DISCUSSION PAPER

Discussion Paper – Interim Mitigation Alternatives for the Chase River Dams

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1 Background

Previously, Associated Engineering prepared the Chase River Dam Breach Flood Inundation Study of September 2012. This study assessed the potential consequences and risks of various dam collapse scenarios for the Middle and Lower Chase River Dams. Six scenarios for possible dam breach and failure were considered. These were:

- Scenario 1 1000-year flood with no breach
- Scenario 2 1000-year flood with Lower and Middle Dam breach
- Scenario 3 PMF with no breach
- Scenario 4 PMF with Lower and Middle Dam breach
- Scenario 5 100-yr flood with Lower Dam breach
- Scenario 6 Seismic Event

Of these, Scenario 4 resulted in the most significant flooding with Scenario 6 resulting in the highest loss of life with little to no warning. As a result of the analysis in that study, which included an assessment of property damage, timing of inundation and potential loss of life, the consequence classification associated with the dams was increased to Extreme, as per the British Columbia Dam Safety Regulations. The Extreme classification requires that the design standards applied to the dams is based on the Probable Maximum Flood (PMF), and a 1:10,000 year return period seismic event (which is applicable if the dams are modified).

1.1 RECENT ANALYSES

Recently, the City requested that Associated Engineering assess the potential benefit provided by interim measures to reduce the likelihood or consequences of the two dams failing. This is in response to a postponement in taking any action with respect to the dams pending further analysis of mitigation alternatives. These measures include:

- Temporary draining of the two reservoirs,
- Lowering of the spillway crests to improve capacity and permanently lower the normal full pool elevation, and
- Temporary raising of the dam crests using Lockblock™ walls.

The City also requested that Associated Engineering assess the consequences of alternative dam collapse scenarios in order to evaluate these potential short term risk mitigation alternatives. These scenarios would also account for new information indicating that there is some reinforcing steel present in the concrete core of the Lower Dam, potentially slowing the rate of failure or otherwise modifying the dam collapse modes.

The information provided to us indicates minimal reinforcing composed of approximately 16 mm square bars, on 750 mm intervals, located at the center of the core. One interpretation is that the steel bars detected in the core are merely dowels used at cold joints between concrete pours, rather than a complete reinforcing mat. However, for the purposes of this analysis we will assume that the detected steel bars are indicative of a general reinforcing of the concrete core.

Our interpretation is that this configuration would not be sufficient to prevent collapse due to the bending moments produced by overtopping and loss of support on the downstream side of the Lower Dam, but could produce a slower progressive collapse of the core, in contrast to a massive simultaneous failure over its entire depth used in earlier analyses. We note that the presence and impact of the reported reinforcing has not been confirmed by an engineering assessment. Therefore, the benefit of the reinforcing, as discussed below is conjectural in nature.

Based on the indication that the reinforcing is minimal, we assumed a step-wise failure mode, in which the concrete core of the lower dam would fail in steps of 4 m as the support provided by the outer shell is washed away due to overtopping. We investigated intervals of 5 minutes and 10 minutes between each successive collapse.

As with the earlier analysis, we assume that dam failure occurs at the peak of the flood hydrograph in the case of flood induced failures. For seismically induced failures, when the Middle Dam is considered, we assumed that the floodwave from collapse of the Middle Dam induces failure of the Lower Dam.

Accordingly, AE simulated 12 additional scenarios, nine for the flood event related failures and three seismic event related failures, as follows:

- PMF SC1: Lower Dam breach only, 4 stage collapse, 5 minute intervals
- PMF SC2: Lower Dam breach only, 4 stage collapse, 10 minute intervals
- PMF SC3: Lower Dam breach only, Singe stage collapse
- PMF SC4: Lower and Middle Dam breach, 4 stage collapse, 3 minute failure duration, Existing Dam characteristics
- PMF SC5: Lower and middle Dam Breach, 4 stage collapse, 3 minute failure duration, Existing Dam characteristics plus the addition of Lockblocks™ on the Lower Dam
- PMF SC6: Lower and Middle Dam breach, 4 stage collapse, 5 minute failure duration, Existing Dam characteristics

- PMF SC7: Lower and Middle Dam breach, 4 stage collapse, 5 minute duration, Existing Dam characteristics plus the addition of Lockblocks™ on the Lower Dam
- PMF SC8: Lower and Middle Dam breach, Rebar reinforcement and lowered spillway, Lower Dam collapse
- PMF SC9: Lower and Middle Dam breach, Rebar reinforcement and lowered spillway, Lower and Middle Dam collapse
- Seismic SC1: Lower Dam breach only, Single stage collapse of entire dam
- Seismic SC2: Lower and Middle Dam breach, Rebar reinforcement and staged failure of Lower Dam
- Seismic SC3: Lower and Middle Dam breach, lowered spillways

The results from the additional PMF scenarios (PMF SC1 through SC9) are compared to original Scenario 4 from the Chase River Dam Breach Flood Inundation Study, which represents the PMF with Lower and Middle Dam Breach and resulted in the most significant flooding. The additional Seismic scenarios (Seismic SC1 through SC3) are compared to the earthquake scenario in the Chase River Dam Breach Flood Inundation Study, which was Scenario 6. AE performed a high level, qualitative analysis of the difference in flood depth and extents between the 12 new scenarios and the original scenarios to determine whether there is an apparent difference significant enough that it could result in a lower consequence classification under the BC Dam Safety Regulations.

The results of the depth comparison are summarized below for each scenario. Figure 1 shows the maximum flooding depth and extents for the original Scenario 4 with the building damage estimates, with which the new PMF scenarios will be compared. The new seismic scenarios will be compared to Figure 2, which shows the maximum flooding depth and extents for the original Scenario 6. Staged or incremental collapses represent the potential stabilizing effect of the minimal reinforcing identified in the Lower Dam concrete core. The qualitative results of each new scenario are discussed briefly below.

The variation in results between each scenario is also indicative of the sensitivity of the estimated flooding impacts to the assumed failure modes and scenarios.

PMF – SC1: Lower Dam breach (Middle dam assumed decommissioned), 4 stage collapse at 5 min intervals.

- The maximum depth of flooding and extents is shown in Figure 3.
- For the majority of the flood area, the decrease in flood depth between that indicated by PMF-SC1 and indicated by Scenario 4 is in the range of 0 to 0.5 m.
- In the areas north of the river, near Howard Ave, between Georgia and Bruce Ave, and areas around Park Ave the decrease in flood depth reaches 1 m. These are all areas where the

peak depth will still be in the range from 3 m to greater than 5 m and will not significantly affect the building damage estimates.

- There is not as much flooding in the area between Howard Ave and Georgia Ave, however, this area is predominantly a park space.
- Based on a visual comparison between the depth of flooding shown in Figure 1 compared to Figure 3, approximately 30 properties may have lower building damage estimates by one level (eg. drop from the 25 to 50% range to the 5 to 25% range).

PMF – SC2: Lower Dam breach (Middle dam assumed decommissioned), 4 stage collapse, 10 min intervals.

- The maximum depth of flooding and extents is shown in Figure 4.
- For the majority of the flood area, the decrease in flood depth between that indicated by PMF-SC1 and indicated by Scenario 4 is in the range of 0 to 0.5 m.
- In the areas north of the river, near Howard Ave, between Georgia and Bruce Ave, and areas around Park Ave the difference in flood depth reaches up to 1 m. These are all areas where the peak depth will still be in the range of 3 to 5 m.
- The flooding coverage area is marginally less than that seen in Scenario 4. There is not as much flooding in the area between Howard Ave and Georgia Ave, however, this area is predominantly a park space.
- Based on a visual comparison between the depth of flooding shown in Figure 1 compared to Figure 4, approximately 30 properties may have lower building damage estimates by one level (eg. drop from the 25 to 50% range to the 5 to 25% range).

PMF – SC3: Lower Dam breach (Middle dam assumed decommissioned), single stage collapse, 10 minute duration.

- The maximum depth of flooding and extents is shown in Figure 5.
- The inundation area is less than Scenario 4 upstream of Georgia Ave, especially south of the river, however, the number of buildings affected does not change.
- For the majority of the flood area, the decrease in flood depth between PMF-SC3 and Scenario 4 ranges between 0.25 and 0.5 m.
- In the areas north of the river, near Howard Ave, between Georgia and Bruce Ave, and areas around Park Ave the decrease in flood depth is up to 1 m. However, the peak depth will still be in the range of 3 m to greater than 5 m.
- Based on a visual comparison between the depth of flooding shown in Figure 1 compared to Figure 5, approximately 30 properties may have lower building damage estimates by one level (eg. drop from the 25 to 50% range to the 5 to 25% range).

PMF –SC4: Lower and Middle Dam Breach, 4 stage collapse, 5 minute intervals, Existing Conditions.

- The maximum depth of flooding and extents is shown in Figure 6.
- The overall flood extents are not significantly different, but the flooding does cover slightly more area between Howard Ave and Georgia Ave.
- There is essentially no change in flood depth for the majority of the flood area. Small areas of flooding may be reduced by up to 0.5 m but these areas are insignificant.
- Based on a visual comparison between the depth of flooding shown in Figure 1 compared to Figure 6, it is not anticipated that any properties will see a reduction in building damage.

PMF –SC5: Lower and Middle Dam Breach, 4 stage collapse, 3 minute duration, Existing Conditions with Lockblocks™ on Lower Dam.

