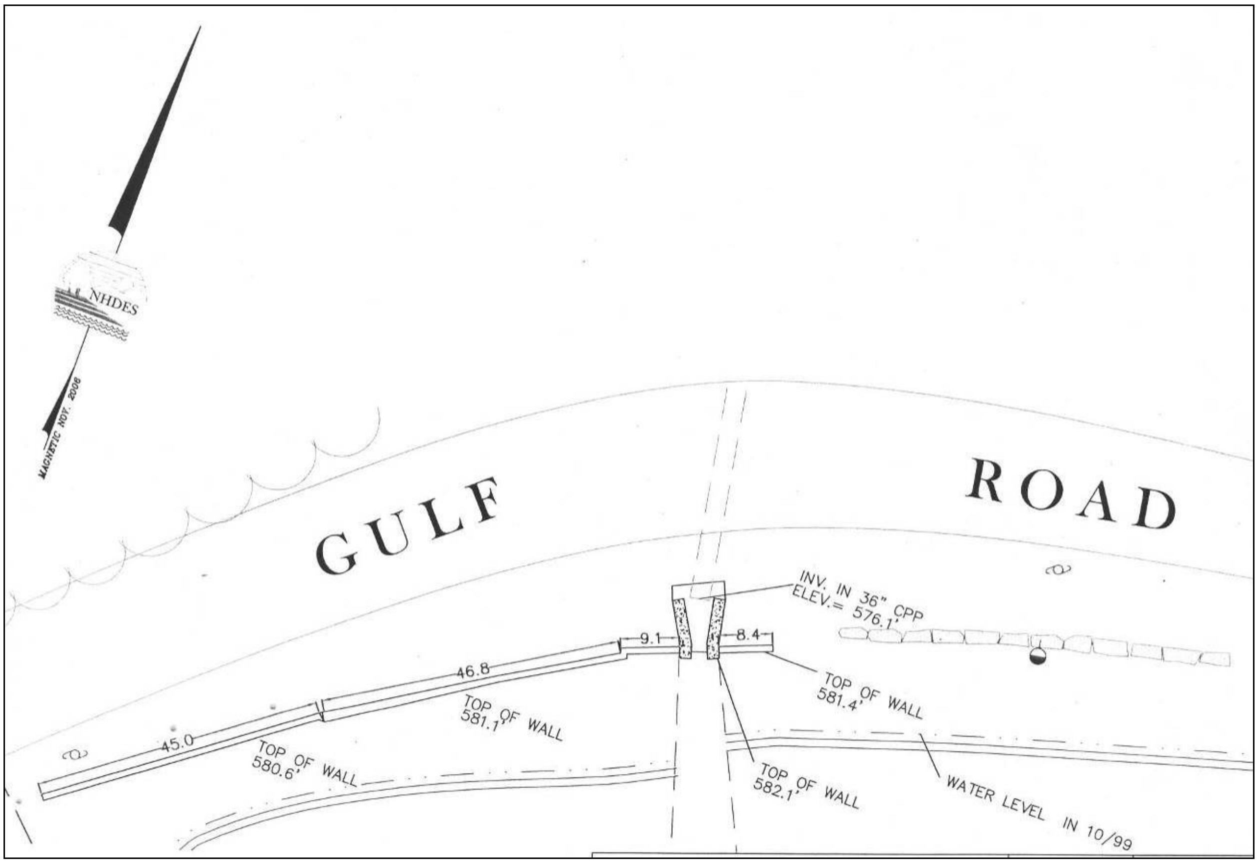


Figure 3-22: Plan View of Pleasant Lake Dam

B-3.6.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the normal lake elevation of 578.7 feet minus 6.30 feet. Table 3-11 and Table 3-12 list the pool elevation and the dam operations.

Table 3-11: Pleasant Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	TIME	POOL ELEVATION	LOG BAY	COMMENTS	INT
5/5/2006		6.10	1HALF LOG OUT	OK/F/F	CT
5/8/2006		6.12		WINDY	CT
5/11/2006		6.1		NO CHANGE	CT
5/13/2006	6:30 AM	6.26	1 FULL/1 HALF LOG OUT	PULLED ONE LOG	CT
5/13/2006	5:00PM	6.4	2 FULL/1HALF LOG OUT	PULLED ONE LOG	CT
5/15/2006		9.6	2 FULL/1HALF LOG OUT	MINUS 1 FOOT@CORE WALL/OVER ROAD WATER OVER ROAD/BOIL ON D/S SIDE	CT
5/17/2006		9.6	2 FULL/1HALF LOG OUT	MINUS 1 FOOT@CORE WALL/OVER ROAD	CT
5/18/2006		9.5	2 FULL/1HALF LOG OUT	OK	CT
5/20/2006		9.45	3 FULL/1 HALF LOG OUT	PULLED ONE LOG	CT
5/21/2006		9.05	ONE LOG IN	PULLED ONE LOG/ALL OUT EXCEPT BASE LOG	CT

Table 3-12: Pleasant Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	LOG BAY	COMMENTS	INT
4/10/2007		5.5	ALL OUT	CLEAR/STILL ICE ON LAKE	PA
4/19/2007		7.5	ALL OUT	0.8 OVER TOP OF LAKE GAGE	AS
4/23/2007		7.1	ALL OUT	OK/LET RUN	CT

One half stoplog was out at the beginning of May 2006, with a pool elevation of 0.2 foot below normal lake elevation. Lake inflows began to rise on May 13, and two stoplogs were removed. The pool elevation continued to rise, spilling over the road and reaching the maximum recorded height of 3.3 feet above normal lake elevation on May 15. Additional stoplogs were pulled on both May 20 and May 21, resulting in a 0.5 foot drop in the pool elevation.

In April 2007, no stoplogs were present and no operations were performed at the dam. On April 10, the pool was 0.8 foot below normal lake elevation. After the storm on April 19 the pool had risen to its maximum recorded height of 1.2 feet over normal lake elevation. Given this, the simulations suggest that the pond quickly rose above normal pool elevation and started spilling over the road next to the highest portion of the dam.

The NHDES states that flooding is a problem both upstream and downstream of the dam—and while the lake did hold back significant flow volumes, the configuration of the dam and the limited possibilities for operation seem to have hindered additional flood prevention measures at the site.

B-3.6.3 Alternative Operations

A simulation of Pleasant Lake with a lower pool elevation on April 14, 2007, was tested and is shown in Figure 3-23 and Figure 3-24. All other operations were assumed to be unchanged. These alternative operations would have dropped the maximum pool elevation reached during the event by approximately half a foot. The maximum releases during the event would not have changed because they would have been restricted by the capacity of the culvert at the outlet.

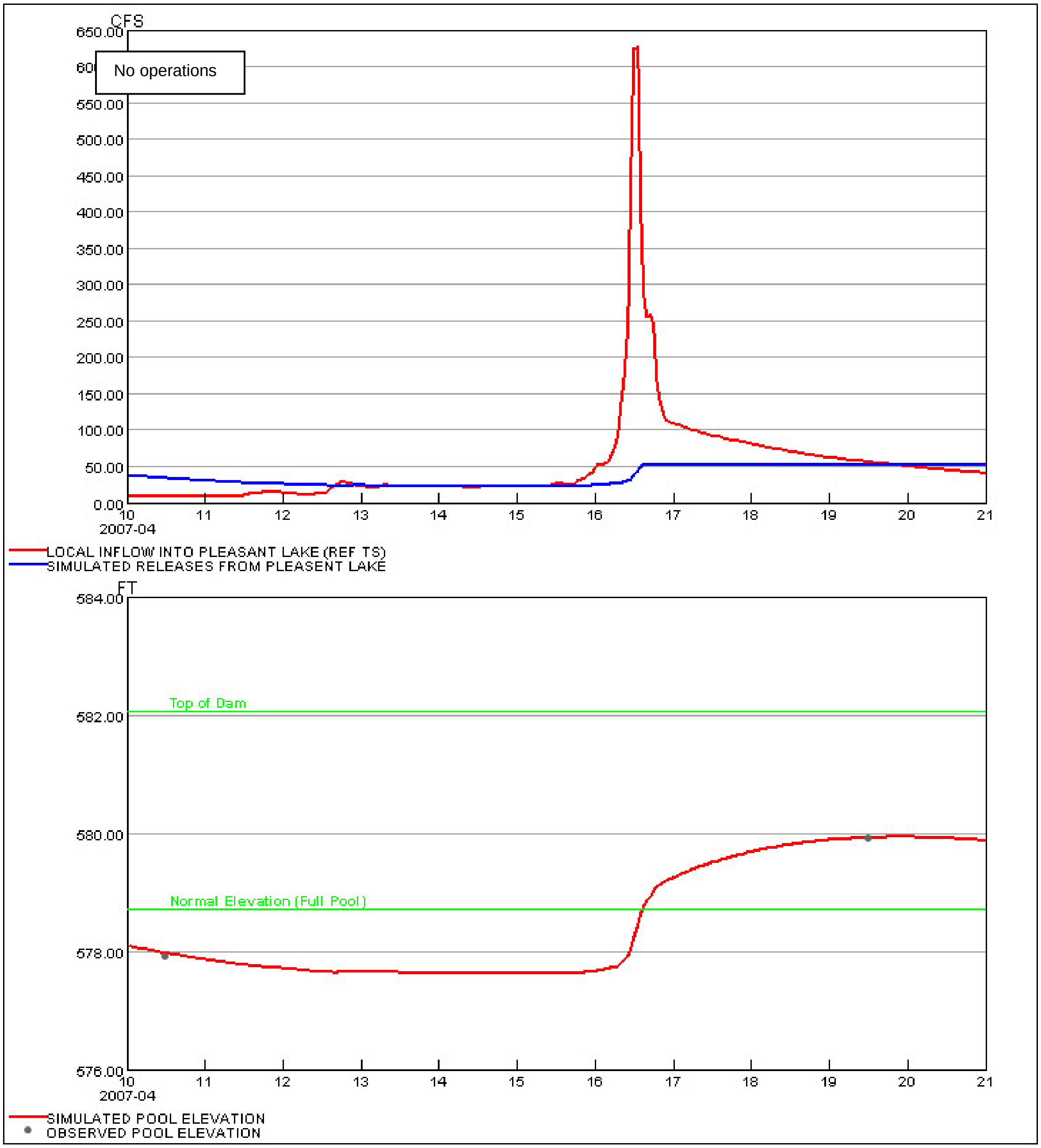


Figure 3-23: Pleasant Lake Simulation Results for the April 2007 Flood Event

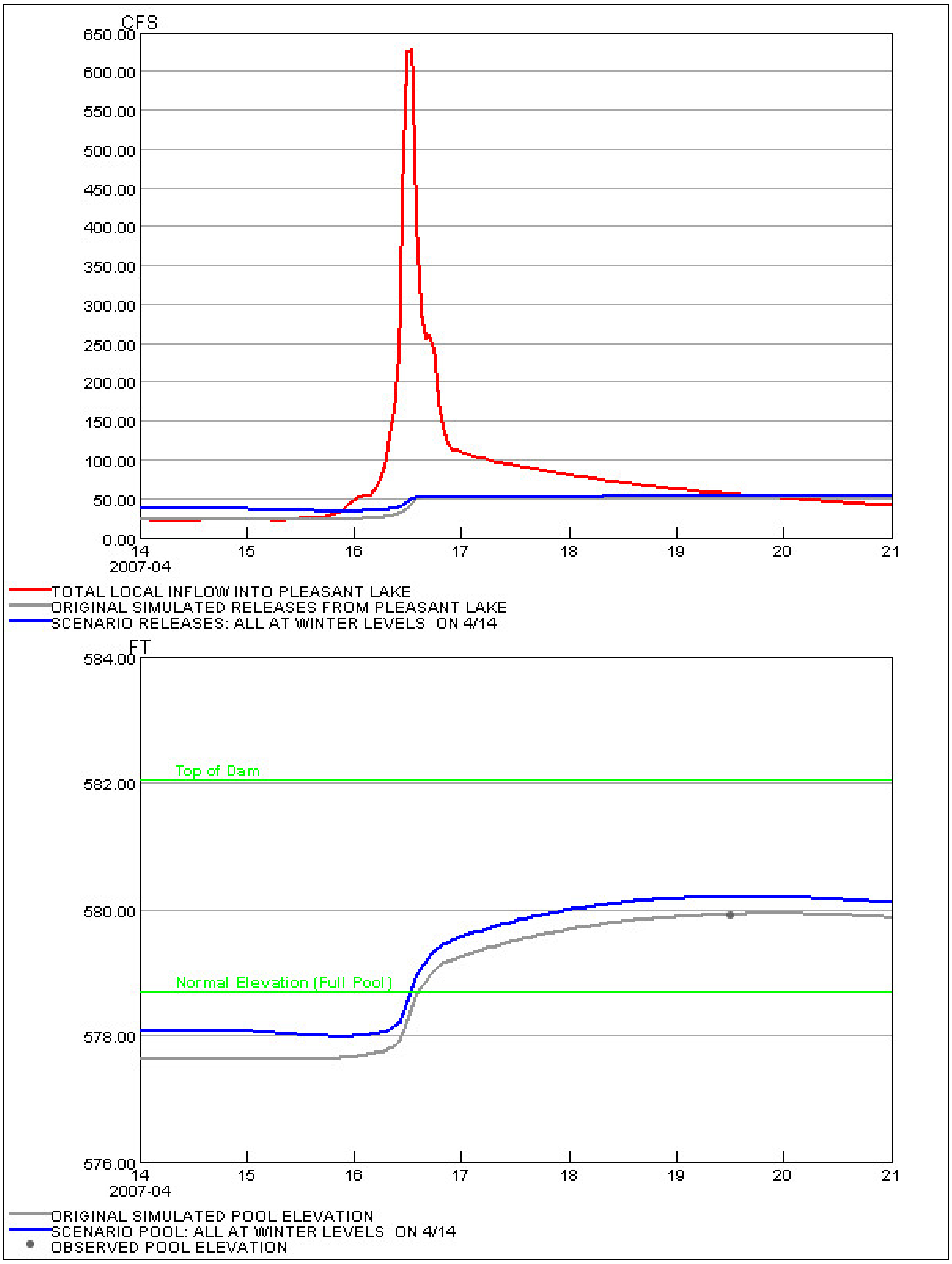


Figure 3-24: Pleasant Lake Alternative Operations - Starting at Minimum Pool on April 14

B-3.7 Northwood Lake (NHDES# 079.01)

B-3.7.1 General Description

Northwood Lake is located on the Little Suncook River, along Dover Road or Highway 4. The lake has a storage capacity of 2,400 acre-feet at normal levels, and 3,200 acre-feet at its maximum elevation. Between those levels, Northwood Lake can store about 0.75 inch of runoff.

The water levels are regulated through a dam structure located at the west end of the lake in Epsom. This is typically done by manual operation of a gate and four stoplog bays.

The full pond elevation, which is maintained in the summer, corresponds to an elevation of 516.94. As with most lakes in the area, drawdown begins after Columbus Day. The lake has a target six feet below full pond, although it usually only reaches five to five and a half feet. This information was obtained from the NHDES Dam Bureau website. Other information received by NHDES indicates an annual drawdown of four feet.

The lake is filled just after ice out or by May 1. The filling rate is controlled through the stoplog bays. It requires about 2.24 inches of runoff to refill the lake from the lower winter pool to the normal summer pool. Given this, the lake can provide limited flood control in winter and spring.

B-3.7.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 516.94 feet. Table 3-13 and Table 3-14 list the pool elevation and the dam operations performed by the NHDES at Northwood Lake.

Table 3-13: Northwood Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	TIME	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	GATE	COMMENTS	INT
5/1/2006		-0.15	ALL IN	ALL IN	ALL IN	ALL IN	CLOSED	LET RUN/CLEAR	PA
5/5/2006		0.3	ALL IN	ALL IN	ALL IN	ALL IN	CLOSED	ALL LOGS IN	CT
5/8/2006		0.3	ALL IN	ONE OUT	ALL IN	ALL IN	CLOSED	PULLED ONE LOG/RAIN COMING	CT
5/9/2006		0.3	ALL IN	2 OUT	ALL IN	ALL IN	CLOSED	PULLED ONE MORE LOG/OK	AS/CT
5/11/2006		0.2	ALL IN	5 OUT	ALL IN	ALL IN	CLOSED	PULLED 3 LOGS/TOTAL 5 OUT ONE BAY	CT
5/13/2006	6:00AM	0.2	3 OUT	5 OUT	ALL IN	ALL IN	CLOSED	RISING/PULLED MORE LOGS	CT
5/13/2006	5:30PM	0.4	4 OUT	6 OUT	1 OUT	1 OUT	CLOSED	PULLED ONE STRING/SANDBAGGED LOWER LEFT CORE WALL	CT
5/14/2006		1.5	4 OUT	6 OUT	1 OUT	1 OUT	CLOSED	NOTHING	MHC
5/15/2006		1.6	4 OUT	6 OUT	1 OUT	1 OUT	2.60 OPEN		CT
5/15/2006	6:00PM	1.4	4 OUT	6 OUT	1 OUT	1 OUT	2.60 OPEN		CT
5/16/2006		1	4 OUT	6 OUT	1 OUT	1 OUT	2.60 OPEN	NO CHANGES	CT
5/17/2006		0.85	4 OUT	6 OUT	1 OUT	1 OUT	2.60 OPEN	GATE @ 2' 6" OPEN	CT
5/18/2006		0.6	4 OUT	6 OUT	1 OUT	1 OUT	2.60 OPEN	LET RUN	CT
5/19/2006		-0.3	1 OUT	1 OUT	1 OUT	ALL IN	CLOSED	SET LOGS	CT
5/20/2006		0.25	2 OUT	2 OUT	2 OUT	1 OUT	CLOSED	PULLED LOGS	CT
5/21/2006		0.3	2 OUT	3 OUT	3 OUT	2 OUT	CLOSED	PULLED LOGS	CT

Table 3-14: Northwood Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	GATE	COMMENTS	INT
4/4/2007	-2.85	6 OUT	6 OUT	6 OUT	6 OUT	CLOSED	SET ONE STRING/ICE BLACK/CHECKED AREA	CT
4/6/2007	-2.6	5 OUT	6 OUT	6OUT	5 OUT	CLOSED	SET 2 LOGS/1,0,0,1	PA/AS
4/10/2007	-2.45	5 OUT	6 OUT	6OUT	5 OUT	CLOSED	LET RUN/CLEAR/ICE IS OUT	PA
4/16/2007	0.65	5 OUT	6 OUT	6OUT	5 OUT	CLOSED	SANBAGGED LEFT LOWER SIDE	GL
4/17/2007	1.2	5 OUT	6 OUT	6OUT	5 OUT	CLOSED	RAIN EVENT/7" OF FREEBOARD	PA
4/19/2007	0.45	5 OUT	6 OUT	6OUT	5 OUT	CLOSED	OK/LET RUN	AS

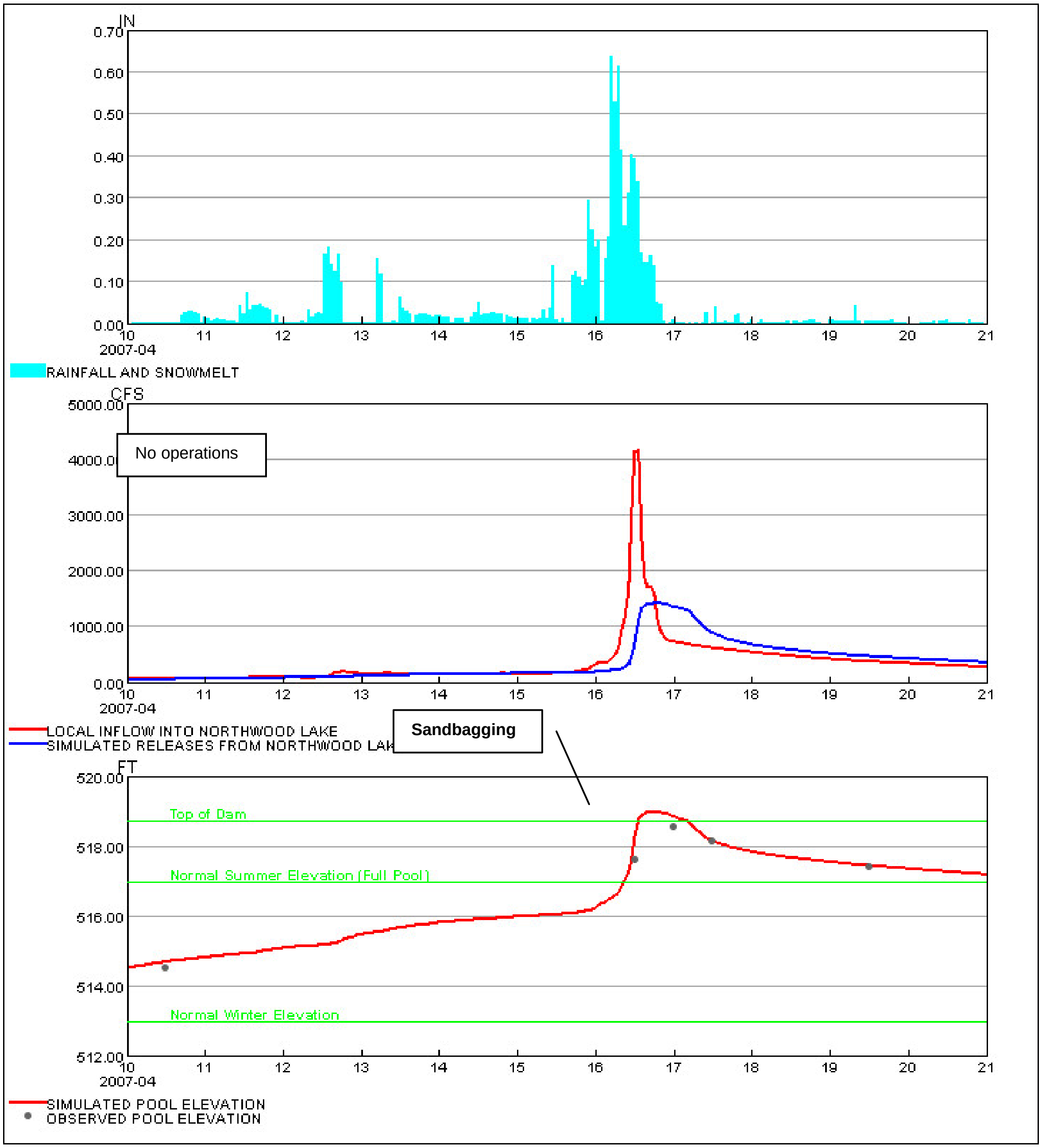


Figure 3-25: Northwood Lake Simulation Results for the April 2007 Flood Event

The pool elevation was 0.15 foot below the spillway crest on May 1, 2006. At this time all stoplogs were in place and the gate was closed. On May 5 the pool elevation had risen to 0.3 foot above the spillway crest. In anticipation of rain, one stoplog was removed on May 8, one on May 9, and three on May 11. This prevented the pool elevation from rising further. In response to the rain event, inflows to the lake started to rise on May 13. Seven more stoplogs were removed and the lower left core wall was sandbagged. The pool continued to rise, and the maximum recorded pool elevation reached 1.6 feet above the spillway on May 15, 0.16 foot below the top of the dam. At this time the gate was opened 2.6 feet and the pool elevation began to drop. No more action was taken until nine stoplogs were set and the gate was closed on May 19. The pool elevation dropped below the spillway crest at this time. However, the next day the pool began to rise again, overtopping the spillway by 0.25 foot. Four stoplogs were removed on May 20 and three more on May 21, with the pool elevation 0.3 foot above the spillway.

Northwood Lake was refilling during the first weeks in April 2007. On April 4 the pool was 2.85 feet below the spillway crest, rising slightly to 2.45 feet below the spillway by on April 10. The pool rose quickly in response to the storm and overtopped the spillway by 0.65 foot on April 16. No operations were performed and the pool reached a maximum recorded height of 1.2 feet above the spillway on April 17. This was 0.56 foot below the top of the dam. During the event the lake provided significant local downstream flood control (see the differences in inflows and releases in Figure 3-25) and filling it prevented possible damage along Route 4 downstream. For that reason, no operations were performed during the April 2007 event; instead, the dam was sandbagged to prevent overtopping. Nevertheless, the downstream side of the dam developed some sinkholes.

The area contributing runoff to Northwood Lake downstream of Pleasant Lake is about 5 times as large as the area controlled by Pleasant Lake. Inflows into Northwood Lake during the April 2007 event (peaking at approximately 4100 cfs on April 16) were therefore significantly larger than the releases from Pleasant Lake (peaking at 25 cfs).

B-3.7.3 Alternative Operations

Figure 3-26 shows a simulation of Northwood Lake with the winter drawdown held until April 14. All other operations were unchanged. These operations would have reduced the peak water level to only minimally overtop the dam. Maximum releases would have been reduced from approximately 1400 cfs to approximately 1350 cfs.

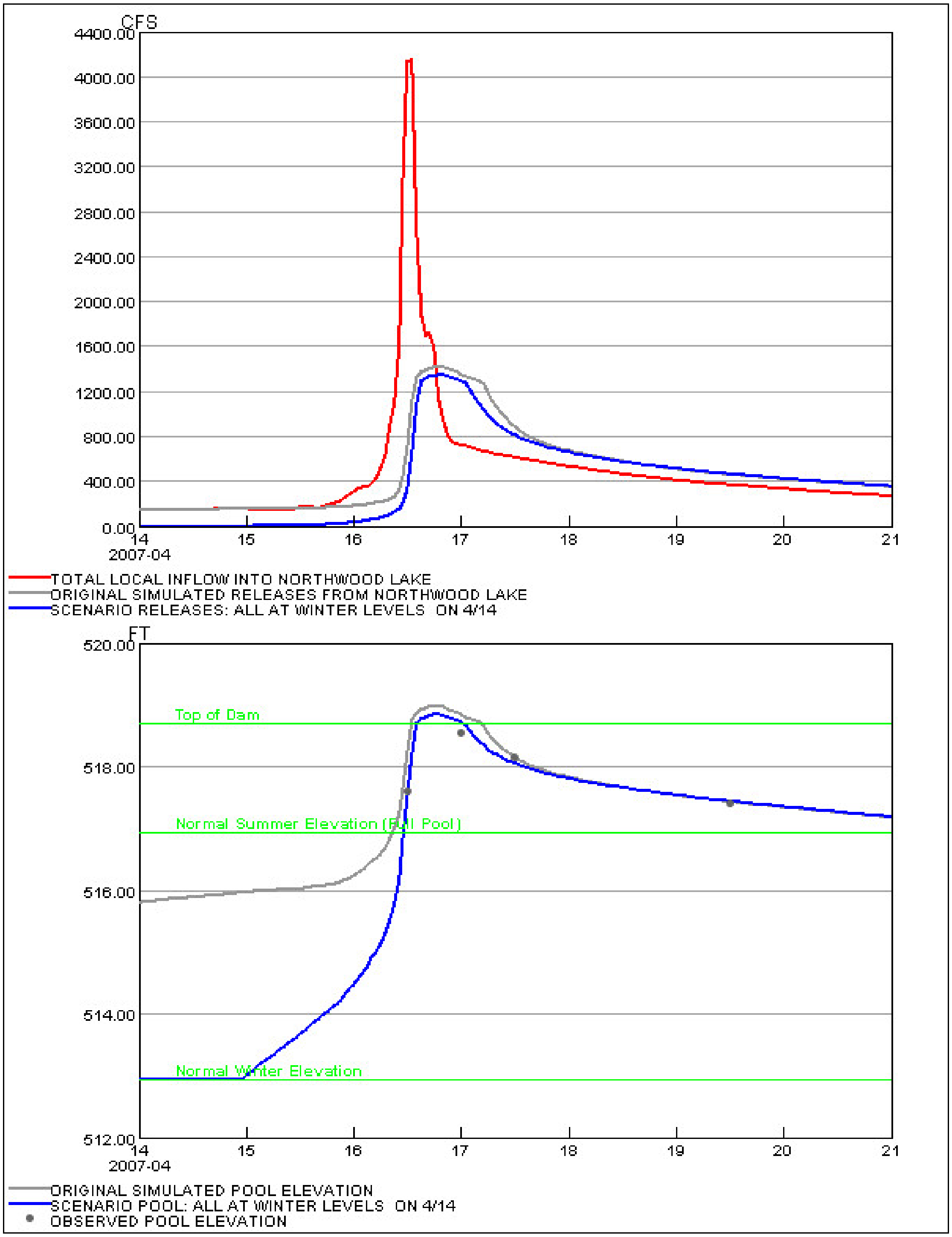


Figure 3-26: Northwood Lake Alternative Operations - Starting at Minimum Pool on April 14

B-3.8 Buck Street Dams (NHDES# 004.16 and 190.05)

B-3.8.1 General Description

The two Buck Street Dams are located on the Suncook River, where Route 28 meets Buck Street. Being a run-of-river project, the pond has virtually no storage—83 acre-feet at normal levels and up to 413 acre-feet at its maximum elevation. The pool elevation is controlled by NHDES staff at the east and west dams. The east dam operates with two conventional gates; the west dam is operated through three stoplog bays.

The typical summer lake elevation is 291.59 feet, which corresponds to the elevation of the spillway on the east dam. The lake is usually drawn down five feet after Columbus Day through manual operation of the gates and stoplogs bays. It takes only 0.02 inch of rainfall to refill the lake.

A plan view and a photograph of East Buck Street Dam are shown in Figure 3-27 and Figure 3-29 respectively and West Buck Street Dam in Figure 3-28 and Figure 3-30.

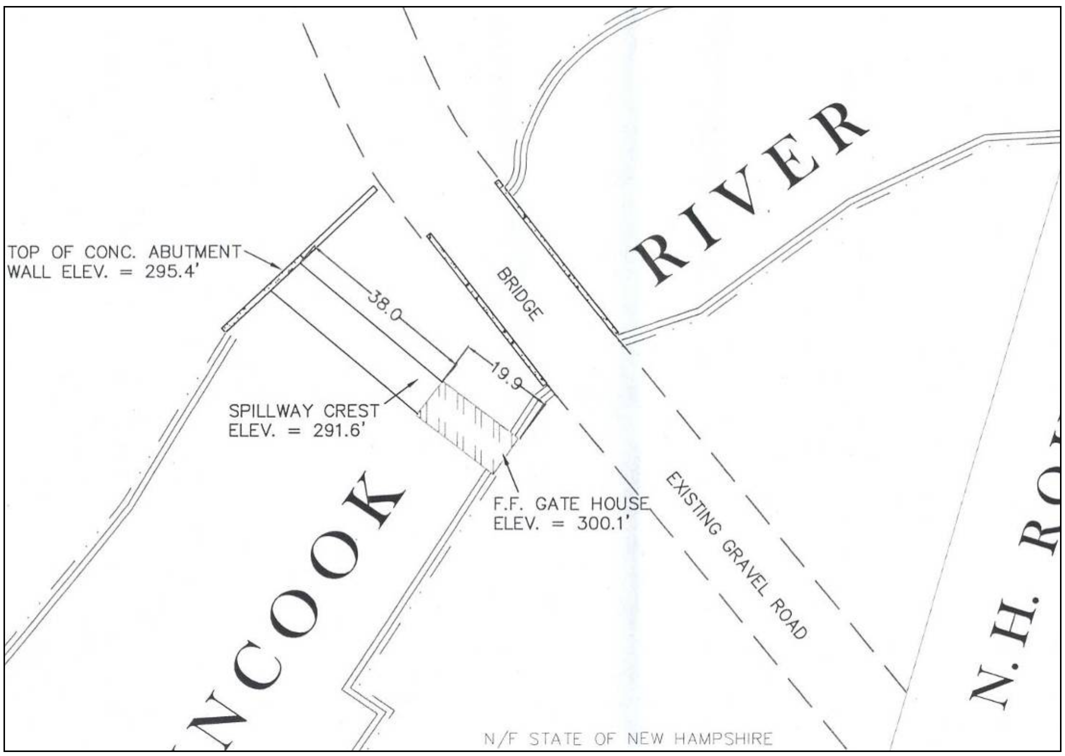


Figure 3-27: Plan View of East Buck Street Dam

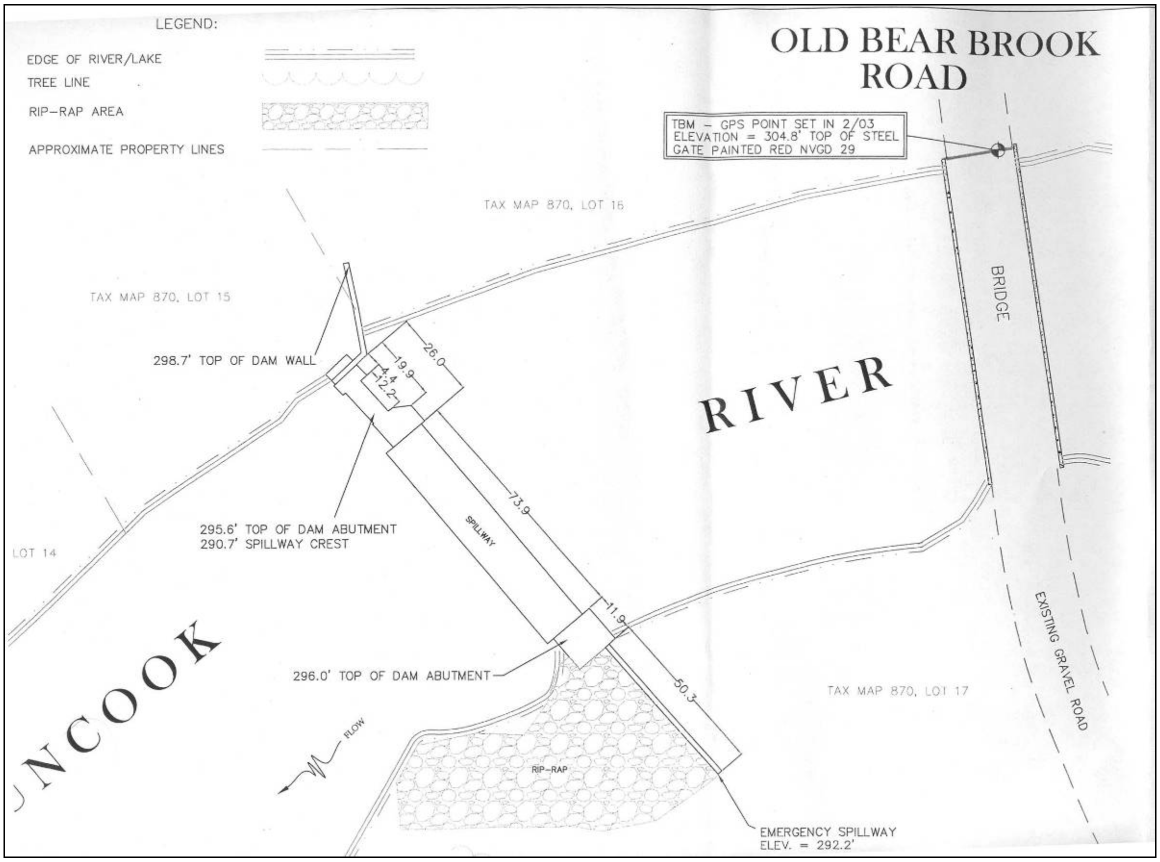


Figure 3-28: Plan View of West Buck Street Dam

Figure 3-29: Photograph of East Buck Street Dam

Figure 3-30: Photograph of West Buck Street Dam

B-3.8.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 291.59 feet. Table 3-15 and Table 3-16 list the pool elevation and the dam operations performed by the NHDES at East Buck Street Dam. Table 3-17 and Table 3-18 list the pool elevation and the dam operations performed by the NHDES at West Buck Street Dam.

