METHODOLOGICAL NOTE:

2023 REACH - CCCM NATIONAL FLOOD HAZARD ANALYSIS OF IDP SITES IN YEMEN (FEBRUARY 2023)

Background & Objectives

Next to conflict and eviction, flooding is one of the major threats to Internally Displaced Person (IDP) sites in Yemen. Based on the CCCM Site Report, Key Informants reported flooding as a site threat for 304 (19.9%) out of 1,529 IDP sites in Yemen.[1] Moreover, according to the CCCM Flood Report between June 2021 and January 2023, 521 flood events were reported in 343 sites.[2] Since there currently exists no updated data source that shows the flood hazard of all IDP sites in Yemen, REACH, in collaboration with the Camp Coordination and Camp Management Cluster (CCCM) Cluster, aims to better understand the extent of this issue. Overall, this analysis aims to provide a complementary data source for the 2023 flood contingency planning of the CCCM Cluster and OCHA. This analysis builds on the findings and methodology of the **2022 CCCM National IDP Site Flood Hazard Analysis**.

Scope & Data Sources

This analysis aims to provide Estimated Flood Hazard Scores for all IDP sites in Yemen. The data sources and their coverage include:

- **REACH Regional Flood Hazard mapping (called HEC-RAS modelling[3])**: 17 watershed basins covering 592 IDP sites with about 37% of site population, across 53 districts and partially covering 8 governorates (production date: January 2022 – September 2022)
- **CCCM Flood Report**: Official CCCM Flood Tracking system, established in 2021. 521 number of flood events reported in 343 IDP sites in 82 districts across 18 governorates (status: June 2021 – January 2023)
- **CCCM IDP Hosting Site Master List**: Official CCCM Master List presenting the total number of IDPs in IDP hosting sites per district (n = 2,302 sites), covering 220 districts across 22 governorates (status: December 2022)
- **CCCM Site Report:** Site information reporting whether flooding is considered a site threat based on Key Informant interview. 1,529 IDP Site reports available, covering 159 districts across 21 governorates (status: April 2021 – November 2022)
- **2022 CCCM National IDP Site Flood Hazard Analysis**: Covering 2,422 IDP sites and including estimated flood hazard scores of Sub-National Cluster Coordinators for 899 IDP sites (status: March 2022)

[1] REACH Yemen & Yemen CCCM Cluster. Site Report. April 2021 – November 2022.
[2] Yemen CCCM Cluster. Flood Report. April 2021 – January 2023.
[3] HEC-RAS stands for Hydrologic Engineering Center's - River Analysis System.

Below **Table 1** shows clearly that the most extensive data source is the CCCM Site Report.

Table 1. Coverage of Flood data sources 2021-2022

Data source	Number of IDP sites reported on
2022 National IDP Site Flood Hazard Analysis	Total scores for **2,422 IDP sites** Estimated flood hazard scores of SNCCs: **899 sites**
CCCM Site Report (April 2021-October 2022)	**1,529 sites**
REACH HEC-RAS modelling (January-September 2022)	30 M: 475 sites 12 M: 42 sites 2.5 M: 75 sites **Total: 592 sites**
CCCM Flood Report (June 2021-January 2023)	**343 sites**

Interpretation of Flood Hazard Scores

Flood Hazard Scores per IDP site mostly refer to the likelihood of flooding in a site based on at least one reported historical flood event or perception of interviewed Key Informants. In general, this does not include a specific analysis of value of assets or vulnerability criteria of IDP site residents. However, REACH's HEC-RAS Flood Hazard derived scores also refer to the *potential extent* of a flood event. In addition, SNCC derived Estimated Flood Hazard Scores might also refer to the number of people/assets affected, number of flood events happening or whether any flood prevention activities have been implemented in the site (and thereby reducing the flood hazard). In general, the developed estimated Flood Hazard Scores may be used to **support prioritization of flood prevention activities for specific IDP sites at national level**. Nevertheless, further detailed site flood hazard assessments with field partners are necessary to understand the exact potential extent and impact of a flooding event as well as appropriate flood response plans per site.

