Scenario-based Analysis of Transportation Impacts in Case of Dam Failure Flood Evacuation in Franklin County, Massachusetts (Paper # 10-1352)

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ABSTRACT
Emergency planning is an important practice that allows government officials and planners to prepare for disasters and to make prompt responses that can save lives and property. One of the foremost concerns during an emergency is to save as many lives as possible. Thus, whether people can leave the disaster areas safely and efficiently is a prime consideration in emergency planning and management. Usually, transportation planners use a four-step model to predict system-level performance regarding how people move from one place to another, and to determine the network’s weak points and critical areas. In this project, a computer-based software package, TransCAD, is used to evaluate traffic impacts of the evacuation of riverside communities in Franklin County, Massachusetts in the event of flood caused by a hypothetical failure of the Harriman Dam. This scenario was partially designed by representatives of Franklin County. The probable maximum flood (PMF) case is considered; for safety concerns, an evacuation-planning zone (EPZ) is defined as 500 feet beyond inundation area. One important concern is that people living upstream, near the dam, have much less time to evacuate than those who live downstream. The basic consideration behind the model is to evacuate people in a progressive manner in order to take into account the dynamic nature of flood. Using the four-step model together with altered inputs, an analysis is conducted to identify when and where the traffic problems will be the most severe. Following this, general conclusions and recommendations are made.

INTRODUCTION
Emergency evacuation planning is a critical part of the decision-making process to determine what actions should be taken during disasters. There are several types of disasters: man-made disasters (including civil and technological) and natural disasters (1). Civil disasters include terrorist attacks and other malicious acts such as war. Technological disasters include events that are a result of human negligence or omission such as a nuclear release or a chemical spill. Natural disasters are events that would occur on their own without human interaction such as a tornado, hurricane, or flood. This document is concerned with a flooding disaster resulting from a dam failure.

Natural disasters can cause significant monetary damages, physical harm, or at worst death. At the end of the 19th century, the South Fork Dam failed flooding the downriver town of Johnstown. The flood killed over 2,000 people and caused $17 million of financial loss (2). In 1993, extreme floods in the Midwest caused significant damage. At some storm gauges the event was rated as a 100-, 200-, or at worst a 500-year flood (3). The flood killed over fifty people and caused $18 billion of financial loss (2). In the almost thirty years leading up to 1991 there were almost 4,000 deaths for an average of nearly 120 deaths per year (4).

It is extremely important to plan for an emergency evacuation. One way to accomplish this goal is to simulate the evacuation scenario on the regional network to identify the weaknesses and critical points of the transportation network. An approach to locate these problems is to run a computer-based model that assists in the implementation of the traditional four-step transportation planning model: trip generation, trip distribution, mode split, and traffic assignment. A commercial computer-based software package called TransCAD is used in this project to help analyze how the transportation patterns change. It will also help identify when and where congestion and other problems are expected to occur. This software is not specially designed to address evacuation planning, but it can be adapted to serve this purpose.

A flood evacuation caused by a dam-failure is evaluated in this study. Dam failures can be different for different types of conditions. Failure during a sunny day during a draught would
look very different from a failure during a torrential downpour after a prolonged series of storms. The storm intensities and the geologic conditions of both situations will affect the nature of the flood.

Two types of dam failure scenarios are probable maximum flood (PMF) and the sunny-day case (5). According to the Ohio Department of Natural Resources, a PMF “is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.” (6). In a PMF failure, rainwater would build up behind the dam. This rain is not constrained to the dam of concern. The rain falling over this area could cause flooding in up- and downstream rivers. These floods could disable roads before the dam fails, and could cause evacuations ahead of the dam failure (5).

Using a computer-based simulation package, along with transportation data, planners and engineers can examine evacuation scenarios. In this case, a flood evacuation is examined using TransCAD in Franklin County, Massachusetts.

**OBJECTIVES**

The objective of this project is to identify how traffic patterns change during the flood, when and where to expect traffic problems such as congestion, and what roads and bridges will be critical links in the evacuation network. This will allow transportation management tools and resources to be better allocated to address these problems and increase network efficiency. Another objective of this study is to determine alternative routes that can be used when roads inside inundated areas become unavailable. Other important information available from the study includes whether shelters provide enough capacity for evacuees and whether people have enough vehicles to evacuate in a timely manner.