Table 3-15: Buck Street East Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
5/3/2006	1.40	GATES CLOSED	GATES CLOSED		AS
5/14/2006	5	FULL OPEN	FULL OPEN	OPENED GATES FULL	WPH
5/15/2006	6	FULL OPEN	FULL OPEN	BASED ON 5/14 AND 5/16 DATA FROM WEST SIDE	AS
5/16/2006	3	FULL OPEN	FULL OPEN	DROPPED APPOX. 1.50 OVERNIGHT	PA

Table 3-16: Buck Street East Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LEFT GATE	RIGHT GATE	COMMENTS	INT
3/28/2007	0.8	FULL OPEN	FULL OPEN	ALL CLEAR	CT
4/16/2007	5	FULL OPEN	FULL OPEN	GATES FULL OF DEBRIS	PA
4/17/2007	7.75	FULL OPEN	FULL OPEN	MINUS 2 FOOT 4 INCHES/BRIDGE ON RIGHT	GL
4/19/2007	3	FULL OPEN	FULL OPEN	DEBRIS/SINKHOLES/WASHOUTS	PA

Table 3-17: Buck Street West Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	COMMENTS	INT
5/3/2006	1.40	4 OUT	5OUT	4OUT	W/ SOME LOGS OUT OK	AS
5/14/2006	5	4 OUT	5OUT	4OUT	WATER AT SLAB	WPH
5/15/2006	6	4 OUT	5OUT	4OUT	WATER 1 FOOT OVER SLAB	WPH
5/16/2006	3	4 OUT	5OUT	4OUT	WATER OFF DECK/DAM CLEAR	PA

Table 3-18: Buck Street West Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	COMMENTS	INT
3/28/2007	0.8	7 LOGS OUT	7 LOGS OUT	7 LOGS OUT	ALL CLEAR	CT
4/16/2007	5.6	7 LOGS OUT	7 LOGS OUT	7 LOGS OUT	OVER EMERG. SPILL/OVER TOP OF LOG AREA BY .60	PA
4/17/2007	7.75	7 LOGS OUT	7 LOGS OUT	7 LOGS OUT	SIX INCHES BELOW RIGHT CUT OFF WALL	GL
4/19/2007	3	7 LOGS OUT	7 LOGS OUT	7 LOGS OUT	WASHOUT RIGHT SIDE	PA

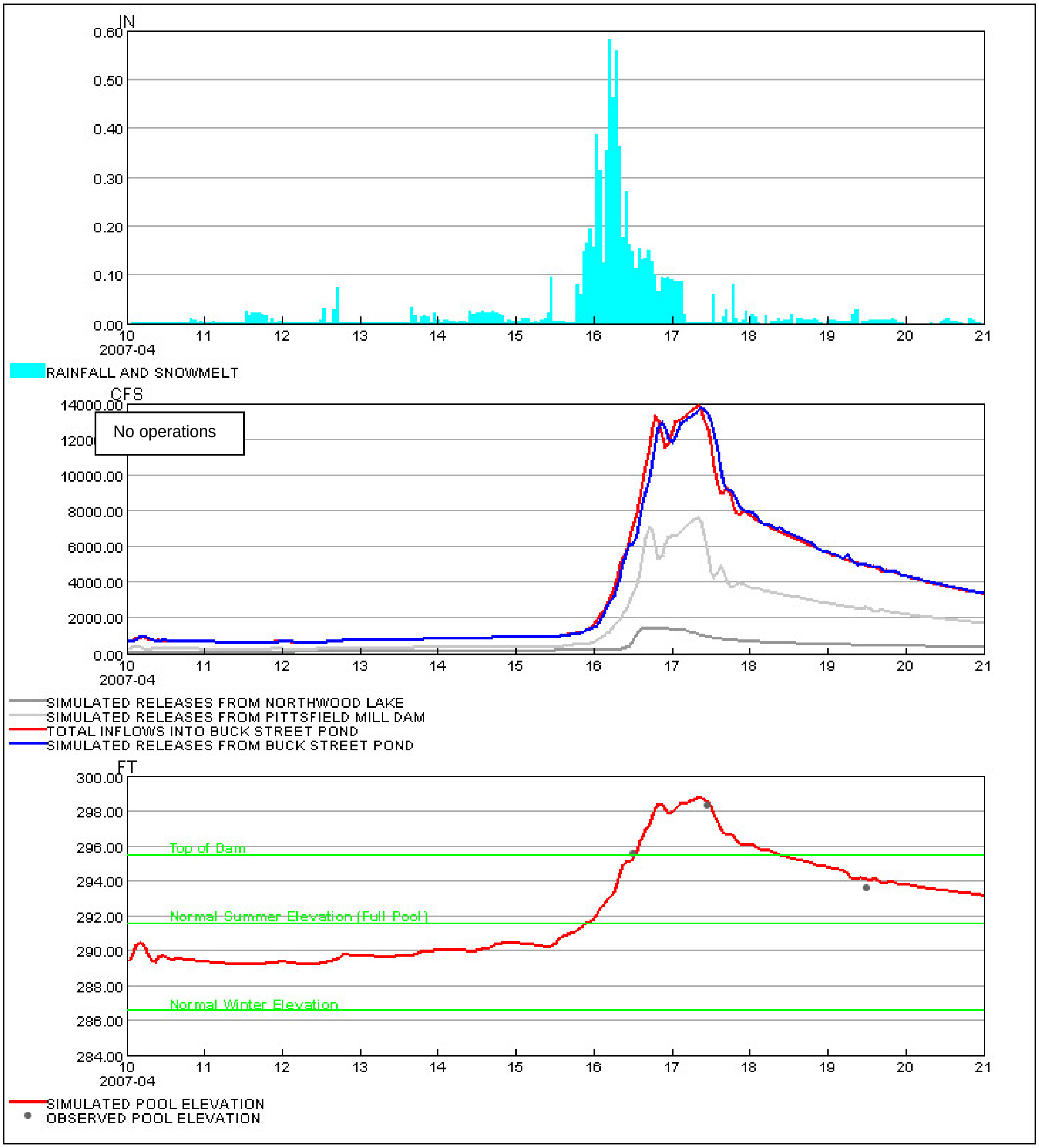


Figure 3-31: Buck Street Dams Simulation Results for the April 2007 Flood Event

On May 3, 2006 both gates were closed on the East Dam, and 13 stoplogs were out on the West Dam. The pool elevation was 1.4 feet over the East spillway crest and 1.3 feet over the West spillway crest, but still 2.5 feet below the top of the dam. Pool elevation rose rapidly and reached the top of dam on May 14.

At this time the East Dam gates were fully opened but no additional stoplogs were removed from the West Dam. The pool elevation continued to rise and reached the maximum recorded elevation of 2.1 feet over the dam on May 15. No action was taken that day, given that the stoplogs were submerged considerably. Still, the pool dropped and was 0.9 foot below the top of dam on May 16.

At the beginning of the April 16 event, all gates at the Buck Street Dams were open and seven of ten stoplogs were removed. Nevertheless the pool rose far beyond the top of the dam during the event, in part caused by debris that was clogging the gate bays. The simulation can reproduce this fairly well. Given the flat terrain upstream of the dams, the simulation assumes a significant increase in storage capacity behind the dam once they overtop. This causes a brief delay in the rise of the releases once the dam overtop.

The simulation (see Figure 3-31) demonstrates that the project had no flood control potential, but caused, according to the NHDES, significant upstream flooding on a side road of Route 28.

B-3.8.3 Alternative Operations

Figure 3-32 is simulation of the Buck Street Dams with the pool elevation held at its winter drawdown until April 14. Upstream reservoirs were also held at their winter pool. All other operations were unchanged. Maintaining the winter drawdown had little effect on the maximum pool elevation, due to the very limited storage capacity behind the Buck Street Dams. The flows at the dams would have been virtually unaffected by operations at the site itself. The reduction in peak release of approximately 500 cfs (from an actual 13,700 cfs) on April 17 would have been caused by alternative operations at the upstream dams.

On the other hand, opening all the gates and stoplogs (Figure 3-33) would have resulted in some reduction in the peak water level while not affecting the releases.

An additional scenario assessed the effects of lower spillways on the maximum pool elevations reached. Figure 3-34 demonstrates that lowering both spillways by 2 feet each would have resulted in a drop of the maximum pool elevation by approximately 1.5 feet without affecting the releases.

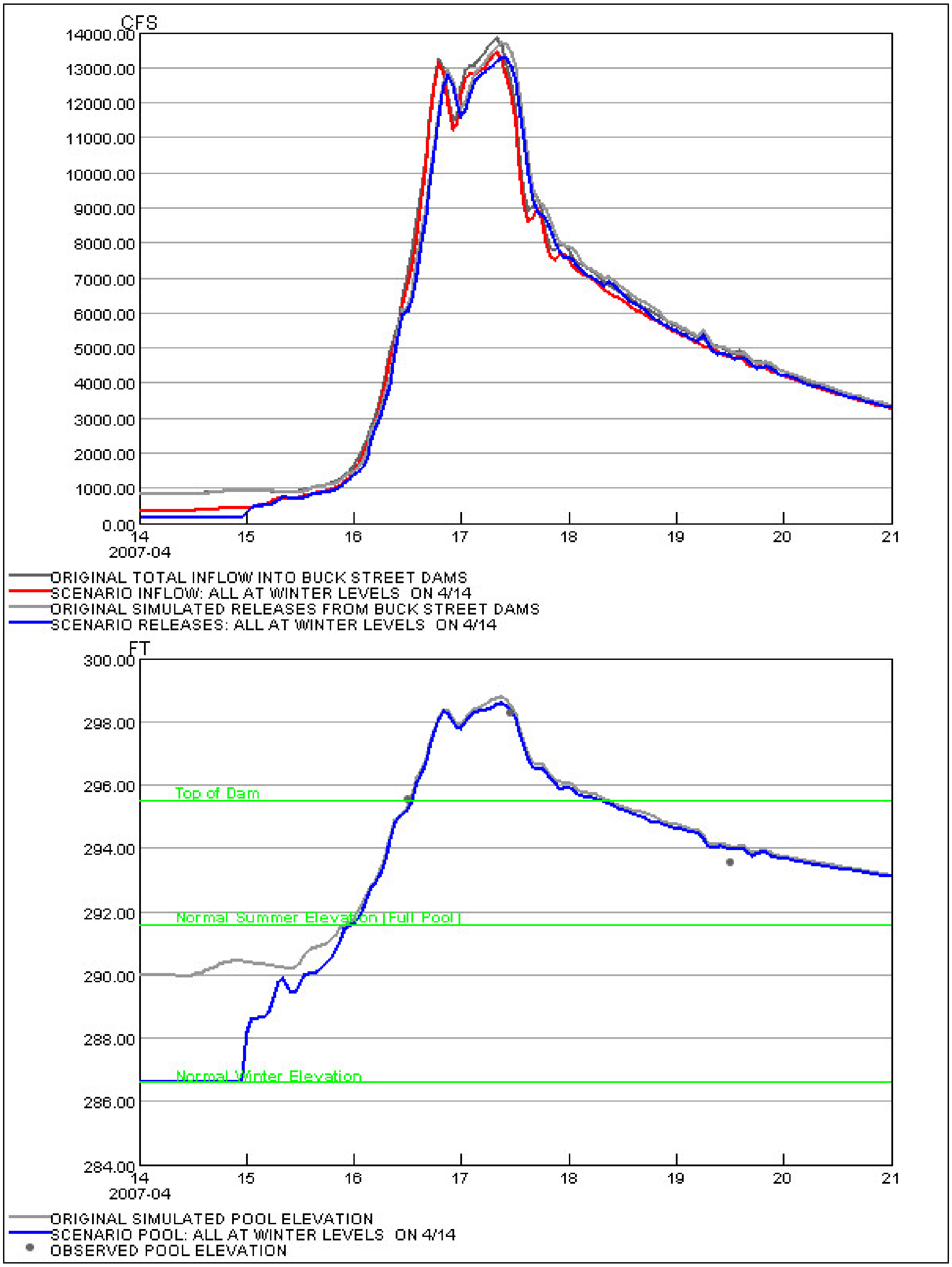


Figure 3-32: Buck Street Dams Alternative Operations - Starting at Minimum Pool on April 14

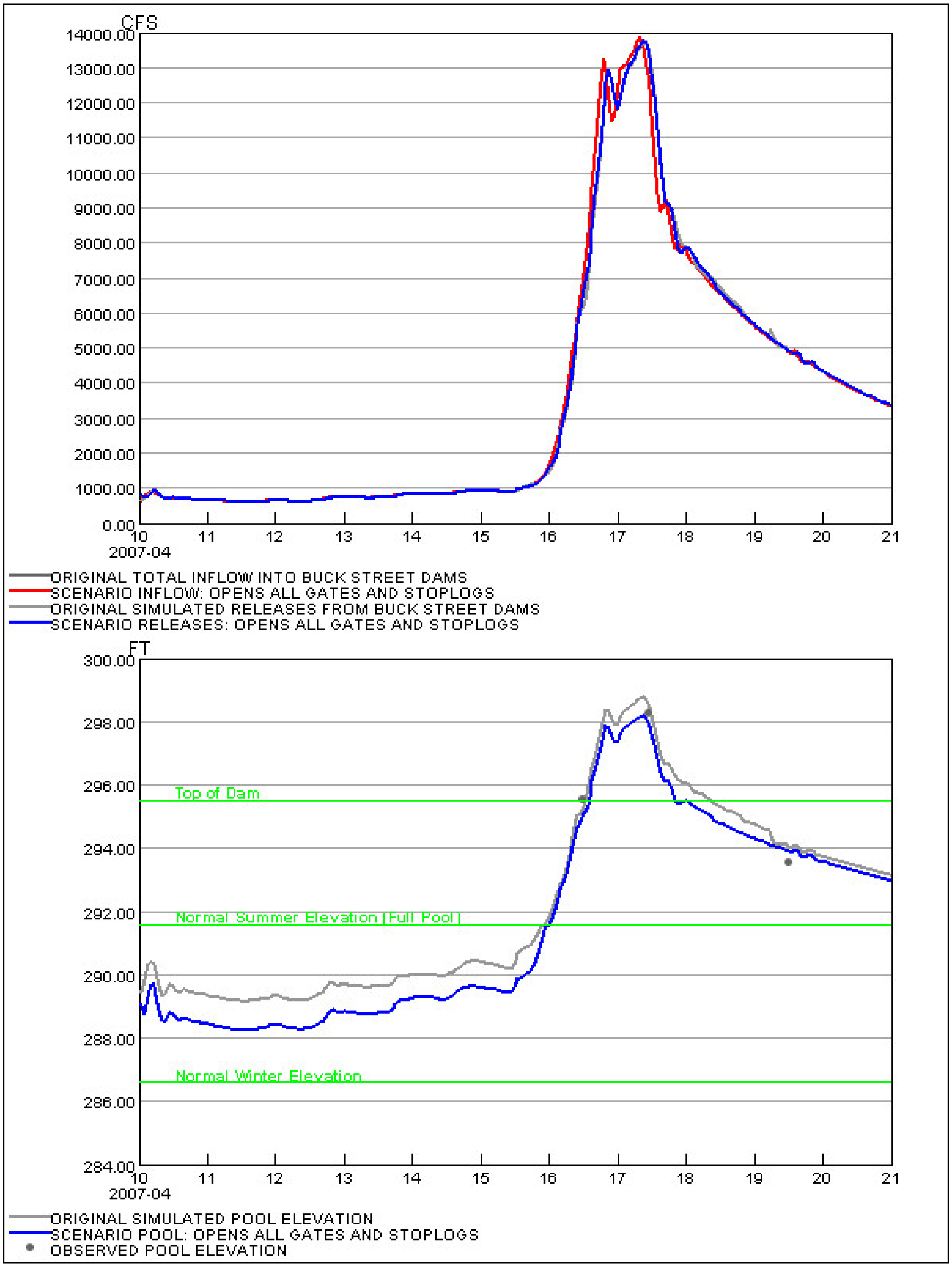


Figure 3-33: Buck Street Dams Alternative Operations - Opens all Gates and Removes Stoplogs

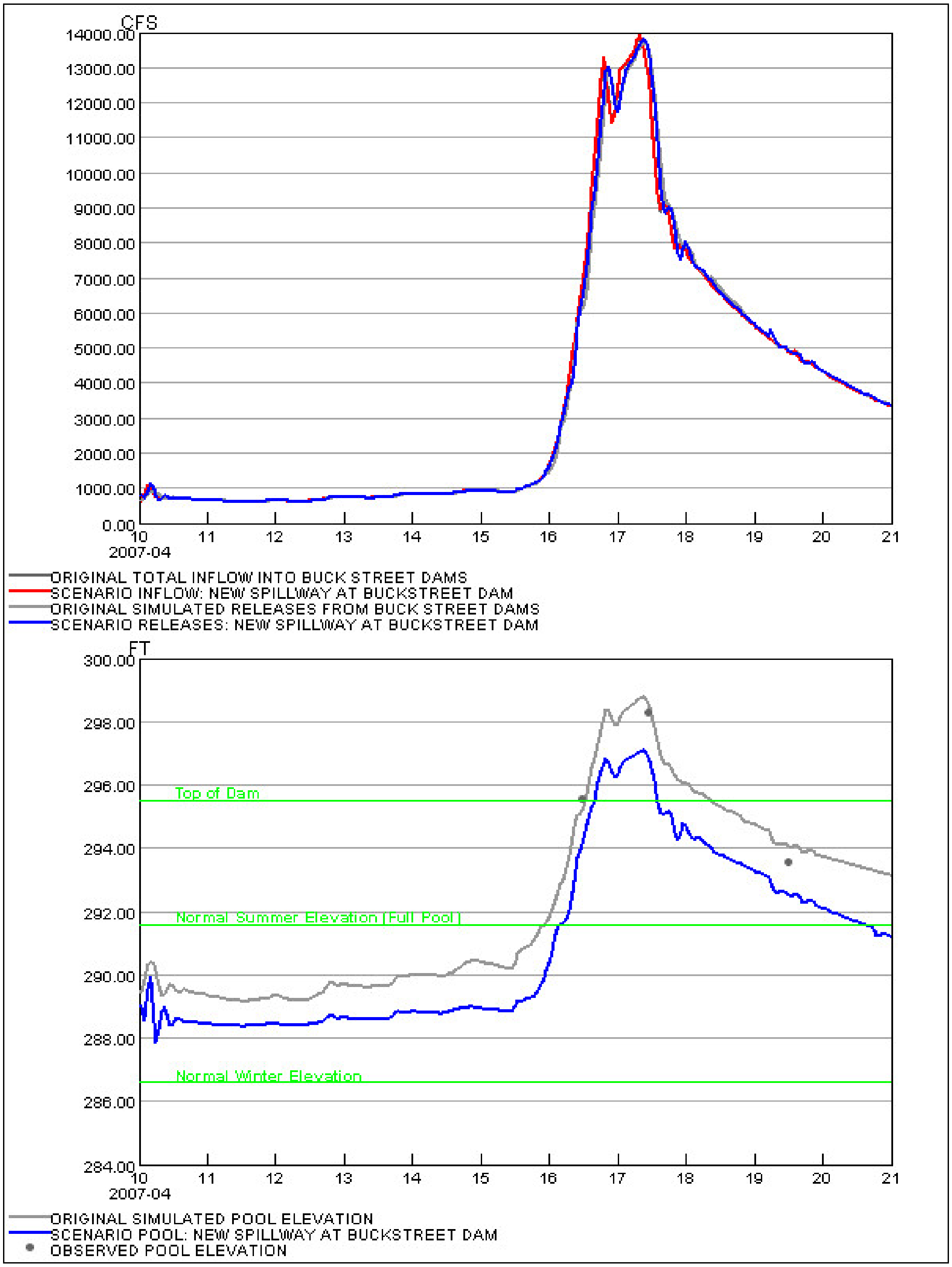


Figure 3-34: Buck Street Dams Alternative Operations - Spillways lowered by two feet

B-3.9 Webster Mill Dam / Pembroke Generating Station (NHDES# 190.03)

B-3.9.1 General Description

Webster Mill Dam is located on the Suncook River in the town of Suncook. It is a small run-of-river hydropower project, with a normal storage capacity of 60 acre-feet and a maximum capacity of 165 acre-feet. The dam is privately owned and operated through a sluice gate, two stoplog bays, and an Obermeyer panel. The typical summer lake elevation is 276.8 feet, which corresponds to the elevation of the Obermeyer panel raised by 3.8 feet over the spillway.

A plan view of Webster Mill Dam / Pembroke Generating Station is presented in Figure 3-35. A photograph of Webster Mill Dam is shown in Figure 3-36.

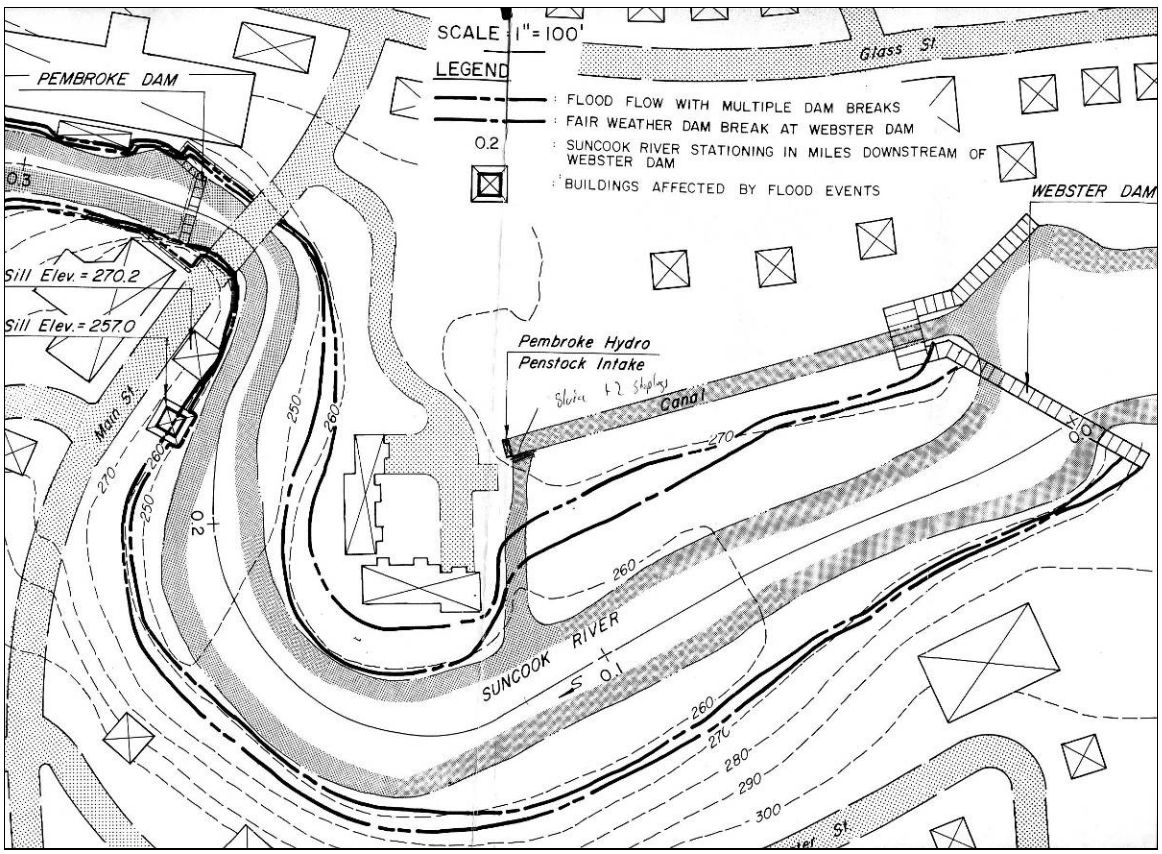


Figure 3-35: Plan View of Photograph of Webster Mill Dam / Pembroke Generating Station

Figure 3-36: Photograph of Webster Mill Dam

B-3.9.2 Actual Operations

Observed data for the 2006 and 2007 flood events consisted of daily values for pool, releases, and power generation provided by the dam operators. Important operations are listed in Table 3-19 and Table 3-20.

Table 3-19: Webster Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	OBERMEYER	STOPLOGS	SLUICE GATE	TURBINES
5/13/2006			Deflating			Generating
5/14/2006			Fully deflated	All removed	Open	Generating
5/18/2006			At 3.8 ft			Generating

Table 3-20: Webster Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	OBERMEYER	STOPLOGS	SLUICE GATE	TURBINES
4/16/2007	10:30 AM		Fully deflated			Generating
4/16/2007	12 noon			All removed	Open	Generating
4/19/2007			At 3.8 ft	All In	Closed	Generating

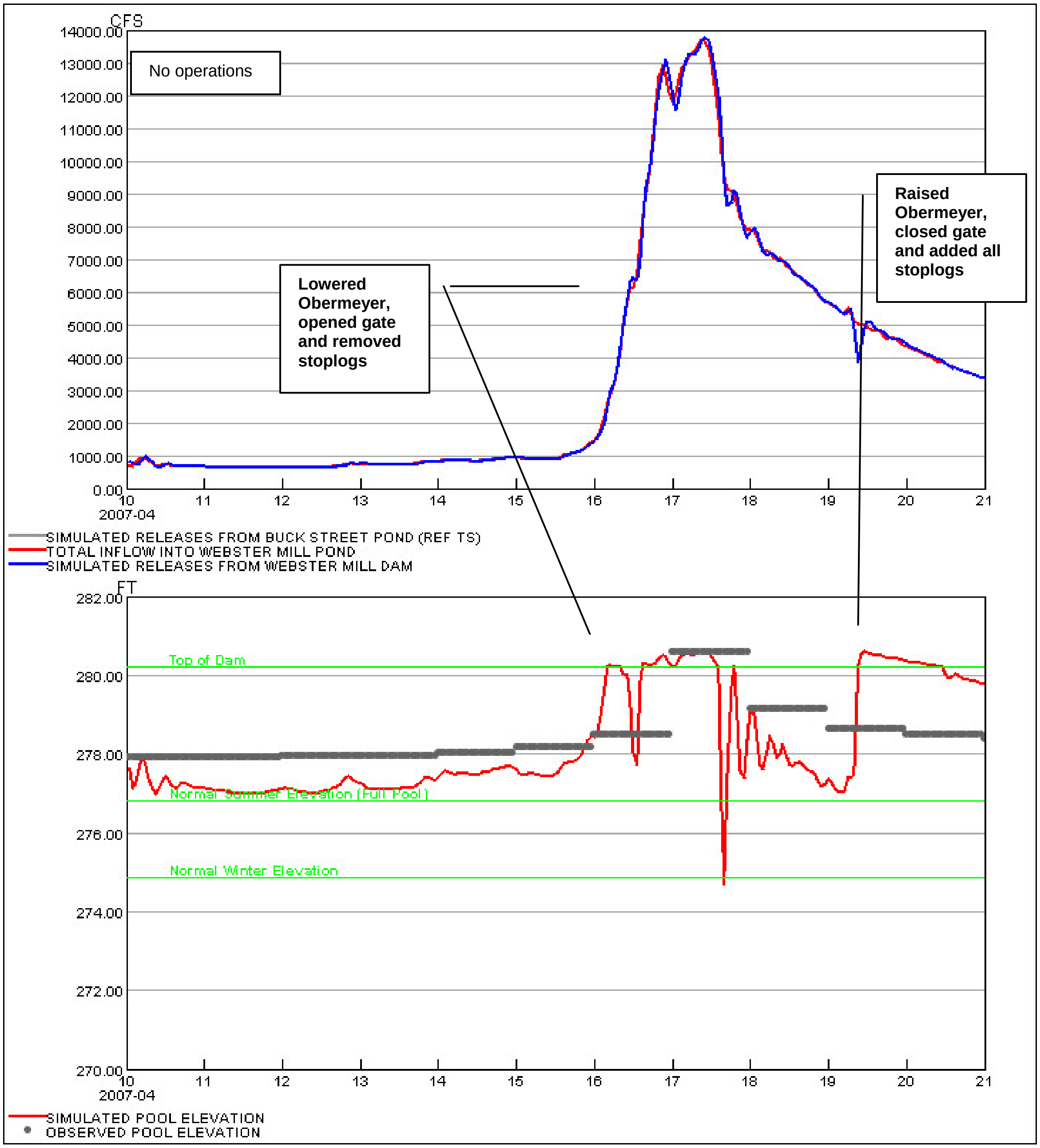


Figure 3-37: Webster Mill Dam Simulation Results for the April 2007 Flood Event

The pool elevation at the site was 1.26 feet above full pond on May 3, 2006 and rose slightly to 1.3 feet above by May 13. In response, the Obermeyer was lowered on May 14 and all stoplogs were removed and the sluice gate was opened. Despite these operations the pool elevation continued to rise, and by May 16 had reached a maximum of 2.88 feet over the normal pool elevation. At this time the pool was 0.52 foot below the top of the dam. The water began to drop on May 17, and the Obermeyer was raised by 3.8 feet on May 18. The pool continued to drop and no further actions were taken.

The pool at Webster Mill was 1.35 feet above full pond on April 3, 2007. Ten days later, on April 13, the pool had dropped to 1.15 feet above full pond. On April 16 the Obermeyer gate was fully lowered, all stoplogs were removed, and the sluice gate was opened in response to rising water levels. By then the pool was 1.70 feet over full pond. It continued to rise to a maximum height of 3.80 feet over full pond on

April 17, reaching almost the top of the dam. On April 19 the pool had dropped 1.07 feet below the top of the dam, 2.33 feet over full pond. At this time the Obermeyer gate was raised to 3.8 feet, all stoplogs were set in place and the sluice gate was closed.

Simulating pool elevation and releases at Webster Mill Dam proved challenging, because the very little storage in the project causes extreme changes in the simulated pool elevation when the inflows differ from the estimated outflows. Estimating exact releases on a one-hour time step was impossible, because only daily observations regarding the operations were available. As a result, the pool elevation oscillates significantly.

One would expect the pool to react very quickly to changes in operation, as evident on April 16, 2007, when the Obermeyer gate was lowered by 3.8 feet, or on the April 19, 2007, when it was raised again.

Operations at the site seem to have had very little impact on the passed flows, as depicted in Figure 3-37. The pool elevation rose almost to the top of the dam during both events, even with all gates and stoplogs open and the Obermeyer panel dropped. Upstream flooding was not reported.

B-3.9.3 Alternative Operations

Figure 3-38 shows a simulation of Webster Mill Dam with the pool elevation held at the winter drawdown until April 14. Upstream reservoirs were also held at the winter pool until this date. All other operations were unchanged. Maintaining the winter drawdown would have had no appreciable affect on the maximum pool elevation, due to the limited storage capacity behind Webster Mill Dam. The reduction in peak releases on April 17 would have been entirely caused by alternative operations at upstream dams.

Another scenario was run, where the Obermeyer gate at Webster Mill Dam was lowered on the 15th of April (Figure 3-39) instead of the 16th. This would have resulted in a very little change of the peak water level without affecting the releases.

The scenario simulations indicate that Webster Mill Dam cannot provide any appreciable flood control storage.

