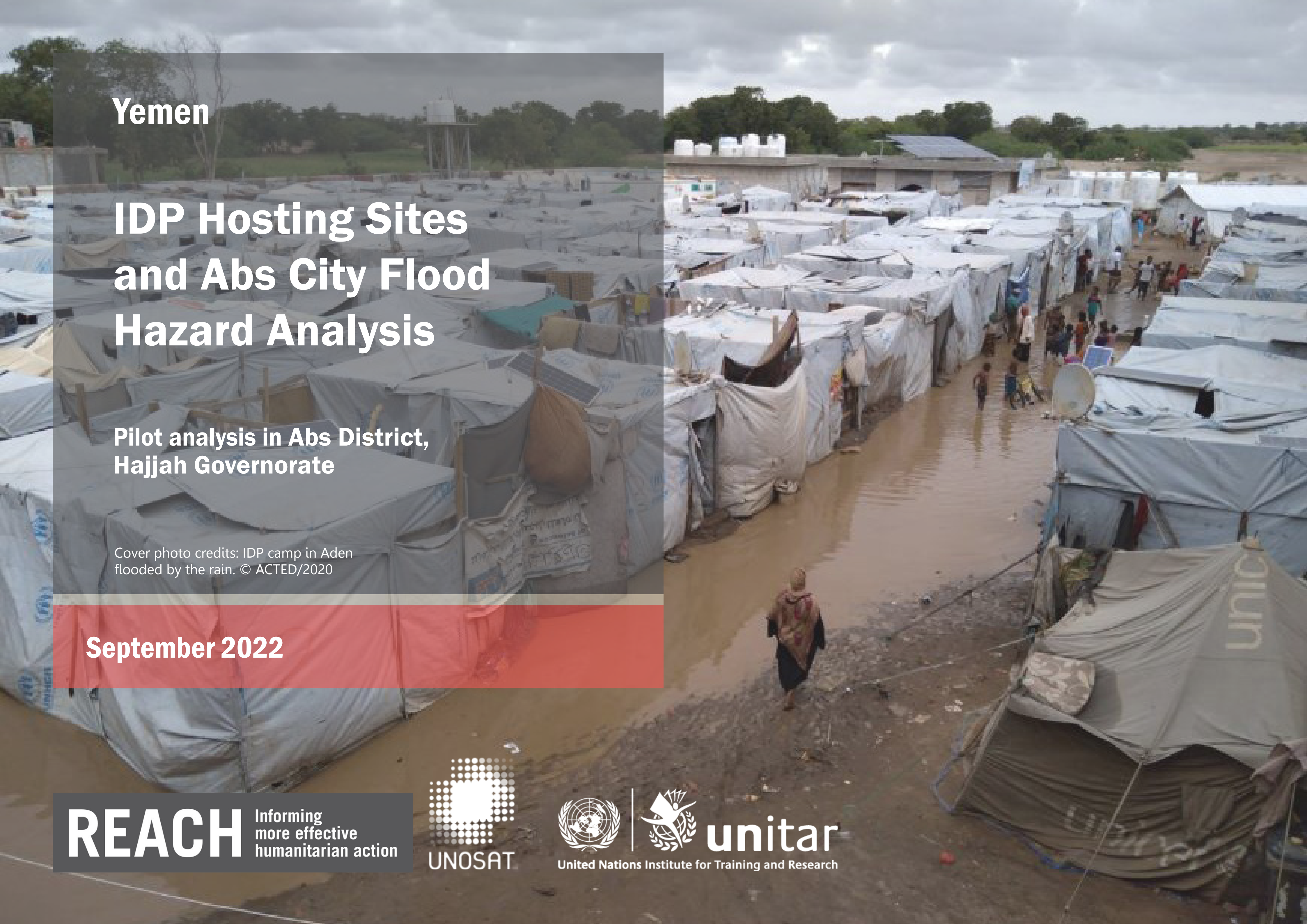

Yemen

IDP Hosting Sites and Abs City Flood Hazard Analysis

Pilot analysis in Abs District, Hajjah Governorate

Cover photo credits: IDP camp in Aden flooded by the rain. © ACTED/2020

September 2022

REACH Informing more effective humanitarian action

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With the Yemen conflict now in its seventh year, the Yemeni people continue to bear the brunt of ongoing hostilities and severe economic decline. Households are increasingly exhausting their coping mechanisms, and as a result the humanitarian crisis remains widespread. As a result of the ongoing crisis, an estimated 4.3 million people are currently internally displaced in the country.[1] Due to the occurrence of torrential rains in Yemen, flash floods are and will continue to be a recurrent hazard with destructive consequences, which exacerbates the effects of ongoing conflict and the humanitarian crisis in the country. In the past years, Yemen has been hit with torrential rain and flooding on several occasions, leading to displacement, injuries, and deaths, and causing severe damage to homes, shelters, and infrastructure, while also driving the spread of diseases, and harming agricultural yields and livestock.[2]

In 2020 the situation was especially drastic, where it was estimated that nearly half a million people were directly affected by flooding by September. A total of 189 districts in 19 governorates were impacted, and approximately 44 people died.[3] According to the Sana'a-based Ministry of Public Health and Population, estimates of casualties are 250 people and a death toll of 131 people in northern Yemen alone.[4] Several international reports[1,2,3] indicated that the lives of tens of thousands of Internally Displaced People (IDPs), many of whom were already in vulnerable shelters because of the conflict, were further disrupted. In this instance, the most affected governorates were Marib, Hajjah, Al Hodeidah, and Sana'a. In 2021, an estimated 13,596 families were affected by heavy rains and flooding across the country by August alone, with country-wide losses of life and property and an immense impact on displaced families in the governorates of Hajjah, Ma'rib, Sana'a, and Ta'iz.[5] In Ibb governorate, key roads such as the Ibb-Sana'a Road, which was already poorly maintained, were further damaged and limited civilian movement and access to services, with one key example of this being the temporary suspension of operations in the Al-Thawra Hospitals in Sana'a.[4] Local media has also reported damage to a bridge linking the Al Musaymir area of Lahj Governorate with Ta'iz City. Water from floods also created physical blockages and logistical barriers for humanitarian personnel and partners in providing urgent interventions.[1,5] Finally, the August 2022 OCHA Situation Update estimated that more than 51,000 households have been affected by heavy rains across the country since mid-April 2022, with Mar'ib and Hajjah governorates being the worst-hit, as more than 13,000 and 9,000 households were affected respectively, and the majority of those affected were reportedly in displacement sites.[6]

Along the western coast of Yemen, one of the more affected districts, Abs in Hajjah governorate, also has one of the highest concentrations of IDPs and vulnerable people in the country. Since 2019, Hajjah has experienced a series of heavy rains that have destroyed shelters in IDP sites and infrastructure, leaving thousands of people in need, and disrupting humanitarian distributions.[7,8] On top of the immediate sectoral needs of the affected population, relief actors have expressed concern regarding the health impacts of the floods, particularly the heightened transmission risk of vector-borne and waterborne diseases amid an ongoing cholera outbreak at the time.[4] In 2020, Hajjah governorate showed the highest number of households affected by flooding events in Yemen (18,195 households).[3] Within IDP hosting sites, from March 2021 to May 2022, Hajjah reportedly experienced infectious diseases, conflict-related incidents, water contamination, and flooding as the most common threats to sites.[9] In August 2022, Hajjah has once again been one of the most affected governorates in Yemen due to recurrent heavy rains and floods that resulted in infrastructure, homes, food stock, and livestock being washed away.[10] Based on findings from the CCCM Site Report aggregated from May 2021-March 2022, in Abs district infectious diseases and flooding were reportedly the most common threats to sites, with 31% and 30% of sites reportedly at risk of infectious disease and flooding respectively.[9] In fact, according to the CCCM Flooding Incidents Report between December 2021 to August 2022, 87% of sites in Abs that experienced a flooding event were reportedly in flood-prone areas, either on agricultural lands, near drainage channels, or on steep slopes.[11] Moreover, during the past year, flooding events obstructed road access in 32% of flood-affected sites in Abs, and water-borne diseases such as typhoid fever, malaria, and dengue have been reported.

The report will continue as follow: the rationale section explains the reason why this analysis was made, followed by the methodology section which highlights the general and technical methods used for the analysis, along with its limitations. Furthermore, the key findings are presented followed by a series of site-level flood hazard and flood depth maps. The report concludes with a summary of the analysis and recommendations for next steps.

Figure 1,2: Effects of flooding events on shelters, roads and infrastructure in Hajjah Governorate in 2019. Images provided by CCCM partners in the field.

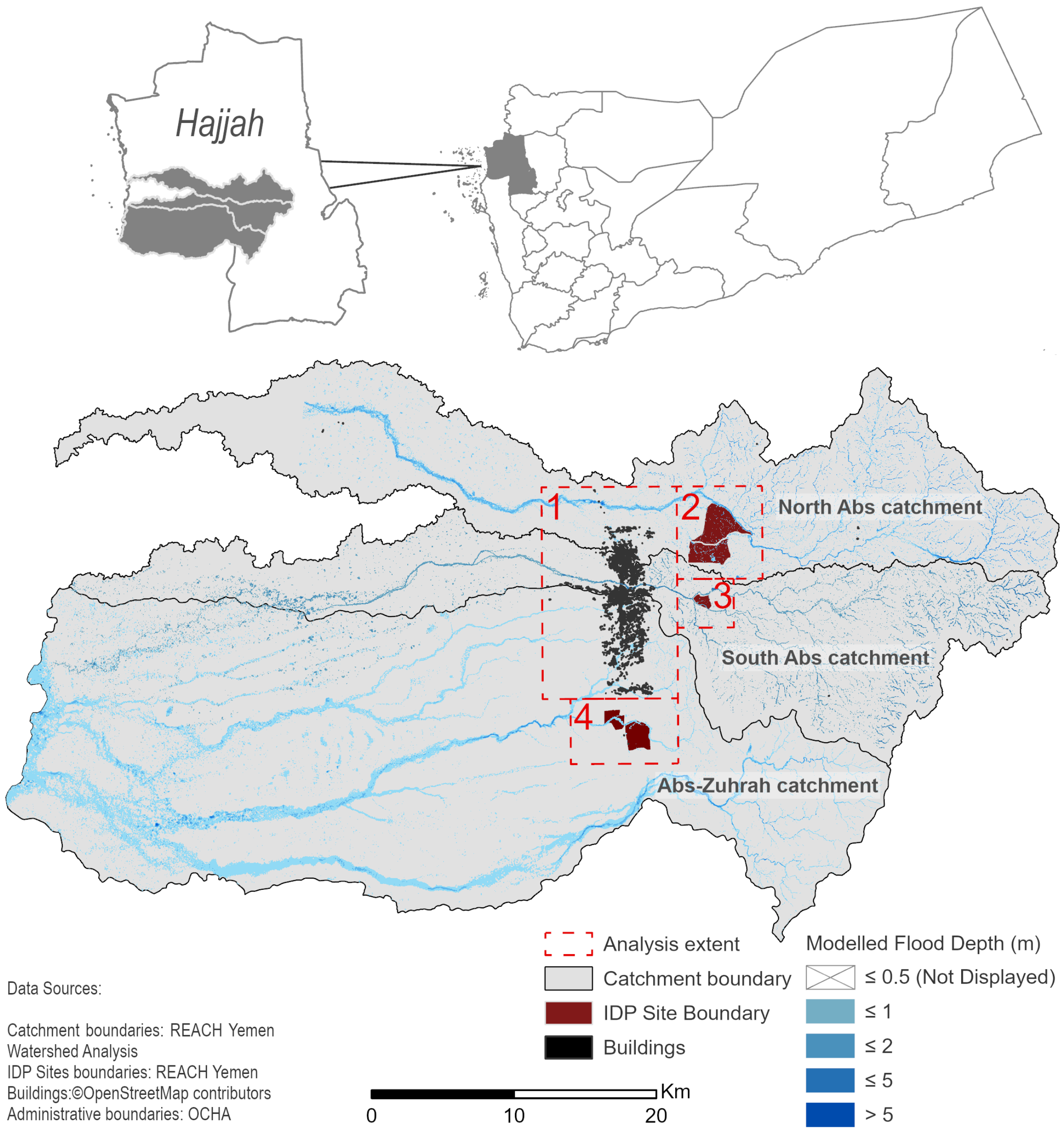
1. Yemen Humanitarian Needs Overview (April 2022)
2. The Disaster of Yemen's Flash Floods - Impact of and Local Responses to the Torrential Rains and Flooding in 2020. Carpo Brief No. 21, December 7th, 2021. Available here.
3. OCHA, Yemen Flood Snapshot, 28 September 2020, available here.
4. USAID, Yemen - Complex Emergency Fact Sheet No. 11, September 4,2020, available here.
5. OCHA Yemen: Flash Update 3 - Humanitarian Impact of Flooding, 12 August 2021, available here.
6. OCHA Yemen Situation Update - Humanitarian Impact of Flooding, 24 August 2022, available here.
7. OCHA, YEMEN: Flash floods, Flash Update No. 1, 11 June 2019, available here.
8. ACAPS, YEMEN Heavy rainfall and flash floods, Briefing note, 23 April 2020, available here.
9. CCCM-REACH Site Report, findings aggregated from March 2021 to May 2022, available here.
10. CARE, Severe and widespread floods across Yemen bring more hardship to tens of thousands of displaced families, 18th August 2022, available here.
11. CCCM Yemen, Flooding Incidents Report, 2021-2022, available here.

