Jordanian Experience Regards Flash Flood Risk Reduction

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Aqaba city is of great strategic importance in Jordan, since it is the Kingdom's only seaport on the Red Sea. In February 2001 and upon the direction of His Majesty King Abdullah II, the Aqaba Special Zone Authority (ASEZA) was established after passage of the Aqaba Special Economic Zone Law, No. 32 of the year 2000. The purpose of ASEZA is to transfer Aqaba into a Red Sea business hub and tourist destination.

Many of ASEZA developments are taking place on alluvial fans of Wadis, which will inescapably be under disastrous conditions when flood happen. Taking into consideration the increased occurrence of high intensity storms in the area of Aqaba, development of flood risk management strategy is inevitable. The most recent flash flood incident occurred in October 2012, affecting Aqaba and the South Aqaba Region. The magnitude of the damage indicates a storm intensity that exceeds the 100-Year storm extracted Ministry of Water and Irrigation Intensity, Duration and Frequency Curves.

Other documented events occurred in February 2006 and March 1966 and many others.
In recent years, development of the Wadi Yutum fan, the largest of the alluvial fans has considerably accelerated. Several industrial parks or estates have been constructed and more are planned. Accordingly and as a part of the task force mobilized to study and recommend flood mitigation measures that could be implemented at the regional level to protect Aqaba from the hazards of possible future storms, a flash flood hazard and risk map for Wadi Yutum has been developed.

Based on detailed and intensive hydrological analysis and by means of hydraulic modeling, hazard map for 25, 50 and 100 year return period was generated with peak flow of 1522.7 m3/s, 1812.7 m3/s and 2111.0 m3/s, respectively, to identify hazard locations within the stream of Wadi Yutum. Together with identified socio-economic map a risk map was generated with recognition of three risk classes; high, medium and low.

Zones of high and medium risk incorporate jeopardy to the current facilities and road and trail users. The most affected element is the Desert Highway, which is the main entrance of Aqaba city. As 2009 data indicates that, the weekday daily traffic flow on the Desert Highway is 14,650 vehicles. Models predicted the 2016 traffic flow to be 20,615 vehicles as actual measurements do not exists. Giving that the vehicle occupancy rate in Jordan is 1.6 person per vehicle a total amount of 33,000 person could be affected on a given day depending on the time and the severity of the storm. No major development exists within the risk zone. Low and no risk zone are safe for any future development. However, the land topography could be the obstacle for such developments.

The railway and other electrical and microwave facilities will be affected and could be in danger. Accordingly, several remedial measures are suggested to assist in adopting the best **mitigation measures**; namely:

I. Improving hydraulic discharge capacity by modifying the natural channel to be lined with concrete or reinforced concrete at certain locations, where flood is expected to reach the main road or railway.

II. Relocate electrical communication utilities outside of the flood area. If not possible, then they need to be well protected by reinforced concrete structure or buried under ground below scour level.

III. Placing rock riprap around bridges' piers and abutment.

IV. Constructing a set of regulatory dams in the upstream.

V. Establishment of flood protection center that will operate a flood early warning system for Aqaba region and will be responsible for managing and operating the flood pathway.

Further recommendations that include the following were put forward:

- No construction should be permitted in the flood way can be permitted in flood fringes after ensuring adequate storm water drainage facilities.
- An outlet drain should be connected to the major drain to drain out excess water.
- A well-planned layout and an organized development should be provided without blocking the natural drainage. Individual development should not be allowed. It should be accompanied with the layout of the surface drainage system having sufficient capacity covering the entire area.
- Roads and service lines should be laid before starting the construction

The Regional Bureau for Science in the Arab States

The Hashemite Kingdom of Jordan
Ministry of Water and Irrigation

Flash Flood Hazard and Risk Maps for Wadi Yutum

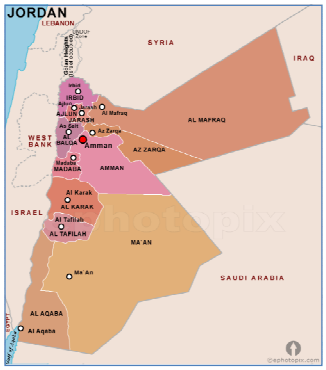
The Second International Symposium on Flash Floods in Wadi Systems

Mohammed Bany-Mustafa

October 25th -27th, 2016
El Gouna-Hurghada, Egypt.

