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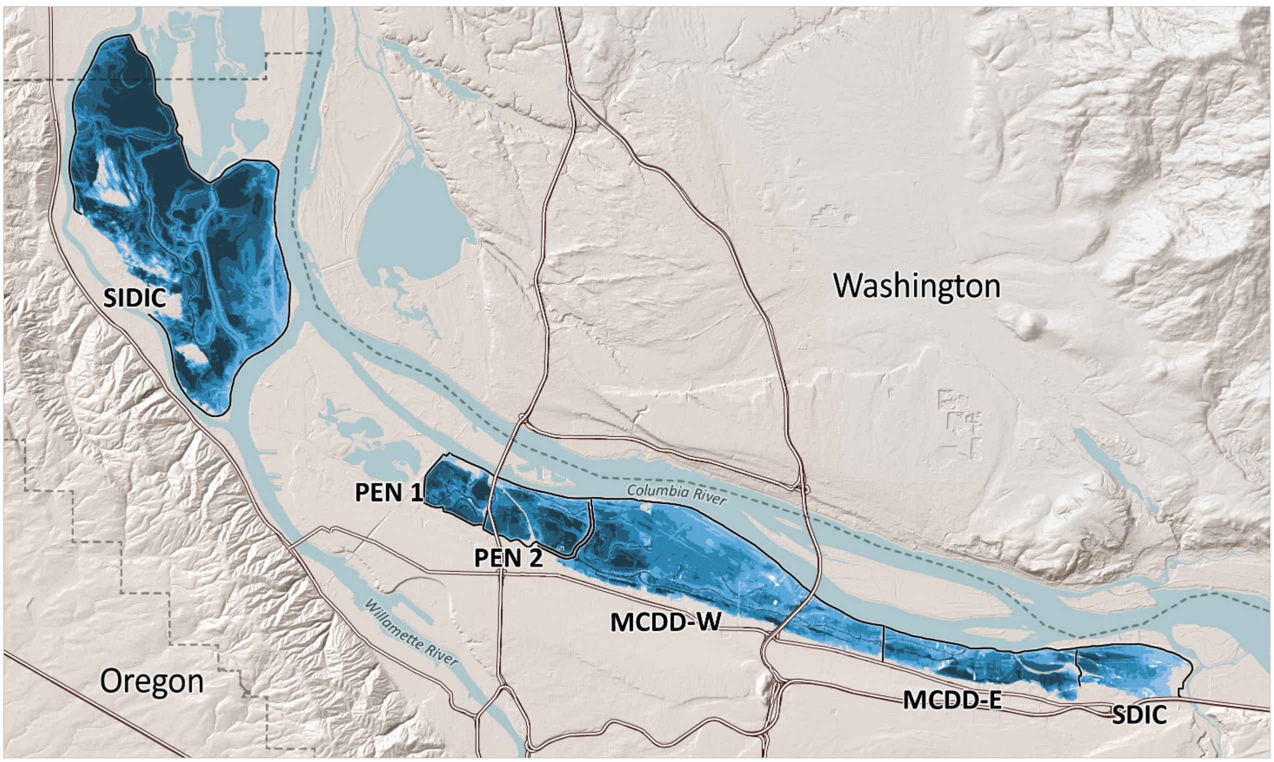
Brad Avy, State Geologist

SPECIAL PAPER 50

FLOOD RISK ASSESSMENT FOR THE COLUMBIA CORRIDOR DRAINAGE DISTRICTS IN MULTNOMAH COUNTY, OREGON



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Cover image: Location map of Columbia corridor drainage districts in Multnomah County showing the extent and relative depth of water during a 100-year flood. Lighter blue indicates a shallower depth of flooding (< 10 ft) and darker blue indicates deeper depth of flooding (> 10 ft). The districts are subdivided into five drainage districts: Sauvie Island Drainage Improvement Company (SIDIC), Peninsula Drainage District 1 (PEN 1), Peninsula Drainage District 2 (PEN 2), Sandy Drainage Improvement Company (SDIC), and Multnomah County Drainage District 1 (MCDD). MCDD is divided by a cross levee into western (MCDD-W) and eastern (MCDD-E) sections.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GEOGRAPHIC INFORMATION SYSTEMS (GIS) DATA

Metadata in .xml file format:

Each feature class and raster listed below has an associated standalone .xml file containing metadata in the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata format.

Columbia_Corridor_Flood_Risk_Assessment.gdb:

Feature dataset: ***Results_Summarized_By_Drainage_District***

Feature classes:

Building_Loss_100yr
Building_Loss_500yr
Impacts_on_Population_Employment_and_Additional_Assets

Rasters:

Flood_depth_100yr
Flood_depth_500yr

SPREADSHEET

Master Excel file "Damage-to-Parked-Vehicles.xlsx" contains two sheets:

Damage Calculation
Depth-Damage Relationship

See the digital publication folder for files. File geodatabase is Esri® version 10.1 format. Metadata is embedded in the geodatabase and is also provided as separate .xml format files. Spreadsheet file is Microsoft Excel 2016 format.

REPORT SUMMARY

On Memorial Day in 1948, Vanport, one of Oregon's largest cities, was destroyed when Columbia River flood waters broke through the existing levee system and flooded the city. In the years since this historic event, increasing demand for land within the greater Portland area has driven the development of thousands of new buildings within the area's drainage districts. Despite the region's history of flooding and proximity to the Columbia and Willamette Rivers, little is known about the chronic flood risk posed to people and assets located behind the levees should the levees breach again.

The objective of this study was to quantify the impact of a levee breach on each of the Columbia corridor drainage districts in Multnomah County during a major (100-year or 500-year, i.e., 1-percent or 0.2-percent annual chance) flood event (**Figure 1**). We considered the (1) damage to buildings, (2) displaced population, (3) employment-related economic loss, (4) damage to above-ground key infrastructure, (5) exposure of hazardous materials, (6) exposure of community facilities, and (7) exposure of transportation networks and damage to parked vehicles. For the purposes of this study, we did not model a specific cause or location of levee failure but instead assumed that should a portion of the modern levee system be structurally undermined during a flood, water would be able to flow freely into the affected drainage district. To assess the impact of flooding, we used the Federal Emergency Management Agency (FEMA) Hazus-MH methodology to estimate damage to assets, and we used Geographic Information Systems (GIS) to assess flooding exposure.

The findings of this study indicate that a major flood in conjunction with a levee breach would have a catastrophic impact on any of the drainage districts (**Table 1**). Depending on the affected district, between 51% and 95% of buildings in the district would be exposed to a 100-year flood. Such an event would result in millions of dollars in building, content, and inventory damage in Sauvie Island Drainage Improvement Company (SIDIC), Peninsula Drainage District 1 (PEN 1), Peninsula Drainage District 2 (PEN 2), or Sandy Drainage Improvement Company (SDIC) and billions of dollars in damage in Multnomah County Drainage District – West (MCDD-W) or Multnomah County Drainage District – East (MCDD-E). Nearly three-fourths of the more than 8,000 residents living behind the levees are located in areas vulnerable to a 100-year flood without effective levee protection. Our assessment indicates that more than 2,200 residents would be displaced from PEN 2 and more than 1,500 residents would be displaced from MCDD-W and from MCDD-E. In addition, most businesses would initially close after a major flood and it could take months or years for some of those businesses to repair and reopen. In MCDD-W, there would be more than 1,300 businesses closed and 35,000 employees unable to return to work, which would result in a substantial loss in wages and employment throughout the region.

Given the potential severe impacts of such a flood, it is critical that local, state, and federal governmental agencies as well as businesses, residents, and community-based organizations act to minimize the risk of flooding and plan for a potential levee failure. We support maintaining or upgrading the geotechnical strength of existing levees to meet federal requirements including FEMA accreditation and U.S. Army Corps of Engineers (USACE) PL84-99 standards. Developing and maintaining evacuation and emergency response plans at household, business, drainage district, city, and county levels will also increase local resilience. In addition, we recommend continuing public outreach and education campaigns to raise awareness of the risk posed by a major 100- or 500-year flood and levee failure.

Our assessment also indicates that the majority of buildings storing hazardous material, community assets, and key infrastructure are located in areas that would be highly vulnerable to flooding without effective levee protection. Given the importance of these sites and the potential risk they pose, we recommend that inspection be performed at each site to identify opportunities to increase flood resilience.

Figure 1. Location of Columbia Corridor drainage districts in Multnomah County, Oregon.

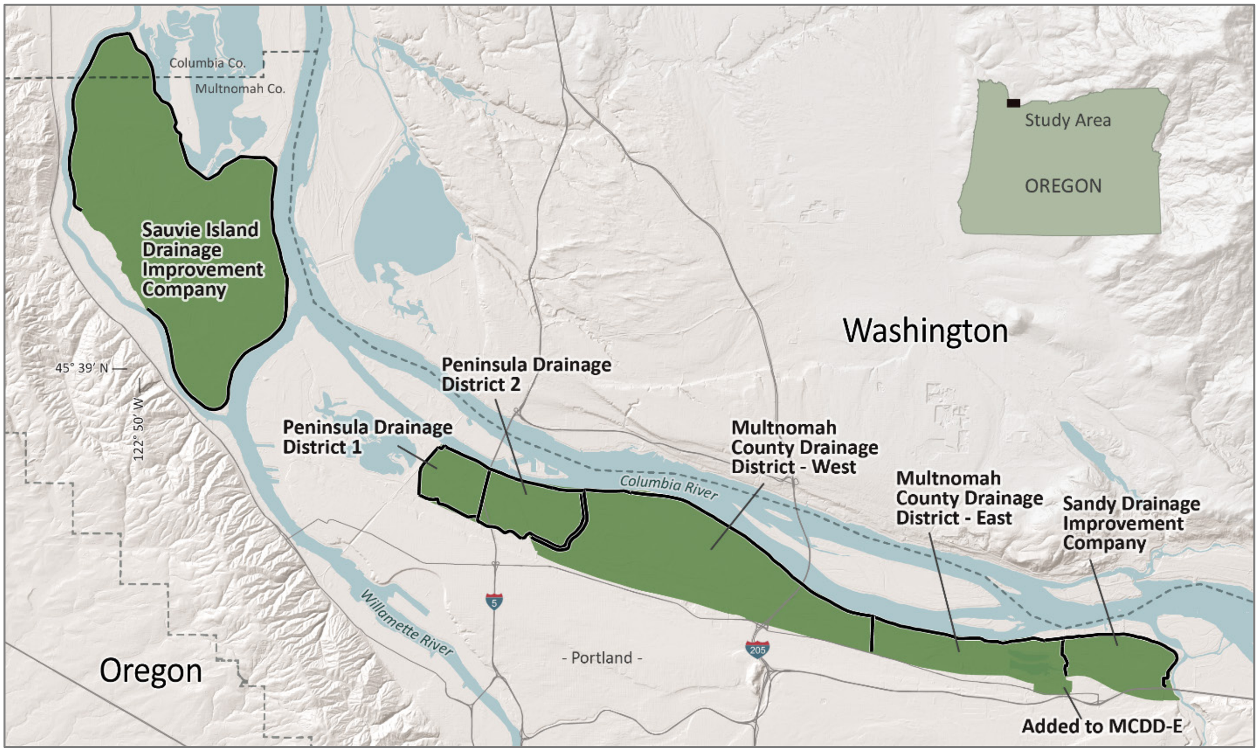


Table 1. Summary of results for a levee breach and 100-year flood in the Columbia corridor drainage districts.

	Sauvie Island Drainage Improvement Company	Peninsula Drainage District 1	Peninsula Drainage District 2	Multnomah County Drainage District–West	Multnomah County Drainage District–East	Sandy Drainage Improvement Company
Initially displaced residents	381	13	2,270	1,799	1,521	—
Number of exposed buildings	486	42	1,075	1,115	740	91
Total repair cost (building, content, and inventory) ($ millions)[1]	$133.3 to 150.0 M	$33.2 to 39.8 M	$672.6 to 760.2 M	$3,588.5 to 4,746.0 M	$1,068.8 to 1,395.0 M	$256.3 to 345.5 M
Number of businesses initially closed due to flooding	29	11	237	1,310	259	93
Number of employees initially unable to return to work	170	902	4,259	35,275	7,554	4,453

[1]Range indicates the standard and long-duration (> 3 day) flood assessment values.

1.0 BACKGROUND

1.1 Purpose

In the United States, flooding causes billions of dollars in damage almost every year (NOAA, 2018). Development within the floodplains of major rivers has placed millions of people at risk from floods and created widespread flood management challenges. Since the early 1900s, the U.S. Army Corps of Engineers (USACE), flood managers, and residents have constructed dozens of dams and thousands of miles of levees throughout the Columbia River basin with the intent of reducing the impact of flooding on communities (USACE, 2018; NPCC, 2018). Despite these efforts to control the Columbia Watershed, a major flood on the Columbia River destroyed the town of Vanport, Oregon in 1948, displacing 18,500 residents and killing at least 15 residents when the adjacent the levees breached (Multnomah County Emergency Management, 2017, Section 3.2). In the decades since this historic event, the levees have been repaired, additional large dams have been constructed in the region, and new homes and business have been built behind the levees. The Columbia River has also experienced three flood events that were greater in magnitude than the designated 100-year flood levels. Although none of these floods have resulted in another complete levee breach, there was significant damage to the levees during 1996 including major seepage, sand boils, and scour which required emergency levee repairs (MCDD, 2016a). Annual maintenance totaling thousands of dollars is required to keep the levees intact (MCDD, 2017), indicating that the people and structures behind the levees are in an area of chronic flood risk (Association of State Floodplain Managers, 2005). In order to make informed and effective management decisions, drainage district executives, land use agencies, government officials, and the public must understand the risk a major flooding event could pose if any of the existing levees breached.

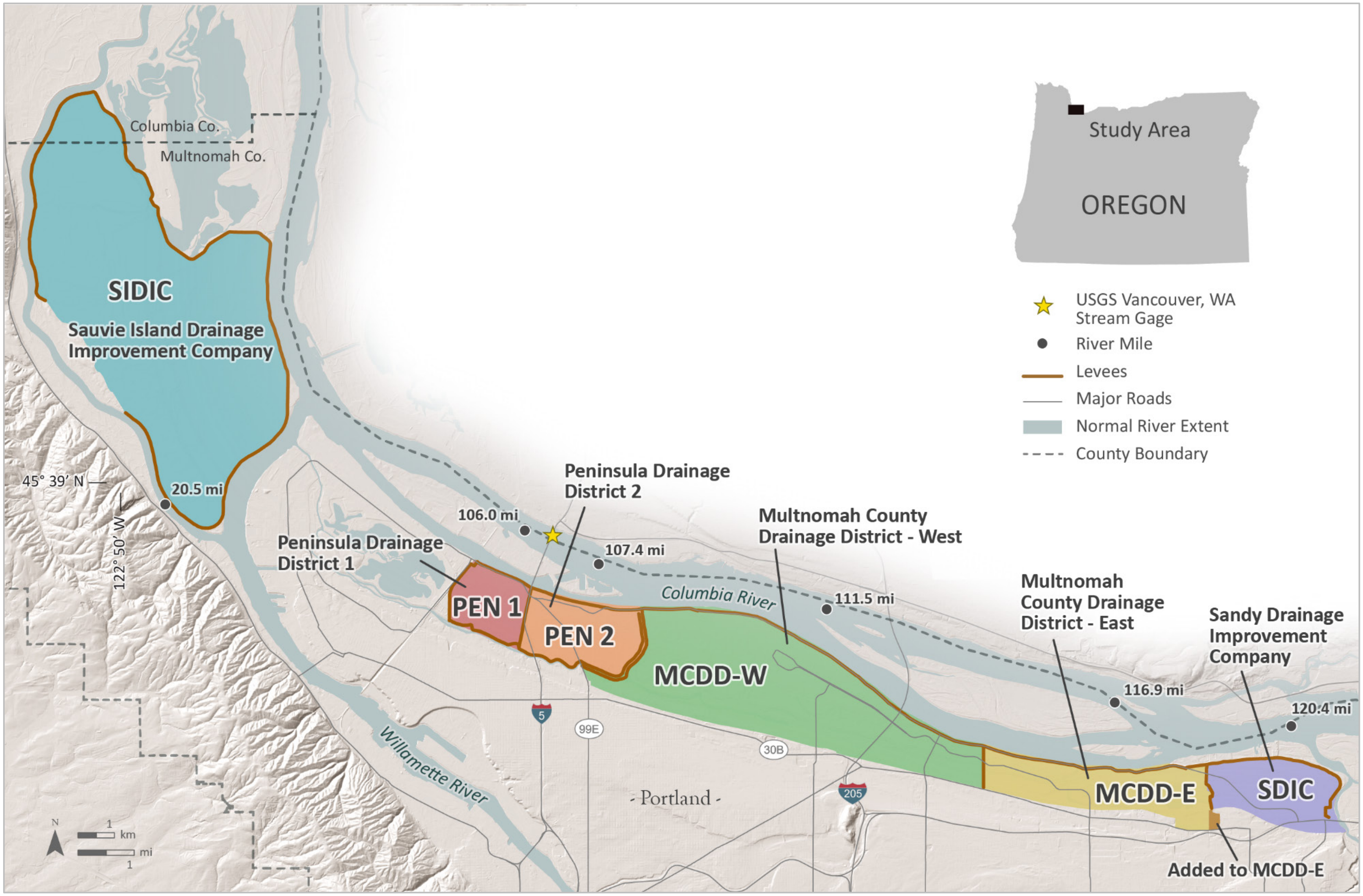
This assessment aimed to increase our understanding of the consequences of a levee breach in conjunction with a major flood on the people and buildings currently located behind the levee systems in Columbia corridor drainage districts in Multnomah County. In this report, we present the results and recommendations from this assessment. Although flooding has occurred in this region in the past, there is a dearth of detailed studies to document risk because this region is perceived to be sufficiently protected from flooding on the Columbia and Willamette Rivers. This assessment addressed this gap in knowledge.

This study was initiated by Levee Ready Columbia, a partnership of over 20 governmental, business, environmental, and community-based organizations committed to a collaborative approach to floodplain management. Funding for this work was provided by the FEMA Risk Map Program for Region 10.

1.2 Study Area

The Columbia corridor drainage district in Multnomah County, Oregon, includes the areas behind the levees along the Columbia River from Sauvie Island to the Sandy River, as shown in **Figure 2**. Five drainage districts exist in this area: Sauvie Island Drainage Improvement Company (SIDIC, extending into Columbia County), Peninsula Drainage District 1 (PEN 1), Peninsula Drainage District 2 (PEN 2), Multnomah County Drainage District 1 (MCDD), and Sandy Drainage Improvement Company (SDIC). MCDD is further divided by a cross levee into western (MCDD-W) and eastern (MCDD-E) sections. Throughout this study, we assume that the cross levees in this system act as hydraulic barriers that unless individually breached or undermined, would contain flooding within a given district. At the request of MCDD staff, the boundary for MCDD-E was amended to include three additional, adjacent buildings that would likely be impacted by 100- and 500-year floods but that are not located in the recognized drainage district boundary (**Figure 2)**. We also analyzed the areas beyond the levees on Sauvie Island and north of SDIC that would have limited access during a major flood event. However, unlike MCDD-E, where three buildings beyond district boundary were added to the area, the study results for the areas beyond the drainage district boundaries in SIDIC and SDIC are presented separately from the rest of the district.

Figure 2. Drainage districts in Multnomah County and levees in study area.



These Columbia corridor drainage districts are members of the Levee Ready Columbia (LRC; http://www.leveereadycolumbia.org/) partnership, which ensures the levee systems meet federal requirements and the systems remain accredited by FEMA and stay active in the USACE PL84-99 Rehabilitation and Inspection Program. LRC is a partnership of more than 20 organizations committed to a collaborative approach to floodplain management. These organizations include local, state, and federal government agencies, as well as business, environmental, and community-based organizations. LRC works with both USACE and FEMA to achieve accreditation compliance. Although most of the land within the study area has been determined to be protected by a levee system (Zone X) on the FEMA 2009 and 2010 revised flood insurance rate maps, some areas behind the levees are currently designated as Special Flood Hazard Areas (FEMA, 2009a, p. 51). Buildings within those areas may be subjected to flooding despite levee protection. Further information on the flood hazard behind the levees can be found in effective and preliminary flood insurance studies and rate maps (FEMA, 2009a, 2016) and the FEMA GeoPlatform (https: //fema.maps.arcgis.com).

This area contains many assets key to the region's economy, most notably the Portland International Airport. In total, more than 2,300 businesses and 50,000 jobs (Oregon Employment Division, 2016) are located within the drainage districts behind more than 45 miles of levees. These additional businesses include numerous local farms, the Portland Metropolitan Exposition Center, and several large shopping complexes that include Home Depot and IKEA and shipping facilities including Amazon and FedEx. In addition, more than 8,000 people live in the study area (U.S. Census Bureau, 2010).

1.3 Scope

1.3.1 Included in analysis

The scope of this assessment focuses on the impacts of a levee breach in conjunction with a major flood on (1) buildings, (2) residential population, (3) employment-related economic loss, (4) above-ground key infrastructure, (5) hazardous materials, (6) community facilities, and (7) transportation networks and parked vehicles. A detailed list of quantified impacts is provided in **Table 2**. We analyzed these impacts for two flood scenarios: a 100-year flood (i.e., the 1% annual chance flood) and a 500-year flood (i.e., the 0.2% annual chance flood) as defined by the effective FEMA flood insurance study (FEMA, 2009a, p. 15). We assumed that if a single section of the current levee breaches, flood water will be able to flow freely into the region behind the levee system, filling the individual drainage district to the same flood river level as on the Columbia or Willamette River. Our analysis did not include new hydraulic modeling or a specific levee breach mechanism, and the results consequently also show the impact of flooding on the region if there were no levees present for a given drainage district. The impact of multiple, simultaneous levee breaches could be inferred by adding together the results from different drainage districts.

Table 2. List of study results by category and value type. See appendices for reported results.

Category	Result	Unit of Measure	Analysis Type
1. Building	building damage	replacement cost[1] and loss ratio[2]	Hazus
	content damage	replacement cost and loss ratio	Hazus
	inventory damage	replacement cost and loss ratio	Hazus
	debris produced	weight[3]	Hazus
2. Residential population	displaced residential Population	count and recovery time[4]	Hazus
3. Economic loss	business closure	count and recovery time	Hazus
	displaced employees	count and recovery time	Hazus
	wages lost	wages[1] and Recovery time	Hazus
4. Key infrastructure	pump stations damage	loss ratio[2]	Hazus
	water treatment facilities damage	loss ratio	Hazus
	natural gas facilities damage	loss ratio	Hazus
	electrical substations damage	loss ratio	Hazus
5. Hazardous materials	storage facility exposure	count	exposure
6. Community assets	site exposure	count	exposure
7. Transportation networks and parked vehicles	bus routes	length[5]	exposure
	freight trucking routes	length	exposure
	light rail lines	length	exposure
	railroad lines	length	exposure
	emergency routes	length	exposure
	damage to vehicles	spreadsheet	Hazus

[1]Reported in dollars; [2]Reported as percentage; [3]Reported in tons; [4]Reported in years; [5]Reported in miles.

1.3.2 Excluded from analysis

Many other direct and indirect impacts from a levee breach and flood are beyond the scope of this study. These include:

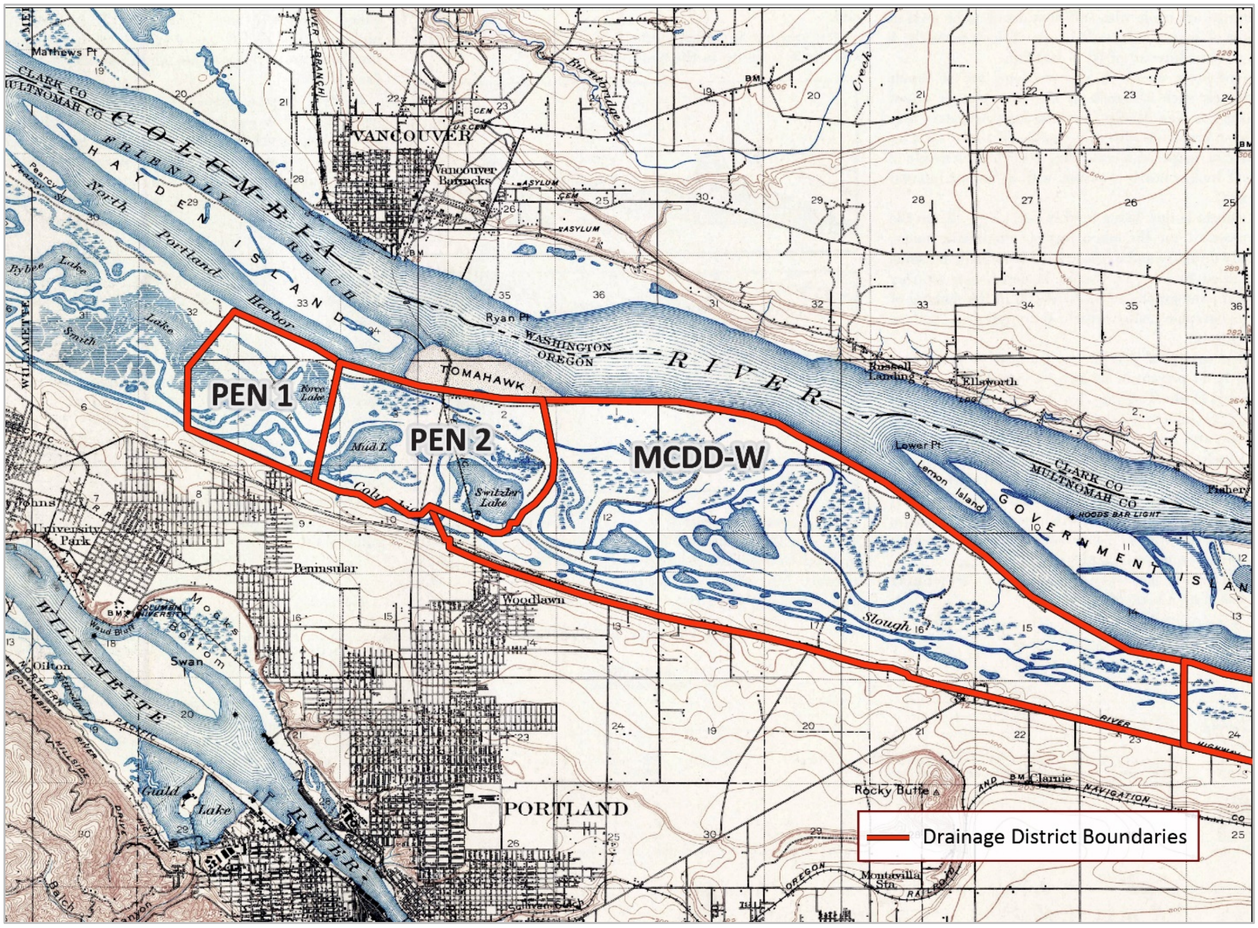
- **Economic:** direct and indirect loss of business revenue; damage to farmland, crops, stored produce, livestock, and outdoor landscaping; damage to airport runways; damage to airplanes or farm equipment; post-flood business relocation; demand surge or rebuilding opportunities; damage to luggage and in-transit inventories; permanent post-disaster business closure; change in current spending by current employees and residents; indirect regional impacts of airport closure
- **Physical:** new hydraulic modeling; specific geotechnical levee failure mechanisms; surface and groundwater interactions; impacts or interactions from storm water runoff or sewer backup; assumptions of functioning water pumps; no reduction in flood stage after levee breach; no change in topography (e.g. sediment deposition or erosion) as a result of flooding; earthquake-induced liquefaction or ground deformation
- **Social:** estimation of casualties; exploration of the demographics of the displaced residents and employees

- **Conditional and response:** evacuation scenarios; time of day or season of flooding
- **Environmental and health:** potential ecological positive or negative impacts; specific health consequences related to hazardous material exposure; impacts on drinking water
- **Future conditions:** changes in hydrologic regime related to climate change; changes in land use; changes in population; unidentified future construction
- **Other:** Underground utilities such as power transmission lines and water lines

1.4 Historical Flood Context

Located along the floodplain of the Columbia River and adjacent to the confluence of the Columbia and Willamette Rivers, the drainage districts are positioned in an area highly vulnerable to flooding. Historical maps, such as the 1905 U.S. Geological Survey (USGS) topographic map reproduced in **Figure 3**, indicate that before the construction of levees and dams in the watersheds, the LRC area was composed of a mix of sloughs, lakes, wetlands, and side channels along the south shore of the Columbia River (USGS, 1905). Surficial geologic maps of the Portland area describe the underlying geology as composed of fine sediments deposited by the Columbia River with landforms that indicate frequent flooding before modern flood control practices (Ma and others, 2012).

Figure 3. Portion of a 1905 U.S. Geological Survey 1:62,500-scale Portland quadrangle topographic map modified to show modern drainage district boundaries.



Since the late nineteenth century, many of the major flood events along the Columbia and Willamette River have been triggered by heavy winter rain, or rain-on-snow events, or high discharges due to late spring snowmelt (FEMA, 2009a; Multnomah County Emergency Management, 2017, Section 3.2). Flooding may also be exacerbated by interactions between these two rivers. When the flood stage on the Columbia River is higher than the Willamette River stage, water has been observed to back up along the Willamette River causing localized flooding near the confluence of the two rivers (FEMA, 2009a).

Historical records indicate that five floods in the Columbia River have exceeded the 100-year flood elevation since 1894 (**Table 3**). According to FEMA's effective flood insurance study for Multnomah County (FEMA, 2009a), the minimum flood stage is 21.3 feet at the Vancouver gage, the 100-year (1% annual chance) flood elevation is 31.6 feet, and the 500-year (0.2% annual chance) flood elevation is 35.2 feet, North American Vertical Datum 1988 (NAVD88). During most of these major floods, the river exceeded flood stage for several weeks (FEMA, 2009a). However, such flood events have been rare in recent years. The average stage at the Vancouver gage during the 2007–2017 water years was 10.85 feet with a peak stage of 22.7 feet NADV88 recorded during March 2017 (USGS, 2018).

Table 3. Observed flood water surface elevations at Vancouver gage, Columbia River (U.S. Geological Survey gage 14144700).

Year	Observed Water Surface Elevation (ft, NADV 88)	Comparison	Source
June 1894	39.7	> 500-year flood (0.2% annual chance)	FEMA (2009a)
June 1948	36.3	> 500-year flood	FEMA (2009a)
June 1956	32.9	> 100-year flood (1% annual chance)	FEMA (2009a)
Dec 1964	33.0	> 100-year flood	FEMA (2009a)
Feb 1996	32.5	> 100-year flood	MCDD (2016a)

MCDD is Multnomah County Drainage District.

During the early twentieth century, residents and local interest groups began to construct levees in the drainage districts to increase access to agricultural land within the floodplain (Spencer, 1950). Following the Flood Control Act of 1936, USACE began to support the levee building effort and also constructed dozens of dams for flood control, hydroelectricity, and navigation in the Willamette and Columbia River Basins between the 1930s and 1980s. Although large dams often substantially reduce peak annual flood discharges on the rivers they regulate (Graf, 2006), the flood of 1996 (**Table 3**) shows that, given the correct conditions, major flooding is still possible in the Portland region and that the area continues to be at risk.

Despite attempts to control flooding, a series of levee breaches occurred on Memorial Day in 1948 that led to floodwaters of the Columbia River destroying the city of Vanport, flooding modern-day PEN 1 and PEN 2 (**Figure 4**). Within the impacted drainage districts, flood waters were observed to be 10 to 20 feet deep, leading to the destruction of 18,000 homes (**Figure 5**) and 15 deaths; land remained flooded weeks to months in many places (Basham and others, 1971, p. 264). In subsequent flooding events the levees have not breached, but seepage, sand boils, and erosion were documented in this levee segment during the 1996 flood (MCDD, 2016a). Without the necessary maintenance required to maintain the structures' integrity, it is possible the levees could again fail during a flood in response to a rupture, overtopping, or groundwater seepage, flooding homes and businesses built behind the levees.

Figure 4. Photograph of Vanport levee breach. [Credit: "Aerial view of Vanport Flood looking south from Hayden Island" from the City of Portland (OR) Archives, A2004-002.7252 with annotations by DOGAMI study authors.]

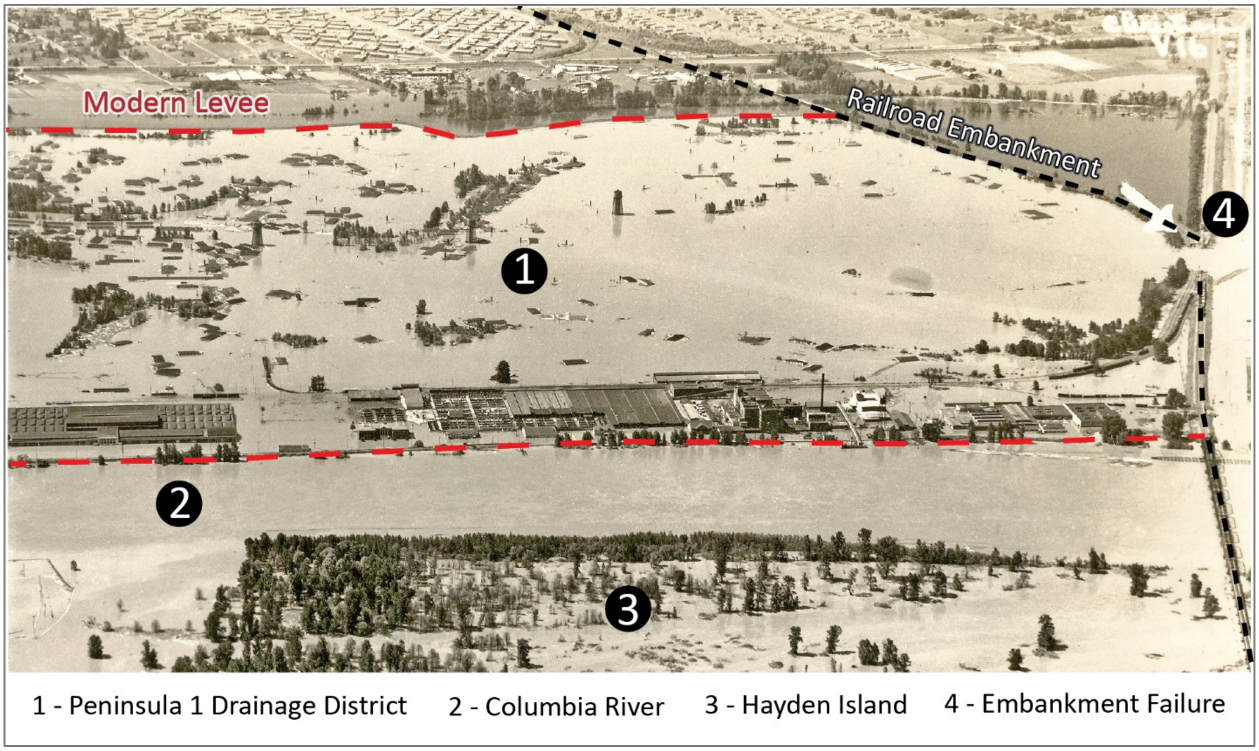


Figure 5. photo Photograph of debris in Vanport after the levee breach. [Credit: "Vanport flood aftermath building debris" from the City of Portland (OR) Archives, A2001-083 (1948)].