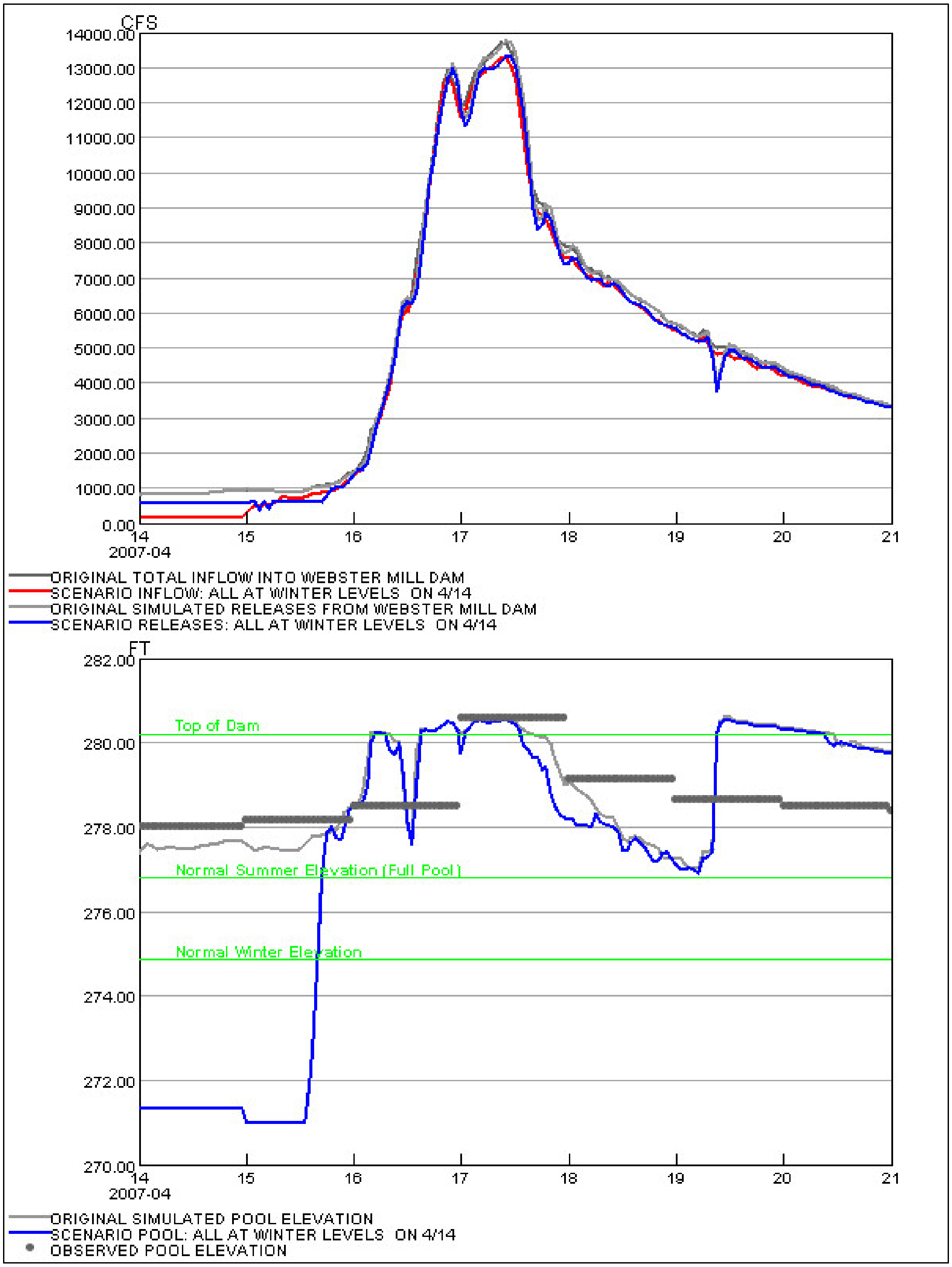


Figure 3-38: Webster Mill Dam Alternative Operations - Starting at Minimum Pool on April 14

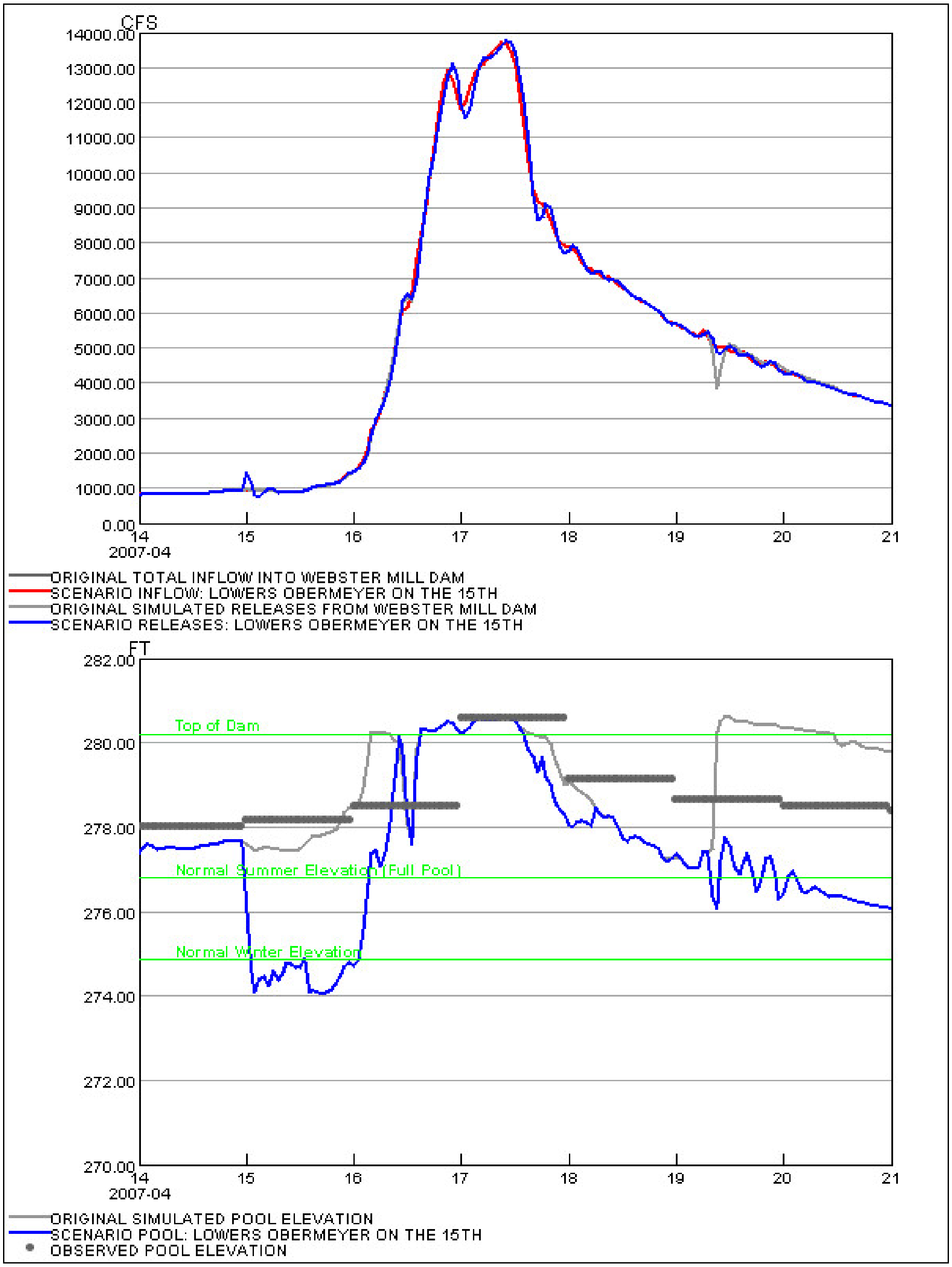


Figure 3-39: Webster Mill Dam Alternative Operations - Lowers Obermeyer on April 15

B-3.10 China Mill Dam (NHDES# 190.01)

B-3.10.1 General Description

China Mill Dam is located close to the mouth of the Suncook River, below Webster Mill Dam. This run-of-river project has a normal storage capacity if 6 acre-feet and a maximum capacity of 14 acre-feet. The dam is privately owned and operated for hydropower generation using four gates that control flow to power turbines as well as a smaller waste gate at the dam. The typical lake elevation is 226.4 feet, which corresponds to the elevation of the spillway.

A plan view and photograph of China Mill Dam are shown in Figure 3-40 and Figure 3-41 respectively.

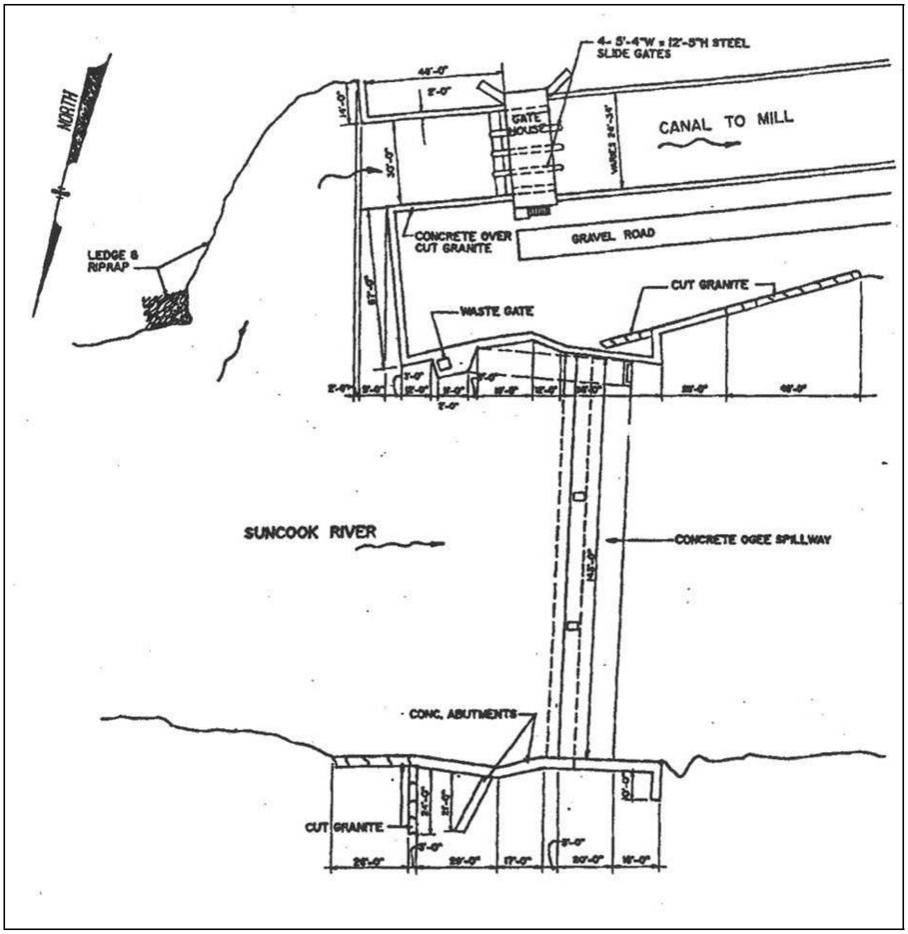


Figure 3-40: Plan View of China Mill Dam

Figure 3-41: Photograph of China Mill Dam

B-3.10.2 Actual Operations

The dam operators provided hourly flow through the turbines, pool elevation, and the status of the waste gate for both the May 2006 and the April 2007 floods. These data were sufficient for modeling.

Figure 3-42: China Mill Dam Simulation Results for the April 2007 Flood Event

At the beginning of May 2006, the pool elevation was about equal to the spillway crest. The pool elevation started to rise on May 13, in response to the storm event and the dam waste gate was opened. At 10:00 p.m. on May 14, a high trash differential was noted. The turbines were not operated from 11:00 p.m. on May 14 through 11:00am on May 16 due to insufficient net head. The pool elevation reached a maximum height of 6.45 feet over the spillway on May 15, but remained 0.85 foot below the top of the dam. On May 16, the pool began a steady decline.

On April 3, 2007, the pool was about 1 foot over the spillway crest. The pool was rising and reached 1.4 feet over the spillway by April 13. During the April 2007 event, the waste gate in the dam was fully open, but flow through powerhouse was prevented due to damaged equipment. The uncontrolled spillway therefore provided the majority of the release capacity. The pool reached a maximum elevation of 6.74 feet over the spillway on April 16, but remained 0.56 foot below the top of the dam.

The simulation of the China Mill project (see Figure 3-42) is plagued by the same issues as the one for Webster Mill Dam: The very small storage causes oscillation in the pool when inflows are not matched exactly by releases. The simulated pool elevations are therefore not usable.

The very small size of the impoundment behind China Mill Dam prevents any flood control, and releases are typically very similar to the inflows. During both events, the waste gate in the dam was fully open, but no flows were passed through the turbines. The uncontrolled spillway therefore provided the majority of the release capacity. Observations at the dam suggest that the dam was not overtopped. Upstream flooding was not reported.

B-4.0 PISCATAQUOG RIVER

The return period of the April 2007 flood event on the Piscataquog River was approximately 75 years, according to observations near Goffstown. These are shown in Figure 4-1 for the May 2006 and April 2007 events. The figure includes the FEMA 10-, 50-, 100-, and 500-year flood flows.

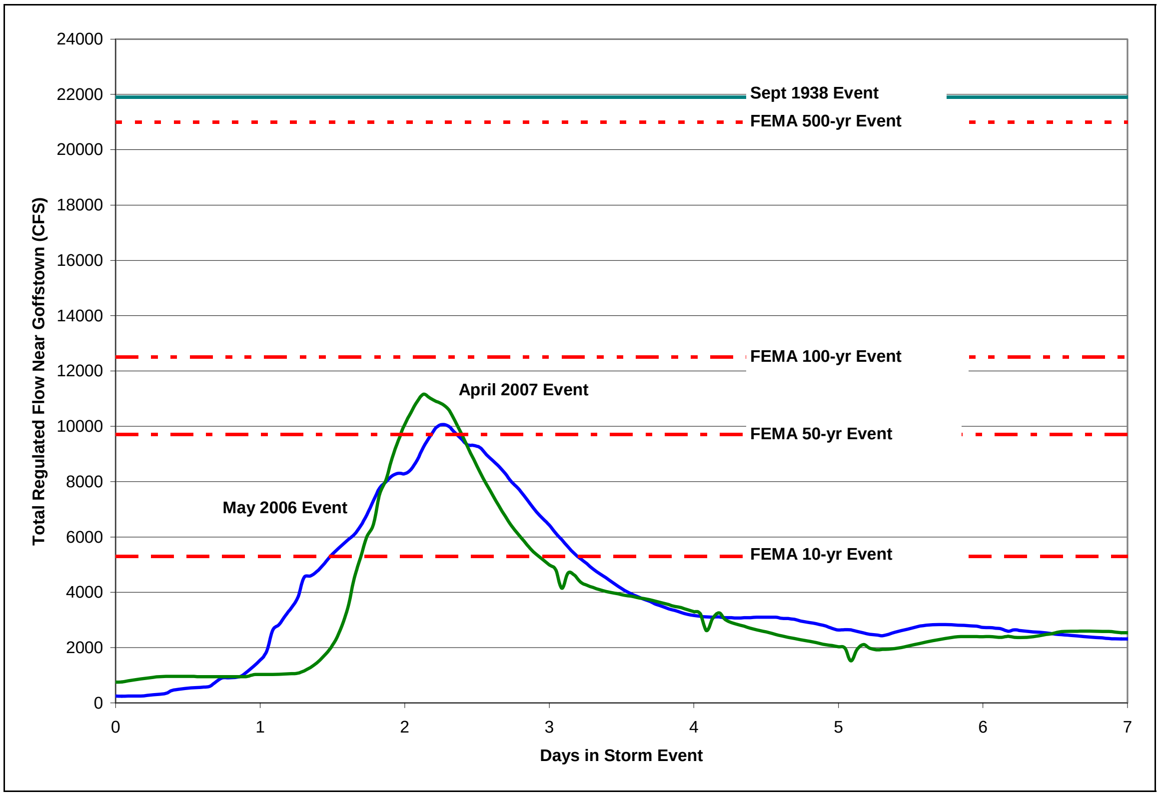


Figure 4-1: Piscataquog River - Comparison of May 2006 and April 2007 Events and FEMA Flood Levels

Figure 4-2 depicts the dams investigated in the Piscataquog River basin.

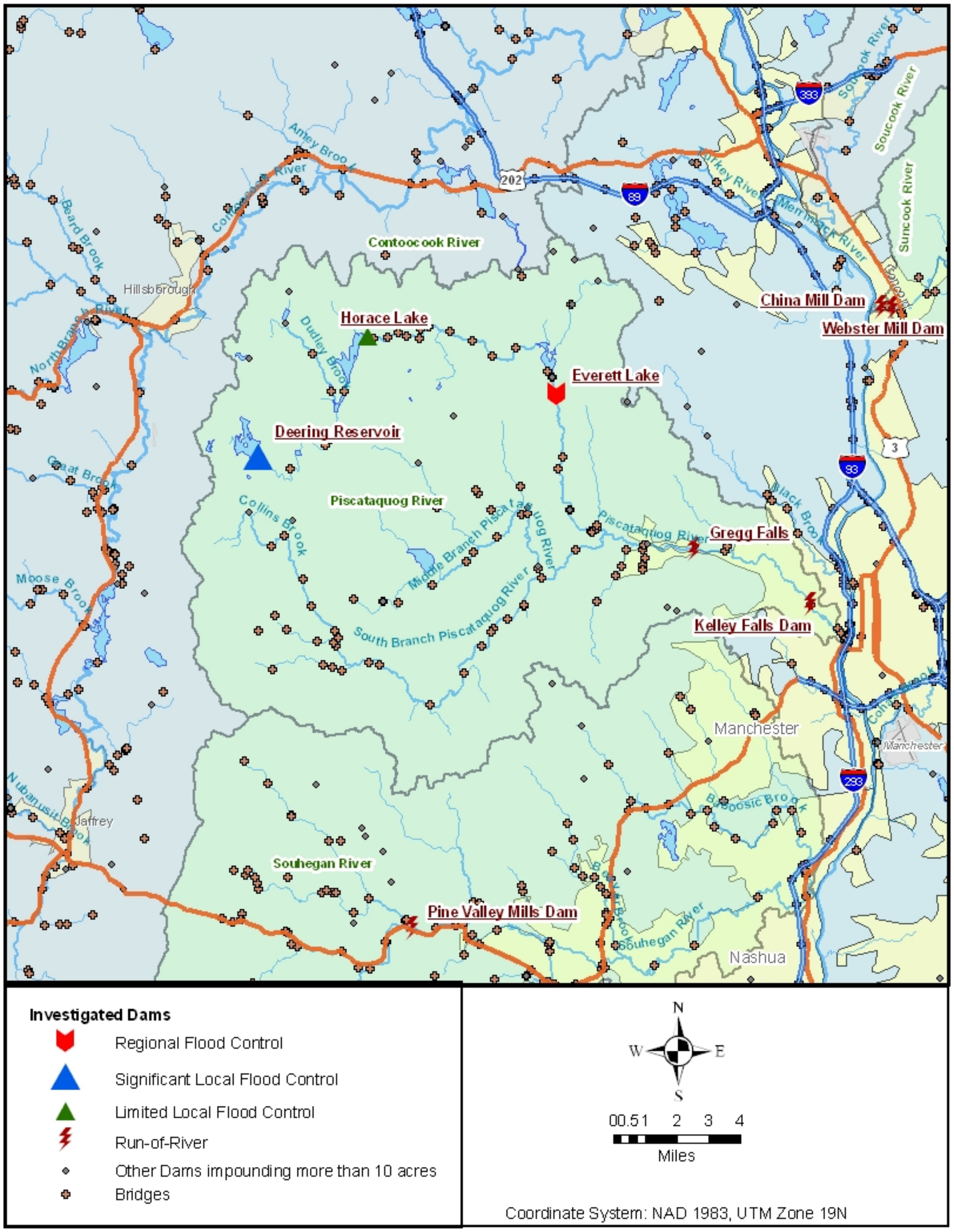


Figure 4-2: Dams Investigated in the Piscataquog River Basin

B-4.1 Deering Reservoir (NHDES # 062.05)

B-4.1.1 General Description

Deering Reservoir is located in the headwaters of the Piscataquog River, to the south of the town of Deering. Most of the lakeshore is undeveloped. At normal and maximum levels the lake can store approximately 3,400 and 4,980 acre-feet respectively. Deering Reservoir can store 7.1 inches of runoff into the lake, providing significant local flood control capacity.

Deering Reservoir is controlled and operated through one stoplog bay. The spillway used to be equipped with flashboards until 2006, when they were permanently removed during a rebuilt of the spillway. During the summer months, the lake elevation is maintained at 919.1 feet, which corresponds to the elevation of the top of the former flashboards (now the elevation of the new spillway). After Columbus Day the lake level is lowered to one foot below full pool by November 1. After this initial target is reached, the pool is lowered another three feet. In the spring, the stoplogs are replaced to catch the spring runoff. It requires about 5.64 inches of runoff to refill the lake from the lower winter pool to the normal summer pool.

A plan view of Deering Dam is shown in Figure 4-3.

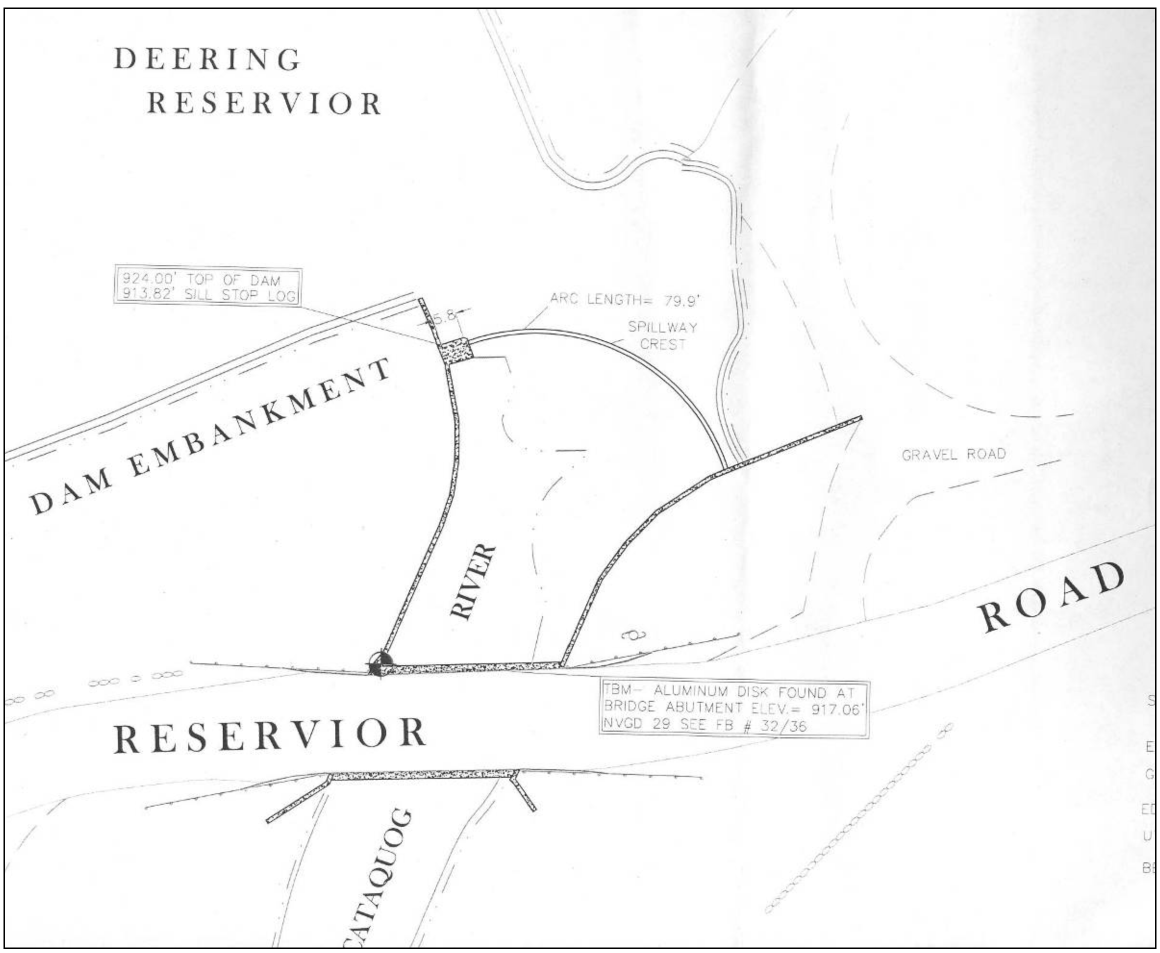


Figure 4-3: Plan View of Deering Dam

B-4.1.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 919.1 feet. Table 4-1 and Table 4-2 list the pool elevation and the dam operations performed by the NHDES at Deering Reservoir.

Table 4-1: Deering Reservoir Pool Elevation and Dam Operations during the May 2006 Flood

DATE	TIME	POOL ELEVATION	LOG BAY	SPILLWAY/FLASHBOARD CONDITION	COMMENTS	INT
5/1/2006		-1.20	1 OUT	FLASH BOARDS UP		CT
5/5/2006		-1	1 OUT		NO CHANGES MADE	PA
5/14/2006		0.5	3 OUT		PULLED TWO LOGS	AS
5/15/2006		0.45	3 OUT		LET RUN W/ THREE LOGS OUT	AS
5/17/2006		0.18	ALL IN		SET THREE LOGS	AS/MC
5/22/2006		0.25	ALL IN			PA

Table 4-2: Deering Reservoir Pool Elevation and Dam Operations during the April 2007 Flood

DATE	TIME	POOL ELEVATION	LOG BAY	SPILLWAY/FLASHBOARD CONDITION	COMMENTS	INT
4/2/2007		-2.5	3 OUT	NEW CONCRETE SPILLWAY	ICE STILL ON LAKE/CREW ON SITE	AS
4/3/2007		-2.25	2 OUT	AT FULL POND ELEVATION	PUT ONE LOG IN LOG BAY	CL
4/13/2007		-1.5	5 OUT	NO MORE FLASHBOARDS	PULLED THREE LOGS FROM LOG BAY	CREW
4/16/2007	AM	-0.5	5 OUT			WPH
4/16/2007	3:00 PM	-0.1	5 OUT		LET RUN	WPH

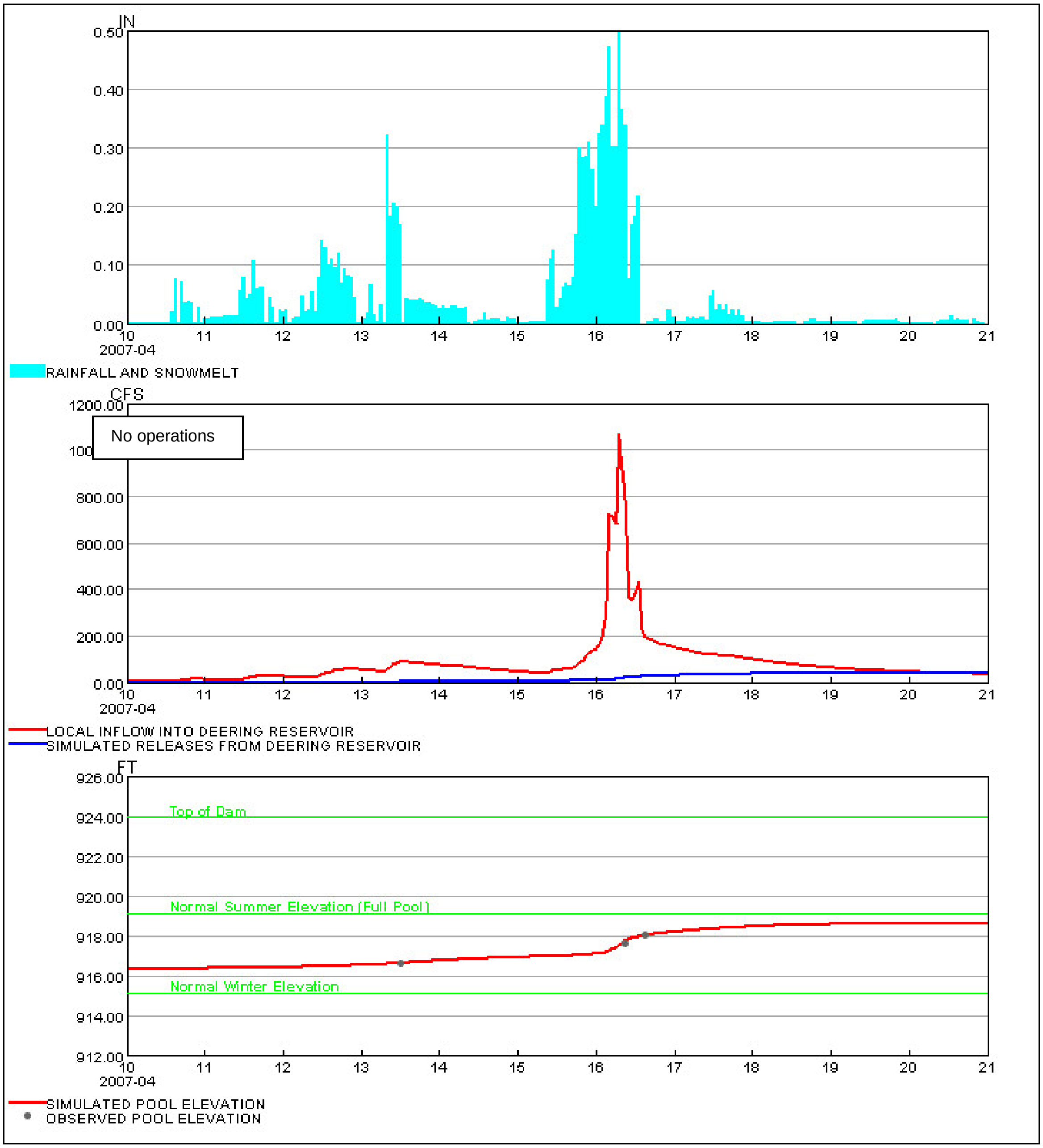


Figure 4-4: Deering Reservoir Simulation Results for the April 2007 Flood Event

At the beginning of May 2006, the flashboards were up, one stoplog was out, and the pool elevation was 1.2 feet below the flashboards. The pool began to rise in response to the storm event and reached a maximum of 0.5 foot above the flashboard elevation on May 14. This was 4.9 feet below the top of the dam. At this time two additional stoplogs were removed. No further action was taken and the pool began to drop but remained above the flashboards. All stoplogs were replaced on May 17. The pool began to rise again and was 0.25 foot above the flashboards on May 22.

Deering Reservoir was refilling from the winter drawdown in April 2007, and was 1.2 feet below the spillway crest on April 3. No flashboards were in place as they had been permanently removed. On April 13, 2007, the pool was 0.45 foot below the spillway and NHDES dam operators removed three stoplogs in anticipation of the flood event. On April 16, the pool reached a maximum recorded height of 0.95 foot over the spillway, but was still 5 feet below the top of the dam. The dam was then not operated any further as it did not rise to the full lake elevation during the event. Given this, the lake provided excellent flood control for the areas immediately downstream.

The simulation for April 2007 is depicted in Figure 4-4 and tracks the observed pool elevations very well.

B-4.1.3 Alternative Operations

A simulation of Deering Reservoir with the pool elevation held at the winter level until April 14 was tested and is shown in Figure 4-5. All other operations were assumed to be unchanged. Given these alterative operations, Deering Lake would have been able to catch the entire April 2007 upstream flood flows. Releases from the dam could have been reduced from an actual 30 cfs to almost zero.

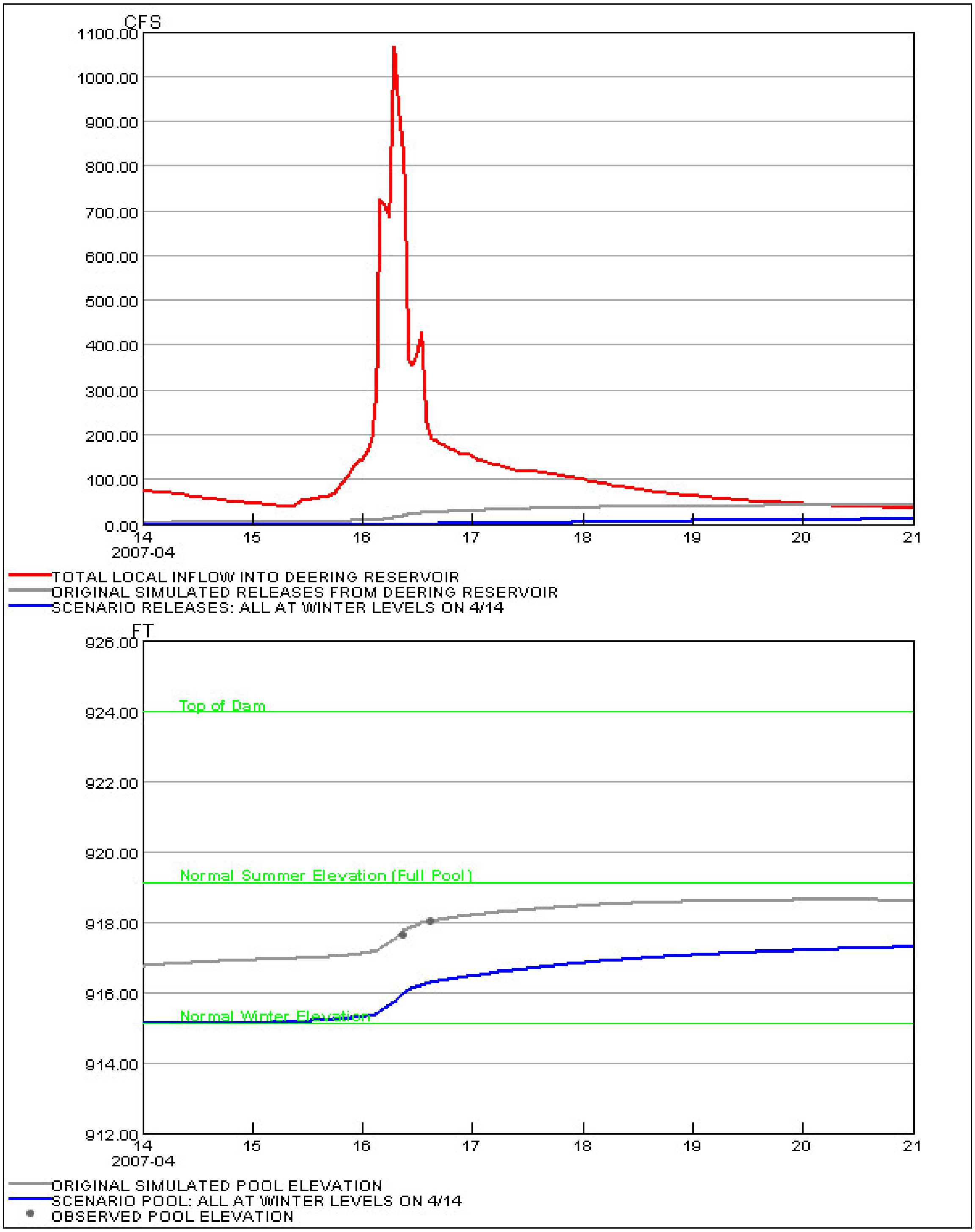


Figure 4-5: Deering Reservoir Alternative Operations - Starting at Minimum Pool on April 14

B-4.2 Horace Lake (AKA Weare Reservoir, NHDES# 247.01)

B-4.2.1 General Description

Horace Lake is a reservoir located on the Piscataquog River, downstream of Deering Reservoir. Horace Lake has sparse housing developments around most of the shoreline. The lake has a storage capacity of about 6,300 acre-feet at normal levels, and up to 8,600 acre-feet at its maximum elevation. Between those levels, Horace Lake can store about 1.49 inches of runoff into the lake, providing limited local flood control.

The pool elevation can be controlled at a dam structure at the southeastern edge of the lake. This is typically done by manual operation of five stoplog bays and a gate.

The normal or summer elevation of the lake is 655.49 feet, which corresponds to the elevation of the spillway crest. The lake is usually drawn down by five feet after Columbus Day. It requires about 1.05 inches of runoff to refill the lake from the lower winter pool to the normal summer pool.

B-4.2.2 Actual Operations

All observed data for the May 2006 and April 2007 flood events were provided by the NHDES. The pool elevation is recorded relative to the summer lake elevation of 655.49 feet. Table 4-3 and Table 4-4 list the pool elevation and the dam operations performed at Horace Lake by NHDES.

Table 4-3: Horace Lake Pool Elevation and Dam Operations during the May 2006 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 5	GATE	COMMENTS	INT
5/1/2006	-3.15	2 OUT	2 OUT	5 OUT	2 OUT	2 OUT	OPEN 2"		CT
5/5/2006	-2	2 OUT	2 OUT	3 OUT	2 OUT	2 OUT	OPEN 2"	SET TWO LOGS CENTER BAY	PA
5/9/2006	-1.45	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	SET SIX LOGS OPENED GATE TO 3"	AS
5/12/2006	-0.9	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	LET RUN AS IS	AS
5/14/2006	1.6	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	LET RUN AS IS	AS
5/16/2006	1.05	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	LET RUN AS IS	AS
5/19/2006	0.4	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	LET RUN AS IS	PA
5/22/2006	0.4	1 OUT	1 OUT	1 OUT	1 OUT	1 OUT	OPEN 3"	LET RUN AS IS	PA

Table 4-4: Horace Lake Pool Elevation and Dam Operations during the April 2007 Flood

DATE	POOL ELEVATION	LOG BAY 1	LOG BAY 2	LOG BAY 3	LOG BAY 4	LOG BAY 5	GATE	COMMENTS	INT
4/2/2007	-3.25	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	CLOSED	LET RUN AS IS/ ICE STILL ON POND	AS
4/16/2007	0.5	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	CLOSED	LET RUN AS IS	WPH
4/18/2007	0.4	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	ALL OUT (8)	CLOSED	LET RUN AS IS	WPH

On May 1, 2006 a total of 13 stoplogs were out and the gate was 2” open. The pool elevation was 3.15 feet below the spillway crest. Two logs were put back in place on May 5. Six additional logs were set and the gate was opened to 3” on May 9. At this time the pool elevation had risen to 0.9 foot below the spillway. No further actions were taken and the pool rose to 1.6 feet above the spillway on May 14. This was the maximum recorded pool elevation and corresponds to 5.40 feet below the top of the dam. The pool started to drop on May 16 and was 0.4 foot above the spillway on May 22.