Under emergency conditions, traffic patterns will be abnormal. Depending on the type of emergency and the amount of lead-time given to the citizens, there will be different levels of preparedness. Hurricanes are broadly reported by the media, while a dam failure may only be reported after the failure. Under some emergency conditions, people have less time than usual to prepare for the event. If planners are knowledgeable about how evacuees will react, they can provide valuable advice to personnel in the field. For example, if congestion is expected to be especially severe in one location, additional roadside assistance vehicles can be deployed to aid citizens with vehicular trouble, thus keeping traffic moving, and more transit can be directed to areas that have fewer vehicles.

**STUDY AREA: FRANKLIN COUNTY**

As was previously mentioned, the area studied was Franklin County, Massachusetts (Figure 1, below). Franklin County is in the northwest corner of Massachusetts, and is bounded by Vermont to the north, Berkshire County to the west, Hampshire County to the south, and Worcester County to the east.

According to the 2000 U.S. Census, the county has a total area of 725 square miles (1,877 square kilometers), of which 702 square miles (1,818 square kilometers) are covered by land and 23 square miles (59 square kilometers) by water. There were 71,535 people, 29,466 households, and 18,416 families residing in the county (7). The population density was 102 people per square mile (39 per square kilometer). There were 31,939 housing units at an average density of 46 per square mile (18 per square kilometer).

The population density of each traffic analysis zone (TAZ) is represented by the darkness of the TAZ in Figure 1. Darker colors signify that the TAZ has a high population density and the lighter colors indicate a low population density. According to census bureau definition, a TAZ is...
a special area delineated by state and/or local transportation officials for tabulating traffic-related data, especially journey-to-work and place-of-work statistics. A TAZ usually consists of one or more census blocks, block groups, or census tracts.

The roadway network is shown in Figure 1. There are 18,284 links and 9,314 nodes in the road network. The geometric shapes outlined in the background are the outlines of the TAZs. The data obtained from Franklin County reported that the county has 67 internal zones and 41 external zones, for a total of 108 TAZs. I-91 is a major route used for trips passing through the county.

![Figure 1 Map of roadway network Franklin County.](image)

**EVACUATION STRATEGY AND METHODOLOGY**

To accomplish the above objectives, this study uses TransCAD, software that implements the four-step transportation planning model. This procedure begins with trip generation and is followed by trip distribution, mode split, and trip assignment. Trip generation determines how many trips will be produced; trip distribution determines how many trips will go from all the traffic analysis zones (TAZs) to all of the other TAZs; mode split determines what type of transportation (public transit or private cars) people use to get to their destinations; and trip assignment determines people’s route choices.

Two common assumptions are that people evacuate at least one hour before the flood arrives, and that households and workplaces are evenly distributed. That is, once an area has been flooded, roads inside the flooded area are no longer usable. People not residing the EPZ use the network as if it were a normal day, and everyone in the EPZ complies with the evacuation order.
Geographically, the entire inundation area is divided into four sections. A section is defined by how far the hypothetical flood travels in two hours. It takes about six hours in total for the flood to reach the end of the inundation area; thus, there are three two-hour periods. Accordingly, there are three sections of the EPZ that need to be evacuated in a progressive manner. Figure 2 (below) notes the time the flood arrives at different sections along the Deerfield River. The time of the maximum elevation can occur several hours after the flood arrives. The two-hour time mark is the end of the first section and the starting point of the second section. The same delineation applies to the four- and six-hour time marks. The scenario assumes that the Harriman Dam breaks at 10:00, and people living in the EPZ of the first section were already evacuated. Recalling the two-hour block evacuation time, the first section starts evacuating at 08:00, which is two hours before the dam failure. In this period, all the road facilities on the network are available. At 10:00, the evacuation in the first section has been completed and people located in the second section begin to evacuate with the road facilities in the first section disabled. The same treatment applies to the third and fourth sections. To clarify, a table is created to illustrate the evacuation strategy in a progressive manner.