- The maximum depth of flooding and extents is shown in Figure 7.
- The overall flood extents are unchanged.
- There is essentially no change in flood depth for the majority of the flood area. Small areas of flooding may be reduced by up to 0.5 m but these areas are insignificant.
- Based on a visual comparison between the depth of flooding shown in Figure 1 compared to Figure 7, it is not anticipated that any properties will see a significant reduction in building damage.

PMF –SC6: Lower and Middle Dam Breach, 4 stage collapse, 5 minute interval, Existing Conditions.

- The maximum depth of flooding and extents is shown in Figure 8.
- The overall flood extents are slightly larger in the new scenario PMF-SC6. This may actually increase the building damage estimates slightly but not significantly.
- For the majority of the flood area, the flood depth increases by a maximum of 0.5 m.

PMF –SC7: Lower and Middle Dam Breach, 4 stage collapse, 5 minute interval, Existing Conditions with Lockblocks™ on the Lower Dam

- The maximum depth of flooding and extents is shown in Figure 9.
- The overall flood extents are slightly larger in this new scenario PMF-SC7. There may actually be a slight increase in the estimates of building damage, but we do not expect it to be significant.
- For the majority of the flood area, the flood depth increases by a maximum of 0.5 m.

PMF-SC8: Lower and Middle Dam breach, Rebar reinforcement (4 stage collapse, 5 minute intervals) and lowered spillway, Lower Dam collapse

- The maximum depth of flooding and extents is shown in Figure 10.
- The overall flood extents are essentially unchanged.

- For the majority of the flood area, there is a decrease in flood depth between PMF-SC1 and Scenario 4 ranging between 0.25 and 0.5 m, however based on a visual comparison, we do not anticipate a significant change in property damage estimates.
- In the areas north of the river, near Howard Ave, between Georgia and Bruce Ave, and areas around Park Ave the flood depth decreases by up to 1 m. However, the peak depth will still be in the range of 3 to greater than 5 m and we do not believe that the property damage estimates will change appreciably.

PMF-SC9: Lower and Middle Dam breach, Rebar reinforcement (4 stage collapse, 5 minute intervals) and lowered spillway, Lower and Middle Dam collapse

- The maximum depth of flooding and extents is shown in Figure 11.
- The overall flood extents are unchanged.
- For the majority of the flood area, the decrease in flood depth changes is a maximum of 0.5 m.
- Based on a visual comparison between the depths of flooding shown in Figure 1 and Figure 11, we do not anticipate that any of the flooded properties will see a significant reduction in building damage.

Seismic SC1: Lower Dam breach only, Middle Dam decommissioned, single stage collapse of entire dam

- The maximum depth of flooding and extents is shown in Figure 12.
- The overall flood extents and maximum depths are significantly less than Scenario 6 from the previous report.
- The building damage estimates would likely be reduced significantly in this scenario.

Seismic SC2: Lower and Middle Dam breach, Rebar reinforcement (4 stage collapse, 5 minute intervals) of Lower Dam.

- The maximum depth of flooding and extents is shown in Figure 13.
- The overall extents of flooding are similar to Scenario 6, and are actually slightly larger in the area of Bruce Ave and Nova Street.
- The maximum depth of flooding, is slightly less than Scenario 6 and may result in slightly lower building damage estimates.

Seismic SC3: Lower and Middle Dam breach, lowered spillways

- The maximum depth of flooding and extents is shown in Figure 14.
- The overall flood extents and maximum depths are significantly less than Scenario 6 from the previous report.

- The building damage estimates would likely be reduced significantly in this scenario.

1.2 DISCUSSION OF OTHER FACTORS

Lowered Spillway Crests

One approach proposed to reduce the potential likelihood or consequences of the dams failing is to lower the spillway crests of both dams, at a concept level a 3 m lowering has been proposed.

For the Middle Dam, this provides a capacity improvement sufficient to ensure that the dam does not overtop during a 1000-year return period flood event, but overtopping will still occur during a PMF event. We note that this reduces the likelihood of the dam failing during a 1000-year return period flood event, but the consequences of a dam collapse are not altered significantly as shown in our preceding discussion.

The Lower Dam spillway has limited inlet capacity at the crest, and has a hydraulic choke point part way down the spillway, as identified and discussed in Water Management Consultant's (WMC) earlier investigations. WMC noted that the choke point would cause flow to exit the spillway onto the dam face, thereby presenting an additional mechanism for scour of the downstream face of the dam. As such, simply lowering the spillway crest will not greatly increase the capacity of the spillway, the entire spillway will need to be modified to significantly improve flow capacity.

Our analysis indicated that an overall increase in spillway capacity as represented by lowering the spillway crest, was insufficient to prevent overtopping of the Lower Dam during either the 1000-year return period or PMF events. Also, any failure of the Middle Dam would still cause failure of the Lower Dam regardless of any improvements in spillway capacity.

Accordingly, improved spillway capacities would reduce the likelihood that the dams would fail due to overtopping, as larger events are necessary for overtopping to occur. The improved performance of both spillways is not sufficient to meet the requirements of the Dam Safety Regulation for Very High or Extreme Consequence structures.

LockBlock™ Crest Extensions

We understand there has been a suggestion to increase the height of the dam crests by addition of temporary Lockblock™ walls on both dams. In principle, this would force more flow to enter the respective spillways prior to overtopping of the dams. However, higher dam crests also imply a greater volume of impounded water behind each dam at the time of a major flood, which would then add to the flood volume inundating the flood plain areas in the event of dam failures. Our assessment indicates that the ability to impound additional water, while forcing increased flow down the spillways may reduce the likelihood of the dams overtopping, it results in marginally greater inundation and damage should the dams fail. With the dam crest extensions, overtopping of the Middle Dam will begin when the rate of spilling exceeds approximately 120 m^3/s, with the current spillway crest elevation. Overtopping of the Lower Dam commences when the rate of spilling exceeds approximately 56 m^3/s.

From a practical basis, it would be difficult to prevent a Lockblock™ wall from allowing seepage and flow down the outer dam faces even prior to overtopping. Issues with overturning and sliding stability may also arise. However, we have not analyzed these aspects of the proposed Lockblock™ walls.

Drained Reservoirs

As a temporary safety measure, both reservoirs could be drained over the winter. Even when starting from a fully drained condition, both reservoirs reach full pool in a major flood event and well before the peak flow rate occurs for the PMF event. Therefore, the mechanisms and likelihood of overtopping failure during the required design flood events are not significantly mitigated by maintaining the reservoirs in an empty state. During the 1000-year return period event minimal overtopping occurs at the Lower Dam, with none at the Middle Dam.

We note that the means to ensure that the reservoirs remain empty over the course of a winter (other than breaching both dams) is problematic. Normal winter flow rates are likely to exceed 1 m^3/s, which would be challenging to pump. Initiating and re-priming a siphon arrangement with sufficient capacity to maintain an empty state during normal winter flows is also uncertain and potentially impractical. Once a flood event begins, it will be nearly impossible to provide sufficient capacity to prevent the reservoirs from filling, and overtopping in the case of a design event, as discussed above.

2 Closure

This discussion paper is intended to provide a qualitative assessment of the changes in flood inundation conditions, and the potential for a reduction in the consequence classification for the dams, due to proposed mitigative actions. In addition, the potential for the presence of rebar to alter the failure characteristics was incorporated in the model assessments.

In summary our evaluations indicate the following:

- The reduction in flood depth and extent seen in the PMF scenarios PMF-SC1, PMF-SC2, and PMF-SC3 will not significantly change the damage cost estimates.
- Permanently lowering the dam spillways by 3 m does potentially improve the seismic related consequences due to the reduced volume of impounded water. The new seismic scenarios involving lowered spillways do show reduced flooding. A detailed assessment of building damage and potential fatalities may indicate that there is sufficient reduction in flood inundation to lower the consequence classifications for the dams from Extreme to Very High.

- The reported presence of minimal reinforcing steel in the concrete core of the Lower Dam does not appear to modify the collapse modes sufficiently to result in a significantly reduced severity of flood inundation. Accordingly, the consequence classification would remain unchanged.
- If both reservoirs are empty, there is a reduced probability that the dams would overtop during a major flood event. However, both reservoirs can potentially refill over time due to normal winter flows, and identifying mechanisms by which the reservoirs can be kept empty is problematic. We note that siphons or pumping are not likely to provide sufficient capacity.

