Urban Flooding Analysis Using Radar Rainfall Data and 2-D Hydrodynamic Model: A Pilot Study of Back Cove Area, Portland, Maine

Environmental Science Division

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ABSTRACT

This project is a part of the Regional Resiliency Assessment Program, led by the Department of Homeland Security, to address flooding hazards of regional significance for Portland, Maine. The pilot study was performed by Argonne National Laboratory to identify differences in spatial rainfall distributions between the radar-derived and rain-gauge rainfall datasets and to evaluate their impacts on urban flooding. The flooding impact analysis utilized a high-resolution 2-dimensional (2-D) hydrodynamic model (15 ft by 15 ft) incorporating the buildings, streets, stream channels, hydraulic structures, an existing city storm drain system, and assuming a storm surge along the coast coincident with a heavy rainfall event. Two historical storm events from April 16, 2007, and September 29, 2015, were selected for evaluation. The radar-derived rainfall data at a 200-m resolution provide spatially-varied rainfall patterns with a wide range of intensities for each event. The resultant maximum flood depth using data from a single rain gauge within the study area could be off (either under- or over-estimated) by more than 10% in the 2007 storm and more than 60% in the 2015 storm compared to the radar-derived rainfall data. The model results also suggest that the inundation area with a flow depth at or greater than 0.5 ft could reach 11% (2007 storm) and 17% (2015 storm) of the total study area, respectively. The lowland areas within the neighborhoods of North Deering, East Deering, East and West Baysides and northeastern Parkside, appear to be more vulnerable to the flood hazard in both storm events. The high-resolution 2-D hydrodynamic model with high-resolution radar-derived rainfall data provides an excellent tool for detailed urban flood analysis and vulnerability assessment. The model developed in this study could be potentially used to evaluate any proposed mitigation measures and optimize their effects in the future for Portland, ME.

1 INTRODUCTION

Most evaluations of flood hazard have been based on rain gauge data. Studies such as Ricardo et al. (2013) have shown that rainfall intensity can vary from one place to another at scales on the order of tens of millimeters, meaning that gauge-based modeling could lead to inaccuracies in runoff predictions for highly heterogeneous rain events. The purpose of this pilot study is to identify differences in spatial and temporal rainfall distributions between the radar-derived and rain-gauge rainfall datasets for selected extreme storms and to evaluate their impacts on urban flooding. The high-resolution radar rainfall data (200 m), generated with Argonne National Laboratory's Atmospheric Radiation Measurement (ARM) Python radar toolkit (Collis 2016), were used for this study. The flooding impact analysis was performed using a high-resolution two-dimensional (2-D) hydraulic model to quantify (1) flow depth development, (2) the extent of the inundation area, where it is flooded, (3) the maximum water depths across the study area, (4) flow velocity, and (5) the locations likely to become hazardous due to flooding. The pilot study area was selected on the recommendation of the City of Portland, Maine, based on its vulnerability to flood hazards in the past.

This pilot study is a part of the Regional Resiliency Assessment Program (RRAP), which addresses a range of hazards that could be regionally significant for Portland, Maine. The RRAP is led by Department of Homeland Security (DHS). Argonne is a partner in the RRAP for Portland, Maine.

2 BACKGROUND

This section mainly presents background information on the pilot test area, the past extreme storm events selected for the flood impact analysis, and some of the motivations to conduct the pilot urban flooding analysis at Portland, Maine, in particular.

2.1 Description of Pilot Study Area

The City of Portland is located in Cumberland County toward the southern tip of Maine. The city is built around Back Cove, a bay along the Atlantic Ocean. The pilot study area covers a drainage area of 5.83 mi², or 3,731 acres, delineated by LiDAR data at a 2-m resolution from the National Resources Conservation Service (NRCS) Geospatial Data Gateway (NRCS 2015a). Elevations across the study area decrease from roughly 180 ft at the northwestern to sea level in the area surrounding the bay (Figure 2.1). Runoff from the study area is diverted to the lowest areas, to the bay and nearby coastline. Within the study area, two areas with lower ground surface elevations extend inland: one in East Deering (north of Back Cove Bay) and the other in East Bayside, West Bayside, the northeastern part of Parkside, the northeastern part of Oakdale (south of Back Cove Bay). One relatively low depression area is located along the main local stream in North Deering, upstream of the drainage area (Figure 2.1).