RATIONALE

Given the recurrence of flash flood events consistently affecting IDP sites and livelihood activities of site residents and the general population in Abs, REACH used a high-resolution flood hazard mapping and analysis to understand where flood hazard and flood exposure are more severe in Abs and Abs-Zuhrah catchments (as shown in Map 1) and to complement the existing information from other assessments. The aim in conducting this high-resolution analysis is to add a localized lens to REACH's National Flood Risk Analysis of IDP Hosting Sites performed in March 2022. In fact, at the beginning of 2022, REACH carried out a Flood Risk Analysis for all IDP sites in Yemen for which information was available to understand the risk of flooding at IDP site level and inform OCHA's and the CCCM Cluster's Flood Contingency Planning. However, some general and hydraulic model's limitations were found, such as the lack of datasets for all sites, the lack of site extents and sites correct location, or the usage of a 30-meter Digital Elevation Model (DEM) that underestimated depth and overestimated hazard extent. For this, a localized and more detailed flood risk analysis was deemed more appropriate to assess flood risk at site level, coupled with the desire to add more value to outputs by operationalizing findings directly with CCCM partners managing IDP sites. As a result, to test the analysis at site level, REACH collaborated with CCCM partners (RADF and DRC) to identify IDP sites for the analysis and complement the remote analysis with CCCM Partners' information on flood exposure and flood-related consequences to livelihood activities on the ground. Finally, this type of analysis will allow the humanitarian response to consider flood-risks at a lore local and case-specific level, allowing for more targeted response and disaster risk reduction (DRR) strategies.

ASSESSMENT METHODOLOGY

Starting from the National Flood Risk Analysis results from March 2022 and the available high-resolution imagery for Abs, CCCM Partners have been involved in the process of selecting sites based on their field knowledge and on their perceived risk of flooding of their managed sites. As a result of conversations with CCCM Partners, 5 sites were selected in Abs district for the pilot flood risks analysis, namely Hayjat Albataryah, Al Maqayet, Malakhah, Al Malab, and Alkasarah – Wadi Qoor. All the 5 sites were scored at medium or high risk of flooding in the National Flood Risk Analysis and presented a total household population of 223 households and above. Moreover, Abs City has also been included in the analysis to be able to map infrastructures using an open street mapping. Following a collaborative approach, REACH and CCCM Partners drew site boundaries of selected sites, while shelters' mapping was completed by REACH utilizing ArcGIS Pro. An in-house HEC-RAS analysis was run to understand flood depth and hazard of selected sites (for more technical explanation around the model, please refer to the "Rapid Flood Hazard Modelling" section). Preliminary results were discussed with CCCM Partners to get an informal field validation of the results and collect additional information about the consequences of flooding on livelihood activities and water-borne diseases.



Map 1: Area of interest map shows North/South Abs and Abs-Zuhrah catchments boundaries, modelled flood depth extent and the four analysis extents in Abs district, where extent 1 has the infrastructure and buildings in Abs city, extent 2,3 and 4 contain the selected IDP sites.

REGIONAL CHARACTERISTICS

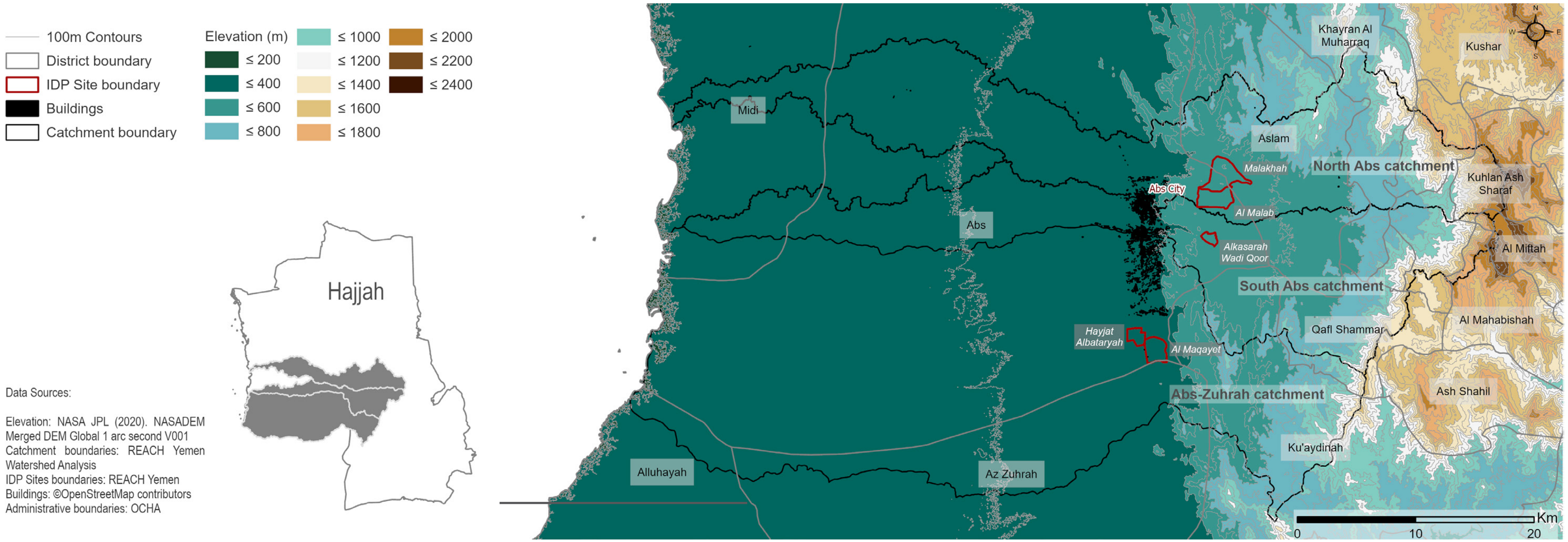
The topography of the western region of Yemen is characterized by mountain ranges running parallel to the Red Sea coast through the capital Sana'a, affecting temperatures and rainfall gradients as the elevation and distance from the sea increases. Specifically, the rainfall gradient rises from less than 50 mm along the Red Sea coast to a maximum of 700-800 mm to the west of the main watershed west of Sana'a and falls steadily to below 50 mm along the Gulf of Aden and inland.[12] The region also boasts a tendency to produce precipitation in the form of convective storms of high intensity and limited duration and extent that can be associated with the annual rainfall distribution and its relationship with the orographic influence of the mountain ranges in a combination with regional rainfall mechanisms such as the Red Sea Convergence Zone (RSCZ) and the monsoonal Intertropical Convergence Zone (ITCZ).

Considering the regional hydro-meteorological conditions, the water flows generated by the rainfall supplies streams that are often characterized by an intermittent or ephemeral regime, due to the short duration of rainstorms coupled with high rates of evapotranspiration that is a characteristic of dry, desert areas. These streams form the typical dryland river valleys locally known as wadis. Wadi (the Arabic word for valley) is defined as the bed or valley of a stream that is usually dry except during the rainy seasons[13] and is characterized by high levels of flow unpredictability due to their severe dry-wet hydrological regimes.[14] These catchments vary immensely in size and can carry a great amount of water from the western mountain slopes to the Red Sea, causing flood hazards in flood-prone areas. In Yemen, two flood seasons tend to occur, one in spring and one in summer, and they occasionally form a single prolonged season extending from April to September.

CATCHMENT CHARACTERISTICS

In order to understand the flood risk of the selected 5 IDP hosting sites and Abs city, the flood hazard and exposure in two main catchments in the Abs region are analyzed: the Abs catchment and another catchment which is defined here as the Abs-Zuhrah catchment, as displayed in the Map 2 below. The geographical extent of the Abs catchment can be subdivided into two main parts, north and south, delineated by the major river flow and the streams feeding into it. The Abs-Zuhrah catchment is larger, with 1,811.85 km^2 of total drainage area. The Abs-Zuhrah catchment is also an aggregation of two main river channels, but unlike the Abs catchment, they were modelled together. The southern portion presents very similar characteristics as the Abs catchment, starting in a mountainous area and flowing west, while the northern portion starts more to the west, in significantly flatter terrain.

The drainage pattern in the eastern part of the catchments is mostly determined by the peaks of the central mountain range, locally peaking with a maximum elevation of approximately 2100 meters above sea level. From this mountainous area, several small intermittent streams (or wadis) flow west and as they leave the central part of the catchment, they narrow down into single dry-river valleys at an elevation of approximately 250 meters. The streams continue west towards the lowest-lying areas between 30 and 100 meters of elevation, and as is typical for a Red Sea basin's wadi, the catchment intersects coastal plains, and the shallow dry riverbeds degenerate, becoming difficult to recognize flows as they traverse the porous alluvium[15] of the plain.



Map 2: Catchment characteristics map illustrates the topography and drainage limits of North/South Abs and Abs-Zuhrah catchments.