Introduction

- Jordan is mostly covered desert (**90% of its area**)
- Rainfall averages vary **from 35 mm annually** in the desert to as much **as 800 mm in the** northern hills.
- Aqaba city is located in the south of Jordan



Introduction

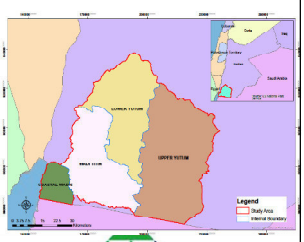
- Aqaba is **located 330** km south of Amman on the gulf of Aqaba
- **Only access for Jordan to open sea**
- Very important **economical city**
- Aqaba is **subject to frequent flash flood**.

Introduction

- Aqaba city is **of great strategic importance in Jordan**
- ASEZA was established **to transfer Aqaba into a Red Sea business hub and tourist destination**
- The climate is **extremely arid consisting of two distinct seasons**

Introduction

- ASEZA developments are taking place on **alluvial fans of wadis**
- Increased occurrence of **high intensity storms in the area of Aqaba**
- The most recent flash flood **incident occurred in October 2012, before that 2006 and others**
- Development of **flood risk management strategy is important**



AQABA
SPECIAL ECONOMIC ZONE AUTHORITY

The Problem

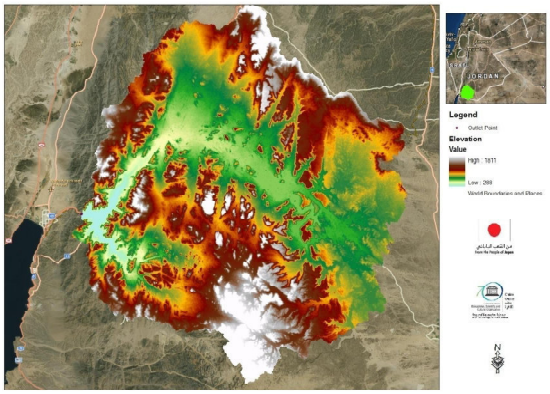
- **Flash Floods, pose risk to human life and infrastructure in Aqaba**
  - **Life losses**
  - **Destroy properties and infrastructures**
  - **Disturb the daily life**

Characteristics of flash flood

- Short duration
- High rainfall intensity
- High peak flow
- Short time to peak
- Randomness of areal distribution
- Sharp and unexpected

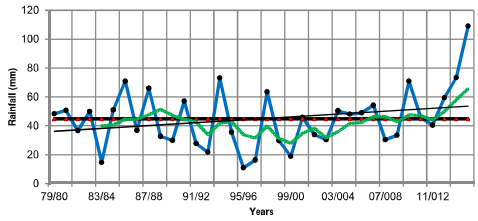
Area description

- Wadi Yutum area =4269 km^2

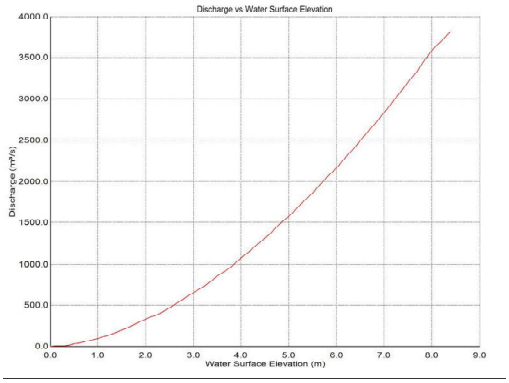


Rainfall Trend Analysis

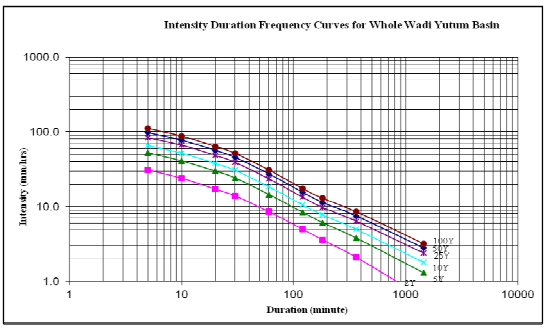
- Average precipitation = 35 mm/yr
- Five Years Moving Average
- Prediction of the coming water years