2.0 METHODS

2.1 Introduction

We have divided this section into two phases: data development and flood impact analysis. During the data development phase, we established depth grids to model the variation in flood depth across the drainage districts for two major flooding scenarios. We also gathered and refined spatial information about key features including buildings, population, employment, infrastructure, and transportation networks. During the second phase, we used the FEMA Hazus-MH methodology to produce standard and long-duration flood damage estimations for both modeled floods, the 100-year and the-500 year. Hazus-MH uses observed flood damage and expert opinions to predict future damage to structures based on the structure type and depth of flooding experienced by a structure (FEMA, 2009a). Where we were unable to use Hazus-MH to estimate damage, we performed an exposure analysis to determine which structures would be directly impacted by flooding.

2.2 Data Development

2.2.1 Flood depth grids

This study assessed the impact of both a 100-year (1-percent annual chance) and 500-year (0.2-percent annual chance) flood as requested by our project partners. We assumed that a levee breach would occur at an arbitrary point along the levee and that the area behind the levee would fill with water to meet the adjacent river flood elevation. We further assumed the north-south oriented levees located between drainage districts (i.e., cross-levees) would effectively contain floodwaters within an individual district. Thus, we performed our assessment and reported flooding impacts by district and not as overall loss. For PEN 2, we assumed the causeway supporting NE Martin Luther King Jr. Boulevard does not function as a cross-levee due to a series of underpasses that would allow water to move throughout the district.

To model the impacts of a 100- and a 500-year flood, we first established the potential depth of flooding (i.e., depth grids) within each drainage district without the protection from levees. With the exception of SIDIC, this was accomplished by constructing a series of water surface elevations along the Columbia River and Multnomah Channel provided by MCDD, which coincided with FEMA's flood profiles (FEMA, 2009a, Plates 06P–08P and Plate 47P). For Sauvie Island, we used the flood values provided in FEMA's flood insurance study (2016, Table 6) to determine the flood water surface elevations adjacent to the Sauvie Island Bridge. The river mile location and flood elevation for each district are summarized in **Table 4**.

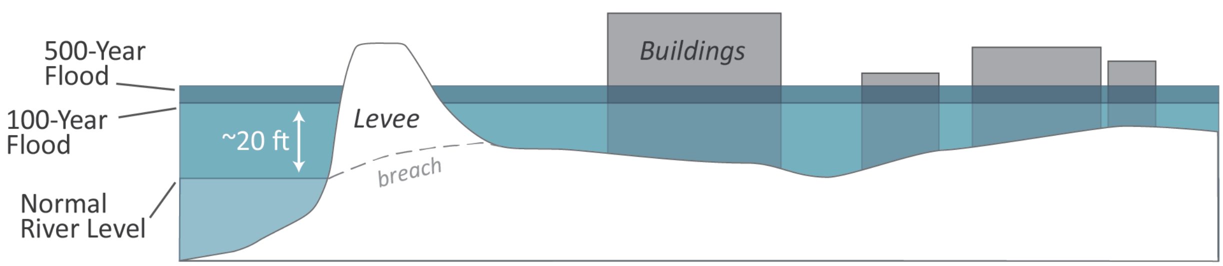
Next, we created a continuous, high-resolution ground surface elevation for the full study area. For most areas, we used the 1-meter, 2014 bare-earth topographic lidar for all of MCDD and adjacent districts (Oregon Lidar Consortium, 2015). For the portions of Sauvie Island not covered by the 2014 lidar project, we used the 1-meter, 2010 lidar and combined it with the 2014 elevation model (Watershed Sciences, 2010).

Table 4. Flood elevations defined for the 100- and 500-year events by river mile (Sara Morrissey, MCDD, written commun., 2016; FEMA, 2009a, Table 6) in the Columbia corridor drainage districts, Multnomah County, Oregon. Elevations in feet, NAVD88 vertical datum.

Drainage District	River Name	FEMA River Mile	100-Year Elevation (ft)	500-Year Elevation (ft)
SIDIC	Multnomah Channel	20.50	30.8	34.9
PEN 1	Columbia River	106.00	31.5	35.0
PEN 2	Columbia River	107.40	31.8	35.3
MCDD-W	Columbia River	111.49	32.7	36.0
MCDD-E	Columbia River	116.90	34.0	37.2
SDIC	Columbia River	120.40	34.8	38.0

We created flood depth grids by subtracting the lidar-derived, digital elevation model from the fixed water surface elevation listed in **Table 4**, setting negative values to null. The water surface elevation was assumed to be uniform within each drainage district (**Figure 6**). The flood depth grids and damage estimates focused on the areas behind the existing levees, but also included a few hundred buildings on Sauvie Island and near Chinook Landing Marine Park, which are outside of the levee systems but to which access would be limited during flooding.

Figure 6. Example of generalized flood depth relationships in drainage districts.



The 100- and 500-year flood depth grids provide reference points that are well understood, but a levee failure can occur at any elevated river level. To improve our understanding of the flood damage model and to better communicate the damage to buildings from a levee breach at other river levels, we prepared ten additional flood depth grids that allowed us to refine our model runs at ± 1-foot intervals around the 100-year elevation level (±5 feet). For example, for the MCDD-E district we created flood depth grids using 29.0, 30.0, 31.0, 32.0, 33.0, 35.0, 36.0, 37.0, 38.0, and 39.0 water surface elevation levels (in feet, NAVD88).

2.2.2 Asset database

2.2.2.1 Buildings

To characterize the buildings in the study area, we modified the building database developed by Bauer and others (2018). Each building was represented by a geographic point in the dataset and had many associated attributes including the following information:

- **Occupancy class**: Bauer and others (2018) assigned each building one of 33 occupancy classes that described the building's dominant use. For example, within the category of commercial facilities, a retail store (COM1) can be distinguished from a professional office (COM4). For single-family residential buildings, additional attributes defined the number of stories and if the structure contained a finished basement.
- **First floor height**: This represents the estimated elevation at which water begins to enter the structure (e.g., bottom of a door or other entryway). We initially assigned first-floor heights to buildings based on their occupancy class (**Table 5**) and the bare-earth lidar elevation. Large buildings often required manual corrections as the bare-earth lidar values do not accurately capture elevation within the interior of the buildings.
- **Area**: The building area was determined from the value provided in the Multnomah County tax assessor database (B. Harper, written commun., 2016) or from the building footprint area.
- **Number of stories**: This value was from the Multnomah County tax assessor database (B. Harper, written commun., 2016) or from the building height as determined from 2014 highest-hit lidar data (Oregon Lidar Consortium, 2015).

While most of the attributes were taken directly from Bauer and others (2018), the attributes listed above were modified based on field visits, analysis of oblique and street-level imagery, and insights provided by MCDD staff (Sara Morrissey, MCDD, written commun., 2017). Additional attributes that indicate the number of occupants, building value, and associated business data are discussed in the following sections. By leveraging and refining the database developed by Bauer and others (2018), we created a highly detailed and comprehensive building dataset that served as the user-defined facility database for our Hazus-MH analysis, discussed in Section 2.3.1.

Table 5. List of default first-floor height assignments. Heights are expressed in feet above ground surface.

Building Category	First-Floor Height (ft)
Single-family Residential, no basement	3.0
Single-family Residential with basement	4.0
Manufactured Housing	2.0
All other building types	0.0

For this project, several large buildings that were planned or were under construction at the time of the assessment were included in the risk assessment and represented in the building database as fully occupied, completed structures. We manually digitized these buildings based on available plans and attributed them with available information from planning and permitting documents provided by MCDD (Sara Morrissey, MCDD, written commun., 2017). Floating structures adjacent to the levee, including houseboats, may float or become unmoored during a large flood event and thus do not have a predicted level of damage in Hazus-MH; as such, they were not included in our damage models nor in the overall building inventory.

2.2.2.2 Building, content, and inventory valuation

To determine the value of buildings in the study area, we used the RSMeans valuation method for estimating a building's replacement cost, multiplying the building square footage by a standard cost per square foot (Charest, 2017). We used Hazus-MH SQL database tables (`[dbo].[hzReplacementCost]` and `[dbo].[hzRes1ReplCost]`) that incorporated the 2014 RSMeans national valuation to compute the replacement cost based on occupancy class. We made no inflation or regional adjustments to the tabular data; the difference in consumer price index (CPI) between 2014 and 2017 was minimal and the RSMeans location factor adjustments for regional differences in labor and material costs were negligible. We did not apply regional cost adjustments to the replacement cost. According to Charest (2017), the Portland area location factor of 0.98 for residential construction and 1.0 for commercial construction suggested no need for correction.

It is important to recognize that a building's replacement cost is not the same as its assessed value. For analysis purposes, we used replacement cost because we assumed that new construction materials would be used to make post-flood repairs and to rebuild structures at a standard construction rate independent of the building's age or location. By contrast, assessed building value includes both the land value, which may fluctuate greatly depending on real estate markets, and commonly the building's depreciated improvement value.

An abnormal shortage of skilled labor or materials can occur after a large-scale disaster. Demand surge is a process resulting in a higher cost to repair building damage after large disasters, compared with repair costs associated with a small disaster (Olsen and Porter, 2011). Adjusting repair and replacement costs due to a likely demand surge was beyond the scope of this project.

To determine the value of content and inventory, we followed the assumption used by Hazus-MH that the value of a building's content and inventory is proportional to that building's value. A building's content includes furniture, appliances, computers, and equipment not integral to the structure. Inventory consists of items for direct sale or distribution and items used directly in the production of a good. Only some types of buildings, such as COM1 (retail trade) and IND2 (light industrial), have an associated business inventory. Inventory cost is a percentage of the annual gross sales in production per square foot of the facility, with estimates of cost provided by FEMA (2011b, Table 14.8). The Oregon Department of Geology and Mineral Industries (DOGAMI) flood script uses the standard Hazus-MH multipliers to calculate content cost and business inventory per building (FEMA, 2011b, Table 14.6 and Table 14.8). Where better data on content and inventory were available, we included that in our database. If a content and/or inventory cost is provided, the DOGAMI flood script will use that value; otherwise, the script computes the content and inventory cost per the Hazus-MH approach (Bauer, 2018).

Certain buildings in the study area were unusual and required closer attention. In the case of the Portland International and Troutdale Airports, we estimated the building value based on the value to which the airports, Port of Portland headquarters, and the long- and short-term parking lots are insured based on information provided by the Port of Portland (Ira Zuckerman, written commun., 2017). The airport facilities in the study area commonly have inventory in transit whose monetary value is significant and variable; we determined that this inventory should be included in a flood loss estimation. However, Hazus-MH provides no guidelines for such facilities. Insurance coverage for this inventory is carried by individual airline companies, which could provide dollar estimates, but such data were not available. For this study, we therefore modeled inventory for air cargo and commercial air facilities using the COM2 (commercial warehouse) rates listed in the FEMA technical manual for flood modeling (2011b, Table 14.6).

2.2.2.3 Permanent residents

To determine the displaced population during a flood, we first established the number of people within individual buildings as determined by Bauer and others (2018). The number of residents were assigned by Bauer and others (2018) to individual residential buildings by distributing the U.S. Census Bureau 2010 population total per census block group on a building square footage prorated basis. We used the 2010 census data as this was the highest-resolution data available at the time of the assessment. Although our examination did not show any visual discrepancies between the older population counts and more recent building footprints, the Portland State University Population Research Center estimates that the population of Multnomah County increased by ~9% between 2010 and July of 2017 (Portland State University Population Research Center, 2017). The U.S. Census Bureau dataset included the incarcerated population in Columbia River Correctional Institution and Multnomah County Inverness Jail. At the request of MCDD, we added the 60 residents living in Dignity Village (Angela Carkner, MCDD, written commun., 2017).

2.2.2.4 Average employment and annual wages paid

We obtained detailed employer unemployment insurance data from Oregon Employment Division (OED, 2016) as a georeferenced, tax lot-specific pointfile. These data contain information on the number of employees, annual wages paid, and a six-digit North American Industrial Classification System (NAICS) code that classifies the type of activity in which the business is primarily engaged. The dataset included wage and employment information on small businesses operating out of residential homes. We expanded the NAICS code to Hazus-MH occupancy class mappings listed in Table C1 (Wein and others, 2013, Table C1, p. 38), refining the occupancy class assignment for non-residential buildings. Where multiple employers existed within a building, we used the largest employer by wages paid to determine the dominant use of the building. For tax lots containing building(s) that house multiple employers, we totaled the number of employees and annual wages paid in that tax lot, and we prorated those amounts across all buildings within the tax lot on a per square footage basis.

As a quality check, we inspected the dataset for commercial and industrial buildings without employment and wage data. We noted that, by building area, there were no OED data for 15% of commercial and industrial facilities, including several facilities that were under construction or newly constructed. To address these gaps, we defined an average wage and employees per square foot value based on available employment and wage data for the commercial and industrial buildings in our study area. The per square footage basis is an established method for estimating economic data where otherwise not available (FEMA, 2011b, Tables 14.8 and 14.14). For our study area, commercial structures were assigned 1.22 employees and $57.3 thousand dollars per thousand square feet. Industrial structures were assigned 1.39 employees and $78.2 thousand dollars per thousand square feet.

2.2.2.5 Additional datasets

To complete the risk assessment, we gathered additional Geographic Information Systems (GIS) datasets from a variety of sources. The elevation and depth of flooding for each of these assets and sites were extracted from the lidar compilation and depth grids discussed in Section 2.2.1. Each feature was characterized by a point, line, or polygon based on information from the data source. Both the community assets and the parking lots and parked vehicle lists were created by MCDD staff for the purposes of this study (Sara Morrissey, MCDD, written commun., 2017). More information on the site-selection process can be found by contacting MCDD staff.

- Key infrastructure
  - Electrical substation (Office of Emergency Management (OEM), 2017, modified using 2016 USDA NAIP imagery)
  - Natural gas facilities (OEM, 2017)
  - Pump stations (Sara Morrissey, MCDD, written commun., 2017)
  - Water Treatment Facilities (OEM, 2017)
- Hazardous materials (Oregon Office of State Fire Marshal, 2017)
- Community assets (Joel Schoening , MCDD, written commun., 2017)
- Parking lots and parked vehicles (Sara Morrissey, MCDD, written commun., 2017, modified using 2016 USDA NAIP imagery)
- Transportation networks
  - Bus routes (Metro, 2016)
  - Light rail lines (Metro, 2016)
  - Railroad tracks (Metro, 2016)
  - Trucking routes (Metro, 2016)
  - Metro emergency routes (Sara Morrissey, MCDD, written commun., 1996)

2.3 Analysis

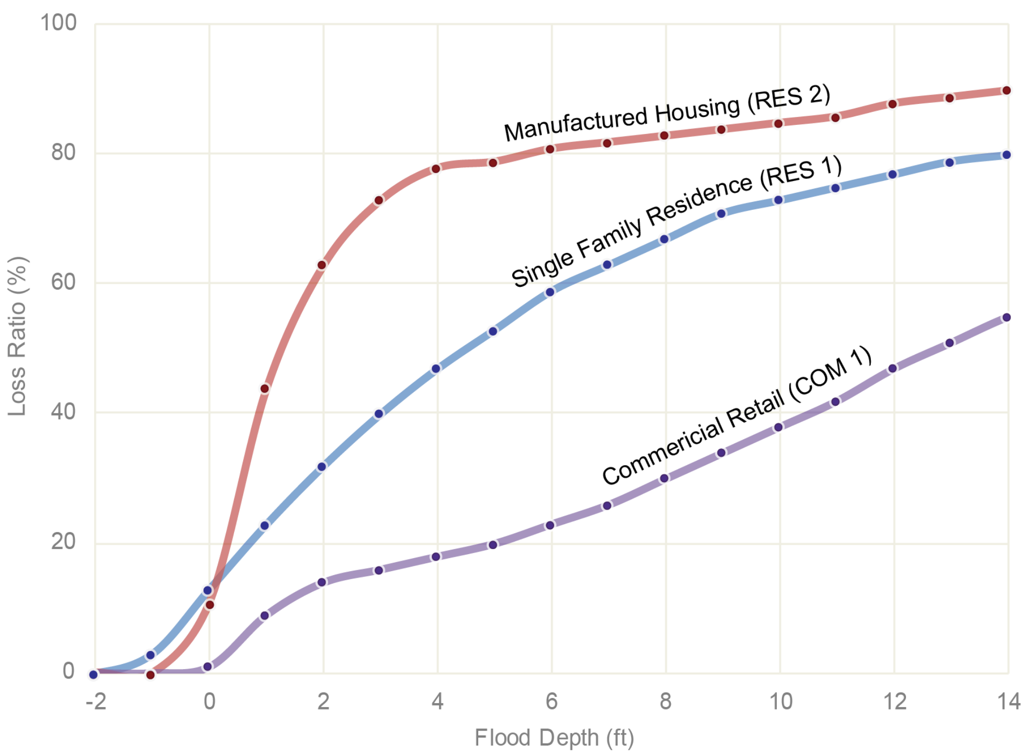
2.3.1 Hazus flood damage estimations

2.3.1.1 Building, content, and inventory losses

Hazus-MH is a nationally applicable, standardized methodology that estimates potential losses from earthquakes, floods, and hurricanes. Hazus-MH was developed by FEMA and uses GIS technology to estimate the physical, economic, and social impacts of disasters (FEMA, 2011a). To predict damage from flooding, the Hazus-MH model assumes that building damage is proportional to the depth of flooding experienced by a given building. This assumption is supported by decades of observations of flood impacts. In the past, qualified inspectors have recorded the flooding depth for buildings relative to their first-floor elevation and provided repair cost estimates. Inspectors have recorded a sufficient number of depth and damage relationships to allow Hazus-MH to accurately estimate building damage prior to flooding (Scawthorn and others, 2006).

The Hazus-MH flood model uses an individual building's depth of flooding, first-floor height above ground, and presence of a basement to calculate the loss ratio for a given building, encapsulated into a depth-damage function (DDF). DDFs are unique to each building's occupancy class; a full set of DDFs, from various sources is defined by FEMA (2011b, Chapter 5). **Figure 7** shows the relative damage to structures as a loss ratio (i.e., the cost of flood damage divided by the total value of the building). Damage to buildings can occur when the flooding elevation is at or below the first floor because damage can occur to structures in the crawl space. Manufactured homes (RES2 type) are particularly vulnerable to flood damage when the flood level rises above the first floor (FEMA, 2006, Chapter 4).

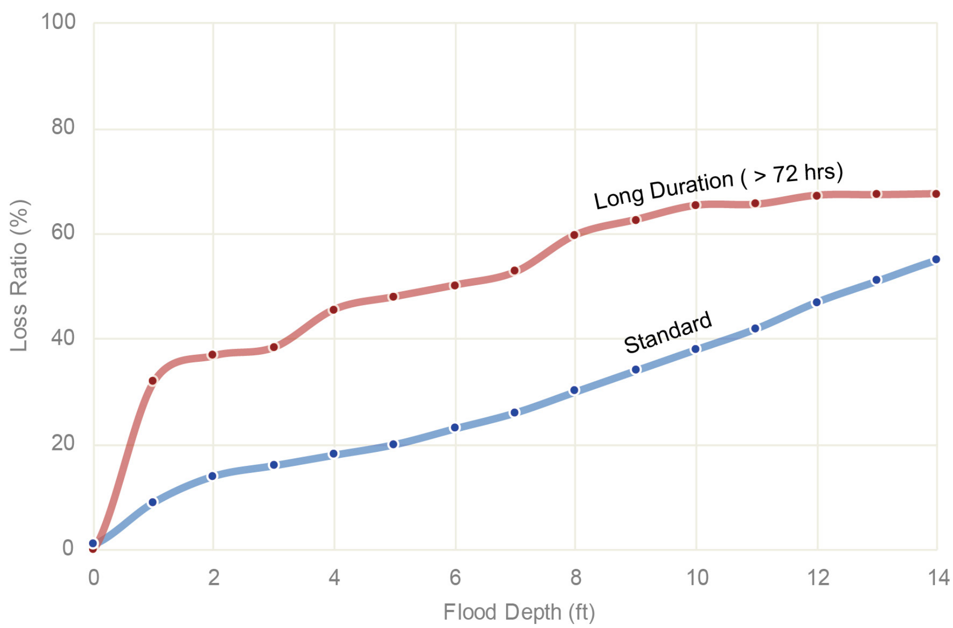
Figure 7. An example of standard depth-damage functions (DDFs) for building repair cost for three common building occupancy classes. The single family residence (RES1) shown is a non-basement structure. Data from Hazus-MH 4.0 software (FEMA, 2017a).



DOGAMI developed a Python script intended to complement a structure-level Hazus-MH analysis of flood risk by providing rapid estimates of damage to building, content, and inventory, building debris, and building restoration times for a given flood depth grid or suite of flood depth grids (Bauer, 2018). The script also provides several structure-level results that are calculated using the methods defined in the Hazus-MH Flood Technical Manual (FEMA, 2011b) but were not reported at an individual building level by the original Hazus-MH tool. For example, the script explicitly states the quantity of building debris produced by an individual building and the number of days needed to repair or replace the damaged building. The temporal element is derived following the Hazus-MH methods specified by FEMA (2011b).

Given the flexibility afforded by the Bauer (2018) script, we performed two types of model runs for each flood scenario. During the initial run, we estimated damage to buildings, contents, and inventory based on standard (Hazus-MH default) DDFs. These standard relationships represent an average estimate for a given occupancy class category. During the second model run, we estimated damage to buildings, contents, and inventory based on freshwater, long-duration DDFs from USACE (2006, Tables 1, 3, 4, and 5). Although depth-in-structure has long been recognized as the single best predictor of building loss (de Moel and Aerts, 2011), damage to a building can increase significantly for a particular flood depth given long flood duration (FEMA, 2005); FEMA (2008) defines a long flood duration as >72 hours. A cursory review of regional hydrographs and the historical accounts of the 1948 Vanport flood (Maben, 1987) suggests that any future levee breach in the study area will result in multiple days of flooding, far exceeding the 72-hour threshold. Providing the range of default and long-duration flood damage results allows us to better represent the uncertainty and the range of loss that could result from a levee breach. **Figure 8** shows a comparison between the standard DDF and long-duration flood DDF. In most cases, the long-duration DDF results in a higher loss ratio than the default DDF provided in Hazus-MH. However, long-duration DDFs were not available for all types of occupancy classes. For these latter cases, we reported losses using the standard Hazus-MH DDF.

Figure 8. Comparison between standard and long-duration depth-damage functions for a retail commercial (COM1) occupancy class for a wood-steel frame building (USACE, 2006, Table 3).



Finally, to increase our understanding of the uncertainty and assumptions inherent in this DDF-based model, we performed a basic model sensitivity test by re-running the damage analysis at ± 1-foot intervals around the 100-year elevation level (± 5 feet).

2.3.1.2 Economic losses and outage times

The Hazus-MH flood model currently does not provide structure-level estimates for direct economic impacts of relocation expenses, capital-related income losses, wage losses, and rental income losses. Common to each of these calculations is an estimate of the time needed to repair or replace the building for post-flood occupancy (FEMA, 2011b, Table 14.12). The flood script developed by Bauer (2018) provides that key piece of information on a per-building basis, allowing minimum and maximum repair/replace time estimates based on the methods outlined by FEMA (2011b).

To characterize direct economic losses, DOGAMI, using the Bauer (2018) script, estimated the number of jobs and the total wages lost. Per input from MCDD, we did not factor in the capacity of a business to temporarily relocate to another facility and resume business while the damaged building is repaired or replaced. Our wage and employment analysis assumed an impacted business would be shut down in its entirety for the specified repair time. The job and wage loss calculation, on a per-building basis, then becomes a simple implementation of Equation 14-7 (FEMA, 2011b), with the income recapture factor set to zero: wages paid per day times the number of days the building is repaired or replaced. We recognize this approach provides a conservative estimate on job and wage loss due to a flood. In addition to providing a single loss number of a given flood scenario, we can express the cumulative wage and employment impact and recovery graphically, using each building's unique business outage time and wage and job disruption.

2.3.1.3 Key infrastructure

To evaluate damage to above-ground, key infrastructure, we used the Hazus-MH model depth-damage functions for water treatment plants, pumping plants, wastewater treatment plants, and electrical substations (FEMA, 2011b, Tables 7.4 and 7.9). Our research did not uncover any long-duration depth-damage functions for such facilities. As the tables in the technical manual indicate, Hazus-MH provides damage estimations for key infrastructure that is flooded only 0 to 10 feet in depth. In the absence of damage estimations for more deeply flooded infrastructure, we assigned key infrastructure experiencing > 10 feet of flood the maximum damage levels (i.e., the damage state for 10 feet of flooding).

2.3.1.4 Debris

The FEMA Hazus-MH flood model currently does not estimate building debris at a structural level. The flood script by Bauer (2018) incorporates the methods outlined by FEMA (2011b, Chapter 11), providing debris tonnage on an individual building basis. We summarized the building debris tonnage for each flooding scenario by drainage district. Accounting for the quantity of building debris produced from a flood can be import

2.3.1.5 Vehicle damage

Although the Hazus-MH flood model provides DDFs for automobiles, it is challenging to estimate how many and what type of vehicles would remain parked in areas impacted by a levee breach. Instead of creating a single, specific damage estimation, we created a Microsoft Excel® spreadsheet (SP-50_Damage-to-Parked-Vehicles.xlsx) that allows users to predict damage for a variable number of vehicles of different types and costs as entered by the user for several of the largest, long-term parking lots in the study area. The DDFs in the spreadsheet were obtained from USACE (2006, Table 6).

2.3.2 Flood exposure

A flood exposure analysis provides a simple method to determine which people, places, and assets are impacted by flooding. Because there are no applicable Hazus-MH damage models, we used this approach to understand the impact of flooding on community assets, hazardous material storage sites, and transportation networks. Although we are able to estimate building damage, we used an exposure analysis to calculate the number of displaced residents under the assumption that even though a home may not be damaged by flooding (e.g., if its first floor elevation is greater than the flood height), the residents may not be able to safely remain in their home if it is surrounded by flood water. Following a similar logic, we included businesses exposed but not damaged by flooding, when quantifying buildings unable to remain open during a flood.

2.3.3 Analysis limitations

Given our choice to rely on a Hazus-MH and exposure methodology, there are several limitations to our analysis. These limitations include but are not limited to the following:

- One of the larger uncertainties in our database is the valuation of a building's content and inventory. We used Hazus-MH standard valuations, which are an average estimate based on occupancy class. For example, we recognize that the numerous shipping facilities within the study area contain diverse equipment and inventory that vary with time.
- Our loss estimation for content and inventory did not factor in any potential benefit from a flood warning system or successful evacuation plans, as summarized by Carsell and others (2004) and noted by FEMA (2011b, Section 5.5).
- The Hazus-MH flood model does not provide damage functions for such entities as aircraft, semi-trailer trucks, tractors, or railroad cars.
- Debris estimates are limited to the building itself, which includes building finish work and the building's foundation. The debris estimate does not include the building's content or inventory, nor does it include additional debris loads such as vegetation and sediment. Additional information on debris management resulting from flooding is given by FEMA (2007).
- Casualties are not modeled in the FEMA Hazus-MH flood tool (FEMA, 2011b, Chapter 11). Life-loss models are available with the USACE HEC-FIA (Flood Impact Analysis) software (USACE, 2015); however, such modeling was beyond the scope of this project.

3.0 RESULTS

This section presents an overview of the findings from our flood risk analysis for each of the Columbia corridor drainage districts in Multnomah County. As described in the Methods section, we assumed that districts are hydrologically separate and that it is improbable that all districts would flood simultaneously. As such, it is prudent to consider the flood risk results for each drainage district separately and not cumulatively. For the sake of simplicity, only the key results are presented in the main body of the report, with a focus on the 100-year flood results. Drainage district-level impact summaries are provided in **Appendix A**. Additional, detailed tables that include both the 100- and 500-year flood results and results for areas beyond the levees on Sauvie Island and north of SDIC are presented in **Appendix B**.

3.1 Impact on Buildings and People

Although each of the drainage districts is vulnerable to flooding, the potential severity and amount of damage varies across the districts. The results from this study show several notable, overarching impacts on buildings and residents listed below.

- **Displaced population:** Within each of the districts except SDIC, more than half of the residents would be initially displaced by a levee breach and 100-year flood (**Figure 9**). The PEN 2 drainage district could experience more than 2,200 displaced residents, while both MCDD W and MCDD E would each have more than 1,500 displaced residents during a 100-year flood (**Table 6**). **Figure 10** shows concentrations of displaced population in PEN 2, in the Columbia River Correctional Institution and Multnomah County Inverness Jail in MCDD W, and in the homes southeast of Fairview Lake in MCDD E. **Figure 11** shows that the residential neighborhoods in PEN 2 and MCDD E have some of the highest loss ratios throughout the districts due to the heavy damage sustained by prefabricated homes.
- **General building exposure:** At least half of the buildings within each of the drainage districts would be exposed to flooding during a levee breach caused by a 100-year event. **Table 8** shows between 65% and 75% of buildings across most of the drainage districts are exposed to flooding; in PEN 2 as many as 95% of buildings are exposed to flooding. In PEN 2 and in MCDD W over 1,000 buildings would be exposed to flooding.
- **Building, content, and inventory damage:** As summarized in **Table 8**, a 100-year flood would result in millions if not billions of dollars in combined building, content, and inventory damage depending on upon which drainage districts were impacted. Our results indicate that SIDIC and PEN 1 have both the lowest building, content, and inventory value ($377 million to $488 million) as well as the lowest repair and replacement costs ($40 million to $150 million) during a 100-year, long-duration flood. **Figure 12** shows that within these two districts, damages are not strongly concentrated within any single area. Our results also indicate that MCDD-W stands apart from all the other districts both in terms of highest current value and highest estimated damage due to flooding. As can be seen in **Table 8** there is more than $8.3 billion in building, content, and inventory value spread across ~1,500 buildings. MCDD-W also has the greatest potential total damage (estimated at ~$3.6 billion to $4.7 billion depending on the duration of the flood), the greatest number of buildings exposed to flooding (> 1,000), and the greatest source for potential debris (>430,000 tons) (**Table 8, Appendix B, Table B-1**). As shown in **Figure 12**, there are concentrations of damage within MCDD-W, including around the Portland Airport terminal and

concourses, Port of Portland headquarters, and the short- and long-term parking garages which account for 7–11% of this potential damage in the district.

- **Differences due to flood magnitude:** There are moderate differences between the impact of a 100-year and a 500-year flood in each of the districts. During a 500-year event, building flooding depths increase by 3–5 feet for most buildings (**Table 4**), resulting in 20–50% more damage than during a 100-year flood (**Table 8** and **Table 9**). PEN 1 shows the greatest proportional difference in estimated damage between a 100-year and 500-year flood with damages increasing by 2 to 3 times more than a 100-year flood. A 500-year flood would also displace an additional ~140 residents from PEN 2 and ~450 residents from MCDD-E (**Table 6** and **Table 7**).

A summary of the impact on buildings can be found in **Table 6** through **Table 9**. **Figure 10** through **Figure 12** were created to display the spatial patterns in potential building damage and displaced population across the drainage districts. We generated the continuous surface using an inverse-distance weight interpolation for each building point's damage in dollars, loss ratio, or number of displaced residents. These spatial patterns are further discussed in **Appendix A**. In addition, more detailed results for 100-year and 500-year flood scenarios are provided in **Appendix B**.

Figure 9. Number of residents initially displaced, after a levee breach and 100-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.

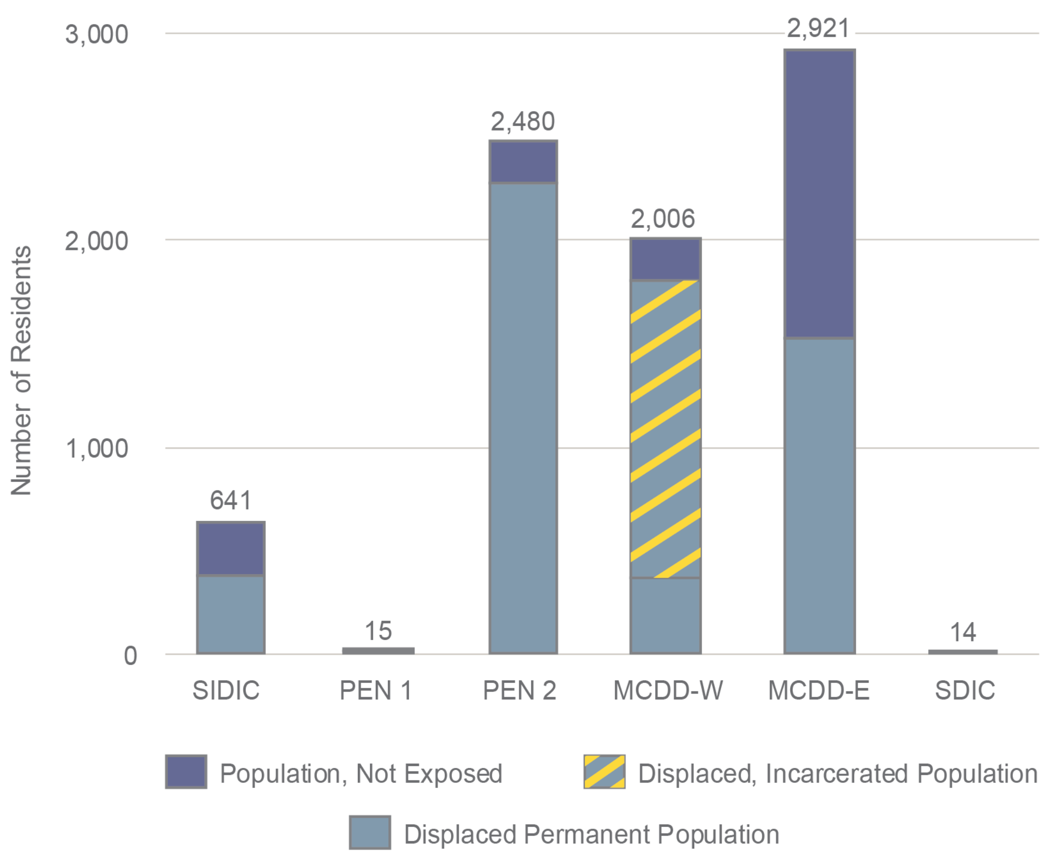


Table 6. Summary of the impact on residents and residences, after a levee breach and 100-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon. The number of residential buildings and residents includes prisons and incarcerated population.