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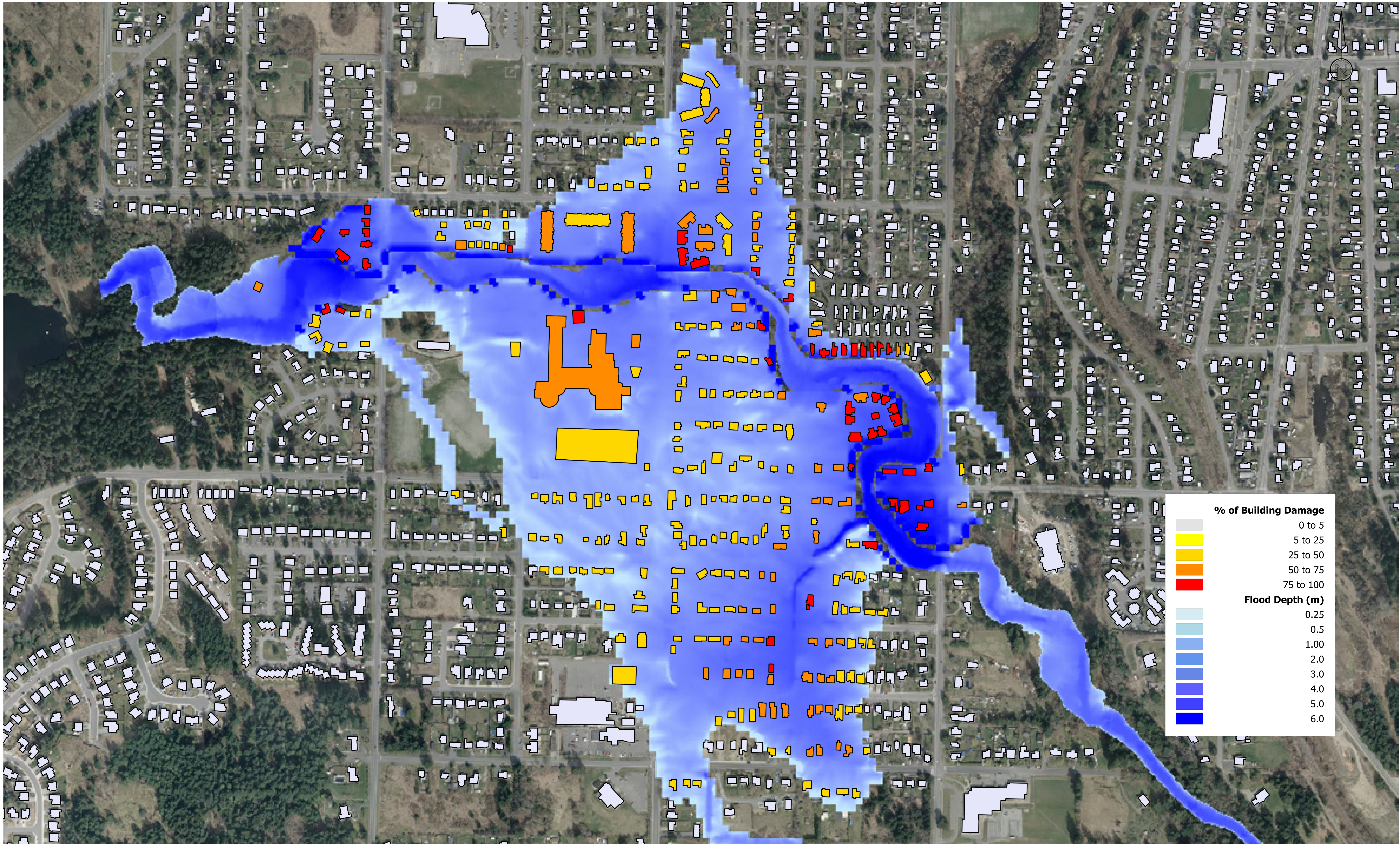

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Chase River Dam Breach Flood Inundation Study

SC4: PMF with Lower and Middle Dam Breach
Maximum Flooding Depth and Extents

Figure 1

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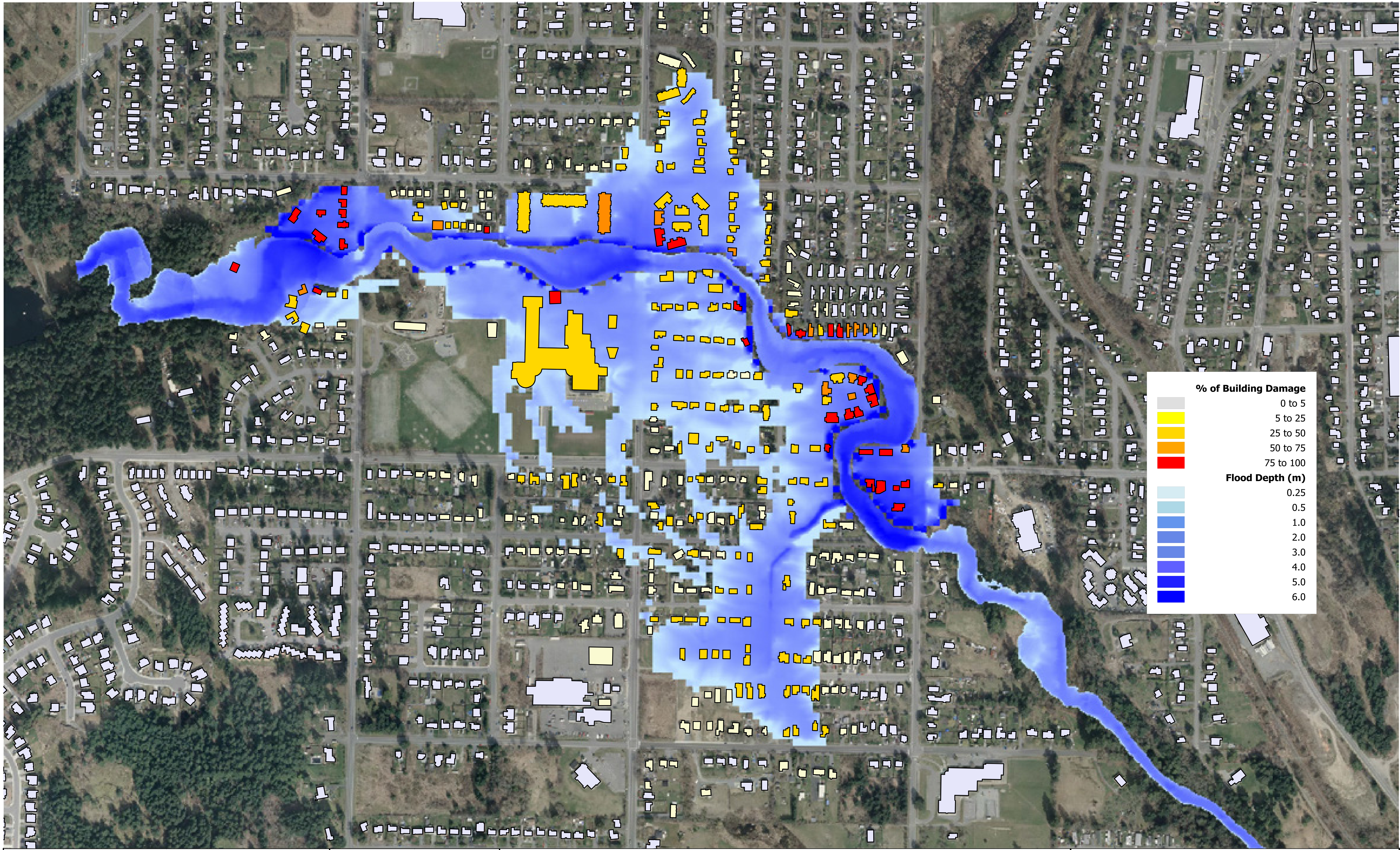
Map - SC4_Depth



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Chase River Dam Breach Flood Inundation Study

SC6: Earthquake
Maximum Flooding Depth and Extents

Figure 2

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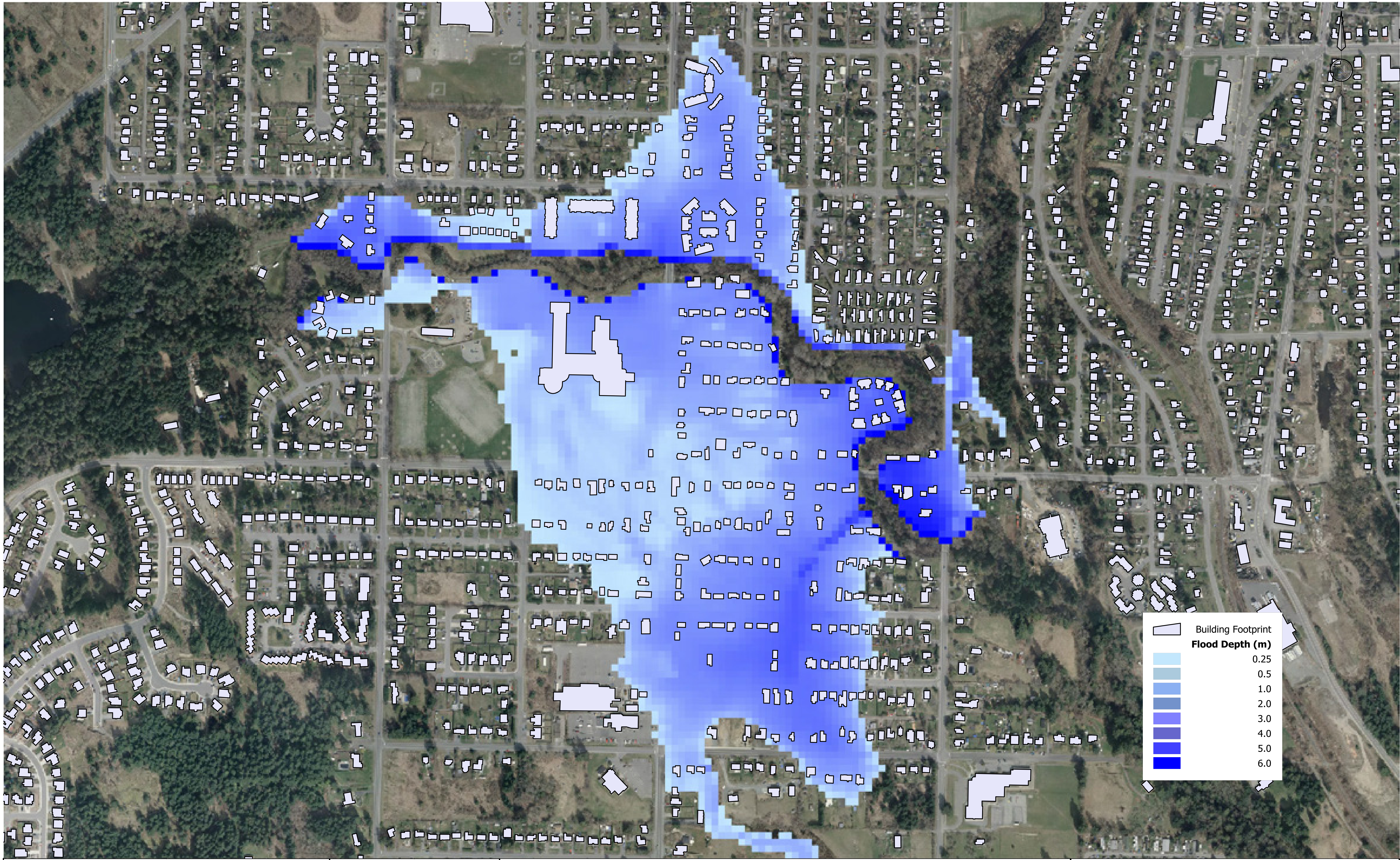
Map - SC6



