The Hydrology of Arid Areas: Hydrological processes and modelling for water resources management

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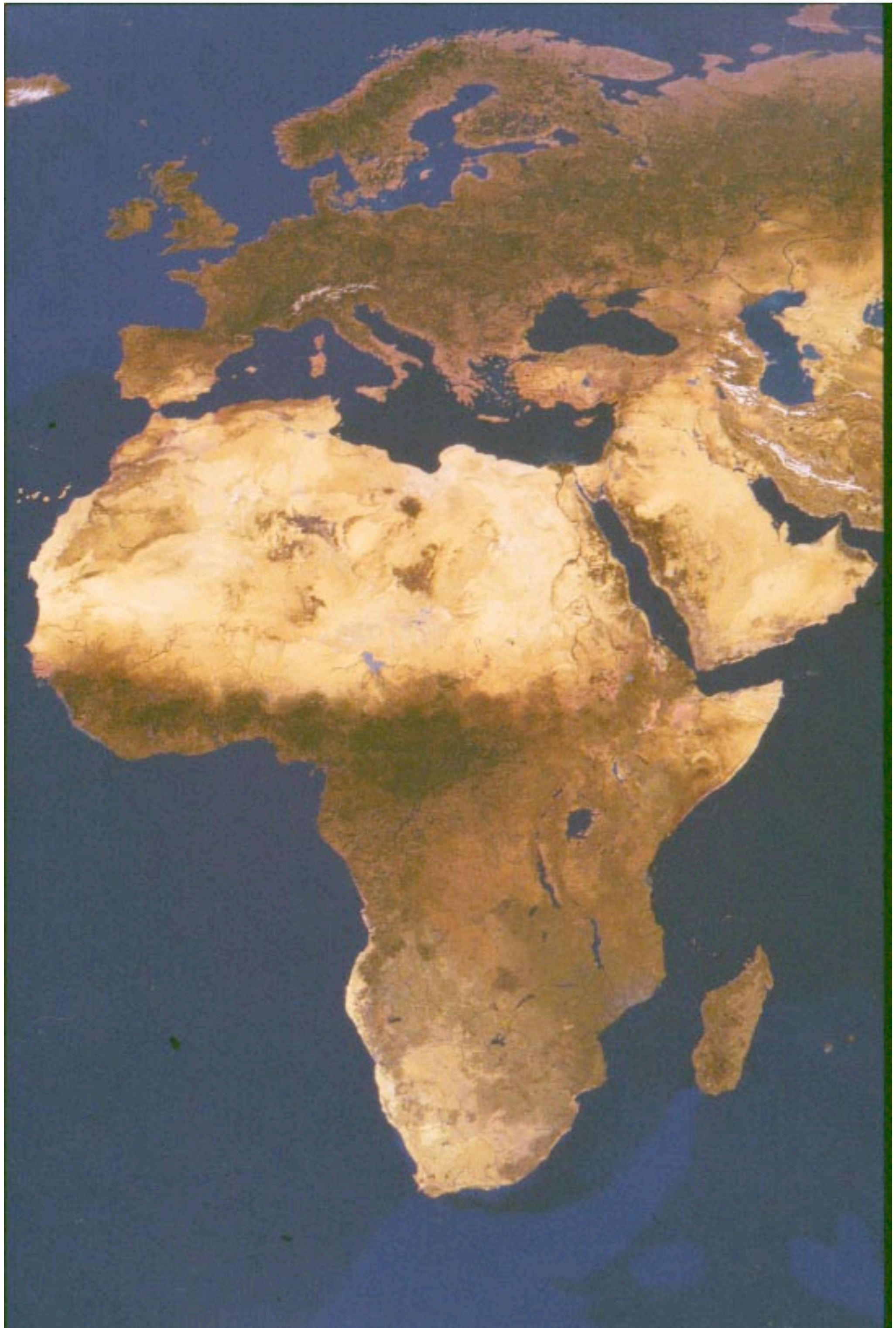
Motivation

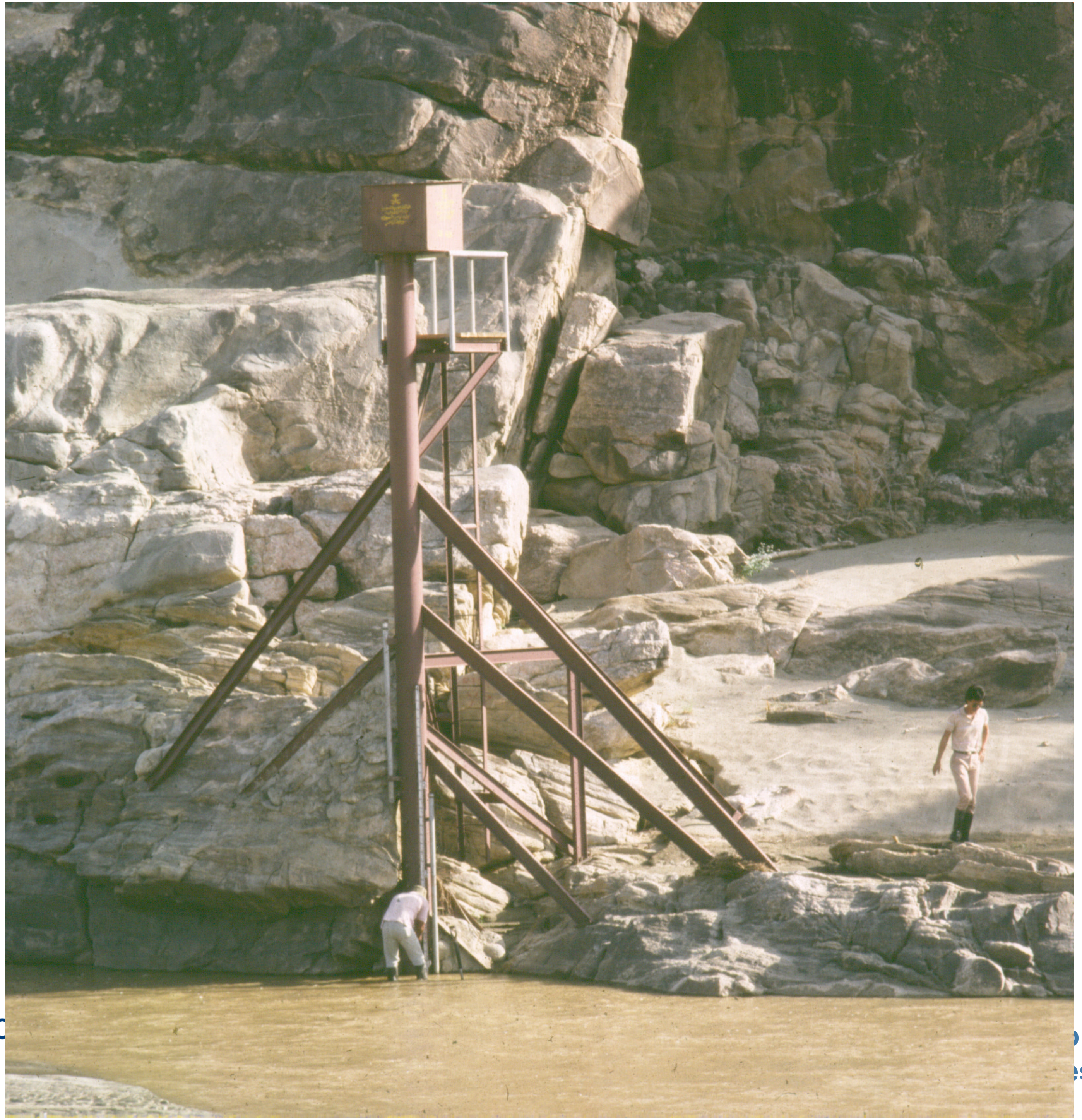
- Arid zone hydrology has important differences from humid zone hydrology
- Hydrological processes in arid and semi-arid areas are difficult to observe and poorly understood; data are generally limited
- Rainfall spatial and temporal variability and transmission losses are of particular importance for runoff and recharge processes
- Integrated management of water resources requires modelling support, but modelling is particularly challenging