Table 1 Evacuation Sections and the Characteristics

<table>
<thead>
<tr>
<th>Period</th>
<th>Evacuation Section</th>
<th>Cities in Period</th>
<th>Roads Disabled</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 8:00 AM – 10:00 AM</td>
<td>Section I</td>
<td>Charlemont, East Charlemont, Shelburne Falls</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2 10:00 AM – 12:00 PM</td>
<td>Section II</td>
<td>Shelburne Falls, Bardwell</td>
<td>Sec. I</td>
<td>Figure 3(a)</td>
</tr>
<tr>
<td>3 12:00 PM – 2:00 PM</td>
<td>Section III</td>
<td>West Deerfield, Greenfield, Cheapside, Turners Falls, Montague, North Sunderland, South Deerfield</td>
<td>Sec. I and II</td>
<td>Figure 3(b)</td>
</tr>
<tr>
<td>4 2:00 PM – 4:00 PM</td>
<td>Not Modeled</td>
<td>North Hadley, Hadley</td>
<td>Sec. I, II, III</td>
<td>Figure 3(c)</td>
</tr>
</tbody>
</table>

Figure 2 Map of inundation area and evacuation-planning zone (EPZ) in Franklin County.
By the request of the county representatives, the following disclaimers are made: “The inundated areas shown on these maps reflect an event of an extremely remote nature. These results are not in any way intended to reflect upon the integrity of the Deerfield River Project. Depicted boundaries are approximate; these shapefiles are intended for planning use only, and are not intended for survey or engineering use.” The notes were found on the original maps or were explicitly noted in communications with the representatives.

**Trip Generation**

Trip generation is the first step in the conventional four-step transportation forecasting process including trip production and trip attraction. Trip generation predicts the number of trips originating in or destined for a particular TAZ. The original model’s generation step was completed by the Franklin Regional Council of Governments. The following sections describe how the modified productions and attractions are calculated. The modified productions and attractions are based off the data obtained from Franklin County.

**Productions and Attractions**
In the case of a flood caused by a dam failure, there are two major features above all others that must be understood before creating a transportation model. That is the warning time and the bounds of the inundation area. It is never easy to know either one precisely. In this project, the nature of the dam failure is assumed as an instantaneous dam failure. An instantaneous dam failure is a sudden failure that constitutes the most adverse conditions; it allows for prescribing upper bounds for expected damages. In the trip production process, normal trips will be reduced and evacuation trips will be increased. The attractions for evacuees are shelters or friends and families’ homes.

When a flood evacuation order is given, people will take some time to make a decision on when they think they will need to leave the area. The amount of time that people take to evacuate may be derived from the perception of danger. This perception may be influenced by who is ordering the evacuation or the distance to the dam. In some situations, people living downstream may leave before the evacuation order is given.

Table 2 gives the percentage of each TAZ’s area that is contained in the EPZ. These numbers will be used to calculate the evacuation productions. It is worth noting that TAZ 41 and 66 are totally inundated. The trip production rate is based on the percentage of vehicles used to evacuate. Families may use multiple vehicles to evacuate.

During an emergency, planners care more about evacuation trips than normal traffic. Estimation of evacuation productions for each TAZ is an important step in the trip production process. The first assumption is that people will take all of their vehicles to evacuate. People may want to pack as many things as possible, and they do not want their cars to be flooded. This implies that the evacuation rate across the population in the inundated areas is 100% (i.e., every resident in the EPZ evacuates). On average, the capacity of a vehicle was assumed to be four seats per vehicle. This method is shown below:

\[
\text{EvacP} = \alpha \times \% \text{Flooded} \times \text{Vehicles} + \beta \times \% \text{Flooded} \times \text{TE} + \text{Buses}
\]  

(1)

Where:

- \(\text{EvacP}\) = Evacuation production
- \(\alpha, \beta\) = Parameters
- \% Flooded = Percent of TAZ in the EPZ
- \text{TE} = Total Employment
- \text{Buses} = Number of extra buses required to evacuate schools
It is more difficult to predict where people will go during a flood evacuation. In this project, shelters are available across Franklin County. There are 126 shelters available in the area; the maximum available capacity is 61,615. Among these there are 22 shelters in the inundation area; these are not usable for evacuees. The non-available capacity is about 9,490. The estimated number of residents that need to be evacuated is around 11,000. A simple calculation tells us that ample space is available for the evacuees. Though there are enough shelter spaces for evacuees, some portion of people may not choose shelters as destinations to evacuate. Instead, they might have friends and relatives’ homes available to them. A new method is developed to determine the number of attractions. The attractions are balanced to the productions. The number of evacuation attraction is obtained from the following equation:

\[
\text{EvacA} = \gamma \ast \text{ShelterSpace} + \delta \ast (1 - \%\text{Flooded}) \ast \#\text{HH}
\]  

(2)

Where:

\[
\gamma, \delta = \text{parameters}
\]

\[
\text{ShelterSpace} = \text{Available shelter space}
\]

\[
\#\text{HH} = \text{Number of households in the TAZ}
\]

**Trip Distribution**

The trip distribution step has three major components: finding the shortest path between all of the centroids, obtaining the production-attraction (PA) matrix, and converting the PA matrix into an origin-destination (OD) matrix.