12. Farquharson FAK, Plintson DT, Sutcliffe JV (1996) Rainfall and runoff in Yemen. J Hydrol. Sci. https://doi.org/10.1080/02626669609491546
13. Wheater, H., & Al-Weshah, R. A. (2002). Hydrology of wadi systems: IHP regional network on wadi hydrology in the Arab region. Paris: Unesco
14. Shahin, M. (2007). Wadis and wadi flow. In M. Shahin (Ed.), Water resources and hydrometeorology of the Arab region (Vol. 59, pp. 279–332). Dordrecht: Springer
15. Material deposited by rivers consisting of silt, sand, clay, gravel and often a good deal of organic matter, and usually yielding fertile soils. Source: https://www.britannica.com/science/alluvium

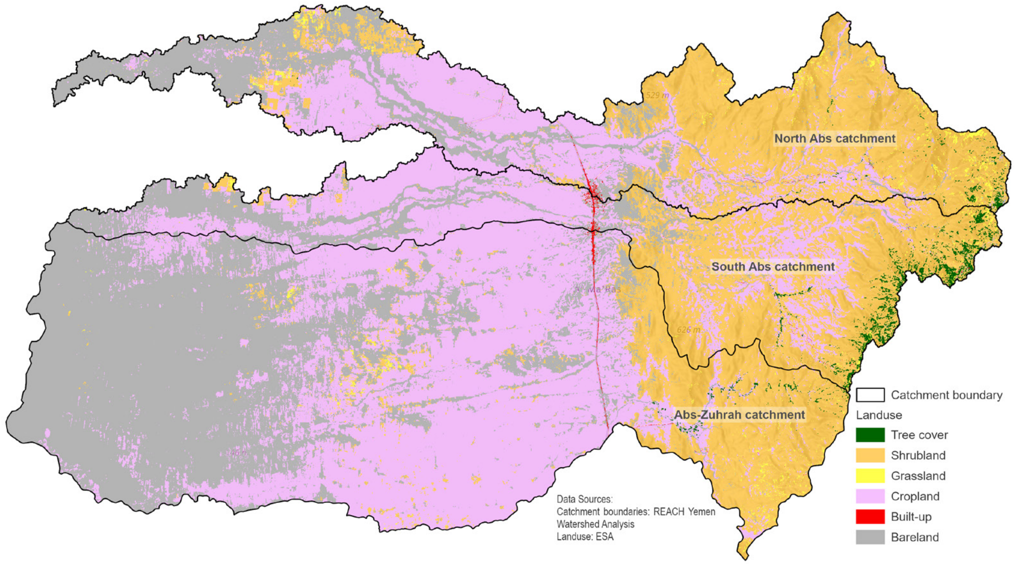
RAPID FLOOD HAZARD MODELLING

A two-dimensional (2D) unsteady flow hydraulic model was set up using HEC-RAS software for the two catchments in the Abs region. The approach allows an understanding of flood hazards on a catchment-wide scale and identify areas prone to flood risk, especially areas exposed to flash flooding.[16] This method of 2D flood modeling is also referred to as a Rapid Flood Hazard Assessment (RFHA). As a result of the precipitation values and simulation parameters used, the model attempts to reproduce the conditions of storms that would cause actual flash flood events. The flow model approach applies a direct precipitation on Digital Elevation Model (DEM) method, where precipitation is applied evenly to all cells generated in a computational grid, and the areas where water flows and puddles are naturally determined as iterations of the model are running. The outputs of the models inform the flow extent, depth, and velocity (and consequentially hazard) of areas where flooding may occur after applying the statistically determined extreme precipitation events. Two separate models were produced for the two catchment areas, with minor differences in model parameters used, mainly due to the different datasets available for each area. The following section outlines the methodology used to obtain the flood extents, depth, and hazard results presented in this report.

MODEL INPUTS - TERRAIN, LAND COVER AND INFILTRATION

The terrain used for the HEC-RAS 2D unsteady flow analysis of the Abs catchment was a satellite-derived DEM product of 2.5 meters resolution acquired from the Japan Aerospace Exploration Agency (JAXA). The DEM was hydrologically conditioned to remove artificial dams, and other errors such as depressions and noise, and include elevation of buildings, to allow it to accurately represent expected flow and drainage patterns. For the Abs-Zuhrah catchment, a 12-meter DEM was used.
Landcover data is employed by the model to represent both the roughness of the terrain and to be used in the infiltration layer to integrate the infiltration patterns of each land cover class in the modeling process. The land cover dataset used in the modeling exercise analysis makes use of Sentinel-2 imagery from 2019, classified in-house, that allows for a resolution of 10 meters. The land cover dataset used in the Abs-Zuhrah catchment is the WorldCover dataset developed by the European Space Agency (ESA), which also uses Sentinel-2 satellite imagery, and features 11 land cover classes with worldwide coverage and 80% classification accuracy in Asia, ESA landcover dataset of the area of interest is shown below in Map 3. The different landcover classes are assigned a roughness coefficient (Manning's value) based on literature reference values.[17]

The infiltration layer is introduced to allow the model to account for precipitation losses and determine a more realistic representation of the hydrological processes occurring at the surface level. To create this layer, the landcover classes are intersected with a hydrological soil group layer obtained from the global dataset HYSOGs[18] and the different land cover and soil group combinations are attributed a Soil Conservation Service (SCS) Curve Number (CN). The CN values are derived from reference tables in the HEC-RAS documentation.[19] The SCS-CN method is a simple but well-established method that accounts for many of the factors affecting runoff generation in a single parameter[20].



Map 3: The land cover map illustrates the land uses in the area of interest from the European Space Agency (ESA) WorldCover 2020 Global land cover product at 10 m resolution.

PRECIPITATION

Due to the lack of reliable and up-to-date precipitation data from weather stations in Yemen, REACH-UNOSAT completed a review of available data, where different sources such as scientific papers, regional precipitation data, and satellite data were examined to define appropriate and consistent rainfall inputs for the hydraulic models. From the available literature, it was possible to calculate rainfall temporal distribution for a simulated rainfall event (also referred to as a synthesized, or designed storm), by using intensity-duration-frequency (IDF) curves from Sabya wadi [21], a coastal Saudi Arabian wadi with similar characteristics as the Abs catchments, located only 150 km north of Abs district. The IDF relationship consists of the estimates of rainfall intensities of different durations and recurrence intervals, which can be processed to create artificial storms. The Saudi precipitation time-series data used to derive the IDF curves originates from different climatological stations in the region and were aggregated through the alternating block method[7] to derive the final temporal distribution of the simulated rainfall event for the 25-year return period. The hyetograph of the 3-hour storm event with approximately 20 mm peak intensity is displayed below in Figure 3.

To validate the synthesized rainfall distribution data, REACH-UNOSAT performed a comparison with real rainfall events in Hajjah. In this comparison, six reported flood events spanning from 2000-2020 were considered from the historical flood event records of the Centre for Research on the Epidemiology of Disaster (CRED) database.[22] The rainfall data on the date of the registered flood events was reviewed through the satellite-detected rainfall values of NASA's Global Precipitation Measurement (GPM) half-hourly dataset.[23] Among the observed storms, a rainfall event on the 20th of June 2003, presented 43 mm rainfall depth over 3 hours, a value that is comparable to the total depth of the 25-year return hyetograph of 45 mm of the designed storm.

16. Flash flooding is generated by heavy rainfall over a short period of time. Flash floods are characterized by relatively high peak discharges and short response times between rainfall and the onset of flooding, usually within 12 hours. Source: World Meteorological Organization - No.57720.
17. Chow, 1959, table. Chow and O'Brian, table.
18. Ross, C.W., L. Prihodko, J.Y. Anchang, S.S. Kumar, W. Ji, and N.P. Hanan. 2018. Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling. ORNL DAAC, Oak Ridge, Tennessee, USA. Avaiable here.
19. SCS. 1956. Hydrology. National Engineering Handbook, Supplement A, Section 4. Soil Conservation Service, US Department of Agriculture: Washington, DC; Chapter 10.
20. Soulis, K.X. Soil Conservation Service Curve Number (SCS-CN) Method: Current Applications, Remaining Challenges, and Future Perspectives. Water 2021, 13, 192. https://doi.org/10.3390/ w13020192
21. Ibrahim H. Elsebaie (2012) Rainfall intensity-duration-frequency relationship for some regions in Saudi Arabia, Science Direct https://doi.org/10.1016/j.jksues.2011.06.001
22. CRED EM-DAT (2020). Emergency disaster database, Centre for Research on the Epidemiology of Disasters, http://www.em-dat.net
23. The Integrated Multi-Satellite Retrievals for GPM (IMERG), https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGHH_06/summary

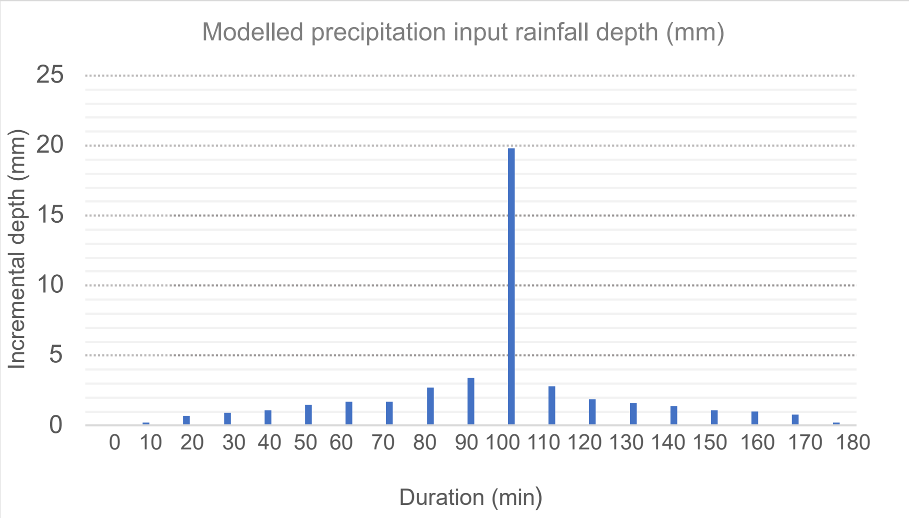


Figure 3: Modelled precipitation rainfall depth chart, where the peak rainfall intensity is 119 mm/hr and the total rainfall depth is 45 mm, for the 25-year return period of the designed rainfall.

HAZARD AND DEPTH SEVERITY CLASSIFICATION

Flood hazard is obtained by multiplying flood depth and velocity and is a useful indicator of flood severity and exposure. The classification of flood hazards in this analysis considers the simplified approach presented in the US Federal Emergency Management Agency guidance on Flood Depth and Analysis Grids[24], which separates hazard severity into 5 classes from low to extreme. Flood depth alone is also a useful indicator of flood exposure, as it represents water flow extents and static accumulation of water, which depending on the severity, can also be the cause of flood risk and harmful consequences. The flood water depth can be classified into 5 flood hazard categories from very low to extreme according to the Japanese criteria of the Ministry of Land Infrastructure, where each hazard category is associated with the risk of damage, the threat to human safety, and the possibility of evacuation.[25] Table 1 below visualizes the hazard and depth severity classification. For the purpose of this pilot analysis, mapped shelters were overlayed with the flood depth and flood hazard models to verify the number of shelters falling within the two models, as it can be seen in the site-level maps displayed in the “Results” section. If at least 1% of each shelter was touching the highest severity calssification, then the shelter was calssified at the highest severity classification.

Hazard severity category	Depth x Velocity (m^2/s)	Depth severity category	Depth (m)
Low	< 0.2	Low	< 0.5
Medium	0.2 - 0.5	Medium	0.5 - 1
High	0.5 - 1.5	High	1 - 2
Very High	1.5 - 2.5	Very High	2 - 5
Extreme	> 2.5	Extreme	> 5

Table 1: Flood hazard and depth severity categories used to produce the hazard and depth maps.