There is one main local stream, Fall Brook, which drains from the northwestern part of the study area toward the southeast to a small pond and is released to the bay. There are four parks in the area: one on the western edge of the area, the second to the west of the bay (Deering Center), the third along the northern shore of the bay (Back Cove); and the last one just south of the bay (Parkside). The urban center of the city includes several neighborhood areas around the bay, especially south of the bay. The storm drain system contains three underground storage tanks and releases directly into the bay (PWD

2013). Additionally, there are no seawalls or levees along the bay and other coastal areas of Portland (Maine GeoLibrary 2016).

2.2 Descriptions of Selected Storm Events: April 2007 and September 2015

Two storm events were chosen for this study to simulate flooding conditions across the city of Portland. The storms were chosen for their different attributes: the first storm represents a prolonged rainfall event, with steady rainfall occurring across a few days, accompanied by a severe storm surge from Atlantic Ocean; the second storm was a shorter, more intense rainfall event with a moderate storm surge. Selecting these two storms for flooding analysis may provide a better understanding of Portland flooding behaviors under different scenarios of combined heavy rain and storm surge.

The first storm for this study occurred on April 16, 2007; it is also known as the Patriot's Day storm. The storm hit the southern coast of Maine, including Portland, bringing 3.36 in of rain and additional runoff from melted snowpack (Lombard 2009). The 3.36 in of rain fell over a 62-hr period, with 3.1 in occurring within the first 28 hr. The coincident storm surge also brought the seventh highest coastal water level ever recorded, 13.3 ft, with high winds ripping out buoys and producing waves up to 32.0 ft (Bogden et al. 2009).

The second storm occurred on September 29, 2015. During this storm, Portland received 5.63 in of rainfall, its sixth heaviest recorded rainfall. The storm lasted one day, with 2.22 in of rain falling over the course of a single hour (Graham et al. 2015). The storm was accompanied by a high coastal water level of 8.268 ft.

The flooding at Portland in both storm events resulted from the combined effects of heavy rainfall and severe storm surge that raised water level in the bay and blocked runoff discharge from inland to the bay. Due to the Patriot's Day Flood in 2007, federal disaster areas were claimed in Cumberland and 12 other counties. The storm caused damage to public infrastructure across Maine, estimated at \$45 million, with \$31.5 million for road repairs alone (Lombard 2009). Both of these storms, along with many other Portland storms, have caused similar destruction to the city of Portland, leaving thousands without power, requiring local evacuations, and washing out downtown streets (Brogan and Koenig 2014). Additionally, when storms coincide with high coastal water levels induced by a storm surge, the storm drain system is prevented from discharging to the bay and manholes are dislodged by the unreleased runoff (Graham et al. 2015).

2.3 Motivation for Portland

Flooding accounts for 90% of disasters in the United States (Fears 2015). Portland, particularly in the Bayside area, has experienced flooding impacts for decades. Since 2007, Portland has had three record-breaking storms: (1) in 2007, with the seventh highest recorded tide, 13.3 feet; (2) in 2014, with the fifth heaviest recorded rainfall of 6.28 in; and (3) in 2015, with the sixth heaviest recorded rainfall of 5.63 in (Brogan and Koenig 2014; Graham et al. 2015). Sea level rise exacerbates flooding caused by storms as higher tides often occur along with inland storms. Starting at a higher low-tide means smaller storm surges are capable of flooding the coast and preventing drainage discharge from the storm drain system. Although the main purpose of the pilot study is to evaluate the feasibility of using radar-derived

rainfall data for urban flooding analysis, the high-resolution 2-D hydraulic model and radar data may also provide a useful tool to identify areas in the city most vulnerable to severe storms and to address potential flooding hazards where they are projected to occur.