	Current		100-Year Flood			
Drainage District	Residential Buildings	Residents	Buildings with Residents Exposed to Flood	Residents Exposed to Flood	% Residents Exposed to Flood	Residents in Buildings Damaged by Flood
SIDIC	297	641	176	381	59%	365
PEN 1	2	15	1	13	87%	—
PEN 2	863	2,480	812	2,270	92%	1,918
MCDD-W	312	2,006	204	1,799	90%	1,789
MCDD-E	927	2,921	553	1,521	52%	1,414
SDIC	3	14	—	—	0%	—

Table 7. Summary of the impact on residents and residences, after a levee breach and 500-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.A 500-year flood includes displacement estimates from 100-year flood and additional residents displaced due to the increased flood depth levels.

	Current		500-Year Flood			
Drainage District	Buildings with Residents	Residents	Buildings with Residents Exposed to Flood	Residents Exposed to Flood	% Residents Exposed to Flood	Residents in Buildings Damaged by Flood
SIDIC	297	641	195	425	66%	415
PEN 1	2	15	2	15	100%	15
PEN 2	863	2,480	841	2,409	97%	2,054
MCDD-W	312	2,006	216	1,820	91%	1,809
MCDD-E	927	2,921	670	1,972	68%	1,956
SDIC	3	14	—	—	0%	—

Table 8. Building, content, and inventory damage estimates for a levee breach and 100-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.

	Current				100-Year Flood				
Drainage District	Number of Buildings	Building Replacement Value ($ Million)	Content Replacement Value ($ Million)	Inventory Replacement Value ($ Million)	Number of Exposed Buildings	Building Repair Cost ($ Million) [1]	Building Loss Ratio (%)[1]	Content Repair Value ($ Million) [1]	Inventory Repair Value ($ Million)
SIDIC	709	203.1	162.4	12.1	486	56.2−68.7	28−34%	68.6−72.9	8.4
PEN 1	54	214.9	249.9	23.3	42	11.5−15.9	5−7%	20.1−22.3	1.6
PEN 2	1,137	763.7	602.7	22.4	1,075	286−342.3	37−45%	367.7−399	18.9
MCDD-W	1,479	4,427.1	3,775.3	178.7	1,115	1,241.9 −1,852.9	28−42%	2,232.7−2,779.1	113.9
MCDD-E	1,143	1,262.1	1,170.7	69.7	740	324.1−507.7	26−40%	696.3−839.0	48.3
SDIC	180	537.0	594.0	36.7	91	76.5−125.4	14−23%	167−207.3	12.9

[1]Range indicates the standard and long-duration (> 3 day) flood assessment values.

Table 9. Building, content, and inventory damage estimates for a levee breach and 500-year flood in the in the Columbia corridor drainage districts, Multnomah County, Oregon. A 500-year flood includes damage estimates from 100-year flood and additional buildings exposed to the increased flood depth levels.

	Current				500-Year Flood				
Drainage District	Number of Buildings	Building Replacement Value ($ Million)	Content Replacement Value ($ Million)	Inventory Replacement Value ($ Million)	Number of Exposed Buildings	Building Repair Cost ($ Million) [1]	Building Loss Ratio (%)[1]	Content Repair Value ($ Million) [1]	Inventory Repair Value ($ Million)
SIDIC	709	203.1	162.4	12.1	527	83.4−89.7	41−44%	83.6−89.3	10.0
PEN 1	54	214.9	249.9	23.3	50	41.8−65.4	19−30%	90.4−128.6	9.8
PEN 2	1,137	763.7	602.7	22.4	1,110	346.9−372.3	45−49%	402.6−434.8	19.2
MCDD-W	1,479	4,427.1	3,775.3	178.7	1,168	1,666.2–2,224.9	38−50%	2,535.9−2,963.8	126.8
MCDD-E	1,143	1,262.1	1170.7	69.7	870	440.1−618	35−49%	805.4−909.8	69.7
SDIC	180	537.0	594.0	36.7	131	114−187.5	21−35%	250.5−334.4	19.3

[1]Range indicates the standard and long-duration (> 3 day) flood assessment values.

Figure 10. Generalized map of the displaced population due to a levee breach and long-duration, 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. We created the displaced population continuous surface using an inverse-distance weight interpolation of the number of displaced residents within each building point.

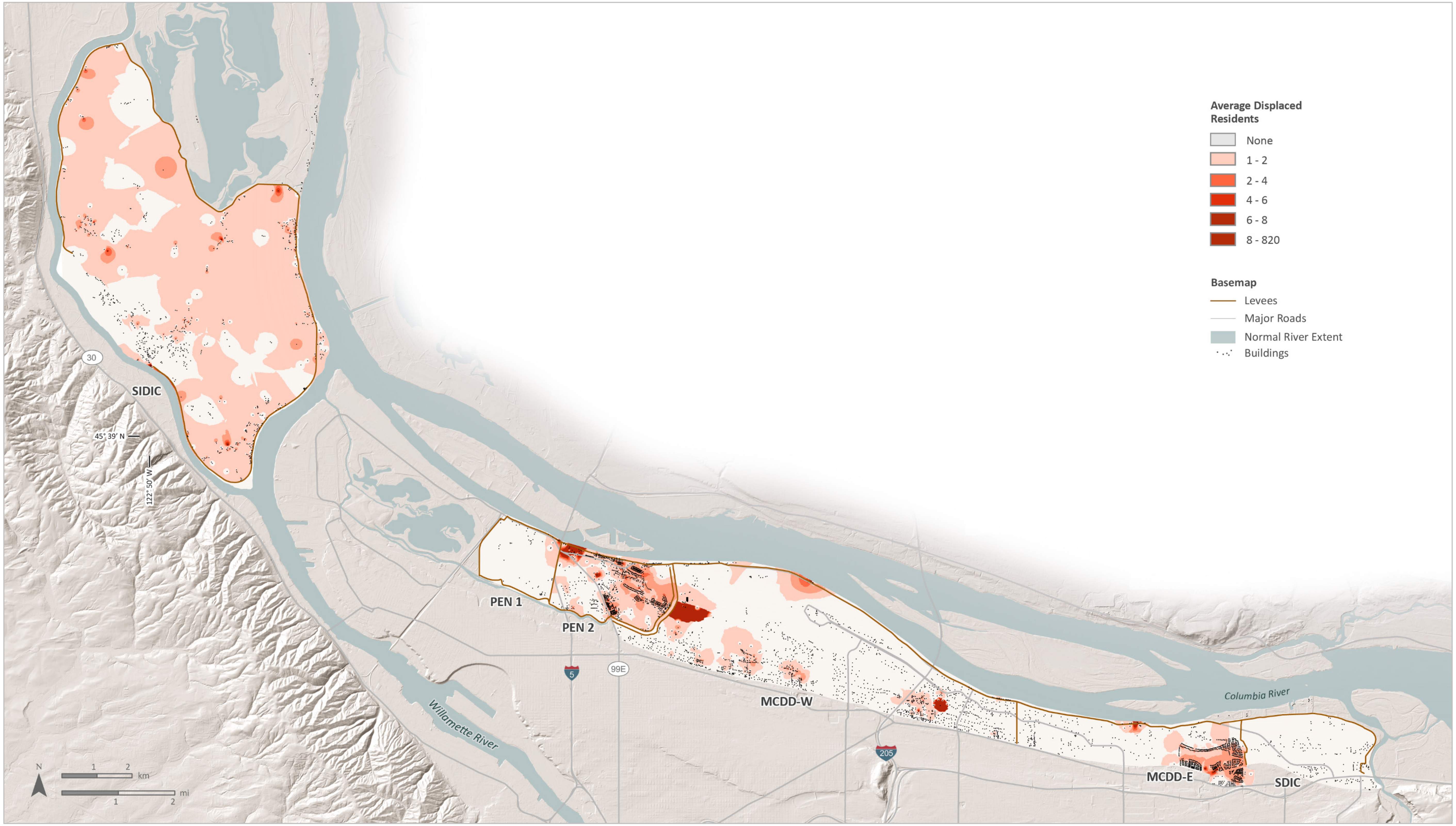


Figure 11. Generalized building loss ratio due to a levee breach and long-duration, 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. We created the loss ratio continuous surface using an inverse-distance weight interpolation for each building point.

Figure 12. Generalized map of the building replacement cost due to a levee breach and long-duration, 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. Building replacement cost surface is defined using an inverse-distance weight interpolation of the building loss values for each building point.

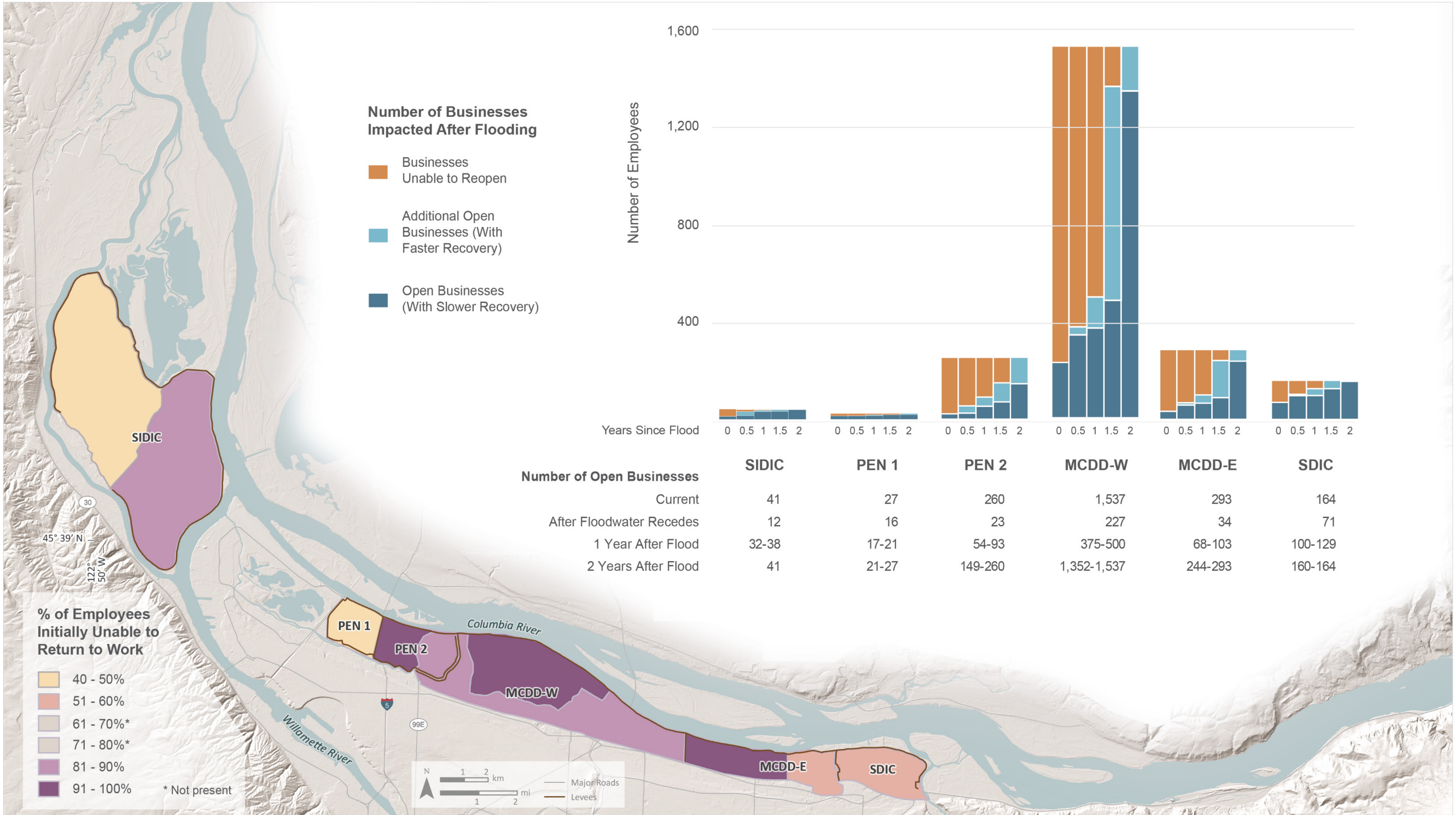
3.2 Impact on Employment

We examined the impact of a levee breach and flooding on business closure, employment, and wage loss for each drainage district. Results are displayed through time, beginning with the day flood waters recede and extending two years after flooding. Restoration times reflect the observed time it takes to physically restore a damaged building, clean, and time required for inspections, permits, approval, and delays due to contractor availability. Although we recognize that, in general, a long-duration flood will result in greater damage to most buildings than a standard flood, the Hazus-MH methodology does not provide a way to predict restoration times specifically for long-duration floods. Instead, it provides a range of building restoration times that represent slower and faster recovery scenarios based on real-world observations.

- **Business recovery time:** The process of reopening businesses and allowing employees to return to work is very gradual after a levee breach and accompanying flood (**Table 10, Figure 13**, and **Figure 14**). In areas where most business are forced to immediately close due to a 100-year flood, the modeling suggests that ~one-third of businesses can be expected to be open one year after flooding. However, past observations of flood recovery indicate that it is normal for most businesses and jobs to be re-established two years after a flood (Scawthorn, 2006). As shown in **Table 10**, the period of time with the greatest variability and uncertainty in recovery is approximately one and a half years after a 100-year flood.
- **Impact on PEN 2, MCDD-W, and MCDD-E:** The businesses in PEN 2, MCDD-W, and MCDD-E would be greatly impacted by a 100-year flood with 88–91% of businesses being directly forced to close following such an event (**Figure 13**). These districts are likely to experience a slower recovery time, with approximately one quarter of employees able to return to work one year after flooding due to significant damage (**Figure 14**). MCDD-W contains the greatest total number of businesses closed (>1,300), and hence the largest number of employees unable to work (>35,000) and wages lost ($1.48–$1.59 billion during the first year) after a 100-year flood (**Figure 14, Table 12**).
- **Impact on SIDIC, PEN 1, and SDIC:** These districts would also be heavily impacted by a flood. However, it is also worth noting that these have between 27 and 164 current businesses, far fewer than other districts. As a result, the initial number of businesses closed in the immediate aftermath of a flood is also far fewer than the remaining districts (**Figure 13**). The rate of business recovery is also faster for these districts, and our analysis shows that it is likely that, one year after a 100-year flood, the majority of employees could return to work due to less severe building damage in these districts (**Table 11**, **Figure 14**). The potential wages lost in these districts during the first year after flooding ranges from as little as $2.1 million with faster recovery in SIDIC to as much as $140 million in SDIC with slower recovery (**Table 12**).

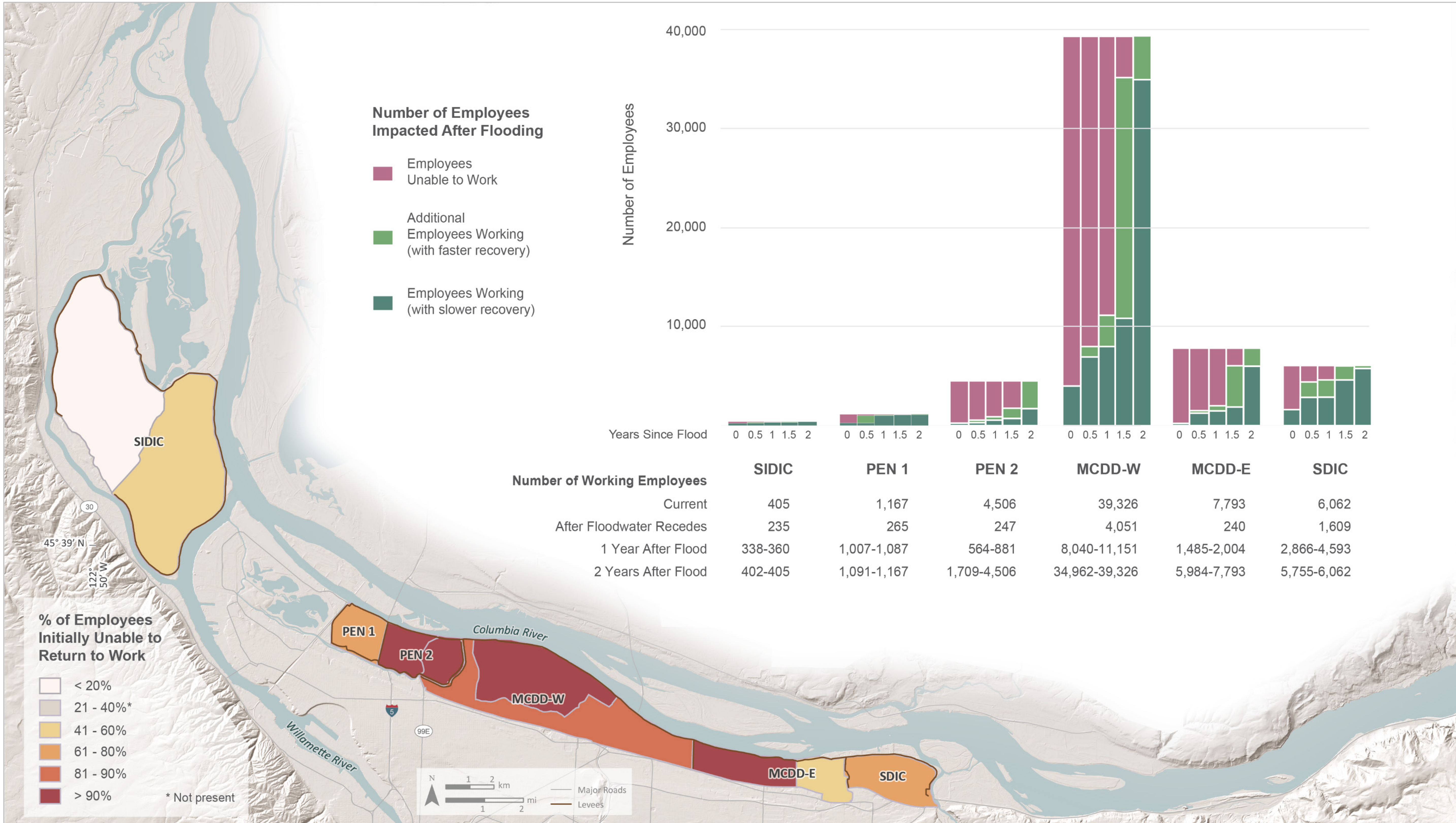
A summary of the impact on employment can be found in **Figure 13**, **Figure 14**, and **Table 10** and **Table 12**. In addition, district-level impact information can be found **Appendix A**, and more detailed results for both 100-year and 500-year floods are provided in **Appendix B, Section B.2.**

Figure 13. Impact of flooding on business closure in each drainage district through time, after a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. For each time period, the number of businesses able to open is shown in dark blue (given a slower recovery process) or light blue (given a faster recovery process) and businesses unable to open are shown in orange.



Number of Open Businesses	SIDIC	PEN 1	PEN 2	MCDD-W	MCDD-E	SDIC
Current	41	27	260	1,537	293	164
After Floodwater Recedes	12	16	23	227	34	71
1 Year After Flood	32-38	17-21	54-93	375-500	68-103	100-129
2 Years After Flood	41	21-27	149-260	1,352-1,537	244-293	160-164

Figure 14. Impact of flooding on number of employees in each drainage district through time, after a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. For each time period, the number of employees able to work is shown in dark green (given a slower recovery process) or light green (given a faster recovery process) and businesses unable to open are shown in dark pink.



Number of Working Employees	SIDIC	PEN 1	PEN 2	MCDD-W	MCDD-E	SDIC
Current	405	1,167	4,506	39,326	7,793	6,062
After Floodwater Recedes	235	265	247	4,051	240	1,609
1 Year After Flood	338-360	1,007-1,087	564-881	8,040-11,151	1,485-2,004	2,866-4,593
2 Years After Flood	402-405	1,091-1,167	1,709-4,506	34,962-39,326	5,984-7,793	5,755-6,062

Table 10. Proportion of businesses able to open over time by district, after a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon.

		% of Reopened Businesses at End of Time Period				
District	Current Number of Businesses	After Floodwaters Recede	0.5 Years	1 Year	1.5 Years	2 Years
SIDIC	41	30%	39–79%	79–93%	82–99%	99–100%
PEN 1	27	58%	58–62%	62–79%	78–79%	79–100%
PEN 2	260	9%	10–21%	21–36%	28–59%	57–100%
MCDD-W	1,537	15%	23–24%	24–33%	32–89%	88–100%
MCDD-E	293	12%	20–24%	23–35%	31–85%	83–100%
SDIC	164	43%	61–64%	61–79%	79–99%	97–100%

Table 11. Proportion of employees able to return to work over time by district, after a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon.

		% of Employees Returned to Work at End of Time Period				
District	Current Number of Employees	After Floodwater Recede	0.5 Years	1 Year	1.5 Years	2 Years
SIDIC	405	58%	61–83%	83–89%	85–99%	99–100%
PEN 1	1,167	23%	23–86%	86–93%	93%	93–100%
PEN 2	4,506	5%	6–13%	13–20%	16–39%	38–100%
MCDD-W	39,326	10%	18–21%	20–28%	28–90%	89–100%
MCDD-E	7,793	3%	16–19%	19–26%	24–77%	77–100%
SDIC	6,062	27%	47–72%	47–76%	76–99%	95–100%

Table 12. Annual employee earnings over time by district, after a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon.

	Annual Employee Earnings			% of Current Earnings	
District	Current	First Year After Flood	Second Year After Flood	First Year After Flood	Second Year After Flood
SIDIC	$12.9 M	$9.2–10.8 M	$11.5–12.6 M	72–83%	89–97%
PEN 1	$66.5 M	$37.1–58.1 M	$62.8–63.7 M	56–87%	94–96%
PEN 2	$193.6 M	$13.4–21.4 M	$28.2–53.6 M	7–11%	15–28%
MCDD-W	$1.9 B	$316.6–427.3 M	$689.6 M–1.3 B	17–22%	36–68%
MCDD-E	$392.8 M	$53.9–85.1 M	$138.3–245.1 M	14–22%	35–62%
SDIC	$240.7 M	$100.7–158.8 M	$154.6–210.7 M	42–66%	64–88%

M is million; B is billion.

3.3 Impact on Key Infrastructure

We examined four types of above-ground, key infrastructure for this study: electrical substations, natural gas facilities, pump stations, and water treatment facilities (**Figure 15**). Within the drainage districts, many of the identified facilities are at significant risk from flooding after a levee breach as summarized below. As noted in the methodology, Hazus-MH does not provide damage predictions for key infrastructure that is flooded to depths greater than 10 feet. Thus, if a particular piece of infrastructure was determined to experience more than 10 feet of flooding, it was assigned the maximum available loss ratio (i.e., that which is provided for 10 feet of flooding), but damages may greater than listed. These assumed loss ratios are noted in **Table 13** and **Table 14** with an asterisk.

Electrical substations: Of the eight substations in the study area, seven substations would be exposed to at least 6 feet of flooding during a 100-year flood if the levees fail. Based on Hazus-MH damage models (FEMA, 2011b, Table 7.9), the loss ratio for these substations may be 9 to 15% or higher during a 100-year flood given that several substations experience more than 10 feet of flooding (**Table 13**). Although most of these substations are located in SDIC, we identified solitary substations in SIDIC, MCDD-W, and MCDD-E as well as shown in **Figure 15**. The SDIC substations include the Bonneville Power Administration Sundial Substation, which aids in providing power throughout the Portland and Columbia Gorge area.

Natural gas facilities: There are two natural gas facilities identified in the study area and both are in MCDD-W. They would be exposed to 7 and 10 feet of flooding, respectively, during a 100-year flood and levee failure (**Table 13**). According to FEMA (2011b, Table 7.9), these facilities would both experience the maximum loss ratio of 40% during a 100-year flood.

Pump stations: All of the 14 pump stations in the drainage districts are located in areas vulnerable to flooding without protection from levees (**Figure 15**). These pump stations would all experience >7 feet of flooding, and one pump station could experience as much as 26 feet of flooding during a 100-year flood (**Table 14**). Given this minimum depth of flooding, all pumps would experience a loss ratio of 40%, the maximum estimation given by Hazus-MH for pump stations (Table 7.5, FEMA, 2011b). Although there is at least one pump station in each drainage district, most of the stations are located in MCDD-W and MCDD-E.

Water treatment facilities: Of the three water treatment facilities identified in the study area, the drinking water facility located in in MCDD-E is vulnerable to both a 100-year and 500-year flood, one waste water facility in SDIC would experience shallow flooding in a 500-year flood, and one waste water facility in SDIC is not exposed to either flood scenario (**Figure 15**). The drinking water facility is expected to experience 9 feet of flooding and a 30% loss ratio during a 100-year flood (**Table 14**). This facility is a component of the Columbia South Shore Well Field system, which serves as a key source of drinking water for more than 800,000 Portland, Gresham, and Fairview residents; flooding in this district would likely lead to disrupted water distribution. The waste water treatment facility in SDIC vulnerable to a 500-year flood would experience less than 1 foot of flooding and a loss ratio of about 5%, and may recover quickly.

Additional information regarding individual key infrastructure results is provided in the drainage district summaries in **Appendix A** and **Appendix B, Section B.3**.

Table 13. Electrical substation and natural gas facility flood depths and loss ratios, during a levee breach and 100- or 500-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. A 500-year flood includes damage estimates from 100-year flood and additional damage to facilities due to increased flood depth levels. The range of estimated depths indicates the highest and lowest depth experienced by all the facilities. Facility-level results are given in Appendix B.

	Electrical Substations							Natural Gas Facilities						
		100-Year Flood			500-Year Flood				100-Year Flood			500-Year Flood		
District	Current Number of Total Facilities	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Current Number of Total Facilities	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)
SIDIC	1	1	8	12	1	12	15*	—	—	—	—	—	—	—
PEN 1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PEN 2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MCDD-W	1	1	6	9	1	9	14	2	2	7–10	40	2	10–13	40*
MCDD-E	2	1	10	15	1	13	15*	—	—	—	—	—	—	—
SDIC	4	4	6–16	9–15*	4	9–19	14–15*	—	—	—	—	—	—	—

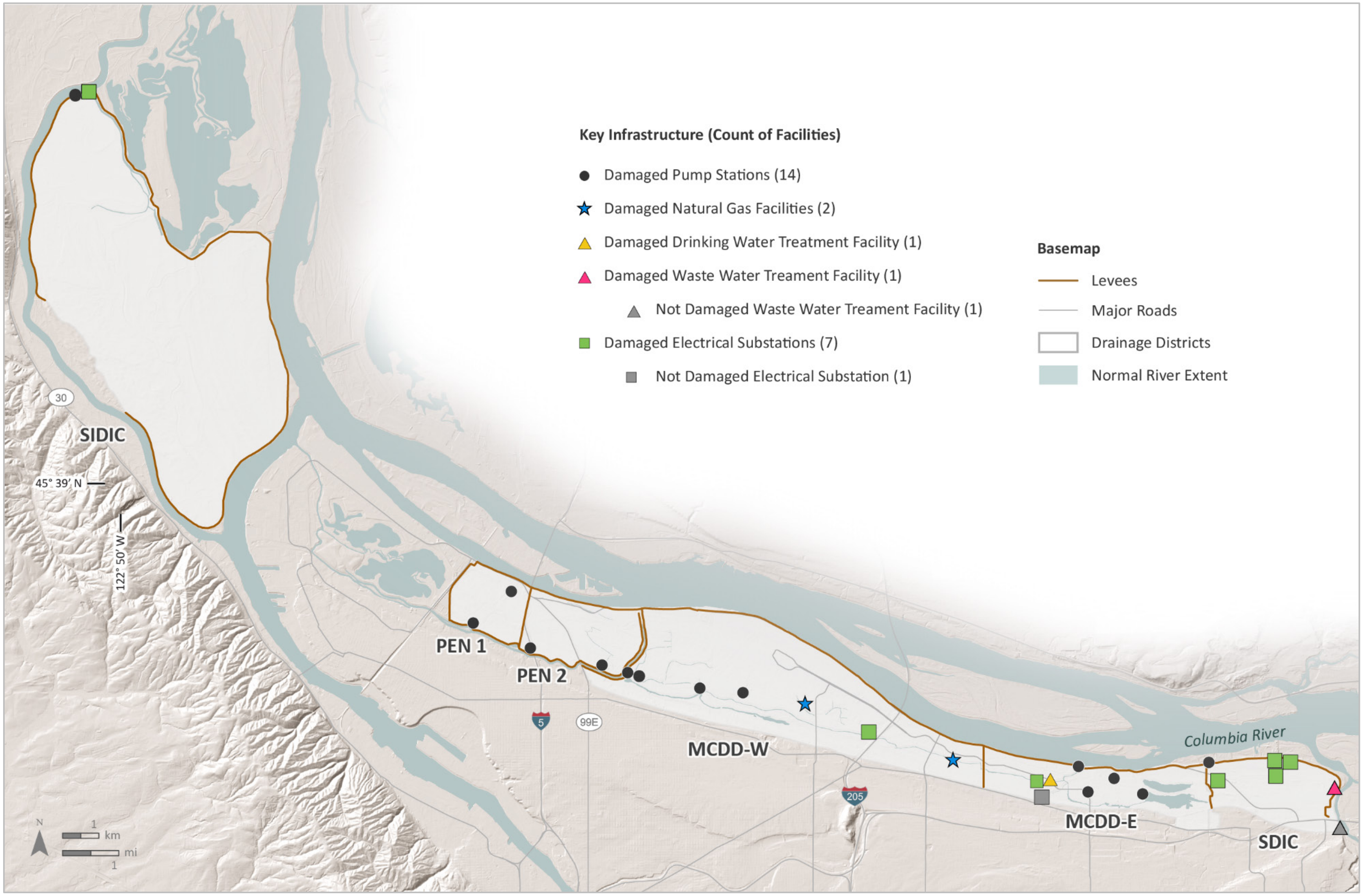
* Indicates that the highest listed loss ratio was used because Hazus-MH does not provide damage estimates for structures experiencing more than 10 feet of flooding.

Table 14. Pump station and water treatment facility flood depths and loss ratios, during a levee breach and 100- or 500-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. A 500-year flood includes damage estimates from 100-year flood and additional damage to facilities due to increased flood depth levels. The range of estimated depths indicates the highest and lowest depth experienced by all the facilities. Facility-level results are given in Appendix B.

	Pump Stations							Water Treatment Facilities						
		100-Year Flood			500-Year Flood				100-Year Flood			500-Year Flood		
District	Current Number of Total Facilities	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Current Number of Total Facilities	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)	Number of Facilities Exposed	Est. Depth (ft)	Loss Ratio (%)
SIDIC	1	1	9	40	1	13	40*	—	—	—	—	—	—	—
PEN 1	2	2	20–26	40*	2	23–29	40*	—	—	—	—	—	—	—
PEN 2	2	2	17–23	40*	2	20–27	40*	—	—	—	—	—	—	—
MCDD-W	4	4	12–22	40*	4	15–25	40*	—	—	—	—	—	—	—
MCDD-E	4	4	7–20	40*	4	10–23	40*	1	1	9.0	30	1	12.0	40*
SDIC	1	1	2	40	1	23	40*	2	0	—	—	1	< 1	5

* Indicates that the highest listed loss ratio was used because Hazus does not provide damage estimates for structures experiencing more than 10 feet of flooding.

Figure 15. Key infrastructure sites categorized by type and damage state resulting from a levee breach and 100-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon.



3.4 Impact on Hazardous Materials

Hundreds of hazardous materials are stored throughout the Columbia corridor drainage districts in Multnomah County (**Table 15**). According data provided by the Oregon Office of State Fire Marshal through the Community Right to Know unit (OSFM, 2017) these materials are classified into groups such as acute health hazards, flammable and combustible liquids, and flammable gases, which are made up of materials including diesel, propane, lead acid batteries, and nitrogen (**Table 16**). Our analysis indicates that MCDD-W contains the largest number of stored hazardous materials and hazardous material storage sites vulnerable to flooding following a levee breach, with the majority of the materials stored in the MCDD-W B section (**Table 15** and **Figure 16**). SIDIC has the fewest number of stored hazardous materials.

Table 15 shows a list of the number of buildings containing hazardous materials, the number of materials stored within each district, their flooding exposure, and the most common category of hazardous material stored. **Table 16** provides examples of the types of materials with each of those categories. **Figure 16** demonstrates how many materials are located within each district and defines the boundaries for the subdivided districts. As requested by the OSFM, the specific locations of hazardous materials are not shown in the figures in this report due to the sensitive nature of the data. Additional information indicating the exposure of hazardous materials provided in **Appendix B, Section B.4**.

Table 15. Number of unique hazardous materials stored in drainage districts and exposed to either a 100- or 500-year flood after a levee breach, in the Columbia corridor drainage districts, Multnomah County, Oregon.It is not uncommon for a single building to store several different hazardous materials. A 500-year flood includes the number of exposed hazardous materials given a 100-year flood and additional exposure of hazardous materials due to the increased flood depth levels. See Table 16 for examples of the kinds of hazardous material in each class.