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PMF SC1: Lower Dam Only, 4 Stage Collapse, 5 Min Intervals
Maximum Flooding Depth and Extents

Figure 3

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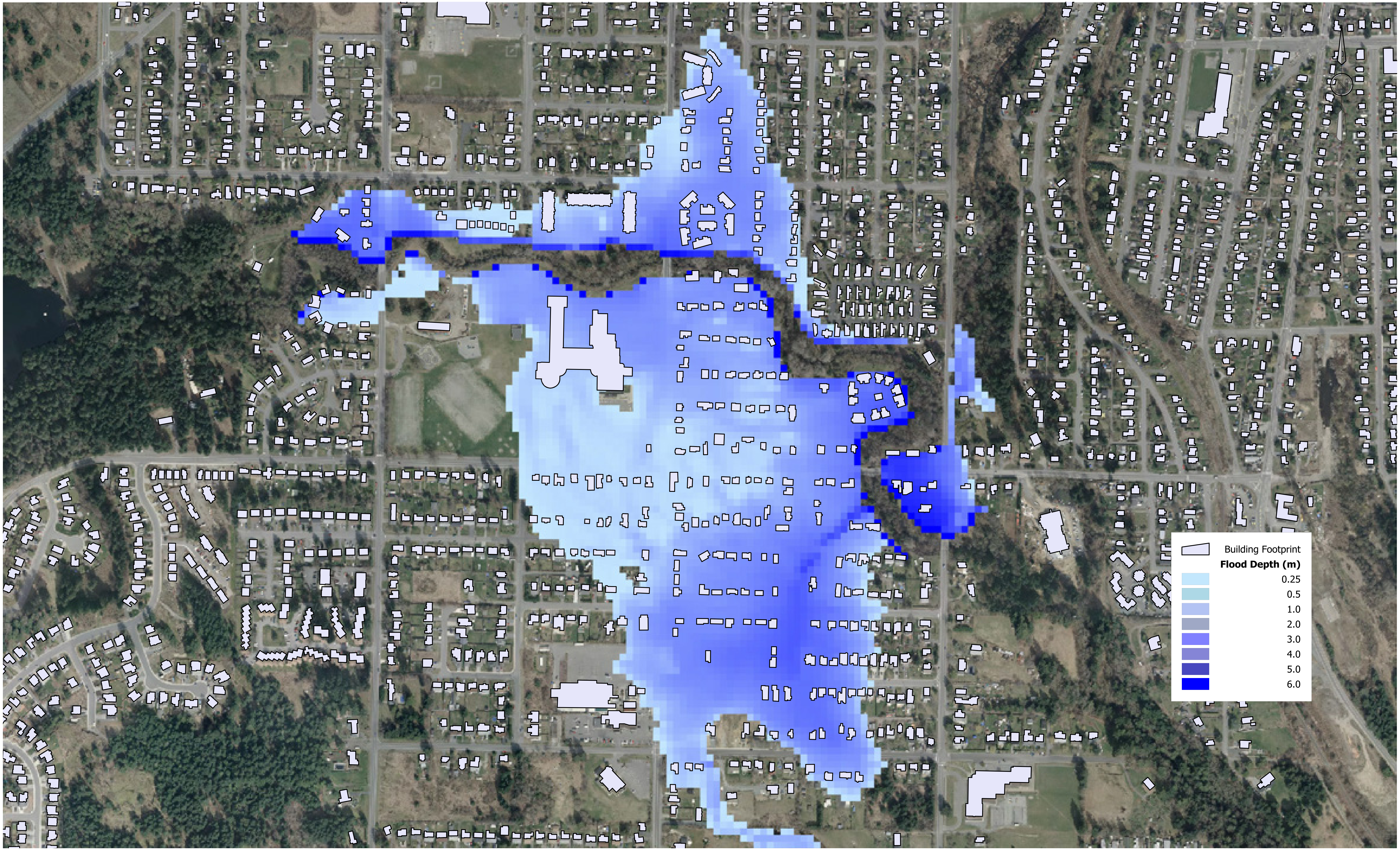
Map - PMF_SC1_Depth



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PMF SC2: Lower Dam Only, 4 Stage Collapse, 10 min Intervals
Maximum Flooding Depth and Extents

Figure 4

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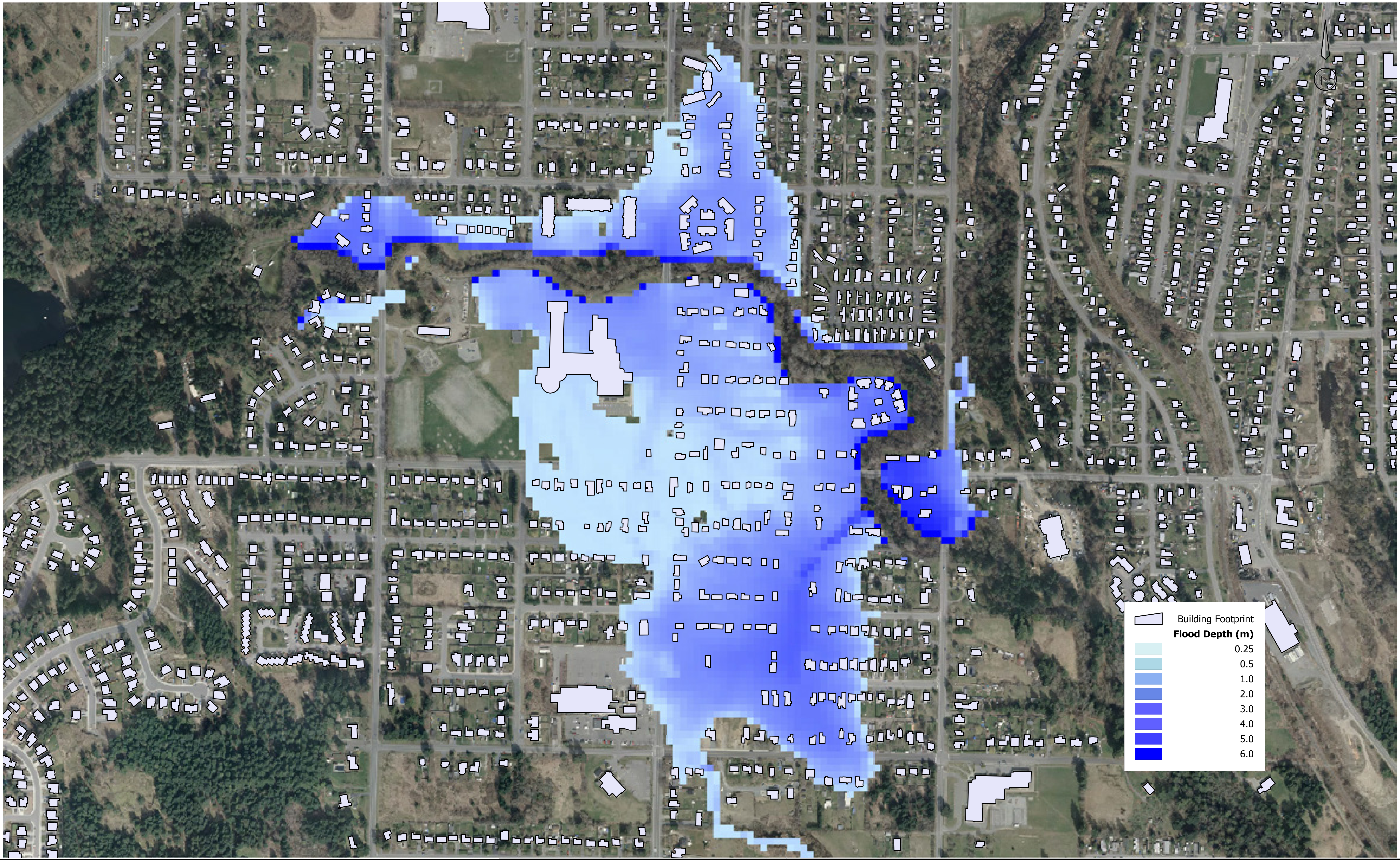
Map - PMF_SC2_Depth



