Distributed Hydrological Modeling at Wadi Samail, Oman

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Recently, flash floods are frequently occurring in the arid region as Oman, which counter with various challenges to the management of wadi flash floods. In the past, Oman hit by cyclone Gonu in June 2007 causing torrential flooding and severe damages where the economic loss was about 4 billion USD, as well as nearly 50 deaths. Mitigation measures and warning system have become more critical given the expected increased extreme events due to climate changes. Oman is an arid country, where the average annual rainfall, in its capital Muscat, is only 100 mm, while the average of the whole country is only 51 mm/yr varying from less than 20 mm/yr in the internal desert regions to over 350 mm/yr in the mountain areas. Wadi Samail at the coastal area of Oman is selected as case study for flash flood hydrological modelling. Rainfall–runoff responses predictions in arid climate as wadi system always presents unique challenges. One of the main challenges beside data limitation is the hydrological models themselves, where the majority of models developed for catchments that have different characteristics than other wadi systems. Hence, the need to evaluate the suitability of alternative modelling approaches for wadi system and its scarce dataset arises. In that regard, two distributed hydrological models are selected in this study. The first one is the Hydrological River Basin Environmental Assessment Model (Hydro-BEAM) and the other is the Rainfall-Runoff-Inundation (RRI) Model. Another aspect of this contribution is to focus on both structural measures for flash flood retention as dry dams, and water harvesting. The location of such mitigation structures must be carefully designed to avoid transferring the problems to the developed downstream area of the wadi. Moreover, mitigation structures should be designed in a coordinated manner, to assess their overall effect. This study analyzes the wadi flash flood mitigation for three cases: 1) no dams, 2) distributed small dams all over the catchment in the upstream, and 3) proposed large dam in the middle or downstream area of the wadi. The effect must be quantified through a comparison of the consequences with and without mitigation structures over the whole wadi. Various factors are considered to study and improve the assessment methodologies. The simulated scenarios highlighted significant differences in calculated hydrographs when using either distributed or concentrated dams scenarios for wadi Samail. This study is expected to conclude recommendations for hydrological modelling and management at wadi system in arid environments. The next questions address how to define dam height and reservoir volume. For better assessment of several dams options, clear quantification of evaluation factors and cost-benefit approaches should be included in future. Small dry dams are effective structures. Both, Hydro-BEAM and RRI models are efficient, and emphasizes the importance of taking into account the variability and spatial properties of rainfall patterns.

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Wadi System& Flash Floods

- Wadi: Arabic term referring to valley.
- Wadi channel is usually dry except during heavy rain events.
- Flash flood: caused by heavy rainfall in short duration< 6 hrs.

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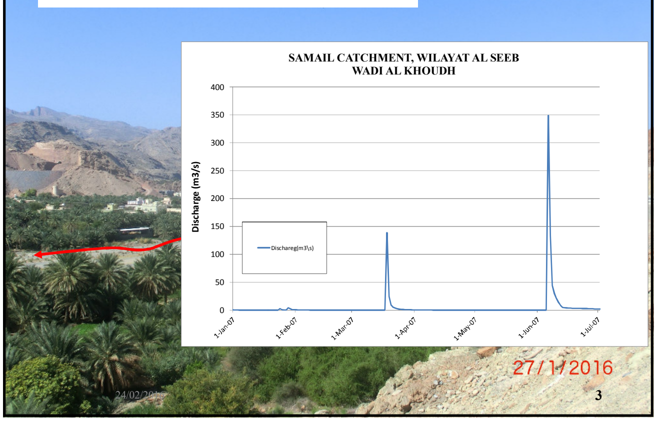
Characteristics of Wadi



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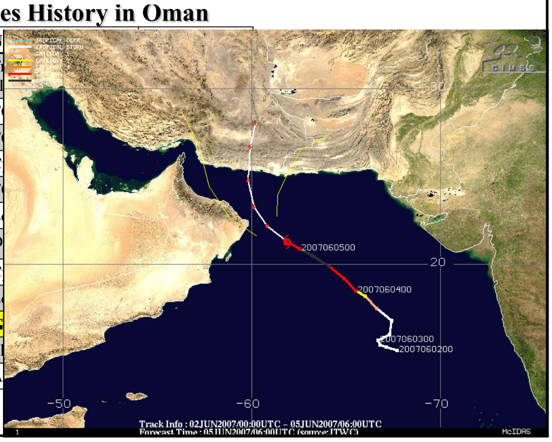
Damages of Flash Floods Disasters

Source: A. Al Barw... Floods, 2015, Kyot...