GENERAL LIMITATIONS

There are some general limitations to this pilot flood hazard severity analysis that should be kept in mind when reading the findings and when planning for future flood analyses. Firstly, vulnerability indicators are not yet incorporated at this stage of the hazard modelling but are an important factor for determining overall flood risk to IDP sites. Moreover, the findings that were envisioned before starting the discussions with partners and before running the analysis were more severe than the final findings REACH got. This is because the detailed pilot analysis highlighted some of the limitations already known of the national analysis, such as the lack of exact sites locations and boundaries. Thanks to the collaboration with CCCM Partners, REACH was able to verify sites' location and draw exact site boundaries which differed from the estimated boundaries used for the National analysis – and hence the number of shelters and sites at risk differed. Therefore, this detailed analysis provided an additional layer of information to the previously run National analysis, and its findings are backed up by informal evidence from partners on the ground. Once again, a key take-away from this report is that localized analysis and collaboration with partners in the field can provide more accurate information and can better inform the response.

TECHNICAL LIMITATIONS

There are several technical limitations of the modeling exercise to consider, as these have a significant impact on results and can affect the model's ability to provide precise flood hazard and depth extents. As with any remote analysis, model results need to be calibrated and validated with information and inspections on the ground. Since this was not the case for the outputs presented in this report, results should be considered as estimates and can serve as an indication of susceptible floodplain locations. The following limitations should be considered when interpreting model outputs:

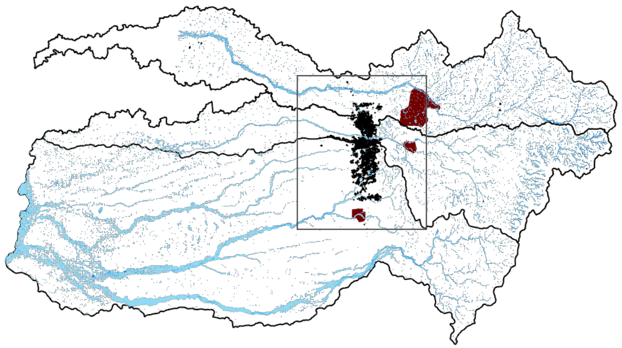
- The DEM dataset was not validated by information on the ground and relies on satellite-derived elevation data with a vertical accuracy of 5 meters or less.
- Several input parameters of the hydraulic model were not calibrated through field inspections, including the Manning's roughness coefficients and infiltration Curve Numbers. Instead, literature reference values were used.
- The hydraulic model results were not validated on the ground to confirm extent of modelled events match real-life flood events.
- The hydrological conditioning of the DEM was not validated on the ground and was done manually by digitizing hydrographic features using only satellite-derived knowledge.
- The infiltration losses are estimated with the SCS-CN method from a coarse hydrological soil group dataset and a land cover dataset that was not field validated.
- The estimation of the dimensions of essential hydraulic structures relied upon observation through satellite imagery and photographs.
- Other obstacles to flow (except Abs bridge and buildings) are not included in the model.

24. FEMA (2018), Guidance for Flood Risk Analysis and Mapping
25. Quiroga, V.M.; Kurea, S.; Udoa, K.; Manoa, A. Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5. Ribagua 2016, 3, 25–33.

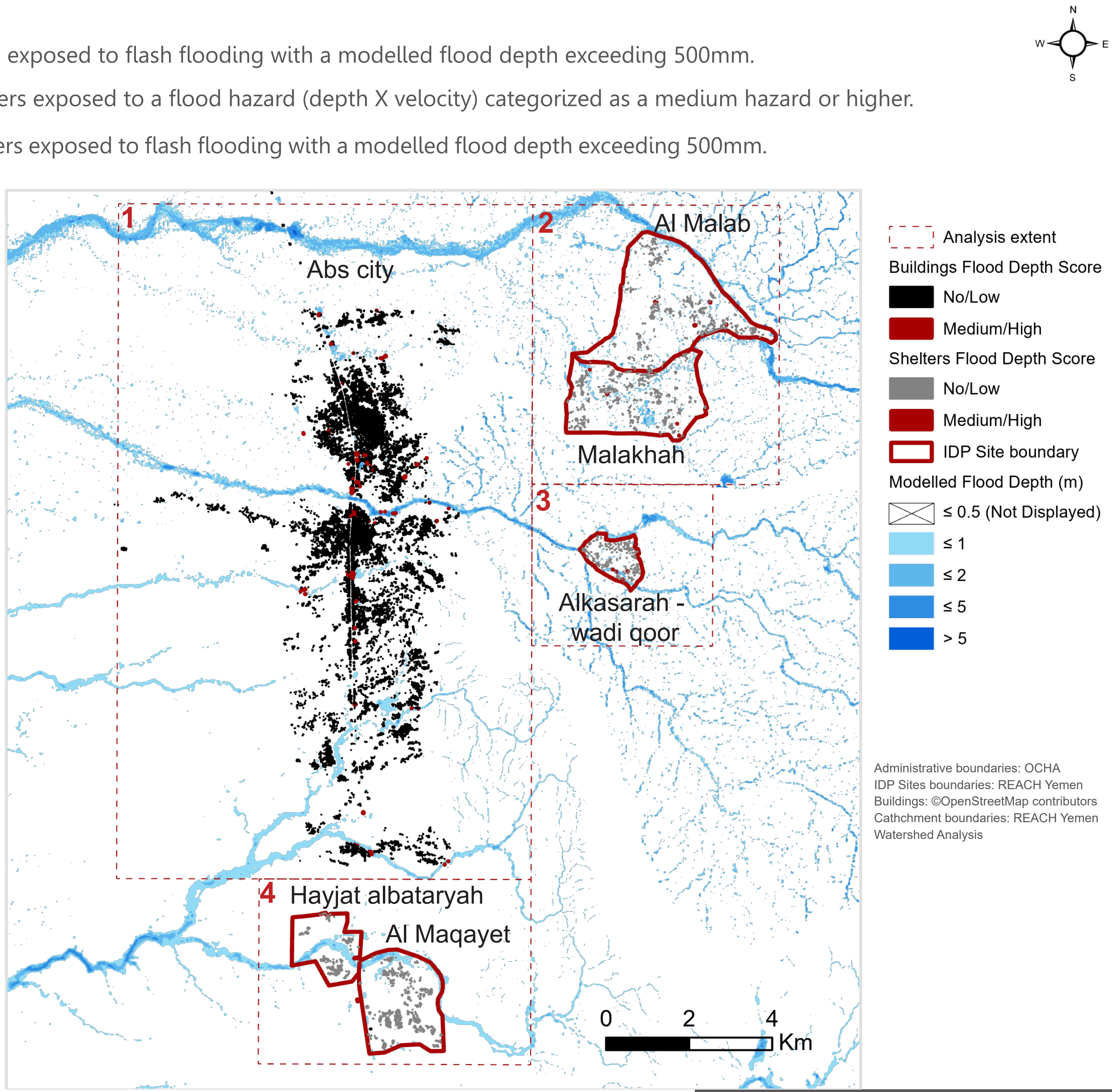
124 Estimated number of buildings exposed to flash flooding with a modelled flood depth exceeding 500mm.

43 Estimated number of IDP shelters exposed to a flood hazard (depth X velocity) categorized as a medium hazard or higher.

22 Estimated number of IDP shelters exposed to flash flooding with a modelled flood depth exceeding 500mm.



Analysis extent	Area Name	# Shelters & buildings within modeled flood extents (exceeding 500mm)	# Shelters & buildings exposed to hazard (medium hazard or greater)
1	Abs city	124	102
2	Al Malab & Malakhah	12	16
3	Alkasarah - Wadi qoor	7	16
4	Hayjat albataryah & Al Maqayet	3	11



Administrative boundaries: OCHA
IDP Sites boundaries: REACH Yemen
Buildings: ©OpenStreetMap contributors
Catchment boundaries: REACH Yemen Watershed Analysis

After applying the HEC-RAS analysis to the 5 selected IDP sites in Abs district and Abs City, REACH identified the flood hazard and flood depth for each selected area. In addition, anecdotal evidence from CCCM partners on the ground was used to better understand and triangulate the remote findings. The section below outlines the most important findings, including flood hazard areas, and health and livelihood consequences per analysis area. Key findings are linked to the flood depth and flood hazard maps presented in the Results section, and the reader is encouraged to look at the maps while reading the key findings.

Abs City

- Approximately 102 buildings in Abs City are in an area of medium hazard severity or higher, with 5 buildings in an area of very high hazard. This represents a minority of the total number of infrastructures in Abs City and are mostly located in the center and south of Abs City.

- The Hodeidah-Harad road, the main road passing through Abs City, has extreme hazard areas flowing through it at multiple points in the North and South of Abs City, and in many of these points there is no detectable presence of bridges or other drainage structures, meaning that residents most likely won't be able to cross this road in the event of heavy rains and flooded roads.

Al Malab and Malakhah sites

- Malakhah and Al Malab sites are presented together as they share one main road and are both managed by the same CCCM partner - RADF. In total, a minor portion of the total amount of shelters and infrastructure buildings are in medium or high hazard areas (16 in total), mostly in the north-east part of Malakhah site and central parts of Al Malab site, as displayed at pages 12 & 13 in the Results section. Anecdotal information from the partner on the ground indicates that heavy rains and wind greatly affected shelters and non-food items in these two sites in 2020 and 2022. This implies that households need to spend several days after the natural event collecting materials and rebuilding their homes and stopping their livelihood activities, as reported by the partner on the ground.

- A small portion of the road separating Malakhah and Al Malab sites intersects two high hazard areas, at the northern extremes of Al Malab site and the southern extreme of Malakhah site, and it also intersects an area of extreme hazard at the southern border of Malakhah site. A secondary road intersects an area of high hazard in the eastern part of Malakhah site, as represented at pages 12 & 13 in the Results section. As highlighted by anecdotal information by the partner organisation on the ground, due to heavy rains, residents are usually unable to go to work or reach markets for livelihood activities as roads are flooded, and site residents are scared to leave their families.

- Flood depth and hazard maps of Al Malab site indicate the presence of water flowing across the center of the site and continuing east and south, isolating the eastern part of the site from the west and the southern and western portion of the site from the main road.

- Anecdotal information from the partner on the ground highlights that flooding events in these two sites not only affect shelters but livelihood activities as well. In fact, rains reportedly damage crops and entire farms, preventing residents from cultivating.

Alkasarah – Wadi Qoor Site

- 16 shelters in medium or high hazard areas are found in Alkasarah – Wadi Qoor Site, with 1 shelter in an area of very high flood hazard in the southern part of the site. An anecdotal information from the partner on the ground (RADF) shows that flooding events greatly affected shelters in the site in 2022, and there are approximately 30 to 40 families whose homes are threatened by flooding due to its proximity to the edge of the valley and the course of torrential rains. Moreover, some casualties were also reported as a consequence to torrential flooding in the site in 2022.

- Flood depth and hazard maps for Alkasarah – Wadi Qoor site exhibit intense water flowing parallel to the road directly south of the site, cutting-off road access for most shelters. The flow categorized as an extreme hazard not only intersects the road in two different locations but also appears to fully cover the road in a roughly 200-meter cross-section. As highlighted by information from the partner on the ground, in 2022 due to heavy rains, site residents were unable to go to work or reach markets for livelihood activities, as roads were flooded, or completely damaged and available works are generally outside of the site.

- Very high and extreme hazard areas also enclose the shelters in the site from the East and North, leaving the IDPs in the shelters with little options for evacuation or to seek alternative livelihoods during a flood occurrence.