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Map - PMF_SC3_Depth

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PMF SC3: Lower Dam Only, Single Stage Collapse, 10 min Intervals
Maximum Flooding Depth and Extents

Figure 5

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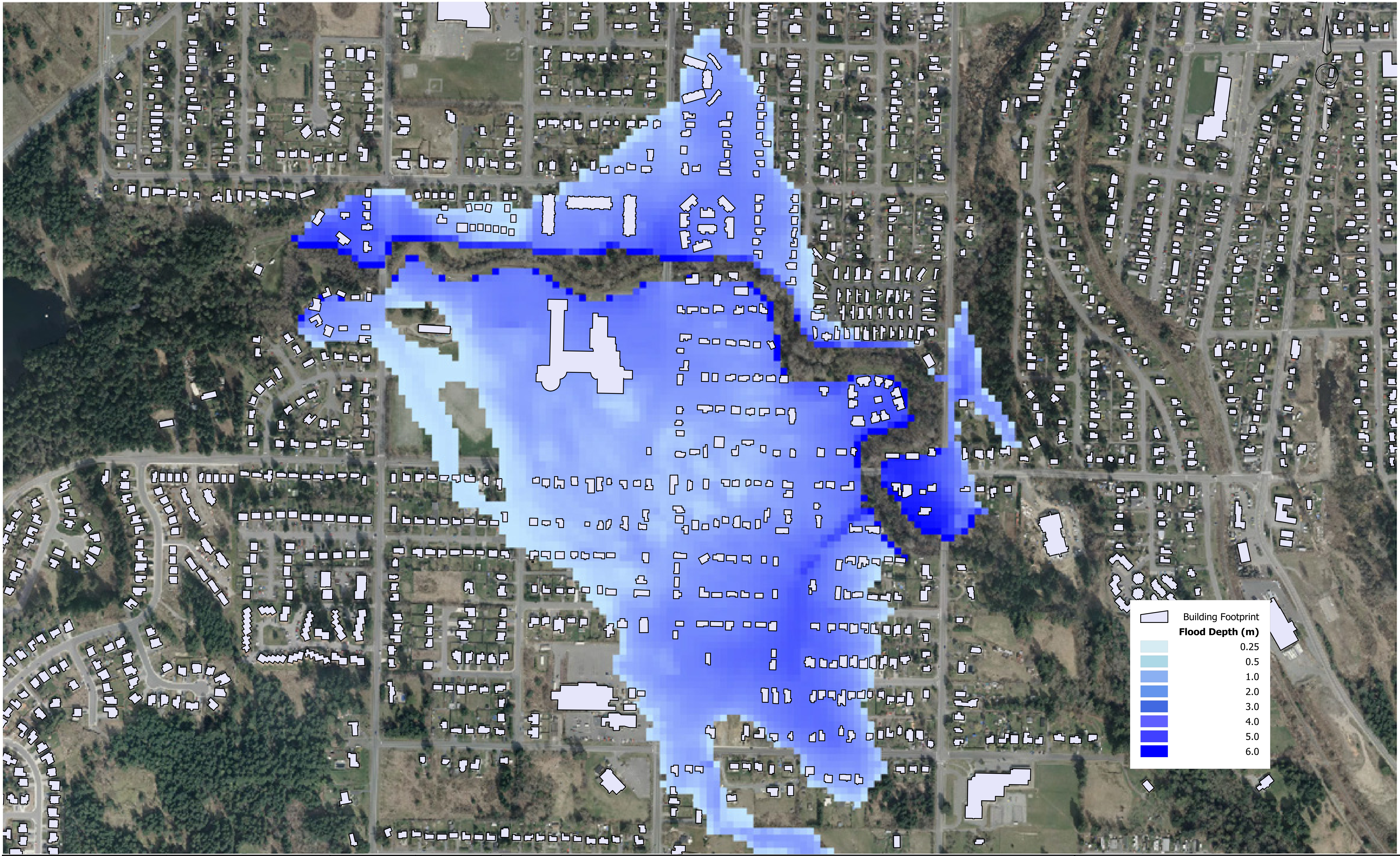

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PMF SC4: Lower and Middle Dam Only, 4 Stage Collapse, 3 min failure duration

Existing Conditions

Maximum Flooding Depth and Extents

Figure 6

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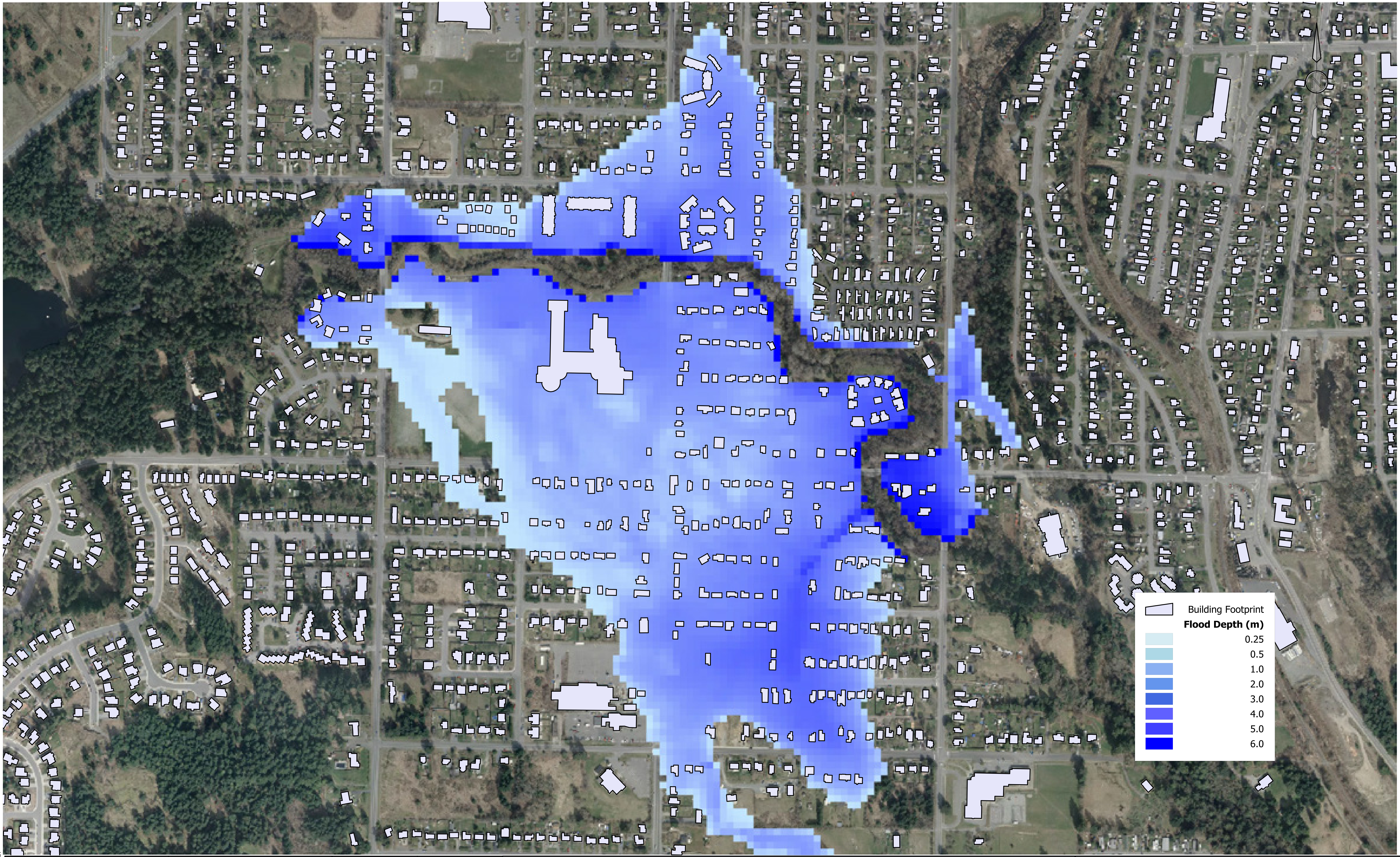

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PMF SC5: Lower & Middle Dam Onlu, 4 Stage Collapse, 3 min failure duration
Existing Conditions plus Lock Blocks on Lower Dam
Maximum Flooding Depth and Extents