Rating Curve

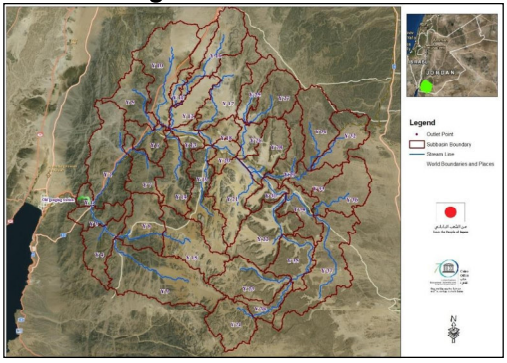


Developed IDF Curve



Development of Flash Flood Hazard and Risk Maps

- The basin was divided into sub-basins in order to get more accurate results



Wadi Yutum sub-basins Characteristics

- Manning's n- values used for the channel flow was 0.05 (as typically used for natural mountain stream with no vegetation)
- The runoff was calculated using the SCS Unit Hydrograph transform method

Sub-basin Name	Area (km^2)	Stream Length (m)	Elevation (m – MSL)		Slope (m/m)
			High	Low	
Y 1	19.6	8,306.3	1132	289	0.1015
Y 2	229.7	38,037.1	1331	445	0.0233
Y 3	63.5	16,029.4	1376	444	0.0581
Y 4	111.5	20,936.0	1333	605	0.0348
Y 5	114.6	29,341.3	1335	744	0.0201
Y 6	73.1	17,745.9	1069	77	0.0570
Y 7	87.3	23,554.5	1325	706	0.0263
Y 8	130.6	22,452.2	1386	663	0.0322
Y 9	305.6	44,286.9	1701	667	0.0233
Y 10	230.1	38,274.9	1128	752	0.0098
Y 11	63.5	34,356.5	1302	777	0.0152
Y 12	74.3	26,432.3	1178	754	0.0160
Y 13	48.1	15,372.7	1087	734	0.0217
Y 14	128.7	32,135.8	1220	750	0.0146
Y 15	163.7	27,097.5	1523	855	0.0247
Y 16	133.2	39,785.4	1624	777	0.0213
Y 17	173.0	39,093.6	1586	765	0.0211
Y 18	47.6	15,681.7	981	763	0.0139
Y 19	154.9	40,819.8	1508	771	0.0180
Y 20	41.1	11,021.3	995	772	0.0202
Y 21	156.6	31,849.8	1510	785	0.0228
Y 22	185.6	38,941.1	1369	798	0.0170
Y 23	143.7	28,112.4	1623	989	0.0226
Y 24	115.4	21,004.5	1732	1214	0.0247
Y 25	73.7	23,910.0	1433	828	0.0253
Y 26	52.2	20,422.5	12120	785	0.5555
Y 27	113.4	23,311.2	1445	828	0.0265
Y 28	109.7	28,288.0	1142	785	0.0126
Y 29	86.0	30,768.0	1137	789	0.0120
Y 30	47.6	13,537.0	1316	787	0.0382

Wadi Yutum Curve Numbers

Sub-basin Name	Area(km^2)	% Alluvium	% Rock	% Impervious	Initial abstraction	CN (Normal)	CN (Dry)	CN (Wet)
Y1	19.6	30	70	69	7.3	87.5	74.6	94.2
Y2	229.7	44	56	55	10.7	82.6	66.6	91.6
Y3	63.5	26	75	73	6.1	89.3	77.7	95.0
Y4	111.5	42	58	57	10.2	83.3	67.7	92.0
Y5	114.6	49	51	51	12.0	80.9	63.9	90.7
Y6	73.1	50	50	50	12.3	80.5	63.4	90.5
Y7	87.3	9	91	87	2.8	94.9	88.6	97.7
Y8	130.6	35	65	64	8.4	85.8	71.7	93.5
Y9	305.6	35	65	64	8.4	85.8	71.7	93.5
Y 10	230.1	67	33	33	17.3	74.6	56.2	87.1
Y 11	63.5	65	35	37	16.7	75.3	56.1	87.5
Y 12	74.3	83	17	20	22.9	68.8	48.3	83.6
Y 13	48.1	61	39	40	15.5	76.7	58.0	88.5
Y 14	128.7	54	46	46	13.4	79.1	61.4	89.7
Y 15	163.7	35	65	64	8.4	85.8	71.7	93.5
Y 16	133.2	65	35	37	16.7	75.3	56.1	87.5
Y 17	173.0	55	45	45	13.7	78.6	60.9	89.5
Y 18	47.6	73	27	30	19.3	72.5	52.5	85.8
Y 19	154.9	54	46	46	13.4	79.1	61.4	89.7
Y 20	41.1	54	46	46	13.4	79.1	61.4	89.7
Y 21	156.6	63	37	38	16.1	76.0	57.0	87.9
Y 22	185.6	15	85	81	4.0	92.8	84.3	96.7
Y 23	143.7	36	64	63	8.7	85.4	71.1	93.1
Y 24	115.4	67	33	34	17.3	74.6	56.2	87.1
Y 25	73.7	25	75	73	6.1	89.3	77.7	95.0
Y 26	52.2	39	61	60	9.4	84.4	69.4	92.5
Y 27	113.4	25	75	73	6.1	89.3	77.7	95.0
Y 28	109.7	15	85	81	4.0	92.8	84.3	96.7
Y 29	86.0	15	85	81	4.0	92.8	84.3	96.7
Y 30	47.6	22	78	76	5.3	90.3	79.6	95.5
Y 31	143.1	15	85	81	4.0	92.8	84.3	96.7
Y 32	109.7	37	63	62	8.9	85.1	70.5	92.9
Y 33	61.3	15	85	81	4.0	92.8	84.3	96.7
Y 34	88.6	36	64	63	8.7	85.4	71.1	93.1
Y 35	106.9	35	65	64	8.4	85.8	71.7	93.5
Y 36	149.5	24	76	75	5.9	89.6	78.3	95.2
Y 37	242.7	36	64	63	8.7	85.4	71.1	93.1
Y 38	55.2	44	56	56	10.7	82.6	66.6	91.6