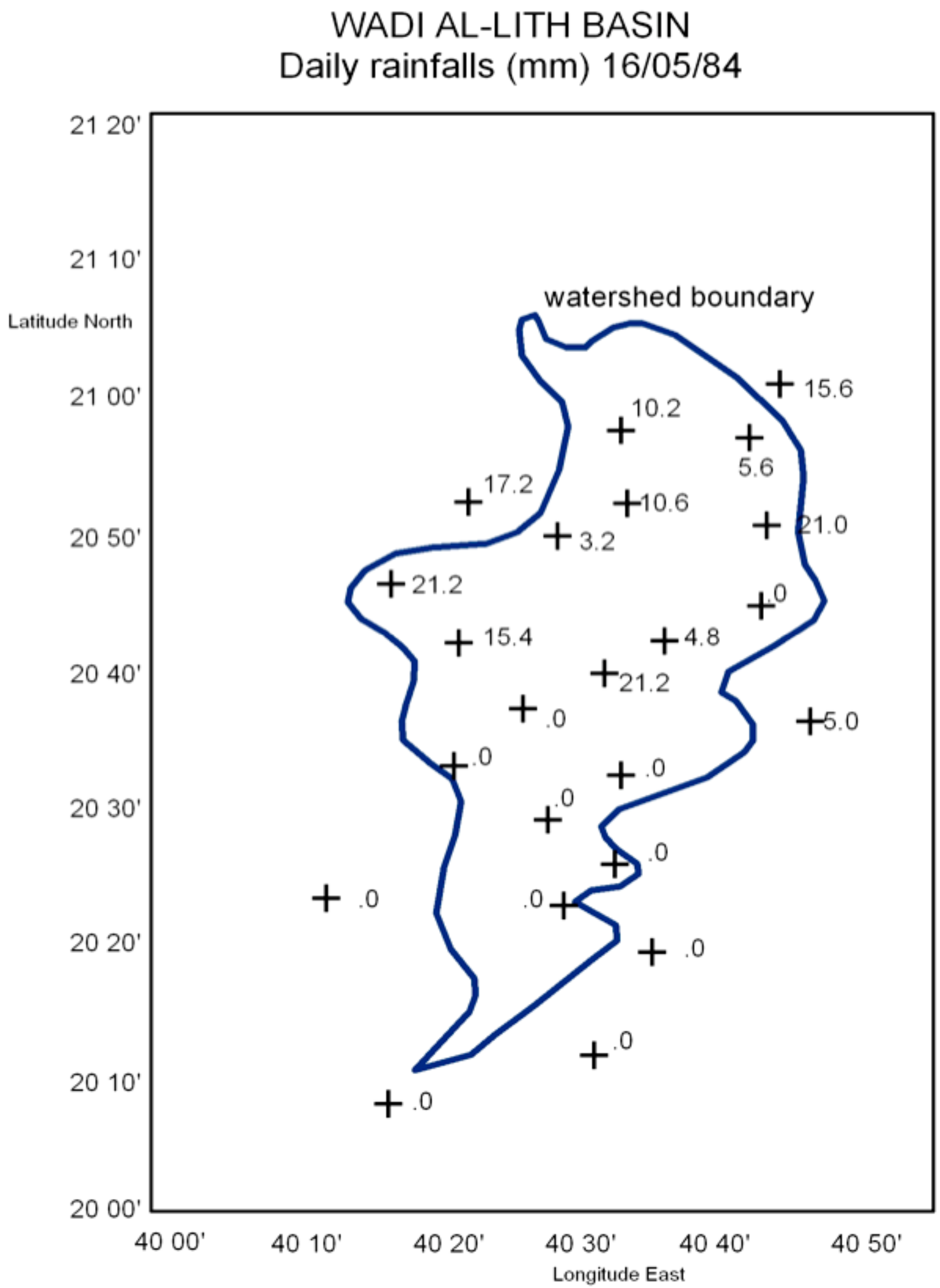
I. Some observations on the hydrology of arid areas

