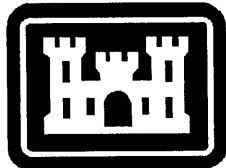

FLOOD PLAIN MANAGEMENT SERVICES PROGRAM

**MARTINS BROOK FLOOD REDUCTION
STUDY**

NORTH READING, MASSACHUSETTS

AUGUST 2004



**US Army Corps
of Engineers
New England District**

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MARTINS BROOK FLOOD REDUCTION STUDY
NORTH READING, MASSACHUSETTS

BY
DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS 01742-2751

AUGUST 2004

MARTINS BROOK FLOOD REDUCTION STUDY
NORTH READING, MASSACHUSETTS

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NORTH READING, MASSACHUSETTS

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Martins Brook, North Reading, Massachusetts
Flood Reduction Study

1. Purpose of Study

The purpose of this study is to investigate the cause(s) of flooding at Burroughs Road and Lakeside Boulevard (both located along the shores of Martins Pond in North Reading) and to identify the impacts of making various structural modifications for the purpose of reducing flooding of these roads. The study focuses on relatively rare floods, those with a 10-year recurrence interval and greater.

2. Authority

This study was conducted at the request of the Commonwealth of Massachusetts Executive Office of Environmental Affairs under the Corps of Engineers' Flood Plain Management Services (FPMS) program. The FPMS program is authorized under Section 206 of the Flood Control Act of 1960 PL 86-645. This program allows the Corps to provide planning and technical assistance to states, regional authorities, and communities in matters relating to flooding and flood plain management.

3. Description of Study Area

The 14.9 square-mile Martins Brook watershed (see Figure 1) is a tributary to the Ipswich River, with the confluence with the Ipswich River located in the Town of North Reading, Massachusetts. The watershed includes portions of the towns of Andover, North Reading, North Andover, and Wilmington. Martins Brook originates at Martins Pond in North Reading, and flows southwest through North Reading, then through Wilmington, and then again through North Reading where it eventually joins the Ipswich River. The largest tributary to Martins Brook is the Skug River, which drains an area of 7.2 square miles before discharging to Martins Pond. The outlet of Martins Pond is considered to be the beginning of Martins Brook. Drainage area of the Ipswich River just upstream of its confluence with Martins Brook is 22.9 square miles.

4. Problem Identification and Possible Causes

According to Mr. Michael Soraghan, Town Engineer for the Town of North Reading, floodwaters in the vicinity of Martins Pond rise to such an extent as to cause portions of Burroughs Road and Lakeside Boulevard to become submerged, forcing closure of the roads for safety reasons, sometimes for extended (multi-day) periods of time. These roads serve as the only legal access to approximately 100 residences and the town's Lakeside Water Treatment Plant. These roads begin to get overtopped when the water surface of Martins Pond reaches an elevation of 78.0 feet above National Geodetic Vertical Datum of 1929 (NGVD) according to the FEMA cross-sections of Burroughs Road. Other information indicates that flooding of Burroughs Road occurs at a lower elevation. Mr. Soraghan has stated that there was 18 inches of flooding over Burroughs Road during the spring 2001 flood. With a high watermark measured during this flood

Figure 1: Martins Brook Sub-Watersheds

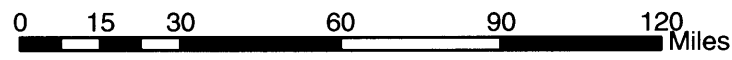
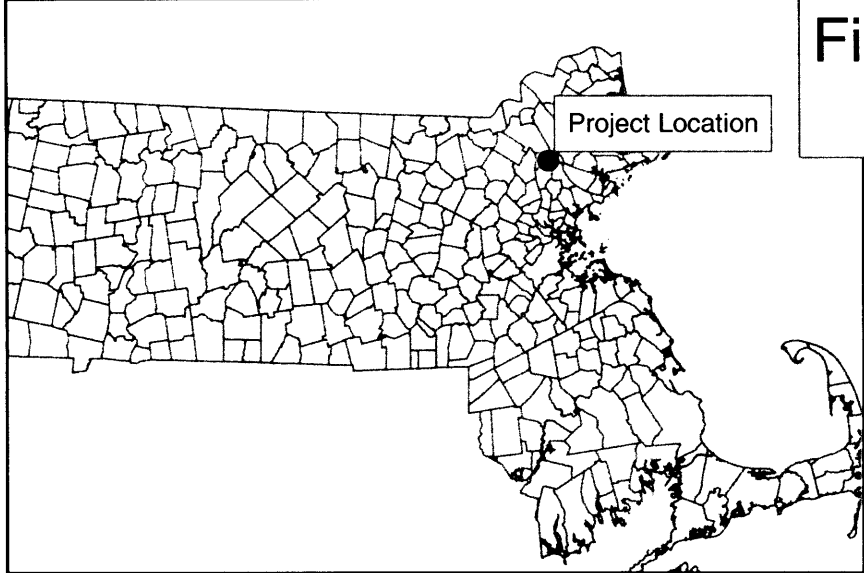
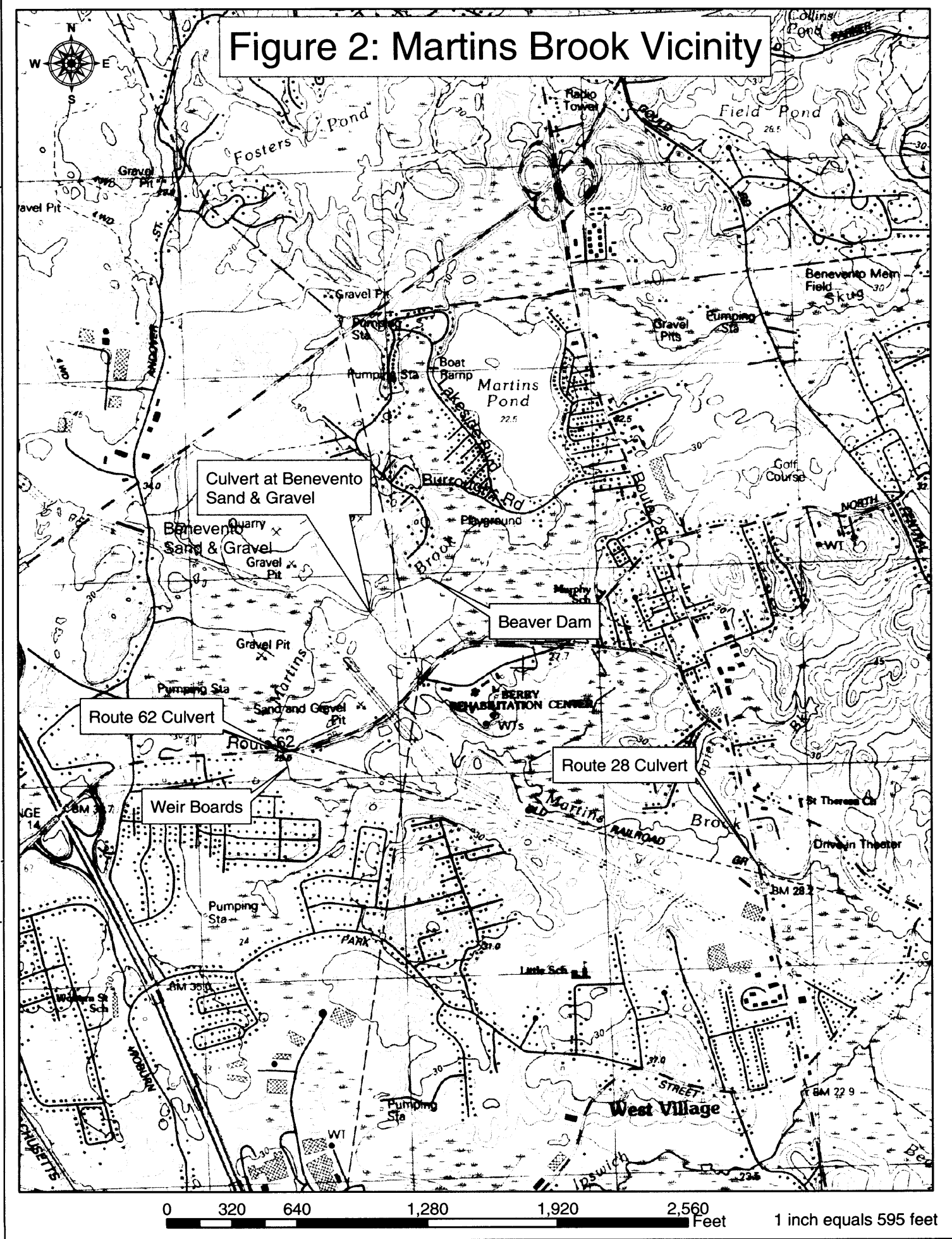