Horace Lake was 3.25 feet below the spillway crest on April 3, 2007, nearing the halfway point in refilling from the winter drawdown level to the summer pool elevation when the April 16 event occurred. At that time all stoplogs were removed from the bays and the single gate was closed. The NHDES did not operate the dam during the event and the reservoir filled to about 0.5 foot above the spillway crest on April 16. This was the maximum recorded pool elevation, and corresponds to 6.5 feet below the top of the dam. The NHDES did not open the gate during the event to prevent downstream flooding, assuming that no upstream flooding was likely. Horace Lake was able to delay and mute the highest inflows during the April event, thus providing some flood control immediately downstream.

The simulation for April 2007 is depicted in Figure 4-6 and tracks the observed pool elevations reasonably well.

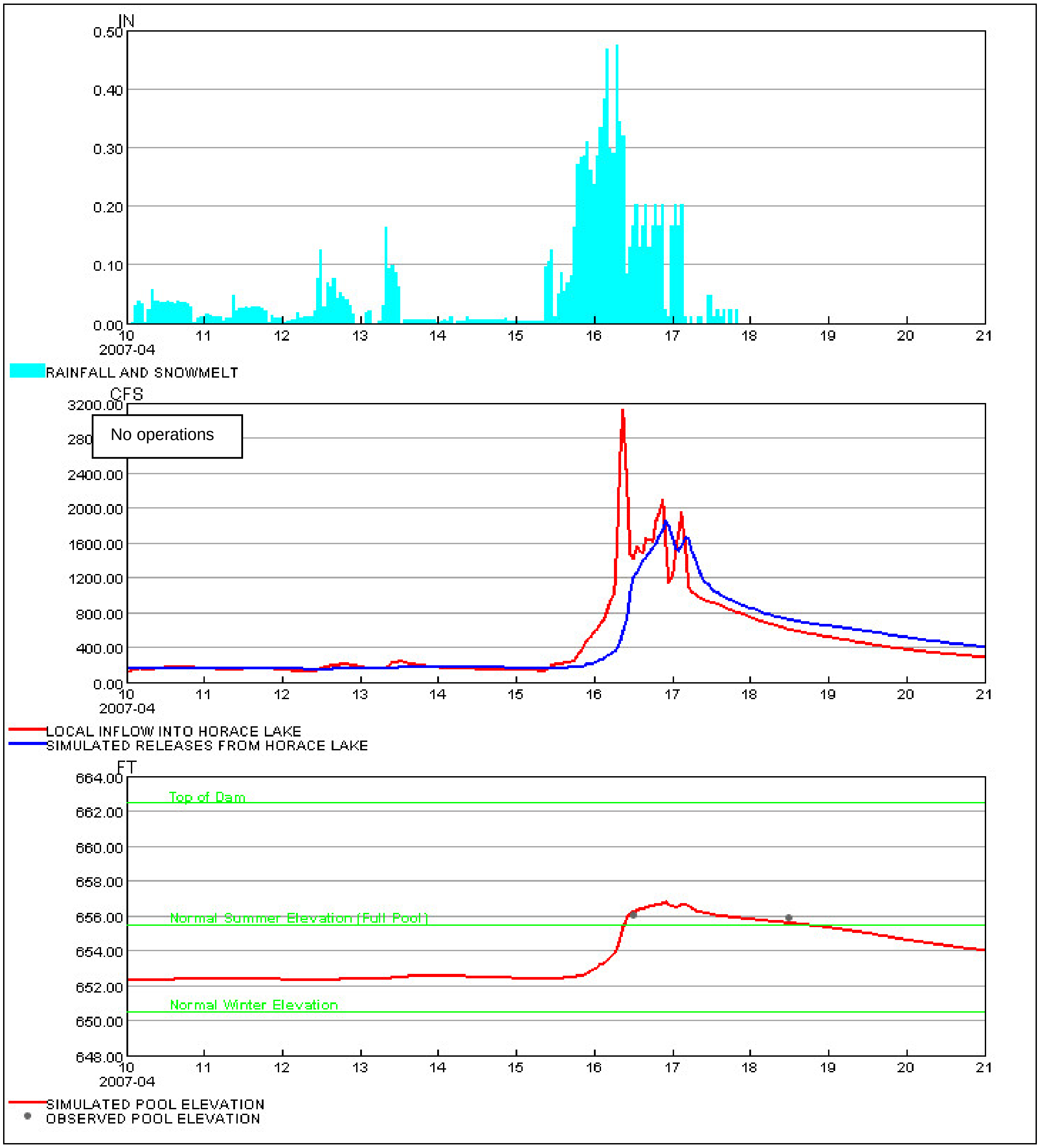


Figure 4-6: Horace Lake Simulation Results for the April 2007 Flood Event

B-4.2.3 Alternative Operations

A simulation of Horace Lake with the pool elevation at the winter drawdown level on April 14 was tested and is shown in Figure 4-7. All other operations were unchanged.

Lowering the pool elevation more did not provide any appreciable reduction in the peak water level or flow.

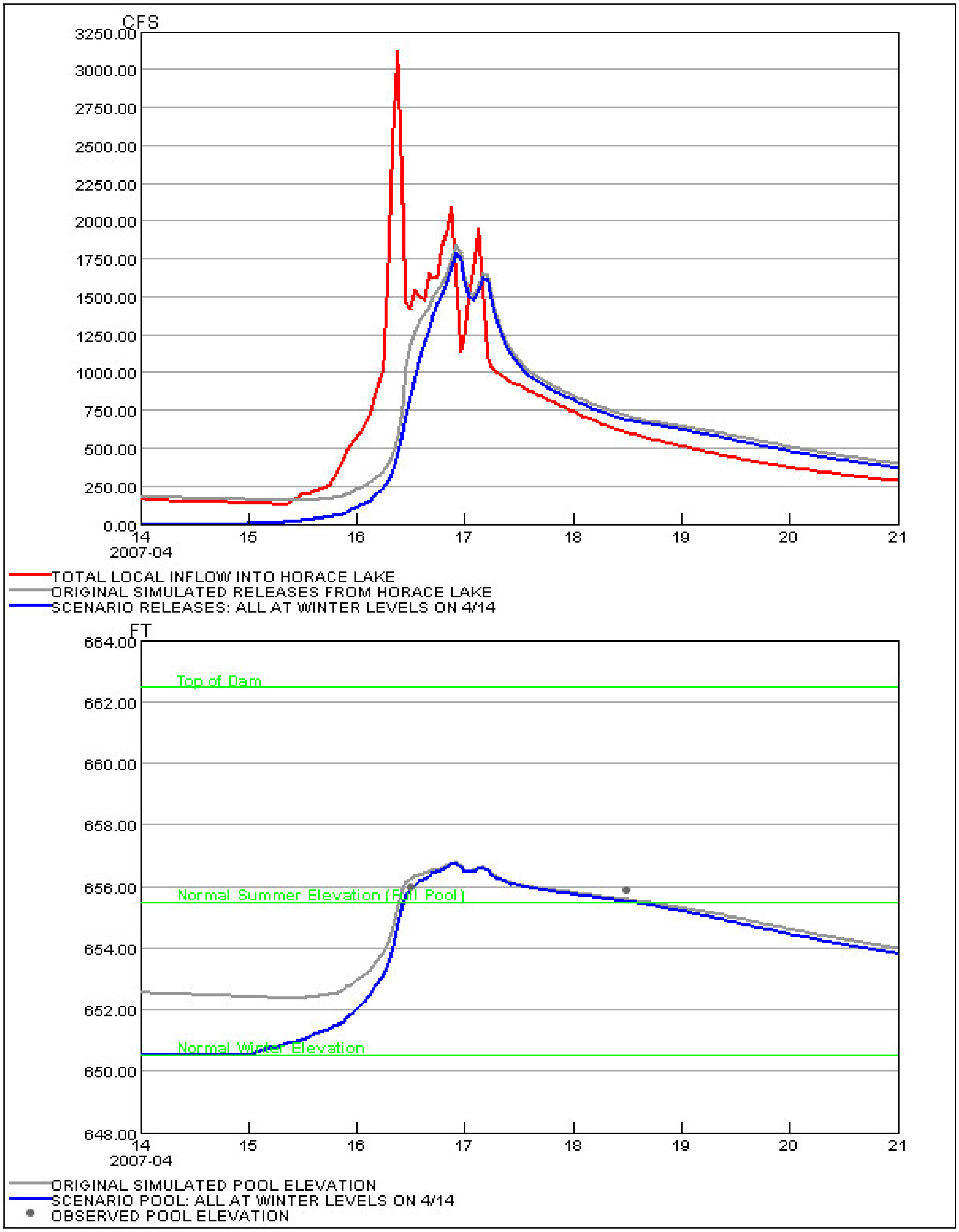


Figure 4-7: Horace Lake Alternative Operations - Starting at Minimum Pool on April 14

B-4.3 Everett Dam (NHDES# 247.14)

B-4.3.1 General Description

Everett Dam is located on the Piscataquog River, downstream of Horace Lake. Most of the lakeshore is developed, except for a park on the east side of the reservoir. The Lake has a storage capacity of about 1,000 acre-feet at normal pool elevation of 340 feet, and up to 132,800 acre-feet at its maximum elevation of 430 feet. Between those levels, Everett Dam can store 25.76 inches of runoff into the lake, providing significant regional flood control. With this amount of storage, the lake has never filled to capacity. The closest it came was in 1987 at 95 percent.

Everett Dam is designed to hold back floods in the upper reaches of the Piscataquog River as well as flood waters from the Contoocook River, which is connected to Everett Lake via a canal originating at Hopkinton Lake. Once Hopkinton Lake reaches a pool elevation of 400.75 feet, water can flow through the canal into Everett Dam if the pool elevation there is lower. Conversely, water from Everett Dam can flow into Hopkinton Lake at high pool elevations.

The pool elevations at Everett Dam are controlled by the US Army Corps of Engineers (USACE) New England District at the dam structure, located at the northeast end of the impoundment. The dam structure uses three hydraulic gates and one 8 feet circular conduit to control releases. Operating instructions for Everett Lake can be found at the USACE website:
www.reservoircontrol.com.

A photograph of Everett Dam is shown in Figure 4-8.

Figure 4-8: Photograph of Everett Dam

B-4.3.2 Actual Operations

Pool elevations, releases, gate settings, and computed inflows for Everett Dam were downloaded at an hourly time step from the USACE website www.reservoircontrol.com. Reports on the benefits of the USACE flood control dams during flood events can be found on the same website.

Table 4-5 and Table 4-6 list important operation changes and events during the 2006 and 2007 floods.

Table 4-5: Everett Dam Pool Elevation and Dam Operations during the May 2006 Flood

		POOL					
DATE	TIME	ELEVATION	RELEASE	GATE 1	GATE 2	GATE 3	COMMENTS
before 5/13/06				0	3 ft open	0	Normal gate setting
5/13/2006	17:15	342.75	46 cfs	0	0.5 ft open	0	
5/14/2006	8:45 AM	342.75	33 cfs	0	0.3 ft open	0	
5/15/2007	2:00 AM						Flows from Hopkinton Lake start entering
5/17/2006	12 noon	398.04	1002 cfs	1.9 ft open	1.9 ft open	1.9 ft open	
5/17/2006	2:00 PM	398.7	987 cfs	2 ft open	2.9 ft open	2 ft open	
5/18/2006	9:00 PM						Flows return to Hopkinton Lake
5/26/2006	1:45 PM	399.49	1265 cfs	2.3 ft open	2.9 ft open	2.3 ft open	

Table 4-6: Everett Dam Pool Elevation and Dam Operations during the April 2007 Flood

		POOL					
DATE	TIME	ELEVATION	RELEASE	GATE 1	GATE 2	GATE 3	COMMENTS
before 4/15/07				0	3 ft open	0	Normal gate setting
4/15/2007	15:45	342.93	48 cfs	0	0.5 ft open	0	
4/16/2007	7:30 AM	347.82	20 cfs	0	0.1 ft open	0	
4/17/2007	7:00 AM						Flows from Hopkinton Lake start entering
4/19/2007	3:15 PM	395.55	1025 cfs	2 ft open	2 ft open	2 ft open	
4/20/2007	11:15 AM	399.87	1418 cfs	2.7 ft open	2.8 ft open	2.7 ft open	
4/25/2007	8:00 PM						Flows from Hopkinton Lake stop entering

In the beginning of May 2006, Everett Dam gates were set at the normal setting. Two of the gates were closed, and one gate was open 3 feet. The pool elevation at this time was 2.75 feet above the normal pond elevation, but still 73 feet below the spillway crest. As the storm began on May 13 the opening at Gate 2 was reduced to 0.5 foot, and releases were set to 46 cfs. On May 14, the opening at Gate 2 was further reduced to 0.3 foot and releases were cut back to 33 cfs. These operations held back almost all of the upstream contribution, releasing only the required minimum flows. Water from Hopkinton Lake started entering Everett Lake the following day, on the 15. No further operations were performed until May 17 when two gates were opened 2.0 ft, one gate opened 2.9 ft, and releases were increased to about 1,000 cfs. The next day, on the 18th, flows began returning back to Hopkinton Lake. On May 26 two gates were opened to 2.3 feet, and the third was left at 2.9 ft. Releases were increased to 1,265 cfs. On this day the pool reached the maximum recorded elevation, 16.5 feet below the spillway crest. This was 30.5 feet below the top of the dam. All operations at the dam conformed to the published flood operation rules.

Everett Lake was almost empty at the beginning of the April 2007 flood event. The pool was 73 feet below the spillway on April 15. The USACE started to close the single open gate in the afternoon of April 15, even before the inflows increased significantly. This reduced the releases from the project to about 48 cfs, which is close to the minimum releases of 32 cfs required by the outflow guidance for the project during a flood event. Releases were kept at very low levels until after the event, which filled the lake significantly. In the afternoon of April 17, flood water from Hopkinton Lake started entering Everett Lake, eventually raising its pool to 51 percent of the flood control storage capacity. Note in Figure 4-9 that the flows from Hopkinton Lake vastly exceeded the flows entering Everett Lake through the Piscataquog River after April 18. The USACE started releasing significant flows only after the event on April 19, evacuating the lake with releases close to the maximum allowed rate of 1,500 cfs. The pool reached the maximum recorded height on April 20 and was 16 feet below the spillway, 30 feet below the top of the dam.

During both events, Everett Dam provided significant regional flood control benefits, reducing any contributions form the upper reaches of the Piscataquog River to the minimum allowed flows.

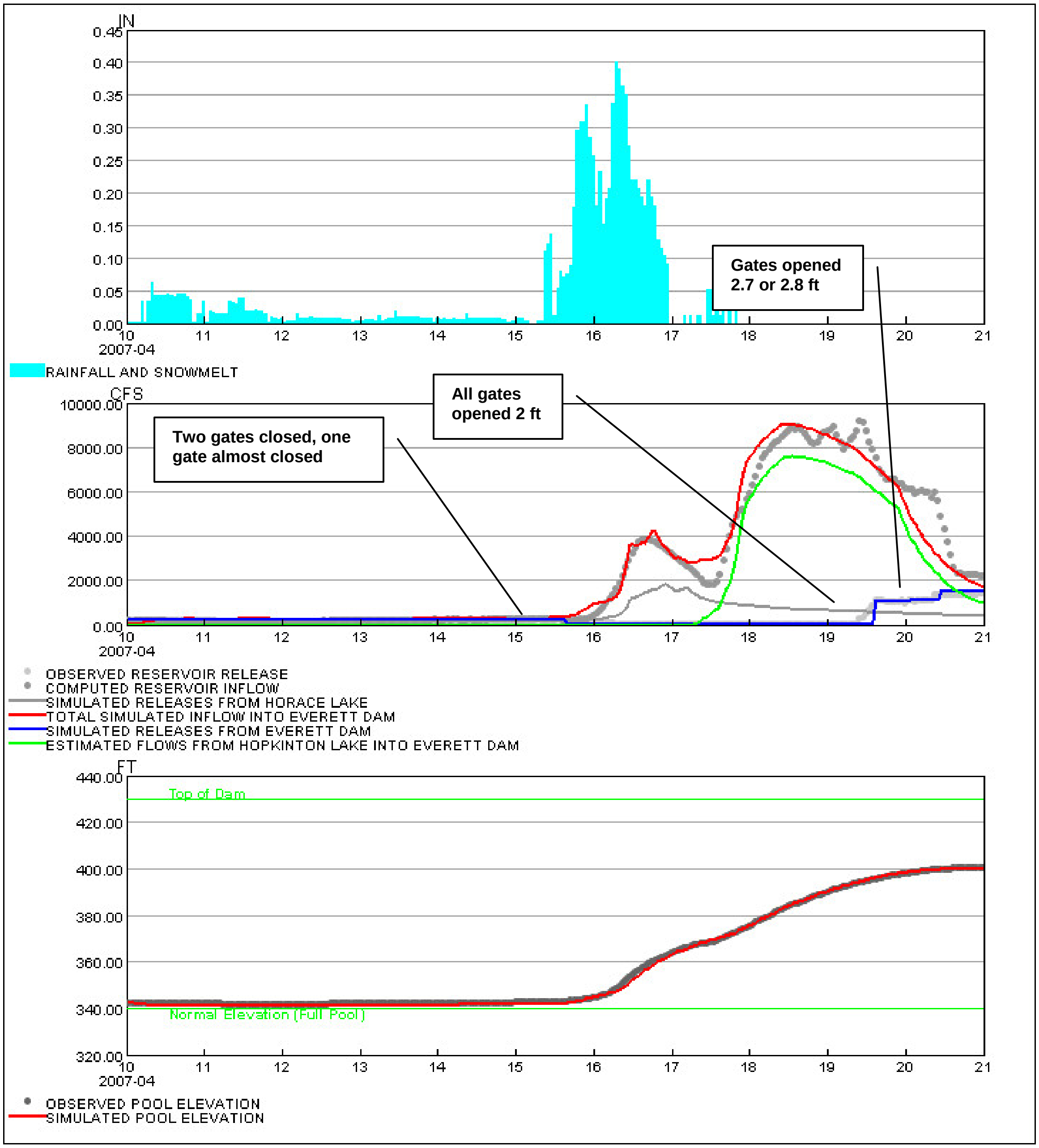


Figure 4-9: Everett Dam Simulation Results for the April 2007 Flood Event

B-4.4 Gregg Falls Dam (NHDES# 093.01)

B-4.4.1 General Description

Gregg Falls Dam is located downstream of Everett Dam, below the confluence of the main stem Piscataquog River with the unregulated South Branch of the Piscataquog River. Gregg Falls is located directly downstream of Goffstown and most of the shoreline is developed. Gregg Falls Lake has a storage capacity of about 1,800 acre-feet at normal levels, and up to 4,700 acre-feet at its maximum elevation, providing 0.27 inch of flood control storage. It is considered a run-of-river hydropower project.

The water levels in Gregg Falls Lake are controlled by Algonquin Power Systems, which leases the dam from the NHDES, through a spillway with flashboards, two gates, and turbines. The site also includes a fish bypass with a maximum discharge capacity of 21 cfs.

A photograph of Gregg Falls Dam is shown in Figure 4-10.

Figure 4-10: Photograph of Gregg Falls Dam

B-4.4.2 Actual Operations

Algonquin Power Systems provided detailed operations as well as pool elevation, discharges through the gates, over the spillway and power generation in 5–minute intervals.

On May 6, 2006 the pool was 0.2 foot below the flashboards and rose to about the height of the flashboards on May 13. During the May 2006 event, all gates and the fish bypass were fully open. Flashboards were in place, but about half of them had been destroyed by ice before the event. Releases from the project were controlled by the two installed turbines. Additional uncontrolled discharge occurred over the spillway. The maximum pool elevation was 3.3 feet over the flashboards and occurred on May 14. This was 2.7 feet below the top of the dam. No upstream flooding was reported.

As depicted in Figure 4-11, most of the inflows into Gregg Falls during the April 2007 event originated in the unregulated South Branch of the Piscataquog River-Everett Dam held back almost the entire contribution from the upper reaches of the Piscataquog River itself. Gregg Falls has no winter drawdown, and the water elevation is typically close to the top of the spillway or flashboards. On April 10, 2007 the pool was 1.5 feet below the elevation at the top of the flashboards, which were not erected at this time. The pool dropped slightly by April 13 to 1.65 feet below the flashboards. During the April 2007 event, all gates and the fish bypass were fully open. Releases from the project were controlled by the two installed turbines. Additional uncontrolled discharge occurred over the spillway. The maximum pool elevation of 2.1 feet over the flashboards (3.9 feet below the top of the dam) was reached in the evening of April 16th. No upstream flooding was reported. However, significant flooding occurred downstream of the project.

Given the data provided by the operator, the simulation captures the peak pool elevation and the peak release very well—however, it is short on volume. The simulation also follows the observed hydrograph at the downstream Goffstown gage, capturing the magnitude and timing of the peak.

B-4.4.3 Alternative Operations

This study investigated whether alternative seasonal or flood control operations could have prevented the flooding downstream. Figure 4-12 shows the results if Gregg Falls had been completely drained before the event on April 14. While unreasonable, this scenario illustrates the maximum flood control benefit that the project could possibly provide. However, even with Gregg Falls completely drained before the event there would have been no appreciable reduction in the peak releases and peak water level because the small reservoir would have filled up rapidly at the beginning of the event.

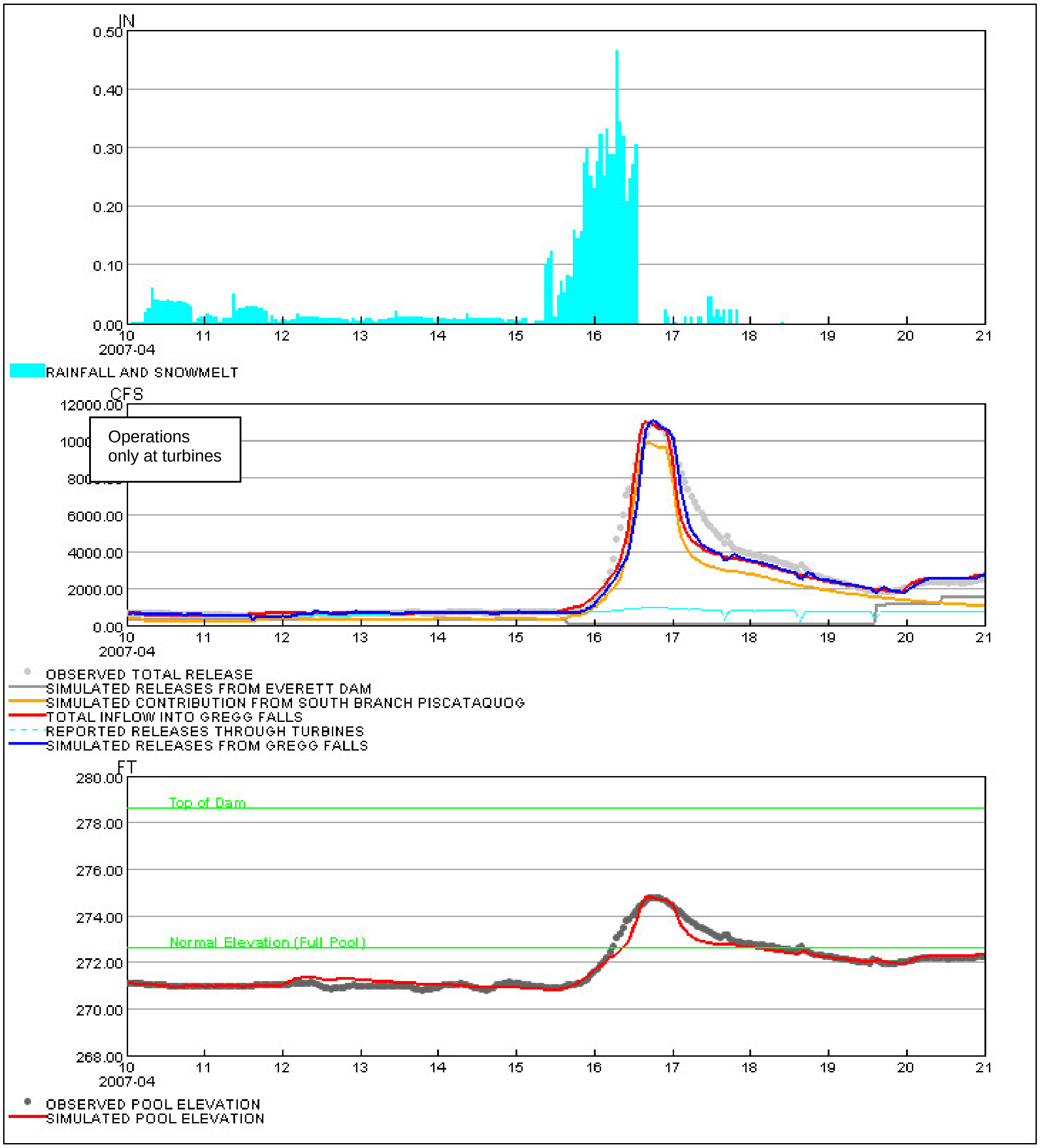


Figure 4-11: Gregg Falls Dam Simulation Results for the April 2007 Flood Event

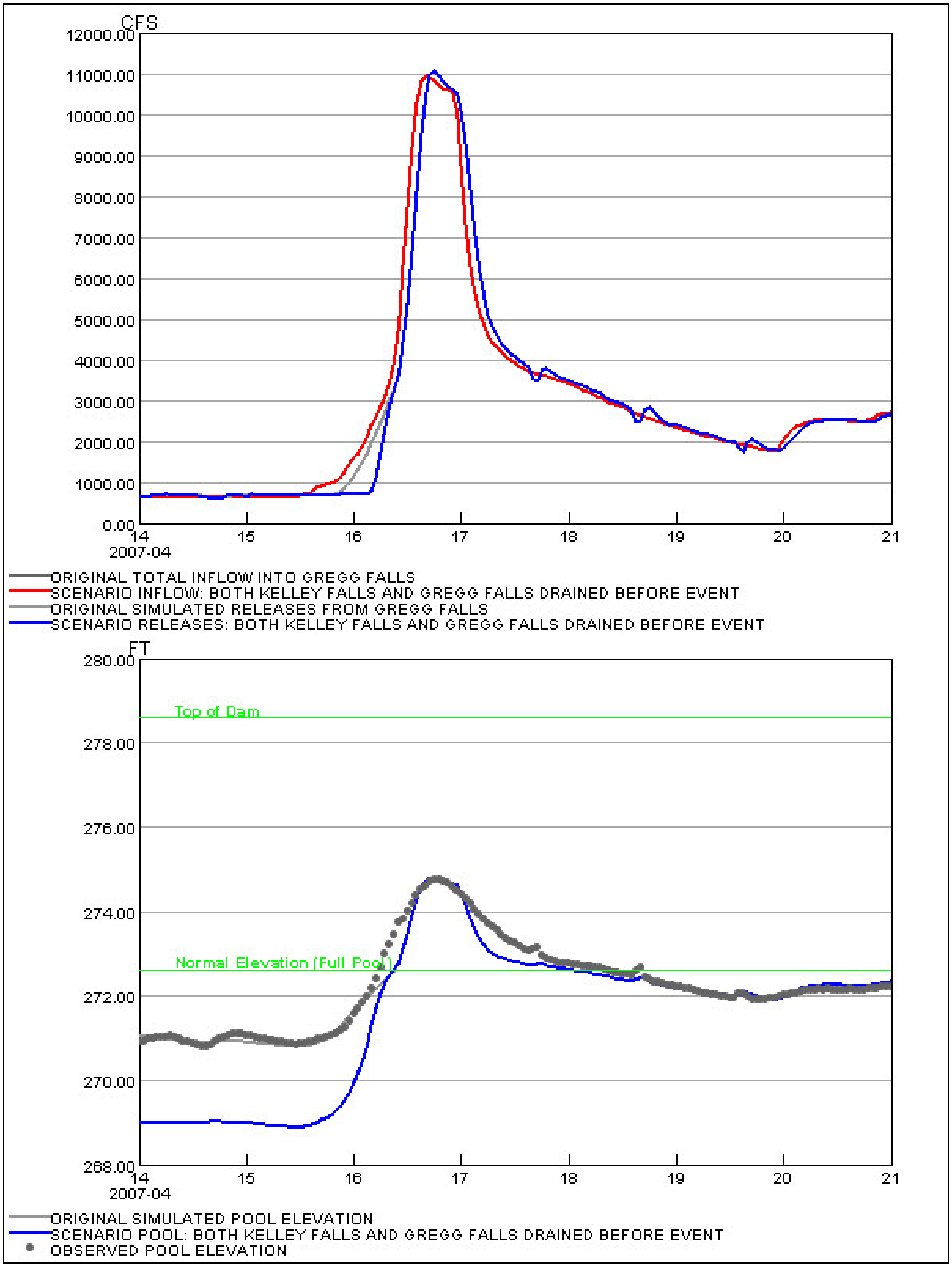


Figure 4-12: Gregg Falls Alternative Operations - Drained before Event

B-4.5 Kelley Falls Dam (NHDES# 150.02)

B-4.5.1 General Description

The run-of-river Kelley Falls hydropower project is located on the Piscataquog River in Manchester. Most of the shoreline is developed. The lake has a storage capacity of about 1,000 acre-feet at normal levels, and up to 2,290 acre-feet at its maximum elevation, providing a flood control storage of only about 0.11 inch. The water levels are controlled through a spillway with flashboards, a waste gate, and a relief gate. The typical summer lake elevation is 160.7 feet, which corresponds to the elevation of the flashboards.

A plan view and photograph of Kelley Falls Dam are shown in Figure 4-13 and Figure 4-14 respectively.

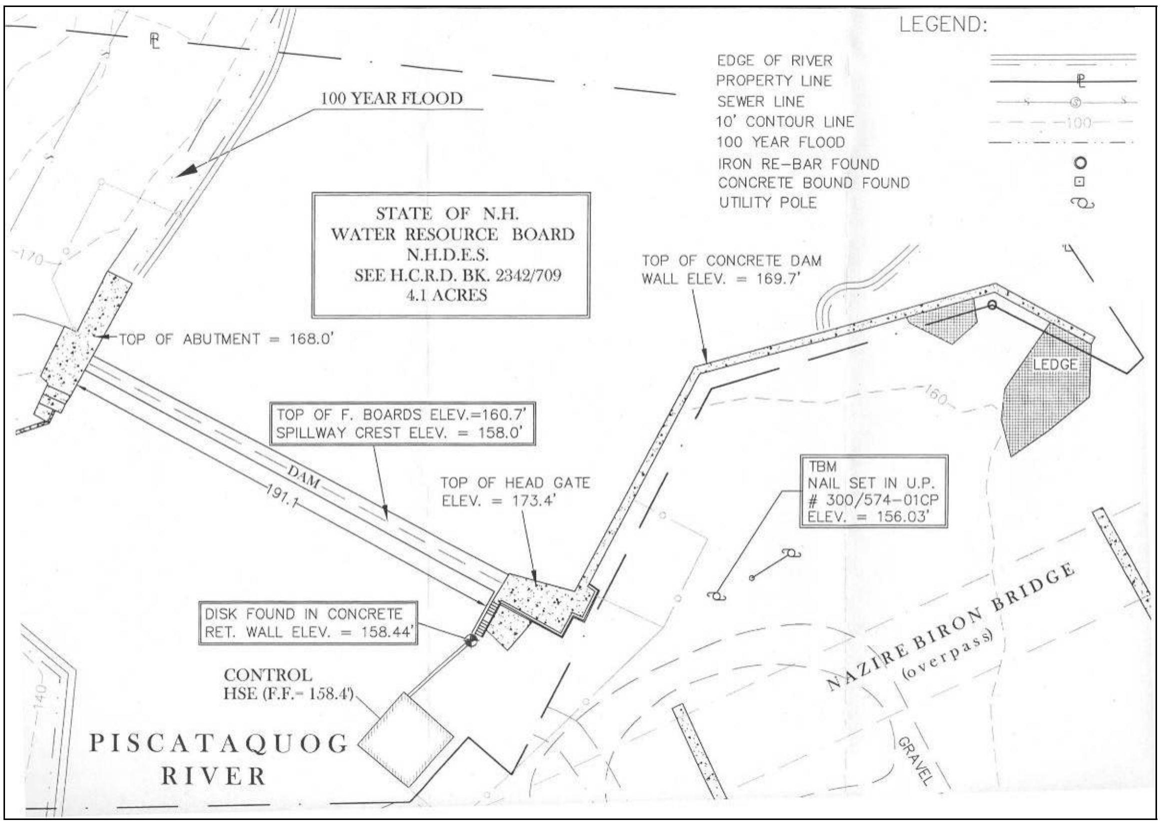


Figure 4-13: Plan View of Kelley Falls Dam

Figure 4-14: Photograph of Kelley Falls Dam

B-4.5.2 Actual Operations

A presentation describing the operations during the April 2007 event was provided by the dam operator Enel North America, Inc. (see Figure 4-15). No information regarding pool elevations or operations at the dam is available for 2006.