	Current Totals		100-Year Flood		500-Year Flood		
District	Number of Buildings	Number of Hazardous Materials Stored	Number of Exposed Buildings	Number of Exposed Hazardous Materials	Number of Exposed Buildings	Number of Exposed Hazardous Materials	Most Common Exposed Hazardous Materials
SIDIC, A	—	—	—	—	—	—	N/A
SIDIC, B	2	2	2	2	2	2	Flammable and Combustible Liquid; Flammable Gas
PEN 1	10	73	4	40	6	51	Acute Health Hazard; Flammable and Combustible Liquid
PEN 2, A	29	82	28	78	28	78	Combustible Material; Flammable and Combustible Liquid
PEN 2, B	10	34	9	32	9	32	Acute Health Hazard; Flammable and Combustible Liquid
MCDD-W, A	44	179	40	170	41	173	Acute Health Hazard; Flammable and Combustible Liquid
MCDD-W, B	172	810	136	605	143	648	Acute Health Hazard; Flammable and Combustible Liquid
MCDD-E, A	51	164	47	124	51	164	Acute Health Hazard; Flammable and Combustible Liquid; Oxidizers
MCDD-E, B	2	4	1	3	2	4	Flammable and Combustible Liquid
SDIC	25	87	17	65	22	78	Acute Health Hazard; Non-flammable Gas

Figure 16. Number of hazardous materials stored in drainage districts and exposed to a 100-year flood after a levee breach, in the Columbia corridor drainage districts, Multnomah County, Oregon. Given the sensitive nature of the data, the number of hazardous materials was aggregated by subdivided drainage districts as requested by the Oregon Office of State Fire Marshal.

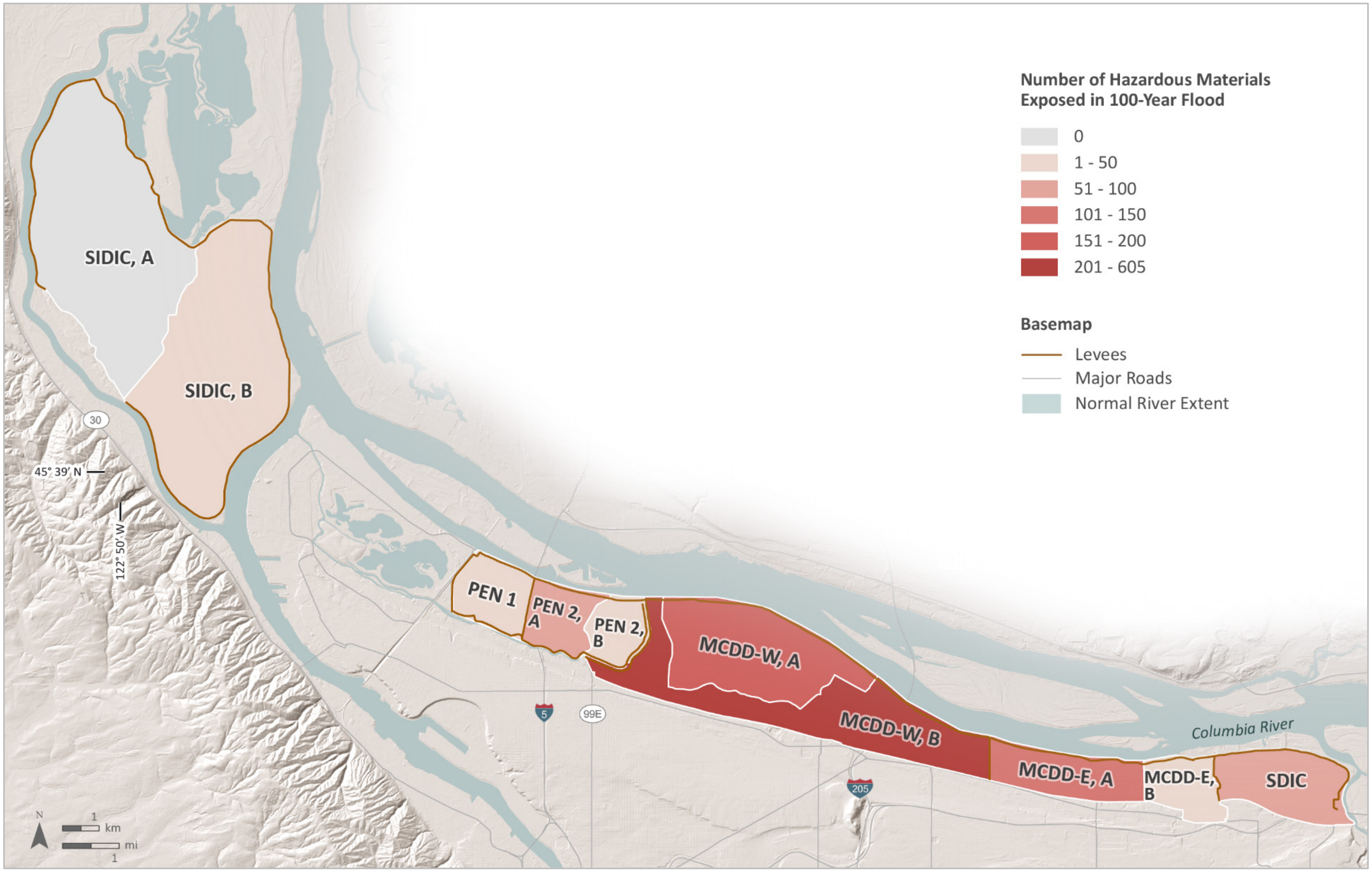


Table 16. Examples of hazardous materials stored by class description in the Columbia corridor drainage districts, Multnomah County, Oregon.

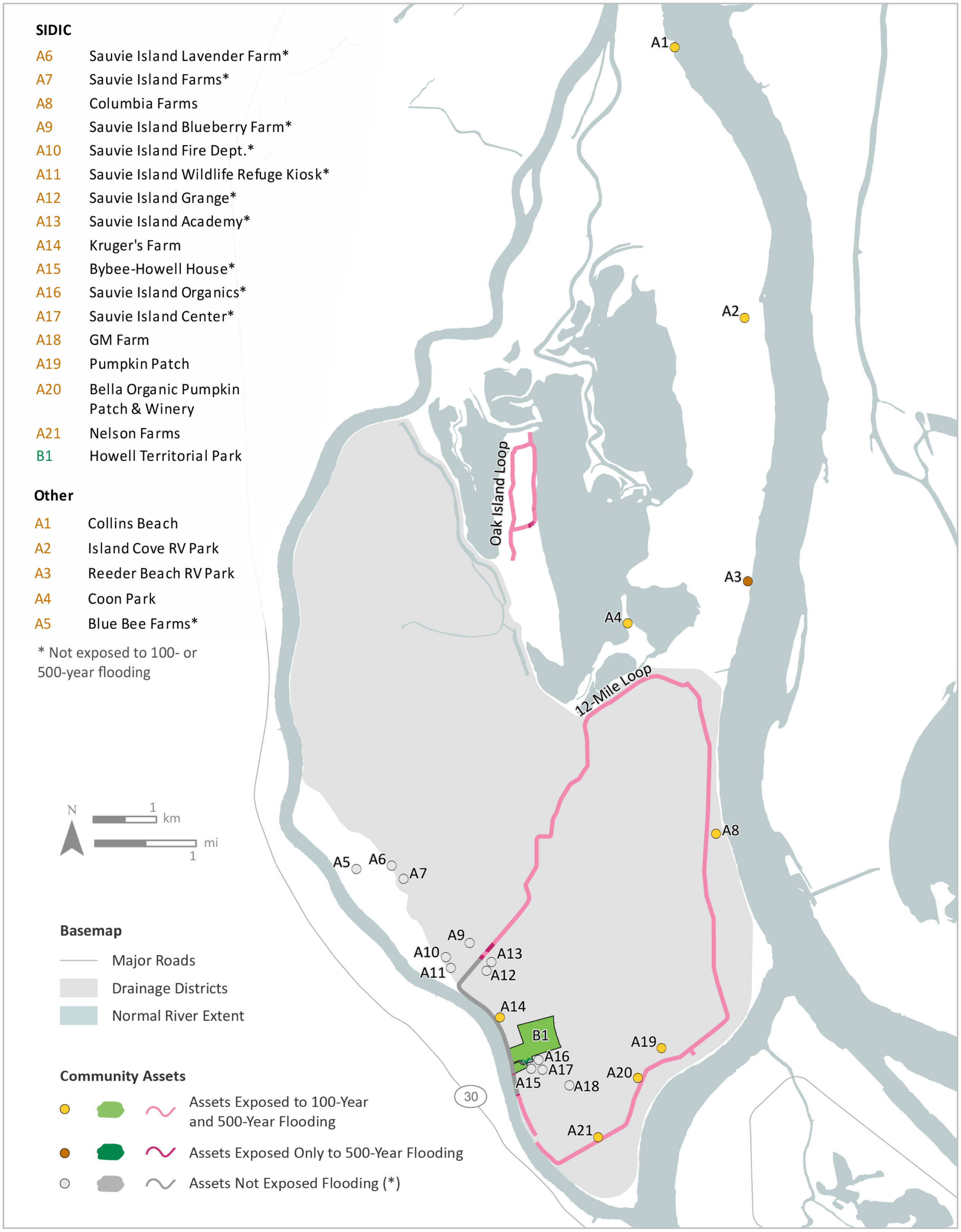
Hazardous Class (OSFM, 2017)	Hazardous Class Description	Example Materials
2.1	Flammable Gas	acetylene, propane
2.2	Non-flammable Gas	argon, nitrogen
3	Flammable and Combustible Liquid	diesel, gasoline, thinners, paints, and solvents
4.1	Flammable Solids	nitrocellulose, waste paint containers
4.4	Reactive Material	sulfuric and phosphoric acid, potassium hydroxide, caustic beads
4.5	Combustible Material	motor, engine, and hydraulic oil
5.1	Oxidizers	oxygen, hydrogen peroxide
5.2	Organic Peroxides	hydrogen peroxide (Zep Peroxy-Serve 15)
6.1	Poisonous Material	hydrofluoric acid, aluminum phosphide
6.3	Acute Health Hazard	lead acid batteries, carbon dioxide, antifreeze
6.4	Chronic Health Hazard	certain types of fertilizers, sand, talc
6.5	Pesticide	certain types of pesticides
8	Corrosive Material	waste lead acid batteries, caustic soda, sulfuric acid, sodium hydroxide
9	Miscellaneous Hazardous Material	deicing fluid, certain types of fertilizers and waste products

3.5 Impact on Community Assets

We performed a 100- or 500-year flood exposure analysis for more than 100 buildings, paths, and places of interest identified by MCDD staff as community assets during interviews with community members (Joel Schoening, written commun., 2017). As shown in **Figure 17** and **Figure 18,** most community assets located in each of the districts would be impacted by a flood during a levee breach. The impact of flooding on these community assets may be as little as a temporary lack of access to complete damage and loss.

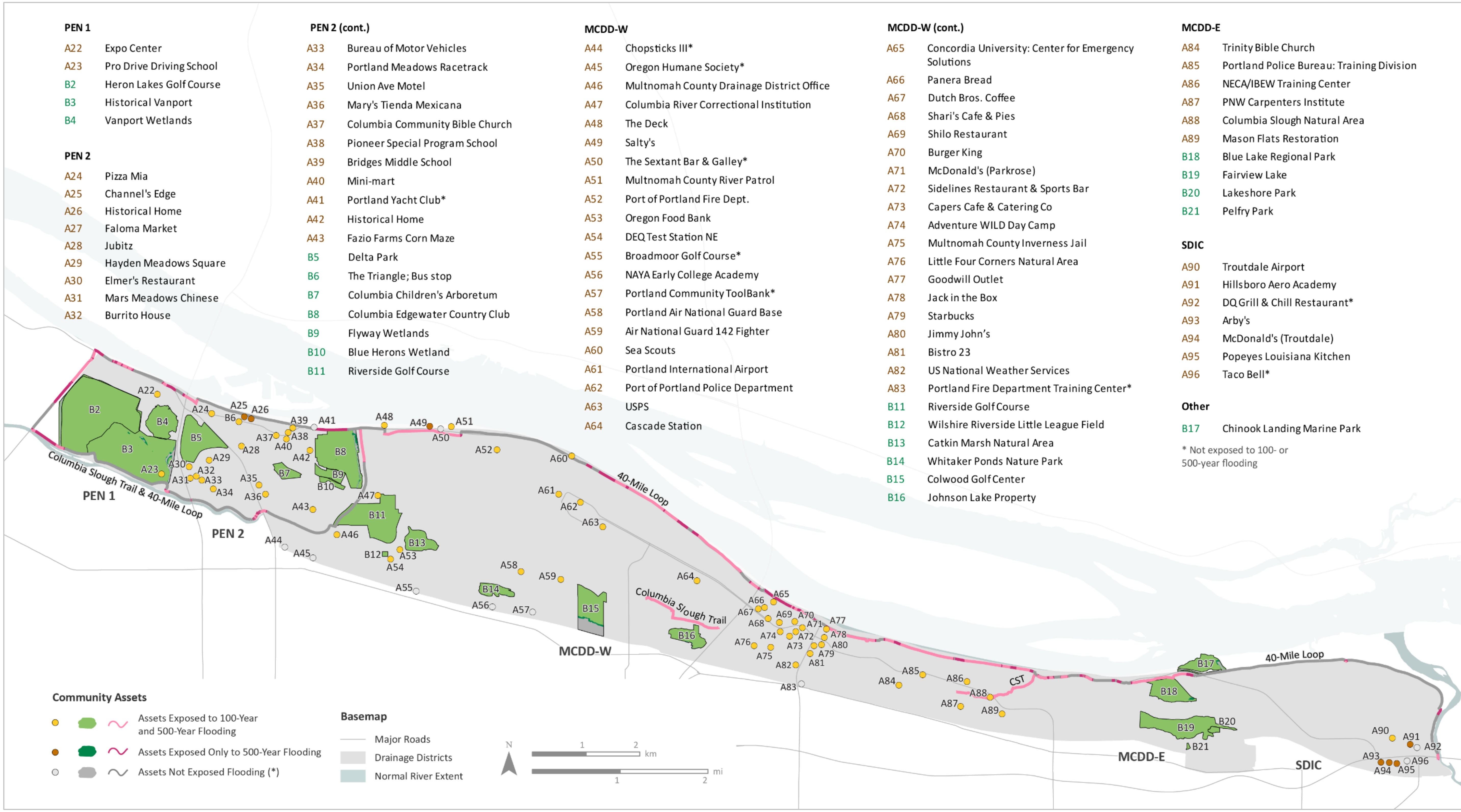
MCDD staff categorized these community assets into three types: point, line, or polygon. Most of the point features represent key business, education, non-profit, government, emergency service, or historical buildings. Two-thirds of these 92 buildings and sites would be exposed to flooding during a 100-year event. All community asset paths represent recreational trails and include Oak Island Loop, the Sauvie Island 12-Mile Loop, the 40-Mile Loop along Marine Drive, and the Columbia Slough Trail. Depending on which drainage districts are flooded, these trails might be minimally affected, as in the case of the Columbia Slough Trail in PEN 2, or heavily impacted, such as the 12-Mile Loop in SIDIC. The community assets shown as polygons are primarily open spaces important for recreational activities or are of environmental significance (e.g., wetlands). All of these assets are highly vulnerable to flooding without levee protection. As shown in **Figure 17** and **Figure 18**, most community assets are vulnerable to both a 100- and a 500-year flood (shown in lighter colored points, lines, and polygons); fairly few additional buildings, path segments, and open spaces are vulnerable to a 500-year flood but not a 100-year flood (symbolized by darker colored points, lines, and polygons). A complete list of community assets with their names, primary category, and exposure to flooding is provided in **Appendix B, Section B.5**.

Figure 17. Community asset exposure to 100-year (light colored points, lines, and polygons) and 500-year flood (both light and dark points, lines, and polygons) on Sauvie Island after a levee breach.



* Indicates that this asset is not exposed to either a 100-year or a 500-year flood.

Figure 18. Community asset exposure to 100-year (light colored points, lines, and polygons) and 500-year flood (both light and dark points, lines, and polygons) after a levee breach within PEN 1, PEN 2, MCDD-W, MCDD-E, and SDIC.



* Indicates that this asset is not exposed to either a 100-year or a 500-year flood.

3.6 Impact on Transportation

In this study, we evaluated the exposure of bus, trucking, light rail, railroad, and emergency routes to flooding after a levee breach. This included over 140 miles of transportation road or rail (**Table 17**, **Table 18**). The transportation routes in MCDD make up the greatest proportion of transportation lines, with just over 60 miles of line, and had the largest overall exposure ratio with approximately half of the transportation lines impacted or impassible during a 100-year flood (**Figure 19**). Below are several overarching patterns for the major roads and highways within the study area that apply to both the 100-year and 500-year flood. These include:

- Marine Drive is vulnerable to flooding within PEN 1, PEN 2, and SDIC. Exposure to flooding along Marine Drive is limited within MCDD-W and MCDD-E. Traffic on the levees may also be affected due to emergency response protocols (MCDD, 2016b).
- Airport Way is vulnerable to flooding in many areas within MCDD-W and MCDD-E.
- Assuming the road embankment remains intact, Martin Luther King Jr. Boulevard (99E), Highway 205, Columbia Boulevard, and Sandy Boulevard (30B) would remain widely passible.
- Although I-84 would be largely unaffected by major flooding, one short section in SDIC would be impassible during a 500-year flood.
- The potential impact of flooding on I-5 would be relatively limited. During a 500-year flood, a short section of I-5 would be impassible where the highway passes under Marine Drive in PEN 1.

Table 17 and **Table 18** present the overall route lengths exposed to flooding. District-level analyses and maps documenting transportation routes impacted by flooding are provided in **Appendix A**.

Table 17. Railroad, light rail, and freight road exposure during a levee breach and 100- or 500-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. A 500-year flood includes exposure from 100-year flood and additional exposure due to the increased flood depth levels.

District	Total Railroad Lines (miles)	Exposed Railroad Lines (miles)		Total Light Rail Lines (miles)	Exposed Light Rail Lines (miles)		Total Freight Roads (miles)	Exposed Freight Roads (miles)	
		100-year flood	500-year flood		100-year flood	500-year flood		100-year flood	500-year flood
SIDIC	—	—	—	—	—	—	—	—	—
PEN 1	7.5	0.5	4.0	0.9	0.6	0.7	3.9	1.4	1.9
PEN 2	—	—	—	0.3	0.0	0.0	7.9	2.0	2.5
MCDD-W	5.6	0.8	1.0	3.1	2.6	2.6	25.3	16.1	16.9
MCDD-E	8.9	0.0	0.0	—	—	—	6.6	3.7	3.9
SDIC	5.4	1.1	1.1	—	—	—	6.4	1.8	2.8

Table 18. Bus and emergency route exposure during a levee breach and 100- or 500-year flood, in the Columbia corridor drainage districts, Multnomah County, Oregon. A 500-year flood includes exposure from 100-year flood and additional exposure due to the increased flood depth levels.

District	Total Bus Routes (miles)	Exposed Bus Routes (miles)		Total Emergency Vehicle Routes (miles)	Exposed Emergency Vehicle Routes (miles)	
		100-Year Flood	500-Year Flood		100-Year Flood	500-Year Flood
SIDIC	0.3	0.2	0.2	—	—	—
PEN 1	2.7	1.7	1.9	1.8	0.9	1.1
PEN 2	5.4	4.0	4.2	7.6	1.2	1.5
MCDD-W	5.2	5.0	5.0	24.9	10.6	11.1
MCDD-E	2.5	2.2	2.3	7.0	2.1	2.2
SDIC	1.2	0.2	0.7	5.3	1.7	2.3

Because the number, type, and value of vehicles varies greatly with time in this region, we have chosen not to provide estimates of the loss value from flood damage. Instead, we created a "Damage to Parked Vehicles" spreadsheet that allows users to estimate the potential damage to the number and types of cars for nine different large parking lots located with MCDD-W (**Figure 20**). It is important to note that all parking lots will be flooded by between 4 and 10 feet during a 100-year flood and 6 and 13 feet during a 500-year flood. Given this degree of flooding, the depth-damage functions of USACE (2006) (**Table 6**) suggest that all vehicles will experience complete damage. As an example, if MCDD-W were flooded and all nine parking lots were half-filled with an equal proportion of sub-compact, compact, mid-sized, large, and truck or SUV vehicles, approximately 9,500 vehicles would be exposed to complete damage. In total, this would equate to ~$250 million in damage, using 2017 market values.

Figure 19.Transportation routes exposed to 100-year (light colored lines) and 500-year flood (light and dark colored lines) after a levee breach in the Columbia corridor drainage districts, Multnomah County, Oregon.

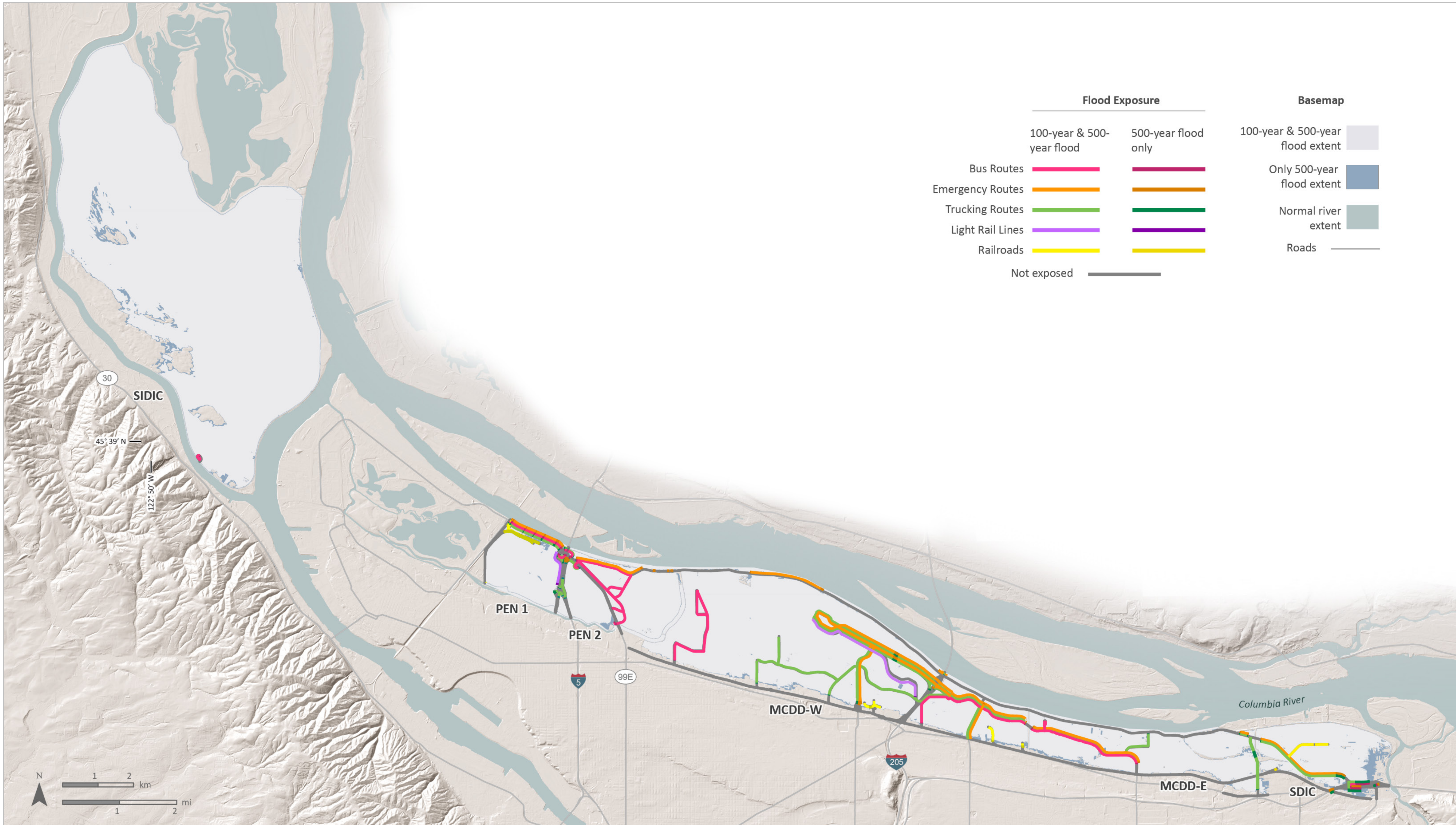
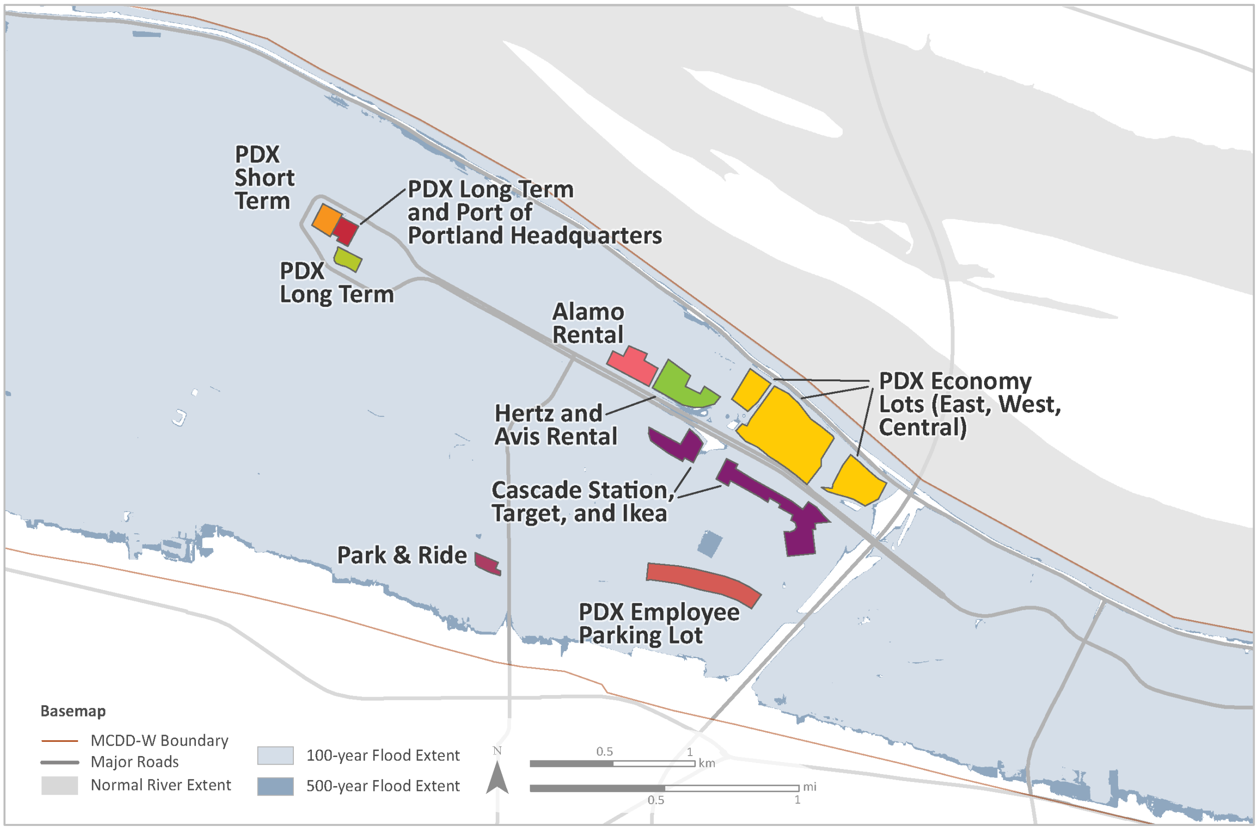


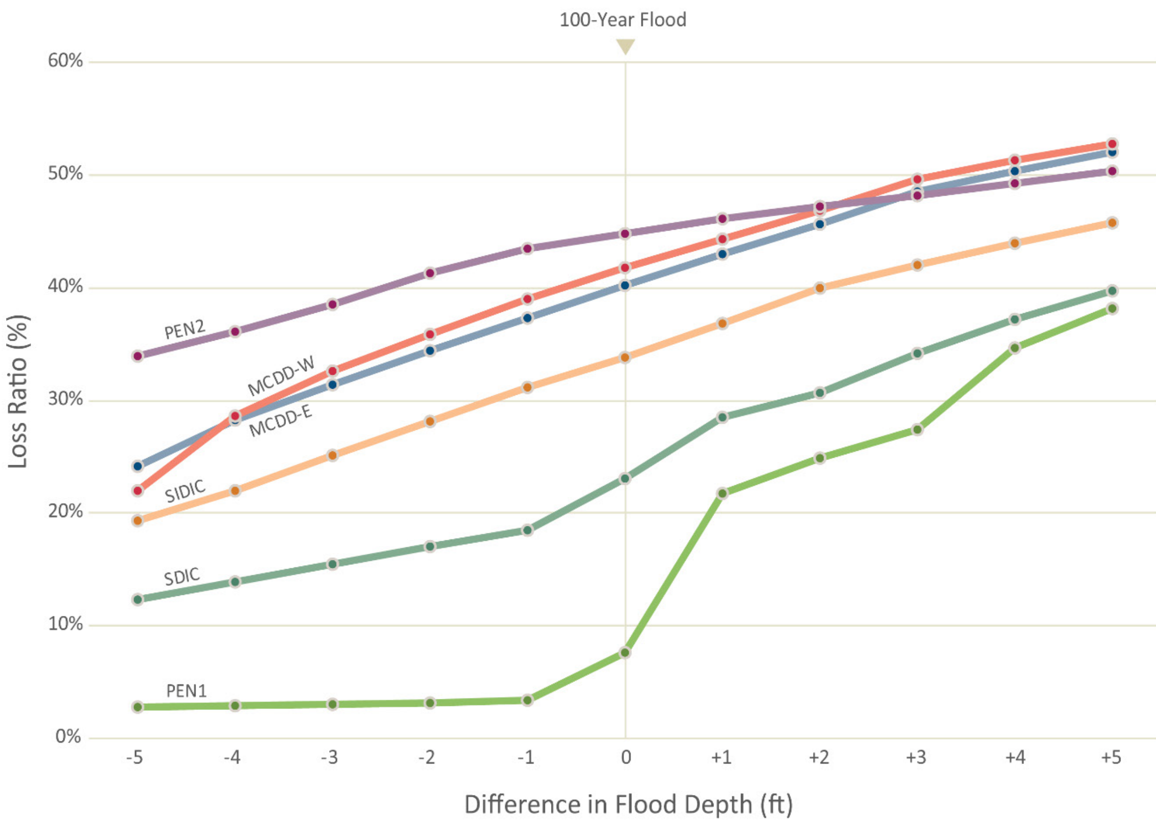
Figure 20. Locations of parking lots with vehicles modeled in “Damage to Parked Vehicles” spreadsheet in the MCDD-W district. Parking lots with the same color have been combined in the spreadsheet into a single parking lot complex.



3.7 Sensitivity Analysis

Our flood depth sensitivity testing confirms the expected relationship: as flood depth increases, overall building damage increases (**Figure 21**). For a direct comparison between districts, we represent the district’s overall building replacement cost as a percentage of its total replacement cost (i.e., its loss ratio) and not the dollar amount. With the exception of PEN 1, the relationship between loss ratio and flood depth is generally linear. The threshold observed for PEN 1 between 0 foot (i.e. 100-year flood levels) and +1-foot levels is largely due the characteristics of the building stock in this district. In PEN 1, there are six buildings, including the Exposition Center, that account for 91% of the overall building value in the district; these buildings are either not exposed or experience minimal loss during a 100-year flood. However, at +1-foot flood depths, damage increases significantly for these six buildings which results in a much higher loss ratio for the district. We observed a similar, generally linear depth-damage relationship for content and inventory for all districts except PEN 1 where, again, we observed a considerable increase above the 100-year flood level.

Figure 21. Total drainage district long-duration loss ratios expressed for 11 different flood depths, in the Columbia corridor drainage districts, Multnomah County, Oregon. The "0" (zero) difference in flood depth level is the 100-year flood depth levels used in our analysis throughout this study. Flood depth grids per district were incrementally adjusted by ± 1 foot, up to ± 5 feet.



Although we chose to model damage using 100-year flood stage levels, we recognize that levee breaches can occur at any flood stage. An upcoming climate change study by the USGS and USACE suggests that future 100-year flood stages along the Columbia River near Vancouver, Washington, may be several feet higher than those experienced during the 1996 flood (Julia Babcock, Oregon Solutions, written commun., 2018). Alternatively, a levee breach could occur at flood stages lower than the currently defined 100-year flood stage. For example, ground motion during an earthquake could induce liquefaction and compromise levees (Sasaki and others, 2012), leaving the drainage districts vulnerable even at minor flood stages.

4.0 DISCUSSION AND RECOMMENDATIONS

4.1 Key Findings and Recommendations

Overall impact: The objective of this study was to quantify the impact of a levee breach on each of the Columbia corridor drainage districts in Multnomah County during a major (100-year or 500-year) flood event. Our analysis shows that a levee failure in conjunction with a major flood would result in catastrophic damage and displace hundreds if not thousands of residents located in the Columbia corridor drainage districts in Multnomah County. Depending on which district is affected, we find that between 51% and 95% of buildings would be exposed to a 100-year flood, resulting in tens of millions or possibly billions of dollars in building and content damage (**Table 6**, **Figure 12**).

Given the potentially severe impacts of such floods, it is critical that efforts be directed at minimizing the risk of flooding and, importantly, planning for a potential levee failure. We strongly recommend maintaining or upgrading the geotechnical strength of the existing levees to meet federal requirements including FEMA accreditation and USACE PL84-99. We support the ongoing updates and improvements to emergency plans, geotechnical studies of the levees by the drainage districts, and the coordination between the districts within the Levee Ready Columbia partnership. We recommend continued efforts to conduct public outreach and education campaigns to raise awareness of the risk posed by a flood and levee failure. In addition, we support consideration given to reducing the risk to the most vulnerable residents, retrofitting assets to increase flood resilience, and the purchase of flood insurance if deemed appropriate.

Vulnerable populations: This study highlights the risks posed to people living within the drainage districts. We find that many residents would be displaced during a 100-year event in all districts except SDIC (**Table 6**, **Figure 9**). As shown in the drainage district profiles in **Appendix A**, specific neighborhoods within the most populated districts (PEN 2, MCDD-W, and MCDD-E) would experience the greatest damage to residences and largest number of displaced residents. These vulnerable populations include those in the low-lying areas in the eastern half of PEN 2, the Columbia River Correctional Institution, Multnomah County Inverness Jail, and Dignity Village in MCDD-W, and the homes southeast of Fairview Lake in MCDD-E (**Figure 10**). In SIDIC, hundreds of people across the district would be displaced by flooding. Evacuation on SIDIC may be particularly challenging given the highly dispersed population and limited access to the Sauvie Island Bridge during flooding.