**Shortest Path**

The original regional model only used roads that had a functional class greater than one. Because the network is divided into several parts by the end of the evacuation, several local roads were added into the model to allow people to access other areas. The characteristics of these local roads took on the characteristics of the smallest modeled road in the original regional model. A set of links was also added outside of the county that would simulate people needing to go to the other side of the country by driving around the flooded area. These travel times were estimated using another mapping program. The shortest paths from all of the origins to all of the destinations were calculated based on free flow speeds using the Bureau of Public Roads (BPR) function.

**Obtaining the PA Matrix**

The number of trips produced and attracted to and from each zone was reviewed in an earlier section. Using these values along with the travel times estimated from the previous step, the production and attraction matrix was obtained by implementing the gravity model. The gravity model is commonly used in transportation planning. This model takes the form of:

\[
T_{ij} = \frac{P_i \ast A_j \ast f(C_{ij})}{\sum_{j=1}^{n} A_j \ast f(C_{ij})}
\]  

(3)

Where:

\[
P_i = \text{Productions of zone } i
\]

\[
A_j = \text{Attractions of zone } j
\]

\[
C_{ij} = \text{Travel cost from zone } i \text{ to } j \text{ (in this case free flow travel time)}
\]

\[
f(C_{ij}) = \text{Friction-factor from zone } i \text{ to } j \text{ as a function of } C_{ij}
\]

Franklin County used a friction factor table for its regional model. The amount of trips for each of the four trip types was calculated. The PA matrix was turned into an origin-
destination (OD) matrix using an algorithm in TransCAD. This algorithm accounts for the mismatches between productions/attractions and origins/destinations. During this algorithm, the occupancy of the vehicles taking each type of trip was taken into account.

Trip Assignment

Trip assignment is the last step of the whole process. The progressive nature of the flood has been taken care of by using a staged evacuation of four periods. In each period, a static traffic assignment was used. The static assignment treats the demands and capacities of the network as fixed and constant over the course of a day or several hours. Another implication in a static traffic assignment is that vehicles will finish their trips within the period they are generated. The function used is the deterministic user equilibrium method. This closely follows Wardrop’s first principle that states, “The journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route. Each user non-cooperatively seeks to minimize his cost of transportation” (8). The volume delay function (VDF) used was the Bureau of Public Roads (BPR) function (9). The BPR function takes the form of:

\[ t(v_i)_{BPR} = t_{f,i} \cdot \left(1 + \left(\frac{v_i}{c_i}\right)\right) \]

Where:
- \( t_{f,i} \) = free flow travel time on link \( i \)
- \( v_i \) = volume on link \( i \)
- \( c_i \) = capacity of link \( i \)
- \( \alpha_i \) = parameter

This function determines how the travel time on the links change as the volume approaches (or exceeds) the capacity of the link. As the \( \alpha \) term increases the speed at which the link becomes congested increases. \( \alpha \) changes for each link depending on the link’s individual characteristics. These values ranged from 0.15 to 2.0 for the Franklin County data.

ANALYSIS AND RESULTS

As noted in the previous section, the model was run for each of the four staged evacuation periods. Each of the four periods provides similar results. The main differences lay in the severity of some critical segments for different evacuation periods when more people need to be evacuated.

General Results

As was previously mentioned, a four-staged evacuation period was carried out in this study to account for the dynamic development of flood. The underlying mechanism behind the modeling is that the flood runs upstream to downstream after the Harriman Dam breaks and takes time to get to different points along the Deerfield River. There are two evacuation options, with some additional variations. The residents can all evacuate instantly after the dam has failed or they can leave in a progressive manner. Arguments can be made for each of the methods, but through talks with Franklin County representatives, the second method was chosen. The flood takes approximately six hours to reach the border between Franklin and Hampshire County. The flood joins the Connecticut River at the fifth hour after the dam breaks, then accelerates; it only takes one hour to get to the southern border of Franklin County. The two-hour time block is chosen due to the consideration of the average trip length in each period. In order to make a connected
network, some local roads are activated and used in the analysis. In addition, some virtual links were created to include those who want to go to the other side of the county but cannot go through the inundated areas. These links help the algorithm converge.