NOTE: When interpreting the Flood Hazard Scores, it is important to keep in mind that their development was challenging, due to the various methodologies of the triangulated data sources. **Thus, Flood Hazard Scores should be interpreted as indicative estimates**. Please see **Table 2** for an overview of each data source and its limitations and **Table 3** for a clear overview of how Flood Hazard Scores were determined, and to ensure the appropriate interpretation of flood hazard scores.

Analysis Framework

Overall, this analysis followed the **2022 Analysis Framework** including below steps:

1. **REACH regional flood hazard mapping (HEC-RAS analysis):** In 2022, REACH mapped a total of 17 watersheds, partially covering 8 governorates. Based on this flood hazard mapping, REACH will develop flood hazard (HEC-RAS) scores for all sites that overlap with REACH's Flood Hazard Mapping.
2. **Determination of Estimated Flood Hazard Scores for all IDP sites**: REACH will triangulate all available data sources (i.e. CCCM Flood Report, CCCM Site Report, REACH HEC-RAS Flood Hazard Mapping, 2022 SNCC Flood estimates from National Flood Hazard Analysis) with each other to devise a 2023 Draft Flood Hazard Score per site.
3. **Review by CCCM National Cluster team & Sub-National Cluster Coordinators**: The CCCM Cluster and Sub-National Cluster Coordinators (SNCC) (potentially in collaboration with Area-Based Coordinators and CCCM partners) will review the Draft 2023 Flood Hazard Scores developed by REACH. Following, the CCCM Cluster will integrate the SNCC feedback to determine the Final Flood Hazard Scores per site.

1. Determination of HEC-RAS Flood Hazard scores

REACH will determine specific Flood Hazard (HEC-RAS) scores per IDP site, which are based on flood hazard models developed by REACH in 2022. Based on this analysis, flood hazard and depth models should be available for a total of 592 sites. In general, REACH will overlay the exact location of IDP sites with the available flood hazard models, and based on an estimated buffer zone around the IDP site determine the HEC-RAS Flood Hazard scores.[4] See **Annex 1** for detailed technical methodology on REACH's flood hazard mapping.

2. Data Triangulation: Determination of Flood Hazard Scores per site

Following the Flood Hazard (HEC-RAS) modelling and scoring, REACH will determine the Draft 2023 National Flood Hazard Scores for all IDP sites by triangulating the HEC-RAS Flood Hazard Severity Scores with the CCCM Site Report, CCCM Flood Report and 2022 SNCC Flood Estimates to **estimate the flood hazard of IDP hosting sites**.

[4] A total of 4 IDP sites were excluded that bordered REACH's Flood hazard models and no clear flood score could be determined.

To properly interpret the Flood Hazard Scores, it is important to note that each data source has a different methodology and limitations, as described in **Table 2**.

Table 2. Overview of methods and limitations of data sources

Data source	Method	Limitations
CCCM Site Report (April 2021-October 2022)	**CCCM Site Report** reports whether a site is at threat of flooding, based on Key Informants perception.	Only provides subjective reports from Key Informants on whether flooding may be a threat to the site based on their perception. No official flood hazard assessment.
CCCM Flood Report (June 2021-January 2023)	**CCCM Flood Report** highlights sites where flooding occurred in 2021/2022. **Overall, the CCCM Flood Report is considered the most authoritative dataset in this analysis, since it reports actual events.** The CCCM Flood Report also allows REACH to validate its HEC-RAS model findings over time.	Only reports sites where flooding has happened in 2021-2022. Flood events might not have been accurately reported, so total number of flooding might be higher.
REACH HEC-RAS modelling (January-September 2022)	**Flood Hazard (HEC-RAS) models** can provide flood hazard and flood depth products based on a *designed* storm. These products are overlaid with IDP site location and an estimated buffer / boundary to derive estimated flood hazard scores.	Based on modelling a designed storm and not an actual flooding event. Also, exact IDP site extents/boundaries are not available, and coordinates might be inaccurate. Thus, the models may overestimate or underestimate Flood Hazard.
SNCC Flood Estimates (March 2022)	In 2022, SNCCs provided feedback on the 2022 Draft IDP Site Flood Hazard scores. Their feedback was based on their and partner's field knowledge, including historical flooding events. **SNCC feedback can provide a new Flood Hazard score, if a clear justification is given.**	SNCC feedback is not available for all sites and subjective interpretation of flood hazard. No official flood hazard assessment.