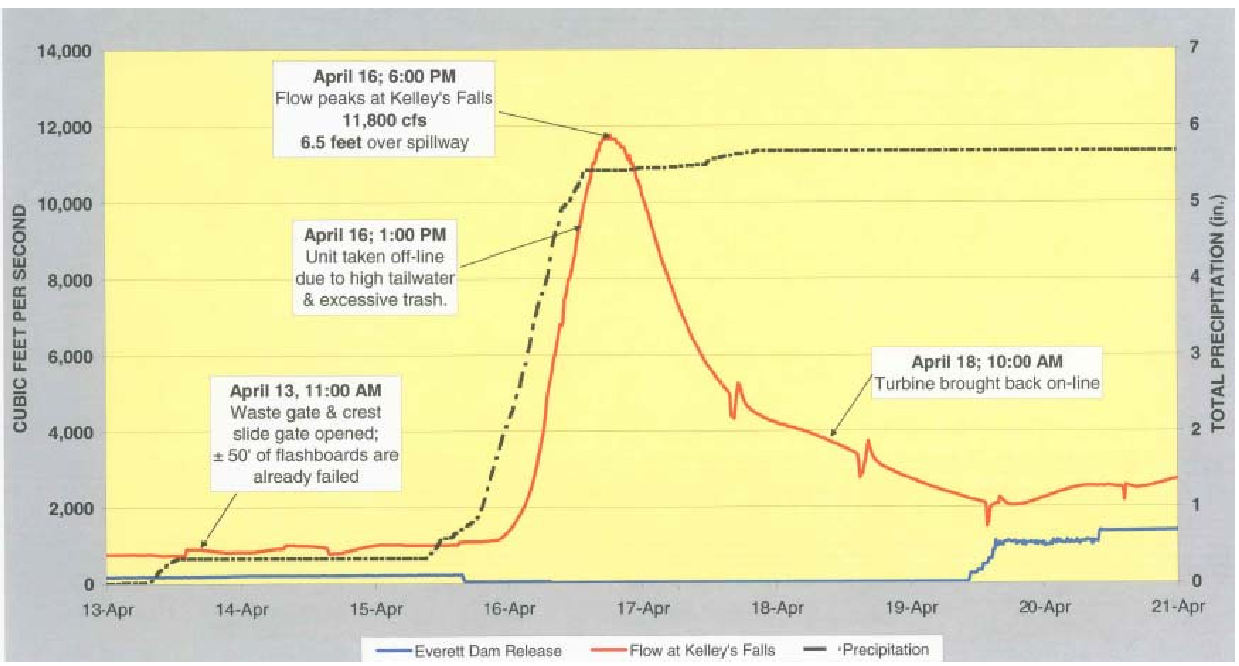


Figure 4-15: Operations at Kelley Falls Dam in April 2007

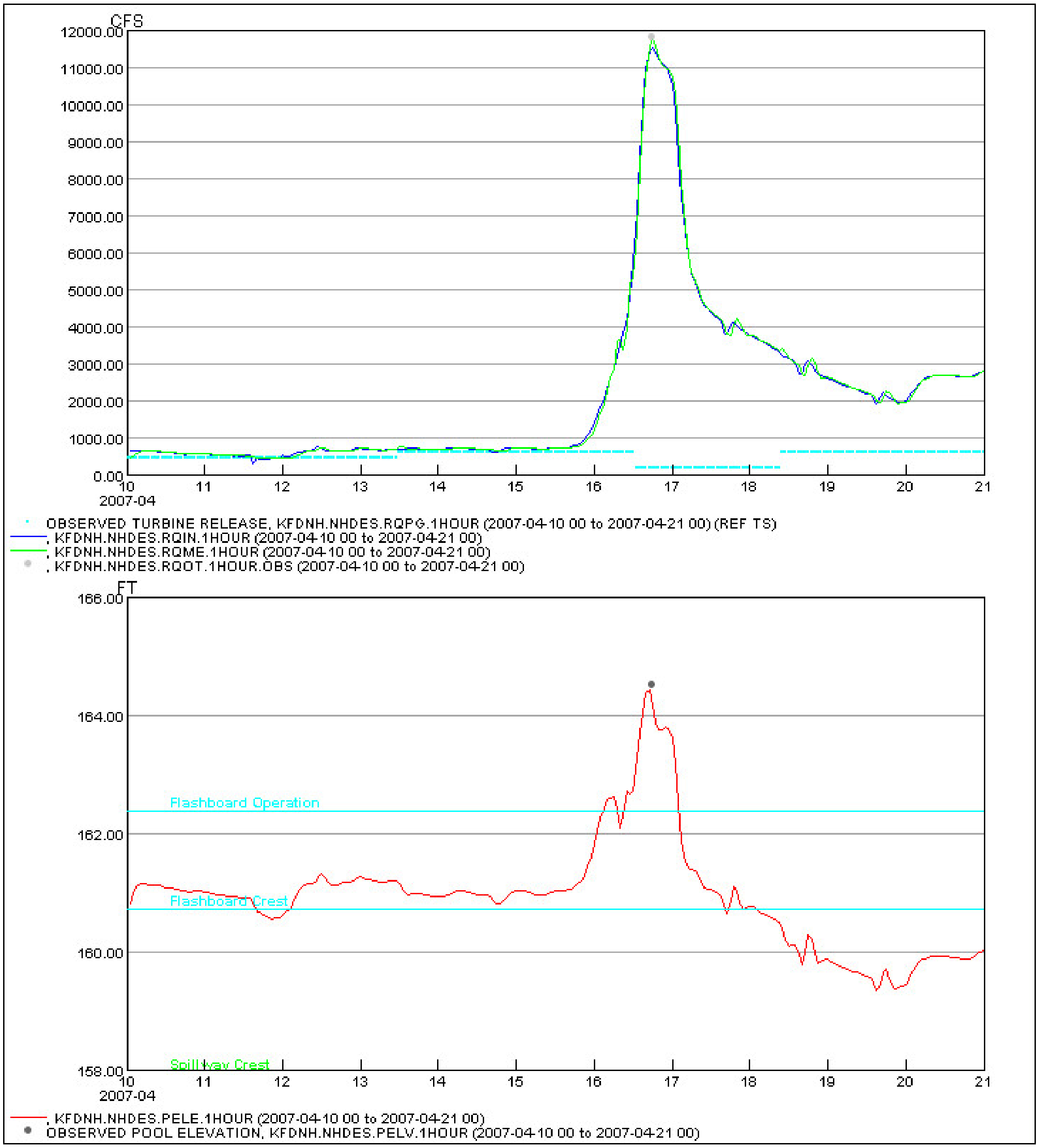


Figure 4-16: Kelley Falls Dam Simulation Results for the April 2007 Flood Event

At the beginning of the April 2007 event, the dam was operated to be close to the elevation of the flashboard crest. On April 13, about 50 feet of flashboards had failed. At 11 a.m. this day the fish bypass and a relieve valve were opened and increased flows through the project. The turbine was taken offline at 1:00 p.m. on April 16 due to high tailwater and excessive debris. Maximum pool height was reached at 6:00 p.m. when it was 6.5 feet over the spillway, but remained 3.8 feet below the top of the dam. It appears from photographs that the entire flashboard section failed at some point during the event—it is assumed that that happened at the peak of the event.

Significant flooding was reported upstream of the project. This was caused by high peak pool elevations behind Kelley Falls Dam and likely aggravated by trash that accumulated at an abandoned trestle bridge upstream of the dam.

The simulation of pool elevations at Kelley Falls Dam worked well, as sown in Figure 4-16. The results indicate that Kelley Falls Dam had only very minor effects on modulating the inflows.

B-4.5.3 Alternative Operations

Given that operations at the project during the April 2007 event had provided for almost the maximum discharge capacity, the assessment of alternative operations focused on the pool elevation before the event. An extreme case was to enter the event completely drained. Figure 4-17 shows the results of this scenario. However, even with the pond drained before the event there would have been no appreciable reduction in the peak flow or water level. This indicates that only structural improvements can minimize upstream flooding during events the magnitude of April 2007.

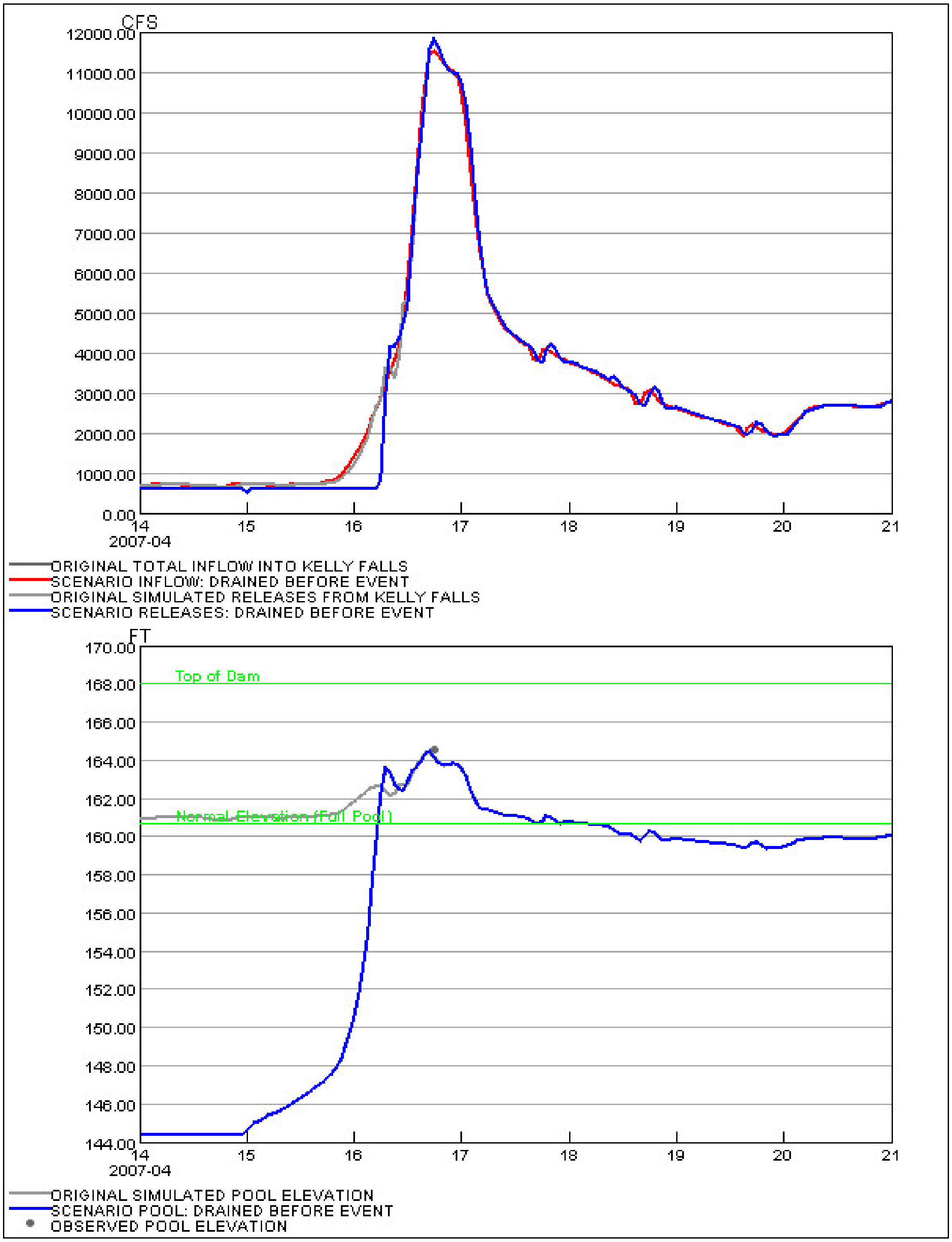


Figure 4-17: Kelley Alternative Operations - Drained before Event

Appendix C

Description of Dam and Typical Operations: Souhegan River Basin

Figures

Tables

C-1.0 INTRODUCTION

C-1.1 Overview

This report describes the methodology, available data, runoff characteristics for the May 2006 and April 2007 runoff events, and reservoir operations in several lakes and reservoirs within the Souhegan River Basin, located in southern New Hampshire. The headwaters of the Souhegan begin in northern Massachusetts and run northeast through the New Hampshire towns of New Ipswich, Greenville, Wilton, Milford, Amherst and Merrimack where it confluences with the Merrimack River. Several of these towns reported heavy flooding in these two events, particularly the towns of Greenville and Wilton during the April 2007 event. Figure C-1 shows this 221 mi^2 watershed and some of the critical data used for this report. For purposes of comparison, this report focuses on the 171 mi^2 upstream of USGS Gage Number 01094000.

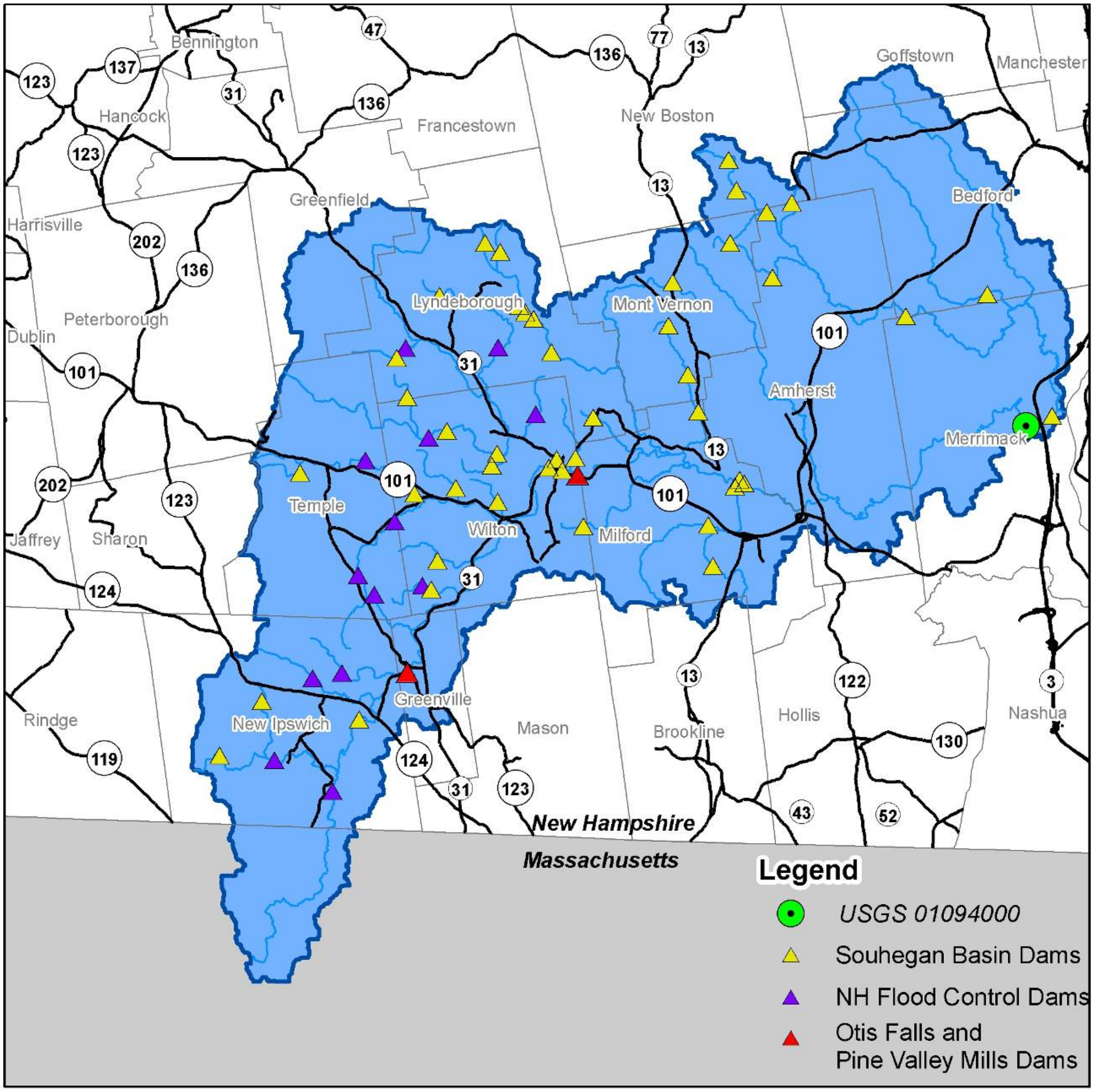


Figure C-1: Souhegan River Basin

Some previous hydrology studies have been conducted of the Souhegan Basin but few have focused on reservoir operations. Zhang (1995) prepared a physically-based distributed rainfall-runoff model with radar data. This study focused more on modeling techniques and procedures rather than flooding implications or reservoir operations for the Souhegan Basin.

FEMA (1979a, 1979b, 1979c, 1979d, 1980, 1991, 1994) studied the Souhegan Basin for the purpose of developing Flood Insurance Rate Maps. For the uncontrolled portions of the watershed, mostly approximate methods and regional regression equations were used. For the controlled portions of the watershed, discharges were obtained from data supplied by the SCS (now the NRCS) (convex routing method) or USACE. No comprehensive modeling effort involving all of the flood control reservoirs and run-of-the-river dams is apparent in any of these studies.

C-1.2 Acronyms

FEMA: Federal Emergency Management Agency

NHDES: New Hampshire Department of Environmental Services

NRCS: Natural Resources Conservation Service (formerly Soil Conservation Service or SCS)

NWS: National Weather Service

USACE: U.S. Army Corps of Engineers

USGS: U.S. Geological Survey

af: acre-feet

cfs: cubic feet per second

C-1.3 Terminology

Channel Capacity: Maximum flow through a river or manmade channel without overtopping.

Curve Number: Number that describes runoff potential of a given drainage area with a given combination of land use and soil type.

Downstream Flooding: Flooding occurring downstream of a dam site. Releases from the dam in certain cases can contribute to downstream flooding.

Flashboards: Bulkheads placed on the crest or top of a channel wall or control structure. Flashboards are sometimes designed to break and wash away under high flow conditions ("to operate") and thus to provide only a temporary diversion. In contrast, stoplogs are intended to be reused.

Flood Control Dams: Large dams constructed for the purpose of attenuating peak discharges and to reduce the effects of flooding.

HEC-HMS: hydrologic computer model developed by the U.S. Army Corps of Engineers used to calculate the flow from a given river basin.

HEC-RAS: hydraulic computer model developed by the U.S. Army Corps of Engineers used to determine the velocity, depth, and flooding effects for flows from a given river basin.

HydroCAD: Computer model used to analyze stormwater and reservoir facilities.

Lag Time (Time of Concentration): Time between the centroid of the precipitation pattern to the peak of the hydrograph. Estimated to be about 0.6 times the time of concentration.

Mean Areal Temperature: Assumed mean temperature over an area, typically a river sub-basin. It is typically estimated from observation at climate sites in the area.

Mean Areal Precipitation: Assumed mean precipitation over an area, typically a river sub-basin. It is typically estimated from observation at climate sites in the area.

Normal Pool Elevation: Typical water elevation of a lake or reservoir. This value might change seasonally.

Precipitation: Rainfall or snowfall onto an area, typical expressed as depth of water over an area.

Recurrence Interval: Time interval in which an event can be expected to occur once on the average.

Rainfall-Runoff Model: Computer model that simulates the effects of rainfall (or snowmelt) onto an area and estimates the resulting runoff into a river or lake.

Snow-water Equivalent: Amount of water contained within the snowpack. It can be thought of as the depth of water that would theoretically result if you melted the entire snowpack instantaneously.

Spillway: A structure used to provide for the controlled release of flood flows from a dam into the dammed river. Spillways release floods so water does not overtop and damage or even destroy the dam.

Stoplogs: A hydraulic engineering control element used in floodgates to adjust the water level and/or flow rate in a river, canal, or reservoir. Stoplogs are typically long rectangular timber beams or boards that are placed on top of each other and dropped into premade slots inside a dam weir (the “stoplog bay”). Placing more stoplogs in a stoplog bay increases the pool elevation of the lake or reservoir and decreases the releases.

Time of Concentration (Lag Time): Time between the centroid of the precipitation pattern to the inflection point of the receding limb of the hydrograph.

Run-of-the-River Dams: small dams used for hydropower, recreation, or water quality that have only a small quantity of storage capacity.

Storage Capacity: Volume of water a lake or reservoir holds at a certain elevation.

Sub-basin: Area draining into a lake or river above a certain point.

Upstream Flooding: Flooding occurring upstream of a dam site due to high reservoir or lake pool elevation.

Winter Drawdown: Difference between the summer normal pool elevation and the winter normal pool elevation.

WISE: GIS-based software program that helps develop and utilize hydrologic and hydraulic data.

C-2.0 METHODOLOGY

The following methodology was used to analyze the Souhegan River Basin. HEC-HMS (Hydrologic Modeling System) developed by U.S. Army Corps of Engineers (USACE 2002) was the model used for the hydrologic analysis.

HEC-HMS has three components: the **basin model**, where drainage area, the unit hydrograph, runoff volume, and reservoir characteristics for each sub-basin are defined; the **meteorologic model**, where the rainfall events are defined; and the **control specifications**, where the time of period being simulated to model the rainfall events is defined. A schematic showing the HEC-HMS representation of the Souhegan River Basin is shown in Figure C-2.

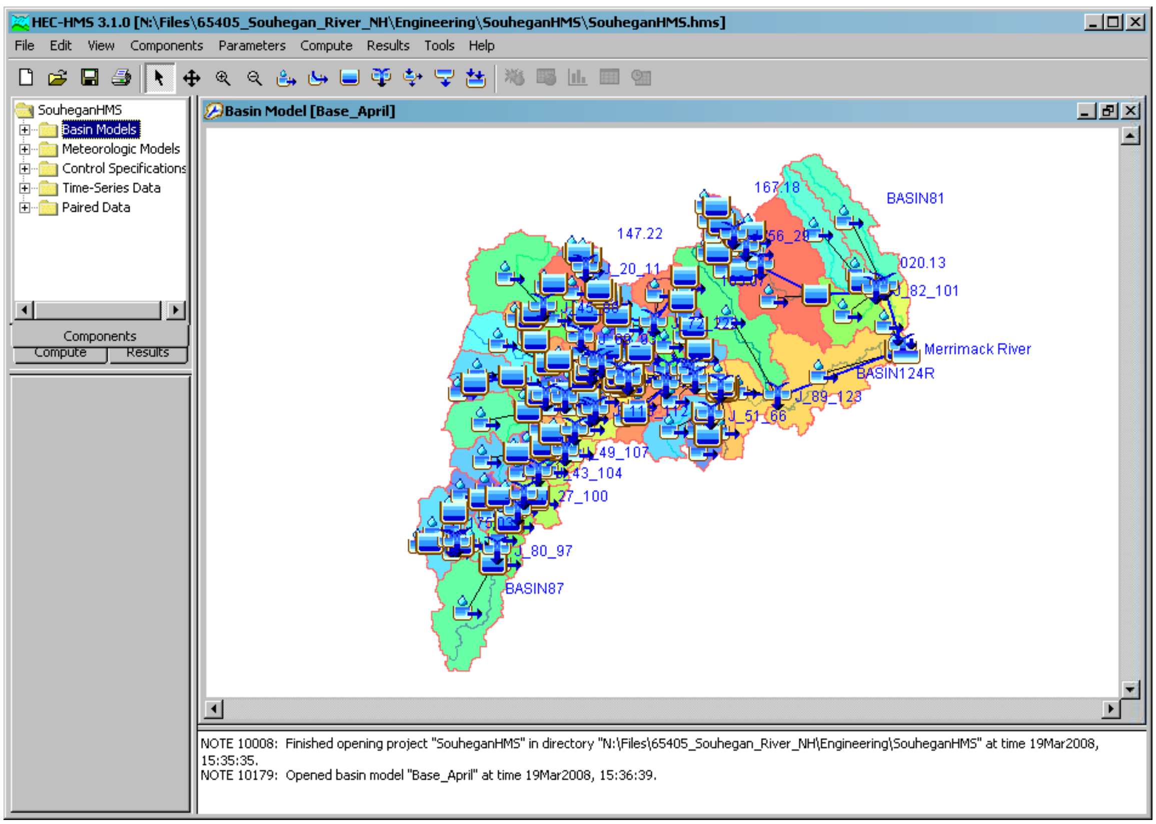


Figure C-2: HEC-HMS Model for the Souhegan River Basin

C-2.1 Basin Model

The Souhegan drainage area was subdivided into 120 subbasins using the automatic drainage area delineation routine in WISE, a GIS-based hydrology and hydraulics software package, and a 10-meter USGS Digital Elevation Model (DEM). The drainage values generally agree with values derived by NHDES in their dam inspection reports. Subbasins were defined at every junction with a major tributary and at every impoundment structure included in this analysis.

A number of unit hydrograph methods are available within HEC-HMS. The unit hydrograph method selected for this analysis was the Snyder's method which is dependent on calibration coefficients. These calibration coefficients were modified so that the runoff for a particular rainfall event produces a hydrograph that is similar to an observed hydrograph for the same event. Refer to Attachment A for a detailed description of the calibration procedure.

For runoff volume computations, the initial and constant-rate method was used. This method uses an initial rainfall abstraction that accounts for interception and depression storage and then an estimate for the ultimate infiltration capacity of the soils. In May 2006, the antecedent conditions were moderately wet with some minor infiltration occurring during the storm event. In April 2007, the antecedent runoff conditions involved heavy rainfall and a substantial amount of snow cover, so very little infiltration occurred during the event.

Base flow, although only a small part of the runoff in events as large as the April 2007 and May 2006 storms, was included using the exponential recession method.

Since the operations of both run-of-river dam and flood control dams have generated a substantial amount of public concern, the HEC-HMS model included every reservoir for which data was available. This resulted in the inclusion of 59 dams in the model. The reservoir characteristics included in HEC-HMS are elevation-storage and elevation discharge curves. These curves are derived using data provided by NHDES and had varying degrees of quality as discussed in the following section.

River routing reaches were also included where one or several sub-basin drains through another sub-basin. The Modified-Puls method was selected for reach routing. The storage-discharge values necessary in applying the Modified-Puls methods were derived using WISE.

C-2.2 Meteorologic Model

The meteorologic model defines the rainstorm distribution type and intensity. As shown on Figure C-3 and Table C-1, four gages provided precipitation data: Everett Dam on the Piscataquog River (WERN3), Nashua River at East Pepperell, Massachusetts (DNSM3), Birch Hill Dam (RYLM3), and the Souhegan River at the Merrimack River (SOHN3). The rainfall for the May 2006 and April 2007 were estimated based on a Thiessen polygon weighting of the rainfall gages within or near the Souhegan River Basin, assuming a single pattern of rainfall for the entire basin.

DNSM3 was excluded from the Thiessen polygon weighting since the rainfall totals for this gage were much smaller and initial model simulations indicated that precipitation in the Souhegan would be underestimated if this gage was used.

C-2.3 Control Specifications

The control specifications, the time periods being simulated, for this project were defined for the dates of May 10-31, 2006, and April 13-30, 2007.

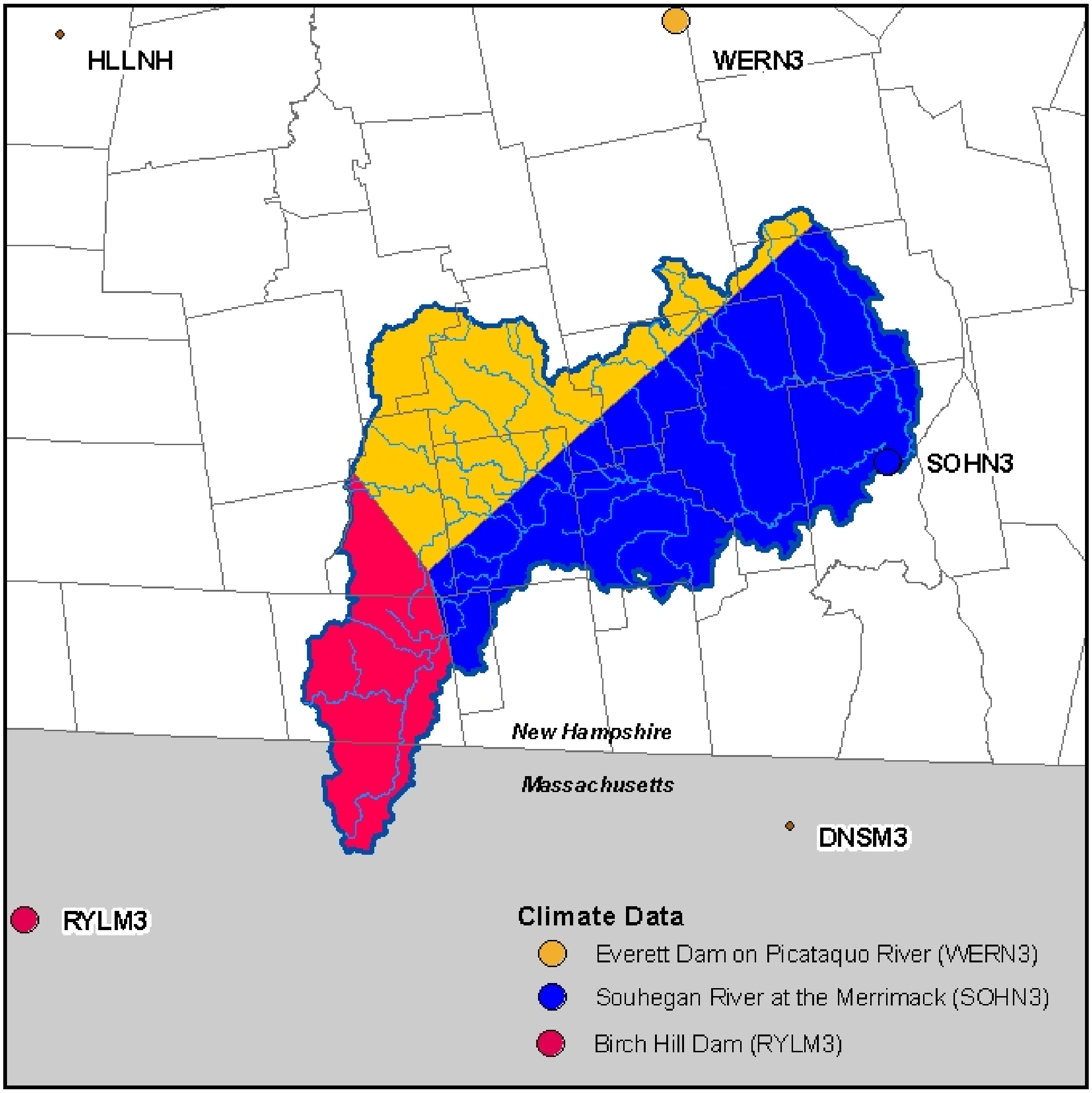


Figure C-3: Thiessen Polygons and Associated Precipitation Gages Basin

Table C-1: Precipitation Data Used for the Souhegan River Basin

		May 10-31, 2006		April 13-30, 2007	
Description	Precipitation Gage	Precipitation (in)	Max Intensity (in/hr)	Precipitation (in)	Max Intensity (in/hr)
Everett Dam on the Piscataquog	WERN3	10.77	0.28	7.07	0.40
Nashua River at East Pepperell	DNSM3	3.72	0.45	4.09	0.20
Birch Hill Dam	RYLM3	5.29	0.39	4.06	0.18
Souhegan River at the Merrimack River	SOHN3	5.43	0.26	4.62	0.31
Thiessen Polygon Weighted Average		6.92	0.29	5.22	0.31

C-2.4 Calibration Procedure

C-2.4.1 Snyder's Method for Unit Hydrograph

The lag time, t_p (in hours), or approximately the time between the rainfall and the peak of the hydrograph, is defined as:

$$t_p = C_t(LL_c)^{0.3}$$

where C_t = basin coefficient; L = length of the main stream from the outlet to the divide; and L_c = length along the main stream from the outlet to a point nearest the watershed centroid. C_t is modified during calibration so that the timing of the simulated runoff peak. The peak discharge of the unit hydrograph (in cfs) is determined by the following function:

$$Q_p = C_p A / t_p$$

where C_p = peaking coefficient; A = drainage area in square miles, and t_p is as previously defined. The unit hydrograph is then convoluted with an historical rainfall event to produce an event hydrograph such as the April 2007 or May 2006 rainfall-runoff event.

Since there was only one runoff gage and limited precipitation data, C_t and C_p are assumed to have the same value throughout the Souhegan watershed for both the May 2006 and April 2007 storm events. For the Souhegan Basin, C_p was found to be 3.2. Typically this ranges between 1.8 and 2.2, with values found to range between 0.4 in mountainous regions and 8.0 in extremely flat areas. C_t was found to be 0.8. Typically this ranges between 0.4 and 0.8 (USACE 2000).

C-2.4.2 Initial and Constant-Rate Loss Method

The initial and constant-rate loss method was used in HEC-HMS to simulate runoff volume. This method assumes a maximum potential rate of precipitation loss, f_c, that is constant throughout an event. Therefore a precipitation value of p_t for a time interval of $t+\Delta t$, the excess runoff volume pe_t is given by:

$$pe_t = \begin{cases} p_t - f_c, & if\ p_t > f_c \\ 0, & otherwise \end{cases}$$

An initial loss, I_a, is also included in the model to represent interception and depression storage. In the May 2006 and April 2007 storms events, no initial loss was used in the final calibration. Table C-2 shows the loss rates that were used to calibrate the May 2006 and April 2007 storm. The soil types and areas were determined for each sub-basin using NRCS SURRGO soils data. Then a weighted loss rate was calculated for each sub-basin.

C-2.4.3 Base Flow Method

The base flow for the Souhegan River Basin was estimated using the exponential recession model where

$$Q_t = Q_0 k^t \text{ with}$$

Q_t = the baseflow at anytime t in cfs,

Q_0 = initial value for baseflow in cfs/mi^2,

k = expotential decay constant, and

t = unit time.

The values used for this study are included in Table C-3. The same values are used for all 120 subbasins.

Table C-2: Precipitation Losses Used in Souhegan River Basin HEC-HMS Model

Hydrologic Soil Group	Description	Typical Range of Loss Rates (in/hr)	Loss Rates for May 2006 Storm	Loss Rates for April 2007 Storm
A	Deep sand, deep loss, aggregated silts	0.30-0.45	0.075	0.00
B	Shallow loess, sandy loam	0.15-0.30	0.038	0.00
C	Clay loams, shallow sandy loam, soils in organic content, and soils usually high in clay	0.05-0.015	0.013	0.00
D	Soils that swell significantly when wet, heavy plastic clays and certain saline soils	0.00-0.05	0.000	0.00

Table C-3: Base Flow Values Used in Souhegan River Basin HEC-HMS Model

Storm Event	Initial Discharge (cfs/mi^2)	Recession Constant	Ratio to Peak
May 2006	1	0.9	0.1
April 2007	5	0.9	0.1

Additional analysis was conducted using the NRCS Soil Complex Method as described in NRCS *National Engineering Handbook-4*, although it was determined that Snyder's method provided a better estimate of the storm hydrograph since the NRCS method could not correctly approximate the volume under the hydrograph. Using detailed land use files and NRCS SURRGO Soils data, the overall basin curve number was found to be 64.

C-3.0 AVAILABLE DATA

Data for this analysis was taken from USGS, NWS, NHDES, and USACE.

C-3.1 Climate Data

The climate data available in this study was primarily precipitation from NHDES, continuous discharge data from the USGS, and temperature and snow water equivalent data from NWS. The temperature and snow water equivalent data were used to examine the general climate trends and antecedent conditions for the two storms, but not explicitly included in the modeling effort. These data are typically recorded every hour at climate sites in the region, and provide a reasonable representation of the weather development during the May 2006 and April 2007 flood events.

Figures C-4 and C-5 show the Thiessen polygon weighted precipitation and temperature data from the station located along the Souhegan River at the Merrimack River (SOHN3). Figure C-5 also shows the snow-water equivalent data for the April storm.

For the May 2006 storm, there is no snow-water equivalency since there was no snowpack. The observed peak for the May 2006 storm occurred on May 15 at 10:00 a.m. It rained 4.7 inches in the 48 hours prior to the peak runoff rate arriving at USGS Gage 00190400. Since the mean areal temperature was above freezing several days prior to the storm event, there was no measurable snowmelt contribution to the May 2006 storm. Rainfall characteristics for the May storm are shown in Table C-4.

Table C-4: Rainfall Characteristics of May 2006 Storm

Date of Runoff Peak of 6,150 cfs: 5/15/2006 @ 10:00 a.m.			
Precipitation Value	Rainfall Total (in)	Approximate Recurrence interval	Dates of Occurrence
Pre 48-hour	4.7	--	5/11/2006 4:00 p.m. to 5/13/2006 4:00 p.m.
Peak 1-hour	0.2	<1 year (0.9 inch)	5/13/2006 4:00 p.m.
Peak 6-hour	0.8	< 1 year (1.5 inches)	5/13/2006 3:00 p.m. to 5/13/2006 9:00 p.m.
Peak 12-hour	1.4	< 1 year (2.3 inches)	5/14/2006 3:00 p.m. to 5/15/2006 3:00 a.m.
Peak 24-hour	2.5	< 2 year (2.9)	5/13/2006 8:00 a.m. to 5/14/2006 8:00 a.m.
Peak 48-hour	4.8	~5 year to 10 year	5/13/2006 7:00 a.m. to 5/15/2006 7:00 a.m.
Peak 120-hour	5.9	~10 year	5/12/2006 5:00 p.m. to 5/16/2006 5:00 p.m.