*Period 08:00am – 10:00am (Section I)*

In this period, people living in the first section of the EPZ in the first two hour time block after the dam breaks need to be evacuated before the dam really breaks. An overview showed us that not many people will need to be evacuated from this section of the EPZ. Therefore, we expect less congestion from the TransCAD results. The assignment results are shown in Figure 4. The weight of the line denotes the volume on the road, with thick lines representing large volumes, and the color of the line representing the volume over capacity (v/c) ratio with green showing a low v/c and a red line showing a high v/c. A close-up of some congested areas is shown in Figure 4. The v/c ratio is still lower than one, at around 0.5 to 0.75, which is acceptable.

![Figure 4 Close-up of a relatively congested area (Period 1| Section I evacuating| All roads open)](image.png)

*Period 10:00 AM – 12:00PM (Period 2)*

In this period, it is assumed that the evacuation in the previous period has been completed and the first section has been flooded. Correspondingly, the inundated roads and bridges in the first section have been disabled and they are no longer usable. The results with a fine level of detail can be seen in Figure 5. It is not difficult to see that the generated results look similar to the results from last period. The critical locations remain the same and the highest v/c ratio is still lower than one.
Wang, H., Andrews S., and Collura, J.

Figure 5 Close up view of some segments carrying a high V/C ratio (Period 2| Section II evacuating| Section I roads disabled).

Similar to the first period, there should not be problems with evacuating during the second period. The section of roads that have been disabled (Section I) are not heavily used by the region as a whole or by the potential evacuees that reside in the inundation area or EPZ. Notifications relaying information to the public should be placed at important locations, such as on Route 2 westbound towards Shelburne Falls. This notification should be placed before Cooper Lane Road, in order to allow people a place to detour. Traffic heading towards Berkshire County may detour up to Route 9 in Vermont, but should avoid using Interstate 91, which will become congested in the next few hours.

Water crossings that will be cut off include Depot Street in Monroe Bridge, Tunnel Road near Hoosac Tunnel, River/Zoar Road roughly one mile west of Zoar, Route 2 west of Charlemont, Route 8A in Charlemont, and Route 2 north of Shelburne Falls (east and west side of the meander).

**Period 12:00PM – 14:00PM (Period 3)**

Applying the same logic to this period it is assumed that the evacuation in the previous two periods (08:00 AM – 10:00 AM; 10:00 AM – 12:00 PM) have been completed. Thus, the flood has arrived to the time mark of 12:00 PM. The roads and other road facilities in the first two sections (I and II) are disabled in this period. As expected, the increased number of closed roads and bridges leaves evacuees with fewer potential evacuation routes. More severe congested locations are shown which has been verified from the results in Figure 6, Figure 7 and Figure 8.

This section begins the times where problems may develop for evacuees. The Interstate 91 bridge is no longer an option so people must use Route 5/10 to access Greenfield. This congestion decreases the mobility of the evacuees that will be trying to reach shelters along with people that will be making their normal trips. If it is desired to keep traffic moving in this pattern a variable message sign or police patrol should be placed before Exit 24 of Interstate 91. Likewise, the bridge to Interstate 91 should also be closed (at Exit 25) to ensure traffic does not try to cross the bridge if is still above water. Other water crossings that the bridges should be closed (if
they are not underwater) include Bridge Street in Shelburne Falls, Route 2 north of Shelburne Falls, and Upper Road next to the Interstate 91 bridge.

Figure 6 Traffic assignment results for period (Period 3| Section III evacuating| Section I and II roads disabled).

Figure 7 Finer view of some relatively congested locations (Period 3| Section III evacuating| Section I and II roads disabled).
Figure 8 Another finer view of some relatively congested locations (Period 3 | Section III evacuating | Section I and II roads disabled).