Overall, the 2023 Flood Hazard Scores for each IDP site were developed based on the below scenarios (see **Table 3**). First, REACH developed a 2023 Draft Flood Hazard Scores based on three data sources (i.e., CCCM Flood Report, CCCM Site Report, REACH HEC-RAS Modelling). Following, REACH compared the Draft scores to the 2022 Flood Hazard Scores, including 2022 Sub-National Cluster Flood Estimates, and made manual adjustments, where necessary. Lastly, SNCCs reviewed the Draft scores and the CCCM Cluster integrated their feedback to determine the Final 2023 Flood Hazard Scores.

Table 3. Determination of Flood Hazard of IDP sites

Scenarios	IF	THEN, ESTIMATED Flood Hazard of IDP site			
		High hazard	Medium hazard	No/low hazard	Unknown
Scenario A	Flood report recorded for IDP site	x			
Scenario B	Flood Report recorded for IDP site BUT CCCM Site Report does not report flood as site threat	x			
Scenario C	Flood Report recorded for IDP site BUT REACH HEC-RAS model does not suggest site at hazard of flooding	x			
Scenario D	Sub-National Cluster Coordinator puts site at high hazard of flooding	x			
Scenario E	Site Report and/or HEC-RAS records High hazard for sites	x			
Scenario F	HEC-RAS records Medium hazard for sites		x		
Scenario G	Sub-National Cluster Coordinator puts site at medium hazard of flooding		x		
Scenario H	Available data source suggests IDP site is at no/low hazard of flooding (Flood Report, Site Report, HEC-RAS model)			x	
Scenario I	Sub-National Cluster Coordinator puts site at low hazard of flooding			x	
Scenario J	CCCM Site Report AND REACH HEC-RAS model at conflict				x
Scenario K	No HEC-RAS modelling, CCCM Site Report OR Flood Report available				x

3. Field validation by CCCM Cluster & Sub-National Cluster Coordinators

Following the Data Triangulation and REACH's estimate on which IDP sites are at hazard of flooding, the CCCM National Cluster Coordination team, with support from the CCCM Sub-National Cluster Coordinators (SNCCs), will review the findings. This is especially relevant for sites for which the various data sources provide different results or no data source is available. SNCCs may reach out to CCCM Area Coordinators or CCCM partners in the field to verify the results.

Ultimately, the CCCM Cluster will integrate the SNCC feedback to derive the Final 2023 Flood Hazard Scores per IDP site. In addition, with support from CCCM partners the CCCM Cluster will identify the total number of IDP sites that will be targeted for flood prevention and response activities based on REACH's analysis.

Outputs

Outputs can be found via **REACH's Resource Centre** on the dedicated REACH Yemen page:

- **Dataset** containing suggested 2023 Flood Hazard Scores per IDP sites
- **National map** highlighting Final 2023 Flood Hazard Scores per IDP sites
- **National map** illustrating historical flood events in affected IDP sites from 2021-2022
- **Regional HEC-RAS maps** highlighting total 2023 Flood Hazard Scores per IDP sites (Hajjah, Al Hodeidah, Taiz, Marib)
- **Presentations** of findings to CCCM Cluster and partners

Limitations

As part of this analysis, REACH identified the below limitations both for the analysis in general, and the HEC-RAS flood hazard modelling specifically:

- **General limitations**
  - **Information gaps:** All data sources from which flood hazard scores can be derived have diverging data gaps (i.e., HEC-RAS modelling, CCCM Site Report and Flood Report). Based on these datasets, Estimated Flood Hazard Scores could be derived for 2,016 sites out of 2,302 sites (88%).
  - **Contradictory information:** All data sources have contradictory information over time and between each other. This could stem from reporting errors, actual changes over time or the fact that each dataset has a different methodology and limitations.
  - **Different methodologies of data sources:** All data sources have a very different methodologies and results in terms of deriving the potential flood hazard per site, with each of them having unique limitations. Thus, overall triangulating the results was challenging.
  - **Interpretation of results:** Based on the limitations noted in this section, Flood Hazard scores should be considered as indicative estimates.
- **REACH Flood Hazard Mapping (HEC-RAS) limitations**
  - **Site boundaries**: The exact site extent/site boundaries of IDP sites in Yemen are not available to this date. Thus, REACH/CCCM had to develop an estimate of the extent of each IDP site used in the HEC-RAS analysis. This was done by establishing estimated buffer radiuses based on population size, which may not be perfectly accurate since IDP population density per site is also not known (see section: Phase 1. HEC-RAS Analysis – Buffer radius).
  - **Site location:** Exact site location is only available for 1,153 out of 2,302 sites. In addition, not all site locations have been verified, so they might contain errors.
  - **HEC-RAS score**: HEC-RAS modelling might slightly overestimate or underestimate flood hazard, due to above mentioned limitations and the fact that REACH's developed scoring system is not an officially hydrologically tested system.

Annex 1. REACH Flood Hazard Mapping (HEC-RAS modelling) – Technical Note

Background & Objectives

To map flood hazard across Yemen, REACH modelled 17 separate watershed basins through Hydrologic Engineering Center's - River Analysis System (HEC-RAS). A two-dimensional (2D) unsteady flow hydraulic model was built using HEC-RAS to enable deriving flood hazard and depth products. The results from these types of modeling outputs can provide a high-level understanding of flood hazards on a catchment-wide scale and help to identify flood susceptible areas, especially areas at hazard of flash flooding.[5] These products can be overlaid with any relevant spatial information (i.e., IDP sites, cities, critical infrastructure) to understand its hazard of flooding. For this specific national assessment, REACH overlaid the HEC-RAS models with IDP site locations to derive estimated flood hazard scores.

Coverage

REACH conducted flood hazard (HEC-RAS) models covering **17 basins** that partially cover 8 governorates, as described below.

- **30 M DEM:** 13 basins across Hajjah, Al Hodeida, Taiz, Al Mahwit, Raymah, Dhamar, Sana'a, and Marib
- **12 M DEM:** 1 basin in Abs, Hajjah
- **2.5 M DEM:** 3 basins in Abs, Hajjah

Catchment areas with a higher overall number of IDP population and IDP population density were prioritized for this initial phase of the exercise, which included primarily basins from the Hajjah, Al Hodeida, Taiz and Marib governorates. HEC-RAS 2D modeling is a detailed and computationally intensive process, which makes it a time-consuming task. Due to its complexity and the amount of data required, it is not possible to model the country at once. It would require large computational power, a vast amount of data and a lot of time. Instead, the model is typically applied to specific areas and watersheds.

Input data

Precipitation data

The model output products inform the extent, depth, and hazard of areas where flooding may occur based on extreme precipitation events of a 25-year return period. The model applies a direct precipitation method, where precipitation is applied to all cells generated in a computational mesh.

[5] Flooding that begins within 6 hours, and often within 3 hours, of the heavy rainfall (or other cause). Flash Floods can be caused by a number of things, but is most often due to extremely heavy rainfall from thunderstorms. Flash Floods can occur due to Dam or Levee Breaks, and/or Mudslides.

Due to the lack of trustworthy precipitation data from weather stations in Yemen, data from Saudi Arabia was used in basins in the Hajjah governorate, near the northern border, and for all other basins modeled in this analysis, precipitation data derived from satellite imagery was used.