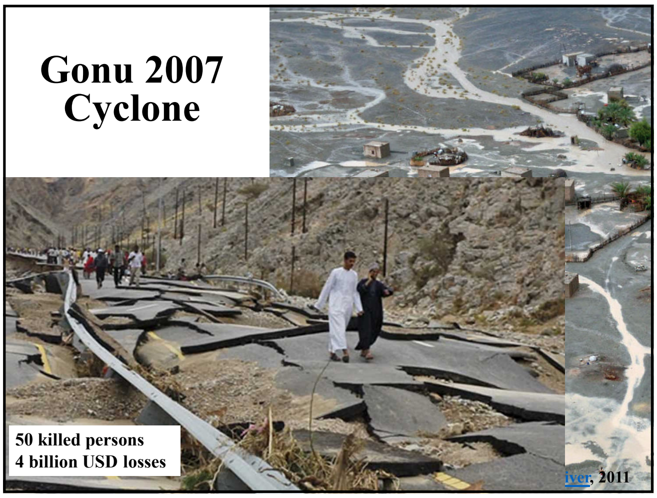
Flash Floods Caused By Cyclones

Cyclones History in Oman

Date	N...
June 1890	T... (T...
May 1963	T...
Nov 1966	T...
Dec 1971	C...
Jun 1977	T...
Mar 1999	L...
Oct 1999	D...
May 2002	C...
Sep 2004	L...
Jun, 2007	**G...**
June, 2010	P...
June, 2015	A...

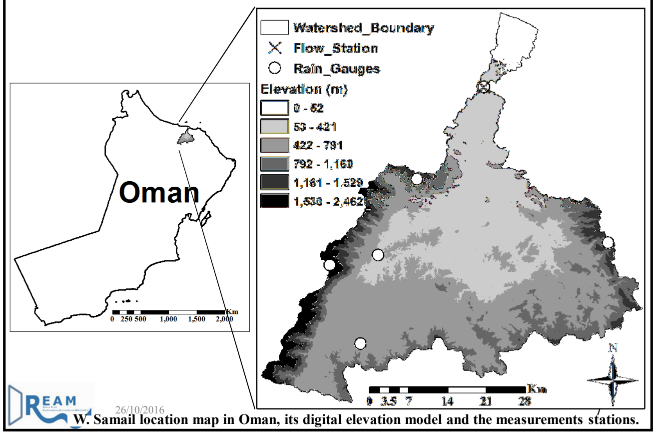


Gonu 2007 Cyclone



Iyer, 2011

Target Research Area of W. Samail



W. Samail location map in Oman, its digital elevation model and the measurements stations.

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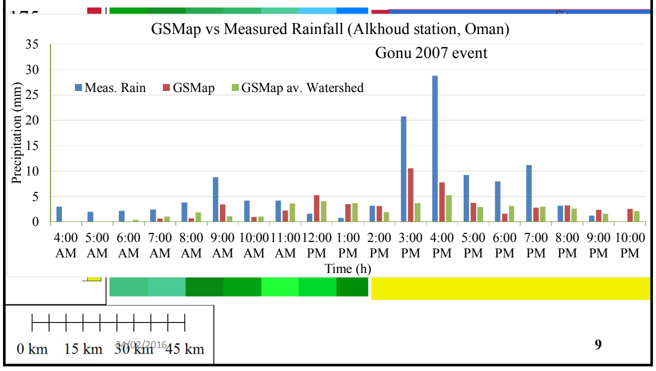
Satellite and Measured Rainfall