Figure 2: Martins Brook Vicinity



at 78.6 feet NGVD (“Martins Pond Assessment Study” by Merrimack College and Malcolm Pirnie Engineers, March 2003), that would indicate that flooding of Burroughs Road begins at 77.1 feet NGVD. Mr. Larry Soucie, a Martins Pond resident, who also happens to be a Hydraulic Engineer employed by another private engineering firm, has provided information indicating that flooding at the intersection of Burroughs Road and Lakeside Boulevard begins at an elevation lower than 77.3 feet NGVD. However, for purposes of this report, an investigation of relatively rare flood events (10-year recurrence interval and greater), we have assumed that flooding begins at the FEMA-surveyed elevation of 78.0 feet NGVD. Examination of the flood profiles from an advance copy of the Federal Emergency Management Agency’s Flood Insurance Study (FIS) for the Town of North Reading (scheduled to be effective on June 16, 2004) indicates that this happens at approximately the 10-year and greater recurrence intervals. According to these profiles, depth of flooding over Burroughs Road is 0.2 feet, 1.3 feet, 1.9 feet, and 3.6 feet for the 10-, 50-, 100-, and 500-year recurrence intervals, respectively.

Several sources were used to identify potential causes of flooding along Burroughs Road and Lakeside Boulevard including the flood profiles of the new North Reading FIS and those shown in the Town of Wilmington’s FIS (revised January 18, 1989), and the “Martins Pond Assessment Study” referenced above (see Figure 2 for a detailed map of the study area). Potential causes of flooding were also identified through conversations with various parties including Mr. Soraghan, Mr. Peter Richardson (Hydraulic Engineer with the engineering firm of Green International, the firm that prepared the new North Reading FIS revision); and Mr. Soucie. The hydraulic restrictions identified as potentially impacting Burroughs Road and Lakeside Boulevard (during minor and/or major floods) include:

1. the Salem Street (Route 62) crossing of Martins Brook in the Town of Wilmington;
2. the Benevento culvert and embankment in Wilmington;
3. the Main Street (Route 28) crossing of lower Martins Brook in North Reading;
4. the Martins Brook weir boards owned by the Town of Wilmington, located immediately downstream of Route 62;
5. beaver dam(s) located along the channel of Martins Brook; and,
6. the Martins Brook channel immediately south of Burroughs Road, thought to have lost hydraulic capacity due to sediment deposition and/or vegetation.

5. Methodology

Hydraulic and hydrologic models set up by the private engineering firm of Green International (as part of their efforts in preparing the new Flood Insurance Study (FIS) for the Town of North Reading) were adopted for use in this study.

Green International’s steady-flow HEC-RAS hydraulic model (using HEC-RAS version 3.0.1) was converted to an unsteady-flow HEC-RAS hydraulic model (using HEC-RAS version 3.1.1). The U.S. Army Corps of Engineers chose to model Martins Brook

flooding using an unsteady-flow hydraulic model instead of a steady-flow hydraulic model because an unsteady flow model is believed to produce superior results in comparison to those from a steady flow modeling in areas where wetland and pond storage is significant (as is the case for Martins Brook). Additionally, unsteady flow modeling can be used for such things as determining the length of time that a road would be flooded under various scenarios, something considered highly important at Burroughs Road. The unsteady-flow modeling capability of HEC-RAS was not yet available when Green International began their modeling, and therefore was not used by Green International.

The geometric coding developed by Green International for their steady flow hydraulic model was incorporated into the new unsteady flow model with a few small changes. Changes were made to the shape of Martins Pond cross-sections, so as to better reflect the volume of storage in Martins Pond at various water surface elevations as had been determined by Green International. Additional changes include the modeling of Burroughs Road as a weir with "gates" (to allow low flows to pass under the road crest) instead of as a bridge, and the inclusion of several extra cross-sections at the downstream end of the model (along the Ipswich River) in order to reduce starting water surface elevation impacts on the subject reach. Unobstructed flow at all culverts was assumed.

Since there are no stream flow gages on Martins Brook, stream flows for various recurrence intervals were determined by rainfall-runoff modeling of Martins Brook sub-watersheds. The Corps converted the HEC-1 rainfall-runoff hydrologic model, developed by Green International for the various sub-watersheds, into a HEC-Hydrologic Modeling system (HEC-HMS) model. Seven sub watershed areas (refer to Figure 1) were modeled, with four of the sub watersheds being located upstream of Burroughs Road. Both HEC-1 and the HEC-HMS model use rainfall amounts (rainfall depths obtained from U.S. Weather Bureau's Technical Paper No. 40, except for that for the 500-year recurrence interval which was obtained by extrapolating values from the other recurrence intervals) and temporal distribution, "Curve Numbers" (which reflect sub watershed soil types, land use, and antecedent moisture conditions), and the physical features of the sub watersheds in order to determine sub watershed flow hydrographs. Both models produced comparable results for each of the various recurrence interval floods (10-year, 50-year, 100-year, and 500-year recurrence intervals). The 25-year recurrence interval was additionally examined by the Corps.