Period 14:00 PM – 16:00 PM (Period 4)

No evacuations in Franklin County take place during this period, though citizens of Hampshire County should now begin evacuating. The network inside Franklin County has been bifurcated such that people can no longer cross the river and must use the virtual links to access the other half of the network. This, along with some close ups of congested areas, is shown in Figure 9, Figure 10, and Figure 12.

Figure 10 Plots of Veh HH and Pop HH.
Figure 12 plots the autos per household (Auto/HH) and household size against sixty-seven internal TAZs. Autos per household are plotted as a green, solid line while population per household is plotted as a red, dotted line. It is apparent that there are two TAZs whose autos per household rates are lower than one; they are TAZ 19 and 35, which are shown in Figure 13. From Figure 13, it is clear that TAZ 19 is outside the EPZ and TAZ 34 partially inundated. Theoretically, people living in TAZ 19 do not have to be evacuated since they will not be inundated but people living in TAZ 35 have to be evacuated because it is partially inundated. Assuming the average vehicle has four seats and the vehicles are filled to capacity, there should be sufficient space to evacuate everyone.

Figure 13 TAZs with a low vehicle per household density.

### Table 3 Critical Locations

<table>
<thead>
<tr>
<th>Time</th>
<th>Max V/C</th>
<th>Street</th>
<th>Street</th>
<th>Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00-10:00</td>
<td>1.25</td>
<td>Route 2/2A</td>
<td>from Mohawk Trail</td>
<td>to River St.</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>Ramp from R. 2 to I91</td>
<td>from I91 North (Exit 26)</td>
<td>to Mohawk Trail</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>Ramp from I91 to R.2A</td>
<td>from Mohawk Trail</td>
<td>to I91 South</td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>Route 5/10</td>
<td>from Deerfield St.</td>
<td>to Bank Row St.</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>Hope St.</td>
<td>from Hope St.</td>
<td>to Main St.</td>
</tr>
<tr>
<td>10:00-12:00</td>
<td>2.0</td>
<td>Ramp from I91 to R.2A</td>
<td>from I91 North (Exit 26)</td>
<td>to Mohawk Trail</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>Ramp from R.2 to I91</td>
<td>from Mohawk Trail</td>
<td>to I91 South</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>Route 5/10</td>
<td>from Deerfield St.</td>
<td>to Bank Row St.</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>Meridian St.</td>
<td>from Meridian St.</td>
<td>to Deerfield St.</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>Mill Village Rd.</td>
<td>from Old Main St.</td>
<td>to Mill Village St.</td>
</tr>
<tr>
<td>12:00-14:00</td>
<td>2.0</td>
<td>Colrain Rd.</td>
<td>from Thayer Rd.</td>
<td>to Colrain St.</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>Route 5/10</td>
<td>from S Deerfield Bypass</td>
<td>to Federal St.</td>
</tr>
</tbody>
</table>
Because the network becomes cut into two pieces, this period represents the network until the region has recovered from the flood. People normally using Interstate 91 for access into and out of Greenfield now must find an alternative route. After the flood has eliminated that choice, they end up using Route 63, a much smaller route to the east, paralleling Interstate 91 on the other side of the river. The only access point into Greenfield becomes Route 10 to the north. The usual point of access to Greenfield from the east is Route 2. Unfortunately, Route 2 is cut off, and therefore people only have the choice of Route 10. This is not a major problem during the two-hour period examined in this study, but if people still need to get into Greenfield in spite of the flood, this will cause notable problems.

In this period all water crossings now are disabled. These include Route 5/10 bridge in Cheapside, Montague City Road in Montague City, Turners Falls Road in Turners Falls, Route 2 in Riverside, Interstate 91 north of Greenfield, and Route 116 in Sunderland. In advance of these locations signs should be erected or a patrol place to notify people not to attempt to cross the water.

In this time period people should already be at shelters or their friends and families’ homes and the main focus should be to prevent people from accessing inundated areas. Prior to this time period support equipment may need to be separated to each side of the water in order to provide support to the citizens on each side of the river. In most cases the distance to an area outside of the inundation zone is not far away. The residents only challenge past getting out of the flood plain is getting to a shelter. This portion of the trip is not as critical as the departure from the inundation zone.
Figure 9 Traffic assignment results for period (Period 4| No evacuations | All sections of roads disabled).

Figure 10 Finer view of roads carrying more traffic during evacuation (Period 4| No evacuations | All sections of roads disabled).
Figure 11 Route 10 connecting Interstate 91 to Route 63 (Period 4 | No evacuations | All sections of roads disabled).