Hayjat Albataryah and Al Maqayet sites

- Hayjat Albataryah and Al Maqayet sites are presented together as they share one main road and are both managed by the same CCCM partner - DRC. In total, a small proportion of the total amount of shelters and infrastructure points are in medium or high hazard areas (11 in total), and they are mostly located in the center of Hayjat Albataryah and in the north of Al Maqayet, as displayed at pages 16 & 17 in the Results section. From the maps, it is also possible to notice how the flood extent cuts Hayjat Albataryah site in two.

- A small part of the road that separates Hayjat Albataryah and Al Maqayet sites intersects an area of extreme hazard in the south of Hayjat Albataryah site and the north of Al Maqayet site. Additionally, a secondary road intersects an area of high hazard in the north of Al Maqayet site. However, the partner on the ground highlighted that site residents are generally able to use secondary roads to reach markets and other livelihood activities.

- The flood hazard map shows high, very high, and extreme hazard areas stretching across the Hayjat Albataryah in areas that are typically used for agriculture and fallow. The partner on the ground indicated that crops in Al Maqayet site got damaged in 2021 and 2022 as floods obliterate croplands at their initial germination stage.

- The flood depth map of these sites (page 16) suggest the presence of large, deep areas of stagnant water across the extent of the Hayjat Albataryah and near the northern border of Al Maqayet sites. This area surrounds shelters from nearly all sides and likely makes access to the rest of the site and between sites more difficult.

- Waterborne diseases are usually linked to the presence of stagnant water. An anecdotal information from CCCM partner on the ground shows that some site residents, particularly children, suffered in 2021 and 2022 from diarrhoea and fever as unprotected water sources, such as open wells, were polluted during the heavy rains, and due to the spread of mosquitoes.

ABS CITY - FLOOD DEPTH

September 2022

1,368

Buildings lie within the modelled flood extents in Abs City, Hajjah.

Breakdown of buildings within modelled flood depth extents

Low Flood Depth	1,244
Medium Flood Depth	87
High Flood Depth	32
Very High Flood Depth	5

Abs City

Roads

Primary

Secondary

Subdistrict

Buildings

No/Low

Medium/High

Modelled Flood Depth (m)

≤ 0.5

≤ 1

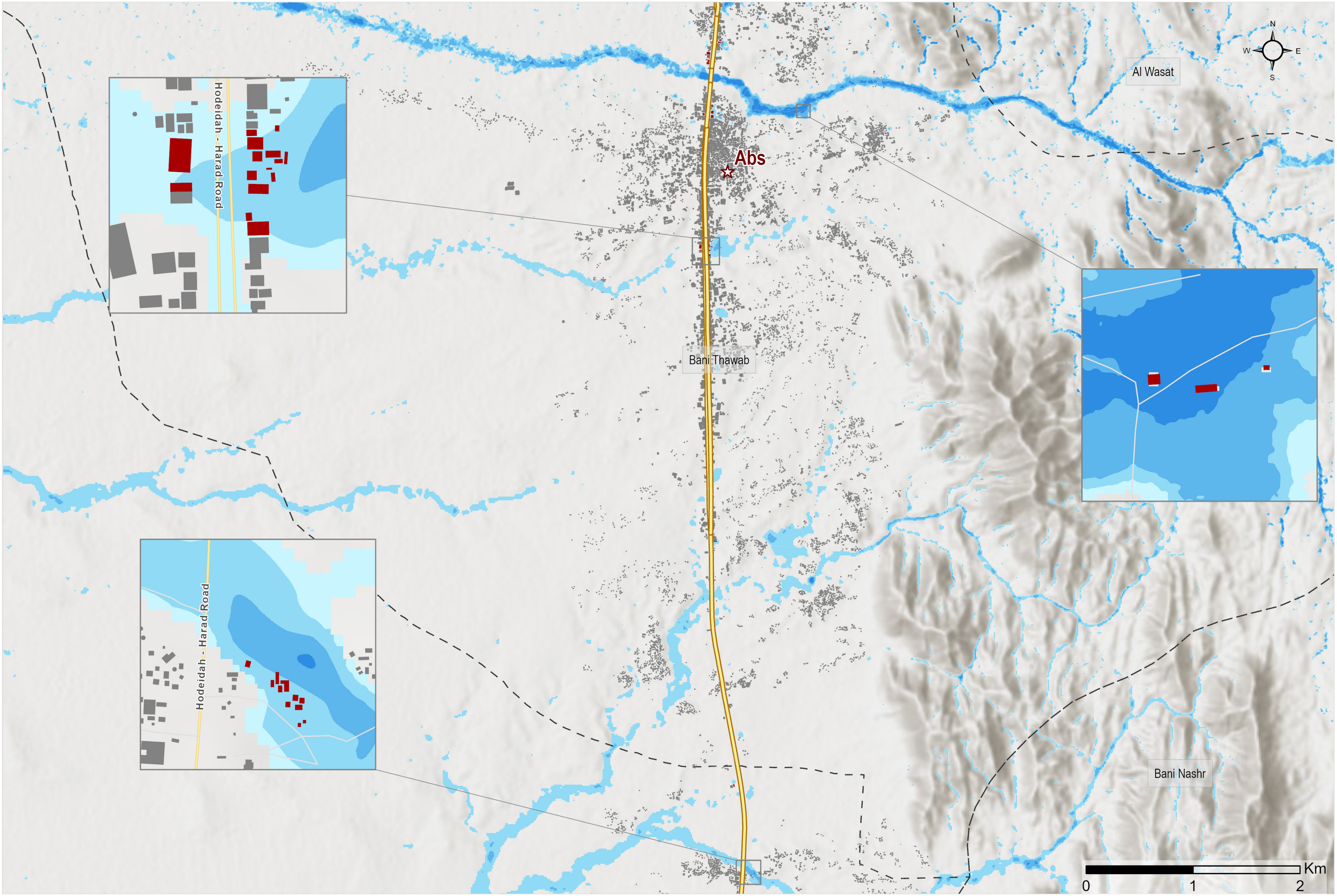
≤ 2

≤ 5

> 5

Roads and Buildings: ©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Admin Layers: OCHA

The flood water depth represents water flow extents and static accumulation of water in meters. It was classified into 5 flood hazard categories from very low to extreme according to the Japanese criteria of the Ministry of Land Infrastructure, the where each hazard category is associated with the risk of damage, the threat to human safety, and the possibility of evacuation.



1,368

Buildings lie within the modelled flood extents in Abs City, Hajjah.

Breakdown of buildings within modelled flood hazard extents

Low Flood Hazard	1,266
Medium Flood Hazard	62
High Flood Hazard	31
Very High Flood Hazard	5
Extreme Flood Hazard	4

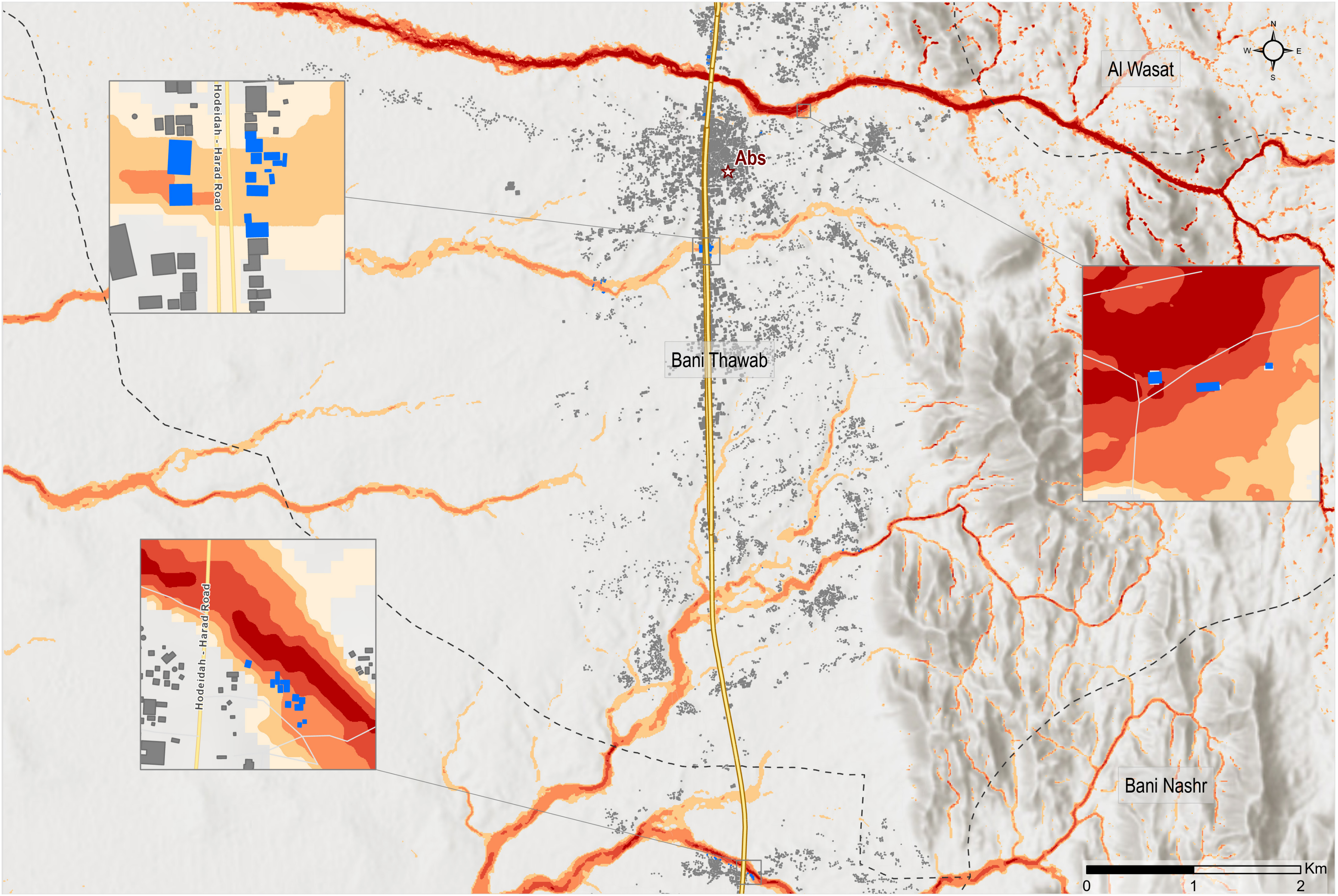
Abs City

Roads
- Primary
- Secondary

Subdistrict

Buildings
- No/Low
- Medium/High/Extreme

Modelled Flood Hazard classification
- Low
- Medium
- High
- Very High
- Extreme



Roads:©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Admin Layers: OCHA
Background: ESRI

Flood hazard was obtained by multiplying depth and velocity. The classification of flood hazards in this analysis considers the simplified approach presented in the US Federal Emergency Management Agency guidance on Flood Depth and Analysis Grids, which separates hazard severity into 5 classes from low to extreme.

41

Shelters lie within the modelled flood extents in Al Malab and Malakhah IDP Sites.