Figure 2.1 Ground surface elevations and Portland neighborhoods in study area; 2-D hydraulic model boundary shown in red outline.

3 URBAN FLOODING ANALYSIS USING A TWO-DIMENSIONAL HYDRODYNAMIC MODEL

The urban flooding analysis for Portland, Maine, was performed using FLO-2D, a combined hydrologic and hydraulic modeling software. FLO-2D is a flood routing model, capable of routing rainfall and flood hydrographs over unconfined flow surfaces and in channels. The software is helpful with hazard delineation, regulating floodplain zoning, and designing flood mitigation. The FLO-2D model computes flow in eight directions, and operates with a variable time step that increments and decrements based on the numerical stability of the model. The model is able to simulate a number of other components, including but not limited to street flow, sediment transport, and spatially-varied rainfall and infiltration (FLO-2D 2015).

3.1 Model Construction

The model domain was determined to encompass a drainage area surrounding the Back Cove Bay. The drainage area was delineated using the ground surface elevation data (LiDAR 2m) from the NRCS Geospatial Data Gateway (NRCS 2015a; see Figure 2.1 for elevation rendering). Within the model, a grid-element size of 15 ft x 15 ft was chosen for a high-resolution analysis. The eastern shoreline of the study area was assigned a variable water-level boundary condition based on the coastal water-level elevations resulting from the storm surge, and the rest of the model boundary is delineated mainly along the drainage dividers that were assigned as no-flow boundary conditions. Hourly water-level time series data during the storm surge were taken from the National Oceanic and Atmospheric Administration (NOAA) buoy, located along the coast near Portland, Maine, for both the 2007 and 2015 storms (NOAA 2015). The total area of FLO-2D model is 5.83 mi², or 3,730 acres.

3.2 Buildings

In urban flooding analysis, buildings represent an obstacle for flow and decrease the amount of runoff storage available within the study area. All of the buildings located within the study area were identified using aerial images (NRCS 2015b; Figure 3.1). The buildings were then modeled in FLO-2D by making a portion of the building area unavailable for flow storage, and blocking flow in the direction of the building. Precipitation falling on buildings is less than 0.6 % of total precipitation and was assumed to be discharged to the local storm drain system.

3.3 Streets

Streets help convey and direct flow into the storm drain system of the city (Figure 3.1). All streets along the storm drain system were modeled to allow flow in two of eight possible directions, and assigned a width of 10 ft and curb height of 1 ft. Streets were located using a shapefile from the Maine Office of GIS (2016).

3.4 Manning's Roughness

Manning's roughness, or Manning's n , was used to represent the roughness of a surface, which affects the surface flow velocity and flow depth. The roughness was estimated from the land use types based on a shapefile from the Maine Office of GIS (2004) containing the land use across Portland.

The n values were based on those from the FLO-2D PRO Reference Manual (FLO-2D 2015). The assignments were as follows:

- An n value of 0.035 was assigned to land uses “transportation, communication, and utilities,” “residential,” “commercial services,” “industrial,” and “other urban or built-up land,”
- An n value of 0.040 was assigned to the land uses of “bays and estuaries” and “reservoirs,”
- An n value of 0.090 was assigned to the land use “strip mines, quarries, gravel pits,”
- An n value of 0.100 was assigned to the land use “cropland and pasture,” and
- An n value of 0.325 was assigned to the land uses “mixed forest land” and “evergreen forest land.”