Figure 12 Plots of Veh/HH and Pop/HH.

Figure 12 plots the autos per household (Auto/HH) and household size against sixty-seven internal TAZs. Autos per household are plotted as a green, solid line while population per
household is plotted as a red, dotted line. It is apparent that there are two TAZs whose autos per household rates are lower than one; they are TAZ 19 and 35, which are shown in Figure 13. From Figure 13, it is clear that TAZ 19 is outside the EPZ and TAZ 34 partially inundated. Theoretically, people living in TAZ 19 do not have to be evacuated since they will not be inundated but people living in TAZ 35 have to be evacuated because it is partially inundated. Assuming the average vehicle has four seats and the vehicles are filled to capacity, there should be sufficient space to evacuate everyone.

![Figure 13 TAZs with a low vehicle per household density.](image)

<table>
<thead>
<tr>
<th>Time</th>
<th>Max V/C</th>
<th>Street</th>
<th>Street</th>
<th>Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00-10:00</td>
<td>1.25</td>
<td>Route 2/2A</td>
<td>from Mohawk Trail</td>
<td>to River St.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Ramp from R. 2 to I91</td>
<td>from I91 North (Exit 26)</td>
<td>to Mohawk Trail</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Ramp from I91 to R.2A</td>
<td>from Mohawk Trail</td>
<td>to I91 South</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>Route 5/10</td>
<td>from Deerfield St.</td>
<td>to Bank Row St.</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>Hope St.</td>
<td>from Hope St.</td>
<td>to Main St.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Max V/C</th>
<th>Street</th>
<th>Street</th>
<th>Street</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Ramp from I91 to R.2A</td>
<td>from I91 North (Exit 26)</td>
<td>to Mohawk Trail</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Ramp from R.2 to I91</td>
<td>From Mohawk Trail</td>
<td>to I91 South</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Route 5/10</td>
<td>From Deerfield St.</td>
<td>to Bank Row St.</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Meridian St.</td>
<td>from Meridian St.</td>
<td>to Deerfield St.</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Mill Village Rd.</td>
<td>from Old Main St.</td>
<td>to Mill Village St.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Max V/C</th>
<th>Street</th>
<th>Street</th>
<th>Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00-14:00</td>
<td>2.0</td>
<td>Colrain Rd.</td>
<td>from Thayer Rd.</td>
<td>to Colrain St.</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>Route 5/10</td>
<td>from S Deerfield Bypass</td>
<td>To Federal St.</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>Route 116</td>
<td>from Conway Rd.</td>
<td>To Sunderland Rd.</td>
</tr>
</tbody>
</table>
FINDINGS AND CONCLUSIONS

The previous section discussed the results of the analysis conducted for Franklin County in the event of flood evacuation. This flood evacuation modeling was based on the traditional four-step planning process with some assumptions. This analysis leads to the following conclusions:

- People will be able to evacuate in response to a flood evacuation order given two hours before the flood arrives.
- The four-staged evacuation is able to represent the dynamic development of the flood (from where the dam breaks to where the flood reaches the downstream end of the inundation area) and generates reasonable results.
- There are two TAZs where the Veh/HH is less than one. Hence, ridesharing or carpooling may be needed to evacuate everyone in these TAZs.
- The shelters are able to provide enough space for evacuees.
- The elderly, disabled, and people living in the low-lying areas should be encouraged to evacuate early.

Recommendations

There are several possible solutions that can help ensure an orderly evacuation.

- During the first evacuation period (08:00am – 10:00am), encourage people to use major routes I-91, Route 2/2A and Route 5/10 etc. to increase evacuation speed and efficiency since no roads are disabled in this period.
- At the identified critical locations, police officers and extra supplies such as gas and food can help evacuees to keep traffic moving smoothly. In addition, moving maintenance vehicles are recommended to help those stranded vehicles which might jam some segments of evacuation routes and decrease evacuation efficiency.
- For those who do not have to be evacuated, encourage them to reduce their normal trips such as traveling, or shopping etc. during the evacuation to reduce traffic load for some critical locations.
- It has been observed that traffic can build up at the on- and off-ramps connecting I-91 to Route 2/2A and Route 5/10. Close monitoring of these locations is recommended to ensure a quick release of queued traffic.
REFERENCES