DOGAMI supports the continued collaboration and coordination between drainage district executive directors and local city and county emergency managers to enhance existing evacuation plans. At this time, all drainage districts have evacuation plans except SIDIC. We believe it is important for all drainage districts to develop and maintain evacuation plans. This should be accompanied by appropriate education and outreach to the public, residents, and employees, in order to raise awareness of these plans; careful consideration should also be given to the evacuation of the incarcerated population. If more detailed demographic information can be collected, this information could be leveraged to help emergency managers and responders identify the homes of those unable to evacuate without assistance.

In addition, we encourage residents to better understand their property's flood risk and create evacuation plans specifically for their household or neighborhoods. Residences may also consider purchasing flood insurance and seeking ways to increase their home's flood resilience such as elevating their property or utility systems. Many educational materials exist online such as www.ready.gov/floods and FEMA and American Society for Civil Engineers (ASCE) guides including *Protecting Manufactured*

*Homes from Floods and Other Hazard*s (FEMA, 2009b), *Protecting Building Utility Systems from Flood Damage* (FEMA, 2017b), *Above the Flood: Elevating Your Floodprone House* (FEMA, 2000), and *So, You Live Behind a Levee!* (ASCE, 2010).

Risk to hazardous materials, community assets, and key infrastructure: Our assessment indicates that the vast majority of buildings storing hazardous material, community assets, and key infrastructure would be impacted by a levee breach and major flooding (**Figure 16** through **Figure 19**). Given the importance of these sites and the potential risks they pose, we recommend that site inspection be performed at each site storing hazardous materials in order to identify opportunities for increasing flood resilience. For example, hazardous materials and key infrastructure could be contained within flood resilient structures, relocated to a height above flood levels, or stored in containers that would expedite their removal during an evacuation to reduce the risk of flood exposure or contamination. We recommend that potential hazardous material contamination and the lack of functioning key infrastructure, including drinking water facilities, pump stations, and electrical substations, be considered in emergency management and recovery plans.

Inaccessible emergency routes: Our assessment shows that many of the designated emergency routes in each of the districts would become impassible during a levee breach and major flood (**Table 18**, **Figure 19**). As such, we recommend evaluating alternative routes that may be used depending on which or how many drainage districts are impacted by flooding. Given the large extent of potential flooding within each of the districts, we support the consideration of the potential use of watercraft for rescue and emergency transportation as identified in the MCDD Flood Emergency Action Plan (2016b).

Business closure and recovery: This study indicates that most businesses in the drainage districts are vulnerable to flooding and that, for buildings damaged by flooding, post-event recovery will be gradual. For example, of the 1,537 businesses and 39,326 employees in the MCDD-W, only 24 to 33% of businesses would be able to reopen within one year of a breach and flood, affecting some 20% to 28% of employees. As a result, as much as 2.8 billion dollars in direct wages may be lost in the two years following a major flood. Because the area is vital to the region's and the state's economy, indirect economic impacts may be even greater. If business income data had been available, the economic analysis in this study could have be enhanced to characterize some of these indirect impacts.

Although DOGAMI supports continued maintenance of the levees to protect businesses and employees from floods, we again encourage the continued collaboration and coordination between drainage district executive directors and local city and county emergency managers to enhance existing evacuation plans. We support outward communication of evacuation orders to businesses using a range of relevant media as stated above. In addition, we suggest that individual businesses understand the flood risk posed to their specific businesses, review evacuation plans for their district, develop evacuation and business continuity plans specific to their businesses, and discuss these plans with their employees. We also suggest businesses evaluate their property for opportunities to increase flood resiliency such as elevating vital equipment and utilities, creating off-site copies of important documents, or retrofitting structures. Many educational resources for businesses are available online on sites such as www.ready.gov/business and www.ready.gov/floods and in FEMA guides including *Protecting Building Utility Systems from Flood Damage* (2017b). Flood insurance may be considered if deemed appropriate for the business.

Post-earthquake levee inspection: Although the likelihood of a 100-year flood occurrence simultaneous with a major earthquake is relatively small (USACE, 2001), earthquakes can induce liquefaction that could further compromise levees (Sasaki and others, 2012). As a result, we encourage the prioritization of the inspection and potential maintenance of the levee system after a major earthquake.

Flood damage models: This study provides an example of an assessment for regions where the duration of flooding is difficult to estimate and could last many days. We modeled both the standard (<3 days) and long-duration (>3 days) depth-damage relationships within Hazus-MH to create a range of potential impacts. This approach allows us to more accurately characterize the potential impact of a flood and allows communities to better prepare for the range of conditions that might occur in this region.

We recommend that all Hazus-MH users carefully consider which depth-damage relationships are used when performing flood assessments. Although the standard relationships are often useful, they are by no means the only relationships documented within Hazus-MH that can be applied. Where appropriate, we encourage users to model long-duration or alternative flood damage relationships.

4.2 Future Studies

On the basis of this assessment, we recommend examining the following topics that were beyond the scope of this study:

- Perform a detailed demographic survey of residents and employees living and working in drainage districts to better understand evacuation assistance needs.
- Recalculate the flood recurrence intervals and magnitudes using all available flood and discharge records on the Columbia and Willamette Rivers and with consideration given to flow regulations and climate change impacts.
- Perform an on-the-ground site inspection for each community asset, hazardous material storage site, and key infrastructure to determine the specific depth of flooding and identify opportunities for increasing flood resilience.
- Perform a detailed economic impact study that includes an assessment of direct business income loss and long-term, regional indirect impacts of the closure and restoration of the Portland International Airport.
- Use information from the recent Levee Ready Columbia geotechnical assessment of the levees to identify the most likely modes and locations of levee failure (http://www.leveeready columbia.org/updates/drilling/).
- Perform hydraulic modeling (e.g., 2D HEC-RAS) to simulate a range of levee breach scenarios to better understand potential timing and form of flooding. If possible, incorporate into the model both functioning and nonfunctioning pump stations and local ponding.
- Use information from the recent Levee Ready Columbia geotechnical assessment (http://www.leveereadycolumbia.org/updates/drilling/) of the levees to evaluate the likelihood of levee system potential failure as a consequence of a local fault or Cascadia Subduction Zone earthquake.

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APPENDIX A. DRAINAGE DISTRICT FLOOD IMPACT SUMMARIES

A.1 Sauvie Island Drainage Improvement Company

Current conditions: There are approximately 380 agricultural and utility buildings, 300 residences, and an additional 20 commercial, industrial, governmental, and non-profit buildings behind the levees on Sauvie Island. This is the largest district by area and includes many large farms. We estimate that the combined replacement cost for all buildings, contents, and inventory in the district is approximately $378M, which is the lowest value of any of the districts.

Buildings, content, and inventory: Flooding would cause severe damage to structures within SIDIC. During a 100-year flood, nearly 70% of buildings in the district would be exposed to flood water (**Figure A-1** and **Figure A-2**). It would cost between $56M and $69M to replace these buildings and an additional $69M to $73M to replace their content. On average, agricultural and utility buildings would be flooded by 8 feet and residences would be flooded 5 feet.

Because more agricultural buildings would be exposed to flood waters than residences, approximately two-thirds of the building damage in the drainage district would be incurred in damage to agricultural facilities and much of the remaining one-third would be due to damage to residences. When combined, it would cost between $133M and $150M to replace the damage to buildings, content, and inventory. Approximately 20,000 tons of debris would be produced during a 100-year flood.

For a 500-year flood, the typical depth of building flooding is approximately 3 to 4 feet higher in a 500-year flood compared with a 100-year flood. The number of buildings exposed to flooding would increase from 70% to 75% and there would be an additional $20M to $30M in building damage and $15M to $17M to replace damaged building contents. Additional information about the impacts of both a 100-year and 500-year flood can be found in **Appendix B, Section B.1**.

Approximately 160 additional structures on Sauvie Island are not currently protected by levees. Most of these buildings are located on topographically higher areas; only 31% of them are impacted by a 100-year flood and 44% are impacted by a 500-year event.

Population: Within the boundaries of SIDIC, there are just over 640 permanent residents. Approximately 380 (nearly 60%) of these residents would be initially displaced during a 100-year flood, but 425 residents (approximately 65%) would be displaced during a 500-year flood (**Figure A-3**). Beyond the drainage district boundaries, there are more than 280 additional residents. During a 100-year flood, approximately 105 people would be displaced; 140 people would be displaced during a 500-year flood.

Businesses and employees: In SDIC, a 100-year or 500-year flood would have a moderate impact on businesses and employees in the district. However, the impact in this district is less pronounced than in other districts in the Columbia corridor and businesses in the district would recover relatively quickly. During a 100-year flood, 70% of businesses would be forced to close initially, although the vast majority would be able to reopen within one year. Similarly, just under half of the 405 current employees would initially be unable to work, but 75% of employees could return to their same jobs within six months. Furthermore, the Hazus-MH models suggest that it is highly likely that employment could fully return to pre-flood levels within two years. SIDIC would experience the smallest loss in paid wages, with $2M to $5M lost across the two years following a 100-year flood event. A 500-year flood would have a greater impact on businesses and employees in SIDIC particularly during the flood event itself and in the first year after flooding. An additional 27% of the workforce would be unable to work during and just after a 500-year flood. However, after the first year, recovery rates quickly match recovery rates for a 100-year flood.

Additional information detailing the impacts of levee breach and a 100-year and a 500-year flood can be found in **Appendix B, Section B.2**.

Key infrastructure: There is one electrical substation and one adjacent pump station in SIDIC, and both are susceptible to flooding. During a 100-year flood, the substation would experience 8 feet of flooding, resulting a 12% loss ratio (i.e., it would cost 12% of the substation's value to repair the substation) and the pump station would experience 9 feet of flooding with 40% loss ratio. We did not identify any water treatment facilities or natural gas facilities in this district. More information is provided in **Appendix B, Section B.3**.

Hazardous materials: According to Oregon Office of State Fire Marshal hazardous materials records (2017), SIDIC has the fewest number of hazardous materials stored throughout the district. Two buildings were found to each contain one type of stored hazardous substance, one of which is a flammable gas, while the other is a flammable or combustible liquid. Both are located in the southern half of SIDIC and are in buildings exposed to flooding during a 100-year or a 500-year flood (**Figure 16**). More information is provided in **Appendix B, Section B.4**.

Community assets: SIDIC contains relatively few community asset points exposed to flooding. This may reflect the historical placement of buildings in the less flood-prone areas in the southwestern corner of the Island (Spencer, 1950). Notably, the Sauvie Island Fire Department and Sauvie Island Academy are located above the 500-year flood elevation. However, nearly all of Oak Island Loop, Howell Territorial Park, and the vast majority of the Sauvie Island's 12-mile Loop will be exposed to both 100-year and 500-year flooding. See **Figure 17** in the report and **Appendix B, Section B.5** for more detailed results.

Transportation: There are no mapped railroads, light rail lines, freight roads, or designated emergency vehicles routes in SIDIC. There is 0.3 miles of road that accommodates TriMet Bus line 16 and one bus stop adjacent to Sauvie Island Bridge. Approximately 0.2 miles of this road would be impassible during a 100-year or 500-year flood. Due to the limited transportation route exposure, this report provides no map for this district.

Figure A-1. Generalized map of building loss ratio due to a long-duration, 100-year flood in Sauvie Island Drainage Improvement Company district.

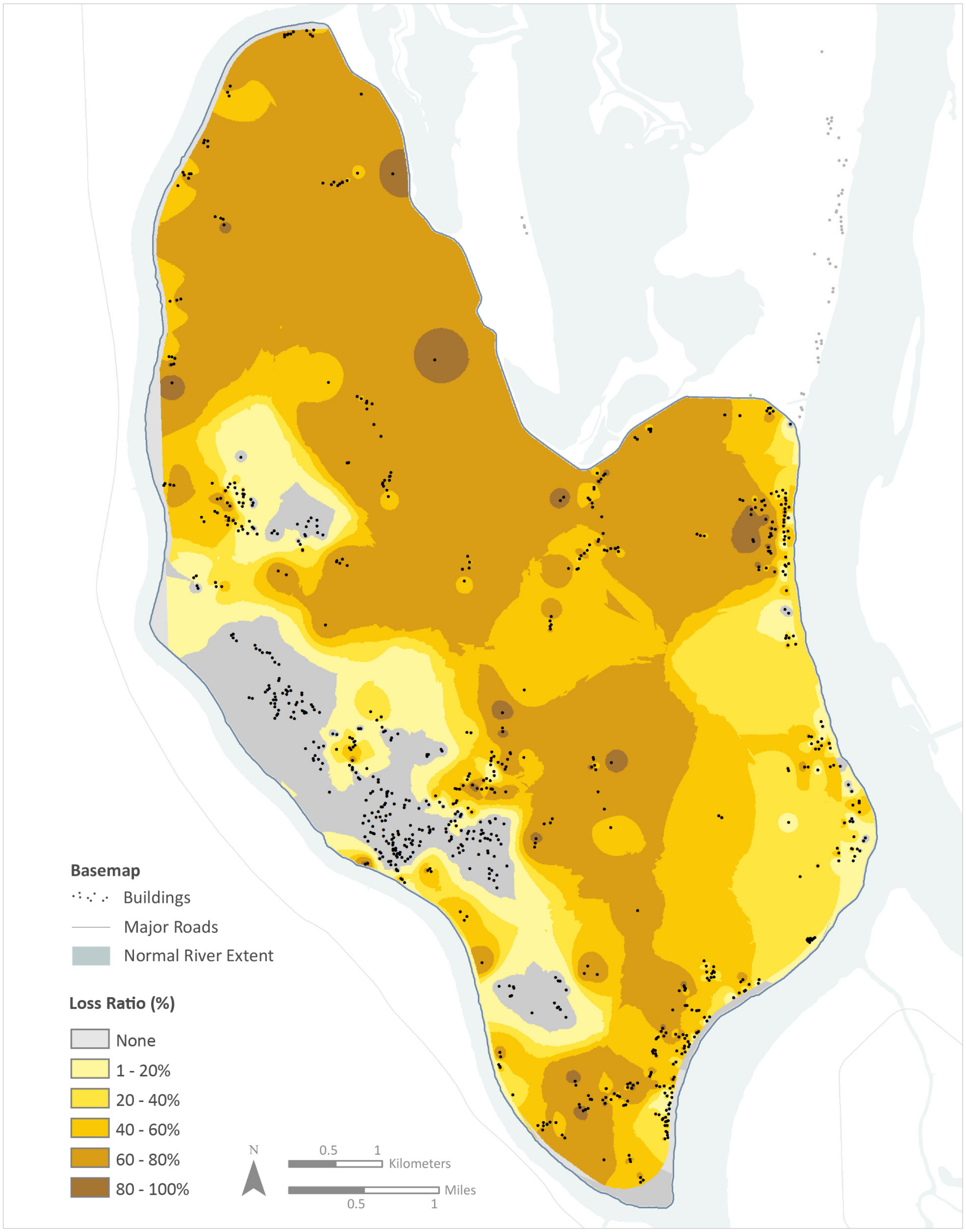


Figure A-2. Generalized map of building replacement cost due to a long-duration, 100-year flood in Sauvie Island Drainage Improvement Company district.

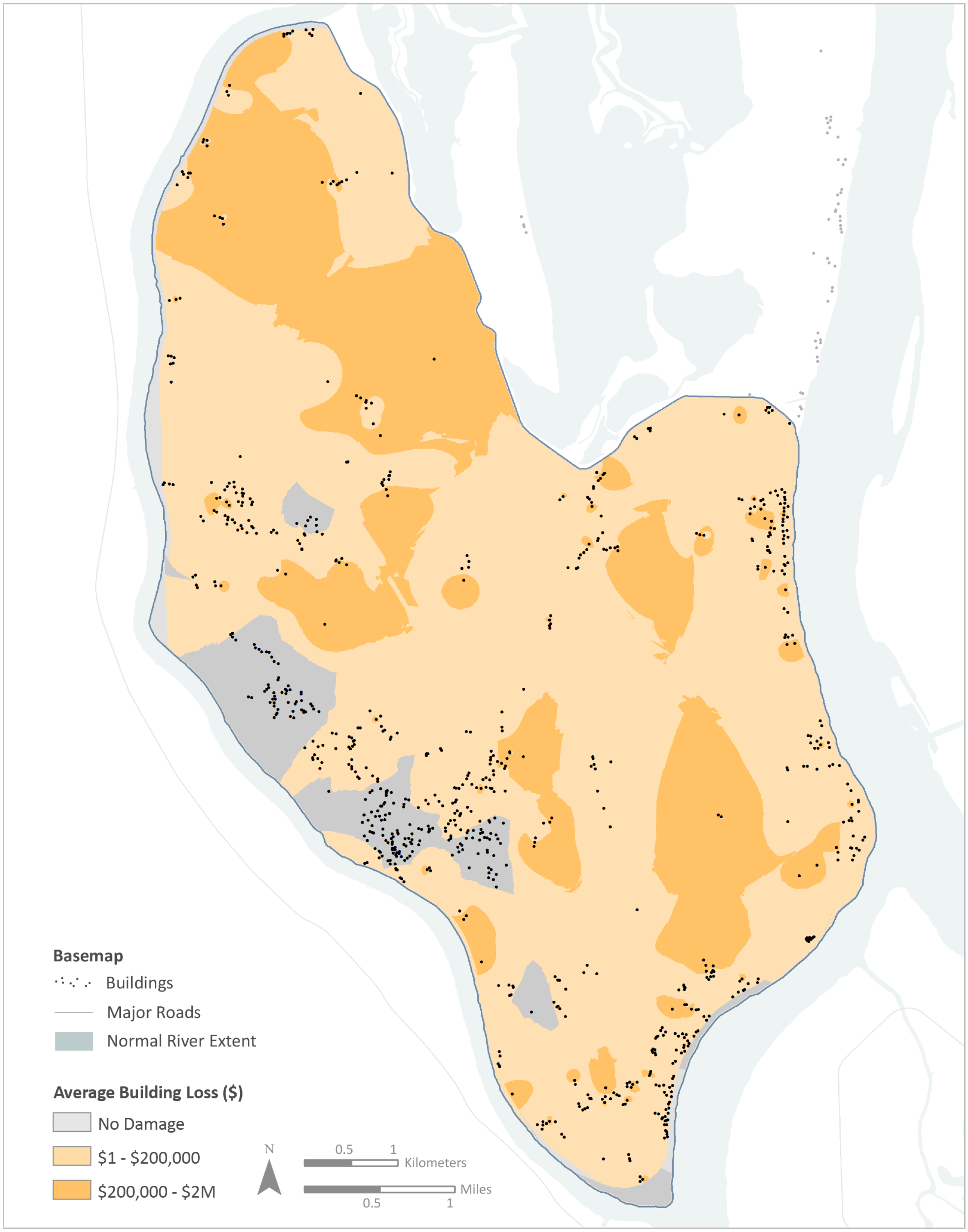
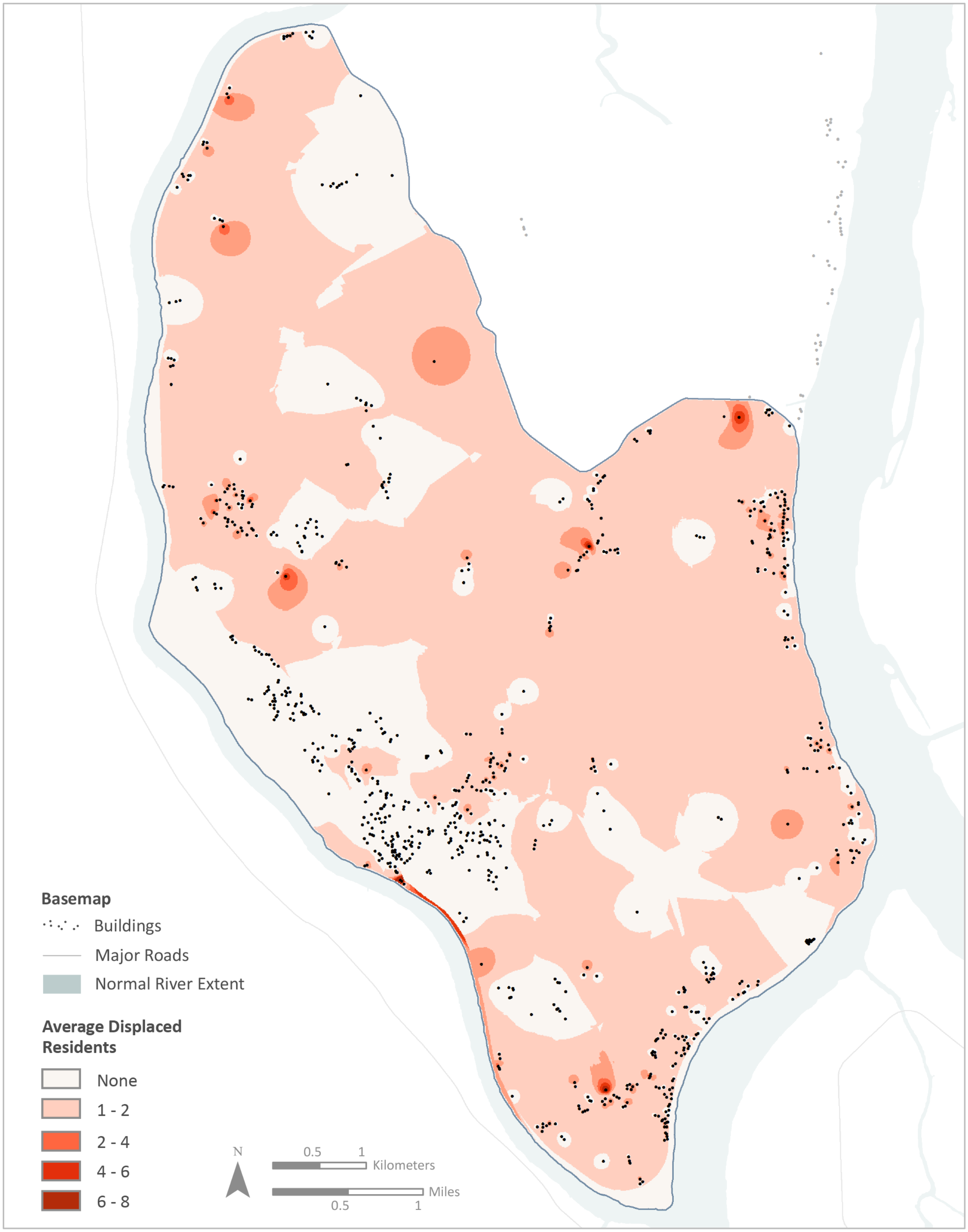


Figure A-3. Generalized map of displaced population due to a long-duration, 100-year flood in Sauvie Island Drainage Improvement Company district.



A.2 Peninsula Drainage District 1

Current conditions: PEN 1 contains just over 50 buildings, making it the smallest drainage district in the study area by building count. Nearly all the buildings in PEN 1 are commercial or industrial facilities, including the Portland Expo Center and several large shipping and manufacturing facilities. We estimate that the combined replacement cost for all buildings, contents, and inventory in the district is approximately $488M, which is one of the lowest values in the study area.

Buildings, content, and inventory: A flood would cause relatively less damage to buildings and assets in PEN 1 than in many of the other districts (**Figure A-4** and **Figure A-5**). During a 100-year flood, approximately 80% of the buildings in the district would be exposed to flooding, and the average flood depth for exposed commercial or industrial facilities would be very deep (~13 feet). However, many of the highest-value structures in the district would not be significantly impacted by such a flood, resulting in an overall low total damage value. It would cost $12M to $16M to repair and replace buildings, and between $20M and $22M to replace the damaged content. The combined replacement cost of the damaged buildings, content, and inventory is estimated to be between $33M to $40M. Essentially, all of the damage is incurred by commercial and industrial buildings. Expressed as a ratio of damage to building value, the loss ratio for this district is 5–7%. Approximately 5,000 tons of building debris could be produced in PEN 1.

During a 500-year flood, damages to buildings, content, and inventory would be 22–34% greater than during a 100-year flood. The average depth of flooding for commercial and industrial buildings increases to 14 feet, exposing more than 90% of buildings to flood water. It would cost $41M to $65M to repair and replace buildings and between $90M and $129M to replace the contents damaged during a 500-year flood. Additional information about the impacts of both a 100-year and 500-year flood can be found in **Appendix B, Section B.1**.

Population: We estimate 15 people live within PEN 1. During a 100-year flood, essentially all residents will be initially displaced due to flood water exposure, but their houses would not be expected to be significantly damaged by flood water, allowing the residents to return to their homes after flood waters recede (**Figure A-6**). In contrast, during a 500-year flood, all residents in the district would be displaced and their homes would experience damage.

Businesses and employees: A 100-year or 500-year flood would have a moderate impact on businesses and employees in PEN 1. Although the district would experience significant flooding during a 100-year flood, several of the larger businesses with many employees would experience only shallow flooding. As a result, most of the PEN 1 businesses would recovery relatively quickly in this district. During 100-year flood, about half of businesses would be directly impacted and initially closed by flooding and about 75% of employees would not be able to work. However, one year after flooding, approximately two-thirds of businesses could be re-opened, and the majority of employees would be able to return to their jobs. Within two years of flooding, employment and business numbers would likely be at or near pre-flood levels. We estimate $11–$33M in wages would be lost within these first two years after a 100-year flood. A 500-year flood would result in greater damage, with nearly all workers unable to work and nearly all businesses initially closed; recovery during the first year following such a flood is expected to be slower. Additional information detailing the impacts of levee breach and a 100-year or 500-year flood can be found in **Appendix B, Section B.2**.

Key infrastructure: There are two pump stations within PEN 1, and both could be severely damaged during a flood. Respectively, they would experience 20 feet and 26 feet of flooding during a 100-year event. That would result in at least a 40% loss in value to the pumps. We did not identify any electrical substations, water treatment facilities, or natural gas facilities in this district. More information is provided in **Appendix B, Section B.3**.

Hazardous materials: There are 10 buildings in PEN 1 that store over 70 different hazardous materials. These are composed primarily of materials classified as acute health hazards, flammable or combustible liquids, and combustible materials. These types of materials typically include fuels like gasoline, lead acid batteries, carbon dioxide, antifreeze, or motor, engine, and hydraulic oil. Of the 70 stored materials, 40 and 51, are in buildings exposed during a 100-year flood and a 500-year flood, respectively. More information is provided in **Appendix B, Section B.4.**

Community assets: PEN 1 contains the fewest number of community asset points (2), and both locations, the Expo Center and Pro Drive Driving School, are vulnerable to either a 100-year or 500-year flood. A very short section of the two community asset trails in PEN 1 are exposed to flooding, and the Heron Lakes Golf Course, Historical Vanport, and Vanport Wetlands would all be inundated during a 100-year flood. See **Figure 18** in the main body of the report and **Appendix B, Section B.5** for more detailed results.

Transportation: PEN 1 contains nearly 17 miles of bus, light rail, railroad, trucking, and emergency routes. Sections of the levee in the western half of the district, along Marine Drive, are vulnerable to overtopping when the Columbia River reaches its 100- or 500-year stage. **Figure A-7** shows the transportation route exposure to flooding.

- Approximately two-thirds of the 3 miles of bus lines in PEN 1 would be exposed during both a 100-year and 500-year flood. Flooding would impact TriMet bus line 11, which runs along Marine Drive, and TriMet bus line 6 along the off-ramps from Martin Luther King Boulevard.
- About one mile of the TriMet Yellow MAX light rail line is located in PEN 1, west of Interstate Avenue. Just over half of the light rail line in PEN 1 would be exposed to flooding.
- PEN 1 contains more than 7 miles of railroad line, but only about half a mile of this railroad would be exposed to flooding during a 100-year flood; as much as 4 miles of railroad would be exposed during a 500-year flood. Most of the railroad potentially exposed to flooding is owned by BNSF Railway.
- Nearly 4 miles of road are designated as major trucking routes. 1.5 to 2 miles of these roads would be exposed to flooding during a 100-year flood and a 500-year flood, respectively. This flooding would be focused around Marine Drive and the I-5 and Martin Luther King Boulevard off-ramps.
- Approximately 2 miles of road are designated as emergency transportation routes. About half of these routes are exposed to both a 100-year and 500-year flood. The exposure is concentrated along Marine Drive but also includes I-5 at its lowest point just south of the intersection with Martin Luther King Boulevard.

Note that according to MCDD staff, portions of Marine Drive may be impassable even if the levee is intact, because a temporary barrier may be erected across Marine Drive to act as flood protection during flood stage (Colin Rowan, MCDD, written commun., 2017).

Figure A-4. Generalized map of the building loss ratio due to a long-duration, 100-year flood in Peninsula Drainage District 1.

Figure A-5. Generalized map of the building replacement cost due to a long-duration, 100-year flood in Peninsula Drainage District 1.

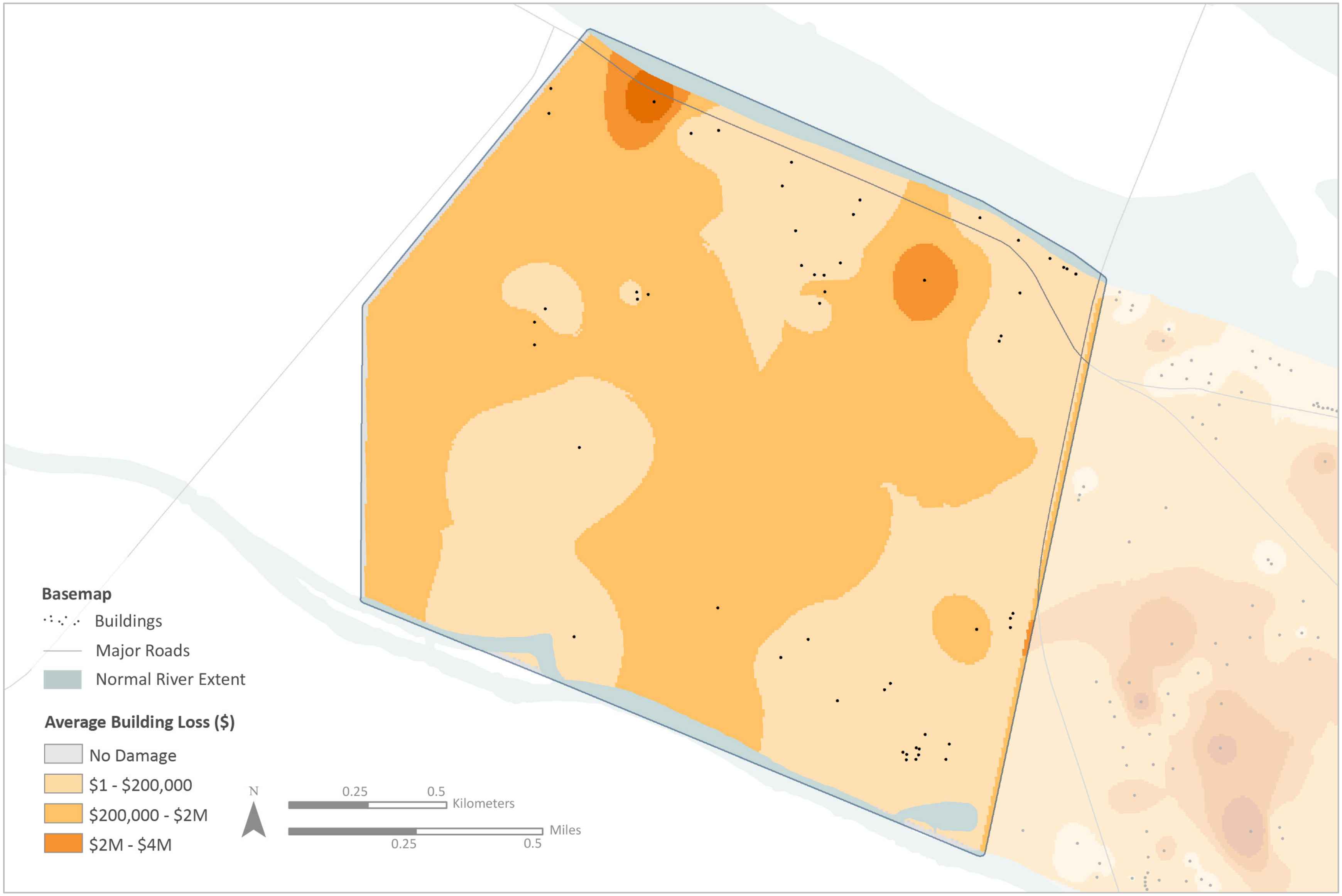


Figure A-6. Generalized map of the displaced population due to a long-duration, 100-year flood in Peninsula Drainage District 1.

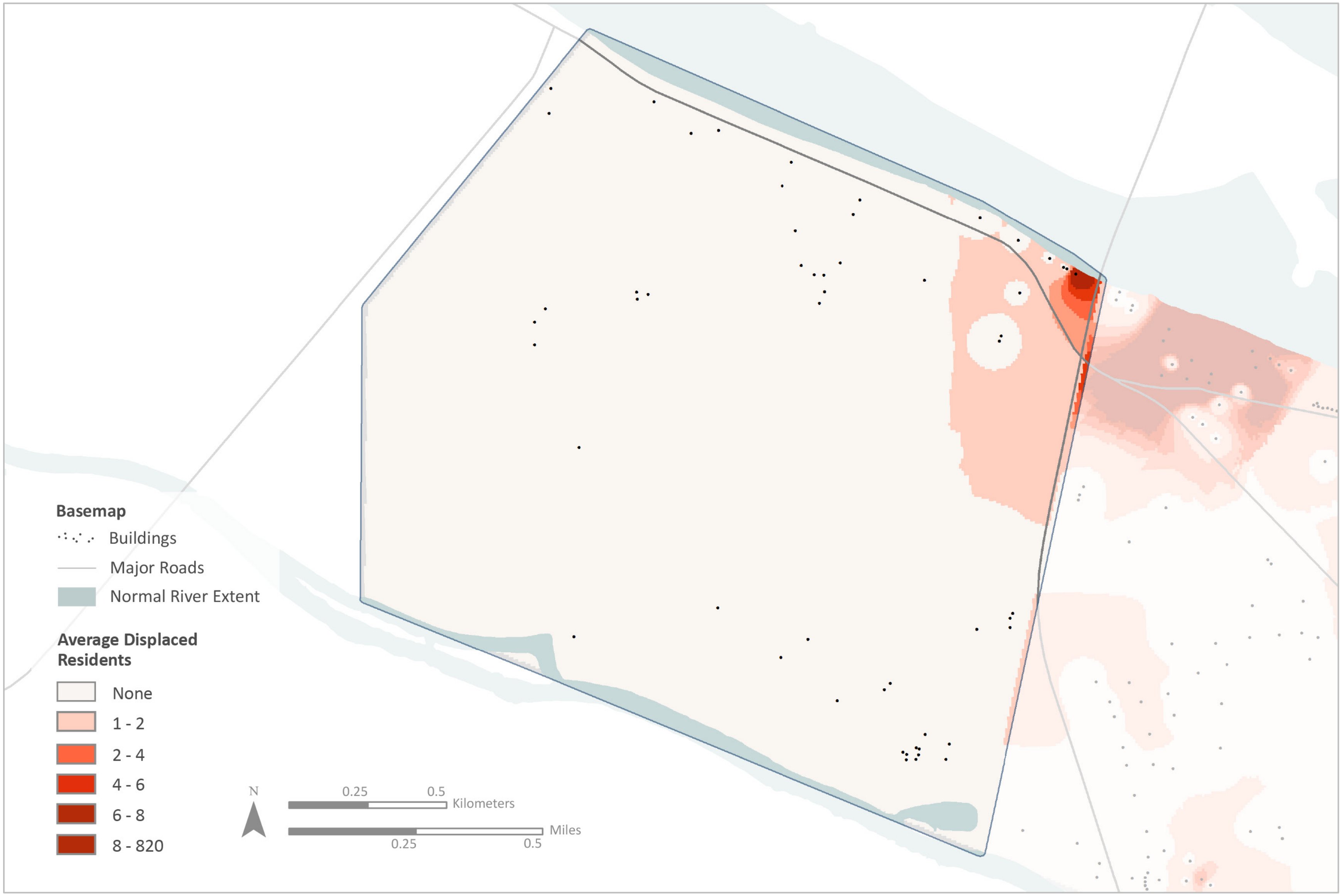


Figure A-7. Transportation routes exposed to 100-year and 500-year flood in Peninsula Drainage District 1.