For the April 2007 storm, the snow water equivalent peaked at around 1.36 inches at 96 hours prior to the storm event. By the time the peak flow arrived at USGS Gage 00109400 on April 17 at 3:00 a.m., the snow water equivalent had been reduced to 0.20 inches. This is the equivalent of another 1.16 inches of rain falling during this time period. The mean areal temperature during this time period stayed above freezing, so the high temperatures contributed to significant runoff volume around the same period of heavy rainfall. Table C-5 summarizes the rainfall characteristics for the April 2007 storm. The peak 24-hour rainfall falls between the 2- and 5-year recurrence interval, but these values do not account for the snowmelt contribution.

Table C-5: Rainfall Characteristics of April 2007 Storm

Date of Runoff Peak of 10,550 cfs: 4/17/2007 @ 3:00 a.m.			
Precipitation Value	Rainfall Total (in)	Approximate Recurrence interval	Dates of Occurrence
Pre 48-hour	4.0	--	4/14/2007 7:00 a.m. to 4/16/2007 7:00 a.m.
Peak 1-hour	0.3	< 1 year (0.9 inch)	4/16/2007 7:00 a.m.
Peak 6-hour	1.1	< 1 year (1.5 inches)	4/16/2007 6:00 a.m. to 4/16/2007 12:00 p.m.
Peak 12-hour	2.1	~ 2 year (2.5 inches)	4/16/2007 2:00 a.m. to 4/16/2007 2:00 p.m.
Peak 24-hour	3.3	~2 year (2.9 inches) to 5 year (3.8 inches)	4/15/2007 3:00 p.m. to 4/16/2007 3:00 p.m.
Peak 48-hour	4.1	~5 year	4/15/2007 6:00 a.m. to 4/17/2007 6:00 a.m.
Peak 120-hour	4.5	~2 year to 5 year	4/13/2007 0:00 a.m. to 5/18/2007 0:00 a.m.

The May 2006 storm was caused by a large quantity of rainfall over a long period of time. The longer the duration of rainfall, the more severe the event as is approximated for the 120 hour rainfall. In contrast, the April 2007 storm involved almost as large a quantity of rainfall in a shorter period of time combined with heavy snow melt. As discussed in the following sections, the consequence of these differences was dramatic in some locations throughout the Souhegan Basin. The flooding associated with both of these storms was greater than would be expected if other conditions in the basin had been more normal. However, the high rate of runoff in May was attributable to nearly saturated soil conditions coupled with seasonally high baseflow; while the even higher runoff in April was attributable to very intense rainfall coincident with rapid snowmelt on ground that had now yet thawed with even higher seasonal baseflow.

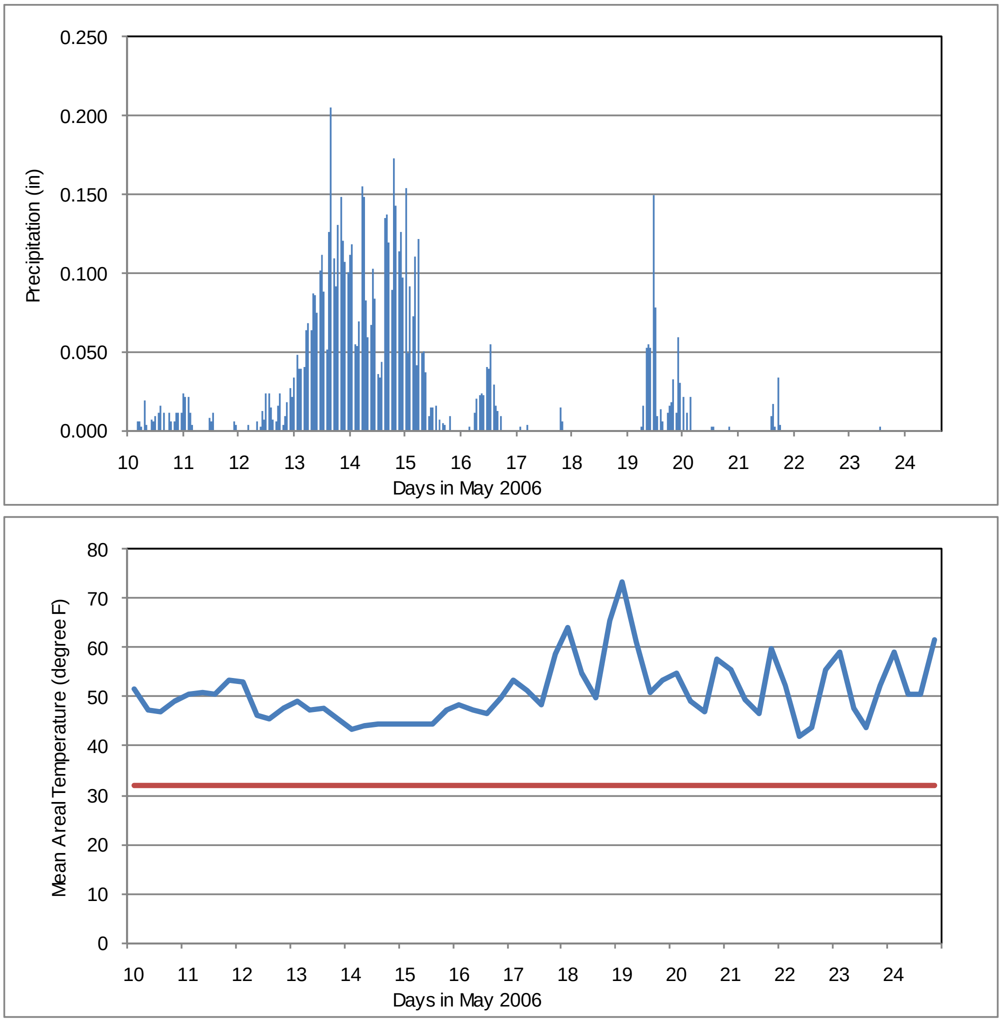


Figure C-4: Precipitation and Temperature during the May 2006 Storm Event

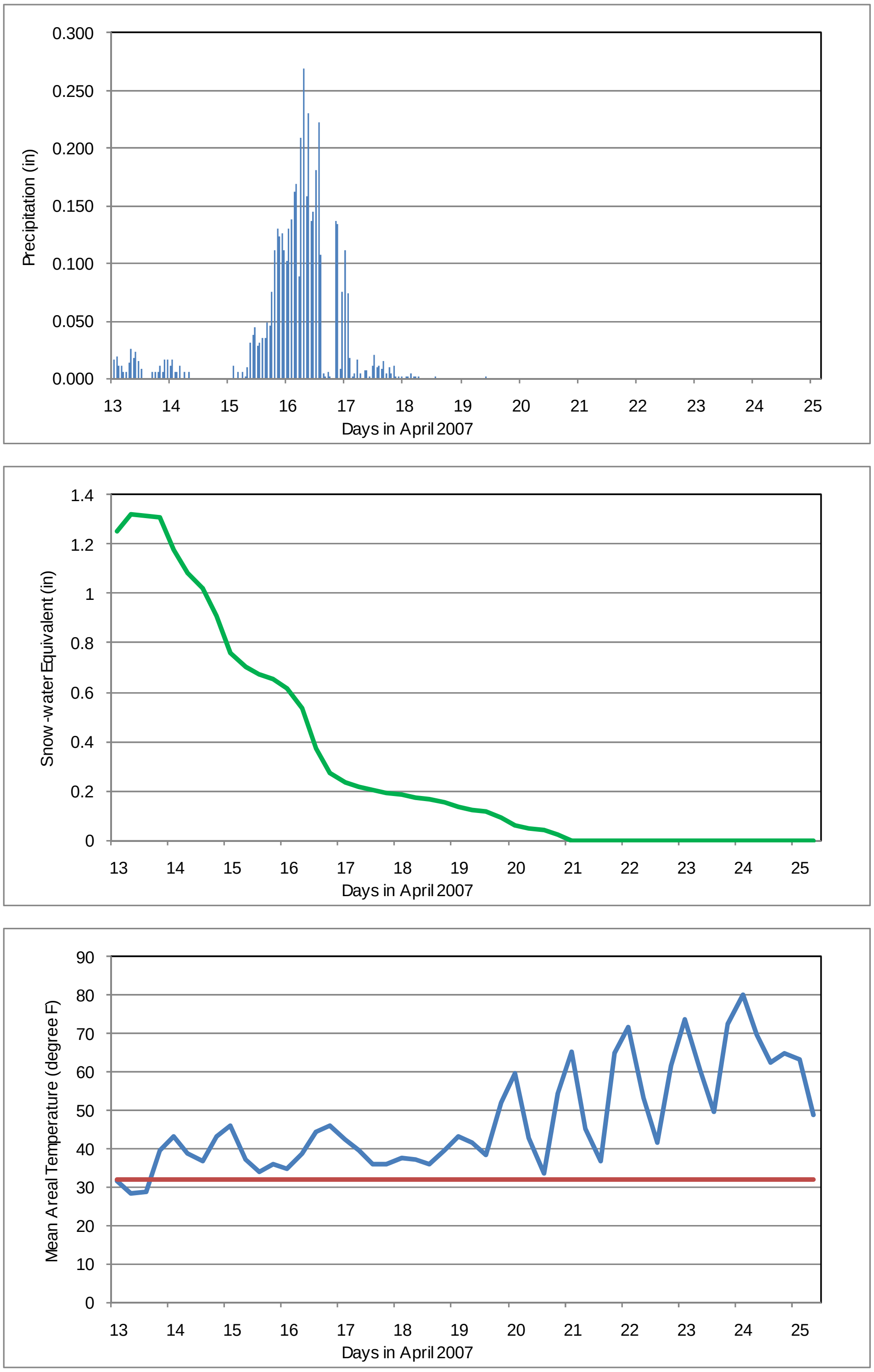


Figure C-5: Precipitation, Snow-Water Equivalent, and Temperature During the April 2007 Storm Event

Observations of streamflow data were obtained primarily from the USGS and USACE. Although five USGS gaging stations exist within the Souhegan Basin, only one of these (USGS Gage 00109400 Souhegan River at Merrimack) has hourly flow records and a sufficient length of record to be included in this study. This gage is located above the Merrimack Village Dam (NHDES# 156.01) and the confluence with Baboosic Brook. All comparisons in this study that examine overall basin results use the inflows to Merrimack Village Dam as a point of analysis. This location is very similar in drainage area with USGS Gage 00109400 (~171 sq mi for both).

The hydrographs of the May 2006 and April 2007 storm events are shown in Figure C-6. The April 2007 event corresponds roughly with the 50 year runoff event and the May 2006 event corresponds roughly with the 10-year runoff event. The timing and magnitude of these hydrographs is included in the HEC-HMS model.

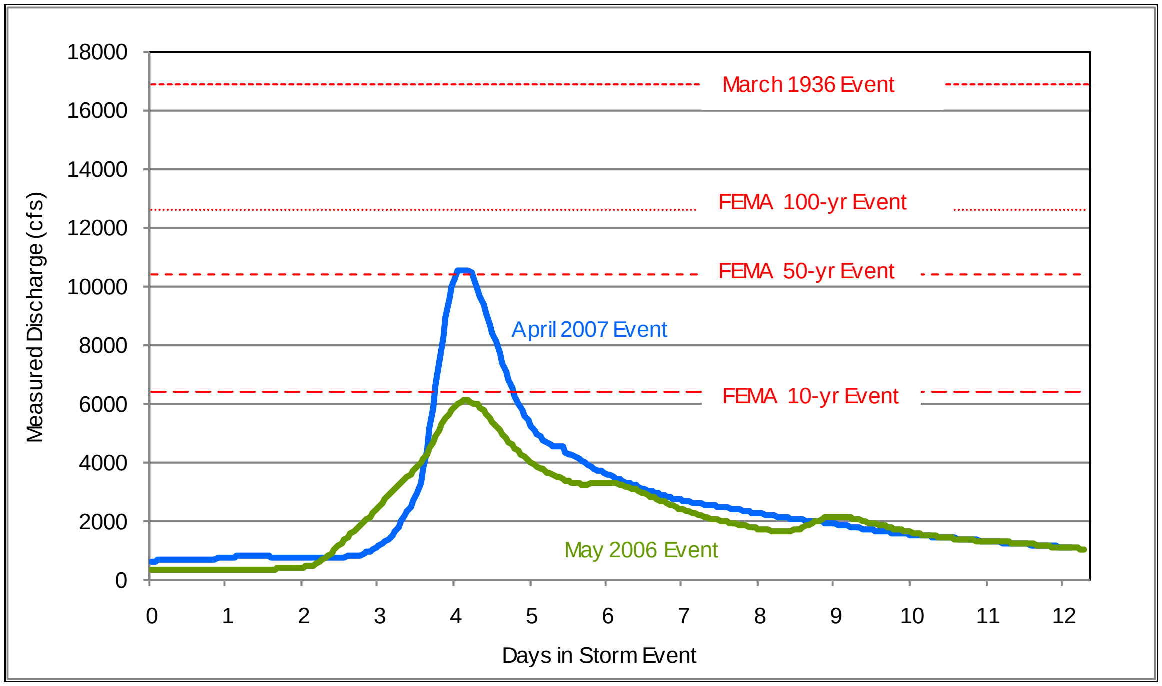


Figure C-6: Comparison of Measured Discharge for May 2006 and April 2007 with FEMA Storm Events

The recurrence interval of rainfall and runoff events is rarely coincident. A rainfall storm of relatively low intensity and low recurrence interval (e.g., 1- or 2-year event) can result in a more significant runoff event with a greater recurrence interval (e.g., 5- or 10-year event) if ground conditions exacerbate the effect of the rainfall on the watershed. However, the disparity in the May 2006 (<1-year, 24-hour rainfall with 10-year runoff) and April 2007 (2- to 5-year rainfall event with a 50-year runoff) storms may indicate the Souhegan Basin (and other similar basins in New Hampshire) is particularly vulnerable to heavy rainfall during the snowmelt season. The rainfall that occurred during both events was heavy but not “historic,” yet they caused extensive flood damage. Had the rainfall been more intense, then flooding would likely have been even more widespread.

C-3.2 Reservoir Data

The overall approach to modeling the reservoirs in the Souhegan Basin was to include every dam with available data: both run of the river and flood control dams. Approximately 80 percent of the reservoir storage is accounted for in 12 New Hampshire flood control sites. The necessary data to conduct a reservoir study include: (1) physical data such as storage capacity and dam release capacity and (2) operations data such as operating records and operating rules.

There are 239 dams listed in the NHDES dam database. Only 142 of these are active since many of the dams listed in the database are in ruins, have been breached, have not been built, or have been removed. This study includes 59 of the active dams that are substantial enough in size to require NHDES inspection reports. This includes all dams classified as high or significant hazards and the majority of dams that are classified as low hazard.

NHDES performs varying level of analysis on dams depending on their respective hazard classification and ownership. HydroCAD, a reservoir analysis software package, is used by NHDES engineers to perform analysis on reservoirs for the level of design storm for a particular dam (e.g., 50-year, 100-year, etc.). The data input to the HydroCAD models require the same elevation-storage and elevation-discharge relationships as HEC-HMS, so this data was used wherever available. If no HydroCAD models were available, elevation-storage and elevation-discharge relationships were developed from either NHDES Data Sheets or NHDES Inspection Reports. Table C-6 summarizes the physical data availability (i.e., non-operation related data) for all of the dams included in this study. It is important to note that 96 percent of the reservoir storage in the Souhegan Basin is accounted for with at least a reasonable quality of physical data. Table C-7 provides physical characteristics of the dams as derived from NHDES HydroCAD models; Table C-8 provides characteristics derived from NH Dam Data Sheets, and Table C-9 provides characteristics derived from NH Dam Inspection Reports.

Table C-6: Physical Data Available for Souhegan River Basin Dams

Data Source	Number of Dams	Percentage of Total Basin Storage	Relative Quality of Data	Comments
NHDES HydroCAD Models	37	49	Good	Highly detailed: elevation-storage and elevation-discharge relationship used from HydroCAD models
New Hampshire Dam Data Sheets	7	47	Adequate	Fairly detailed: elevation-storage and elevation-discharge relationship created from available information
New Hampshire Dam Inspection Reports	15	4	Judgment required for estimates	Some information available to estimate elevation-storage and elevation-discharge relationships

Since the majority of dams within the Souhegan River Basin are run-of-the river, few have operation flexibility such as stop logs or gates. Operation sheets are available for some of the dams operated by the state, but these involve little or no operator discretion during storm events aside from clearing debris and simply provide observations such as the presence of ice or water levels. Observations of lake elevations ("pool elevation") were not readily available for the Souhegan Basin aside from sporadic observations made on some of the New Hampshire flood control dams.

The one operation activity that generated public concern during the April 2007 storm was the removal and installation of flashboards, particularly on two run-of-the-river dams located in the mid and upper Souhegan Basin: Otis Falls Dam (NHDES# 101.01) and Pine Valley Mill Dam (NHDES# 254.01). Consequently, much of the simulation effort focuses on these two dams.

Table C-7: Souhegan River Basin Dams with NHDES HydroCAD Models

NHDES#	Dam Name	Height (ft)	Drainage Area[1] (mi^2)	Maximum Storage[2] (af)	Runoff to fill[3] (in)
7.01	JOE ENGLISH POND DAM	5.5	3.13	101	0.61
7.09	VIJVERHOF POND DAM	9.0	0.67	192	5.37
147.13	CURTIS BROOK DAM	10.0	2.23	3	0.02
147.14	PURGATORY BROOK	6.5	2.55	12	0.09
147.18	PURGATORY BROOK DAM	0.0	2.45	19	0.15
147.22	RECREATION POND	4.0	0.16	3	0.33
147.24	WILDLIFE POND	7.5	0.37	13	0.66
147.26	SOUHEGAN RIVER SITE 28 DAM	29.0	1.1	185	3.16
147.28	SOUHEGAN SITE 8 DAM	25.0	4.7	2721	10.86
147.29	MORISON POND	19.0	0.06	15	4.53
147.31	SWARTZ POND DAM	8.0	0.25	42	3.17
147.33	FARM POND	6.0	0.01	2	3.30
147.38	CURTIS BROOK DAM	12.0	3.5	1	0.01
159.01	RAILROAD POND DAM	12.0	10.58	48	0.09
159.04	OSGOOD POND DAM	9.0	5.24	270	0.97
159.05	HARTSHORN POND DAM	14.9	2.55	40	0.29
159.16	COMPRESSOR POND	24.0	2.25	76	0.64
163.02	CURTIS BROOK DAM	5.0	0.41	126	5.77
163.06	TROW DAM	0.0	1.27	1	0.01
163.07	HARTSHORN BROOK II DAM	8.0	0.22	28	2.39
163.12	ROBY POND DAM	3.5	0.34	3	0.17
167.18	BEAVER DAM POND DAM	5.0	0.58	210	6.79
167.29	GARDNER RESERVOIR DAM	8.0	1.16	17	0.27
175.01	SOUHEGAN SITE 14 DAM	35.0	2.1	885	7.90
175.03	PRATT POND DAM	6.5	0.74	110	2.79
175.19	SOUHEGAN RIVER SITE19 DAM	35.5	11.4	2072	3.41
175.20	SOUHEGAN RIVER SITE 13 DAM	13.5	0.8	249	5.84

NHDES#	Dam Name	Height (ft)	Drainage Area[1] (mi^2)	Maximum Storage[2] (af)	Runoff to fill[3] (in)
175.21	SOUHEGAN RIVER SITE 35 DAM	30.0	6.4	647	7.67
175.23	WHEELER POND DAM	5.0	0.25	23	1.73
254.09	NEW WILTON RESERVOIR DAM	24.0	0.4	335	15.70
254.19	PETERS FARM POND DAM	10.0	0.98	6	0.11
254.20	BATCHELDER POND DAM	12.0	1.2	20	0.31
254.21	FROG POND DAM	15.0	0.6	143	4.45
254.30	SOUHEGAN RIVER SITE 15 DAM	13.0	1.1	315	12.75
254.34	SOUHEGAN RIVER SITE 33 DAM	21.0	1	1078	20.21
254.38	RECREATION POND DAM	8.0	0.4	10	0.48
254.43	CAMP POND DAM	11.0	0.76	33	0.80

Notes for Tables C-6, C-7, C-8:

[1] Drainage approximated from WISE or dam inspection report, if available.
[2] Maximum storage in this table is extrapolated to estimated storage above dam to also account for overtopping storage.
[3] Runoff to fill is the ratio of Maximum storage to drainage area as defined in these tables.

Table C-8: Souhegan River Basin Dams with New Hampshire Dam Data Sheets

NHDES#	Dam Name	Height	Drainage Area (mi^2)	Maximum Storage (af)	Runoff to fill (in)
101.01	OTIS FALLS DAM	27.0	29.6	110	0.07
175.09	WATERLOOM POND DAM	22.5	23.1	679	0.55
234.08	SOUHEGAN RIVER SITE 26 DAM	79.0	4.9	1287	4.93
234.11	SOUHEGAN RIVER SITE 12A SOUTH	33.5	5.6	3304	11.06
234.12	SOUHEGAN RIVER SITE 25C DAM	69.0	5.4	1564	5.43
254.01	PINE VALLEY MILL DAM	23.0	97	70	0.01
254.33	SOUHEGAN RIVER SITE 10A DAM	59.0	6.4	2735	8.01

Table C-9: Souhegan River Basin Dams with New Hampshire Dam Inspection Reports

NHDES#	Dam Name	Height (ft)	Drainage Area (mi^2)	Maximum Storage (af)	Runoff to fill (in)
020.09	STOWELL POND	8.0	23.2	26	0.02
020.13	MCQUADE BROOK DAM	14.0	7.9	351	0.83
147.17	BURTON POND DAM	14.0	0.5	2	0.09
156.01	MERRIMACK VILLAGE DAM	20.5	171.0	171	0.02

NHDES#	Dam Name	Height (ft)	Drainage Area (mi^2)	Maximum Storage (af)	Runoff to fill (in)
159.02	GOLDMAN DAM	12.0	137.8	114	0.02
159.03	MCLANE DAM	18.7	138.0	39	0.01
167.17	GREENTREE RES DAM	4.5	0.1	17	2.42
234.04	LEIGHTON POND DAM	10.0	1.1	11	0.19
254.02	WILTON HYDRO DAM	17.0	97.0	18	0.00
254.03	SOUHEGAN RIVER III DAM	19.3	70.3	8	0.00
254.05	STONEY BROOK DAM	20.0	33.5	24	0.01
254.08	OLD WILTON RESERVOIR	17.5	8.3	8	0.02
254.11	MILL BROOK	12.0	6.7	15	0.04
254.18	BLOOD BROOK DAM	18.0	6.6	20	0.06
254.32	ERB WILDLIFE POND DAM	20.0	0.3	16	1.07

C-4.0 MODEL SIMULATION DESCRIPTIONS

Using the available data as described in the previous sections, a HEC-HMS simulation model is developed to examine operational flexibility within the Souhegan Basin. Initially, this model is calibrated so that the simulated inflow hydrograph matches the observed outflow hydrograph within reason. The model is calibrated so that simulated values approximate observed values at USGS Gage 00109400, located just above the confluence with Baboosic Brook, the only location where calibration data is available. The model is a useful tool for evaluating comparisons between different "what if scenarios," the purpose of this modeling effort. The list of modeling scenarios is outlined in Table C-10. This simulation effort focuses on the **relative** effects of specific dam operating scenarios. This does not minimize or refute the consequences to downstream property owners during these two significant storm events; it only serves as an approximation of one scenario versus another.

Table C-10: Simulations for the Souhegan River Basin

Simulation	May 2006	April 2007	Description
Base	X	X	All reservoirs at normal pool with no flashboard operation
1	X	X	All reservoirs initially empty
2	X	X	Removal of all New Hampshire Flood Control Dams
3	X	X	Increase flashboards by 3 feet at all New Hampshire Flood Control Dams
4	X	X	Double storage at Otis Falls and Pine Valley impoundments
5		X	Otis Falls and Pine Valley with Flashboards holding throughout
6		X	Otis Falls and Pine Valley with Flashboards lowering at 0.5 foot of surcharge
7		X	Otis Falls and Pine Valley with flashboards at midnight on April 16
8		X	Otis Falls and Pine Valley with flashboards removed at 6:00 p.m. on April 15 prior to the peak
9		X	Removal of 5 Flashboards on Otis Falls at start of event and all removed by 6:00 p.m. April 15th; Pine Valley set to lower with 1 foot surcharge; both outlets on Pine Valley Mills fully opened.
10		X	Otis Falls panels lowered at 11:00 a.m. on April 16th; Pine Valley set to lower with 1 foot surcharge; both outlets on Pine Valley fully opened.
11		X	Otis Falls panels lowered at 11:00 a.m. on April 16th; Pine Valley set to lower at 6:00 a.m. April 16th
12		X	Otis Falls panels lowered at 11:00 a.m. on April 16th; Pine Valley set to lower at 9:30 a.m. April 16th

The first four simulations examine the impact that specific elements have on the overall basin: initial reservoir water levels; the impact of New Hampshire flood control cams; and the storage capacities of Otis Falls and Pine Valley Mills Dams. Simulations 5 through 12 focus on the various operating scenarios outlined in Table C-9.

C-5.0 OVERALL BASIN ANALYSIS

C-5.1 General Description

The purpose of the base simulation and Simulations 1 through 4 is to provide general conclusions on a basin wide basis. All comparisons are made at USGS Gage 00109400 on the Souhegan River just upstream of its confluence with Baboosic Brook. Later sections discuss more localized flooding impacts.

C-5.2 Observations during Flood Events

The general consensus from public comments and climatologic observations during the two storms is the April 2007 storm was much more severe. In particular there was a general concern that poorly executed dam operations and a general lack of operation policy was the main distinction between the severity in the May 2006 and April 2007 storms.

C-5.3 Simulations

C-5.3.1 Base: May 2006 and April 2007 Storms

The base simulations attempt to simulate actual conditions. As shown in Table C-11, the timing and volume of both the hydrographs match the observed hydrograph within a reasonable range (See Figures C-7 and C-8). These base runs are adequate for examining “what-if scenarios.”

Table C-11: Base Run Comparison for the Souhegan River Basin

Storm Event	HEC-HMS Peak (cfs)	Measured Peak (cfs)	Difference from Measured
May 2006	6,300	6,150	2.3%
April 2007	10,415	10,550	1.3%

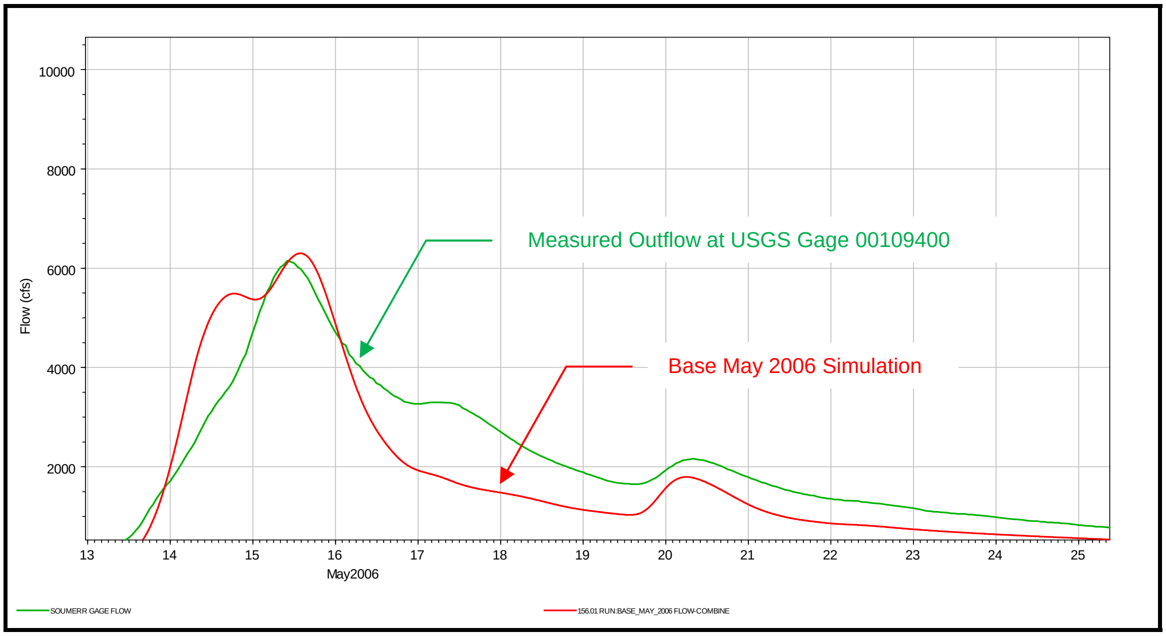


Figure C-7: Base Simulation and Measured Flows for May 2006 Storm Event

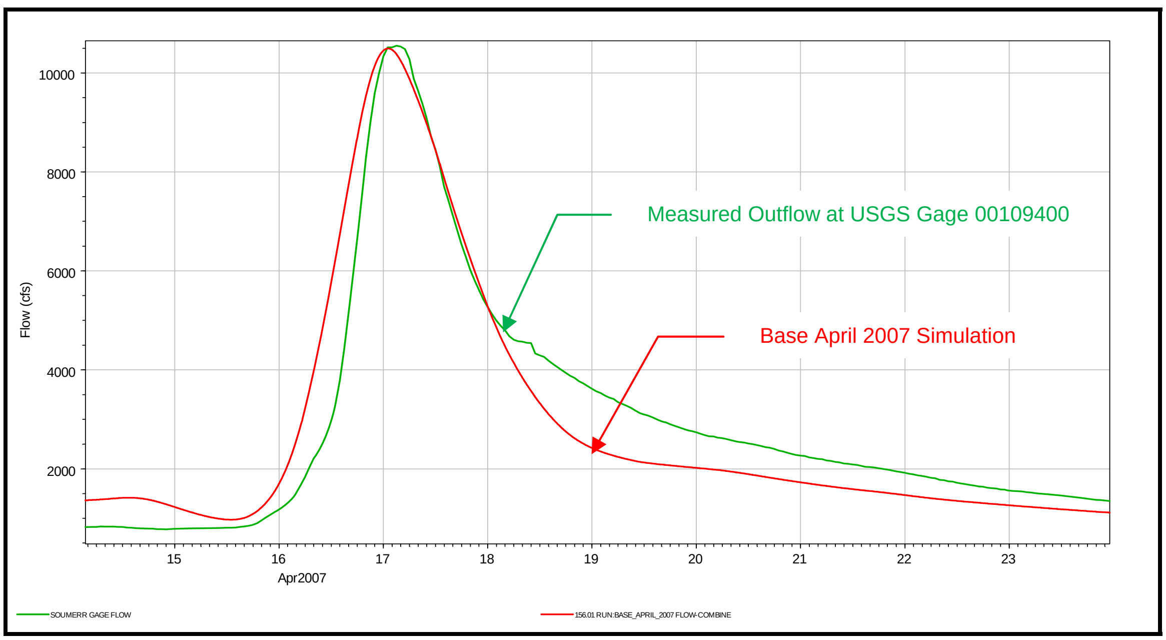


Figure C-8: Base Simulation and Measured Flows for April 2007 Storm Event

C-5.3.2 Simulation 1: All Reservoirs Initially Empty

Simulation 1 was developed to examine the range of operating flexibility in terms of operating pool levels or seasonal discharge requirements. The simulation was designed to assess whether there would be a flood control benefit if the water depth in the reservoirs in the basin were shallower, thus having more room to store runoff and therefore reduce downstream flooding. The results of these simulations are shown in Table C-12, Figure C-9, and Figure C-10.

Table C-12: Base Run Comparison for the Souhegan River Basin

Storm Event	Base Run Peak (cfs)	Simulation 1 (Assuming Reservoirs Empty, cfs)	Difference from Base
May 2006	6,300	6,290	1.5%
April 2007	10,415	10,389	1.3%

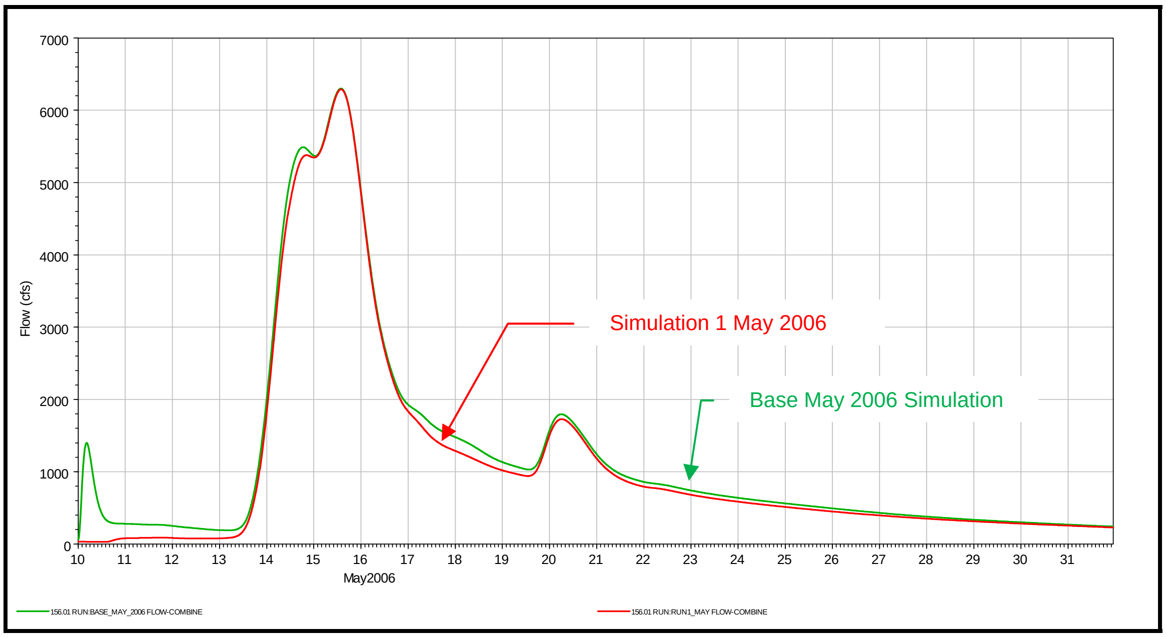


Figure C-9: Base Simulation and Simulation 1 (Assuming “Empty” Reservoirs) for May 2006 Storm Event

To examine the greatest possible effects that maximum water levels might have on the study flood events, Simulation 1 was conducted under the assumption that every reservoir was completely empty prior to arrival of both the May 2006 and April 2007 events. This would involve removing all storage in the Souhegan Basin that currently supports environmental flows, water levels for lakeside properties, and hydropower generation. Although this is not a technically realistic alternative, it does define the maximum range of operating possibilities for the Souhegan Basin.

Under this idealized set of circumstances, there is a negligible difference in peak flows even if all reservoirs in the basin were empty prior to the storms. Initially, between May 10 and May 14, there is a reduction in discharge as the reservoirs begin to fill, but the storage capacity and potential flood discharge attenuation of the reservoirs is maximized prior to the peaks of both events arriving.