The HEC-HMS model was used only to obtain sub watershed flow hydrographs for the various recurrence intervals. It was not used to route inflow hydrographs through storage areas. The HEC-HMS sub watershed flow hydrographs were incorporated into the unsteady HEC-RAS models at the appropriate inflow reaches. The model was run for each of the five recurrence intervals studied. For each recurrence interval, the starting water level at the downstream end of the HEC-RAS model, located downstream of the confluence of Martins Brook with the Ipswich River, was set at a fixed elevation, equal to that of the flood level for the Ipswich River as published in the FIS for North Reading. (Note: flood profiles for the Ipswich River in North Reading were not revised as part of the recent North Reading FIS revision). The starting water surface elevations of Martins Pond and the wetlands upstream of Route 62 were set at 73.8 feet above National Geodetic

Vertical Datum (NGVD) and 73.55 feet NGVD, respectively. The starting elevation for Martins Pond was that shown (22.5 meters) on the U.S. Geological Survey's Reading 7.5-minute topographic map. For the Route 62 wetlands, the starting water surface was nearly 0.5 feet over the stoplogs of the Wilmington weir structure, and nearly to the top of concrete of the weir structure.

6. Unsteady-Flow Modeling Results

Hydraulics of Existing Condition

Unsteady-flow HEC-RAS modeling was performed for the 10-year, 25-year, 50-year, 100-year, and 500-year recurrence interval floods to determine peak water surface elevations associated with the existing condition, and results were compared to high watermarks at various reaches of Martins Brook. In all model runs of the existing condition, it was assumed that all culverts were unobstructed. Model results appeared reasonable when compared to the high watermarks at various locations along Martins Brook, and no additional calibration was made beyond that done by Green International on the original steady flow model that was converted to an unsteady-flow model.

Unsteady-flow model results for the existing condition for floods of various recurrence intervals are shown on Figure 3, and listed in Table 1 at various locations along Martins Brook and Martins Pond.

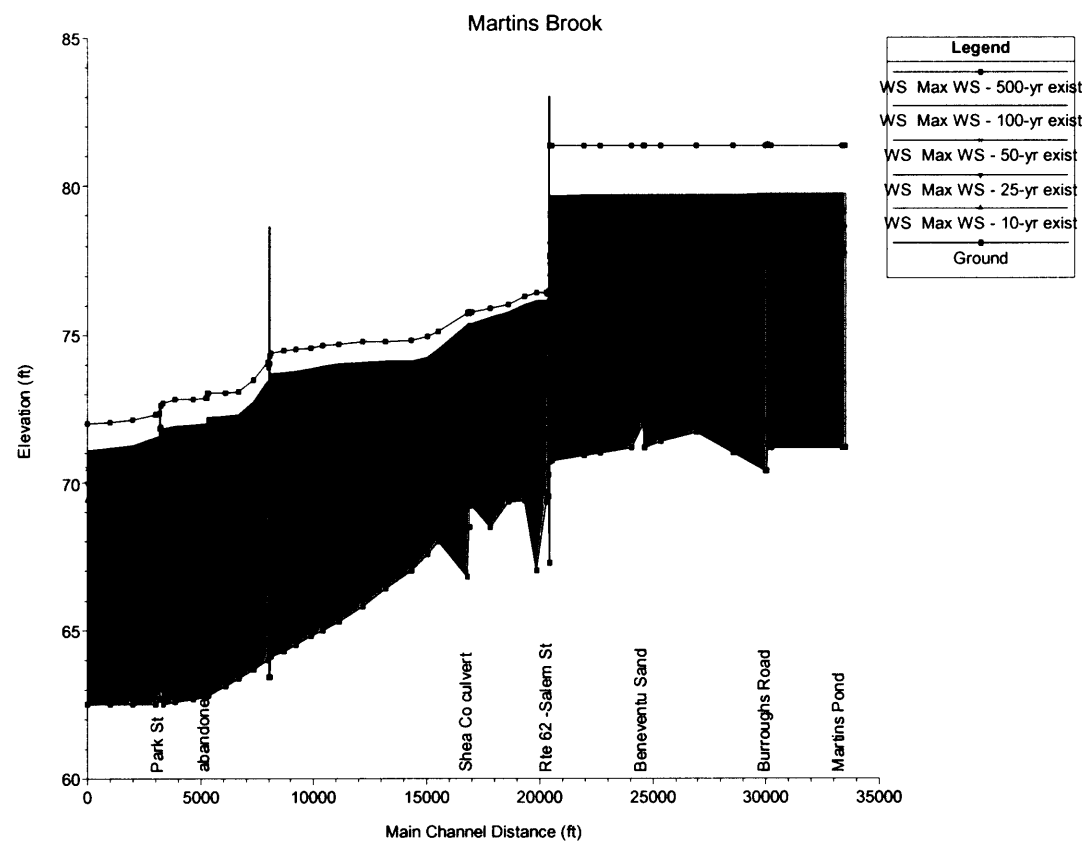


Figure 3- Peak Flood Elevations for Martins Brook for Various Recurrence Intervals (Results of Unsteady-Flow Modeling)

**Table 1 – Peak Water Surface Elevations (feet above NGVD)
Along Martins Brook at Various Locations with the Existing Condition**

Recurrence Interval	At Martins Pond	Just upstream of Route 62 (Salem Street)	Just upstream of Route 28 (Main Street)
10-year	77.8	77.1	71.8
25-year	78.6	78.1	72.5
50-year	79.2	79.1	73.0
100-year	79.7	79.7	73.7
500-year	81.4	81.4	74.4

Examination of Figure 3 and Table 1 yields conclusions as to probable hydraulic constrictions impacting Burroughs Road flood levels. These conclusions appear to be somewhat different from those made through examination of the Martins Brook flood profiles in the two Flood Insurance Studies (North Reading and Wilmington), developed using steady-flow hydraulic modeling. For all recurrence intervals examined, the unsteady flood profiles appear to indicate the only serious hydraulic restriction to be at Route 62,

with the flood profiles for the rarer floods (the 50-year, 100-year and 500-year floods) appearing as level “pools” that extend from Route 62 to Martins Pond and beyond. The unsteady flow analysis indicates that there is negligible hydraulic impact associated with the Benevento Sand and Gravel culvert/embankment, and only minor hydraulic impact from the Route 28 road crossing of Martins Brook. In addition, Burroughs Road does not appear to be a significant hydraulic constriction. (Note: There could be additional hydraulic restrictions at the more common flood events. This report only investigated flood events of 10-year recurrence interval and greater). Water surface elevations are approximately the same on either side of Burroughs Road under most recurrence intervals.