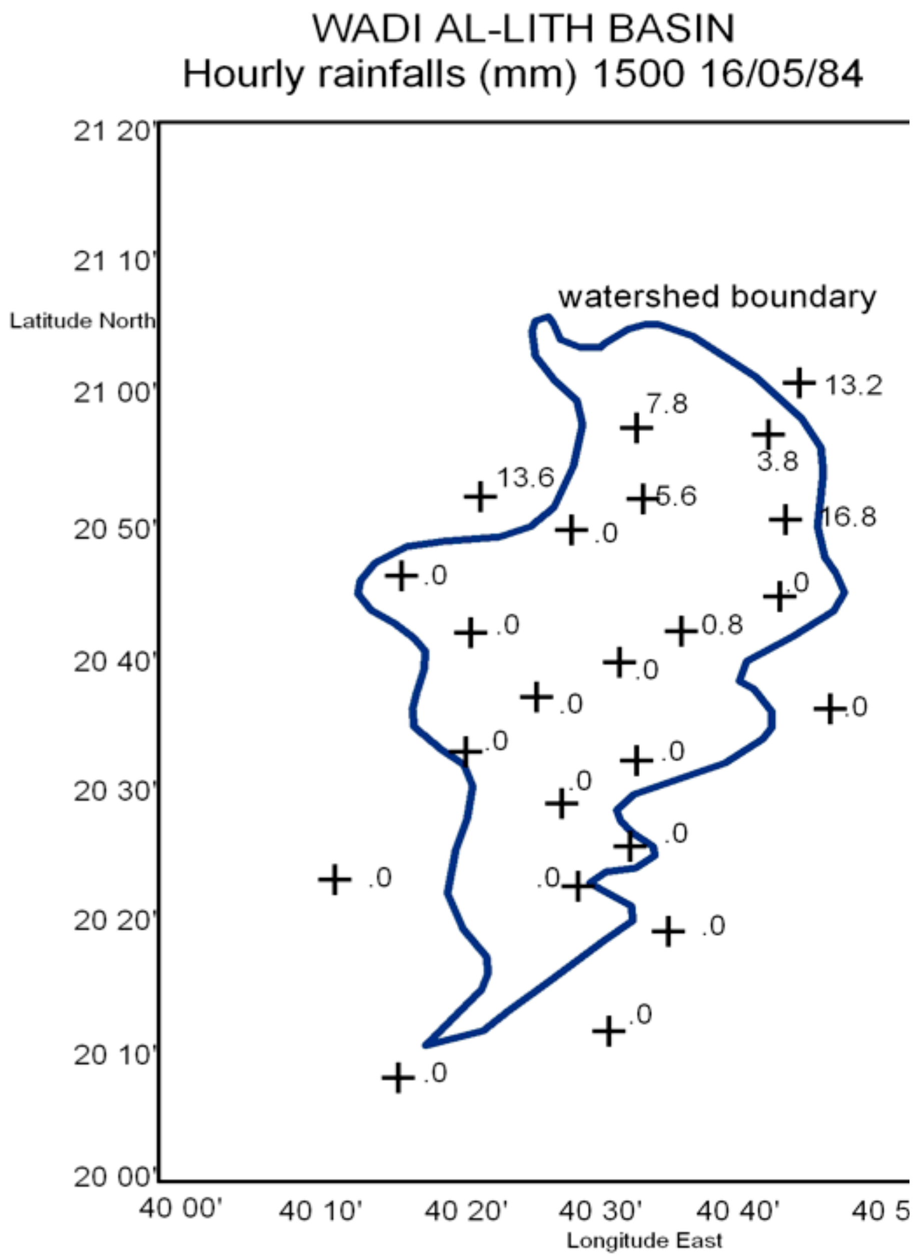


South West Saudi Arabia

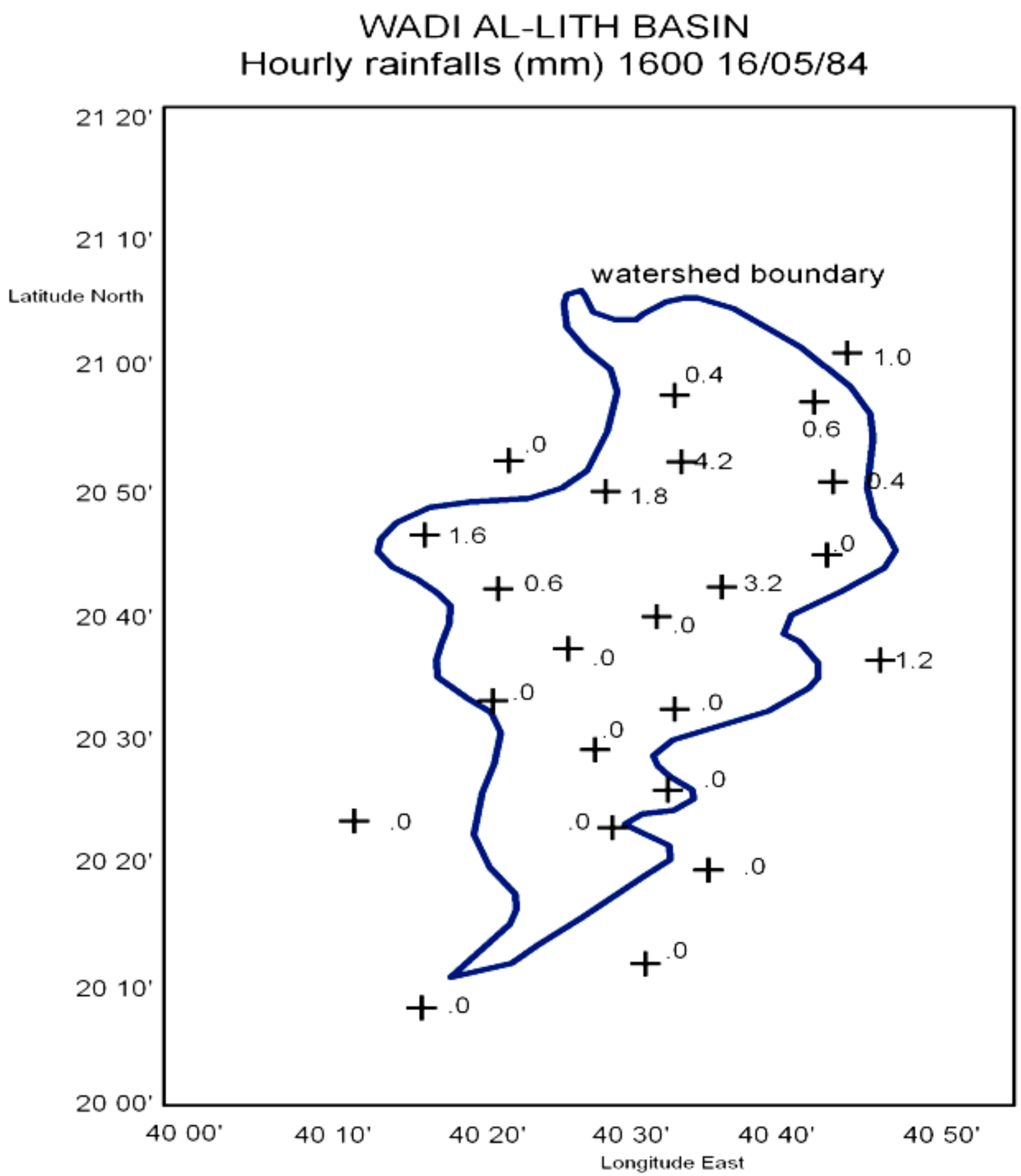

SA221




WADI AL-LITH BASIN
Daily rainfalls (mm) 16/05/84
watershed boundary
Latitude North
Longitude East
21 20'
21 10'
21 00'
20 50'
20 40'
20 30'
20 20'
20 10'
20 00'
40 00'
40 10'
40 20'
40 30'
40 40'
40 50'
15.6
10.2
5.6
17.2
10.6