3.5 Storm Drain System

To estimate the effects of the local drainage system during the storm event, a U.S. Environmental Protection Agency (EPA) storm water management (SWMM) model of the system provided by the City of Portland was incorporated in the FLO-2D model (PWD 2013). The drainage system defined in the EPA SWMM model is shown in Figure 3.2. The SWMM model of the system includes the piping, inlets, outlets, and other various features such as storage tanks and pumps used in the Portland storm drain system. The geometry of each inlet was then defined using FLO-2D model. All inlets were assumed to be grate inlets, with a surface area of two square feet. Outfalls were assigned to discharge to Back Cove Bay.

3.6 Fall Brook: Channel bed, Hydraulic Structures, and Streamflow

The Fall Brook is the main local stream in the study area extending from the northwest area in North Deering toward the southeast discharging to Back Cove Bay. The stream is ungauged. There are three components to creating a realistic channel (Figure 3.1): channel shape, hydraulic structures, and stream flow. Channel shape was determined by creating representative channel bed cross sections using elevation data from the NRCS (2015a). Hydraulic structures were placed where Fall Brook crossed man-made structures, such as streets. The locations, type of structure, and dimensions were determined using scaled aerial images, and discharge was determined using culvert properties. Finally, the pre-existing stream flow prior to the precipitation event was based on the outflow from a nearby stream because no flow measurements were available for Fall Brook. The substitute channel, Stoney Brook, was chosen due to its proximity and similar watershed size and channel slope. Streamflow values were taken from the USGS (2015), using the average outflow on the first day of each model run as the input of initial inflow. The initial streamflow was determined to be 6.7 ft^3 , and 0.33 ft^3 , for the 2007 and 2015 storms, respectively.

3.7 Precipitation

Two data sources, rain gauge and spatially variable radar-derived rainfall data, were used as model input for each of the storms in April 2007 and in September 2015. Hourly data from a single rain gauge, located on Baxter Boulevard was provided by the Portland Water District and used as a uniform rainfall across the study area. Hourly radar data from 950 locations across the model area spaced every 200 m provided spatially differentiated rainfall across the study area (Figure 3.3). Radar rainfall amounts were determined using data provided by Scott Collis at Argonne National Laboratory for both the 2007 and 2015 storms (Collis 2016). The potential bias of radar-derived rainfall data were analyzed with rain

gauge data over the region including south and west of Maine and New Hampshire and corrected for both selected storms.

For the purposes of this study, the rainfall event was selected to be from the beginning of precipitation to over six hours passed with no significant rainfall. For the 2007 and 2015 storms, the precipitation data cover the periods of April 15, 2007, at 0:00 to April 19, 2007, at 3:00 and September 29, 2015, at 12:00 to September 30, 2015, at 18:00, respectively. The total rain gauge precipitation for the 2007 and 2015 storms was 3.10 in and 5.75 in, respectively.

3.8 Model Limitations

There are certain limitations associated with the use of this model, as we have been unable to perform a calibration of our model due to the lack of observed water level data in the study area during the 2007 and 2015 storms. However, the model results do provide information on the areas most vulnerable to flooding hazard under the two different severe storm scenarios. Once the local water level data are available, the model calibration can be readily performed to improve model accuracy and predictability.

Figure 3.1: Model features across the study area in the City of Portland: channel (light blue), hydraulic structures (dark blue), storm drain system (purple), streets (green), and buildings (orange); the model boundary is shown in red.

Figure 3.2 The storm drainage system in the EPA SWMM model was incorporated in the FLO-2D model.

Figure 3.3 Rain gauge and radar grid locations across the study area in the City of Portland; the model boundary is shown in red.

4 FLOOD SIMULATIONS

Two simulations were performed using the rain-gauge and radar-derived rainfall data from the 2007 storm. Both flood simulations were run for 40 hr, starting on April 15, 2007, at 0:00 UTC.¹ The 40-hr simulation included the release of 90% of the total storm precipitation, and was bounded by the high coastal water-level elevations along the model boundary caused by the coincident storm surge.