GSMAP Gauges



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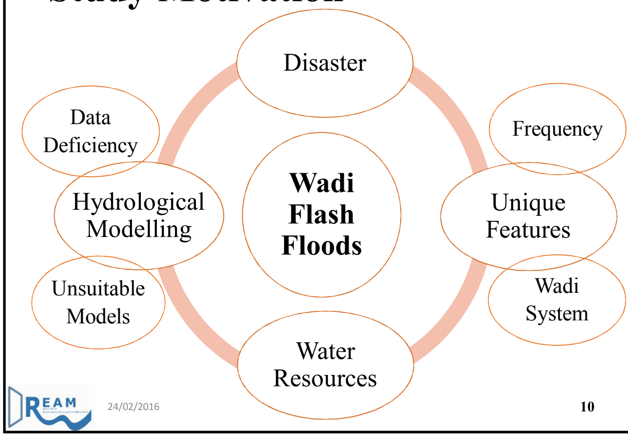
Study Motivation



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Objectives

- Proposing innovative methodology for management of flash floods disaster in ungauged wadis.
- Check the applicability of Hydro-BEAM and RRI models using available data in W. Samail.
- Comparative study by 2 models Hydro-BEAM&RRI
- To find best scenario of DDR (distributed or concentrated dams)

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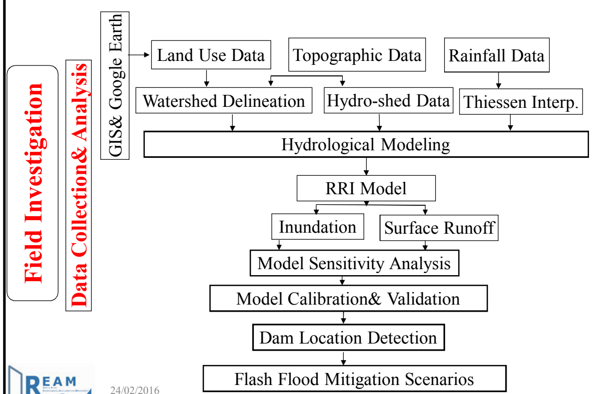
Methodology



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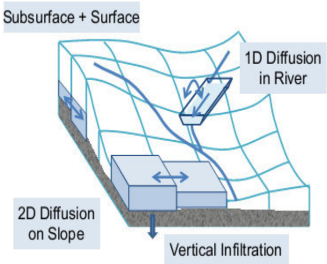
RRI Model

- Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012)



RRI model scheme overview (Sayama, T., 2013)

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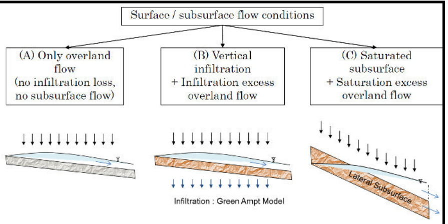
RRI Model



Mass Balance eq. $$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=r$$

Momentum eq. $$\frac{\partial q_x}{\partial t}+\frac{\partial u q_x}{\partial x}-\frac{\partial v q_x}{\partial y}\quad -gh\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_w}$$
$$\frac{\partial q_y}{\partial t}+\frac{\partial u q_y}{\partial x}+\frac{\partial v q_y}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_w}$$

Diffusion Wave approximation

$$q_x=\begin{cases}-kh\frac{\partial H}{\partial x} & (h\le d)\\ -\frac{1}{n}(h-d)^{5/3}\sqrt{\left|\frac{\partial H}{\partial x}\right|}\mathrm{sgn}\left(\frac{\partial H}{\partial x}\right)-k(h-d)\frac{\partial H}{\partial x} & (d<h)\end{cases}$$

$$q_y=\begin{cases}-kh\frac{\partial H}{\partial y} & (h\le d)\\ -\frac{1}{n}(h-d)^{5/3}\sqrt{\left|\frac{\partial H}{\partial y}\right|}\mathrm{sgn}\left(\frac{\partial H}{\partial y}\right)-k(h-d)\frac{\partial H}{\partial y} & (d<h)\end{cases}$$

h water height from local surface, $Q_{x,y}$ unit width discharges, u & v flow velocities, r rainfall intensity, H water height from the datum, ρ_w water density, g gravitational acceleration, τ_x and τ_y shear stresses and n Manning's roughness k lateral saturated hydraulic conductivity d soil depth times effective porosity