21.0
3.2
21.2
.0
15.4
4.8
21.2
.0
5.0
.0
.0
.0
.0
.0
.0
.0
.0
.0
.0

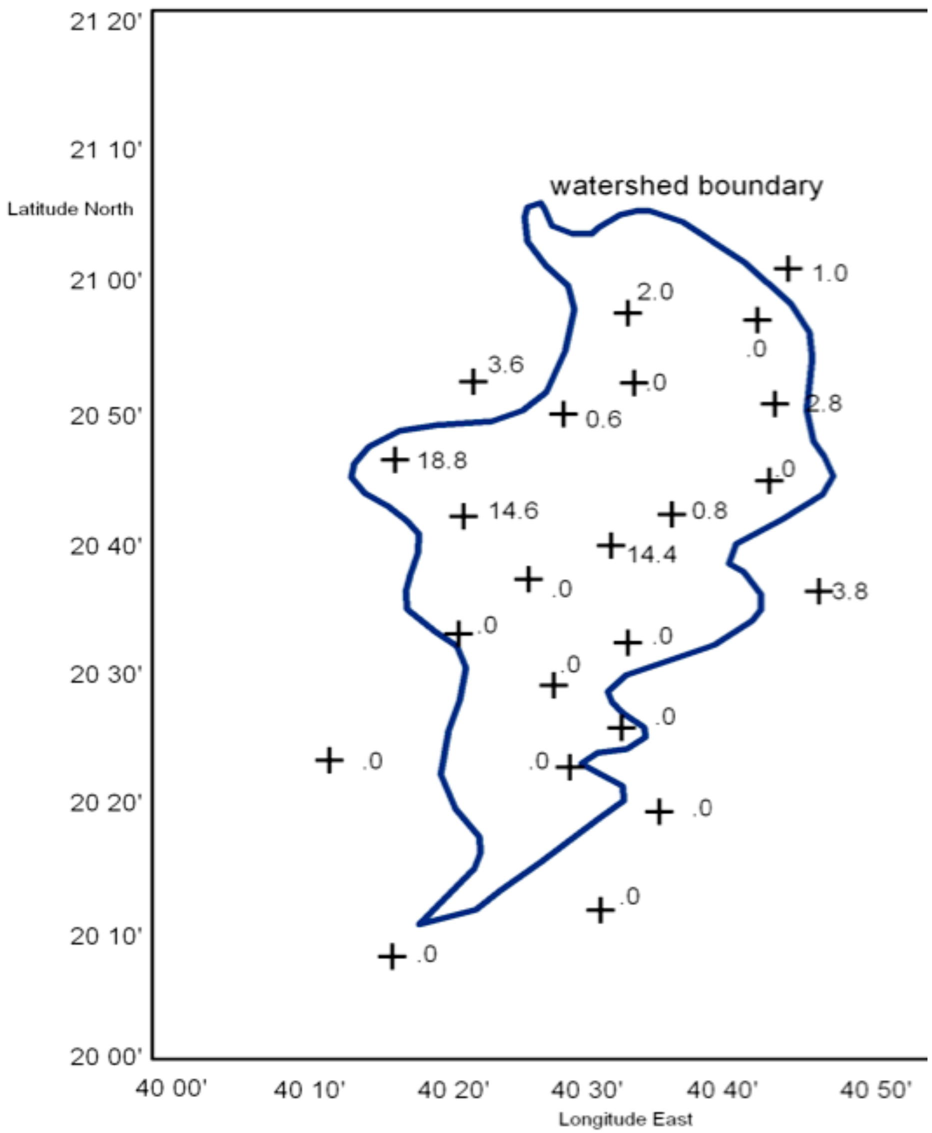


WADI AL-LITH BASIN
Hourly rainfalls (mm) 1500 16/05/84
watershed boundary
Latitude North
Longitude East
21 20'
21 10'
21 00'
20 50'
20 40'
20 30'
20 20'
20 10'
20 00'
40 00'
40 10'
40 20'
40 30'
40 40'
13.2
7.8
3.8
13.6
5.6
16.8
0.8