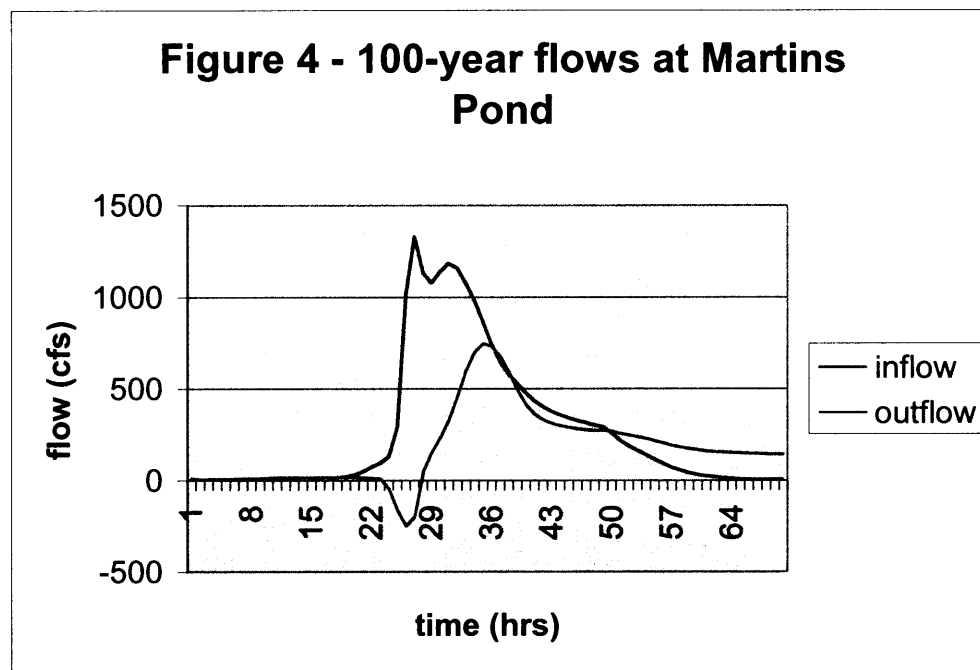
Hydrology of Existing Condition

Unsteady-flow HEC-RAS modeling was also used to determine the 10-year, 25-year, 50-year, 100-year, and 500-year recurrence interval flows at various locations with the existing condition. Table 2 lists the peak flows associated with the existing condition at various locations.

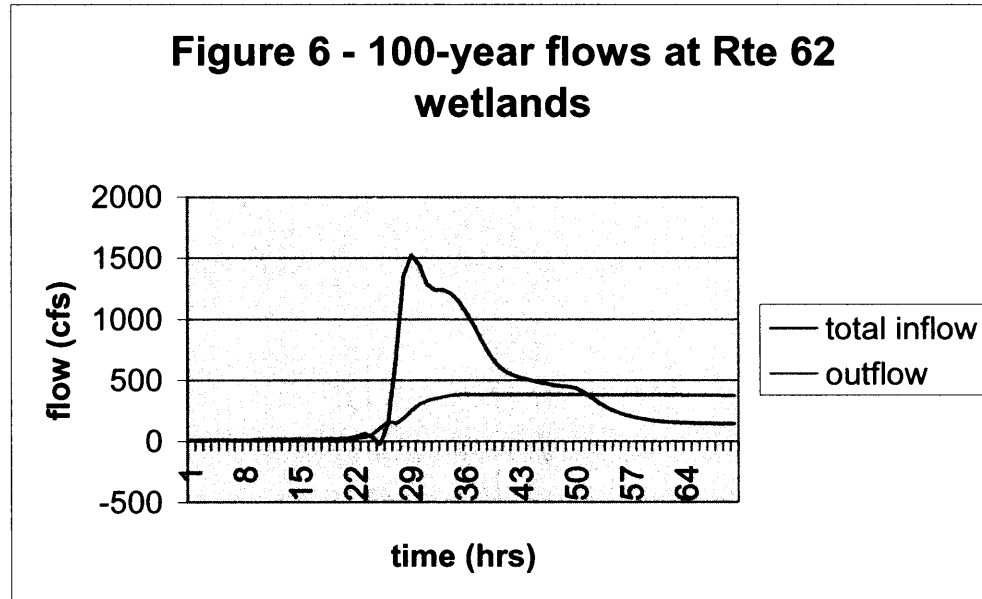
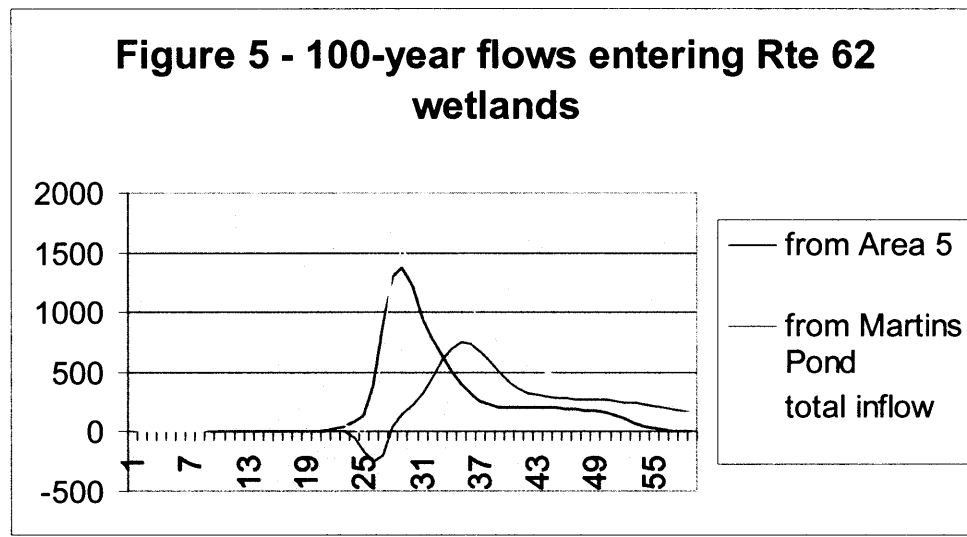
Table 2 – Peak Flows (cubic feet per second) Along Martins Brook at Various Locations with the Existing Condition

Recurrence Interval	Flow into Martins Pond	Flow out of Martins Pond	Flow out of Route 62 (Salem Street) wetlands	Just upstream of Route 28 (Main Street)
10-year	640	240	300	345
25-year	905	335	365	430
50-year	1145	465	385	500
100-year	1330	750	390	635
500-year	1725	875	425	780

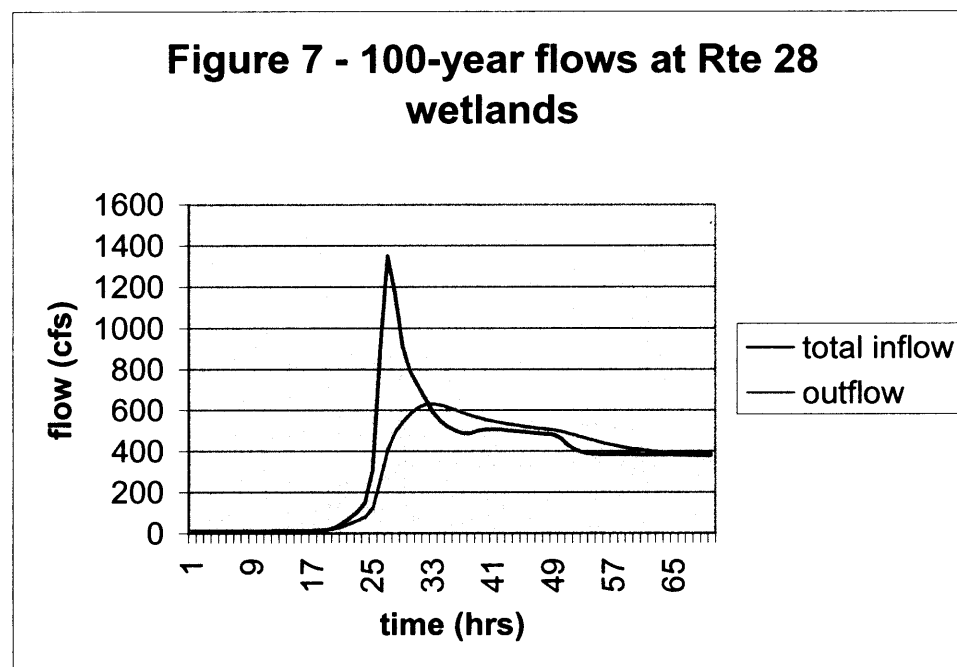
Examinations of findings presented in Table 2 indicate that peak flows out of Martins Pond are much less than flows into Martins Pond for all recurrence intervals examined. Figure 4 shows flows at Martins Pond for the 100-year recurrence interval.