Figure 7

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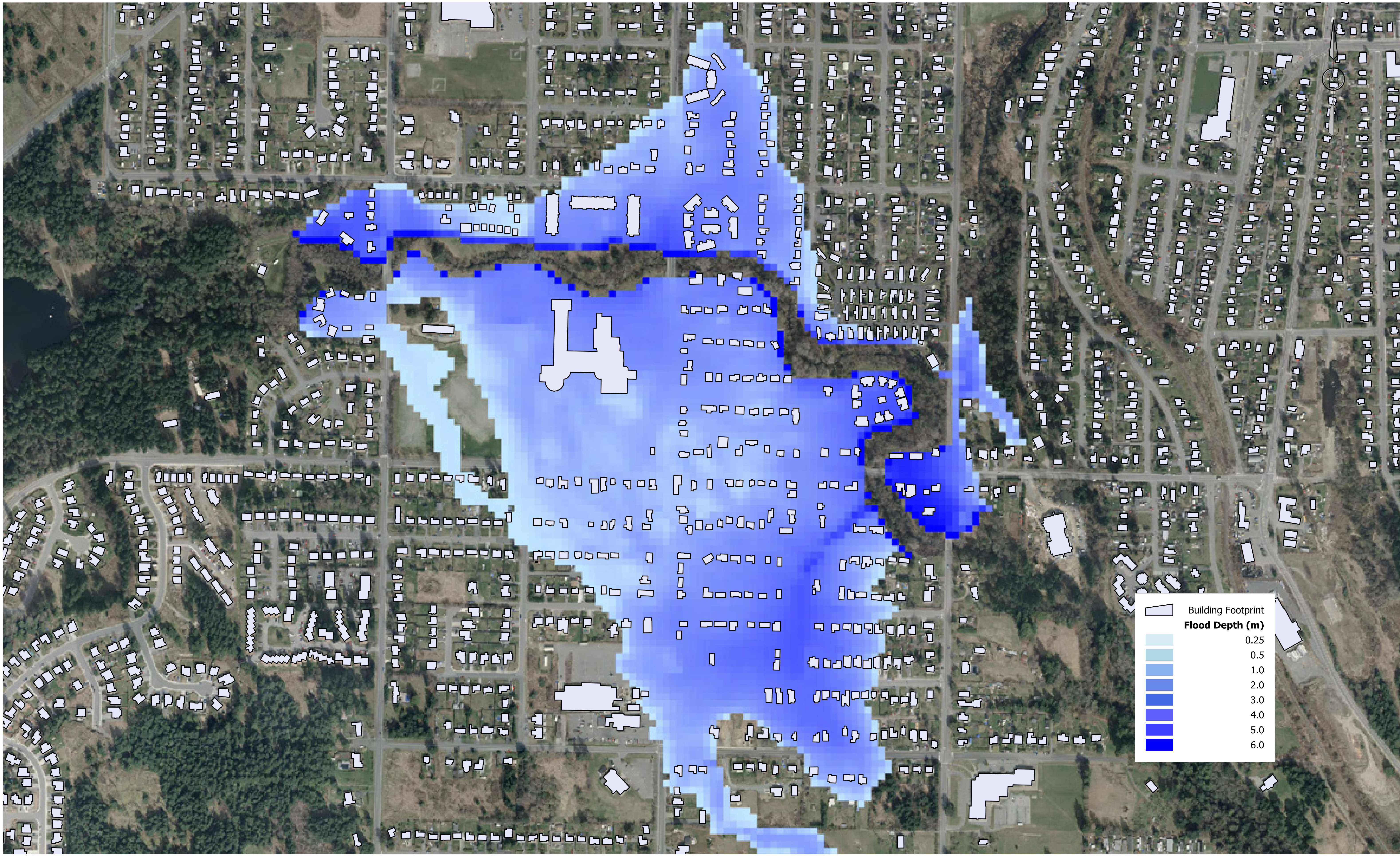

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PMF SC6: Lower & Middle Dam only, 4 Stage Collapse, 5 min failure duration
Existing Conditions
Maximum Flooding Depth and Extents

Figure 8

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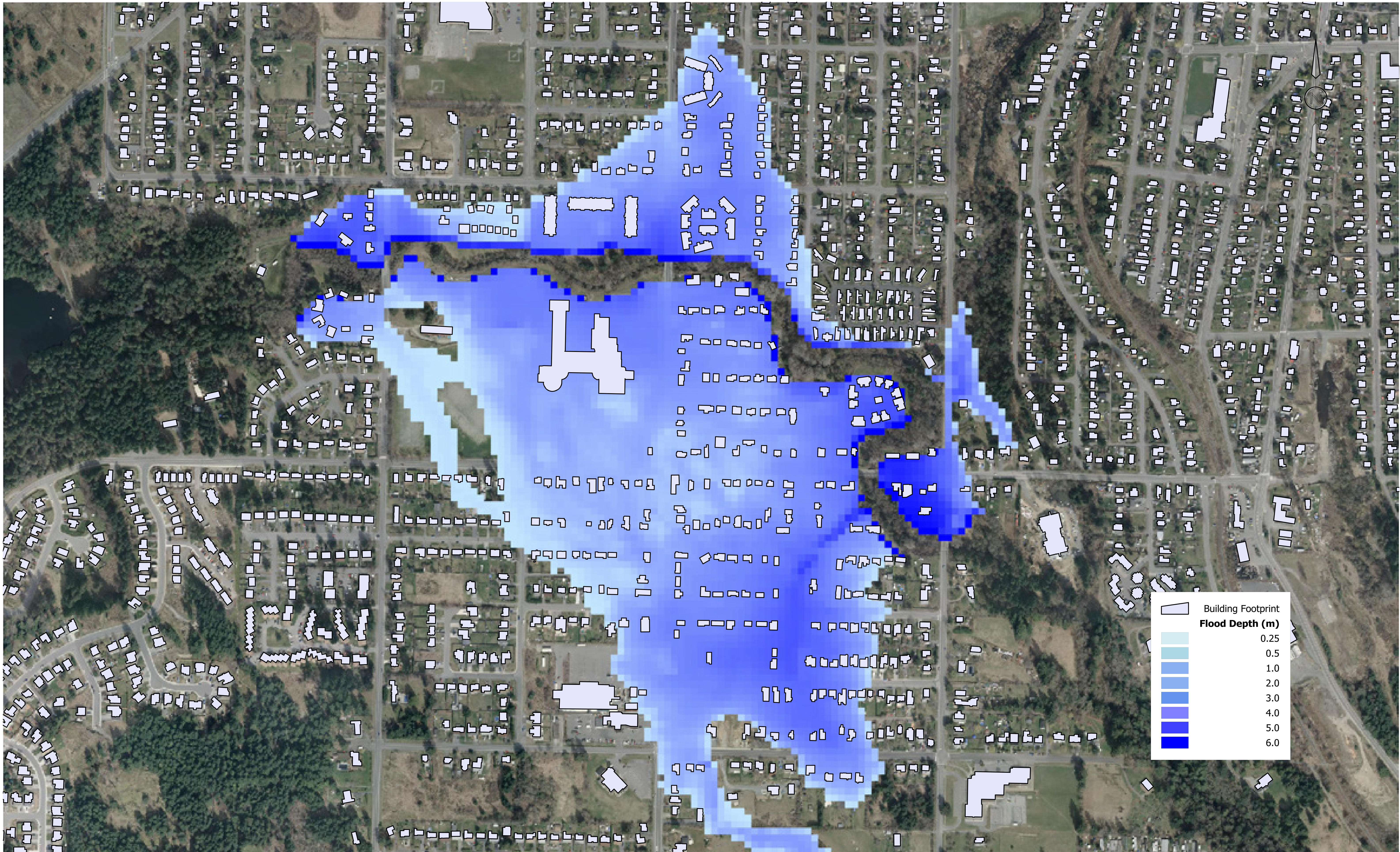
Map - PMF_SC6_Depth



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PMF SC7:Lower & Middle Dam only, 4 Stage Collapse, 5 min failure duration
Existing Conditions plus Lock Blocks on Lower Dam
Maximum Flooding Depth and Extents