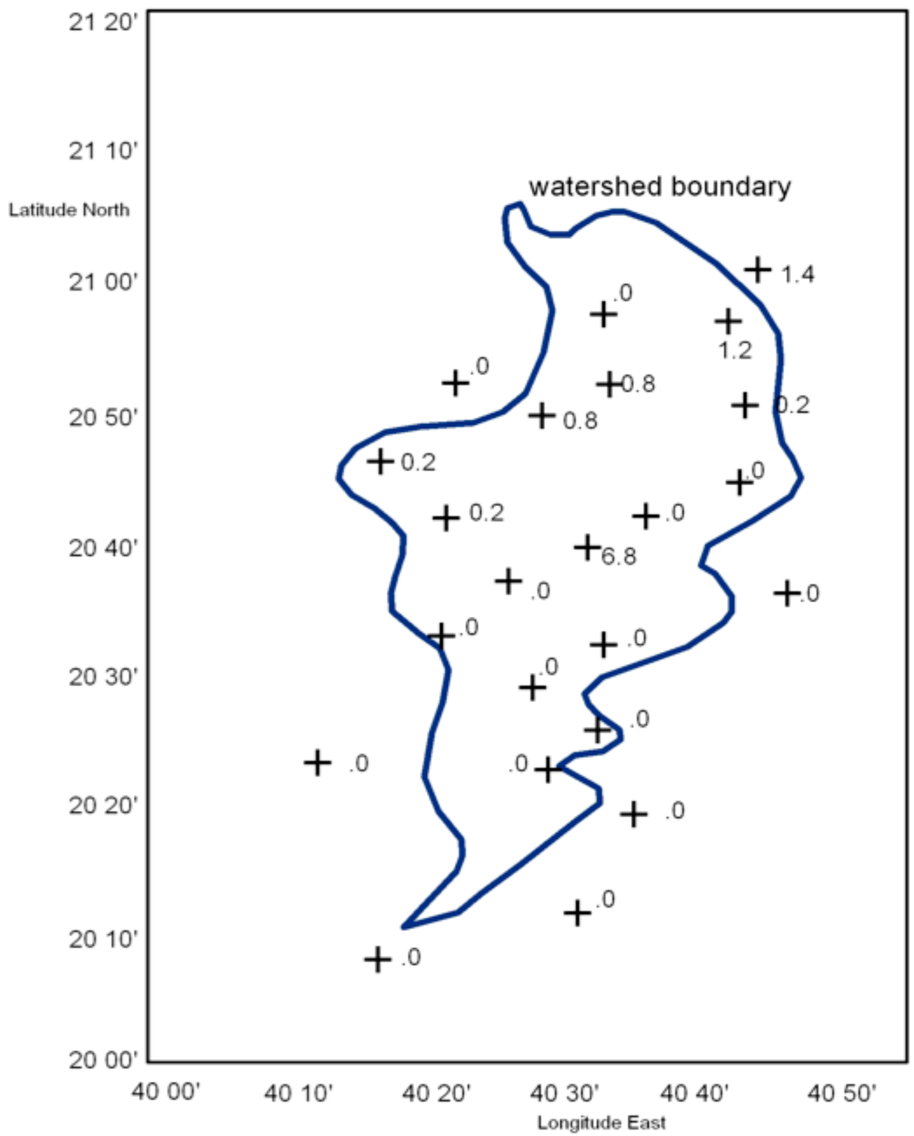


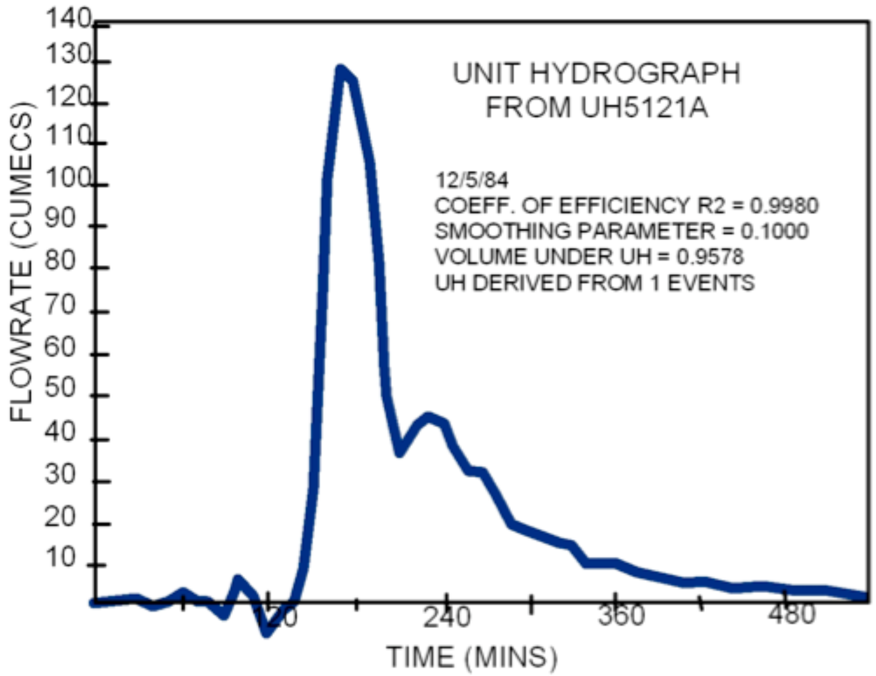
WADI AL-LITH BASIN
Hourly rainfalls (mm) 1600 16/05/84
watershed boundary
Latitude North
Longitude East
21 20'
21 10'
21 00'
20 50'
20 40'
20 30'
20 20'
20 10'
20 00'
40 00'
40 10'
40 20'
40 30'
40 40'
40 50'
1.0
0.4
0.6
4.2
1.8
1.6
0.6
3.2
1.2

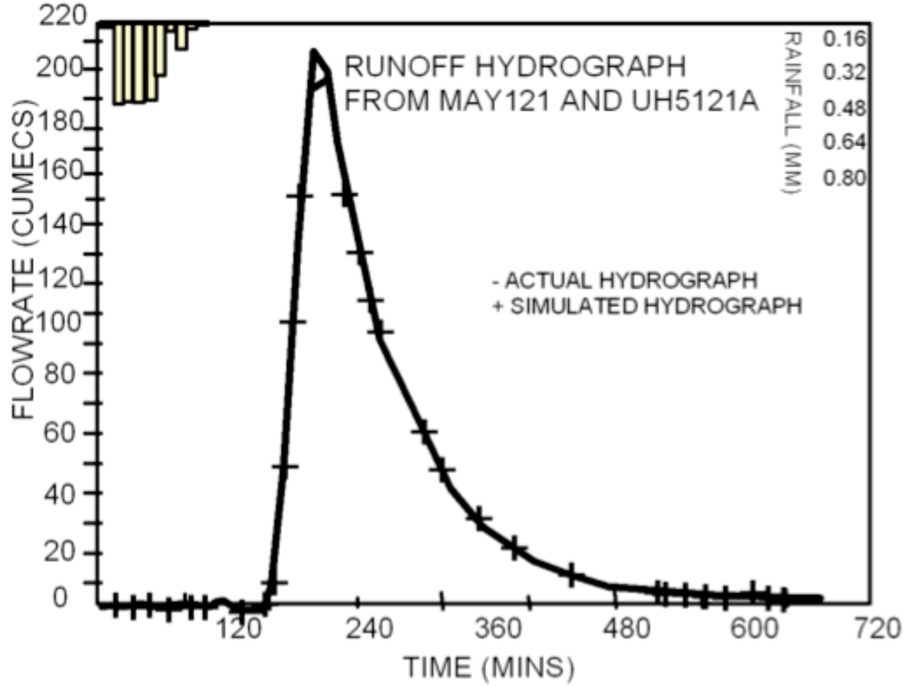
WADI AL-LITH BASIN
Hourly rainfalls (mm) 1700 16/05/84