Wadi Yutum Time of Concentration

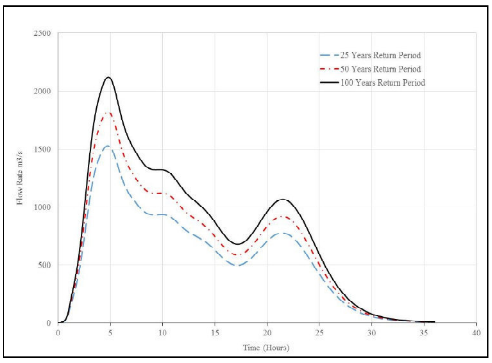
Sub-watershed Name	Time of Concentration (tc)						Lag time	
	Clack Empirical		Kirpich Method		Average			
	min	hr	min	Hr	min	hr	min	hr
Y 1	55.1	0.9	48.4	0.8	51.7	0.9	31.0	0.5
Y 2	313.1	5.2	273.3	4.6	293.2	4.9	175.9	2.9
Y 3	113.2	1.9	99.2	1.7	106.2	1.8	63.7	1.1
Y 4	169.5	2.8	148.2	2.5	158.8	2.6	95.3	1.6
Y 5	271.2	4.5	236.5	3.9	253.8	4.2	152.3	2.5
Y 6	123.3	2.1	108.1	1.8	115.7	1.9	69.4	1.2
Y 7	206.7	3.4	180.5	3.0	193.6	3.2	116.1	1.9
Y 8	184.2	3.1	161.0	2.7	172.6	2.9	103.6	1.7
Y 9	351.7	5.9	306.9	5.1	329.3	5.5	197.6	3.3
Y 10	438.7	7.3	381.2	6.4	410.0	6.8	246.0	4.1
Y 11	342.9	5.7	298.5	5.0	320.7	5.3	192.4	3.2
Y 12	273.1	4.6	237.9	4.0	255.5	4.3	153.3	2.6
Y 13	160.3	2.7	139.8	2.3	150.1	2.5	90.0	1.5
Y 14	329.0	5.5	286.4	4.8	307.7	5.1	184.6	3.1
Y 15	236.0	3.9	206.0	3.4	221.0	3.7	132.6	2.2
Y 16	335.6	5.6	292.7	4.9	314.2	5.2	188.5	3.1
Y 17	332.5	5.5	290.0	4.8	311.3	5.2	186.8	3.1
Y 18	193.1	3.2	168.1	2.8	180.6	3.0	108.3	1.8
Y 19	365.1	6.1	318.2	5.3	341.6	5.7	205.0	3.4
Y 20	127.4	2.1	111.1	1.9	119.2	2.0	71.5	1.2
Y 21	275.6	4.6	240.4	4.0	258.0	4.3	154.8	2.6
Y 22	324.0	5.4	282.3	4.7	303.2	5.1	181.9	3.0
Y 23	251.2	4.2	219.2	3.7	235.2	3.9	141.1	2.4
Y 24	193.9	3.2	169.3	2.8	181.6	3.0	109.0	1.8
Y 25	212.2	3.5	185.2	3.1	198.7	3.3	119.2	2.0
Y 26	57.2	1.0	50.7	0.8	54.0	0.9	32.4	0.5
Y 27	204.5	3.4	178.5	3.0	191.5	3.2	114.9	1.9