Breakdown of shelters within modelled flood depth extents

Low Flood Depth 29

Medium Flood Depth 10

High Flood Depth 2

Landmark

Roads

IDP Site Boundary

Shelters Flood Depth Score

No/Low

Medium/High

Modelled Flood Depth (m)

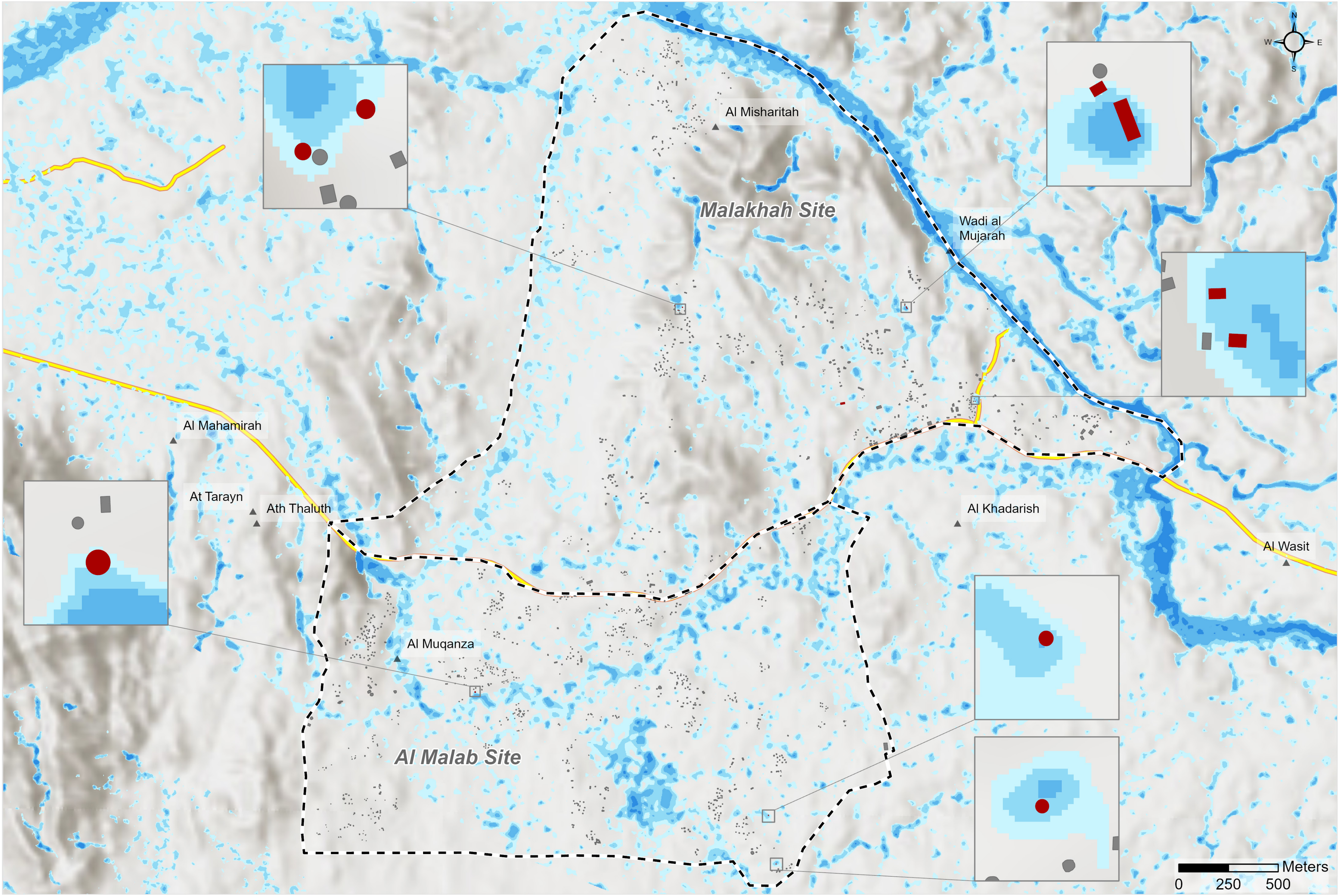
≤ 0.5

≤ 1

≤ 2

≤ 5

> 5



Roads and Buildings: ©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Admin Layers: OCHA

The flood water depth represents water flow extents and static accumulation of water in meters. It was classified into 5 flood hazard categories from very low to extreme according to the Japanese criteria of the Ministry of Land Infrastructure, where each hazard category is associated with the risk of damage, the threat to human safety, and the possibility of evacuation.

41

Shelters lie within the modelled flood extents in Al Malab and Malakhah IDP Sites.

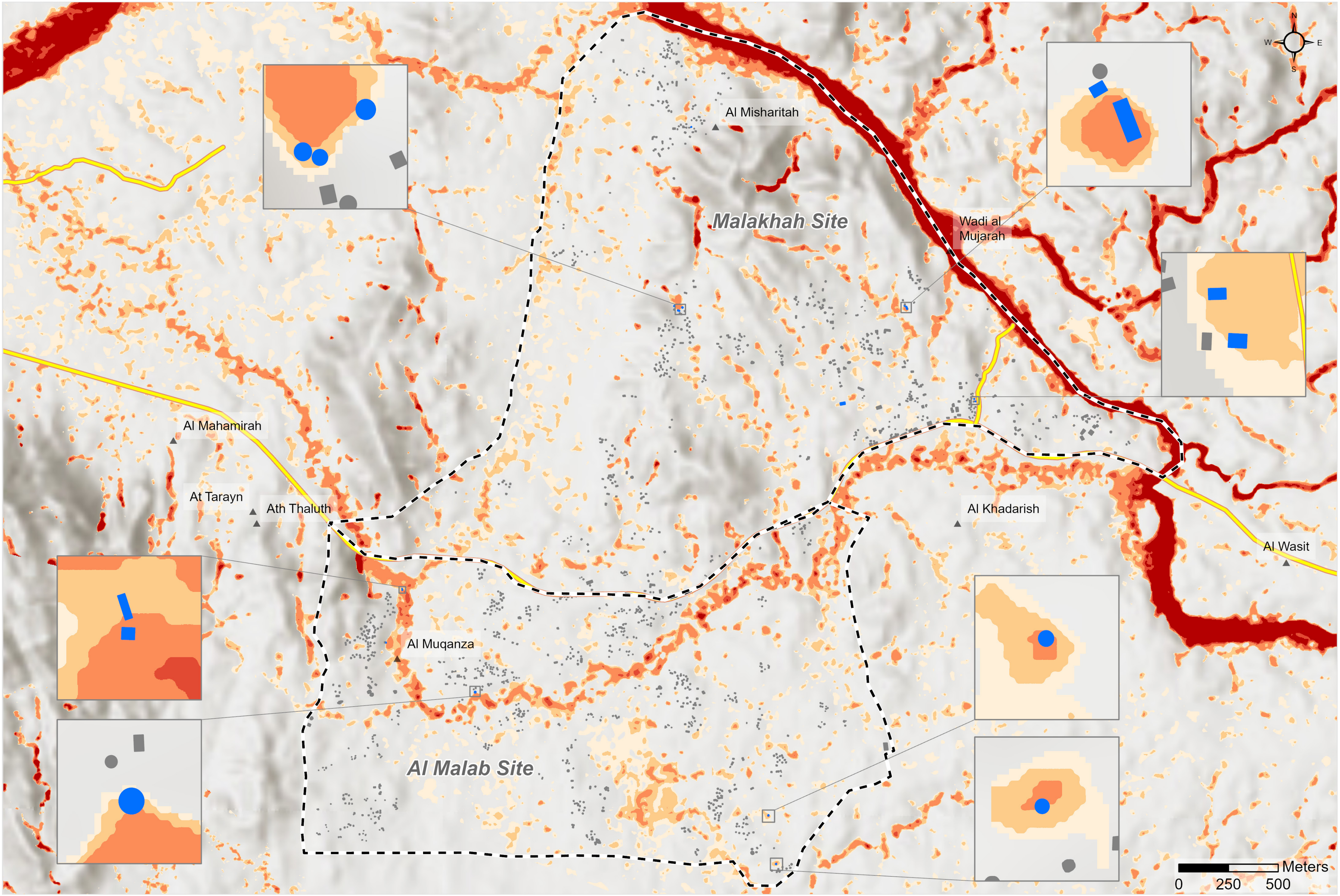
Breakdown of shelters within modelled flood hazard extents

Low Flood Hazard	25
Medium Flood Hazard	8
High Flood Hazard	8

Landmark
Roads
IDP Site Boundary

Shelters Flood Hazard Score
No/Low
Medium/High

Modelled Flood Hazard classification
Low
Medium
High
Very High
Extreme



Roads: ©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Background: ESRI

Flood hazard was obtained by multiplying depth and velocity. The classification of flood hazards in this analysis considers the simplified approach presented in the US Federal Emergency Management Agency guidance on Flood Depth and Analysis Grids, which separates hazard severity into 5 classes from low to extreme.

44

Shelters lie within the modelled flood extents in Alkasarah - Wadi Qoor IDP Site.

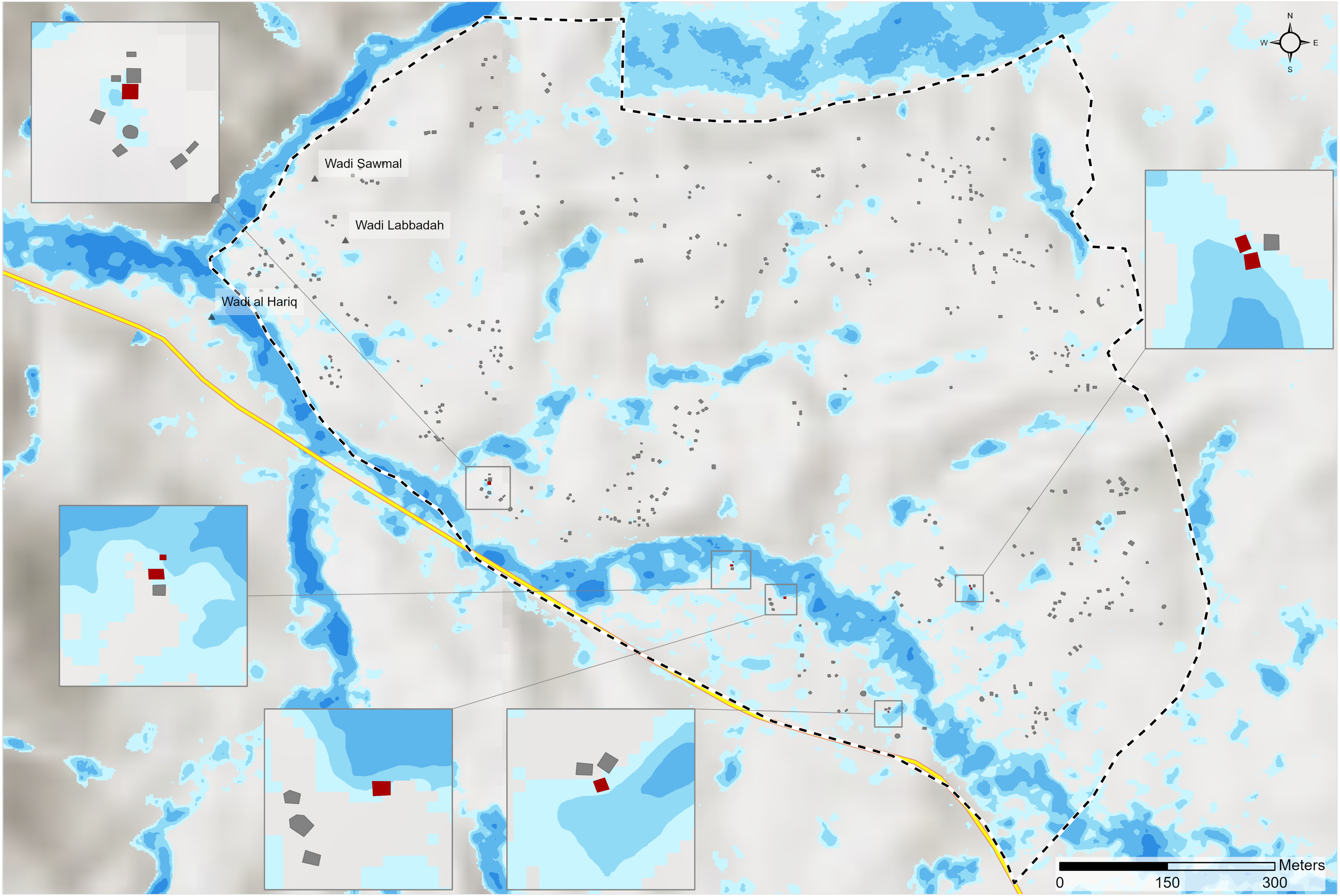
Breakdown of shelters within modelled flood depth extents

Low Flood Depth 37
Medium Flood Depth 7

Landmark
Roads
IDP Site Boundary

Shelters Flood Depth Score
No/Low
Medium/High

Modelled Flood Depth (m)
≤ 0.5
≤ 1
≤ 2
≤ 5
> 5



Roads:©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Background: ESRI

The flood water depth represents water flow extents and static accumulation of water in meters. It was classified into 5 flood hazard categories from very low to extreme according to the Japanese criteria of the Ministry of Land Infrastructure, where each hazard category is associated with the risk of damage, the threat to human safety, and the possibility of evacuation.