A.3 Peninsula Drainage District 2

Current conditions: PEN 2 contains over 1,100 buildings, of which approximately 75% are residences. However, homes make up only roughly half of the building value in the district. The other half of building value is composed of just under 200 commercial and industrial facilities that include the Portland Meadows Racetrack, FedEx, and Reddaway shipping centers. We estimate that the combined replacement cost for all buildings, contents, and inventory in the district is approximately $1.4B.

Buildings, content, and inventory: If the levees were breached, the damage to structures within PEN 2 would be very severe during a major flood (**Figure A-8** and **Figure A-9**). PEN 2 has the greatest proportion of buildings exposed to flooding of any of the districts. During a 100-year flood, more than 1,000 buildings (i.e., 95%) would be exposed to flood water. This district also has the highest loss ratio (cost of damage to current value ratio) of any of the districts, with 37%–45% of building value damaged during a flood. We estimate that it would cost $286M to $342M to repair and replace buildings damaged, and an additional $367M to $399M to replace the content of these buildings. The typical depth of flooding during a 100-year flood throughout this area is 7 feet for residential buildings and 13 feet for commercial and industrial buildings. The combined repair or replacement cost to buildings, content, and inventory is estimated at $672M to $760M. More than 200,000 tons of debris would be produced in PEN 2.

During a 500-year flood, damages to buildings, content, and inventory would be 5–7% higher than during a 100-year flood. The average depth of flooding during a 500-year flood increases to 10 feet for residential buildings and 16 feet for commercial and industrial buildings. At this depth, nearly all buildings would be exposed to flooding. The damaged buildings would cost ~$347M to $372M to repair or replace, while damaged content would be ~$402M to $435M to replace. Additional information about the impacts of both a 100-year and 500-year flood can be found in **Appendix B, Section B.1**.

Population: Approximately 2,500 people live in PEN 2. In a 100-year flood, nearly 2,300 (90%) of those residents would be initially displaced due to exposure to flood water. Approximately 1,900 residents (approximately 75%) would have homes damaged by flooding (**Figure A-10**). The homes most heavily impacted by flooding are divided between the northwestern corner of the district and the lower lying areas in the eastern half of the district.

Businesses and employees: PEN 2 would be severely impacted by either a 100-year or 500-year flood due to the greater depths of flooding. In a 100-year flood, nearly all businesses would be directly impacted and initially closed. Likewise, nearly all employees would be unable to return to work. Furthermore, businesses in PEN 2 would likely experience a relatively slow recovery time due to the degree of building damage expected. One year after flooding, approximately one-fifth of employees would be able to return to their former jobs, while an estimated 10% to 17% of businesses could reopen. Two years after flooding, the Hazus-MH analysis suggests that between 38% and 100% of businesses could reopen. This is an unusually wide range of recovery estimates and reflects the degree of flooding in the district as well as the types of buildings damaged. Between $312M and $346M in wages would be lost during the first two years after a 100-year flood. A 500-year flood would also close nearly every business in the district, resulting in a very gradual reopening in of businesses and return to employment. Additional information detailing the impacts of levee breach and a 100-year or 500-year flood can be found in **Appendix B, Section B.2**.

Key infrastructure: There are two pump stations within PEN 2, and both could be severely damaged during a flood. Respectively, they would experience 17 feet and 23 feet of flooding during a 100-year event. That would result in at least a 40% loss in value to the pumps. We did not identify any electrical substations, water treatment facilities, or natural gas facilities in this district. More information is provided in **Appendix B, Section B.3**.

Hazardous materials: There are 39 buildings that store 116 types of hazardous materials in PEN 2. These are composed primarily of materials classified as acute health hazards, flammable or combustible liquids, and combustible materials. These types of materials typically include fuels like gasoline, lead acid batteries, carbon dioxide, antifreeze, or motor, engine, and hydraulic oil. About 75% of the materials are stored in the western half of PEN 2 (**Figure 16**). During either a 100-year or 500-year flood, approximately 95% of the stored materials are in buildings exposed to flood water. More information is provided in **Appendix B, Section B.4**.

Community assets: Nearly all of the community asset points in PEN 2, including the Bridge Middle School and Portland Meadows Racetrack, would be vulnerable to either a 100-year or 500-year flood. Very little of the designated community asset recreation trails in PEN 2 are exposed to flooding, while all of the community asset areas, including Delta Park and the Columbia Edgewater Country Club, would be inundated during a flood. See **Figure 18** in the main body of the report and **Appendix B, Section B.5** for more detailed results.

Transportation: PEN 2 contains just over 21 miles of bus, light rail, trucking, and emergency routes. Sections of the levee along Marine Drive are vulnerable to overtopping when the Columbia River reaches its 500-year stage. **Figure A-11** shows the transportation route exposure to flooding.

- Approximately 4 of the 5 miles of bus lines in PEN 2 would be exposed to flooding during both a 100-year and 500-year flood. Flooding would impact TriMet bus line 6, which runs along Vancouver Way, and TriMet bus line 11 along Marine Drive.
- A short section of the TriMet Yellow MAX light rail line is located in PEN 2 near Interstate Avenue but is not exposed to either a 100-year or 500-year flood.
- There are no railroad tracks in PEN 2.
- There are approximately 8 miles of road designated as major trucking routes; during a 100-year flood and a 500-year flood, 2 and 2.5 miles, respectively, of these roads would be exposed to flooding. Flooding would be focused around the I-5 and Martin Luther King Boulevard off-ramps.
- Approximately 7.5 miles of road are designated as emergency transportation routes; during a 100-year flood and a 500-year flood, 2 and 2.5 miles, respectively, of these roads would be exposed to flooding. The exposure is concentrated along Marine Drive.

Figure A-8. Generalized map of the building loss ratio due to a long-duration, 100-year flood in Peninsula Drainage District 2.

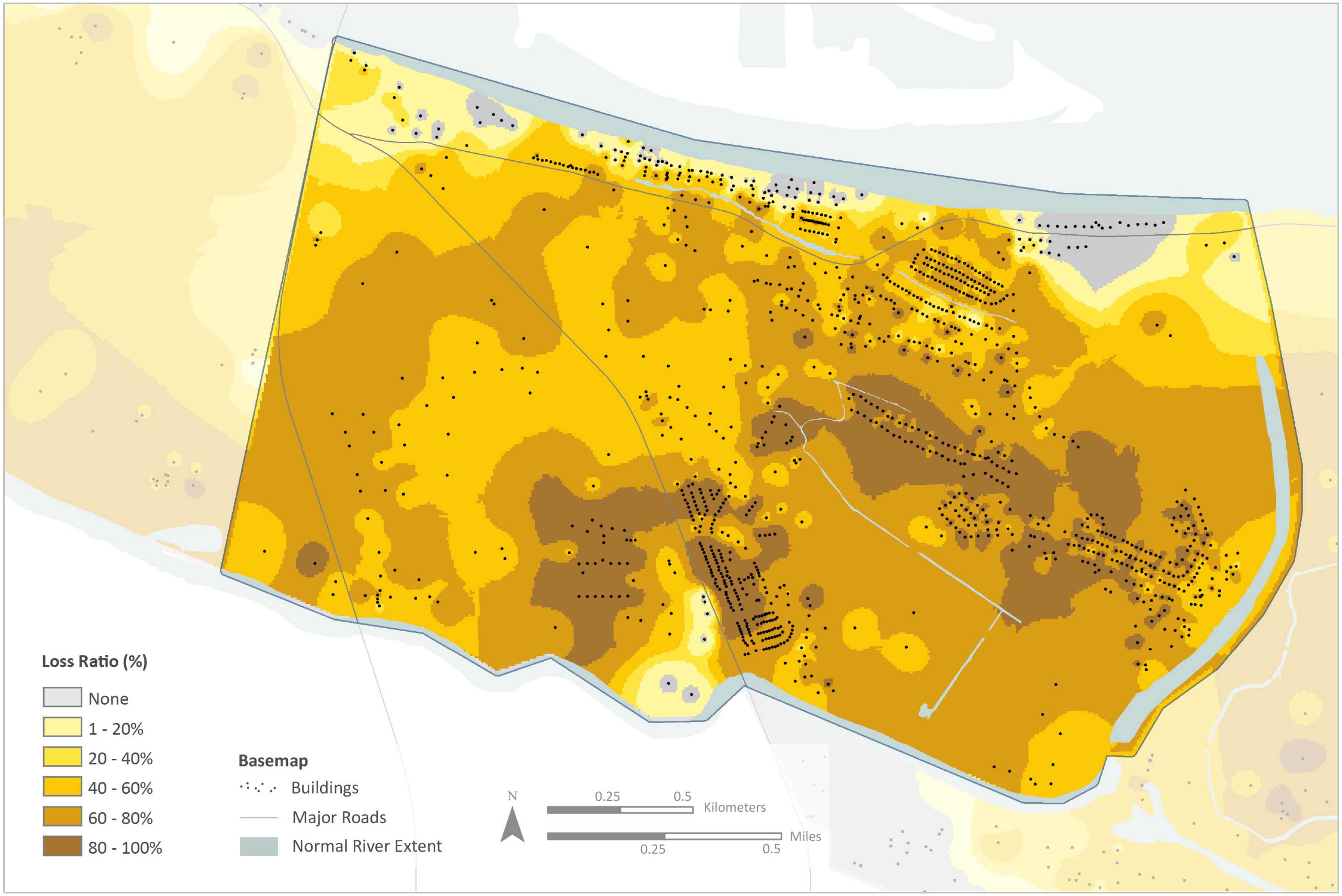


Figure A-9. Generalized map of the building replacement cost due to a long-duration, 100-year flood in Peninsula Drainage District 2.

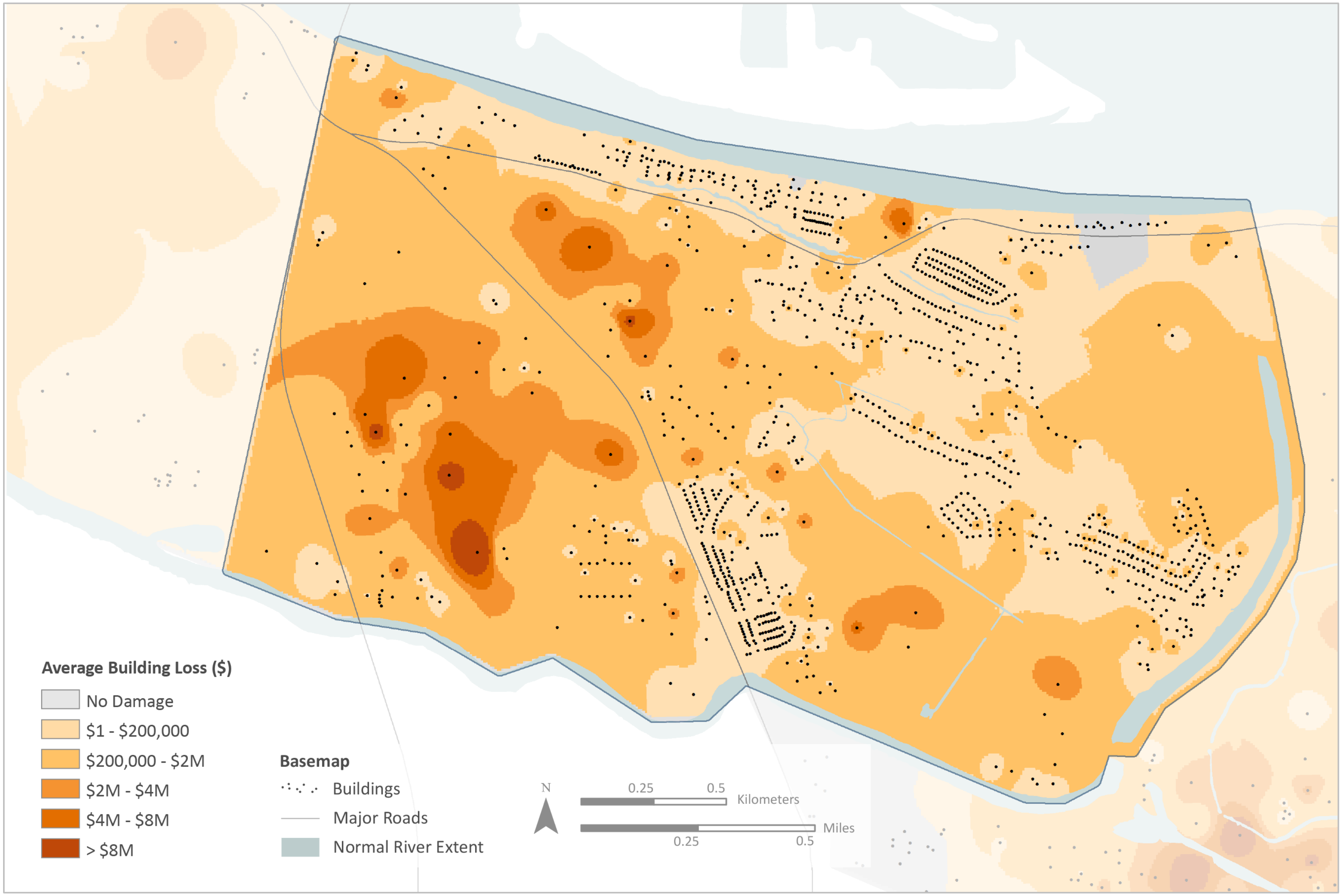


Figure A-10. Generalized map of the displaced population due to a long-duration, 100-year flood in Peninsula Drainage District 2.

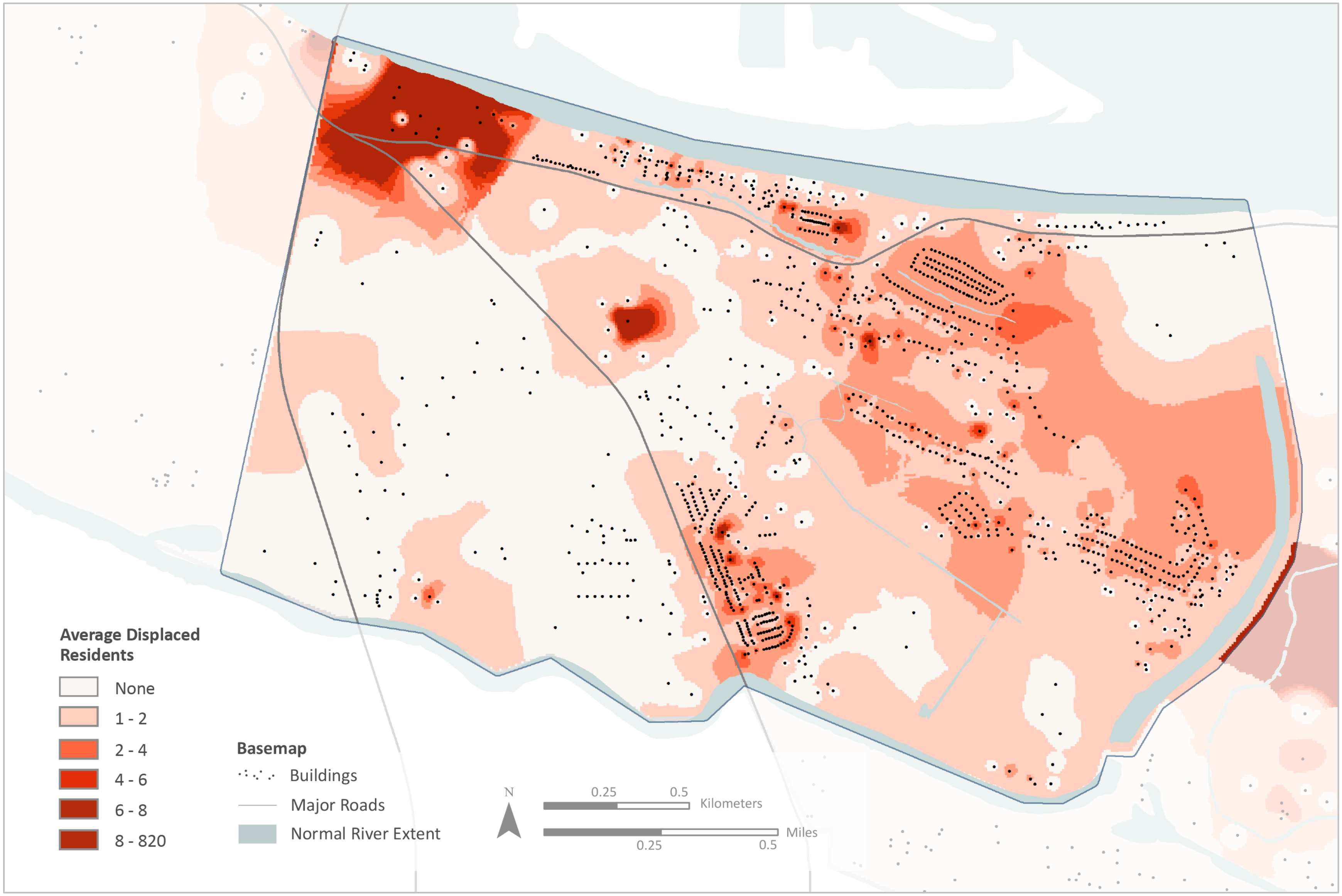
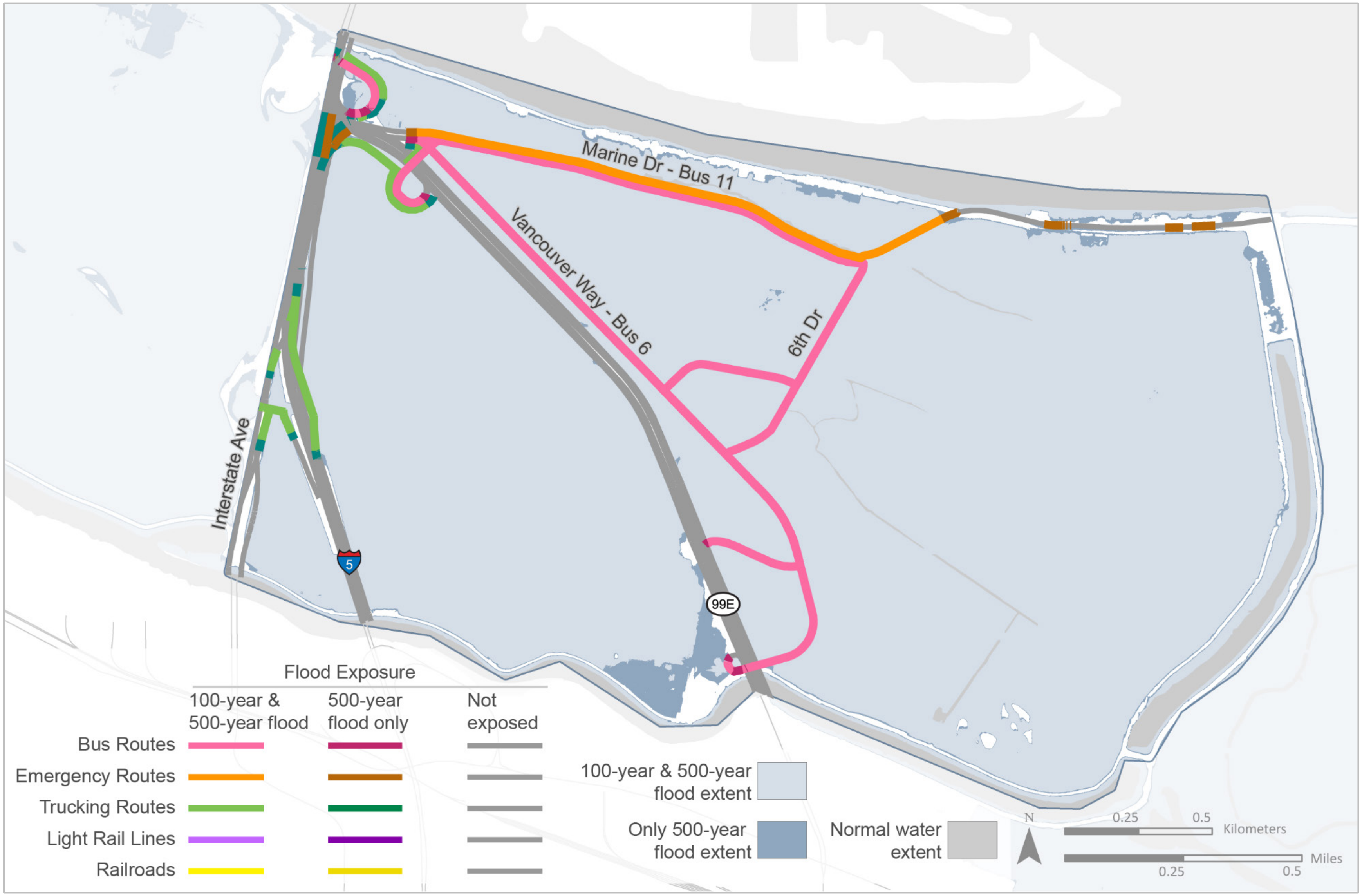


Figure A-11. Transportation routes exposed to 100-year and 500-year flood in Peninsula Drainage District 2.



A.4 Multnomah County Drainage District - West

Current conditions: Containing nearly 1,500 buildings, MCDD-W has the greatest total number of buildings in a single district. Of these, two-thirds consist of commercial and industrial buildings including the Portland Airport, the stores at Cascade Station, and Costco. The remaining one-third are primarily residential buildings with some agricultural, utility, governmental, and non-profit facilities including the Columbia River Correctional Institution and Multnomah County Inverness Jail. MCDD-W contains the greatest combined asset value with approximately $8.4B in building, content, and inventory replacement cost. Just over $1B of this value is attributed to the Portland Airport, Long and Short-Term Parking Lots, and Port of Portland Headquarters.

Buildings, content, and inventory: The damage to structures within MCDD-W would be very severe if the levees failed during a major flood. MCDD-W has the largest number of buildings impacted by flooding, with more than 1,100 buildings exposed to both a 100- and 500-year flood (**Figure A-12** and **Figure A-13**). It also has the greatest total anticipated replacement cost due to flood damage. We anticipate that in total, it will cost between $1.2B and $1.8B to replace and repair buildings in this district, and an additional $2.2B to $2.8B to replace the contents lost during a 100-year flood. The typical depth of flooding for commercial and industrial buildings would be 9 feet, and more than 430,000 tons of debris would be produced. The damaged buildings, content, and inventory would cost between ~$3.6B and $4.7B to repair or replace. Of this total damage, an estimated ~$264M to $484M are associated with Portland Airport, Long and Short-Term Parking Lots, and Port of Portland Headquarters.

For a 500-year flood, damages to buildings, content, and inventory would be 7–9% greater than during a 100-year flood. The average depth of flooding for commercial and industrial buildings would increase to 12 feet. It would cost $1.7-$2.2B to repair or replace buildings damaged during a 500-year flood and an additional $2.5-$2.9B to replace the content damaged. Additional information about the impacts of both a 100-year and 500-year flood can be found in **Appendix B, Section B.1**.

Population: Approximately 2,000 people live in MCDD-W, of whom approximately 600 are voluntary residents (including 60 Dignity Village residents) and 1,400 are incarcerated in two prisons. During a 100-year flood and a 500-year flood, both prisons will be damaged by flooding, and approximately 60% of the non-incarcerated population live in homes that will be exposed to and damaged by flooding (**Figure A-14**). The homes most heavily impacted by flooding are generally those adjacent the Columbia Slough.

Businesses and employees: Of all the districts, MCDD-W contains the largest number of businesses and employees and, thus, exhibits the greatest potential for business closure and employees out of work following a flood. We estimate 90% of the 39,000 employees in the district would be unable to return to work in the immediate aftermath of a 100-year flood. Similarly, 85% of the more than 1,500 current businesses would close, and restoration would occur very gradually. We find that one year after flooding approximately one-quarter of businesses would be able to reopen. However, two years after flooding, nearly 90 to 100% of businesses are expected to be restored. MCDD-W would experience the greatest loss in paid wages, with between ~$2B and $2.8B in lost wages spread across the two years following a 100-year flood. A 500-year flood would have a slightly more severe impact than a 100-year flood. Although the proportion of additional buildings closed after to a 500-year flood is small, the actual number of businesses and employees impacted is significant. With the additional 3 feet of flooding during a 500-year flood, approximately 750 additional employees would be unable to return to work directly following the flood due to an additional 37 business requiring restoration. Additional information detailing the impacts of levee breach and a 100-year or 500-year flood is provided in **Appendix B, Section B.2**.

Key infrastructure: MCDD-W contains one electrical substation, two natural gas facilities, and four pump stations. All facilities are vulnerable to both a 100-year and 500-year flood. The electrical substation would be flooded to a depth of 6 feet and experience a 9% damage, while the natural gas facilities would experience 7 and 10 feet of flooding with an associated 40% of value lost. The four pump stations would experience flooding to depths that range from 12 feet to 22 feet, resulting in lost value of ~40% or more. We did not identify any water treatment facilities in this district. Please review the tables in **Appendix B, Section B.3** for more information.

Hazardous materials: According to Oregon Office of State Fire Marshal hazardous materials records, the MCDD-W district contains the largest number of stored hazardous materials in the study area. There are nearly 1,000 materials stored in 216 buildings across the district. About one-fifth of these buildings are located near the Portland Airport (MCDD-W, A in **Figure 16**). These hazardous materials are primarily composed of materials that are acute health hazards and flammable or combustible liquids such as lead acid batteries, carbon dioxide, antifreeze, gasoline, thinners, paints, and solvents. During both a 100-year and 500-year flood, approximately 95–97% of the stored materials are in buildings exposed to flood water in the area near the Portland Airport (MCDD-W, A). In the areas of MCDD-W beyond the Portland, 75% and 80% of the stored materials are in buildings exposed to a 100-year and 500-year flood water, respectively (MCDD-W, B). More information is provided in **Appendix B, Section B.4**.

Community assets: MCDD-W contains the greatest number of community asset points of any of the districts, and nearly all of them, including two prisons, the Portland International Airport, and the Port of Portland Police Department, are located in areas vulnerable to flooding. This district also contains the longest section of recreation trail exposed to flooding, with about half of the section of the 40-Mile Loop and all of the section of Columbia Slough Trail in MCDD-W in flood prone areas. Many of the community asset areas, including the Riverside Golf Course and Catkin Marsh Natural Area, would be heavily impacted by major flooding while most but not all of the Colwood Golf Center would be exposed to flooding. See **Figure 18** in the main body of the report and **Appendix B, Section B.5** for more detailed results.

Transportation: MCDD-W contains both the greatest number of miles of transportation routes and the greatest amount of transportation routes exposed to flooding of any district. More than half of the 64 miles of bus, light rail, railroad, trucking, and emergency routes is exposed to a 100 and 500-year flood. **Figure A-15** shows the transportation route exposure to flooding.

- Nearly all of the 5 miles of bus routes in MCDD-W would be exposed to flooding during both a 100-year and 500-year flood. Flooding would impact TriMet bus line 70 along 33rd Avenue as well as line 87 along 105th Avenue and Airport Way. Although a portion of TriMet bus line 75 is located within MCDD-W, it would not be impacted by major flooding.
- MCDD-W contains the greatest number of miles of light rail line and light rail line exposure of any of the districts. More than 3 miles of the TriMet Red MAX light rail line is located in MCDD-W and more than 2.5 miles of that line would be exposed to either a 100- or 500-year flood.
- MCDD-W contains approximately 5.5 miles of railroad line, but only approximately 1 mile of this railroad would be exposed to flooding during a 100- or a 500-year flood. Much of the railroad potentially exposed to flooding is owned by Union Pacific Railroad.

- MCDD-W contains the greatest number of miles of trucking routes and trucking route exposure of any of the districts. More than 25 miles of road is designated as major trucking routes. About 16 and 17 miles of these roads would be exposed to flooding during a 100- and 500-year flood, respectively. This flooding includes 82nd Way and Airport Way.
- MCDD-W contains the greatest number of miles of roads designated as emergency routes and route exposure of any of the districts. There about 25 miles of emergency routes in this district; 10.5 and 11 miles of these roads would be exposed to flooding during a 100- and 500-year flood, respectively. This flooding includes sections of Marine Drive, Airport Way, 82nd Way, and 122nd Avenue but does not include Columbia Boulevard or I-205, which are also designated emergency routes.

In addition, all 10 of the identified parking lots in the MCDD-W will experience more than 4 feet of flooding during a 100-year flood and 7 feet of flooding during a 500-year flood. According to the USACE (2006), 3 or more feet of flooding will result in complete damage to sub-compact, compact, mid-sized, large, truck, and SUV automobiles. More information is provided in the "Damage to Parked Vehicles" spreadsheet that accompanies this report.

Figure A-12. Generalized map of the building loss ratio due to a long-duration, 100-year flood in Multnomah County Drainage District – West.

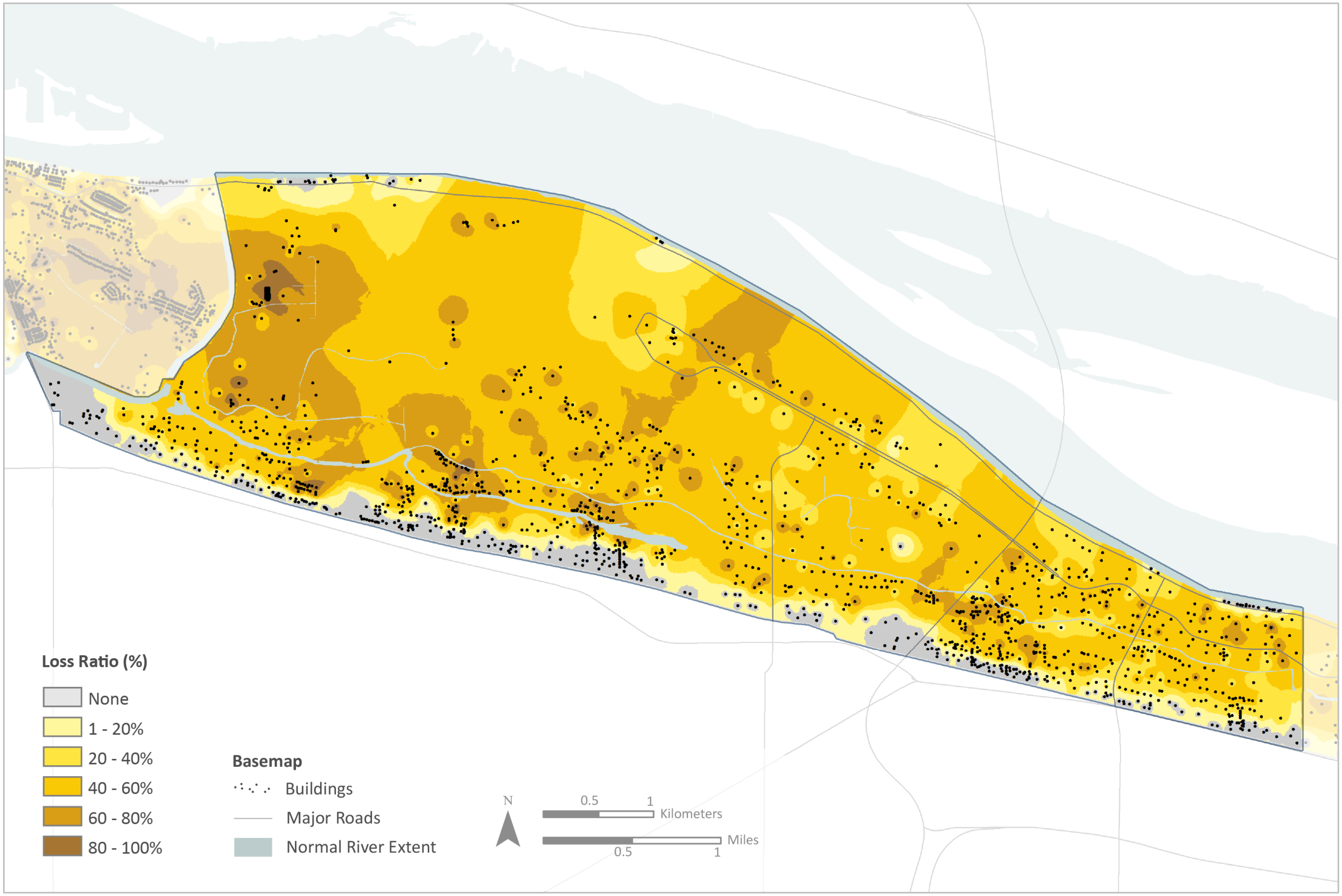


Figure A-13. Generalized map of the building replacement cost due to a long-duration, 100-year flood in Multnomah County Drainage District – West.