(Sayama et al., 2012)

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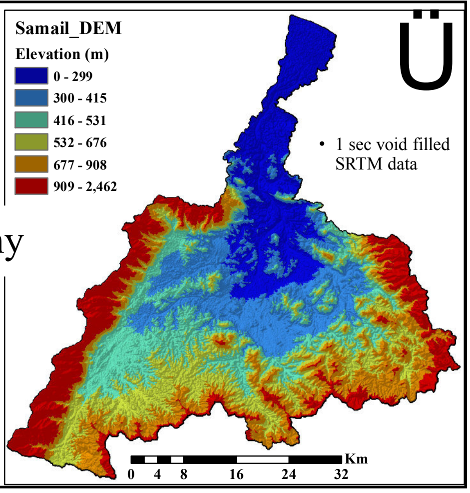
Input Data

Topography



- 1 sec void filled SRTM data

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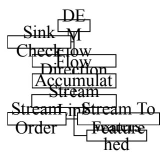
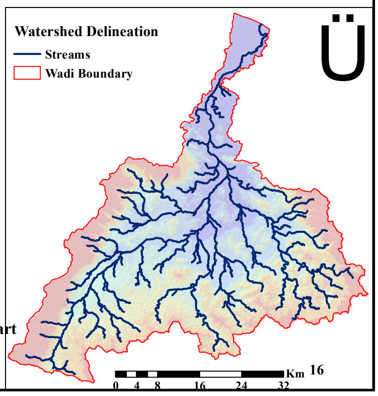
Watershed Delineation



Watershed modelling using GIS flowchart



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RRI Parameter Setting

RRI model major parameter setting for the different land uses showing its default values and ranges.

Parameter (default)	Range	Alluvium	Igneous	Sedimentary
n_{river} (0.03m$^{-1/3}$s)	0.015~0.04	0.022	0.022	0.022
n_{slope} (0.3 m$^{-1/3}$s)	0.15 ~ 1.0	0.3	0.35	0.3
d (0.471 m)	0.15 ~ 1.0	-	0.14	0.3
k (0.1ms^{-1})	0.01-0.3	-	0.05	0.05
k_v(5.56*10^{-7} ms^{-1})	6.54*10^{-5} ~ 1.6710^{-7}	4*10^{-6}	-	-
φ	0.3 ~ 0.5	0.475	-	-
S_f(0.3163 m)	0.0495~0.3163	0.15	-	-

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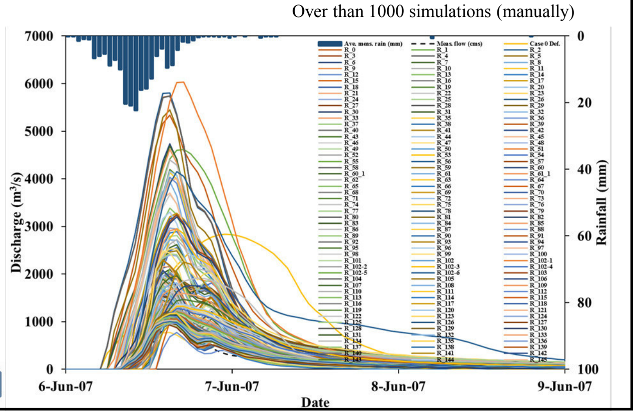
RRI Model Sensitivity Analysis

Over than 1000 simulations (manually)



RRI Model Calibration (Gonu-2007)

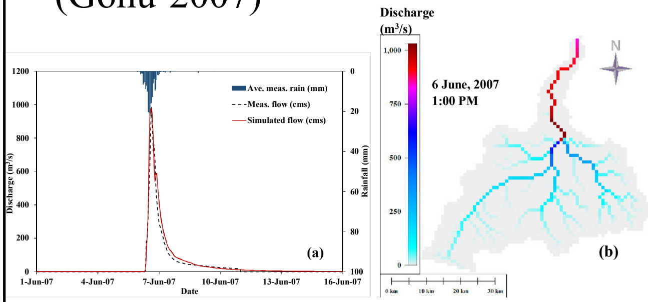


Fig. a) RRI model calibration results (Gonu-2007); b) peak flow spatial distribution.