A great amount of flow attenuation occurs in the Route 62 wetlands, although it is not readily apparent in an examination of the peak flows listed in Table 2, which, for some recurrence intervals, shows flows leaving the Route 62 wetlands greater than those leaving Martins Pond. The explanation for this apparent contradiction is that there is a large amount of additional flow entering into the wetlands from "Area 5", a five square-mile drainage area that enters the Route 62 wetlands downstream of Burroughs Road. Figure 5 shows inflows to the Route 62 wetlands from these two areas for the 100-year recurrence interval. Figure 6 shows the total inflow to the wetlands (from both Martins Pond and Area 5) and the outflow from the wetlands for the 100-year recurrence interval. The Route 62 wetlands do, in fact, serve to "dampen" flows from these two areas very significantly at all recurrence intervals.



A similar situation occurs between Route 62 and Route 28. Although peak flows at Route 28 are higher than at Route 62 (Table 2), there is a large wetlands between Routes 62 and 28 that greatly dampens peak flows. As with the wetlands upstream of Route 62, there is additional inflow from other areas entering Martins Brook into this reach, thus an examination of only Martins Brook flows does not paint a complete picture of the flood storage and flow dampening that occurs. The wetland between Route 62 and Route 28 plays a major role in reducing peak flows. Figure 7 illustrates the role of the Route 28 wetlands for the 100-year recurrence interval.



The unsteady-flow and steady-flow HEC-RAS models (used in FIS preparation) produced fairly comparable peak flow and water surface elevations for the area upstream of Route 62, including Burroughs Road. However, major differences in the magnitude of peak flows and the maximum flood elevations were noted for the lower reach of Martins Brook. The differences appear to be due to the fact that, unlike for the unsteady-flow model, flows used in the steady flow model (used in developing FIS flows and flood profiles) did not reflect the flow-reducing capability of the wetlands located between Routes 62 and 28. (Note: flows in the steady-flow hydraulic model did reflect the major flow-reducing capability of Martins Pond and the Route 62 wetlands, since routing of inflow hydrographs had been performed for these two storage areas in the HEC-1 model used to develop flows for the steady flow model. Routing of inflow hydrographs had not, however, been performed for the Route 28 wetlands). As a result, the peak flows (Figure 7, 100-year flows) and flood elevations of the unsteady-flow model are much lower than those of the steady flow model for the lower reach of Martins Brook. No significant flood damages are reported to occur in the lower reach of Martins Brook (downstream of Route 62), therefore the significance of the different findings of the two models may not be great.

Alternative Scenarios

Various flood reduction alternative scenarios were examined by using the unsteady-flow HEC-RAS model discussed above. Changes were made to the HEC-RAS geometry files to reflect possible flood reduction scenarios. Four alternatives were developed even though examination of the unsteady flood profiles for the existing scenario appeared to indicate that the only significant hydraulic constriction impacting Burroughs Road was Route 62. The four alternatives examined were:

1. Enlargement of the Route 62 (Salem Street) culvert;

2. Removal of the Town of Wilmington's weir, located just downstream of Route 62;
3. Removal of the culvert and embankment at Benevento Sand and Gravel;
4. Enlargement of the Route 28 (Main Street) opening.

Alternative 1 We investigated the enlargement of the box culvert under Route 62 since our examination of the existing scenario unsteady-flow modeling flood profiles indicated that Route 62 had a large impact on flooding at Burroughs Road. Route 62 culvert currently is an 11-foot-wide by 6.2-foot-high box culvert at the upstream end that transitions to two stone rectangular 3.5-foot-wide by 4.6-foot-high culverts in the downstream end. Cross-section area of the culvert opening at the upstream end is much greater (68 square feet), however, the area at the downstream end is only 32 square feet. (Unsteady-flow HEC-RAS modeling of the existing condition had been performed assuming the more constricted culvert opening at the downstream end of the road). The width of the culvert was selected to be 15 feet (versus the two 3.5-foot-wide openings modeled for the existing condition) with a height of approximately 5.3 feet and a cross-section area of the opening of approximately 79.5 feet. This is approximately 2.5 times the cross-sectional area of the existing culvert.

Alternative 2 We investigated the complete removal of the Town of Wilmington's weir, used to keep the level of water in the wetlands upstream of Route 62 higher than they would be otherwise, at least during normal conditions, in order to recharge the Town's nearby groundwater wells. Consideration of removal of the stoplogs inserted into the weir to raise water levels is being made, but complete removal of the entire weir structure serves to identify the maximum possible benefit of altering the opening at this structure.

Alternative 3 We investigated the complete removal of the culvert and embankment on the Benevento Sand and Gravel property. Consideration is reportedly being made of enlargement of the 5.5-foot diameter culvert under this road. Complete removal of the culvert and embankment serves to identify the maximum possible benefit of Benevento Sand and Gravel culvert enlargement.

Alternative 4 We investigated enlargement of the opening of the Route 28 (Main Street) arch culvert, converting it into a large box culvert. We've arbitrarily selected a width of 30 feet for this opening (currently 16 feet), with the top of the opening set to the height of the existing top of arch.

Results of unsteady-flow HEC-RAS modeling of the four alternatives are presented in Tables 3 through 7. Findings are presented at three locations: at Martins Pond/Burroughs Road, in the vicinity of the Route 62 wetlands, and in the vicinity of Route 28. For Martins Pond/Burroughs Road, the maximum water surface elevation that occurs in the model is listed, as well as the duration of flooding above elevation 78.0 feet NGVD (for purposes of this report, Burroughs Road flooding is assumed to begin at elevation 78.0), and above 79.0 feet NGVD. The maximum water surface elevation upstream of Route 62 is listed, as is the maximum flow just downstream of Route 62. The maximum water surface elevation upstream of Route 28 is listed. The locations and

parameters were selected because of the concerns at Burroughs Road, and the observation that the alternatives that may mitigate flooding at Burroughs Road, may also have negative impacts in downstream locations (by sending more water down Martins Brook at a quicker rate than that with the existing condition). Tables 3, 4, 5, 6, and 7 present these flows, elevations, and durations for the various alternatives, including the existing scenario.