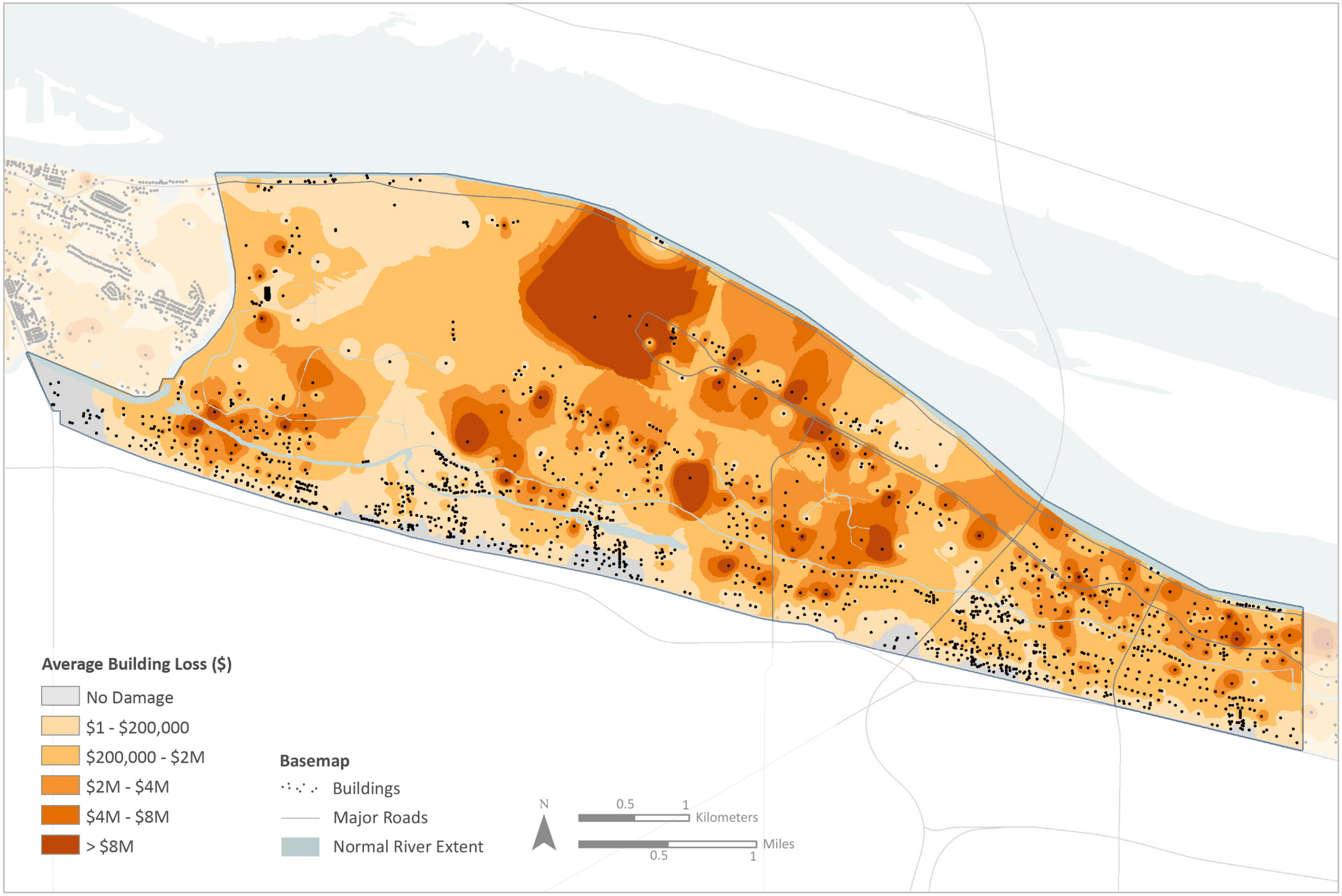
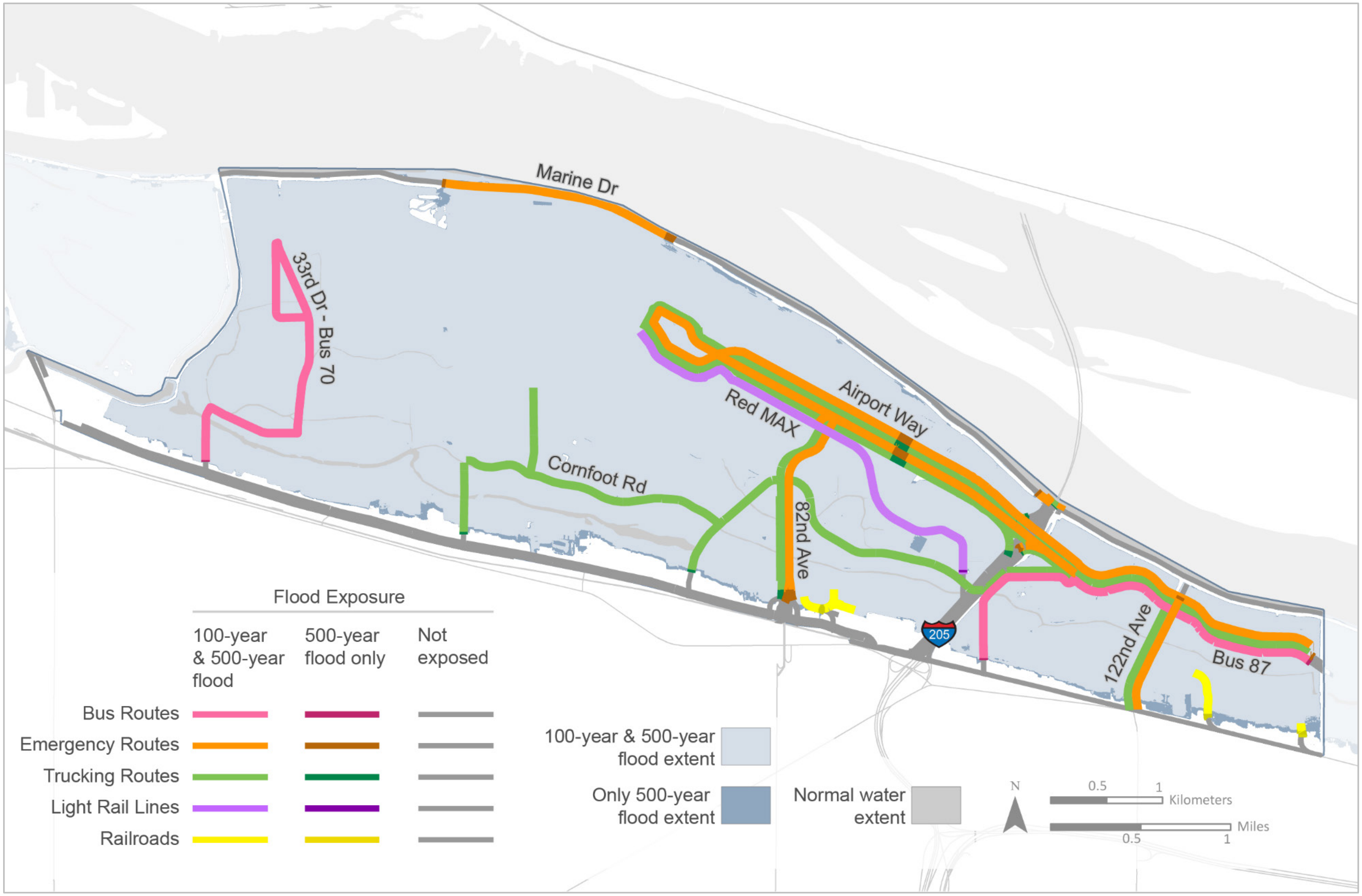


Figure A-14. Generalized map of the displaced population due to a long-duration, 100-year flood in Multnomah County Drainage District – West. Note that many of the displaced resident are located within the two prisons within the district.

Figure A-15. Transportation routes exposed to 100-year and 500-year flood in Multnomah County Drainage District – West.



A.5 Multnomah County Drainage District – East

Current conditions: There are more than 1,100 buildings in MCDD-E, making it the second largest district by building count. More than 80%, of these buildings are defined as residences. However, the commercial and industrial buildings, including many large shipping facilities, make up the majority of the building and content value in the district. The combined building, content, and inventory value for this district is one of the highest, with more than $2.4B in assets.

Buildings, content, and inventory: Like many of the districts in this study, MCDD-E would experience severe damage during a major flood if the levees were to fail (**Figure A-16** and **Figure A-17**). Approximately 65% of buildings would be exposed to a 100-year flood, and an estimated $324M to $508M in building damage would occur. It would cost an additional $695M to $839M to replace the damaged content within those buildings. Most residential buildings would be flooded approximately 6 feet above the first floor height and, on average, commercial and industrial buildings would experience 8 feet of flooding. More than 200,000 tons of debris would be produced from the flooding. In total, damaged buildings, content, and inventory would cost between $1B and $1.4B to repair or replace.

For a 500-year flood, damages to buildings, content, and inventory would be 8–9% greater than during a 100-year flood. The average depth of flooding of residential homes increases to 7 feet of flooding, while commercial and industrial buildings would experience, on average, 11 feet of flooding. More than 75% of buildings would be exposed to flooding, and the building damage would increase to $438M to $612M; content damage would increase to $798M to $893M. Additional information about the impacts of both a 100-year and 500-year flood is provided in **Appendix B, Section B.1**.

Population: Nearly 3,000 people live in MCDD-E, making it the most populated district in the study area. The majority of these residents live in the eastern half of the district in the Interlachen-Fairview area (**Figure A-18**). During a 100-year flood, approximately half of these homes are exposed to and damaged by flooding; during a 500-year flood, approximately two-thirds of the homes are exposed to and damaged by flood water. The homes most heavily impacted by flooding are those to the southeast of Fairview Lake.

Businesses and employees: MCDD-E would also be severely impacted by either a 100-year or 500-year flood. This district contains the greatest proportion of employees initially impacted by a major flood. The majority of the more than 7,700 employees in MCDD-E would be unable to return to work immediately following a 100-year flood, and almost 90% of businesses would be closed. Business recovery is expected to be slow, with ~75% of employees unable to return to work and 65–75% of businesses unable to reopen one year after flooding. As in most of the surrounding districts, it would take at least 2 years for the majority of businesses to reopen. During the two years following a 100-year flood, there would be between $456M to $593M in wages lost. A 500-year flood would result in an additional ~200 employees unable to work and 16 additional businesses closed immediately following a flood. Additional information detailing the impacts of levee breach and a 100-year or 500-year flood can be found in **Appendix B, Section B.2**.

Key infrastructure: There are two electrical substations, four pump stations, and one water treatment facility in MCDD-E. All facilities except for one of the electrical substations are vulnerable to major flooding. The other electrical substation would experience 10 feet of flooding during a 100-year event, resulting in a 15% loss in value. The four pump stations would experience a range of flood depths from 7 to 20 feet with at least 40% estimated damage. The drinking water treatment facility in MCDD-E would experience ~9 feet of flooding, which could result in approximately 30% of the value lost. We did not identify any natural gas facilities in this district. More information is provided in **Appendix B, Section B.3**.

Hazardous materials: MCDD-E contains 53 buildings that store 168 hazardous materials. The vast majority of these buildings are located in the western half of the district and contain materials that are classified as acute health hazards, flammable or combustible liquids, and oxidizers (**Figure 16**). These materials typically include lead acid batteries, carbon dioxide, antifreeze, gasoline, thinners, paints, solvents, oxygen, and hydrogen peroxide. During a 100-year flood, the majority of buildings would be exposed to flooding; for the 500-year flood scenario, all buildings storing hazardous materials would be exposed to flooding. More information is provided in **Appendix B, Section B.4**.

Community assets: MCDD-E contains the greatest proportion of community assets vulnerable to flooding of any of the drainage districts. The six community asset points, including the Training Division of the Portland Police Bureau, in this district are located in areas prone to both the 100- and 500-year flood. All of the Columbia Slough Trail and over half of the section of the 40-Mile Loop along Marine Drive in MCDD-E would be exposed to flooding. Finally, all of the community asset areas, including Blue Lake Regional Park and Lake Shore Park, would be heavily impacted by major flooding. See **Figure 18** in the main body of the report and **Appendix B, Section B.5** for more detailed results.

Transportation: MCDD-E contains 25 miles of bus, railroad, trucking, and emergency routes. **Figure A-19** shows the transportation route exposure to flooding.

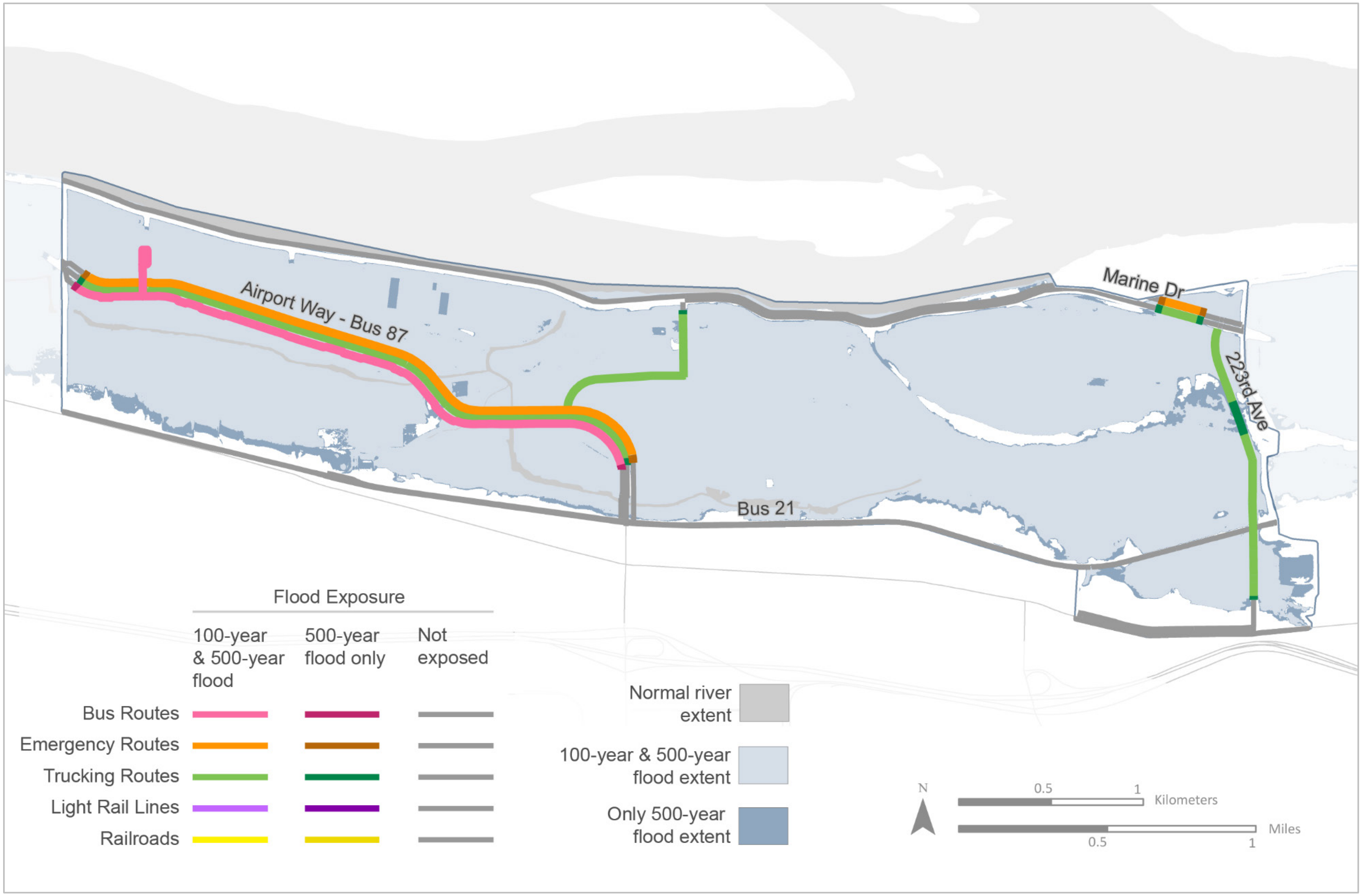
- Nearly all of the 2.5 miles of bus routes in MCDD-E would be exposed to flooding during both a 100-year and 500-year flood. Flooding would impact TriMet bus line 87 along Airport Way. Although a portion of TriMet bus line 21 is located within MCDD-E, it would not be impacted by major flooding.
- There are no light rail lines within MCDD-E.
- MCDD-E contains approximately 9 miles of railroad track, the greatest number of miles for a single district; however, none of these miles of line are exposed to a 100- or 500-year flood due to their elevation and position along the south side of the drainage district. The majority of this railroad track is owned by Union Pacific Railroad.
- There are approximately 6.5 miles of road designated as major trucking routes. Respectively, 3.5 and 4 miles of these roads would be exposed to flooding during a 100- and 500-year flood. This flooding would be focused around Airport Way but also include sections of 223rd Avenue.
- Approximately 7 miles of road are designated as emergency transportation routes. Just over 2 miles these routes are exposed to both a 100- and 500-year flood. The route exposure is concentrated along Airport Way but also includes a short section of Marine Drive.

Figure A-16. Generalized map of the building loss ratio due to a long-duration, 100-year flood in Multnomah County Drainage District – East.

Figure A-17. Generalized map of the building replacement cost due to a long-duration, 100-year flood in Multnomah County Drainage District – East.

Figure A-18. Generalized map of the displaced population due to a long-duration, 100-year flood in Multnomah County Drainage District – East.

Figure A-19. Transportation routes exposed to 100-year and 500-year flood in Multnomah County Drainage District – East.



A.6 Sandy Drainage Improvement Company

Current conditions: SDIC contains 180 buildings, making it a relatively small district by building count. More than 90% of these buildings are commercial and industrial buildings, including the Troutdale Airport, FedEx Ground distribution center, and planned Amazon shipping center. The remaining buildings are agricultural, utility, governmental, non-profit buildings, and residences. Despite the few number of buildings in SDIC, we estimate that the combined replacement cost for all buildings, contents, and inventory in the district is just over $1B.

Buildings, content, and inventory: Despite the high value of assets in this district, damage to structures in the SDIC as a result of a flood would be moderate (**Figure A-20** and **Figure A-21**). Approximately 50% of the buildings in the district would be exposed to flooding in a 100-year flood which would result in ~$76M - $125M in building damage. Damage to the buildings' contents would cost an additional $167M to $207M to replace. The majority of damage to building and contents is experienced by commercial and industrial buildings which would be flooded to ~6 feet deep. SDIC would produce approximately 6,000 tons of debris during a 100-year flood. We estimate that the combined replacement cost for all buildings, contents, and inventory in the district is ~$256M to $346.

A 500-year flood would result in 11–17% greater damage than a 100-year flood. Nearly 75% of buildings would be exposed to flooding and the typical flood depth for commercial and industrial buildings would be 7 feet. The damage to buildings would cost ~$114M to $188M to replace during a 500-year flood and the damage to content would cost ~$251M to $334M to replace. Additional information about the impacts of both a 100-year and 500-year flood can be found in **Appendix B, Section B.1**.

There are an additional 14 commercial and industrial buildings located adjacent to SDIC that are not currently within the drainage district or protected by levees. Very few of these buildings are exposed to the 100-year flood but two-thirds are impacted during a 500-year event. We estimate that the combined replacement cost for all buildings, contents, and inventory in the district is just over $66M and that during a 100-year flood total damages would be ~$5 M to $8M, increasing to $13M and $16 M during a 500-year flood.

Population: There are an estimated 15 people who live within the boundary of SDIC. Fortunately, none of these residences are anticipated to be exposed to or damaged by either a 100- or 500-year flood. As such, no district map has been provided for displaced population in SDIC.

Businesses and employees: In SDIC, a 100-year or 500-year flood would have a moderate impact on businesses and employees in the district. More than half of businesses would be closed due to the initial, direct impacts of a 100-year flood and nearly 75% of the 6,000 employees in the district would be unable to return to work. However, SDIC is predicted to recover quickly when compared with the other drainage districts and, within one year after flooding, 50–75% of employees would be able to return to work. The majority of businesses would be able to reopen 1.5 to 2 years after a 100-year flood. During the 2 years following, there would be between $112M and $226M in wages lost. A 500-year flood would have a substantially worse impact than a 100-year flood in this district. Initially following a flood of this magnitude, an additional 470 employees would be unable to work and 16 more businesses would be closed for restoration. Additional information detailing the impacts of levee breach and a 100-year or 500-year flood can be found in **Appendix B, Section B.2**.

Key infrastructure: SDIC contains four electrical substations, one pump station, and two water treatment facilities. All facilities, except one of the water treatment facilities, are vulnerable to both a 100- and 500-year flood. The electrical substations are expected to experience flooding that will range from 6 feet to 16 feet, resulting in ~9% to 15% damage. The pump station would be flooded to a depth of 20 feet and experience a 40% loss in value. While one of the waste water treatment facilities is located above the modeled flood levels, the other facility is located just within the 500-year floodplain. This facility would flood less than 1 foot and experience approximately 5% damage. We did not identify any natural gas facilities in this district. Please review the tables in **Appendix B, Section B.3** for more information.

Hazardous materials: There are 25 buildings that store 87 hazardous materials in SDIC. These materials are most commonly classified as acute health hazards and non-flammable gases. These types of materials typically include lead acid batteries, carbon dioxide, antifreeze, argon, and liquid nitrogen. During a 100-year flood, 68% of buildings would be exposed to flooding, while the 500-year flood would affect nearly 90% of buildings storing hazardous materials. See additional information in **Appendix B, Section B.4**.

Community assets: SDIC contains only one community asset point, the Troutdale Airport, located in an area exposed to a 100-year flood and six additional community asset points in areas exposed to a 500-year flood. In this district, most of the section of 40-mile Loop would not be directly exposed to flooding but may experience some service interruption during a flood event. While there are no community asset areas designated in SDIC, the Chinook Landing Marine Park north of this district would be exposed to flooding. See **Figure 18** in the main body of the report and **Appendix B** for more detailed results.

Transportation: SDIC contains 18 miles of bus, railroad, trucking, and emergency routes. **Figure A-22** shows the transportation route exposure to flooding.

- SDIC contains just over a mile of bus routes; approximately one quarter of a mile would be exposed to flooding during a 100-year flood and three quarters of a mile would be exposed during a 500-year flood. Flooding would impact the terminus of TriMet bus line 77 along Frontage Road.
- There are no light rail lines within MCDD-E.
- SDIC contains approximately 5.5 miles of railroad track, and approximately 1 mile of this track would be exposed to flooding during a 100- and 500-year flood. The railroad track in this district is owned by Union Pacific Railroad.
- There are approximately 6.5 miles of road designated as major trucking routes. 2 to 3 miles of these roads would be exposed to flooding during a 100- and 500-year flood respectively. This flooding would be focused around Marine Drive but also include sections of Frontage Road.
- There are approximately 5 miles of road designated as emergency transportation routes. Approximately 1.5 to 2.5 miles of these roads would be exposed to flooding during a 100- and 500-year flood respectively. The route exposure is concentrated along Marine Drive but would also include a short section of I-84 during a 500-year flood.

Figure A-20. Generalized map of the building loss ratio due to a long-duration, 100-year flood in Sandy Drainage Improvement Company district.

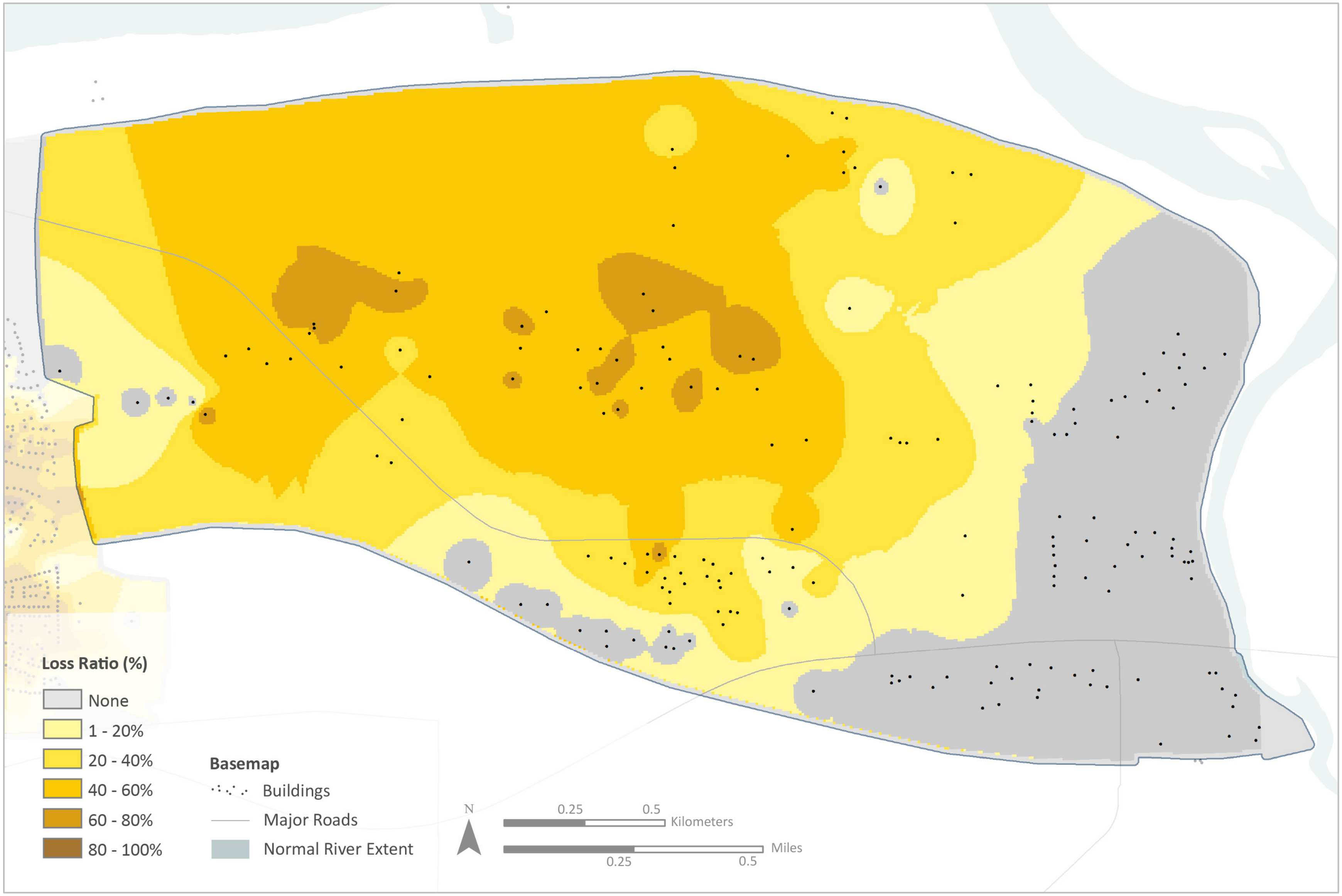


Figure A-21. Generalized map of the building replacement cost due to a long-duration, 100-year flood in Sandy Drainage Improvement Company district.

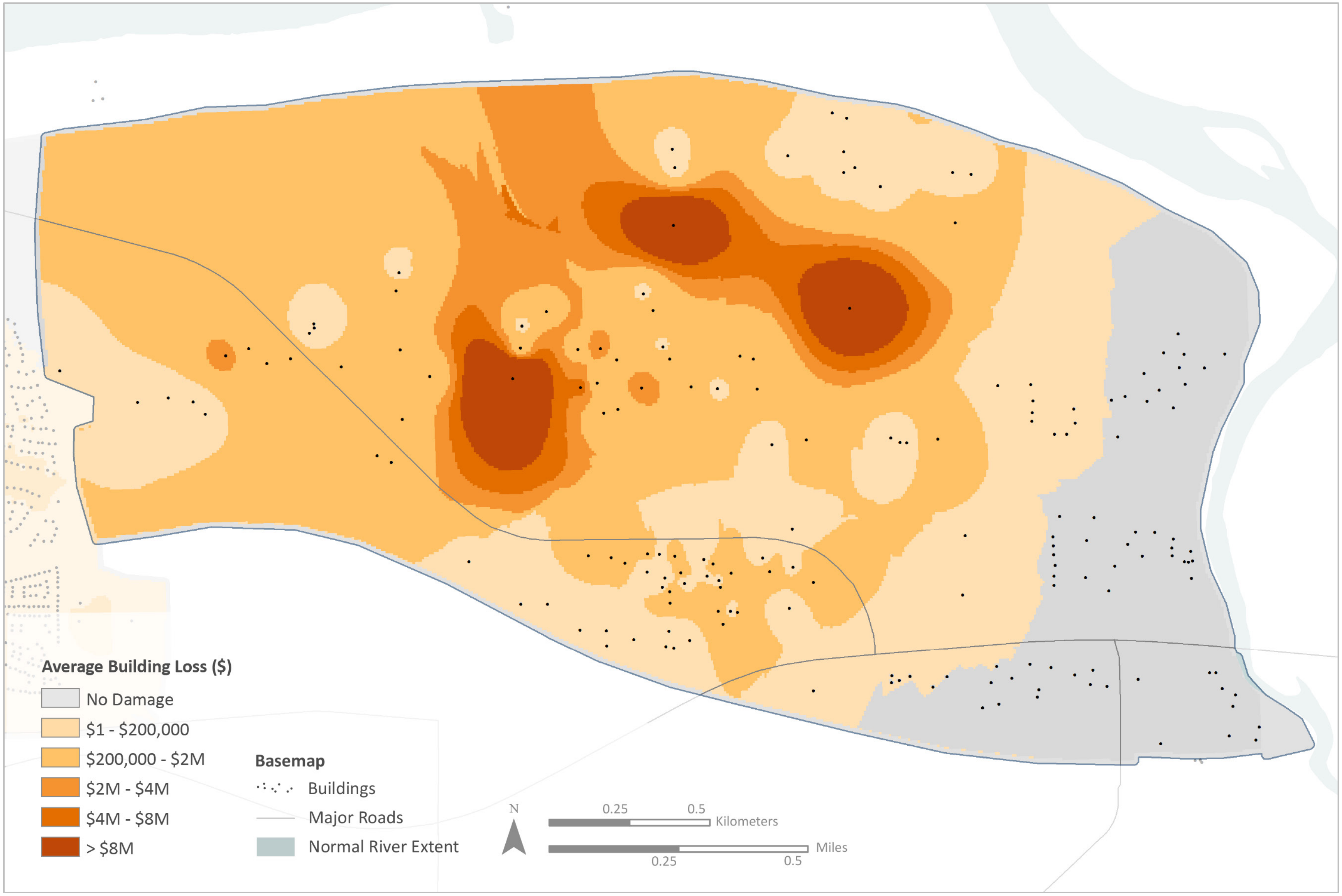
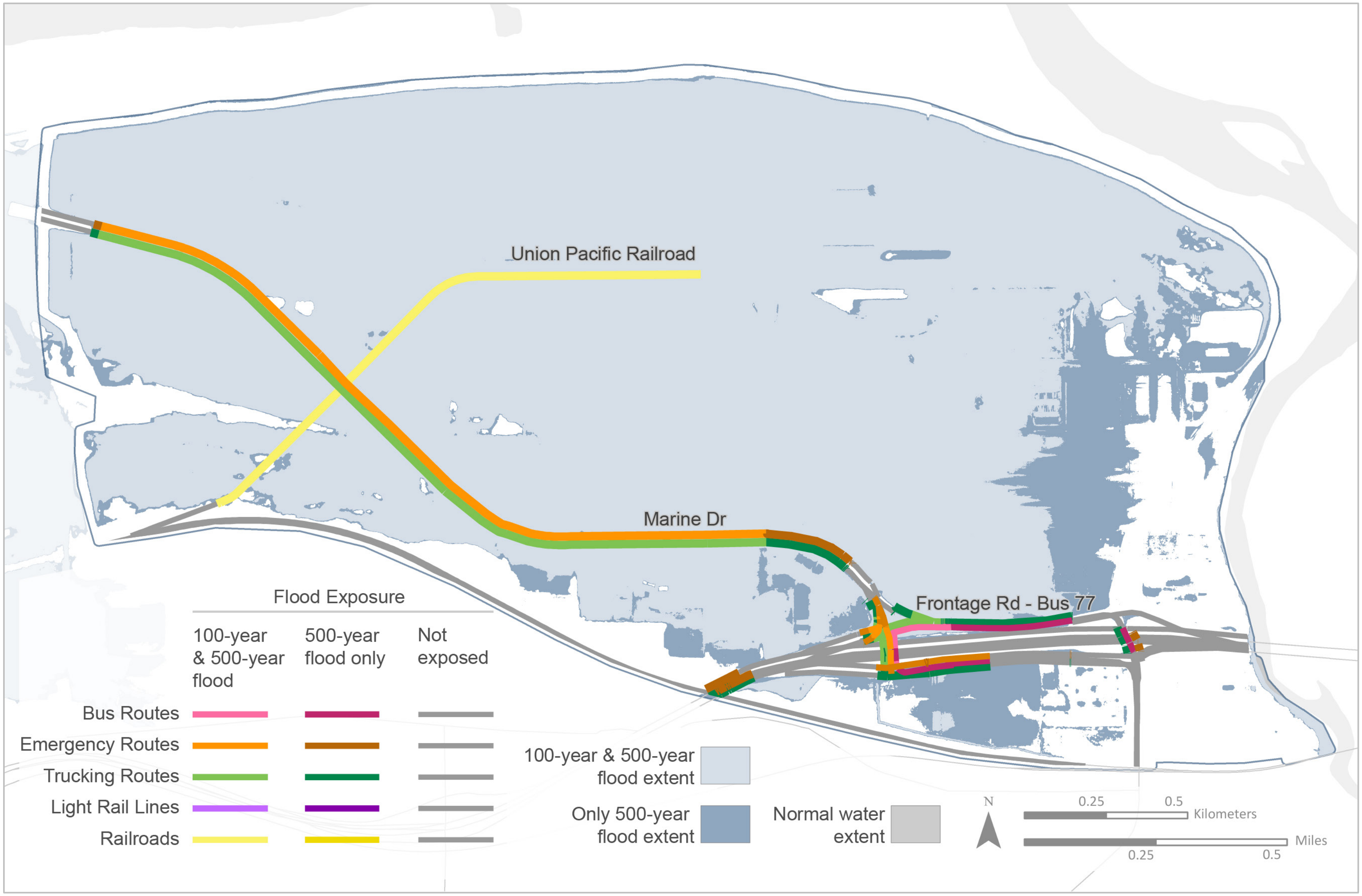


Figure A-22. Transportation routes exposed to 100-year and 500-year flood in Sandy Drainage Improvement Company district.