As a comparison, two simulations for the 2015 storm were conducted using the rain-gauge and radar-derived rainfall data, respectively. Both simulations were run for 30 hr, starting on September 29, 2015, at 12:00 UTC. The 30-hr simulation included the release of 100% of the total storm precipitation, and was bounded by the increased coastal water-level elevations due to the storm surge.

The four simulations were defined mainly based on input data as follows:

- Rain-gauge rainfall, storm surge, and channel inflow data from the 2007 storm event, including the storm drain system in the model;
- Radar-derived rainfall, storm surge, and channel inflow data from the 2007 storm event, including the storm drain system in the model;
- Rain-gauge rainfall, storm surge, and channel inflow data from the 2015 storm event, including the storm drain system in the model; and
- Radar-derived rainfall, storm surge, and channel inflow data from the 2015 storm event, including the storm drain system in the model.

¹ UTC, Coordinated Universal Time, is the primary time standard by which clocks and time are regulated worldwide.

5 RESULTS

This section presents the results for the comparison of rain-gauge and radar-derived rainfall data and their impacts on urban flooding, including the area of inundation, maximum flow depths, and potential hazardous areas across Portland, for both the 2007 and 2015 storms.

5.1 Differences in Rainfall and Flow Depth Using Rain Gauge and Radar-Derived Precipitation Data

The spatial distributions of rainfall based on radar-derived data show two different patterns for the 2007 and 2015 storms. In the 2007 storm, the accumulated rainfall ranged from 2.3 in to 3.1 in, with the heaviest rainfall centered along the Back Cove Bay where the rain gauge is located (Figure 5.1). The total volume of rainfall would be overestimated by more than 6% using data from a single rain gauge (Table 5.1). In the 2015 storm, the accumulated rainfall varies widely from 4.4 in to 6.6 in (Figure 5.2). The heaviest rainfall occurred along the east side of the watershed (East Deering and Munjoy Hill) decreasing to the west (Deering Center and North Deering). The rain gauge is located in the area with a medium level of rainfall. The total volume of rainfall estimated with rain gauge data is slightly lower than that derived from radar data (Table 5.1). However, the rain-gauge rainfall results in an underestimation by 0.5 in in the eastern areas and an overestimation by 1.5 in in the western area of the watershed (Figure 5.2).

Table 5.1 Volume of rainfall using radar and rain gauge data for 2007 and 2015 storms.

	Total Volume of Rainfall Based on Rain Gauge (Acre-ft)	Total Volume of Rainfall Based on Radar (Acre-ft)
2007 Storm	870.74	818.09
2015 Storm	1,615.11	1,624.71

The FLO-2D model for the study area was used to simulate the flow depths on streets and grounds with different types of land uses in the urban areas. The maximum flow depth over the entire storm duration can be determined for each grid element within the model domain. Percent differences in maximum flow depth from simulations using input between rain-gauge and radar-derived data are shown in Figures 5.3 and 5.4. Percent differences were calculated by $[(MFD_{\text{radar}} - MFD_{\text{rain-gauge}}) / MFD_{\text{radar}}] * 100$, where MFD is the maximum flow depth. In the 2007 storm, two lowland areas in Bayside and North Deering receiving less rainfall based on radar data have lower maximum flow depths by more than 10% than those simulated results from the rain-gauge data, as shown in Figure 5.3. In the 2015 storm, the differences indicate MFD was underestimated by nearly 10% for the eastern part and overestimated by more than 60% for the western part of the study area (Figure 5.4). Two lowland areas in East Deering and Bayside have lower flow depths if estimated using rain gauge data for the 2015 storm (shown in the two lower plots in Figure 5.4). In contrast, the lowland area in North Deering has much higher flow depths based on the rain gauge data than what were predicted with the radar data; the flow depth is overestimated by up to 67% (shown in the top plot in Figure 5.4). The rainfall variation captured by the radar data appears to have a significant effect on flooding flow depths. For the flooding predictions and vulnerability evaluation, the radar-derived rainfall at 200 m resolution provides a good basis for the

more detailed and accurate flooding analysis for the urban area and makes it feasible to perform high-resolution hydrodynamic modeling.