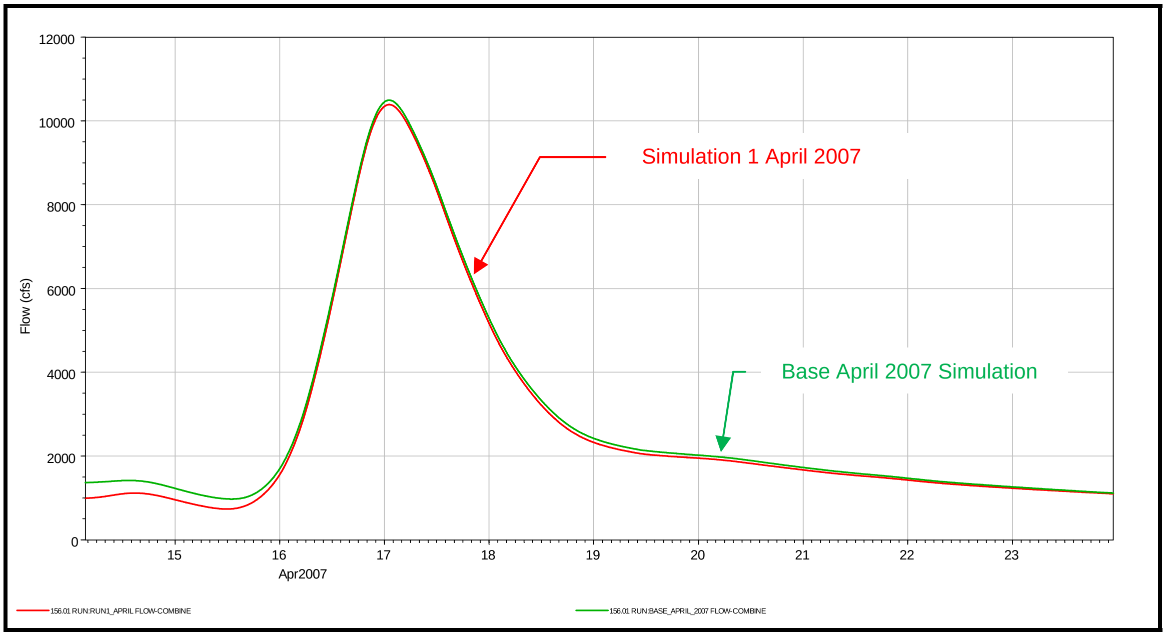


Figure C-10: Base Simulation and Simulation 1 (Assuming "Empty" Reservoirs) for the April 2007 Storm Event

C-5.3.3 Simulation 2: Assessing the Effect of the New Hampshire Flood Control Dams

The State of New Hampshire operates 12 flood control dams located in the upper end of the Souhegan Basin (refer to Figure C-1). These dams were originally built by the National Resources Conservation Service and turned over the State. Since these dams were designed for flood control, the contribution and benefit in the May 2006 and April 2007 storm events was questioned. These dams are summarized in Table C-13 and shown in Figure C-1.

Table C-13: Summary of Souhegan River Basin Dams Operated by the State of New Hampshire

NHDES#	Dam Name	Height (ft)	Drainage Area[1] (mi^2)	Maximum Storage[2] (af)	Runoff to fill[3] (in)
147.26	SOUHEGAN RIVER SITE 28 DAM	29.0	1.1	185	3.16
147.28	SOUHEGAN SITE 8 DAM	25.0	4.7	2721	10.86
175.01	SOUHEGAN SITE 14 DAM	35.0	2.1	885	7.90
175.19	SOUHEGAN RIVER SITE19 DAM	35.5	11.4	2072	3.41
175.20	SOUHEGAN RIVER SITE 13 DAM	13.5	0.8	249	5.84
175.21	SOUHEGAN RIVER SITE 35 DAM	30.0	6.4	647	7.67
234.08	SOUHEGAN RIVER SITE 26 DAM	79.0	4.9	1287	4.93
234.11	SOUHEGAN RIVER SITE 12A DAM S	33.5	5.6	3304	11.06
234.12	SOUHEGAN RIVER SITE 25B DAM	69.0	5.4	1564	5.43
254.30	SOUHEGAN RIVER SITE 15 DAM	13.0	1.1	315	12.75
254.33	SOUHEGAN RIVER SITE 10A DAM	59.0	6.4	2735	8.01
254.34	SOUHEGAN RIVER SITE 33 DAM	21.0	1	1078	20.21

Notes:

[1] Drainage approximated from WISE or dam inspection report, if available.

[2] Maximum storage in this table is extrapolated to estimated storage above dam to also account for overtopping storage.

[3] Runoff to fill is the ratio of maximum storage to drainage area as defined in these tables.

To examine the effect of these reservoirs, Simulation 2 assumed that none of these reservoirs had been constructed.

Simulation 2 was compared with the base run to examine the effects the New Hampshire flood control reservoirs had in the storm events. The peak flows at USGS Gage 00109400 are about 25 percent less than they would have been if the reservoirs were not built (refer to Table C-14 and Figures C-11 and C-12). Although the reservoir storage in the Souhegan Basin is relatively small, these 12 flood control reservoirs do serve the purpose of reducing flooding.

Table C-14: Base Run Comparison for the Souhegan River Basin

Storm Event	Base Run Peak (cfs)	Simulation 2 (No NH Flood Control Dams, cfs)	Difference from Base
May 2006	6,300	7,916	25.7%
April 2007	10,415	13,289	27.6%

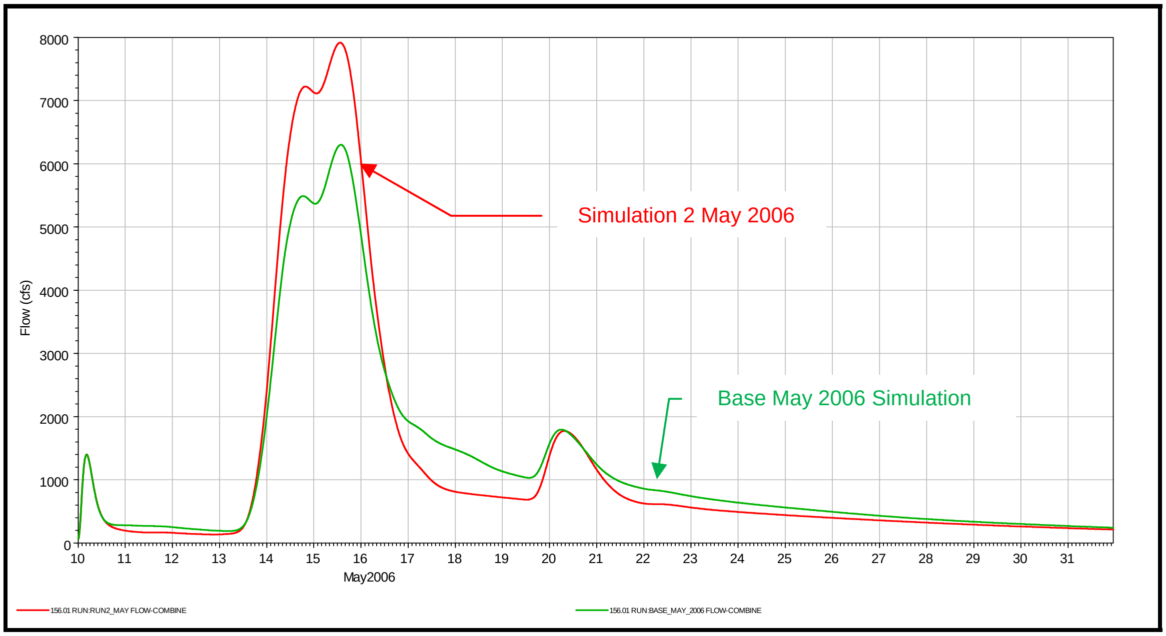


Figure C-11: Base Simulation and Simulation 2 (No New Hampshire Flood Control Dams) for May 2006 Storm Event

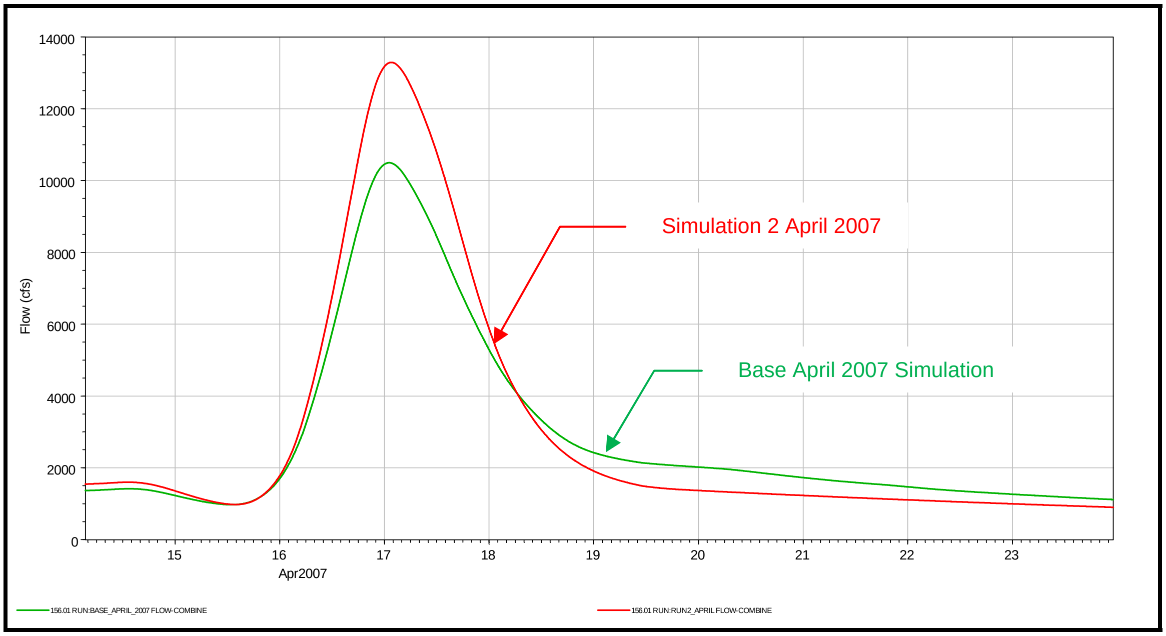


Figure C-12: Base Simulation and Simulation 2 (No New Hampshire Flood Control Dams) for April 2007 Storm Event

C-5.3.4 Simulation 3: Use of flashboards on New Hampshire Flood Control Dams

Simulation 2 established that the New Hampshire Flood Control Dams reduced peak flows by a substantial quantity. The question was then explored: could these dams be used to store more water and further decrease downstream flooding? To examine the incremental effect that greater storage might have had, Simulation 3 was developed with the assumption that 3-foot flashboards were installed on the emergency spillways of all of the New Hampshire Flood Control Dams. This would increase the storage capacity of each reservoir.

Compared to the Base Simulations for both the May 2006 and April 2007 storm events, there was virtually no impact on the overall basin by slightly increasing the storage capacity on the New Hampshire flood control dams. As shown in Table C-15 and Figures C-13 and C-14, there is no measureable difference between Simulation 3 and the Base Simulation.

Table C-15: Base Run Comparison for the Souhegan River Basin

Storm Event	Base Run Peak (cfs)	Simulation 3 (Flashboards Added at NH flood control dams, cfs)	Difference from Base
May 2006	6,300	6,279	0.3%
April 2007	10,415	10,480	0.6%

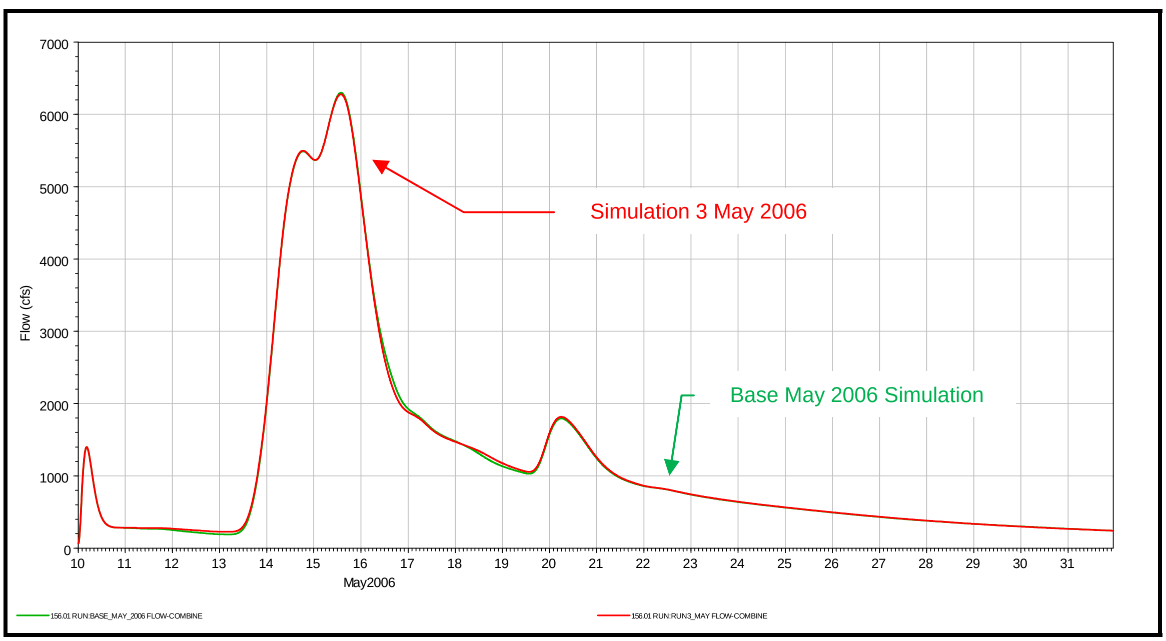


Figure C-13: Base Simulation and Simulation 3 (Flashboards added at New Hampshire Flood Control Dams) for May 2006 Storm Event

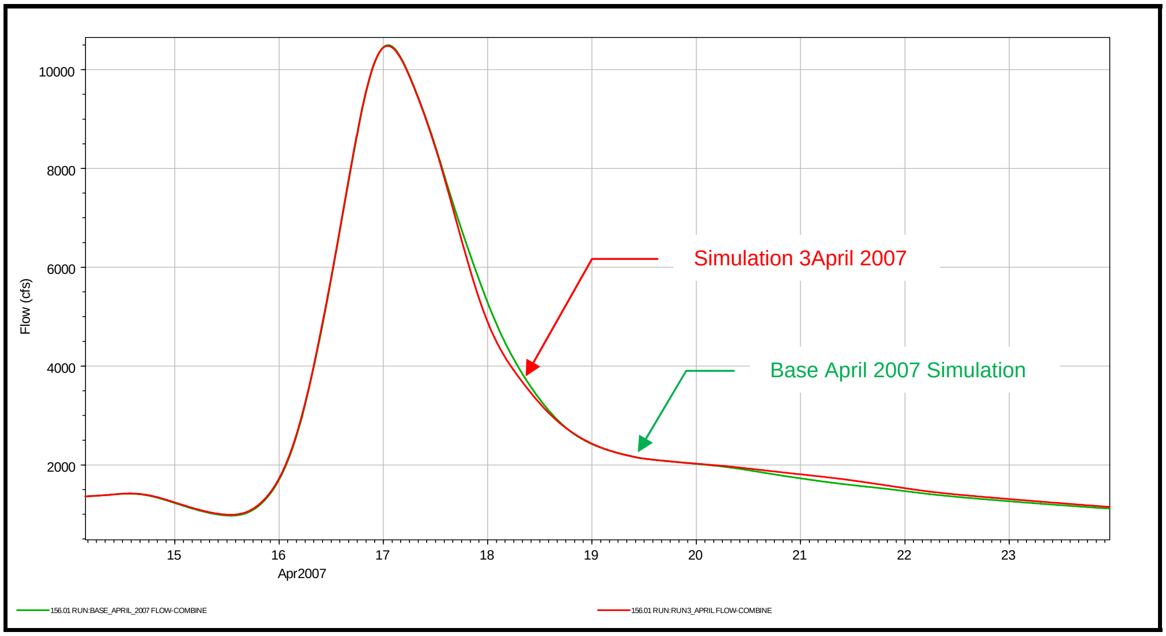


Figure C-14: Base Simulation and Simulation 3 (Flashboards added at New Hampshire Flood Control Dams) for April 2007 Storm Event

C-5.3.5 Simulation 4: Double the storage on Otis Falls and Pine Valley Mill Dam

Much public concern has been expressed regarding the operation of Otis Falls Dam (OFD) and Pine Valley Mill Dam (PVD), two run-of-the-river dams located in the upper half of the Souhegan Basin. The effect that these dams have on the overall Souhegan Basin is examined in Simulation 4. In Simulation 4, the storage capacity of both Otis Falls and Pine Valley Mill Dam is doubled from 105 af to 210 af and from 70 af to 140 af respectively. Given the small amount of storage of these two dams relative to the rest of the Souhegan Basin (~12,000 af), the results from Simulation 4 do not vary from the Base Simulation by any significant quantity for either storm event (see Table C-16 and Figures C-15 and C-16).

It is important here to distinguish between the overall basin perspective in Simulation 4 and the localized effect of these dams in Simulations 5 through 12. Simulation 4 is compared to the Base Simulation at USGS Gage Number 001094000, 20 miles downstream from Pine Valley Dam and 29 miles downstream of Otis Falls Dam. Simulations 5 through 12 focus on the towns of Greenville, Wilton, and Milford, where impacts from these dams' operation are more localized and direct.

Table C-16: Base Run Comparison for the Souhegan River Basin

Storm Event	Base Run Peak (cfs)	Simulation 4 (Increased storage at OFD and PVD, cfs)	Difference from Base
May 2006	6,300	6,297	0.0%
April 2007	10,415	10,493	0.1%

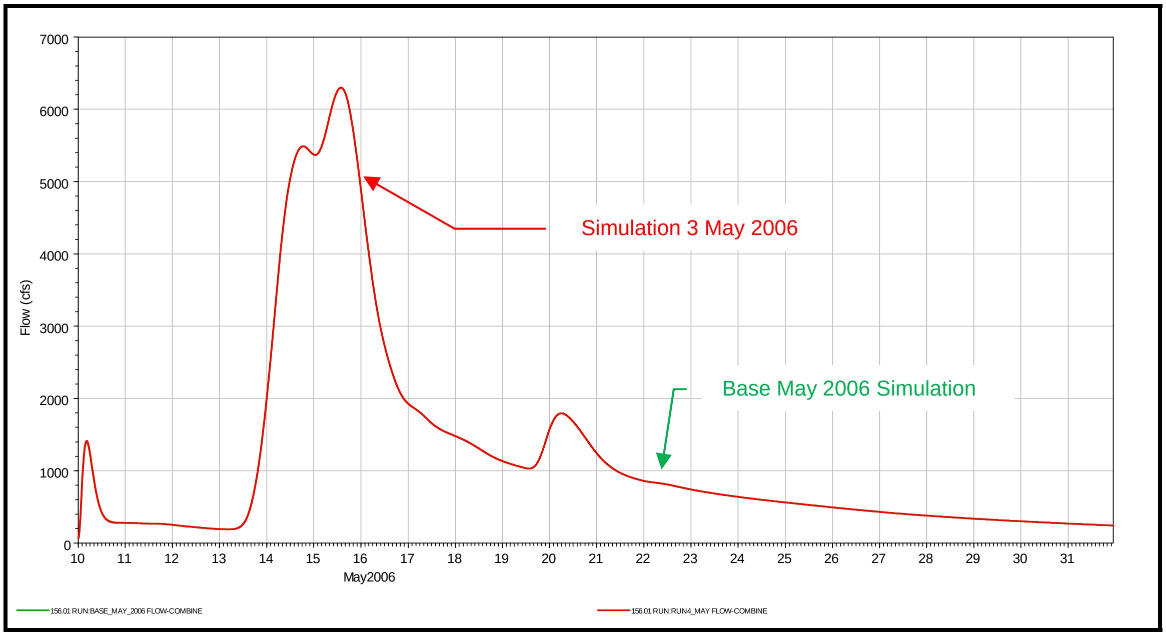


Figure C-15: Base Simulation and Simulation 3 (Increased storage at OFD and PVD) for May 2006 Storm Event

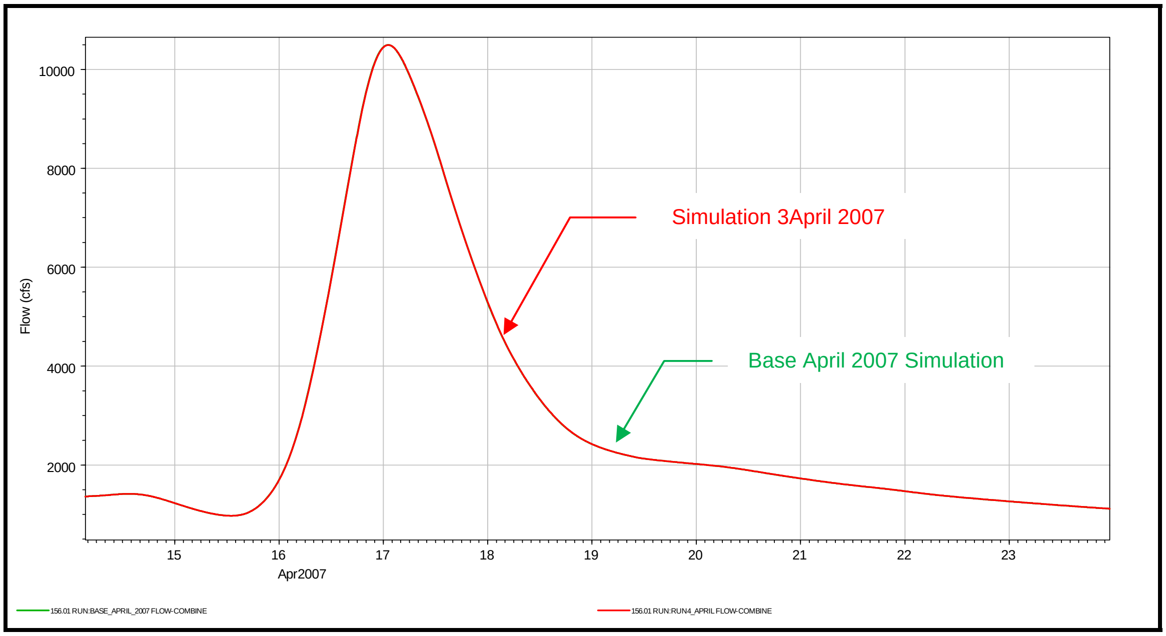


Figure C-16: Base Simulation and Simulation 3 (Increased storage at OFD and PVD) for May 2006 Storm Event

C-5.4 Evaluation of the Results

Comparison between the Base Simulation and Simulation 1 (where all impoundments in the basin are assumed to be empty at the beginning of the storms) shows the entire operating envelope for the Souhegan Basin. Even if it were possible to empty all of the impoundments in the basin prior to these storms, there would have been no flood control benefit.

Only Simulation 2, which assumes none of the New Hampshire flood control dams were built, showed any measureable difference in the flood discharges. If there were not flood control dams, discharges at would have been over 25 percent greater during these events at the USGS gage. It is evident that the New Hampshire flood control dams prevented a substantial amount of flooding; unfortunately, an increase in storage capacity (implied by the use of flashboard in Simulation 3) for the New Hampshire flood control dams has little additional flood control benefit.

Ultimately, the operation of run-of-the-river dams has no effect at the USGS gage as shown in Simulation 4. Even if the storage capacity of these facilities is doubled, there is no measureable difference at this location.

C-6.0 OTIS FALLS DAM (NHDES# 101.01)

C-6.1 General Description

Otis Falls Dam is a run-of-the-river dam located in the upper Souhegan River Basin in the town of Greenville. It was constructed in 1936 and its primary current use is for the development of hydropower. To maximize hydropower output, 3-foot wooden flashboards are installed above the emergency spillway as shown in Figure C-17.

Figure C-17: Otis Falls Dam during March 8, 2008 Rainfall Event

No operable outlet works exist on Otis Falls dam, although two inoperable inlet openings in the forebay area and an intake sluice gate exist as shown in Figure C-18. It does not appear that these provide any functionality nor do they appear to offer any operating flexibility to improve flood control performance.

For the development of hydropower, a FERC license is required to be maintained and periodically updated. Part of the licensing involves the use of flashboards which are required to be used in accordance with the provisions in the license. To avoid deleterious environmental impacts, Otis Falls operators are required to maintain a relatively constant level behind the flashboards.

The informal operating rules on Otis Falls Dam require field personnel to manually remove the flashboards prior to the arrival of flood event (Greenwood 2008). This requires field personnel to visit the dam site either prior or during the event and accurate forecasting data. As discussed in section C-6.2, there is some controversy about the exact procedure that was followed during the April 2007 storm event.

<u>Otis Falls Critical Data</u>

- Maximum storage at top of dam embankment: 105 af
- Drainage area: 30 mi^2
- 3-foot manual flashboards
- Takes only 0.07 inch of runoff to fill

Figure C-18: Otis Falls Plan View

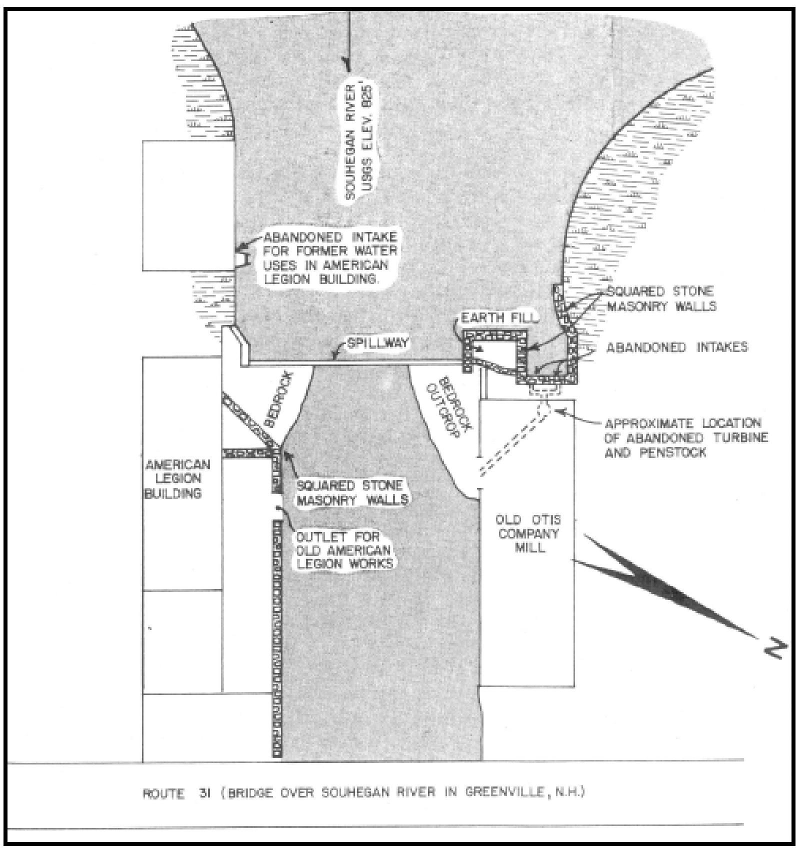


Figure C-19: Otis Falls Plan Schematic (NHDAMS Data Sheet 2007)

C-6.2 Observations During April 2007 Flood Event

Based on a letter to New Hampshire State Representative Peter Leishman dated January 7, 2008 from James Gallagher, Chief Engineer of NHDES, there are slightly varying accounts of the flashboard operation for Otis Falls Reservoir, as described in Table C-17.

Table C-17: Observed Operations at Otis Falls Dam (NHDES# 101.01)

Account of Operations	Source
5 of 24 panels of flashboard removed on Saturday, April 14th; More panels removed on Sunday Morning, April 15th; All flashboards lowered by end of day Sunday April 15th.	Mr. Robert Greenwood
Operator seen lowering panels at 10:30 a.m. on Monday, April 16th	Fire Chief at Wilton
No operations made at 10:30 a.m. on Monday April 16th; for purposes of modeling, it was assumed that "no operations made" meant that all flashboard were in place until 11:00 a.m. on Monday April 16th, at which time they were all removed.	Dam safety engineer with NHDES Dam Bureau

Scenarios were examined evaluating all of these accounts on potential flood impacts downstream of the dam.

C-6.3 Simulations

Simulations 5 through 10 are applicable to the examination of Otis Falls Dam.

In Simulation 5, where the flashboards are simulated to stay in place throughout the entire event, there is an increase in overall pond elevation but there is little to no effect on the discharges since no sudden release or rapid pond draining occurs. There has been little demonstrated public concern over the upstream elevation along the shoreline of the impoundment. However, Figure C-20 shows the general elevation trend: the longer the flashboards are in place, the higher the upstream elevation.

In Simulation 6, where the flashboards are set to be removed with a given depth of overflow, the flashboards fall very early in the storm with a negligible effect on downstream flow.

Simulations 7 and 8 demonstrate that removing the flashboards close to the peak can generate an increase in the downstream discharge rates.

Simulations 9 and 10 demonstrate the time window when the flashboards may have been removed either sometime during April 15th (Simulation 9) or just before noon on April 16th (Simulation 10). Simulation 10 is a worst case scenario since it assumes that no flashboards were removed and all water stored behind the dam was released instantaneously. And since the release on April 16th is closer to the arrival of the peak flow, it has the greatest consequence.

Assuming the worst case condition (Simulation 10), there would have been a large increase in flows (from 1,230 cfs to 2,330 cfs for a difference of 1,100 cfs), and an increase in elevation of about 2.5 feet immediately downstream of the dam (between Otis Falls Dam and Chamberlain Dam). However, this difference diminishes quickly as the flow traverses the downstream floodplain. The differences in peak flow converge as floodplain attenuation stores the additional water caused by the removal of the flashboards. Using the Modified Puls routing method in HEC-HMS, it is estimated that the difference in flow between the Base Simulation (no flashboards) and Simulation 10 is reduced to less than 100 cfs with a corresponding elevation difference of less than 0.1 foot at the point where the Souhegan River intersects Old Wilton Road in the town of Greenville. Using the same methodology, there is no difference in flow by the time these flow arrive at Pine Valley Mills Dam, 9 miles downstream. The approximate area of impact, between Main Street where the dam is located and the intersection of Fitchburg Road (State Route 31) and Old Wilton Road, is shown on Figure C-21.

The effects of this peak were also analyzed by using an approximate unsteady flow approach with HEC-RAS, a widely used hydraulics model (USACE 2002). Immediately downstream of Otis Falls, there is almost a 2-foot increase in water surface elevation. However, within 4,900 feet downstream of Otis Falls Dam, the difference between the Base Run and Simulation 10 (the simulation with the greatest change in flow) become negligible as floodplain storage attenuates the increase in peak flow. Thus, although this increase in peak water surface level is significant to property owners adjacent to Otis Falls Dam, the effect is most likely not noticeable by the time the water arrives at Pine Valley Mills Dam 9 miles downstream.