APPENDIX B. DETAILED RESULTS TABLES

B.1 Building, Content, and Inventory

Table B-1. Building structure, content, and inventory damage results by district and building type with debris produced and average depth of flooded structures during 100-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon. The standard and long-duration inventory damage estimates were nearly if not exactly identical; as such, these results have been consolidated into a single column.

	Current				100-Year Flood										
							Range of Building Damage ($ Million)		Range of Building Loss Ratio		Range of Content Damage ($ Million)				
District and Building Type	Number of Buildings	Building Replacement Cost ($ Million)	Content Replacement Cost ($ Million)	Inventory Replacement Cost ($ Million)	Number of Exposed Buildings	Percentage of Buildings Exposed	Standard	Long Duration	Standard	Long Duration	Standard	Long Duration	Inventory Damage ($ Million)	Debris (tons)	Average Depth of Flooded Buildings (ft)
SIDIC															
Total	709	203.1	162.4	12.1	486	69%	56.2	68.7	28%	34%	68.6	72.9	8.4	20,000	7.0
Agricultural and Utility	381	106.9	106.9	11.9	288	76%	35.4	40.9	33%	38%	54.5	54.5	8.3	13,000	8.5
Commercial and Industrial	15	5.6	5.7	0.2	13	87%	1.7	2.8	30%	50%	4.7	4.5	0.2	<500	10.2
Government and Non-Profit	6	7.6	8.2	—	—	—	—	—	—	—	—	—	—	—	—
Residential	307	83.1	41.5	—	185	60%	19.2	25.0	23%	30%	9.3	13.8	—	6,000	4.6
PEN 1															
Total	54	214.9	249.9	23.3	42	78%	11.5	15.9	5%	7%	20.1	22.3	1.6	5,000	12.9
Agricultural and Utility	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Commercial and Industrial	51	214.5	249.7	23.3	40	78%	11.4	15.8	5%	7%	20.1	22.3	1.6	5,000	13.2
Government and Non-Profit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Residential	3	0.5	0.2	—	2	67%	0.1	0.1	11%	11%	0.02	0.02	—	<500	6.4
PEN 2															
Total	1,137	763.7	602.7	22.4	1,075	95%	286.0	342.3	37%	45%	367.7	399.0	18.9	201,000	8.6
Agricultural and Utility	78	38.1	38.1	4.2	78	100%	29.4	33.4	77%	88%	29.3	29.3	4.2	6,000	13.4
Commercial and Industrial	188	350.2	366.6	18.2	178	95%	169.0	181.1	48%	52%	273.9	286.8	14.7	153,000	13.1
Government and Non-Profit	4	20.7	20.7	—	4	100%	1.8	8.2	9%	40%	9.9	10.6	—	<500	5.5
Residential	867	354.7	177.3	—	815	94%	85.8	119.6	24%	34%	54.6	72.3	—	42,000	7.2
MCDD-W															
Total	1,479	4,427.1	3,775.3	178.7	1,115	75%	1,241.9	1,852.9	28%	42%	2,232.7	2,779.1	113.9	431,000	8.6
Agricultural and Utility	35	4.8	4.8	0.5	28	80%	2.0	2.3	43%	47%	2.6	2.6	0.4	1,000	8.8
Commercial and Industrial	1,052	3,797.3	3,296.7	178.1	814	77%	1,121.9	1,580.6	30%	42%	1,932.8	2,397.2	113.5	392,000	8.9
Government and Non-Profit	51	226.0	274.2	—	40	78%	52.4	84.9	23%	38%	212.4	234.2	—	21,000	8.5
Residential	341	399.0	199.7	—	233	68%	65.6	185.1	16%	46%	84.7	145.0	—	18,000	7.6
MCDD-E															
Total	1,143	1,262.1	1,170.7	70	740	65%	324.1	507.7	26%	40%	696.3	839.0	48.3	207,000	6.2
Agricultural and Utility	12	1.1	1.1	0.1	5	42%	0.1	0.2	10%	18%	0.3	0.3	0.05	—	4.2
Commercial and Industrial	187	932.6	988.0	69.6	165	88%	267.9	422.0	29%	45%	630.9	762.8	48.3	187,000	8.3
Government and Non-Profit	6	34.6	34.6	—	6	100%	4.8	11.3	14%	33%	33.7	33.7	—	—	8.6
Residential	938	293.7	146.9	—	564	60%	51.4	74.1	17%	25%	31.5	42.3	—	20,000	5.6
SDIC															
Total	180	537.0	594.0	36.7	91	51%	76.5	125.4	14%	23%	167.0	207.3	12.9	6,000	6.4
Agricultural and Utility	4	0.6	0.6	0.1	1	25%	0.02	0.02	3%	4%	0.1	0.1	0.01	<500	4.6
Commercial and Industrial	164	499.9	566.8	36.6	90	55%	76.5	125.3	15%	25%	166.9	207.2	12.9	6,000	6.4
Government and Non-Profit	7	16.8	16.8	—	—	—	—	—	—	—	—	—	—	—	—
Residential	5	19.7	9.9	—	—	—	—	—	—	—	—	—	—	—	—
SIDIC — Beyond Levees															
Total	158	38.4	26.5	1.6	49	31%	1.8	3.4	5%	9%	3.3	3.5	0.4	1,000	1.4
Agricultural and Utility	76	14.7	14.7	1.6	21	28%	0.9	1.9	6%	13%	2.8	2.8	0.4	<1000	2.9
Residential	82	23.7	11.9	0.0	28	34%	0.9	1.5	4%	6%	0.5	0.7	0.0	<500	<1
SDIC — Beyond Levees															
Total — Commercial and Industrial	14	5.2	5.4	0.3	1	7%	0.0	0.1	1%	1%	0.2	0.2	0.0	<500	3.7

Table B-2. Building structure, content, and inventory damage results by district and building type with debris produced and average depth of flooded structures during 500-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon. The standard and long-duration inventory damage estimates were nearly if not exactly identical; as such, these results have been consolidated into a single column.

	Current				500-Year Flood										
							Range of Building Damage ($ Million)		Range of Building Loss Ratio		Range of Content Damage ($ Million)				
District and Building Type	Number of Buildings	Building Replacement Cost ($ Million)	Content Replacement Cost ($ Million)	Inventory Replacement Cost ($ Million)	Number of Exposed Buildings	Percentage of Buildings Exposed	Standard	Long Duration	Standard	Long Duration	Standard	Long Duration	Inventory Damage ($ Million)	Debris (tons)	Average Depth of Flooded Buildings (ft)
SIDIC															
Total	709	203.1	162.4	12.1	527	74%	83.4	89.7	41%	44%	83.6	89.3	10.0	28,000	10.3
Agricultural and Utility	381	106.9	106.9	11.9	309	81%	52.6	50.9	49%	48%	65.7	65.7	9.8	15,000	11.9
Commercial and Industrial	15	5.6	5.7	0.2	13	87%	2.5	3.3	44%	59%	5.0	4.6	0.2	2,000	14.3
Government and Non-Profit	6	7.6	8.2	—	—	—	—	—	—	—	—	—	—	—	—
Residential	307	83.1	41.5	—	205	67%	28.3	35.5	34%	43%	12.9	19.0	—	11,000	7.8
PEN 1															
Total	54	214.9	249.9	23.3	50	93%	41.8	65.4	19%	30%	90.4	128.6	9.8	5,000	13.9
Agricultural and Utility	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Commercial and Industrial	51	214.5	249.7	23.3	47	92%	41.7	65.2	19%	30%	90.3	128.5	9.8	5,000	14.0
Government and Non-Profit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Residential	3	0.5	0.2	—	3	100%	0.1	0.2	32%	53%	0.08	0.11	—	<500	6.1
PEN 2															
Total	1,137	763.7	602.7	22.4	1,110	98%	346.9	372.3	45%	49%	402.6	434.8	19.2	252,000	11.7
Agricultural and Utility	78	38.1	38.1	4.2	78	100%	32.9	33.8	86%	89%	29.9	29.9	4.2	6,000	16.9
Commercial and Industrial	188	350.2	366.6	18.2	183	97%	200.5	189.2	57%	54%	289.6	298.6	15.0	186,000	16.2
Government and Non-Profit	4	20.7	20.7	—	4	100%	2.7	10.6	13%	51%	15.0	20.7	—	1,000	9.0
Residential	867	354.7	177.3	—	845	97%	111.0	138.7	31%	39%	68.2	85.7	—	59,000	10.2
MCDD-W															
Total	1,479	4,427.1	3,775.3	178.7	1,168	79%	1,666.2	2,224.9	38%	50%	2,535.9	2,963.8	126.8	1,087,000	11.4
Agricultural and Utility	35	4.8	4.8	0.5	29	83%	2.6	2.5	55%	52%	3.0	3.0	0.4	1,000	11.7
Commercial and Industrial	1,052	3,797.3	3,296.7	178.1	853	81%	1,474.3	1,895.8	39%	50%	2,177.8	2,548.5	126.4	982,000	11.7
Government and Non-Profit	51	226.0	274.2	—	41	80%	77.8	104.0	34%	46%	230.6	238.1	—	24,000	11.6
Residential	341	399.0	199.7	—	245	72%	111.4	222.6	28%	56%	124.6	174.3	—	80,000	10.3
MCDD-E															
Total	1,143	1,262.1	1,170.7	69.7	870	76%	440.1	618.0	35%	49%	805.4	909.8	69.7	325,000	8.0
Agricultural and Utility	12	1.1	1.1	0.1	6	50%	0.2	0.3	17%	25%	0.3	0.3	0.13	<500	6.3
Commercial and Industrial	187	932.6	988.0	69.6	177	95%	363.6	500.4	39%	54%	729.0	818.3	69.6	298,000	10.8
Government and Non-Profit	6	34.6	34.6	—	6	100%	6.0	16.9	17%	49%	34.6	34.6	—	1,000	11.8
Residential	938	293.7	146.9	—	681	73%	70.3	100.4	24%	34%	41.4	56.5	—	26,000	7.3
SDIC															
Total	180	537.0	594.0	36.7	131	73%	114.0	187.5	21%	35%	250.5	334.4	19.3	34,000	7.1
Agricultural and Utility	4	0.6	0.6	0.1	4	100%	0.05	0.09	9%	16%	0.1	0.1	0.02	<500	2.5
Commercial and Industrial	164	499.9	566.8	36.6	126	77%	114.0	187.4	23%	37%	250.3	334.3	19.3	34,000	7.3
Government and Non-Profit	7	16.8	16.8	—	1	14%	—	—	—	—	—	—	—	<500	0.3
Residential	5	19.7	9.9	—	—	—	—	—	—	—	—	—	—	—	—
SIDIC-Beyond Levees															
Total	158	38.4	26.5	1.6	70	44%	5.7	8.0	15%	21%	6.7	7.4	0.8	3,000	4.2
Agricultural and Utility	76	14.7	14.7	1.6	31	41%	2.4	3.8	16%	26%	5.2	5.2	0.8	2,000	5.5
Residential	82	23.7	11.9	0.0	39	48%	3.3	4.2	14%	18%	1.5	2.3	0.0	1,000	3.1
SDIC - Beyond Levees															
Total - Commercial and Industrial	14	5.2	5.4	0.3	9	64%	0.6	1.1	12%	21%	1.7	2.8	0.1	<500	2.3

B.2 Businesses, Employees, and Wages

Table B-3. Number and proportion of businesses able to open over time by district after a 100-year and a 500-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.

	Number of Businesses Open						% of Reopened Businesses				
District	Current	After Floodwaters Recede	0.5 Years	1 Year	1.5 Years	2 Years	Day of Flood	0.5 Years	1 Year	1.5 Years	2 Years
100-Year Flood											
SIDIC	41	12	16–32	32–38	34–41	41	30%	39–79%	79–93%	82–99%	99–100%
PEN 1	27	16	16–17	17–21	21–21	21–27	58%	58–62%	62–79%	78–79%	79–100%
PEN 2	260	23	26–56	54–93	72–152	149–260	9%	10–21%	21–36%	28–59%	57–100%
MCDD-W	1,537	227	346–375	375–500	485–1,373	1,352–1,537	15%	23–24%	24–33%	32–89%	88–100%
MCDD-E	293	34	60–70	68–103	91–248	244–293	12%	20–24%	23–35%	31–85%	83–100%
SDIC	164	71	99–105	100–129	129–163	160–164	43%	61–64%	61–79%	79–99%	97–100%
500-Year Flood											
SIDIC	41	11	13–28	28–38	32–41	41	26%	32–68%	68–93%	79–99%	99–100%
PEN 1	27	2	6–15	7–19	19–21	21–27	8%	22–56%	25–70%	70–79%	79–100%
PEN 2	260	12	16–41	40–81	58–118	118–260	4%	6–16%	15–31%	22–46%	46–100%
MCDD-W	1,537	190	310–341	336–415	388–1,009	995–1,537	12%	20–22%	22–27%	25–66%	65–100%
MCDD-E	293	18	49–55	54–84	69–200	196–293	6%	17–19%	18–29%	24–68%	67–100%
SDIC	164	55	69–70	70–115	115–148	147–164	34%	42–43%	43–70%	70–90%	90–100%

Table B-4. Number and proportion of employees able to return to work over time by district after a 100-year and a 500-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.

	Number of Working Employees						% of Employees Returned to Work				
District	Current	After Floodwaters Recede	0.5 Years	1 Year	1.5 Years	2 Years	Day of Flood	0.5 Years	1 Year	1.5 Years	2 Years
100-Year Flood											
SIDIC	405	235	247–338	338–360	343–402	402–405	58%	61–83%	83–89%	85–99%	99–100%
PEN 1	1,167	265	265–1,007	1,007–1,087	1,085–1,091	1,091–1,167	23%	23–86%	86–93%	93%	93–100%
PEN 2	4,506	247	288–571	564–881	731–1,756	1,709–4,506	5%	6–13%	13–20%	16–39%	38–100%
MCDD-W	39,326	4,051	6,941–8,071	8,040–11,151	10,843–35,222	34,962–39,326	10%	18–21%	20–28%	28–90%	89–100%
MCDD-E	7,793	240	1,262–1,507	1,485–2,004	1,878–6,021	5,984–7,793	3%	16–19%	19–26%	24–77%	77–100%
SDIC	6,062	1,609	2,856–4,385	2,866–4,593	4,593–6,000	5,755–6,062	27%	47–72%	47–76%	76–99%	95–100%
500-Year Flood											
SIDIC	405	125	130–327	327–360	337–402	402–405	31%	32–81%	81–89%	83–99%	99–100%
PEN 1	1,167	48	105–971	847–1,069	1,067–1,087	1,087–1,167	4%	9–83%	73–92%	91–93%	93–100%
PEN 2	4,506	120	164–461	460–759	605–1,158	1,158–4,506	3%	4–10%	10–17%	13–26%	26–100%
MCDD-W	39,326	3,284	6,217–7,434	7,370–8,681	8,287–26,620	26,410–39,326	8%	16–19%	19–22%	21–68%	67–100%
MCDD-E	7,793	52	1,137–1,270	1,263–1,616	1,481–5,061	4,942–7,793	1%	15–16%	16–21%	19–65%	63–100%
SDIC	6,062	1,140	1,615–1,642	1,640–4,463	4,463–5,289	5,098–6,062	19%	27%	27–74%	74–87%	84–100%

Table B-5. Current annual employee earnings and employee earnings during first and second year after a 100-year and a 500-year flood in the Columbia corridor drainage districts, Multnomah County, Oregon.

	Employee Earnings					% of Current Earnings	
District	Current	First Year (Minimum)	First Year (Maximum)	Second Year (Minimum)	Second Year (Maximum)	First Year	Second Year
100-Year Flood							
SIDIC	$ 12,926,000	$ 9,248,000	$ 10,760,000	$ 11,473,000	$ 12,572,000	72–83%	89–97%
PEN 1	$ 66,524,000	$ 37,147,000	$ 58,126,000	$ 62,752,000	$ 63,685,000	56–87%	94–96%
PEN 2	$ 193,554,000	$ 13,446,000	$ 21,251,000	$ 28,181,000	$ 53,627,000	7–11%	15–28%
MCDD-W	$ 1,908,387,000	$ 316,552,000	$ 427,254,000	$ 689,615,000	$ 1,307,165,000	17–22%	36–68%
MCDD-E	$ 392,806,000	$ 53,905,000	$ 85,055,000	$ 138,275,000	$ 245,075,000	14–22%	35–62%
SDIC	$ 240,666,000	$ 100,737,000	$ 158,791,000	$ 154,551,000	$ 210,748,000	42–66%	64–88%
500-Year Flood							
SIDIC	$ 12,926,000	$ 7,320,000	$ 10,222,000	$ 10,963,000	$ 12,265,000	57–79%	85–95%
PEN 1	$ 66,524,000	$ 24,015,000	$ 56,373,000	$ 57,241,000	$ 63,440,000	36–85%	86–95%
PEN 2	$ 193,554,000	$ 8,301,000	$ 16,000,000	$ 22,143,000	$ 38,116,000	4–8%	11–20%
MCDD-W	$ 1,908,387,000	$ 282,729,000	$ 392,289,000	$ 483,879,000	$ 935,126,000	15–21%	25–49%
MCDD-E	$ 392,806,000	$ 46,744,000	$ 74,578,000	$ 101,225,000	$ 188,904,000	12–19%	26–48%
SDIC	$ 240,666,000	$ 78,683,000	$ 91,211,000	$ 133,151,000	$ 185,562,000	33–38%	55–77%

B.3 Key Infrastructure

Table B-6. Electrical substation flood depths and loss ratios for 100-year and 500-year floods in the Columbia corridor drainage districts, Multnomah County, Oregon. Hazus does not provide damage estimates for structures experiencing more than 10 feet of flooding.

	100-Year Flood		500-Year Flood	
District	Est. Depth (ft)	Loss Ratio (%)	Est. Depth (ft)	Loss Ratio (%)
SIDIC	8	12	12	15*
PEN 1	—	—	—	—
PEN 2	—	—	—	—
MCDD-W	6	9	9	14
MCDD-E	0	0	0	0
	10	15	13	15*
SDIC	6	9	9	14
	16	15*	19	15*
	8	12	11	15*
	9	14	13	15*

* Indicates maximum loss ratio estimation by Hazus.

Table B-7. Natural gas facilities flood depths and loss ratios for 100-year and 500-year floods in the Columbia corridor drainage districts, Multnomah County, Oregon. Hazus does not provide damage estimates for structures experiencing more than 10 feet of flooding.

	100-Year Flood		500-Year Flood	
District	Est. Depth (ft)	Loss Ratio (%)	Est. Depth (ft)	Loss Ratio (%)
SIDIC	—	—	—	—
PEN 1	—	—	—	—
PEN 2	—	—	—	—
MCDD-W	7	40	10	40
	10	40	13	40*
MCDD-E	—	—	—	—
SDIC	—	—	—	—

* Indicates maximum loss ratio estimation by Hazus.

Table B-8. Pump stations flood depths and loss ratios for 100-year and 500-year floods in the Columbia corridor drainage districts, Multnomah County, Oregon. Hazus does not provide damage estimates for structures experiencing more than 10 feet of flooding.

		Number	100-Year Flood		500-Year Flood	
District	Pump Station Name	of Pumps	Est. Depth (ft)	Loss Ratio (%)	Est. Depth (ft)	Loss Ratio (%)
SIDIC	Sauvie Island	4	9	40	13	40*
PEN 1	Vanport	1	26	40*	29	40*
	Portland International Raceway	2	20	40*	23	40*
PEN 2	Schmeer Road	2	17	40*	20	40*
	13th Avenue	2	23	40*	27	40*
MCDD-W	Broadmoor	2	22	40*	25	40*
	Pump Station 1	5	12	40*	15	40*
	Pump Station 2	2	21	40*	25	40*
	Airtrans	3	13	40*	17	40*
MCDD-E	Ceregino	1	20	40*	23	40*
	Bridgestone	1	14	40*	18	40*
	Pump Station 4	4	7	40	10	40*
	181 Street	2	10	40*	14	40*
SDIC	Sandy	2	20	40*	23	40*

* Indicates maximum loss ratio estimation by Hazus.

Table B-9. Water treatment facility flood depths and loss ratios for 100-year and 500-year floods in the Columbia corridor drainage districts, Multnomah County, Oregon. Hazus does not provide damage estimates for structures experiencing more than 10 feet of flooding.

		100-Year Flood		500-Year Flood	
District	Facility	Est. Depth (ft)	Loss Ratio (%)	Est. Depth (ft)	Loss Ratio (%)
SIDIC	—	—	—	—	—
PEN 1	—	—	—	—	—
PEN 2	—	—	—	—	—
MCDD-W	—	—	—	—	—
MCDD-E	Portland Water Bureau Groundwater Facility	9	30	12	40*
SDIC	Troutdale Wastewater Services (not in operation?)	0	0	0	0
	Troutdale Water Pollution Control Facility	0	0	< 1	5

* Indicates maximum loss ratio estimation by Hazus.

B.4 Hazardous Materials

Table B-10. Number of hazardous materials, by hazardous material type and drainage district, exposed to a 100-year and a 500-year flood in the subdivided Columbia corridor drainage districts, Multnomah County, Oregon.

District	Section	2.1: Flammable Gas	2.2: Non-flammable Gas	3: Flammable and Combustible Liquid	4.1: Flammable Solids	4.4: Reactive Material	4.5: Combustible Material	5.1: Oxidizers	5.2: Organic Peroxides	6.1: Poisonous Material	6.3: Acute Health Hazard	6.4: Chronic Health Hazard	6.5: Pesticide	8: Corrosive Material	9: Miscellaneous Hazardous Material	Total Number of Materials
100 Year Flood																
SIDIC	North	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	South	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2
	Total	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2
PEN 1	Total	4	3	7	—	—	6	2	—	—	8	1	—	3	6	40
PEN 2	West	7	11	12	—	—	13	10	—	1	16	—	—	5	3	78
	East	4	4	6	—	—	8	3	—	1	5	—	—	1	—	32
	Total	11	15	18	—	—	21	13	—	2	21	—	—	6	3	110
MCDD-W	Airport Region	8	21	33	2	3	17	13	—	—	46	4	—	4	19	170
	Beyond Airport	42	87	71	1	13	43	31	2	24	168	8	—	51	64	605
	Total	50	108	104	3	16	60	44	2	24	214	12	—	55	83	775
MCDD-E	West	6	8	8	—	5	7	13	—	—	59	1	—	9	8	124
	East	—	—	3	—	—	—	—	—	—	—	—	—	—	—	3
	Total	6	8	11	—	5	7	13	—	—	59	1	—	9	8	127
SDIC	Total	6	10	4	—	—	8	6	—	—	25	—	—	3	3	65
500 Year Flood																
SIDIC	North	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	South	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2
	Total	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2
PEN 1	Total	4	3	9	—	—	6	2	—	—	13	3	—	3	8	51
PEN 2	West	7	11	12	—	—	13	10	—	1	16	—	—	5	3	78
	East	4	4	6	—	—	8	3	—	1	5	—	—	1	—	32
	Total	11	15	18	—	—	21	13	—	2	21	—	—	6	3	110
MCDD-W	Airport Region	8	21	34	2	3	19	13	—	—	46	4	—	4	19	173
	Beyond Airport	45	94	81	1	13	51	34	2	24	179	8	—	52	64	648
	Total	53	115	115	3	16	70	47	2	24	225	12	—	56	83	821
MCDD-E	West	11	12	15	—	6	10	15	—	5	64	1	—	14	11	164
	East	—	—	4	—	—	—	—	—	—	—	—	—	—	—	4
	Total	11	12	19	—	6	10	15	—	5	64	1	—	14	11	168
SDIC	Total	8	11	8	—	—	10	7	—	—	27	—	—	4	3	78

B.5 Community Assets

Table B-11. Community asset areas exposed to 100-year and 500-year flooding in the Columbia corridor drainage districts, Multnomah County, Oregon.

District	ID	Name	Primary Category	Total Area (acres)	100-Year Flood Exposure (acres)	500-Year Flood Exposure (acres)
SIDIC	B1	Howell Territorial Park	Recreation & Environment	100.0	96.3	98.5
PEN 1	B2	Heron Lakes Golf Course	Recreation & Environment	353.7	347.0	348.7
	B3	Historical Vanport	Historical Places	622.2	606.3	612.0
	B4	Vanport Wetlands	Recreation & Environment	65.4	65.4	65.4
PEN 2	B10	Blue Herons Wetland	Recreation & Environment	10.1	10.1	10.1
	B7	Columbia Children's Arboretum	Recreation & Environment	22.0	22.0	22.0
	B8	Columbia Edgewater Country Club	Recreation & Environment	155.6	147.0	151.0
	B5	Delta Park	Recreation & Environment	99.6	98.9	99.2
	B9	Flyway Wetlands	Recreation & Environment	24.2	24.2	24.2
	B11	Riverside Golf Course	Recreation & Environment	5.7	5.4	5.7
	B6	The Triangle; Bus stop	Recreation & Environment	0.1	0.1	0.1
MCDD-W	B13	Catkin Marsh Natural Area	Recreation & Environment	43.7	43.7	43.7
	B15	Colwood Golf Center	Recreation & Environment	95.0	67.4	70.9
	B16	Johnson Lake Property	Recreation & Environment	39.9	39.0	39.5
	B11	Riverside Golf Course	Recreation & Environment	145.7	143.2	143.6
	B14	Whitaker Ponds Nature Park	Recreation & Environment	28.1	28.0	28.0
	B12	Wilshire Riverside Little League Field	Recreation & Environment	2.2	2.2	2.2
MCDD-E	B18	Blue Lake Regional Park	Recreation & Environment	62.0	61.2	62.0
	B19	Fairview Lake	Recreation & Environment	105.2	105.2	105.2
	B20	Lakeshore Park	Recreation & Environment	5.1	5.1	5.1
	B21	Pelfry Park	Recreation & Environment	1.3	1.3	1.3
Other	B17	Chinook Landing Marine Park	Recreation & Environment	47.1	40.9	42.4

Table B-12. Community asset routes exposed to 100-year and 500-year flooding in the Columbia corridor drainage districts, Multnomah County, Oregon.

District	Name	Primary Category	Total Length (mi)	100-Year Flood Exposure (mi)	500-Year Flood Exposure (mi)
SIDIC	Oak Island Loop	Recreation & Environment	2.5	2.4	2.5
	Sauvie Island, 12-Mile Loop	Recreation & Environment	12.3	10.5	10.6
PEN 1	Columbia Slough Trail	Recreation & Environment	1.5	0.1	0.1
	Marine Drive, 40-Mile Loop	Recreation & Environment	2.6	0.3	0.6
PEN 2	Columbia Slough Trail	Recreation & Environment	1.1	0.0	0.0
	Marine Drive, 40-Mile Loop	Recreation & Environment	4.2	0.3	0.8
MCDD-W	Columbia Slough Trail	Recreation & Environment	1.0	1.0	1.0
	Marine Drive, 40-Mile Loop	Recreation & Environment	8.3	3.6	4.8
MCDD-E	Columbia Slough Trail	Recreation & Environment	1.1	1.1	1.1
	Marine Drive, 40-Mile Loop	Recreation & Environment	4.1	2.4	3.0
SDIC	Marine Drive, 40-Mile Loop	Recreation & Environment	3.3	0.1	0.2
Other	Columbia Slough Trail	Recreation & Environment	0.4	0.1	0.4
	Marine Drive, 40-Mile Loop	Recreation & Environment	1.6	0.5	1.2

Table B-13. Community assets exposed to 100-year and 500-year flooding, Sauvie Island Drainage Improvement Company district.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A6	Sauvie Island Lavender Farm	Community Impact Business		
A7	Sauvie Island Farms	Community Impact Business		
A8	Columbia Farms	Community Impact Business	X	X
A9	Sauvie Island Blueberry Farm	Community Impact Business		
A10	Sauvie Island Fire Dept.	Government & Emergency Services		
A11	Sauvie Island Wildlife Refuge Kiosk	Recreation & Environment		
A12	Sauvie Island Grange	Community Impact Business		
A13	Sauvie Island Academy	Education & Nonprofit		
A14	Kruger's Farm	Community Impact Business	X	X
A15	Bybee-Howell House	Historical Places		
A16	Sauvie Island Organics	Community Impact Business		
A17	Sauvie Island Center	Education & Nonprofit		
A18	GM Farm	Community Impact Business		
A19	Pumpkin Patch	Community Impact Business	X	X
A20	Bella Organic Pumpkin Patch & Winery	Community Impact Business	X	X
A21	Nelson Farms	Community Impact Business	X	X

Table B-14. Community assets exposed to 100-year and 500-year flooding, Peninsula Drainage District 1.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A22	Expo Center	Government & Emergency Services	X	X
A23	Pro Drive Driving School	Education & Nonprofit	X	X

Table B-15. Community assets exposed to 100-year and 500-year flooding, Peninsula Drainage District 2.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A24	Pizza Mia	Community Impact Business	X	X
A25	Channel's Edge	Community Impact Business		X
A26	Historical Home	Historical Places		X
A27	Faloma Market	Community Impact Business	X	X
A28	Jubitz	Community Impact Business	X	X
A29	Hayden Meadows Square	Community Impact Business	X	X
A30	Elmer's Restaurant	Community Impact Business	X	X
A31	Mars Meadows Chinese	Community Impact Business	X	X
A32	Burrito House	Community Impact Business	X	X
A33	Bureau of Motor Vehicles	Government & Emergency Services	X	X
A34	Portland Meadows Racetrack	Historical Places	X	X
A35	Union Ave Motel	Historical Places	X	X
A36	Mary's Tienda Mexicana	Community Impact Business	X	X
A37	Columbia Community Bible Church	Education & Nonprofit	X	X
A38	Pioneer Special Program School	Education & Nonprofit	X	X
A39	Bridges Middle School	Education & Nonprofit	X	X
A40	Mini-mart	Community Impact Business	X	X
A41	Portland Yacht Club	Historical Places		
A42	Historical Home	Historical Places	X	X
A43	Fazio Farms Corn Maze	Community Impact Business	X	X

Table B-16. Community assets exposed to 100-year and 500-year flooding, Multnomah County Drainage District – West.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A44	Chopsticks III	Community Impact Business		
A45	Oregon Humane Society	Education & Nonprofit		
A46	Multnomah County Drainage District Office	Government & Emergency Services	X	X
A47	Columbia River Correctional Institution	Government & Emergency Services	X	X
A48	The Deck	Community Impact Business	X	X
A49	Salty's	Community Impact Business		X
A50	The Sextant Bar and Galley	Community Impact Business		
A51	Multnomah County River Patrol	Government & Emergency Services	X	X
A52	Port of Portland Fire Dept.	Government & Emergency Services	X	X
A53	Oregon Food Bank	Education & Nonprofit	X	X
A54	DEQ Test Station NE	Government & Emergency Services	X	X
A55	Broadmoor Golf Course	Recreation & Environment		
A56	NAYA Early College Academy	Education & Nonprofit		
A57	Portland Community ToolBank	Education & Nonprofit		
A58	Portland Air National Guard Base	Government & Emergency Services	X	X
A59	Air National Guard 142 Fighter	Government & Emergency Services	X	X
A60	Sea Scouts	Education & Nonprofit	X	X
A61	Portland International Airport	Government & Emergency Services	X	X
A62	Port of Portland Police Department	Government & Emergency Services	X	X
A63	USPS	Government & Emergency Services	X	X
A64	Cascade Station	Community Impact Business	X	X
A65	Concordia University: Center for Emergency Solutions	Government & Emergency Services	X	X
A66	Panera Bread	Community Impact Business	X	X
A67	Dutch Bros. Coffee	Community Impact Business	X	X
A68	Shari's Cafe and Pies	Community Impact Business	X	X
A69	Shilo Restaurant	Community Impact Business	X	X
A70	Burger King	Community Impact Business	X	X
A71	McDonald's (Parkrose)	Community Impact Business	X	X
A72	Sidelines Restaurant and Sports Bar	Community Impact Business	X	X
A73	Capers Cafe and Catering Co.	Community Impact Business	X	X
A74	Adventure WILD Day Camp	Education & Nonprofit	X	X
A75	Multnomah County Inverness Jail	Government & Emergency Services	X	X
A76	Little Four Corners Natural Area	Recreation & Environment	X	X
A77	Goodwill Outlet	Education & Nonprofit	X	X
A78	Jack in the Box	Community Impact Business	X	X
A79	Starbucks	Community Impact Business	X	X
A80	Jimmy Johns	Community Impact Business	X	X
A81	Bistro 23	Community Impact Business	X	X
A82	U.S. National Weather Services	Government & Emergency Services	X	X
A83	Portland Fire Department Training Center	Government & Emergency Services		

Table B-17. Community assets exposed to 100-year and 500-year flooding, Multnomah County Drainage District – East.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A84	Trinity Bible Church	Education & Nonprofit	X	X
A85	Portland Police Bureau: Training Division	Government & Emergency Services	X	X
A86	NECA/IBEW Training Center	Education & Nonprofit	X	X
A87	PNW Carpenters Institute	Education & Nonprofit	X	X
A88	Columbia Slough Natural Area	Recreation & Environment	X	X
A89	Mason Flats Restoration	Recreation & Environment	X	X

Table B-18. Community assets exposed to 100-year and 500-year flooding, Sandy Drainage Improvement Company district.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A90	Troutdale Airport	Government & Emergency Services	X	X
A91	Hillsboro Aero Academy	Education & Nonprofit		X
A92	DQ Grill and Chill Restaurant	Community Impact Business		
A93	Arby's	Community Impact Business		X
A94	McDonald's (Troutdale)	Community Impact Business		X
A95	Popeyes Louisiana Kitchen	Community Impact Business		X
A96	Taco Bell	Community Impact Business		

Table B-19. Community assets exposed to 100-year and 500-year flooding, outside of Sauvie Island Drainage Improvement Company district boundary.

ID	Name	Primary Category	100-Year Flood Exposure	500-Year Flood Exposure
A1	Collins Beach	Recreation & Environment	X	X
A2	Island Cove RV Park	Community Impact Business	X	X
A3	Reeder Beach RV Park	Community Impact Business		X
A4	Coon Park	Recreation & Environment	X	X
A5	Blue Bee Farms	Community Impact Business		