**Table 3 – Results of Unsteady-Flow HEC-RAS Modeling for Martins Brook
– 10-Year Event**

Alt.	Max ws - Martins Pond	Hours > elev 78.0'	Hours > elev 79.0'	Max ws – u/s Rte 62	Max flow d/s Rte 62	Max ws u/s Rte 28
Existing	77.8	0	0	77.1	300	71.8
1	77.7	0	0	76.3	375	72.3
2	77.7	0	0	77.0	290	71.8
3	77.7	0	0	77.0	295	71.8
4	77.8	0	0	77.1	345	71.8

**Table 4 – Results of Unsteady-Flow HEC-RAS Modeling for Martins Brook
– 25-Year Event**

Alt.	Max ws - Martins Pond	Hours > elev 78.0'	Hours > elev 79.0'	Max ws – u/s Rte 62	Max flow d/s Rte 62	Max ws u/s Rte 28
Existing	78.6	27	0	78.1	365	72.5
1	78.6	20	0	76.8	535	73.5
2	78.6	30	0	78.2	315	72.4
3	78.6	27	0	78.1	365	72.5
4	78.6	27	0	78.1	365	72.5

**Table 5 – Results of Unsteady-Flow HEC-RAS Modeling for Martins Brook
– 50-Year Event**

Alt.	Max ws - Martins Pond	Hours > elev 78.0'	Hours > elev 79.0'	Max ws – u/s Rte 62	Max flow d/s Rte 62	Max ws u/s Rte 28
Existing	79.2	41	21	79.1	385	73.0
1	79.1	26	4	77.4	690	74.2
2	79.3	50	25	79.2	340	72.9
3	79.2	41	20	79.0	385	73.0
4	79.2	41	21	79.1	385	73.0

**Table 6 – Results of Unsteady-Flow HEC-RAS Modeling for Martins Brook
– 100-Year Event**

Alt.	Max ws - Martins Pond	Hours > elev 78.0'	Hours > elev 79.0'	Max ws – u/s Rte 62	Max flow d/s Rte 62	Max ws u/s Rte 28
Existing	79.7	51	33	79.7	385	73.7
1	79.4	29	13	77.9	825	74.7
2	79.8	63	41	79.8	365	73.7
3	79.7	51	33	79.7	385	73.7
4	79.7	51	33	79.7	385	73.6

**Table 7 – Results of Unsteady-Flow HEC-RAS Modeling for Martins Brook
– 500-Year Event**

Alt.	Max ws - Martins Pond	Hours > elev 78.0'	Hours > elev 79.0'	Max ws – u/s Rte 62	Max flow d/s Rte 62	Max ws u/s Rte 28
Existing	81.4	81	63	81.4	425	74.4
1	80.6	54	42	80.6	895	75.1
2	81.5	>90	85	81.5	415	74.4
3	81.4	81	63	81.4	425	74.4
4	81.4	81	63	81.4	425	74.3

Analysis of Results

Examination of the results presented in Tables 3 to 7 indicate that none of the alternatives examined would prevent flooding along Burroughs Road and Lakeside Boulevard, however, minor benefits were associated with Alternative 1. Results for each of the alternatives is presented below.

Results for Alternative 1

Analysis of the results for Alternative 1, enlarging the cross-section area of the Route 62 culvert by approximately 2.5 times, indicates that peak water surface elevations at Burroughs Road would be reduced negligibly for the 10-year, 25-year, and 50-year recurrence intervals, with only an approximate 0.3 feet and 0.8 feet reduction in peak levels for the 100- and 500-year recurrence intervals, respectively. The peak 10-year water surface at this location is 77.8 feet, assuming unobstructed flow at the Route 62 culvert. (Because debris often becomes hung up at this culvert due to its transitioning from one large culvert at the upstream end to two small culverts at its downstream end, water surfaces may be higher and the duration of flooding could be extended at Burroughs Road compared to those elevations and durations calculated using the unsteady-flow hydraulic model).

Unsteady-flow modeling indicates that the duration of flooding of Burroughs Road can be significantly reduced with an enlarged culvert at Route 62. (Refer to Figures 8 through 12 for plots of hydrographs for the existing condition and for Alternative 1 at various recurrence intervals). Model results indicate that the duration of flooding for the 25-year recurrence interval would be reduced from 27 hours with the existing scenario to 20 hours with the enlarged Route 62 culvert as described in Alternative 1. For the 50-year recurrence interval, it would be reduced from 41 hours with the existing scenario to 26 hours with the enlarged Route 62 culvert. For the 100-year recurrence interval, it would be reduced from 51 hours with the existing scenario to 29 hours with the enlarged Route 62 culvert. For the 500-year recurrence interval, it would be reduced from 81 hours with the existing scenario to 54 hours with the enlarged Route 62 culvert. In addition, peak water levels immediately upstream from the Route 62 culvert are reduced with an enlarged culvert for all recurrence intervals.

Benefits incurred by enlarging the Route 62 culvert, however, come at the expense of an increase in flows and peak water levels at downstream areas at all recurrence intervals. While we have examined the increase in flows and elevations along the lower reach of Martins Brook (including at Route 28), we have not examined potential increases in flows and water levels on the Ipswich River. Unsteady-flow hydraulic modeling of flows on the Ipswich River is beyond the scope of this study. Performing unsteady flow modeling along the Ipswich River would involve rainfall/runoff modeling of the Ipswich River upstream of its confluence with Martins Brook.

Closer examination of the flood profiles for Martins Brook provides some indication as to why significantly enlarging the cross-sectional area of the Route 62 culvert drops water levels at Burroughs Road so little. The cross-sections used in the HEC-RAS indicate that there is very little slope between the Skug River's confluence with Martins Pond and at the Martins Brook crossing of Route 62. The slope of the channel bottom in this reach is only approximately 0.00004 (0.004%).