Figure 9

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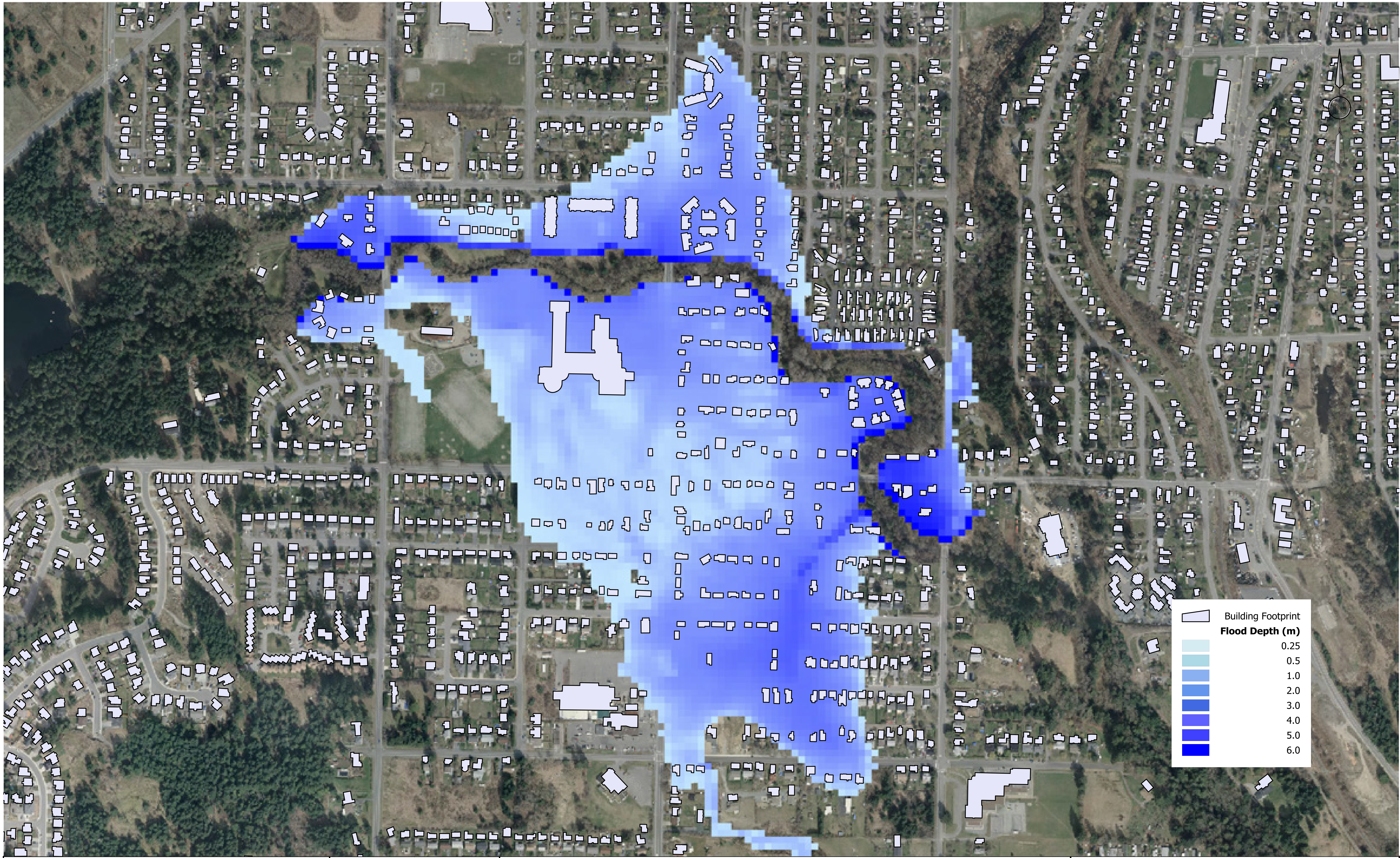
Map - PMF_SC7_Depth



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Chase River Dam Breach Flood Inundation Study

PMF_SC8: Lower & Middle Dam only, Rebar & Lowered Spillway
Lower Dam Collapse Only
Maximum Flooding Depth and Extents

Figure 10

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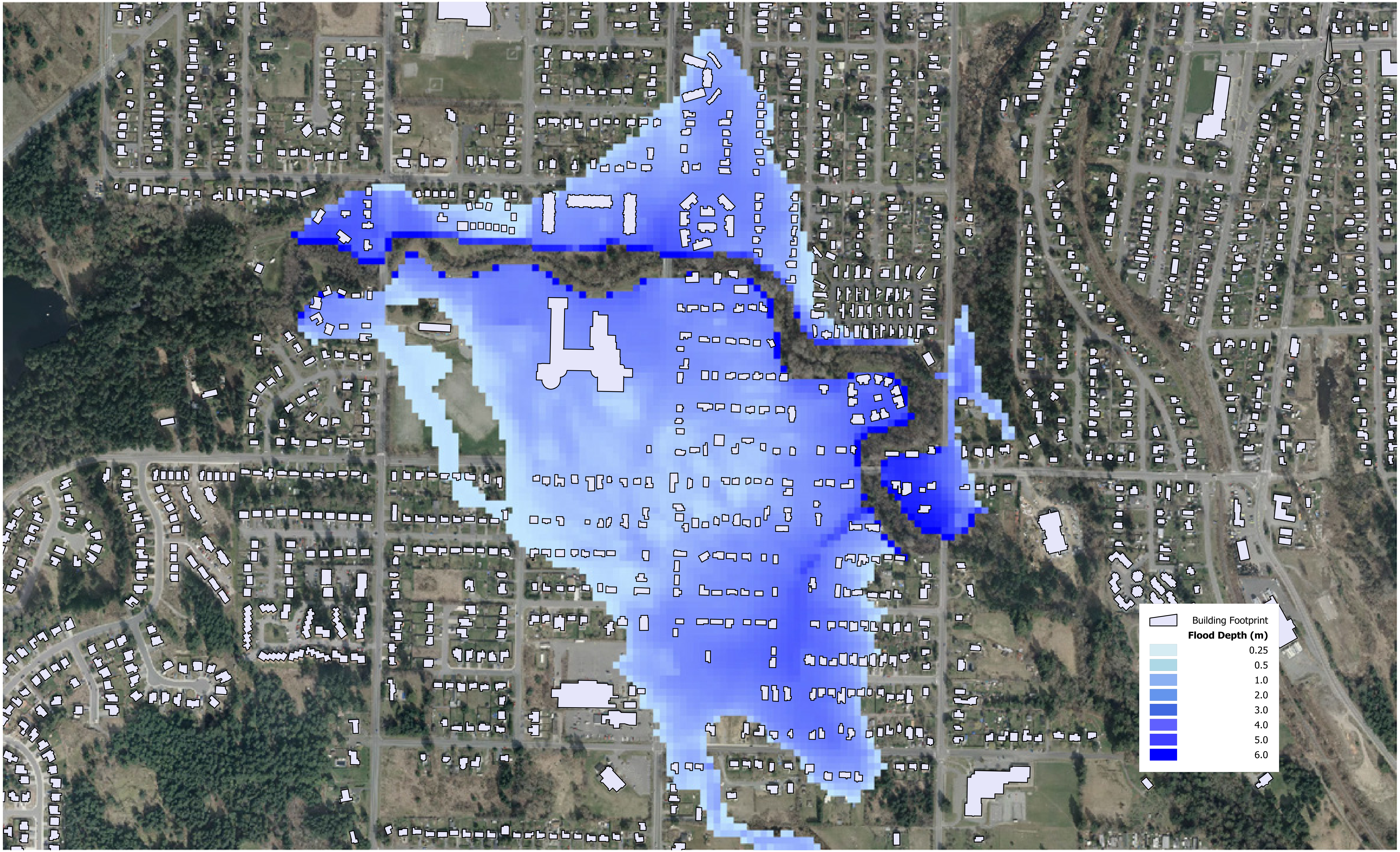

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Chase River Dam Breach Flood Inundation Study

PMF SC9:Lower & Middle Dam only, Rebar & Lowered Spillway, Both dams collapse
Maximum Flooding Depth and Extents

Figure 11

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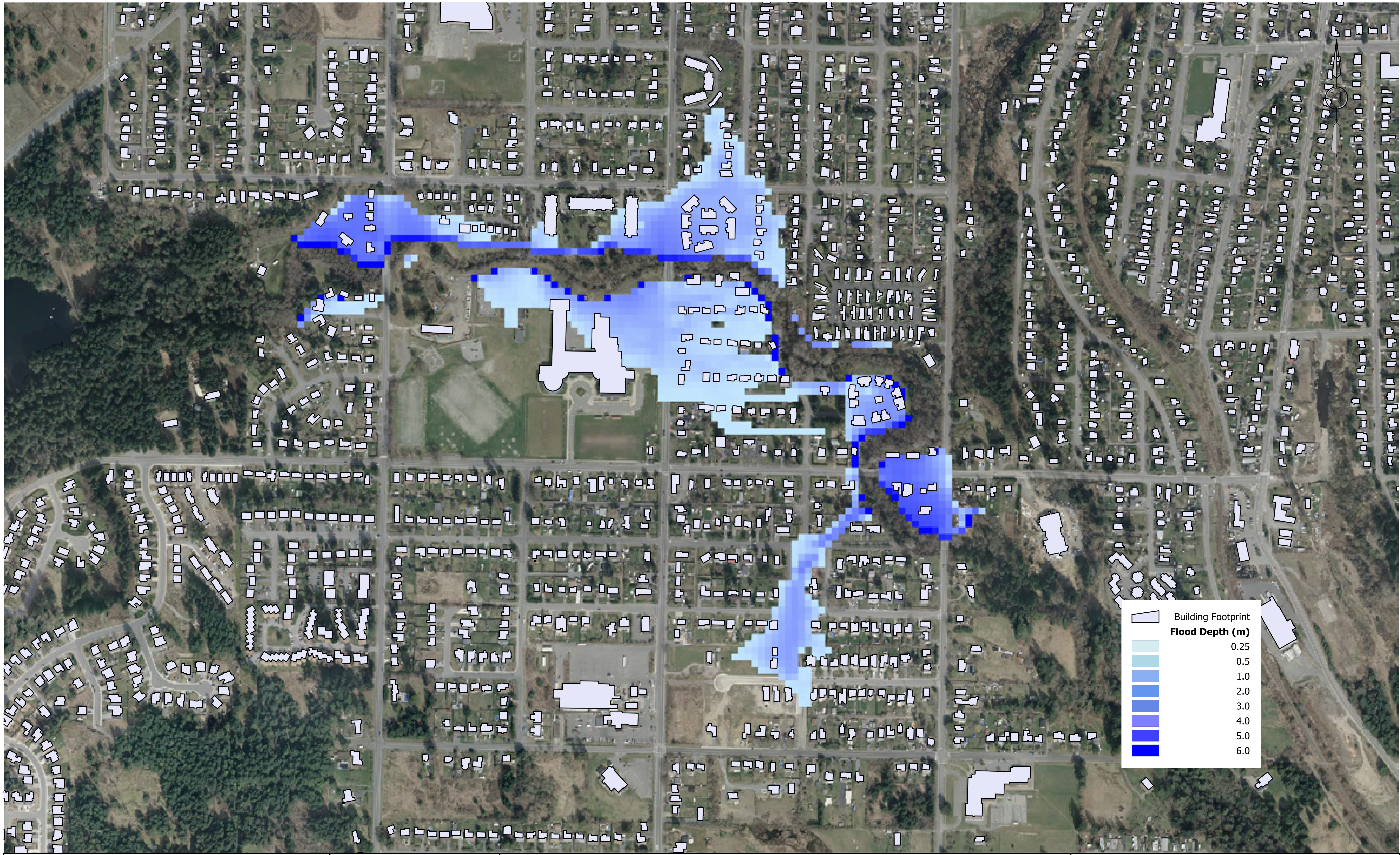