Hydrological model

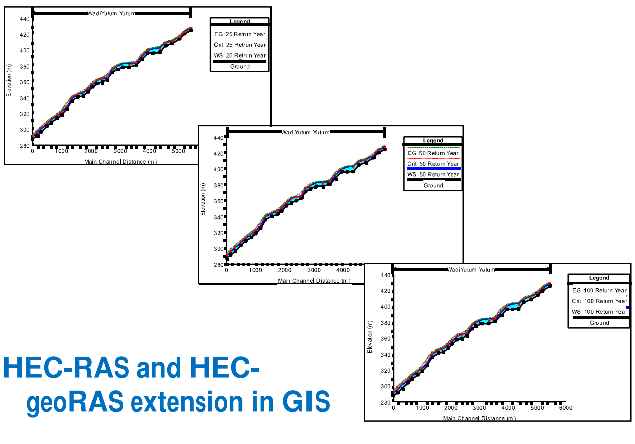
- Hydrological analysis using HEC-HMS
- Flood for the 25, 50, and 100 years return periods using the IDF curves
  - The NRCS Method was chosen as Loss Method, SCS Unit Hydrograph as Transform Method and Muskingum as routing method

Return Period (Years)	Peak discharge (m3/s)	Volume (1000 m3)	Time to peak (hr:min)
25	1522.7	73,820	4:45
50	1812.7	87,973	4:50
100	2111.0	102,588	4:50

Hydrograph at gauging station

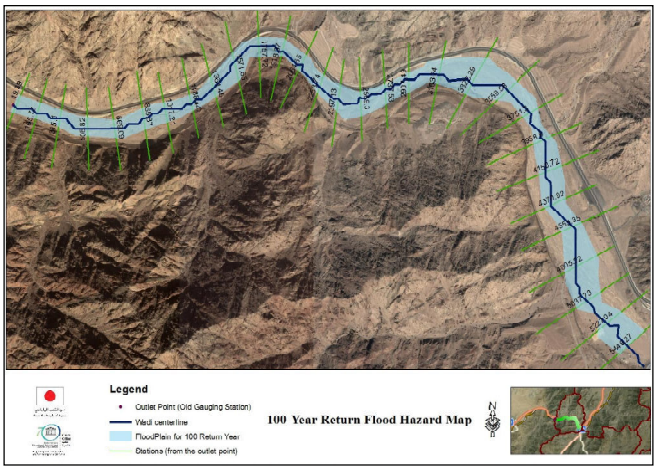


Hydraulic Model



HEC-RAS and HEC-geoRAS extension in GIS

Hazard Maps – 100 Year Flood



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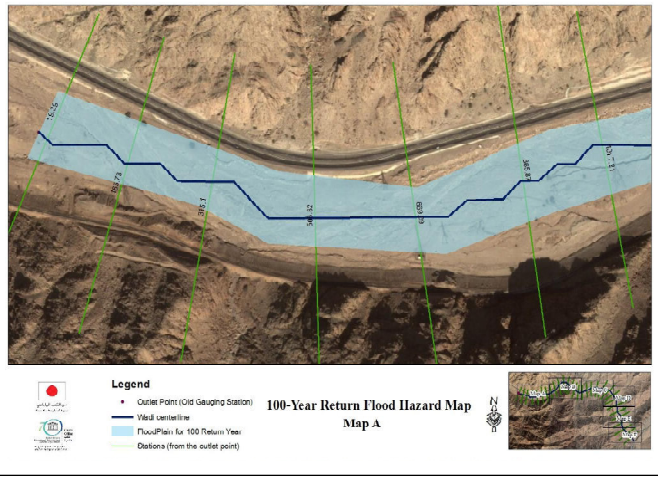

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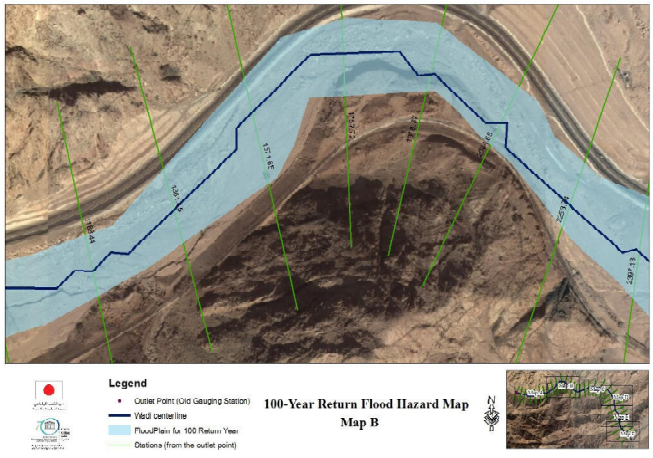