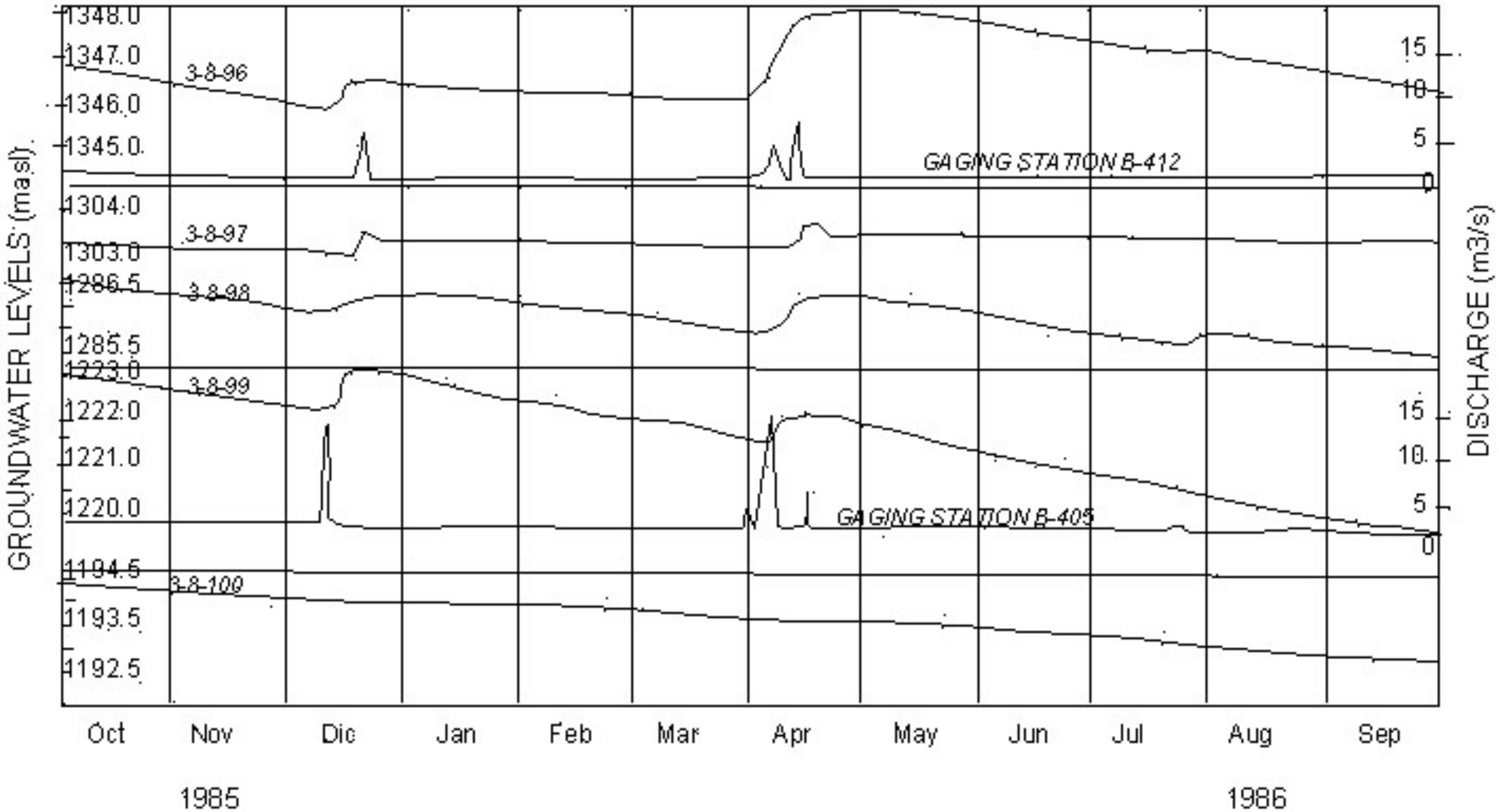


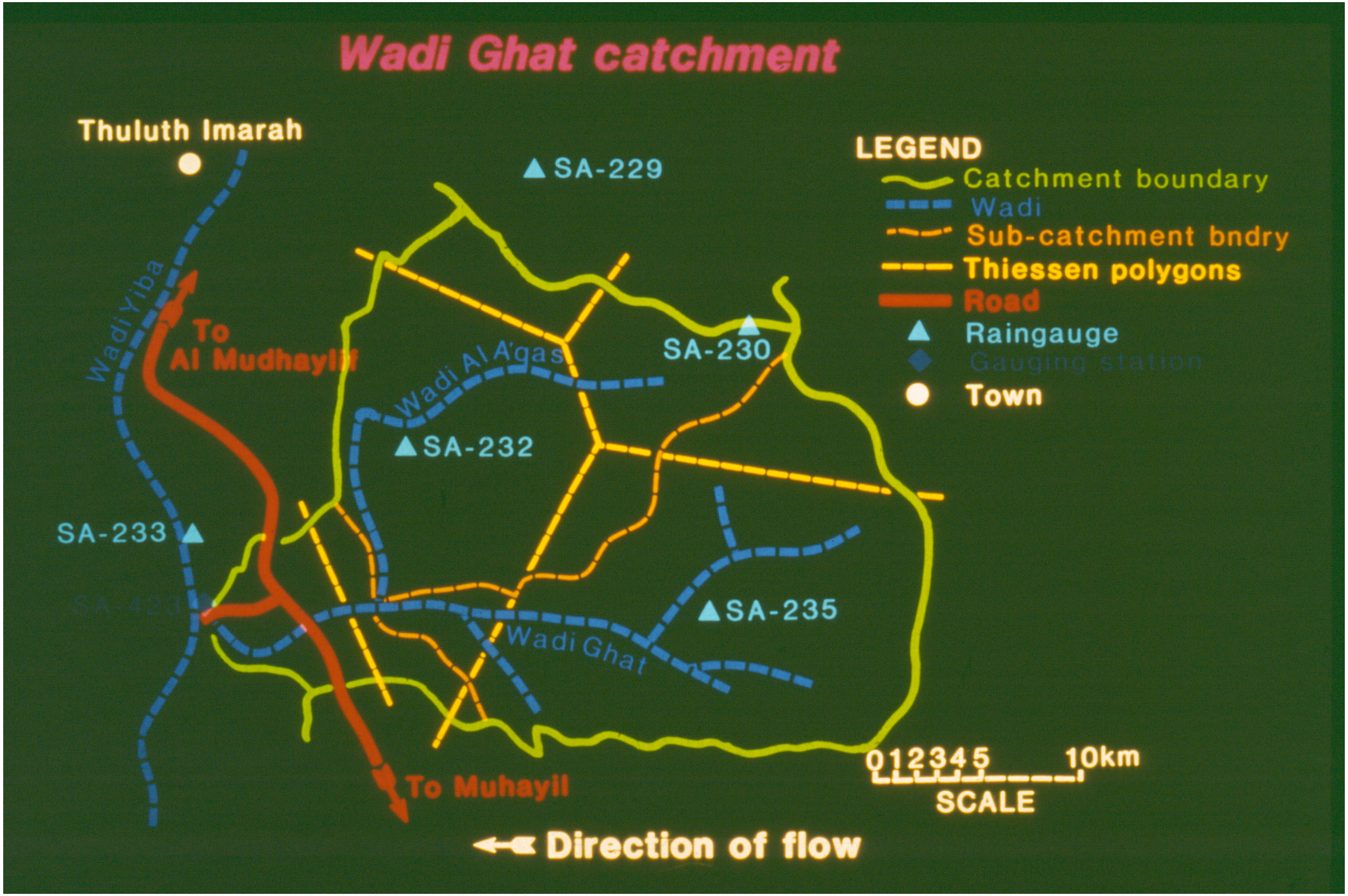
WADI AL-LITH BASIN
Hourly rainfalls (mm) 1800 16/05/84



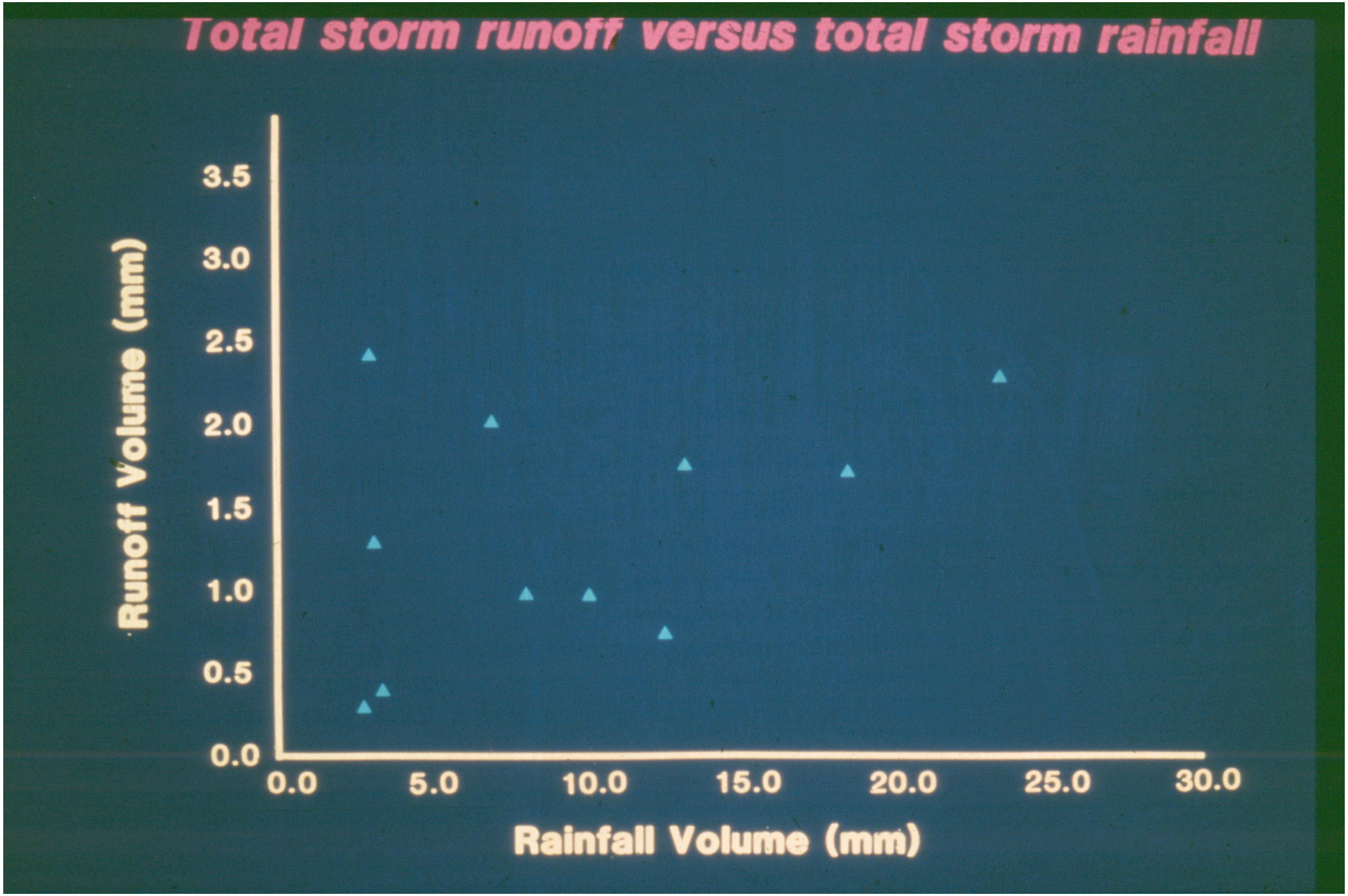

UNIT HYDROGRAPH
FROM UH5121A
12/5/84
COEFF. OF EFFICIENCY R2 = 0.9980
SMOOTHING PARAMETER = 0.1000
VOLUME UNDER UH = 0.9578
UH DERIVED FROM 1 EVENTS
FLOWRATE (CUMECS)
TIME (MINS)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
120
240
360
480