The precipitation data from Saudi Arabia is from the Abha city region, which is a coastal wadi area with similar characteristics as the catchments found in Hajjah, located approximately 100 km north of the Yemeni border in Hajjah.[6] The Saudi precipitation time-series data was processed into intensity-duration-frequencies (IDF) to generate rainfall temporal distribution data. The IDF data was then used to design a 12-hour storm with 10-minute steps for the 25-year return period using the alternating block method.[7] The storm data was validated using Google Earth Engine (GEE) by analyzing a real-life storms that occurred in the same coastal region in Yemen, bordering Saudi Arabia. The storms displayed very similar durations and total depths as the designed storm.

The satellite precipitation data used in the modeling is from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) dataset, which builds on 'smart' interpolation techniques and record precipitation estimates based on infrared Cold Cloud Duration (CCD) observations, incorporating station data and the spatial correlation structure of CCD-estimates in interpolation methods.[8] The CHIRPS data is processed through a series of statistical techniques to estimate extreme precipitation based on the Generalized Extreme Value (GEV), a commonly used statistical distribution in precipitation analysis. The 25-year return precipitation values were disaggregated into 12-hour storm events based on sub-daily ratios of precipitation, also taken from the Jeddah region in Saudi Arabia, with similar characteristics as the Yemeni Coastal area.[9] Ratios for mountainous and transitional areas will also be used in future modelling analyses.

Terrain and infiltration data

The terrain data used to generate the computational mesh of the 2D flow areas for this analysis was as following:

1. **High-resolution 2.5 and 12** meters digital elevation models (DEMs) were used in 4 basins in Abs, Hajjah.
2. **A 30-meter** resolution digital elevation model (DEM) product called AW3D30.[10] This product is available freely online thanks to an open license conceded by the Japan Aerospace Exploration Agency (JAXA), and it was used to model the other basins across Hajjah, Al Hodeida, Taiz, Al Mahwit, Raymah, Dhamar, Sana'a and Marib.

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[6] Al-anazi, K. and El-sebaie, I. (2013) Development of Intensity-Duration-Frequency Relationships for Abha City in Saudi Arabia. International Journal of Computational Engineering Research, 3, 58-65.
[7] A designed storm is an artificial hyetograph that takes the precipitation depths for time intervals over a specified total storm duration.
[8] Funk, Chris, Pete Peterson, Martin Landsfeld, Diego Pedreros, James Verdin, Shraddhanand Shukla, Gregory Husak, James Rowland, Laura Harrison, Andrew Hoell & Joel Michaelsen. "The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes". Scientific Data 2, 150066. doi:10.1038/sdata.2015.66 2015.
[9] Awadallah, A. (2015), Regional I-D-F for Jeddah, Saudi Arabia. J. Flood Hazard Manage, 8: 195-207. https://doi.org/10.1111/jfr3.12085
[10] Japan Aerospace Exploration Agency (2021). ALOS World 3D 30 meter DEM. V3.2, Jan 2021. Distributed by OpenTopography. https://doi.org/10.5069/G94M92HB. Accessed: 2022-03-03.

The 2D flow area extents were defined for each basin in the HEC-RAS processing environment, and computation points were generated. The datasets used to complement the analysis include landcover data[11] from the European Space Agency (ESA) and hydrological soil group (HSG) data.[12] An infiltration layer is created based on these two products, to account for the precipitation losses by infiltration and help determine the excess or net rainfall. For this purpose, the Soil Conservation Service (SCS) Curve Number (CN) approach is adopted, where estimates of the CN are a function of the different combinations of hydrologic soil groups and land cover types present in the terrain.[13] The CNs are derived from reference tables suggested in the HEC-RAS documentation. The landcover product has 11 different categories which are all assigned a roughness coefficient (Manning's value), also based on HEC-RAS documentation.