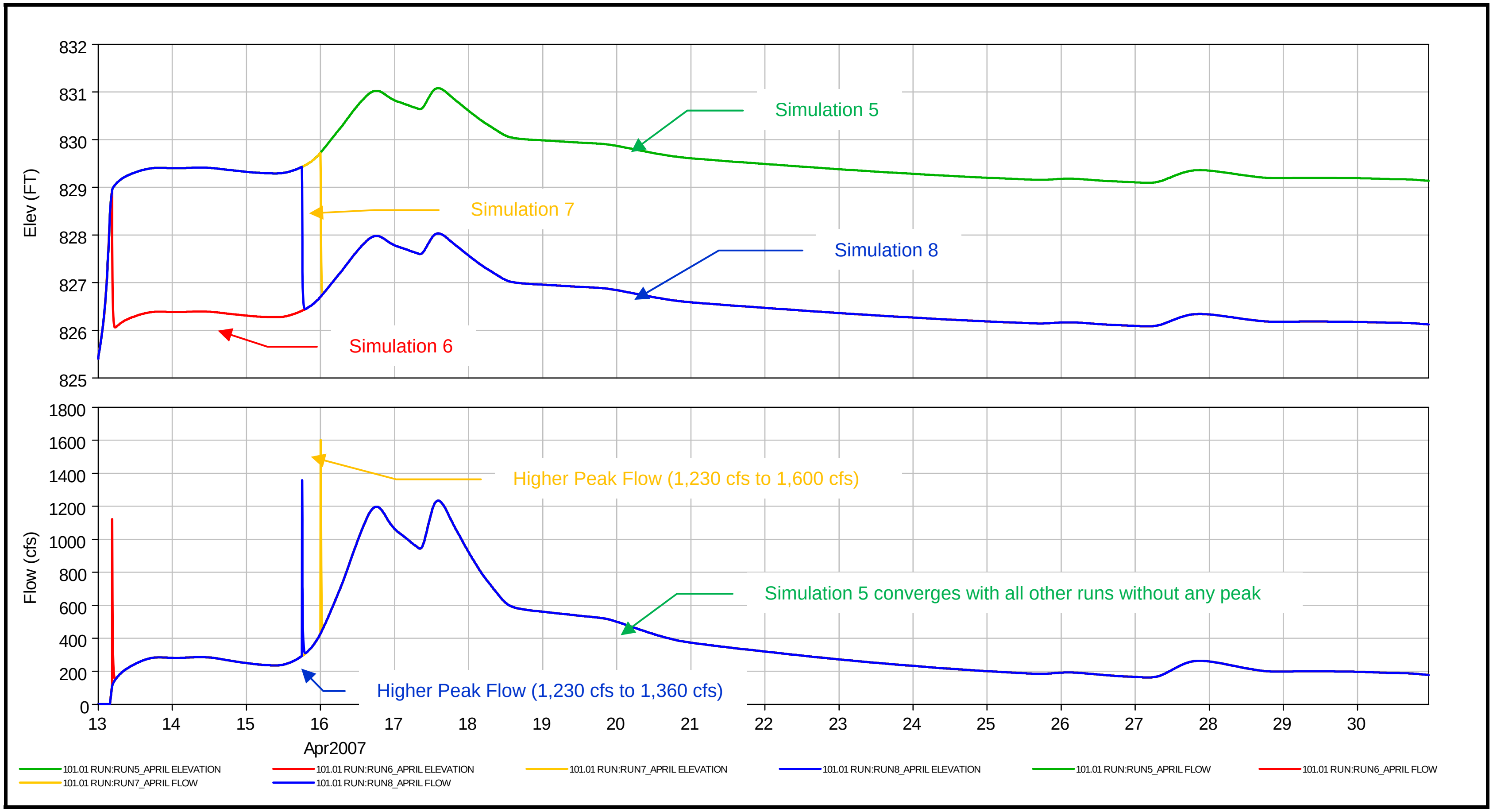


Figure C-20: Otis Falls Elevation and Discharge for Simulations 5, 6, 7, and 8

Simulation 5: Flashboards remain in place
Simulation 6: All flashboards removed when overtopped by 0.5 foot
Simulation 7: All flashboards removed at midnight on April 16
Simulation 8: Flashboards removed at 6 p.m. on April 15

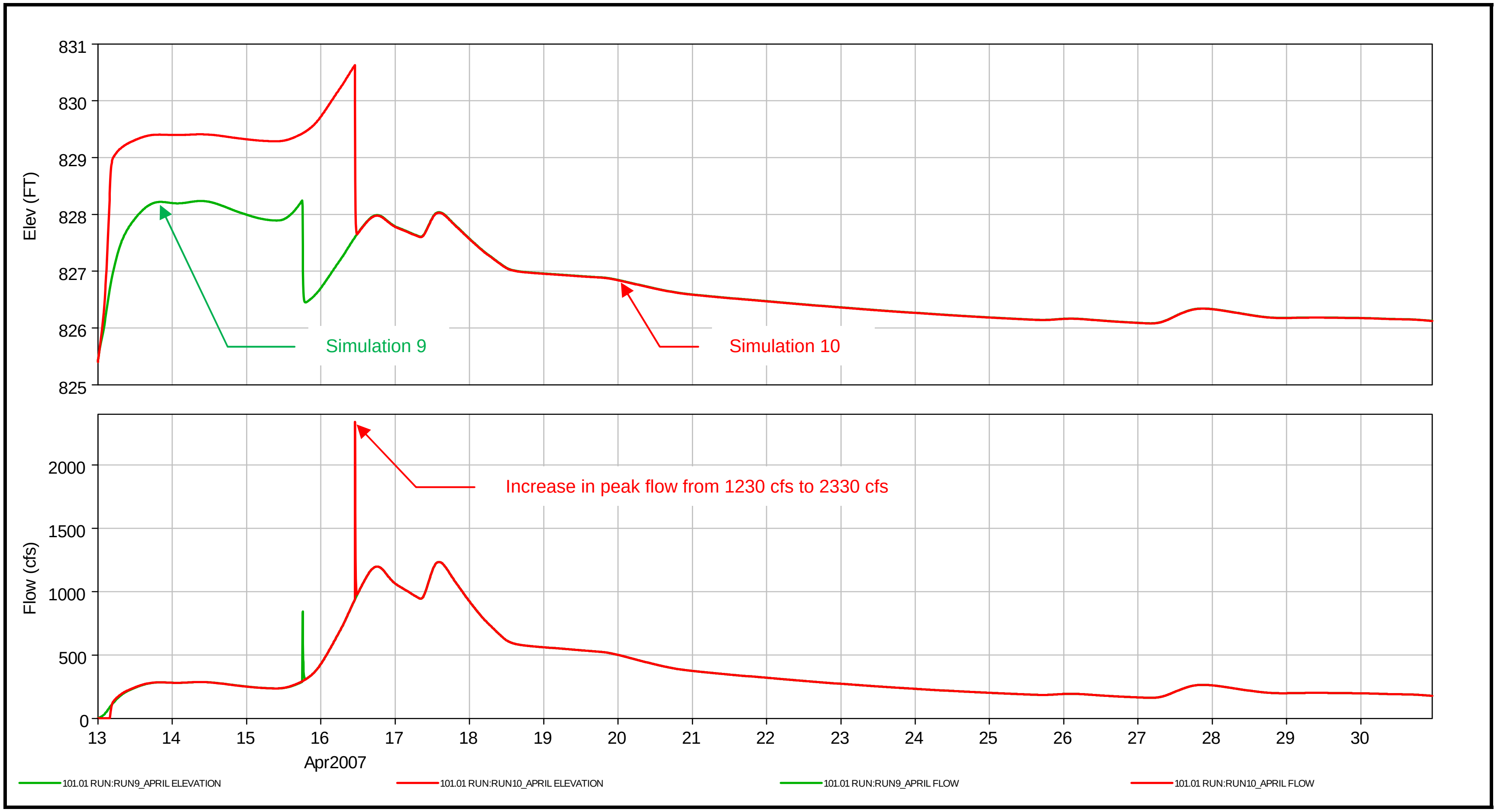


Figure C-21: Otis Falls Elevation and Discharge for Simulations 9 and 10

Simulation 9: Flashboards removed starting April 15th
Simulation 10: Flashboards removed 11 a.m. April 15th

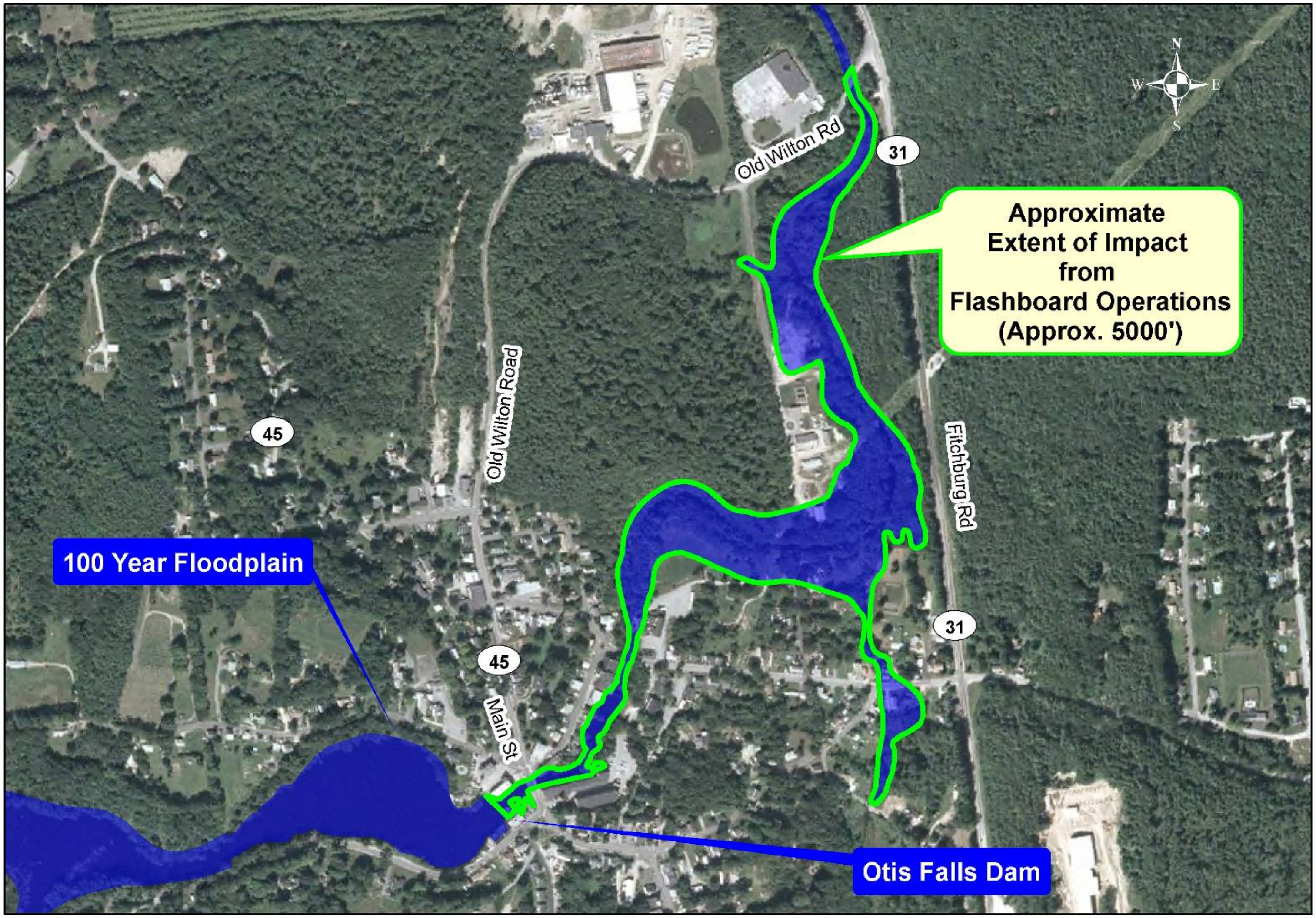


Figure C-22: Approximate Area of Impact from Flashboard Operation on Otis Falls Dam

C-6.4 Evaluation of Results

Simulations 5 through 10 demonstrated that the timing of the flashboard removal impacts the areas immediately downstream of Otis Falls Dam. If the flashboards were gradually removed at the beginning of the storm and totally removed by the evening of April 15th, the peak water surface elevation levels immediately downstream of Otis Falls would not have been affected; if no flashboards were removed until 11:00 a.m. on April 16th, there would have been a substantial increase in discharge and peak water surface elevation immediately downstream from the dam.

Since there are no gages within this area, it would be very difficult to deduce the precise operations of Otis Falls Dam during the April 2007 storm event. Regardless, more formal operating procedures that require the early removal of these particular flashboards may help to protect the downstream properties with the area of impact (shown in Figure C-22).

Because of floodplain attenuation, the effects of the flashboard removal are less noticeable downstream; the effects of the flashboard removal are minor as the Souhegan leaves the town of Greenville and enters Wilton.

C-7.0 PINE VALLEY MILLS DAM (NHDES# 254.01)

C-7.1 General Description

Pine Valley Mills Dam is a run-of-the-river dam located in mid Souhegan River Basin in the town of Wilton. It was constructed in 1912 and its primary current use is for the development of hydropower. To maximize hydropower output, 4-foot automatic flashboards are installed above the emergency spillway. The plan view is shown in Figure C-23. A schematic of the site is shown in Figure C-24.

Two operable outlet works exist on Pine Valley Mills dam, as shown in Figure C-23. Some functionality and operating flexibility to improve flood control performance exists with these outlet works.

For the development of hydropower, a FERC license is required to be maintained and periodically updated. Part of the licensing involves the use of flashboards which are required to be used in accordance with the provisions in the license. Pine Valley Mills operators are also required to maintain a relatively constant level behind the flashboards.

Pine Valley Mills Critical Data

- Maximum storage to top of embankment: 70 af
- Drainage area: 97 mi^2
- 4-foot automatic flashboards
- 0.01 inch of runoff fills lake

Figure C-23: Plan View of Pine Valley Mills Dam

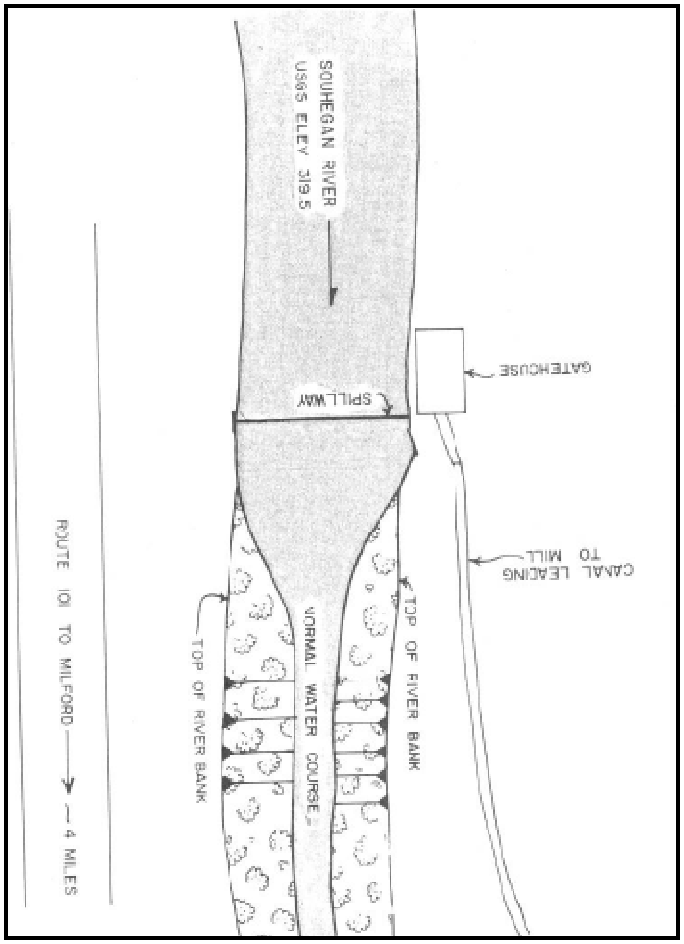


Figure C-24: Pine Valley Mills Plan Schematic (NHDAMS Data Sheet 2007)

C-7.2 Observations During April 2007 Flood Event

Based on the letter to New Hampshire State Representative Peter Leishman dated January 7, 2008, from James Gallagher, Chief Engineer of NHDES, there are slightly varying accounts of the flashboard operation for Pine Valley Mills Reservoir, as described in Table C-18.

Table C-18: Observed Operations at Pine Valley Mill Dam (NHDES#254.01)

Account of Operations	Source
Mr. Greenwood notified Mr. Young at 11:00 a.m. on Sunday April 15th that releases were going to be made from Otis Falls; Mr. Young opened waste gates at 5:00 p.m. on Sunday, April 15th; regardless, the water level caused the flashboards to fall over by 6:30 a.m. on April 16th.	Mr. Michael Young
Flashboards fall over between 9:00 a.m. and 10:00 a.m. on April 16th.	Fire Chief at Wilton

C-7.3 Simulations

Simulations 5 through 8, 11, and 12 are applicable to the examination of Pine Valley Mills Dam. The time window of accounts for the lowering of the automatic flashboards range from 6:30 a.m. to 10:00 a.m. on April 16th. Figures C-25 and C-26 demonstrate the effects of discharge when the flashboards are removed within this time frame.

In Simulation 5, the flashboards are assumed to hold throughout the entire storm event. The resulting peak elevation at the dam is 332.0, but there is no effect on downstream flows since the volume of water behind the flashboards is not released.

In Simulation 6, the flashboards on Pine Valley Mills Dam are set to lower with a 0.5-foot overtopping versus the 1.0-foot overtopping depth that is estimated to be currently installed. This results in an instantaneous peak flow increase from 1,500 cfs to 3,600 cfs, but the subsequent peak flow of over 5,500 cfs is not affected by the early release.

Simulations 7 and 8 simulate the removal the flashboards between 6 p.m. on April 15th and at midnight on April 16th. The earlier removal of flashboards in Simulation 8 is more important with Pine Valley Mills Dam since the lower flows at Pine Valley Mills Dam can be released using the waste gates available on the dam. When the flashboards are removed at 6:00 p.m., there is barely a noticeable difference between elevations and discharges; when the flashboards are removed 6 hours later, there is more noticeable spike in elevation and peak flows (~900 cfs) because the waste gates are at capacity during this time frame.

Simulation 11 and 12 duplicate the account of operations in the table. As shown in Figure C-25, there are noticeable increases in reservoir elevation and discharge with later flashboard removal. However, for Simulations 7, 8, 11, and 12, none of increases in discharges exceed the subsequent peak flow of over 5,500 cfs.

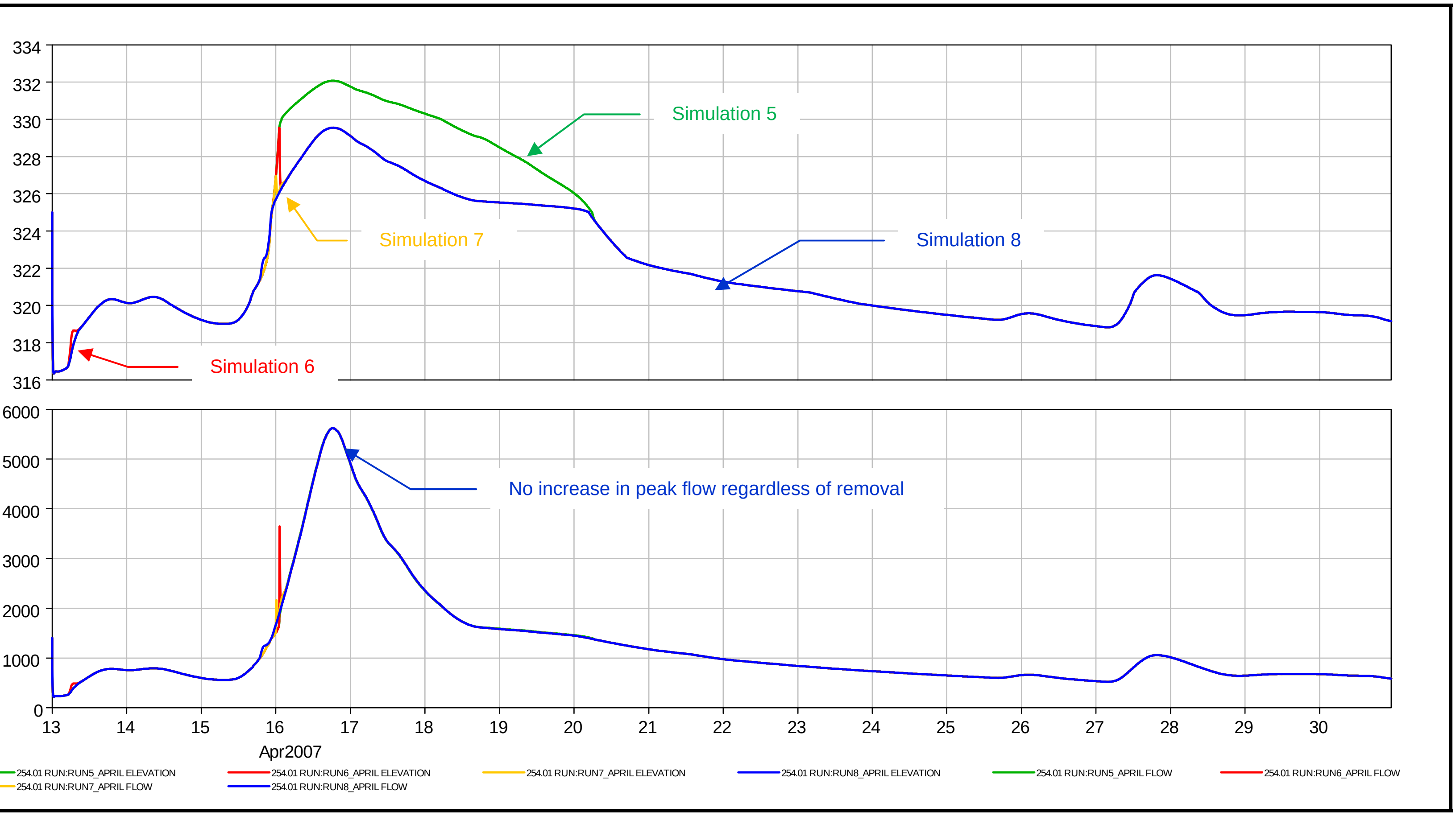


Figure C-25: Pine Valley Mills Elevation and Discharge for Simulations 5, 6, 7, and 8

ulation 5: Flashboards remain in place throughout event
ulation 6: Flashboards lower when overtopped by 0.5 foot
ulation 7: Flashboards removed at midnight on April 16th
ulation 8: Flashboards removed at 6 p.m. on April 15th

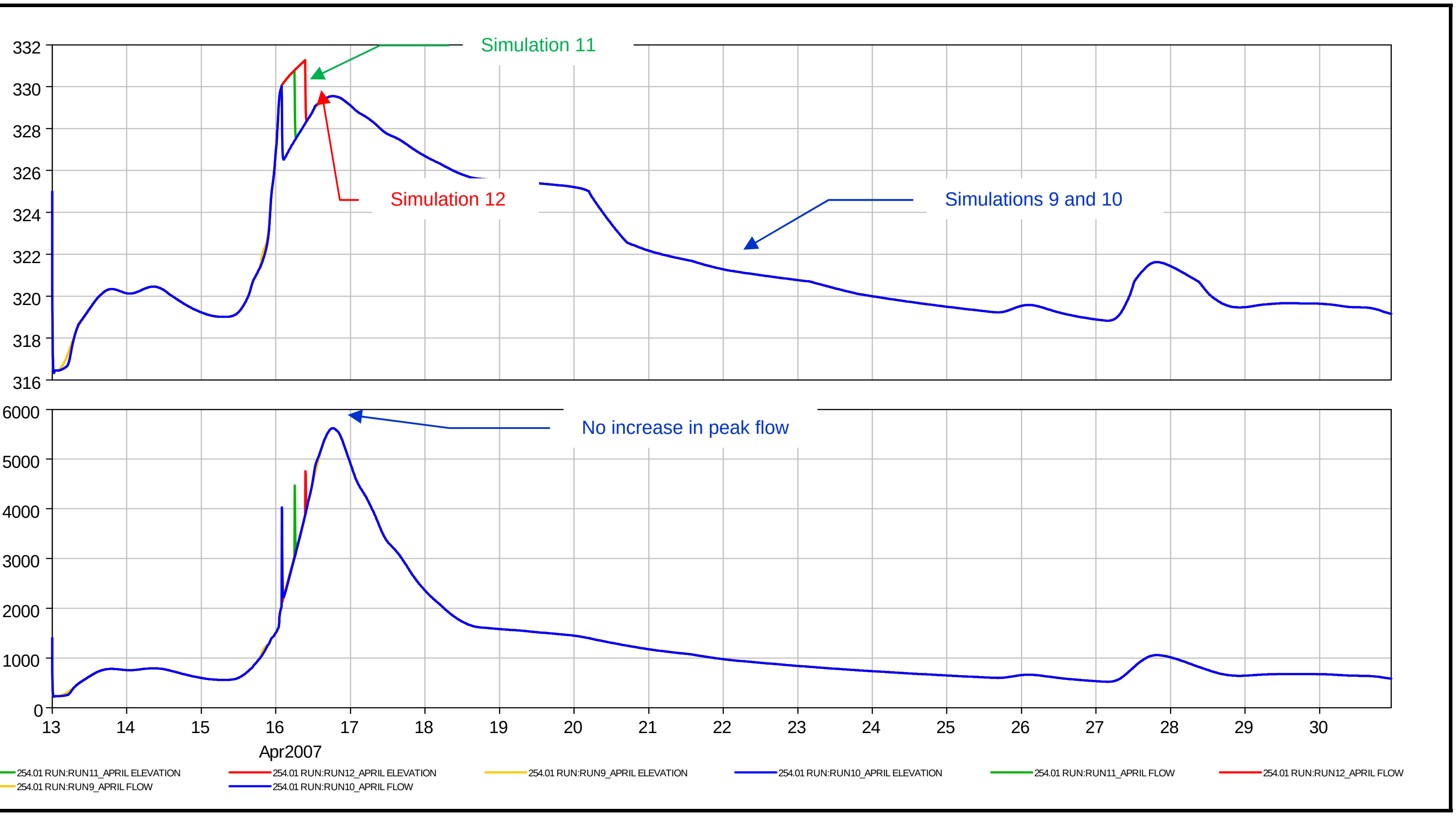


Figure C-26: Pine Valley Mills Elevation and Discharge for Simulations 9, 10, 11, and 12

ulation 9: Impact of operations at Otis Pond not seen at Pine Valley
ulation 10: Impact of operations at Otis Pond not seen at Pine Valley
ulation 11: Flashboards at Pine Valley lowered at 6 a.m. April 16th
ulation 12: Flashboards at Pine Valley lowered at 9:30 a.m. April 16th

C-7.4 Evaluation of the Results

From an observer's perspective located immediately downstream of Pine Valley Mills dam, the removal of the flashboard involves an immediate rush of water; a more substantial rush of water is observed if the corresponding water surface elevation is higher. However, from this same perspective it would also be easy to confuse the peak discharge associated with the removal of flashboards with the subsequent discharge associated with the arrival of the upstream peak discharge.

The location of Pine Valley Mills reservoir relative to Souhegan Basin decreases the impact of its operations. There were increased discharges and elevated water surfaces downstream of the dam because of its operations. However, the ultimate peak flood discharge and the peak downstream water surface elevations were unaffected by these operations

C-8.0 CONCLUSIONS AND RECOMMENDATIONS

1. It is apparent from analyzing climatic and runoff data that the Souhegan Basin incurred a significant runoff event in both the May 2006 and April 2007 storms. The runoff was not as attributable to significant rainfall as it was to the combination of meteorologic factors that existed in the basin prior to onset of the majority of rainfall. In May 2006, this involved moderate antecedent rainfall saturating the soil a few days prior to the event and then moderate intensity rainfall over a long period of time (over 3 days) during the event. In April 2007, this involved substantial antecedent rainfall and snowmelt being followed by a rainfall of significant intensity (between the 2- and 5-year rainfall event for a 24-hour period) over a shorter period of time falling on saturated soil.

2. Given the relatively low recurrence interval of rainfall (1- to 2-years) and the consequent high recurrence interval of runoff (10- to 50-years), any basin-wide policy for flood control protection and floodplain management should account for the influence of antecedent conditions. In particular, snowmelt scenarios should be accounted for in any hydrology and hydraulics analysis that is used for public policy purposes (such as Emergency Action Plans).

3. A comprehensive model was developed for the Souhegan River Basin to examine the effects of reservoir operation in the May 2006 and April 2007 storm events. Several simulations were developed to analyze the effects of both flood control and run-of-the-river impoundments. From an overall basin perspective, the flood control structures operated by the State of New Hampshire reduced flood discharges by substantial quantities, while the overall basin effect of the run-of-the-river impoundments was minor.

4. The localized effects of flashboard operation of the run-of-the-river dams was substantial during the April 2007 storm event and evidenced by the public concern over the flashboard operation and several of the simulation developed in this study. An overall watershed policy for the use and removal of these devices should be developed that considers timing, maintenance, and coordination with FERC permitting.

C-9.0 REFERENCES

1. Federal Emergency Management Agency. 1979a. Flood Insurance Study. Town of Amherst, New Hampshire, Federal Insurance Administration, January.

2. Federal Emergency Management Agency. 1979b. Flood Insurance Study. Town of Merrimack, New Hampshire, Federal Insurance Administration, January.

3. Federal Emergency Management Agency. 1979c. Flood Insurance Study. Town of Milford, New Hampshire, Federal Insurance Administration, October.

4. Federal Emergency Management Agency. 1979d. Flood Insurance Study. Town of Wilton, New Hampshire, Federal Insurance Administration, October.

5. Federal Emergency Management Agency. 1980. Flood Insurance Study. Town of Greenville, New Hampshire, Federal Insurance Administration, November.

6. Federal Emergency Management Agency. 1991. Flood Insurance Study. Town of New Ipswich, New Hampshire, Federal Insurance Administration, May.

7. Federal Emergency Management Agency. 1994. Flood Insurance Study. Town of Bedford, New Hampshire, Federal Insurance Administration, May.

8. Greenwood, Robert. 2008. Personal Conversation, May 18, 2008.

9. U.S. Army Corps of Engineers. 2000. HEC-HMS Hydrologic Modeling System Technical Reference Manual, March.

10. U.S. Army Corps of Engineers. 2002. HEC-RAS River Analysis System Hydraulic Reference Manual, Version 3.1, November.

11. Zhang, Yanlong. 1995. Calibration of a Physically-based Distributed Rainfall-Runoff Model with Radar Data, Master of Science Thesis, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, February.

C-10.0 ATTACHMENT A: CALIBRATION PROCEDURE

Snyder's Method for Unit Hydrograph

The lag time, t_p (in hours), or approximately the time between the rainfall and the peak of the hydrograph, is defined as:

$$t_p = C_t(LL_c)^{0.3}$$

where C_t = basin coefficient; L = length of the main stream from the outlet to the divide; and L_c = length along the main stream from the outlet to a point nearest the watershed centroid. C_t is modified during calibration so that the timing of the simulated runoff peak. The peak discharge of the unit hydrograph (in cfs) is determined by the following function:

$$Q_p=C_pA/t_p$$

where C_p = peaking coefficient; A = drainage area in square miles, and t_p is as previously defined. The unit hydrograph is then convoluted with an historical rainfall event to produce an event hydrograph such as the April 2007 or May 2006 rainfall-runoff event.

Since there was only one runoff gage and limited precipitation data, C_t and C_p are assumed to have the same value throughout the Souhegan watershed for both the May 2006 and April 2007 storm events. For the Souhegan Basin, C_p was found to be 3.2. Typically this ranges between 1.8 and 2.2 with values found to range between 0.4 in mountainous regions and 8.0 in extremely flat areas. C_t was found to be 0.8. Typically this ranges between 0.4 and 0.8 (USACE 2000).

Initial and Constant-Rate Loss Method

The initial and constant-rate loss method was used in HEC-HMS to simulate runoff volume. This method assumes a maximum potential rate of precipitation loss, f_c, that is constant throughout an event. Therefore a precipitation value of p_t for a time interval of $t+\Delta t$, the excess runoff volume pe_t is given by:

$$pe_t = \begin{cases} p_t - f_c, & if\ p_t > f_c \\ 0, & otherwise \end{cases}$$

An initial loss, I_a, is also included in the model to represent interception and depression storage. In the May 2006 and April 2007 storms events, no initial loss was used in the final calibration. Table A1 shows the loss rates that were used to calibrate the May 2006 and April 2007 storm. The soil types and areas were determined for each sub-basin using NRCS SURRGO soils data. Then a weighted loss rate was calculated for each sub-basin.

Base Flow Method

The base flow for the Souhegan River Basin was estimated using the exponential recession model where

$$Q_t = Q_0k^t \text{ with}$$

Q_t = the baseflow at anytime t in cfs,

Q_0 = initial value for baseflow in cfs/mi^2,

k = expotential decay constant, and

t = unit time.

The values used for this study are included in Table A2. The same values are used for all 120 subbasins.

Table A1: Precipitation Losses Used in Souhegan River Basin HEC-HMS Model

Hydrologic Soil Group	Description	Typical Range of Loss Rates (in/hr)	Loss Rates for May 2006 Storm	Loss Rates for April 2007 Storm
A	Deep sand, deep loss, aggregated silts	0.30-0.45	0.075	0.00
B	Shallow loess, sandy loam	0.15-0.30	0.038	0.00
C	Clay loams, shallow sandy loam, soils in organic content, and soils usually high in clay	0.05-0.015	0.013	0.00
D	Soils that swell significantly when wet, heavy plastic clays and certain saline soils	0.00-0.05	0.000	0.00

Table A2: Base Flow Values Used in Souhegan River Basin HEC-HMS Model

Storm Event	Initial Discharge (cfs/mi^2)	Recession Constant	Ratio to Peak
May 2006	1	0.9	0.1
April 2007	5	0.9	0.1

Additional analysis was conducted using the NRCS Soil Complex Method as described in NRCS *National Engineering Handbook-4*, although it was determined that Snyder's method provided a better estimate of the storm hydrograph since the NRCS method could not correctly approximate the volume under the hydrograph. Using detailed land use files and NRCS SURRGO Soils data, the overall basin curve number was found to be 64.

C-11.0 ATTACHMENT B: DAM DATA SUMMARY

Table B1: Souhegan River Basin Dams with NHDES HydroCAD Models

NHDES#	Dam Name	Height (ft)	Drainage Area[1] (mi^2)	Maximum Storage[2] (af)	Runoff to fill[3] (in)
7.01	JOE ENGLISH POND DAM	5.5	3.13	101	0.61
7.09	VIJVERHOF POND DAM	9.0	0.67	192	5.37
147.13	CURTIS BROOK DAM	10.0	2.23	3	0.02
147.14	PURGATORY BROOK	6.5	2.55	12	0.09
147.18	PURGATORY BROOK DAM	0.0	2.45	19	0.15
147.22	RECREATION POND	4.0	0.16	3	0.33
147.24	WILDLIFE POND	7.5	0.37	13	0.66
147.26	SOUHEGAN RIVER SITE 28 DAM	29.0	1.1	185	3.16
147.28	SOUHEGAN SITE 8 DAM	25.0	4.7	2721	10.86
147.29	MORISON POND	19.0	0.06	15	4.53
147.31	SWARTZ POND DAM	8.0	0.25	42	3.17
147.33	FARM POND	6.0	0.01	2	3.30
147.38	CURTIS BROOK DAM	12.0	3.5	1	0.01
159.01	RAILROAD POND DAM	12.0	10.58	48	0.09
159.04	OSGOOD POND DAM	9.0	5.24	270	0.97
159.05	HARTSHORN POND DAM	14.9	2.55	40	0.29
159.16	COMPRESSOR POND	24.0	2.25	76	0.64
163.02	CURTIS BROOK DAM	5.0	0.41	126	5.77
163.06	TROW DAM	0.0	1.27	1	0.01
163.07	HARTSHORN BROOK II DAM	8.0	0.22	28	2.39
163.12	ROBY POND DAM	3.5	0.34	3	0.17
167.18	BEAVER DAM POND DAM	5.0	0.58	210	6.79
167.29	GARDNER RESERVOIR DAM	8.0	1.16	17	0.27
175.01	SOUHEGAN SITE 14 DAM	35.0	2.1	885	7.90
175.03	PRATT POND DAM	6.5	0.74	110	2.79
175.19	SOUHEGAN RIVER SITE19 DAM	35.5	11.4	2072	3.41
175.20	SOUHEGAN RIVER SITE 13 DAM	13.5	0.8	249	5.84
175.21	SOUHEGAN RIVER SITE 35 DAM	30.0	6.4	647	7.67
175.23	WHEELER POND DAM	5.0	0.25	23	1.73
254.09	NEW WILTON RESERVOIR DAM	24.0	0.4	335	15.70
254.19	PETERS FARM POND DAM	10.0	0.98	6	0.11
254.20	BATCHELDER POND DAM	12.0	1.2	20	0.31
254.21	FROG POND DAM	15.0	0.6	143	4.45
254.30	SOUHEGAN RIVER SITE 15 DAM	13.0	1.1	315	12.75
254.34	SOUHEGAN RIVER SITE 33 DAM	21.0	1	1078	20.21
254.38	RECREATION POND DAM	8.0	0.4	10	0.48
254.43	CAMP POND DAM	11.0	0.76	33	0.80

Notes for Tables B1, B2, and B3:

[1] Drainage approximated from WISE or dam inspection report, if available.

[2] Maximum storage in this table is extrapolated to estimated storage above dam to also account for overtopping storage.

[3] Runoff to fill is the ratio of maximum storage to drainage area as defined in these tables.

Table B2: Souhegan River Basin Dams with New Hampshire Dam Data Sheets

NHDES#	Dam Name	Height	Drainage Area (mi^2)	Maximum Storage (af)	Runoff to fill (in)
101.01	OTIS FALLS DAM	27.0	29.6	110	0.07
175.09	WATERLOOM POND DAM	22.5	23.1	679	0.55
234.08	SOUHEGAN RIVER SITE 26 DAM	79.0	4.9	1287	4.93
234.11	SOUHEGAN RIVER SITE 12A SOUTH	33.5	5.6	3304	11.06
234.12	SOUHEGAN RIVER SITE 25B DAM	69.0	5.4	1564	5.43
254.01	PINE VALLEY MILL DAM	23.0	97	70	0.01
254.33	SOUHEGAN RIVER SITE 10A DAM	59.0	6.4	2735	8.01

Table B3: Souhegan River Basin Dams with Inspection Report Data Only

NHDES#	Dam Name	Height (ft)	Drainage Area (mi^2)	Maximum Storage (af)	Runoff to fill (in)
020.09	STOWELL POND	8.0	23.2	26	0.02
020.13	MCQUADE BROOK DAM	14.0	7.9	351	0.83
147.17	BURTON POND DAM	14.0	0.5	2	0.09
156.01	MERRIMACK VILLAGE DAM	20.5	171.0	171	0.02
159.02	GOLDMAN DAM	12.0	137.8	114	0.02
159.03	MCLANE DAM	18.7	138.0	39	0.01
167.17	GREENTREE RES DAM	4.5	0.1	17	2.42
234.04	LEIGHTON POND DAM	10.0	1.1	11	0.19
254.02	WILTON HYDRO DAM	17.0	97.0	18	0.00
254.03	SOUHEGAN RIVER III DAM	19.3	70.3	8	0.00
254.05	STONEY BROOK DAM	20.0	33.5	24	0.01
254.08	OLD WILTON RESERVOIR	17.5	8.3	8	0.02
254.11	MILL BROOK	12.0	6.7	15	0.04
254.18	BLOOD BROOK DAM	18.0	6.6	20	0.06
254.32	ERB WILDLIFE POND DAM	20.0	0.3	16	1.07