Figure 8 - 10-year flood hydrographs at Burroughs Road

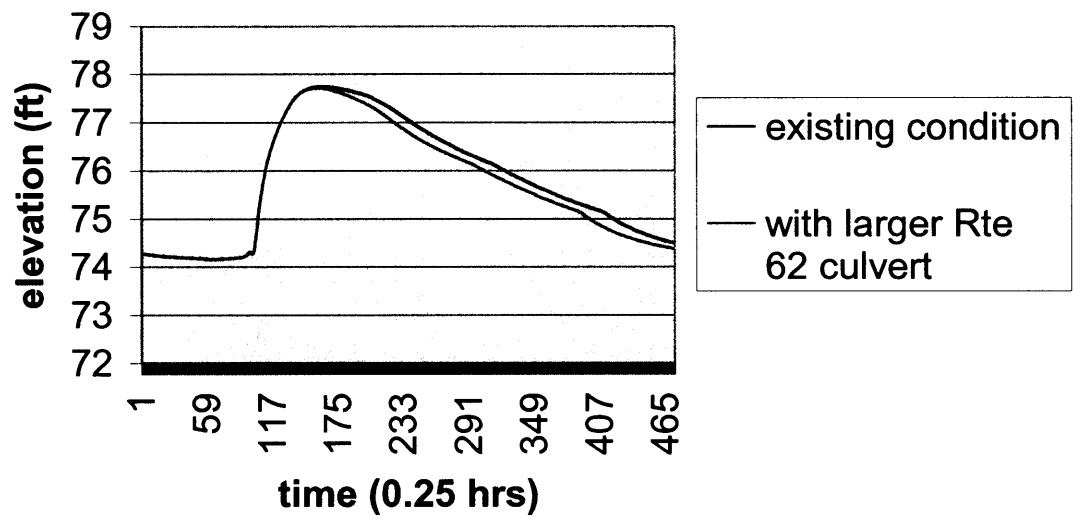


Figure 9 - 25-year flood hydrographs at Burroughs Road

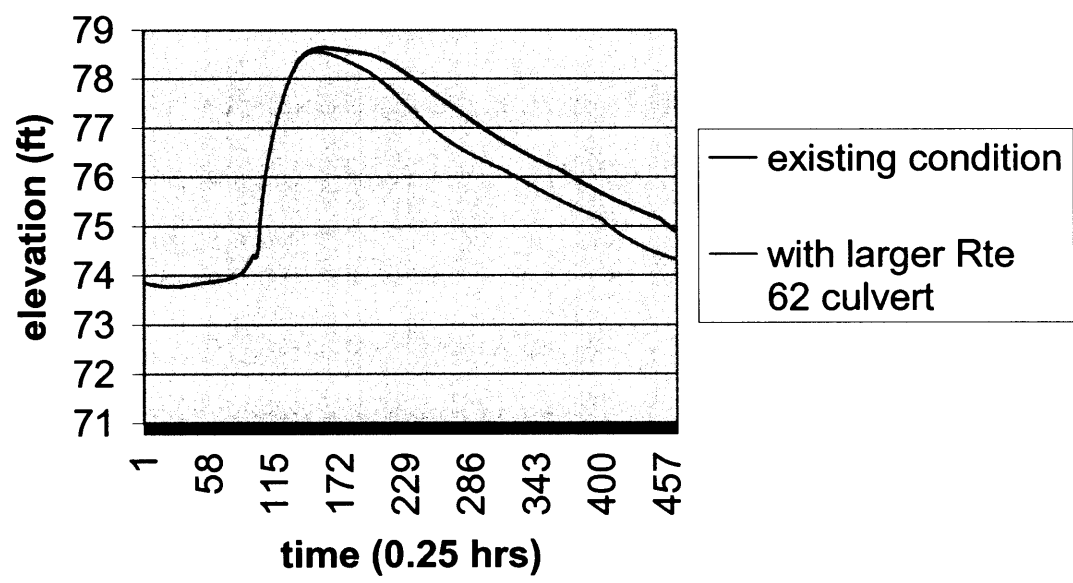


Figure 10 - 50-year flood hydrographs at Burroughs Road

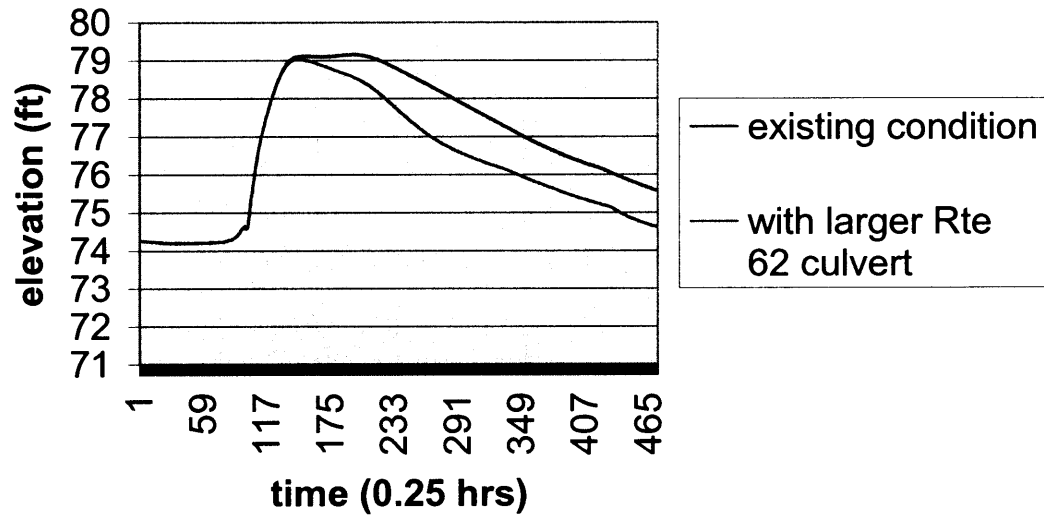


Figure 11 - 100-year flood hydrographs at Burroughs Road

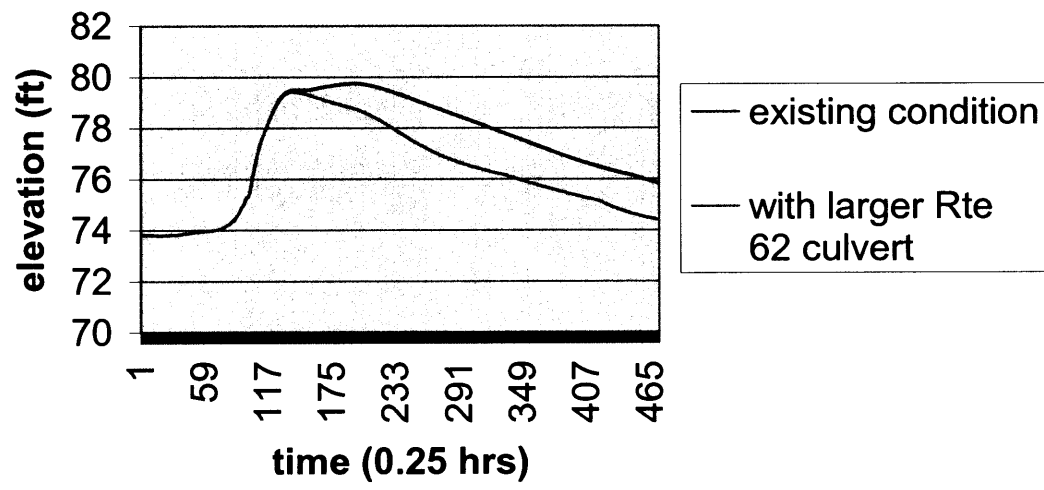
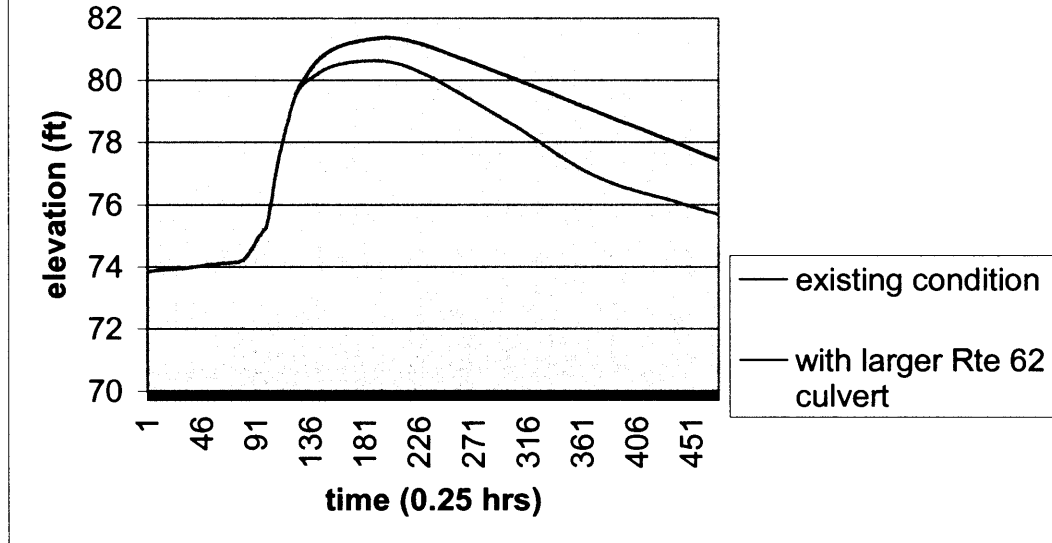


Figure 12 - 500-year flood hydrographs at Burroughs Road



Because flood durations at Burroughs Road can be significantly reduced by enlarging the culvert at Route 62, it may be desirable to investigate this alternative more closely. The recommendations section of this report elaborates on this alternative.