RRI Model Validation (Phet-2010)

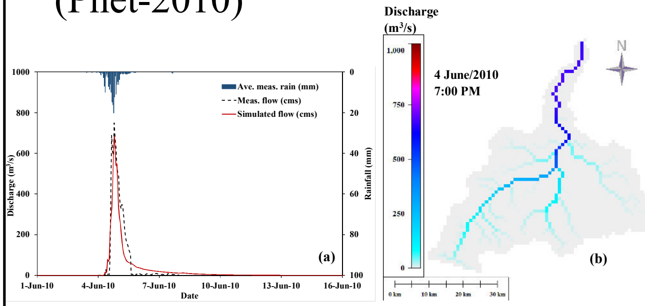


Fig. RRI model validation results (Phet-2007); b) peak flow spatial distribution.

Model Performance Evaluation

$(Y^{obs} - Y^{sim})*100$ … $\sum^{n}\left(\left(Y_i^{sim} - Y_{mean}^{sim}\right)\left(Y_i^{obs} - Y_{mean}^{obs}\right)\right)^2$ … $Y_{mean}^{sim})^2 \sum_{i=1}^{n}\left(Y_i^{obs} - Y_{mean}^{obs}\right)^2$ … $\left(Y_i^{obs} - Y_i^{sim}\right)^2$ / $\left(Y_i^{obs} - Y_{mean}^{obs}\right)^2$ … $-1)^2$

RRI model performance evaluation for Gonu-2007 and Phet-2010 extreme flash floods.

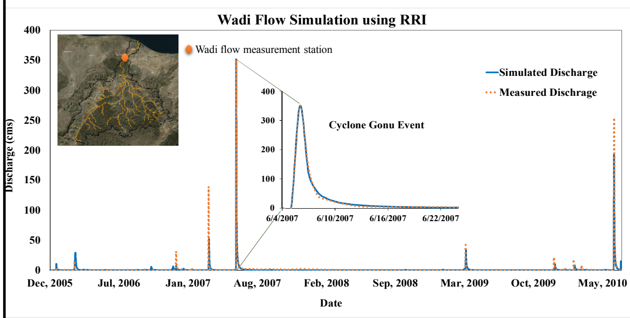
Index (Ideal value)	Gonu 2007	Phet 2010
PE (0 %)	-1.18	-9.05
r^2 (1)	0.96	0.89
PBIAS (0%)	-14.3	-12.04
NSE (1)	0.93	0.86
KGE (1)	0.81	0.74

Relative hydrograph peak (PE), Coefficient of determination (squared correlation coefficient) (r^2), Percent bias (PBIAS), Nash-Sutcliffe efficiency (NSE)[1), Gupta efficiency (KGE)[2)]

where r is the linear correlation, Y_i^{obs} and Y_i^{obs} are observed and simulated discharge at time step i, Y_i^{obs}, Y_i^{obs} are the mean observed and simulate discharge, α is a measure of relative variability and equal to the ratio of standard deviation of the simulated and observed discharge and β represents the bias and equal to the ratio of the mean simulated and observed discharge.

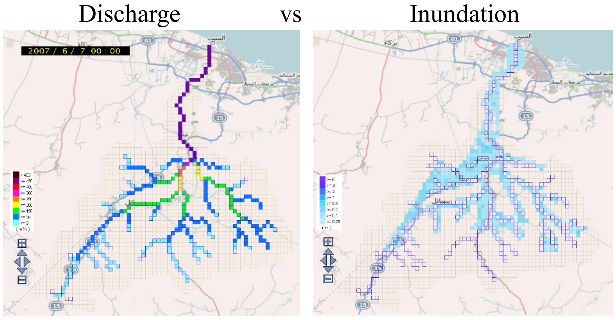
1) Nash, J. E. and Jonh, V. S. : River flow forecasting through conceptual models part I—A discussion of principles, *Journal of hydrology*, Vol. 10, No. 3, pp. 282-290, 1970.
2) Gupta, H. V., Kling, H., Yilmaz, K. K. and Martinez, G. F. : Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling, *Journal of Hydrology*, Vol. 377, No. 1, pp. 80-91, 2009.