Development of Estimated HEC-RAS Flood Hazard Scores

To develop HEC-RAs flood hazard scores per IDP site, REACH had to follow the below steps:

1) Design buffer radius per IDP site, since exact IDP site extents are not available
2) Overlay IDP site location with REACH 2.5M, 12M and 30M Flood Hazard & Depth products
3) Develop estimated HEC-RAS Flood Coverage Severity Scoring

Buffer radius

Information on the extent or boundaries of IDP hosting sites is not available in Yemen. Accordingly, REACH had to establish estimated buffer radiuses for each IDP hosting site. Based on the below two example CCCM Site Plans, REACH created **different estimated buffer radiuses based on IDP population size**. See Table 1 below for more details.

Table 1. Buffer radius of IDP hosting sites

	Very small sites	Small sites	Medium sites	Large sites	Very large sites
Population size	1-200	201-500	501-1,000	1,001-5,000	>5,000
Buffer radius	100m	200 m	300 m	500m	1km

[11] Zanaga, D., Van De Kerchove, R., De Keersmaecker, W., Souverijns, N., Brockmann, C., Quast, R., Wevers, J., Grosu, A., Paccini, A., Vergnaud, S., Cartus, O., Santoro, M., Fritz, S., Georgieva, I., Lesiv, M., Carter, S., Herold, M., Li, Linlin, Tsendbazar, N.E., Ramoino, F., Arino, O., 2021. ESA WorldCover 10 m 2020 v100. https://doi.org/10.5281/zenodo.5571936.
[12] 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. https://doi.org/10.3334/ORNLDAAC/1566.
[13] SCS. 1956. Hydrology. National Engineering Handbook, Supplement A, Section 4. Soil Conservation Service, US Department of Agriculture: Washington, DC; Chapter 10.

The below two example CCCM Site Plans were used to estimate the site boundaries in Table 1.

- Site A: 80 families (around 480 people): 47 M radius
- Site B: 512 families (around 3,072 people): 303 M radius

HEC-RAS Flood Coverage Severity Scoring

For the **HEC-RAS model Flood Hazard Severity Scoring**, REACH will use two main indicators, which are based on flo**od hazard and flood depth** (see Table 2 below). Based on these two indicators, REACH will implement the below **steps** to draw up a HEC-RAS Flood Hazard Severity Score per IDP site:

- **Step 1: Classify** the flood hazard percentage coverage (%) and flood depth coverage (%) per **severity class** (No hazard – Extreme hazard, see Table 2) through ArcGIS.
- **Step 2**: **Aggregate** the flood hazard coverage (%) and flood depth (%) per buffered IDP site to derive the **severity class** per indicator (see Table 3).
- **Step 3:** Determine the **final severity scores per IDP** sites based on the **highest value** of the two indicators.

Table 2. HEC-RAS Flood Hazard Severity Classes per Indicator

The below table shows the severity classes for flood hazard and flood depth.

Nr	Indicator	0 – No value (no hazard)	1 – Low hazard	2 – Medium hazard	3 – High hazard	4 – Very High hazard	5 – Extreme hazard
1	flood hazard[14] (m^2/s)	No value	≤ 0.2	>0.2 – 0.5	>0.5 – 1.5	>1.5 – 2.5	>2.5
2	flood depth (m)	No value	≤ 0.5	>0.5 – 1	>1.0 – 2.0	>2.0 – 5.0	>5.0

[14] Flood Hazard is defined as = flood velocity x flood depth

Table 3. Determination of HEC-RAS Flood Hazard Score per IDP site

The below table will be applied to both flood hazard and flood depth indicators.

No hazard	Low hazard	Medium Hazard	High Hazard		
0 – No value	**1 – Low**	**2 – Medium**	**3 – High**	**4 – Very High**	**5 – Extreme**
No hazard/no value (for 2.5 and 12 M resolution)	All remaining categories **OR** No hazard/no value (for 30 M resolution)[15]	If Severity classes 2, 3, 4 and 5 are >=10% of total buffer site area. **OR** If Severity classes 2, 3, 4 are >=20% of total buffer site area. **OR** If Severity classes 2 and 3 are >=30% of total buffer site area. **OR** If Severity class 2 is >=40% of total buffer site area.	If Severity classes 3, 4 and 5 are >=15% of total buffered site area. **OR** If Severity classes 3 and 4 are >=20% of total buffered site area. **OR** If Severity class 3 is >=30% of total buffered site area.	If Severity classes 4 and 5 are >=15% of total buffered site area. **OR** If Severity class 4 is >=20% of total buffered site area.	If Severity class 5 is >=20% of total buffered site area.