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Chase River Dam Breach Flood Inundation Study

Seismic SC1: Lower Dam only, Single Stage collapse
Maximum Flooding Depth and Extents

Figure 12

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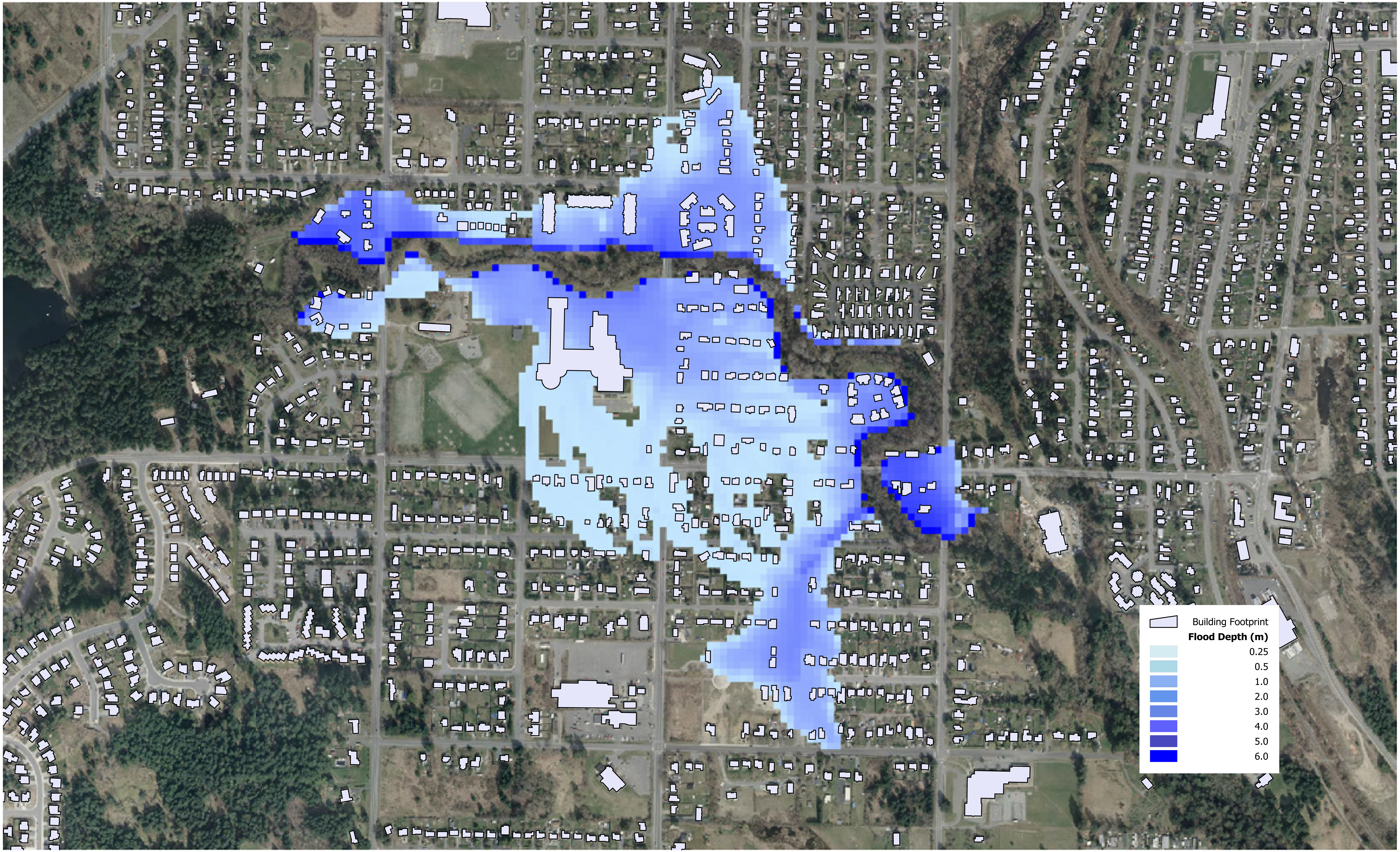

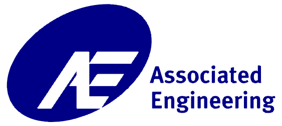

Chase River Dam Breach Flood Inundation Study

Seismic SC2: Lower & Middle Dam only, Rebar & Staged Failure of Lower Dam
Maximum Flooding Depth and Extents

Figure 13

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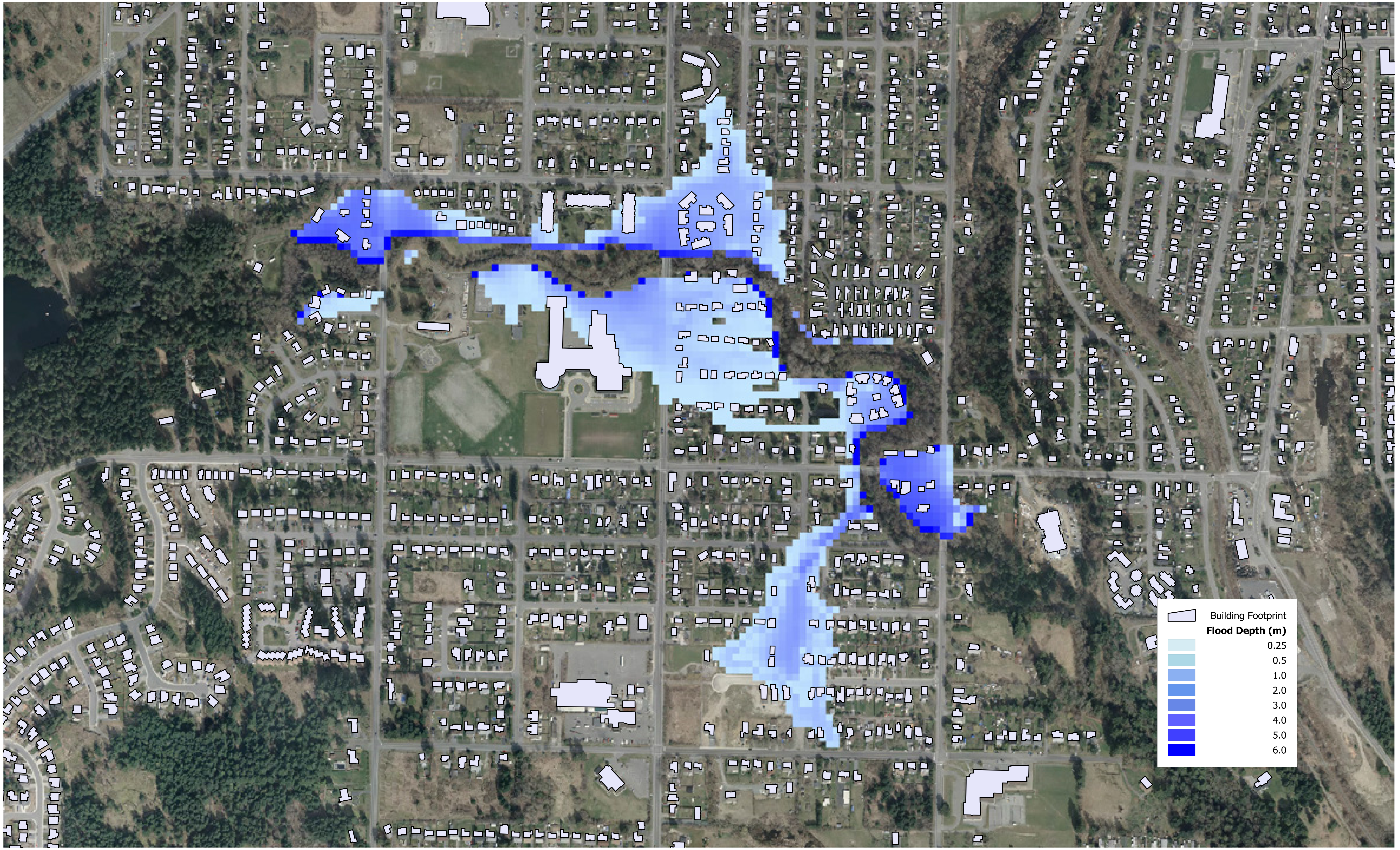

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Chase River Dam Breach Flood Inundation Study

Seismic SC2: Lower & Middle Dam only, Lowered Spillways
Maximum Flooding Depth and Extents

Figure 14

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P:\20132470\00_Alt_Scenarios\Engineering\03.00_Conceptual_Feasibility_Design_Master_Plans\map_nan_newscenarios_tls.map
Map - Seismic_SC3