Long Term Flash Flood Simulation at W. Samail

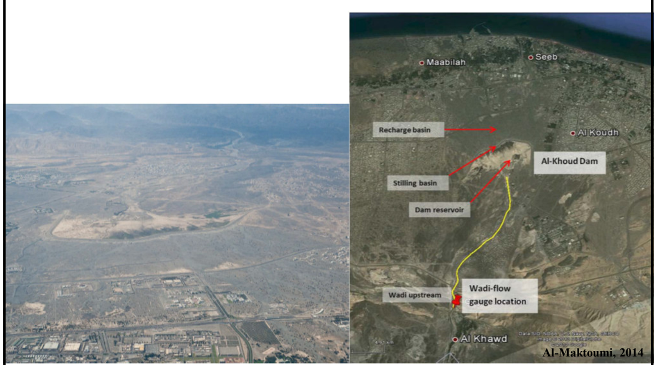


Flash Flood Inundation Simulation

Discharge vs Inundation



Wadi Samail Dam



After Gonu 2007, it was clear that This Dam is not enough and further mitigation structure is needed

Different FF Mitigation Scenarios at Wadi Samail

- Mitigation scenario 1: One big concentrated dam
- Mitigation scenario 2: Three smaller distributed dams

	Concentrated Dam	Distributed Dam 1	Distributed Dam 2	Distributed Dam 3
Location: Y : X	23.554344 58.103665	23.554344 58.103665	23.371503 58.090958	23.368906 58.157186
Reservoir Capacity (MCM)	75	40	9.6	25.8
Height (m)	50	40	22	22

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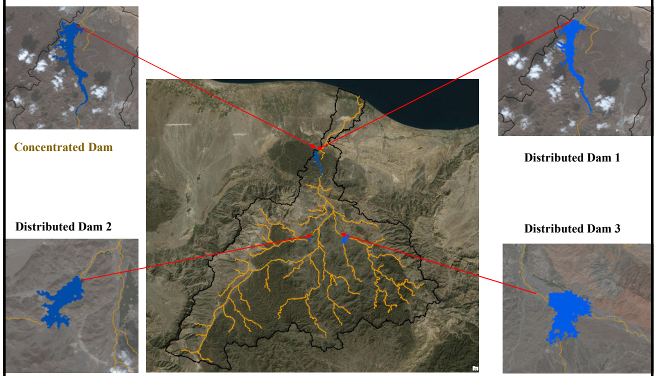
Proposed Flash Flood Mitigation Dams



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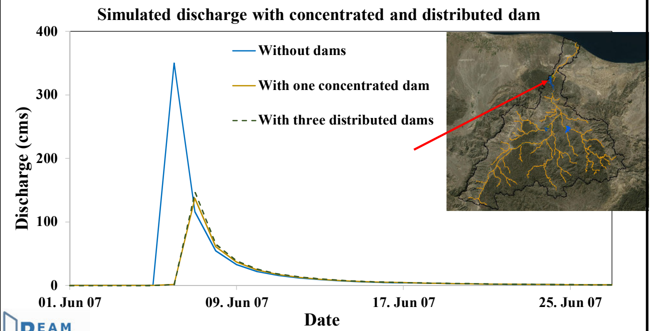
Different Mitigation Scenarios in W. Samail



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Conclusion

- Wadi system have very unique features and should be considered in flash flood hydrological modelling and management.
- RRI model could be calibrated validated efficiently to be used in wadi system
- Distributed dams and concentrated dams strategies are efficient in flash flood mitigation.
- Distributed dams have advantage of upstream protection, local recharge
- More evaluating parameters for the best mitigation scenarios should be considered as:
  - Optimization of each function of dams
  - Economical point of view and maintenance

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