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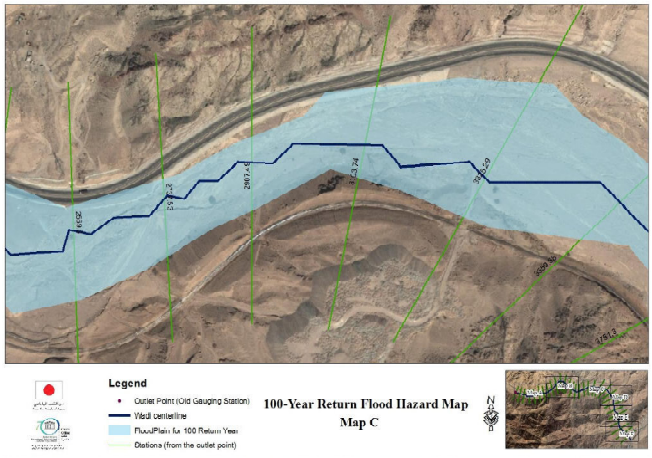

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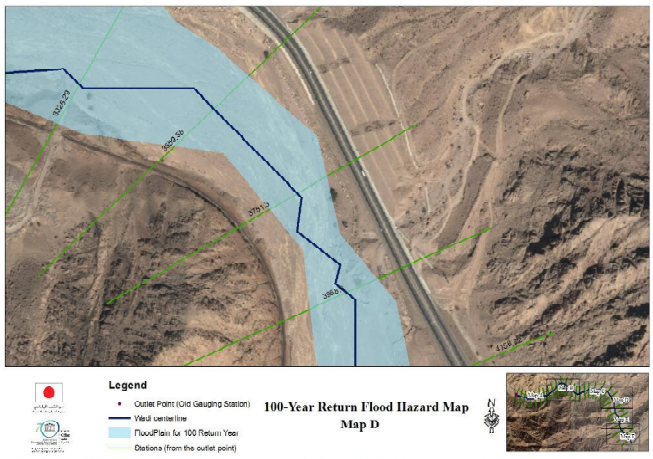

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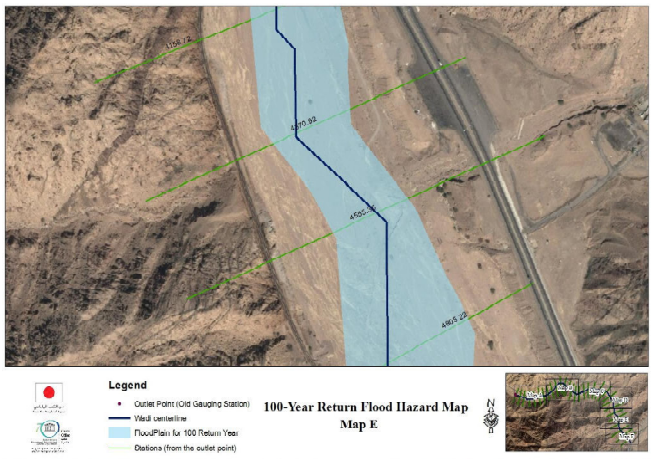
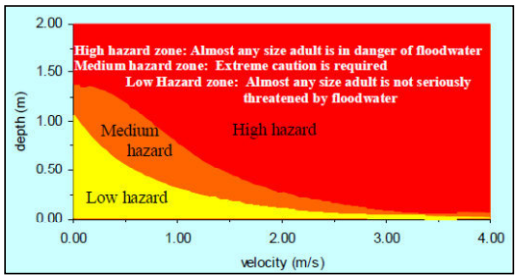
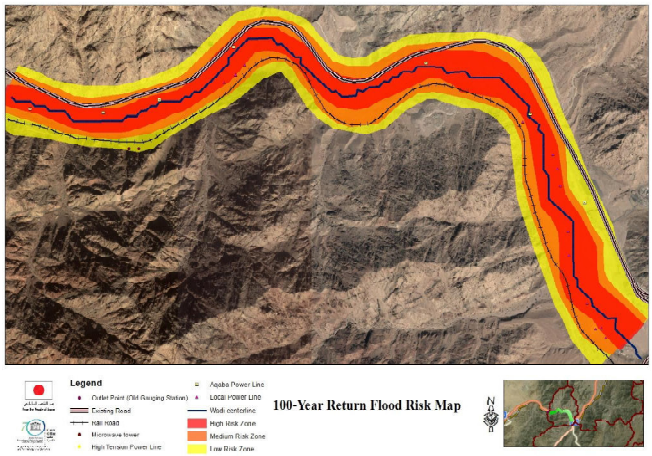