5.2 Inundation Area, Flow Depth Development, and Hazardous Areas

The model results provide flooding flow depth, velocity, and spatial distributions of inundation for each storm. The flow depth and velocity can be further used to determine the level of flooding hazard and the extent of the hazardous area at various levels.

The inundation predicted by the model widely spreads across the entire study area. The estimated area of inundation with a flow depth greater than 0.5 ft is 0.63 mi² for the 2007 storm and 0.98 mi² for the 2015 storm, representing 11% and 17% of total study area, respectively (Table 5.2). Most of the flooded areas across the study area (shown in Figures 5.5 and 5.6) occurred in wooded areas and along the Fall Brook and Back Cove Bay. However, three relatively large inundation areas were predicted in lowland areas within the neighborhoods North Deering, East Deering, East and West Baysides, and parts of Parkside (Figures 5.5 and 5.6). The MFDs in those neighborhoods ranged from 4.7 ft to 6.2 ft for the the 2007 storm and 7.9 ft to 8.7 ft for the 2015 storm (Table 5.2). The detailed spatial distributions of inundation and MFDs are shown in Figures 5.7 and 5.8. The large inundation area in North Deering was flooded likely because of overbank flow from the Fall Brook and the limited conveyance capacity along the Fall Brook channel during the storm. The inundation areas in East Deering, East Bayside, West Bayside as well as parts of Parkside are located in the lowest elevation grade across Portland, receiving flow from the surrounding areas. Those areas are connected to the city storm drainage system, however, the conveyance capacity of the drainage system was limited because of the heavy rainfall coincident with the high coastal water level in Back Cove Bay caused by the storm surge.

Table 5.2 Simulation results for the 2007 and 2015 storms using radar-derived precipitation data.

		2007 Storm	2015 Storm
Average accumulated precipitation depth (in)		2.91 ^a	5.80 ^b
Area of inundation (depth ≥ 0.5 ft)	(mi ²)	0.63	0.98
	% of total area	11	17
Maximum flow depth (ft)	North Deering	6.2	7.9
	East Deering	5.4	7.0
	East Bayside	4.7	8.7

^a Accumulated precipitation over 40 hr, accounting for 90% of total precipitation for the 2007 storm. The remaining 0.26 in are spread out over the next 36 hr and have less effect on peak flooding.

^b Accumulated precipitation over 30 hr, accounting for 100% of total precipitation for the 2015 storm.

For the large storm event, flood hazard can be further evaluated using water flood intensity or mud/debris flow intensity (Fiebiger 1997; Garcia et al. 2003; Garcia and Lopez 2005). Since there is less mud or debris in the urbanized area, the water flood intensity was used to delineate the flooding hazardous area. The water flood intensity was determined using both flood depth and a product of the maximum flow depth multiplied by the maximum flow velocity based on Garcia et al. (2003) and Garcia and Lopez (2005). Three hazard levels (low, medium, and high) were defined as follows:

1. A low hazard is any area where the depth is between 0.1 m (0.328 ft) and 0.5 m (1.639 ft) and the flow velocity multiplied by the depth is between $0.1 \text{ m}^2/\text{s}$ ($1.076 \text{ ft}^2/\text{s}$) and $0.5 \text{ m}^2/\text{s}$ ($5.382 \text{ ft}^2/\text{s}$). A low hazard represents a low or nonexistent danger.
2. A medium hazard is any area where the depth is between 0.5 m (1.639 ft) and 1.5 m (4.922 ft), or where the flow velocity multiplied by the depth is between $0.5 \text{ m}^2/\text{s}$ ($5.382 \text{ ft}^2/\text{s}$) and $1.5 \text{ m}^2/\text{s}$ ($16.147 \text{ ft}^2/\text{s}$). A medium hazard represents danger outdoors.
3. A high hazard is any area where the depth or velocity multiplied by the depth is greater than 1.5 m (4.922 ft) or $1.5 \text{ m}^2/\text{s}$ ($16.147 \text{ ft}^2/\text{s}$), respectively. A high hazard represents danger indoors and outdoors.