44

Shelters lie within the modelled flood extents in Alkasarah - Wadi Qoor IDP Site.

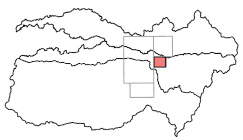
Breakdown of shelters within modelled flood depth extents

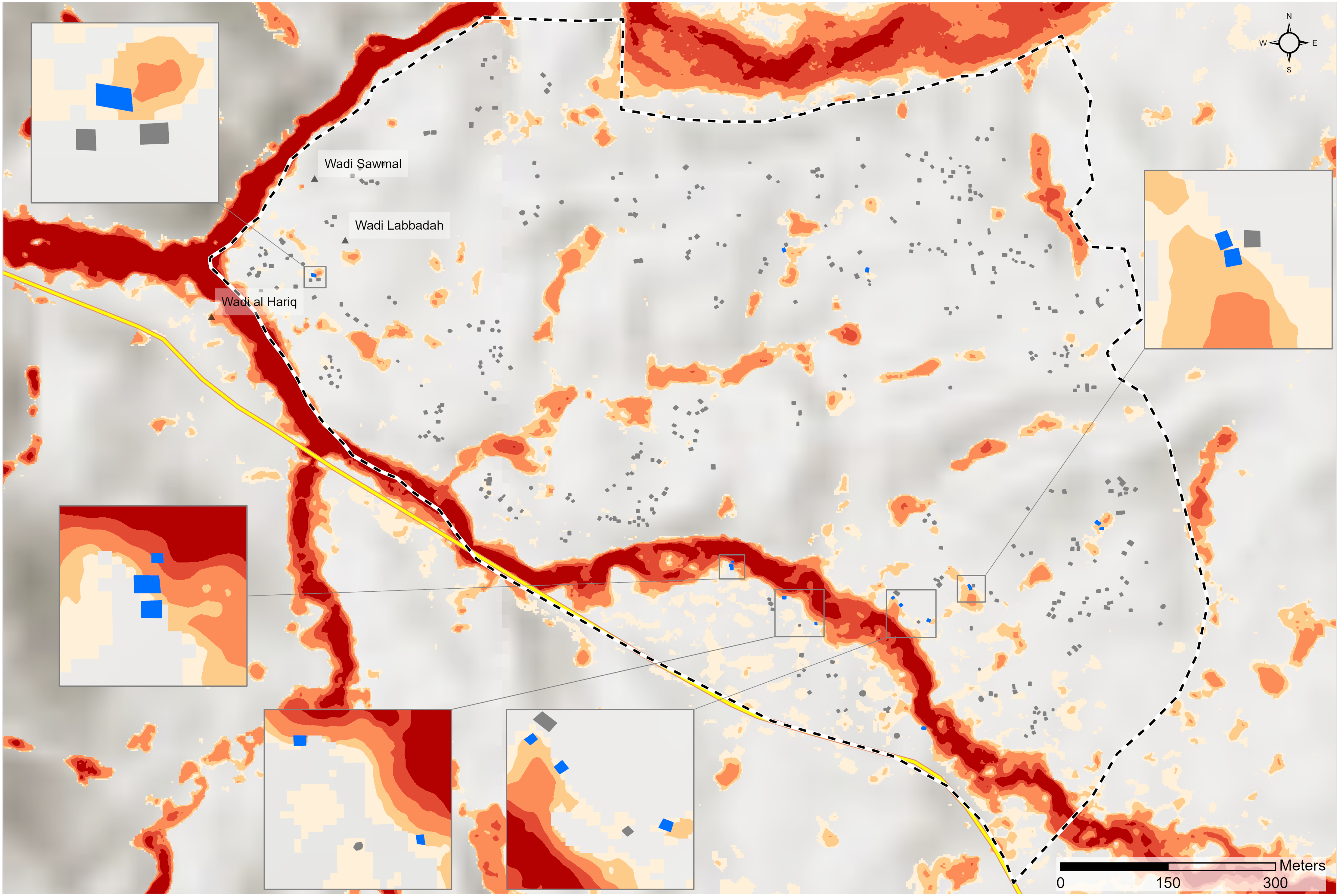
Low Flood Hazard	28
Medium Flood Hazard	13
High Flood Hazard	2
Very High Flood Hazard	1

Landmark
Roads
IDP Site Boundary

Shelters Flood Hazard Score
- No/Low
- Medium/High

Modelled Flood Hazard classification
- Low
- Medium
- High
- Very High
- Extreme





Roads:©OpenStreetMap contributors
Shelters: Manually digitized by REACH Yemen
Background: ESRI

Flood hazard was obtained by multiplying depth and velocity. The classification of flood hazards in this analysis considers the simplified approach presented in the US Federal Emergency Management Agency guidance on Flood Depth and Analysis Grids, which separates hazard severity into 5 classes from low to extreme.

410

Shelters lie within the modelled flood extents in Hayjat Albataryah and Al Maqayet IDP Sites.

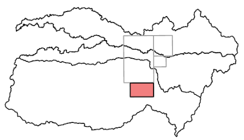
Breakdown of shelters within modelled flood depth extents

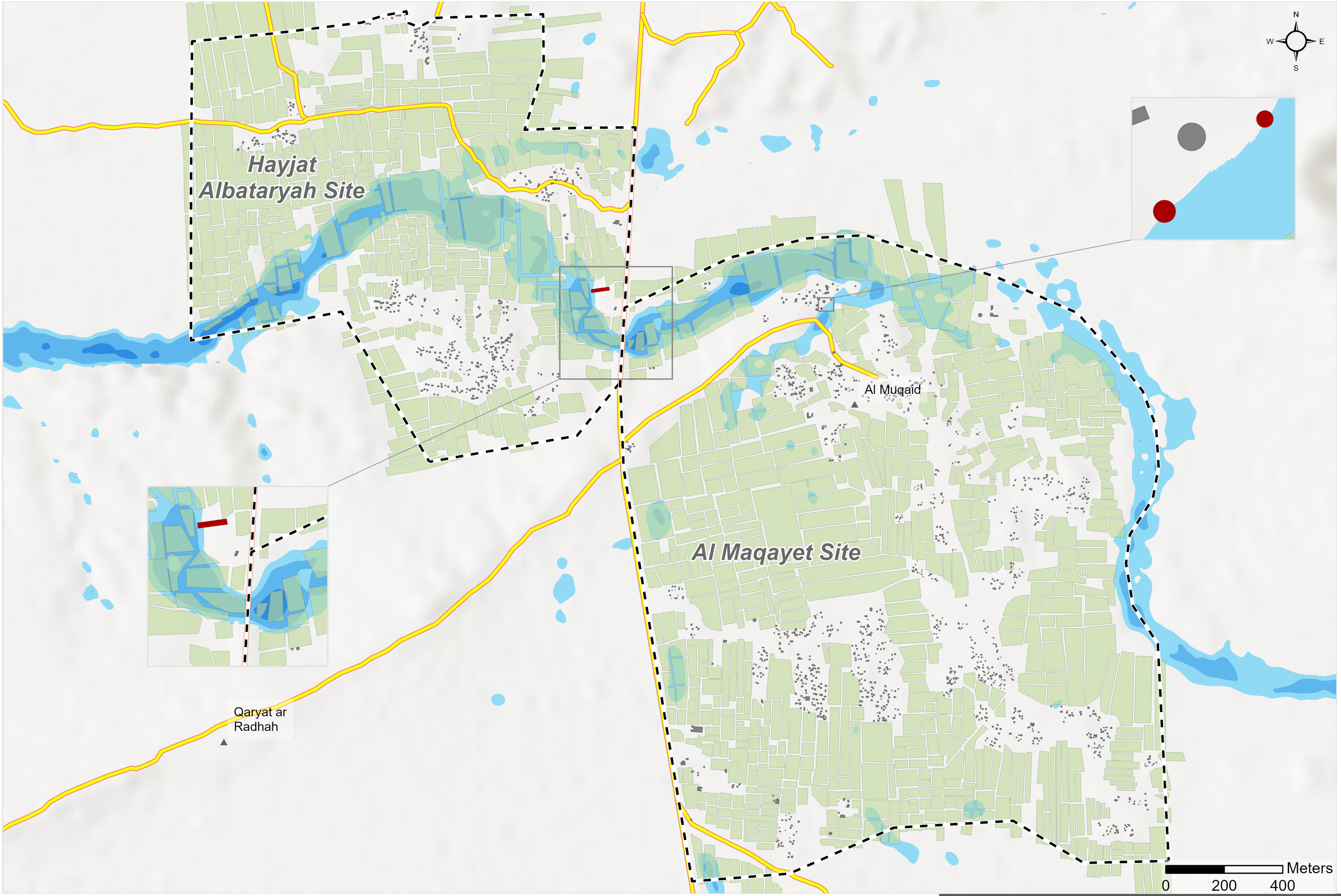
Low Flood Depth	407
Medium Flood Depth	2
High Flood Depth	1

Landmark
Roads
IDP Site Boundary
Agricultural land

Shelters Flood Depth Score
No/Low
Medium/High

Modelled Flood Depth (m)
≤ 0.5 (Not Displayed)
≤ 1
≤ 2
≤ 5
> 5





Roads:©OpenStreetMap contributors
Shelters and Agricultural land: Manually digitized by REACH Yemen
Background: ESRI

The flood water depth represents water flow extents and static accumulation of water in meters. It was classified into 5 flood hazard categories from very low to extreme according to the Japanese criteria of the Ministry of Land Infrastructure, the where each hazard category is associated with the risk of damage, the threat to human safety, and the possibility of evacuation.

410

Shelters lie within the modelled flood extents in Hayjat Albataryah and Al Maqayet IDP Sites.