Risk Maps

- Using the results of the hazard map and by identifying the socio-economic map a risk map was generated based on:
- Classification criteria as a function of water depth and velocity



Risk Maps – 100 Year Flood



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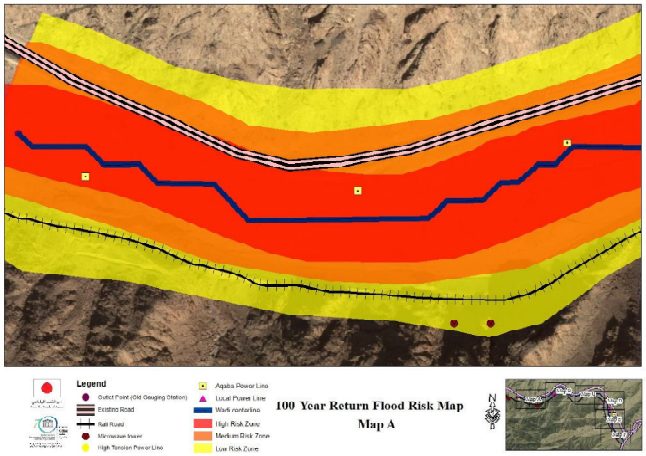

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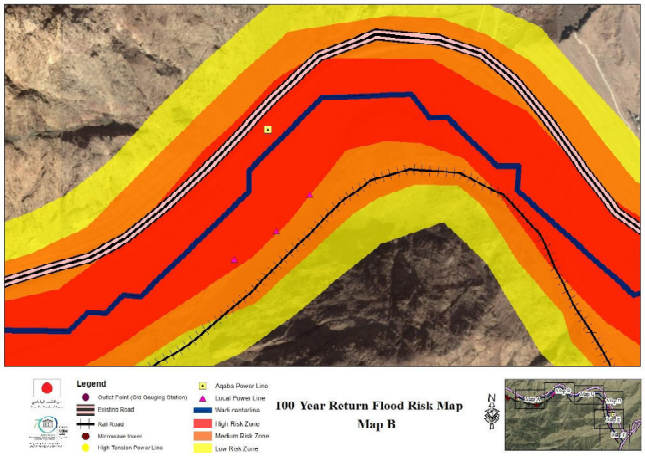

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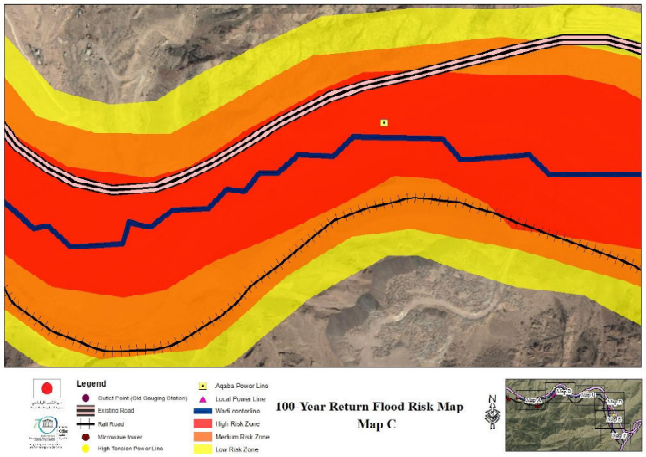

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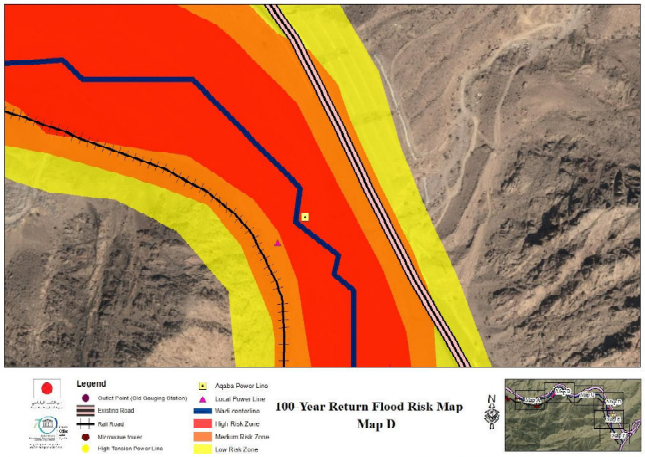