Results for Alternative 2

Analysis of the results for Alternative 2, complete removal of the Town of Wilmington's weir located just downstream of Route 62, indicates a reduction in peak flood elevation at Burroughs Road for the 10-year recurrence interval of only 0.1 feet and no change in elevation for the 25-year recurrence interval flood. For the 50-, 100- and 500-year recurrence intervals, an increase in peak elevation of 0.1 feet is indicated at Burroughs Road. A similar finding concerning peak water levels is also made just upstream of Route 62. The unsteady-flow HEC-RAS hydraulic modeling also indicates Burroughs Road flood duration times to be increased by a small amount for the 25-year (and greater) recurrence intervals. It appears that this counter-intuitive finding is related to the very large flows entering the Route 62 wetlands from the 5.0 square-mile Martins Brook sub watershed between Burroughs Road and Route 62 (Table 2 presented peak flows from this sub watershed). The hydraulic model apparently indicates that the major flows entering the Route 62 wetlands flows upstream more readily without the weir in place (with the slope of the channel in this reach being nearly zero, tributary flows can flow either upstream or downstream, depending on the water levels upstream and downstream of the tributary at that moment). This is the likely explanation of the model's finding of slightly decreased peak flows just downstream of Route 62.

Timing of rainfall and runoff significantly impacts flows experienced at any given point in time, and can even temporarily impact their direction. The exact location of tributary inflows also impacts the flow hydraulics (in the HEC-HMS model used to obtain sub watershed inflow hydrographs, we'd assumed that 50% of the 5-square-mile sub watershed flow enters Martins Brook upstream of the Benevento culvert and embankment, with the remaining 50% entering downstream of this embankment/culvert). All hydrologic and hydraulic models represent a simplification of reality. The occurrence of temporary "upstream" flow, as indicated in the unsteady flow model for Alternative 2, appears realistic, especially at points in time when tributary flow is much greater than that of the mainstem river (as is the case in the vicinity of the Wilmington weir early in the flood event, long before Martins Pond outflow reaches a peak). In any case, the changes to both maximum water levels and flood durations is minor, and it appears that there is not much merit to investigating removal of this weir to reduce flooding from major (10-year recurrence interval and greater) floods.

Results for Alternative 3

Analysis of the results for Alternative 3, complete removal of the culvert and embankment at Benevento Sand and Gravel, indicates a reduction in peak flood elevation at Burroughs Road of only 0.1 foot for the 10-year recurrence interval, and no change at the other recurrence interval flood studied. Duration of flooding at Burroughs Road also remains unchanged for all recurrence intervals. It appears that this alternative has no merit for reducing flooding from major (10-year recurrence interval and greater) floods.

Results for Alternative 4

Analysis of the results for Alternative 4, enlargement of the opening under Route 28, indicates no reduction in peak flood elevation at Burroughs Road for any recurrence interval flood studied. Duration of flooding at Burroughs Road also remains unchanged for all recurrence intervals. It appears that this alternative has no merit for reducing flooding from major (10-year recurrence interval and greater) floods.

Other Alternatives Not Modeled

Two alternatives were not modeled in unsteady-flow HEC-RAS: removal of beaver dams downstream of Burroughs Road; and, increasing the hydraulic capacity of the channel south of Burroughs Road, either through clearing of vegetation or by construction of a separate channel. Results of modeling of the Benevento culvert and embankment indicated no significant benefit at Burroughs Road for any recurrence interval studied (10-year and greater). It is therefore believed highly unlikely that removal of a beaver dam would yield measurable benefits for large flood events.

Our hydraulic model indicated that the Route 62 embankment and inadequately sized culvert is the most significant factor causing flooding at Burroughs Road. Observations of flood profiles when in "animate" mode of HEC-RAS model (when flood profiles can be observed throughout a storm event) indicates a fairly level pool behind Route 62. Our

report has found Route 62 to be the primary hydraulic constraint controlling flood levels at Burroughs Pond. At the peak of the storm events modeled, there is a single level pool extending from Route 62 back to Burroughs Road and including Martins Pond and even into the Skug River.

7. Conclusion and Recommendations

This study has determined that the only alternative that we examined that would significantly impact flooding at Burroughs Road, for floods of a 10-year recurrence interval and greater, involves enlargement of the culvert under Route 62 (Alternative 1). Unsteady flow HEC-RAS hydraulic modeling indicated that maximum flood elevations at Burroughs Road flooding would be decreased by only a small amount (0.3 feet at the 100-year recurrence interval), however, the duration of flooding is significantly reduced with an enlarged Route 62 culvert for all recurrence intervals except for the 10-year (when flooding of Burroughs Road does not occur). However, increasing the size of the Route 62 culvert size is not without adverse downstream consequences. Enlarging the Route 62 culvert increases peak flows and water surface elevations in downstream reaches of Martins Brook at all recurrence intervals. This study has documented the increase in flows and water surface elevations at Route 28 (and other downstream locations along with Martins Brook) associated with enlarging the cross-sectional area of the Route 62 culvert by a factor of 2.5. However, we have not investigated, whether the increased flood levels result in adverse impacts to homes and businesses along Martins Brook. While we are aware of flood damages along Martins Pond, we are not aware of flood damages occurring on the lower reach of Martins Brook. Should there be interest in enlarging the Route 62 culvert, we recommend that flood damage elevations be determined for this downstream reach. Then the unsteady-flow HEC-RAS model (developed for this study) could be used to determine the maximum size of a culvert under Route 62 that would avoid damages to these downstream properties. It is also not known if increasing the peak flood elevations on the lower segment of Martins Brook would result in increased damages along the Ipswich River downstream of the confluence with Martins Brook. To determine this would require a determination of flood damage elevations along the Ipswich River (extending at least one to two miles downstream from the confluence). In addition, it would require determination of stream flow hydrographs associated with the Ipswich River watershed upstream of its confluence with Martins Brook. This is likely to require a major effort, similar to that performed by Green International for the Martins Brook watershed, in which a rainfall-runoff model was assembled. The need for the additional work on the lower Martins Brook and on the Ipswich River depends upon the determinations of flood damage areas in these locations, and the elevation that these damages begin at. Sending water out of the Route 62 wetlands at a quicker rate (by enlarging the Route 62 culvert) is likely to be problematic only if there are downstream flood damage areas. We have not been able to determine if these areas exist under the scope of the existing study. Further study on if there are downstream damage areas, and the determination of the elevation of the start of damages needs to be defined before the magnitude of future study efforts concerning the enlargement of the Route 62 culvert can be defined.