On the basis of the three hazard level thresholds, the model results of MFD and maximum flow velocity for each storm were used to delineate the flood hazard. Figures 5.9 and 5.10 illustrate the detailed flood hazard maps for three large inundation areas (North Deering, East Deering, and East and West Baysides and the northeast part of Parkside). A majority of the three inundation areas was assigned a hazard level of 2 or 3, which indicates a potential danger outdoors and/or indoors (Figures 5.9 and 5.10). The hazard area in the 2015 storm is three times greater than the area in the 2007 storm (Table 5.3). The hazard maps could also be re-delineated using the model results if the thresholds are adjusted according to the local conditions.

The flood hazard level can also be evaluated with a discrete combined function of the water flood intensity and return period (frequency). The frequency analysis for the urban area at a high resolution requires long records of radar data, which is beyond the scope of this pilot study. In the future, however, more radar data can be processed with the tool developed in a parallel study at Argonne (Collis 2016) and the derived rainfall data (for a longer time period) can be used as input to the FLO-2D model for frequency analysis. This would support hazard delineation using both event intensity and frequency.

Table 5.3 Predicted hazard level and area based on flood simulation for the 2007 and 2015 storms.

Storm Analyzed	Model Simulation	Percent of total area with flood hazard [%]			
		Low	Medium	High	Total
2007	Radar data, with storm drain analysis	1.32	2.18	0.229	3.73
2015	Radar data with storm drain analysis	5.06	4.90	0.87	10.83

Figure 5.1 Spatial distribution of input precipitation for the 2007 storm, based on radar-derived rainfall data over a 40-hr peak storm period (one rain gauge is located in the study area, indicated by the yellow dot; the model boundary is shown in red).

Figure 5.2 Spatial distribution of input precipitation for the 2015 storm, based on radar-derived rainfall data, over a 30-hr peak storm period (one rain gauge is located in the study area, indicated by the yellow dot; the model boundary is shown in red).

Figure 5.3 Percent difference between maximum flow depths (MFDs) for simulations using rain gauge and radar-derived precipitations for the 2007 storm. Blue indicates areas where MFDs based on rain gauge data exceed those computed from radar data; yellow indicates no difference; and orange/red shows areas where the MFDs from radar data exceed those from rain gauge data).

Figure 5.4 Percent difference between maximum flow depths (MFDs) for simulations using rain gauge and radar-derived precipitations for the 2015 storm. Blue indicates areas where MFDs based on rain gauge data exceed those computed from radar data (a flow depth plot shows representative flow depth development from the area in North Deering); yellow indicates no difference; and orange/red shows areas where the MFDs from radar data exceed those from rain gauge (two flow depth plots show flow depth development in East Deering and Bayside, respectively).

Figure 5.5 Maximum flow depths across Portland predicted by the simulation using radar data for the 2007 storm. Three focus neighborhoods with relatively large inundation areas are outlined in black: North Deering (top), East Deering (middle), and East and West Baysides and parts of Parkside (bottom).

Figure 5.6 Maximum flow depths across Portland predicted by the simulation using radar data for the 2015 storm.

Figure 5.7 Maximum flow depths across large inundation areas in three neighborhoods: North Deering (upper left), East Deering (upper right), and East and West Baysides and northeastern Parkside (lower left); results from the simulation using radar data for the 2007 storm.

Figure 5.8 Maximum flow depths across large inundation areas in three neighborhoods: North Deering (upper left), East Deering (upper right), and East and West Baysides and northeastern Parkside (lower left); results from the simulation using radar data for the 2015 storm.