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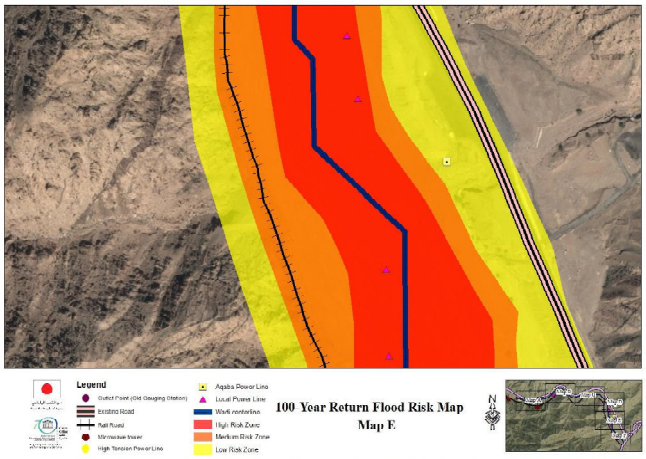

Affected Population

- The most affected element is the Desert Highway
- Traffic flow = 20,615 vehicles
- 33,000 person could be affected on a given day
- The railway and other electrical and microwave facilities will be affected and could be in danger

Remedial Measures for Flash Flood Mitigation

- **Channel Flow Capacity and road crossing structures**

The mainstream discharge capacity can be **improved hydraulically** by modifying the natural channel. This could be done by **lining the channel** with concrete for example in which will improve the channel discharge capacity. At certain locations, where flood is expected to reach the main road or railway, reinforced concrete protection can be used. **Additionally, all road-crossing structures should be redesigned to withstand the 100 year flood**.

- **Highway and Railway**

Based on onsite investigation, protection measures and **improvement should be implemented at the highway and railway embankments where scour damage and erosion is expected.** The main road (Desert Road) going into Aqaba is adjacent to Wadi Yutum mainstream, so is the Railway. Therefore; they **are susceptible to erosion and scour**. The **best protection measure** is **the use of reinforced concrete.** Other options could work after further investigating the velocity of flow and embankment material at the vulnerable locations

Remedial Measures for Flash Flood Mitigation

- **Electrical, Communication and Subsurface Utilities**

It is clear that **electrical transmission**, **communication towers**, and **pipelines** are located in **Wadi Yutum mainstream**. Keeping those utilities in their current location could result in getting them **damaged by future floods**. It is recommended **to relocate the utilities outside of the flood area. If not possible**, then they need to be **well protected by reinforced concrete structure or buried under ground below scour level.**

- **Bridge Pier and Abutment Scour**

The bridge pier and abutment **should be protected against scour**. This can be done by **placing rock riprap around the piers and abutment.** Size and layers of the protection needs detailed investigation.

Remedial Measures for Flash Flood Mitigation

- **Flood Protection Center**

Such a center will operate a **flood early warning system** for region of Aqaba. It will be responsible for **managing and operating the flood pathway.** It will **set the regulations for the protection of the people and utilities in the danger area.** It will be responsible for the **maintenance and cleaning of the flood pathway and the hydraulic structures that could be a danger during a flood event**. **Cleaning the stream from debris and preventing dumping of any construction materials on the floor of the channel.** Because the **dumped material will increase the roughness of the channels and thus increasing the depth of the flow.**

- **Regulatory Dams – Check dam**

A set of regulatory dams could be constructed at the **upstream.** The purpose of these dams will be **to regulate the flood by lowering the peak flood and increasing the flood base time.** These dams act as retention and depression storage to **delay the time of concentration**.

Recommendations

- **No construction** should be permitted in **the flood way** and **can be permitted in flood fringes after ensuring adequate storm water drainage facilities.**
- **An outlet drain should be connected to the major drain to drain out excess water.**
- **A well-planned layout and an organized development should be provided without blocking the natural drainage. Individual development should not be allowed. It should be accompanied with the layout of the surface drainage system having sufficient capacity covering the entire area.**
- **Roads and service lines** should be **laid before starting the construction of buildings.**


THANK YOU