Breakdown of shelters within modelled flood hazard extents

Low Flood Hazard	399
Medium Flood Hazard	9
High Flood Hazard	2

Landmark

Roads

IDP Site Boundary

Agricultural land

Shelters Flood Hazard Score

No/Low

Medium/High

Modelled Flood Hazard classification

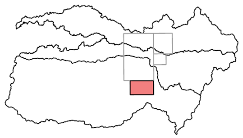
Low (Not Displayed)

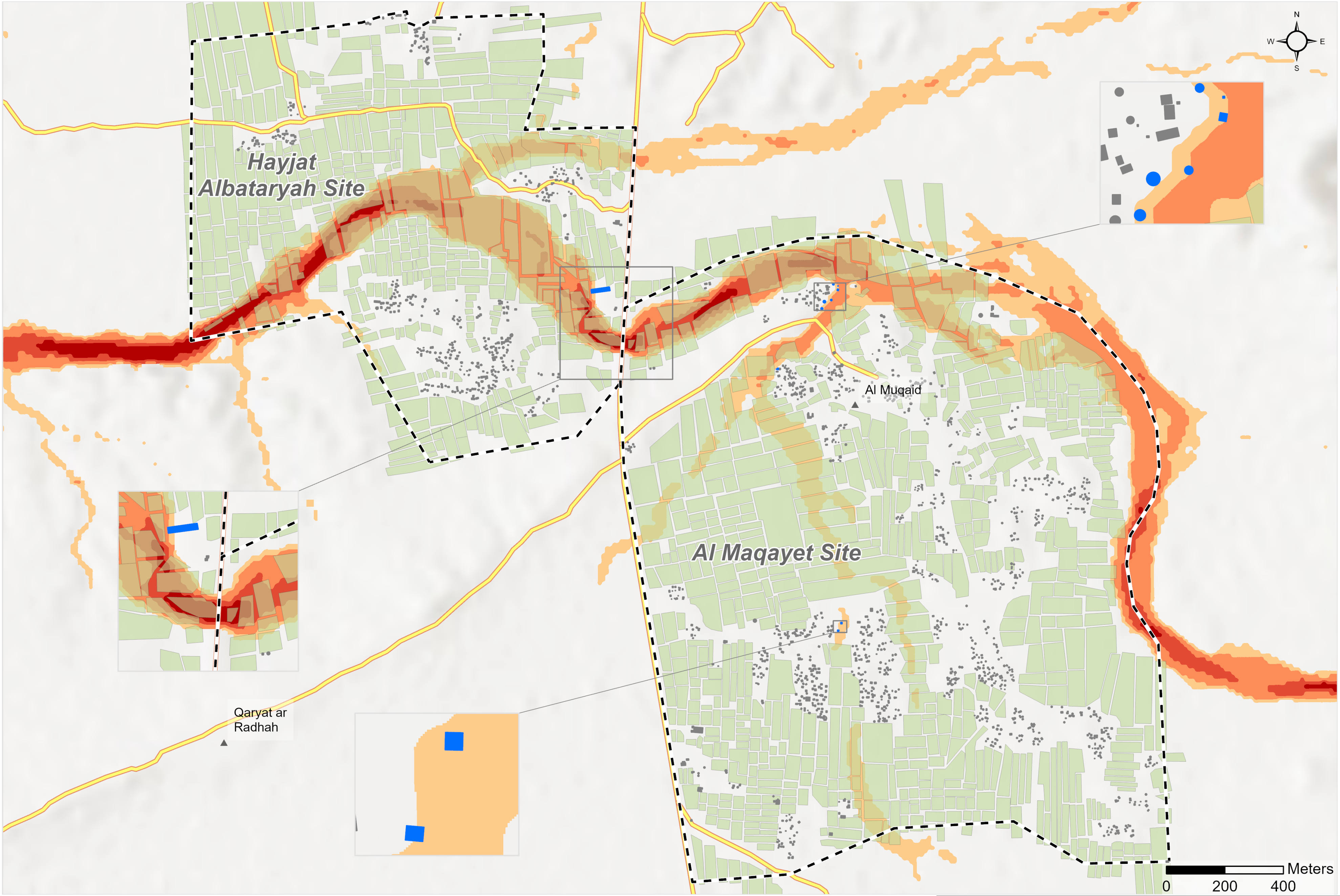
Medium

High

Very High

Extreme





Roads:©OpenStreetMap contributors
Shelters and Agricultural land: Manually digitized by REACH Yemen
Background: ESRI

Flood hazard was obtained by multiplying depth and velocity. The classification of flood hazards in this analysis considers the simplified approach presented in the US Federal Emergency Management Agency guidance on Flood Depth and Analysis Grids, which separates hazard severity into 5 classes from low to extreme.

CONCLUSION

This report aims to inform humanitarian actors about the possible flood-related hazards and exposure at a very localized scale and to understand how flood events can affect IDP hosting sites in Abs district and the infrastructure in Abs city by complementing technical analyses with field observations. A pilot exercise at this resolution is the first of its kind in Yemen and can hopefully emphasize the relevance and potential this type of analysis has in such a data-scarce environment where challenges to access specific areas are widespread.

Analysis findings confirm the existence of several flood hazard zones for each analyzed area, with each hazard zone presenting very nuanced circumstances and different possible impacts on the population. The model outputs and feedback from CCCM partners align on many aspects, including flooding of roads, stagnant water in IDP hosting sites, flooding of agricultural areas, and damage to shelters. The results also help to establish an understanding of how heavy rains and flooding affecting specific roads, infrastructure points, and cropland areas in Abs have been indirectly affecting nearby IDPs and their livelihood activities. Nevertheless, hazard exposure on the ground can be influenced by different factors that are not possible to detect remotely, and hazard severity can have different implications for areas with different vulnerabilities. Areas of higher vulnerability such as make-shift and emergency shelters within IDP hosting sites or vulnerable structures such as exposed WASH infrastructure will presumably be faced with higher risk than the buildings in Abs city.

This pilot analysis is a solid first step toward more comprehensive Disaster Risk Reduction (DRR) activities. The spatially explicit flood maps produced in this report have helped to identify several different flood hazards for the different analysis areas and have given partners a reference to be used in all future flood contingency planning activities. Furthermore, the model outputs of the entire catchment can be used to support partners to understand possible risks to other locations they have access to and can intervene in, and to identify hazards in areas and IDP sites around them. Information gaps in wider communities can also be filled with flood model outputs, allowing different groups to come together and identify common hazards and collaborate to determine long-term solutions and interventions to identified areas of interest. Modelled flood extent can be of further use for organizations within the wider response without a presence in Abs to plan logistic activities, by for example, identifying which areas will not be accessible by which roads during floods and which roads will be compromised in general when planning for assistance activities.

RECOMMENDATIONS

REACH has received confirmation from partners that the hazards identified in the analysis are also observed in the field, that findings accurately represent the reality on the ground, and that there's interest from the partners in implementing DRR activities led by REACH and in collaboration with local authorities, the CCCM Cluster, and other relevant organizations. The next steps will include follow-up discussions with the coordination of each site to understand priorities and challenges at the site level. The extent of the hazard vulnerability should also be made clearer on a site-by-site basis, to clarify the possible risks in areas with limited coping mechanisms and coping strategies already in place. An initial discussion of the findings and next steps with the partners has already revealed several possible challenges in implementing flood mitigation solutions in IDP hosting sites, including restrictions imposed by site landowners, lack of funding for costly infrastructure interventions, pressure from authorities and landowners to restrict the duration of stay of IDPs in sites, access restrictions imposed by the government authorities, lack of available alternative land, and finally, lack of technical expertise in implementing DRR measures.

As the next steps, REACH recommends that the findings of this high-resolution pilot analysis be operationalized by identifying key interventions that can be implemented immediately, while also starting discussions around the creation of detailed contingency plans to serve as a reference for more robust interventions with longer-term impact. Ideally, the relevance, feasibility, and main challenges regarding these flood mitigation interventions would be discussed in a multi-stakeholder exercise involving the CCCM cluster and partners, development actors, local stakeholders, and technical experts. Hosting a publicly announced multi-stakeholder workshop in-country would assist in bringing together relevant groups, such as humanitarian-development actors, civil society groups, governmental organizations, and institutional donors, and would help raise awareness of the critical need for DRR activities in these hazard-prone areas. Bringing decision makers and technical experts together with all relevant stakeholders would facilitate the development of a concrete action plan centered around activities that align with the action agendas and priorities of each of the individual groups. Recommendations and activities defined in the future action plan should also be aligned with higher-level recommendations made by the United Nations Office for Disaster Risk Reduction (UNDRR) [26] and should focus on opportunities to minimize risk and build longer-term resilience while emphasizing that humanitarian and development organizations must work in collaboration with government agencies and civil society groups. Proposed mitigation activities should also consider climate change when incorporating adaptation efforts, as climate-fueled disasters are more frequent, intense, and unpredictable, and have been the main driver of internal displacement over the last decade. [26]

In future contingency plans, proposed activities may include, but are not limited to, relocation of shelters in risk areas, relocation of communal latrines in risk areas to prevent the mixing of sewage and floodwater, ensuring shelters in hazard areas have a raised floor, creating flood retention ponds upstream, and where roads cross the flood water channels, ensuring there are bridges of sufficient height. When accessing the feasibility of large changes to long-term site configuration, it is also relevant to further assess the extent of the hazard vulnerability through field inspections, household level assessments, focus group discussions, and/or collaborative mapping of infrastructure and confirmation of shelter locations. Shelters estimated to be in hazard areas should be inspected to confirm the vulnerability and potentially plan relocation. The severity and extent of hazard exposure displayed in the models can also be further investigated by examining hydraulic structures present on the ground that may alter flows and change model results. Hydraulic structures with the potential to significantly alter flows can include underground canals, drainage systems, and bridges. In a future exercise, any major structures that were unaccounted for in the models should be re-incorporated to produce new results and serve as an improved reference when planning interventions in the IDP hosting sites.

Finally, the analysis presented in this report still had a very limited scope considering the extent of the high-resolution flood models REACH has produced. Areas deemed fit for the exercise were chosen based on partner access and confirmation of observed flood risk on the ground. In Abs, other areas likely suffer similar consequences that should be investigated further. In fact, in Yemen, several other regions where floods are consistently reported would benefit from a detailed remote analysis of flash flood hazards as an initial step towards thorough planning and DRR activities. Regions such as Marib, Lahj, and Sanaa, are confirmed to be at constant flood risk by both news vehicles and humanitarian actors present in the regions. These regions are located within large basins capable of producing vast flows and often present complicated terrain characteristics. Although assessing hazards in these areas would require significant input from partners on the ground and unconventionally complex modeling strategies, the findings will likely be even more substantial.

[26] UNDRR, Scaling up Disaster Risk Reduction in Humanitarian Action 2.0, available here.

ASSESSMENT FUNDED BY:

WITH THE SUPPORT OF:

And the support of the CCCM Cluster in terms of coordination with partners.

About REACH

REACH facilitates the development of information tools and products that enhance the capacity of aid actors to make evidence-based decisions in emergency, recovery and development contexts. The methodologies used by REACH include primary data collection and in-depth analysis, and all activities are conducted through inter-agency aid coordination mechanisms. REACH is a joint initiative of IMPACT Initiatives, ACTED and the United Nations Institute for Training and Research - Operational Satellite Applications Programme (UNITAR-UNOSAT). For more information please visit our website: www.reach-initiative.org. You can contact us directly at: geneva@reach-initiative.org and follow us on Twitter @REACH_info.