[15] Since the HEC-RAS model with 30M resolution is less reliable, IDP sites with no hazard scores are still placed under severity class “No Hazard”. Contrary, for IDP sites with 2.5 and 12M resolution a “No Hazard” score is assigned, since results are considered more reliable.

Example: HEC-RAS Flood Severity Score Calculation per IDP site

Step 1: Classification of flood hazard (%) and flood depth (%) indicator per severity class

REACH will classify the flood hazard percentage coverage (%) and flood depth coverage (%) per **severity class** (No hazard – Extreme hazard, see Table 2) through ArcGIS. *This classification is done automatically in ArcGIS.*

Nr	Indicator	0 – No value (no hazard)	1 – Low	2 – Medium	3 – High	4 – Very High	5 – Extreme
1	% of covered IDP site area by flood hazard	35%	0%	0%	10%	50%	5%
2	% of covered IDP site area by flood depth	35%	45%	15%	5%	0%	0%

Step 2: Aggregation of flood hazard (%) and flood depth (%) per severity class

REACH will aggregate the flood hazard coverage (%) and flood depth (%) per buffered IDP site to derive the **severity class** per indicator. *This aggregation is calculated in Excel, based on the ArcGIS values.*

Indicator	0 – No value (no hazard)	1 – Low	2 – Medium	3 – High	4 – Very High	5 – Extreme	Aggregation
% of covered IDP site area by flood hazard	35%	0%	0%	10%	50%	5%	**55%**

Step 3. Calculate Total Severity Score per IDP site

REACH will determine the **final severity scores per IDP** sites based on the **highest value** of the two indicators. *This is calculated in Excel.*

Example

Indicator 1: Severity Classes 4 and 5 = 55% = **Severity Score 4**
Indicator 2: Severity Classes 2, 3, 4 and 5 = 20% = **Severity Score 2**

Total severity Score = MAX of Indicator 1 and Indicator 2 = 4

Limitations

REACH identified the below technical limitations on the flood hazard (HEC-RAS) models.

- **Technical limitations**
  - **30 M terrain data:** A 30-meter DEM resolution was used for 13 basin out of 17 basins in the modelling, which likely underestimates the depth of smaller water flows and overestimates the extent.
  - **Hydraulic structures**: Bridges and culverts, piped drainage networks, irrigation canals and open channels have not been included in the hydraulic model.
  - **Precipitation**: The precipitation data used in different governorates are from different sources, and although they have been processed using scientifically established methods, they may differ significantly and there is currently no way to validate the data.
  - **Storm-events**: The storm events designed to be used as inputs for the models varied in duration (and intensity) due to the different methods used to disaggregate the data. Storms of 6 to 12-hour durations were used in our analysis, however flooding events can sometimes be caused by several consecutive storm events that can last for several days. This phenomenon was not modelled in this analysis.
- **Analytical limitations**
  - **Site boundaries**: The exact site extent/site boundaries of IDP sites in Yemen are not available to this date. Thus, REACH/CCCM had to develop an estimate of the extent of each IDP site used in the HEC-RAS analysis. This was done by establishing estimated buffer radiuses based on population size, which may not be perfectly accurate since IDP population density per site is also not known (see section: Phase 1. HEC-RAS Analysis – Buffer radius).
  - **Site location:** Exact site location is only available for 1,153 out of 2,302 sites. In addition, not all site locations have been verified, so they might contain errors.
  - **HEC-RAS score**: HEC-RAS modelling might slightly overestimate or underestimate flood hazard, due to above mentioned limitations and the fact that REACH's developed scoring system is not an officially hydrologically tested system.