Figure 5.9 Hazardous areas predicted within three Portland neighborhoods: North Deering (upper left), East Deering (upper right), and East and West Baysides and northeastern Parkside (lower left); results from simulation using the radar data for the 2007 storm.

Figure 5.10 Hazardous areas predicted within three Portland neighborhoods: North Deering (upper left), East Deering (upper right), and East and West Baysides and northeastern Parkside (lower left); results from simulation using the radar data for the 2015 storm.

6 POTENTIAL USE OF THE TWO-DIMENSIONAL HYDRODYNAMIC MODEL

The objective of the 2-D hydrodynamic model developed in this pilot study was to evaluate the benefits of the high-resolution radar-derived rainfall data to urban flooding analysis and to analyze their impacts on the flood hazard. If the local flood water marks during the historical storm events are available, the current 2-D hydrodynamic model can be calibrated to improve the model's predictability for a more accurate urban flooding analysis and vulnerability assessment for the various neighborhood areas in the City of Portland.

The calibrated model also can be used to generate numerical experiments to test the effects of mitigation strategies. The model can incorporate any proposed strategies, such as (1) revisions to infrastructure and ground elevation (such as that for the proposed apartment complex on Somerset Street [Miller, 2015]), (2) expansion of the current storm drain system, (3) placement of levees to reroute runoff, and (4) addition of rain gardens, patches of highly absorptive land and green infrastructure to increase interception and infiltration. The model sensitivity to each mitigation measure can be quantitatively evaluated and optimal configuration of the mitigation components could be identified through multiple model tests.

In addition, a cost comparison can also be performed for any specific mitigation approach. Given information about the cost of damage done to city infrastructure based on flood depth and flow velocity, the damage incurred by various floods with and without the mitigation solution can be determined. Then, using the likelihood of the various flood events, as well as the cost to implement the solution chosen, we can compare costs for implementing the solution against the damage caused by flooding.

7 CONCLUSIONS

The pilot study was performed using the City of Portland, Maine, as a test site to evaluate the feasibility of applying radar-derived rainfall data to the high-resolution 2-D hydrodynamic model and to analyze its benefit to the urban flood analysis. Two storm events (2007 and 2015) with heavy rainfall coincident with high coastal water levels caused by the storm surge were selected for the evaluation. The 2-D hydrodynamic model constructed with the FLO-2D software for the study area included the buildings, streets, stream channels, hydraulic structures, an existing storm drain system, and assumed a storm surge along the coast coincident with heavy rainfall event. For the 2007 storm, the accumulated rainfall would be overestimated by more than 6% using data from a single rain gauge. In the 2015 storm, the rain-gauge rainfall could result in underestimation by 0.5 in in the eastern areas and overestimation by 1.5 in in the western area of the watershed due to a wide variation of rainfall from 4.4 in to 6.6 in across the study area. The results from 2-D hydrodynamic model with radar-derived rainfall data suggest that the maximum area of inundation with a flow depth at or exceeding 0.5 ft was 11 % of the total study area for the 2007 storm and 17 % for the 2015 storm. The three lowland areas in the neighborhoods, North Deering, East Deering, and East and West Baysides and parts of Parkside, are most vulnerable to the flood hazard. The maximum flow depths in those neighborhoods ranged from 4.7 ft to 6.2 ft for the 2007 storm and 7.9 ft to 8.7 ft for the 2015 storm. The total hazardous area across Portland could reach 3.7 % of the total study area for the 2007 storm and 10.8 % for the 2015 storm. The hazard mapping was based on the three hazard levels defined by the MFD and a product of the MFD multiplied by the maximum flow velocity. Although the 2-D hydrodynamic model requires further calibration with observed flood water marks, it can be potentially used as an excellent tool to evaluate mitigation measures and their effects, as well as for cost-benefit comparisons.

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