RUNOFF HYDROGRAPH
FROM MAY121 AND UH5121A
- ACTUAL HYDROGRAPH
+ SIMULATED HYDROGRAPH
FLOWRATE (CUMECS)
RAINFALL (MM)
TIME (MINS)
220
200
180
160
140
120
100
80
60
40
20
0
0.16
0.32
0.48
0.64
0.80
120
240
360
480
600
720

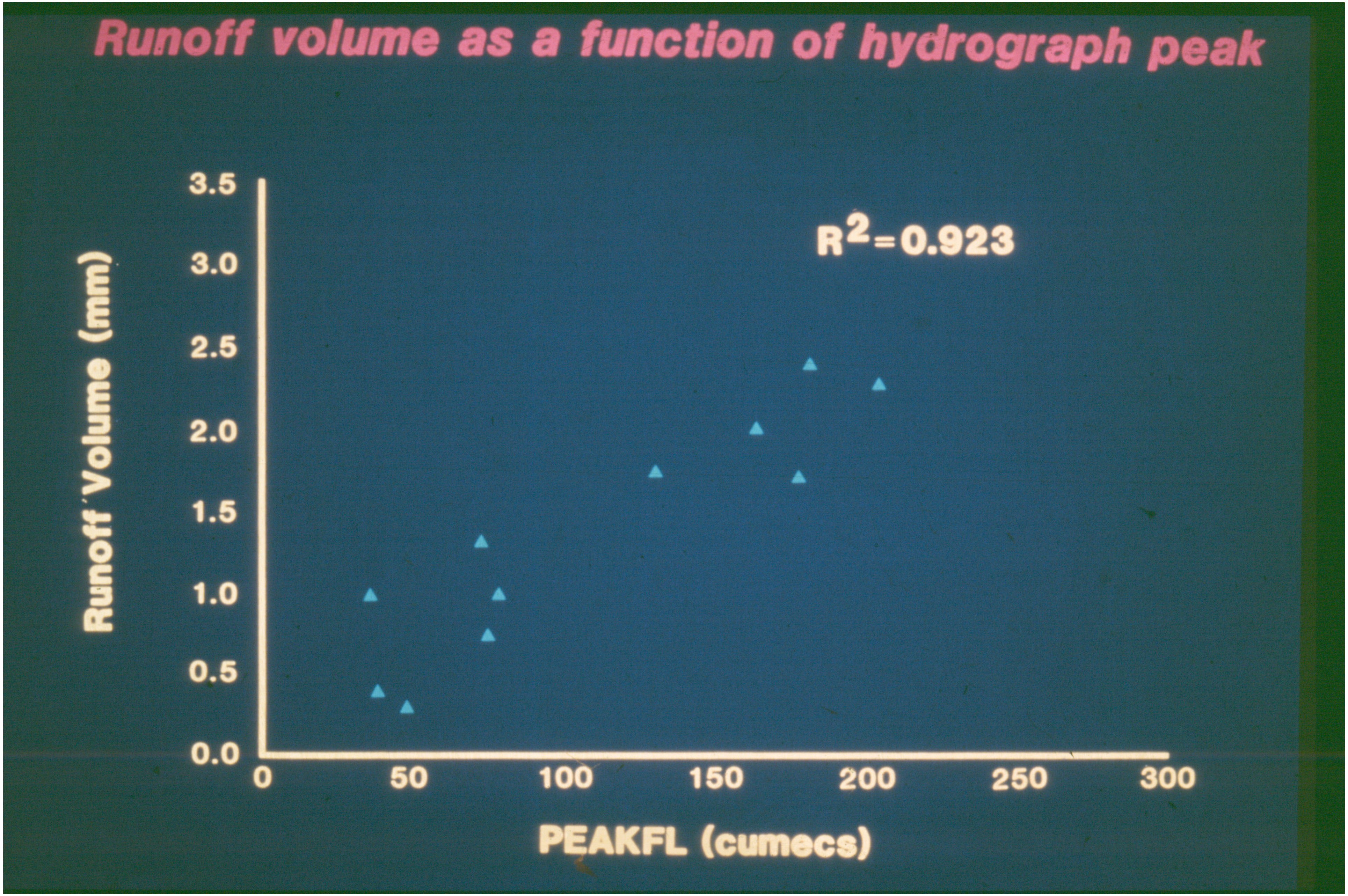

GROUNDWATER LEVELS (masl)
DISCHARGE (m3/s)
1348.0
1347.0
1346.0
1345.0
1304.0
1303.0
1286.5
1285.5
1223.0
1222.0
1221.0
1220.0
1194.5
1193.5
1192.5
3-8-96
3-8-97
3-8-98
3-8-99
3-8-100
GAGING STATION B-412
GAGING STATION B-405
15
10
5
0
Oct
Nov
Dic
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
1985
1986



Wadi Ghat catchment
Thuluth Imarah
SA-229
LEGEND
Catchment boundary
Wadi
Sub-catchment bndry
Thiessen polygons
Road
Raingauge
Gauging station
Town
Wadi Yiba
To Al Mudhaylif
Wadi Al A'gas
SA-230
SA-232
SA-233
SA-423
SA-235
Wadi Ghat
To Muhayil
0 1 2 3 4 5 10km
SCALE
Direction of flow



Total storm runoff versus total storm rainfall
Runoff Volume (mm)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Rainfall Volume (mm)


Runoff volume as a function of hydrograph peak
R^2=0.923
Runoff Volume (mm)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
300
PEAKFL (cumecs)

Some conclusions

Rainfall spatial and temporal variability and transmission losses are of particular importance for runoff and recharge processes

Appropriate models and decision support tools are needed for hydrology and water resources management; these must be based on appropriate understanding of hydrological processes

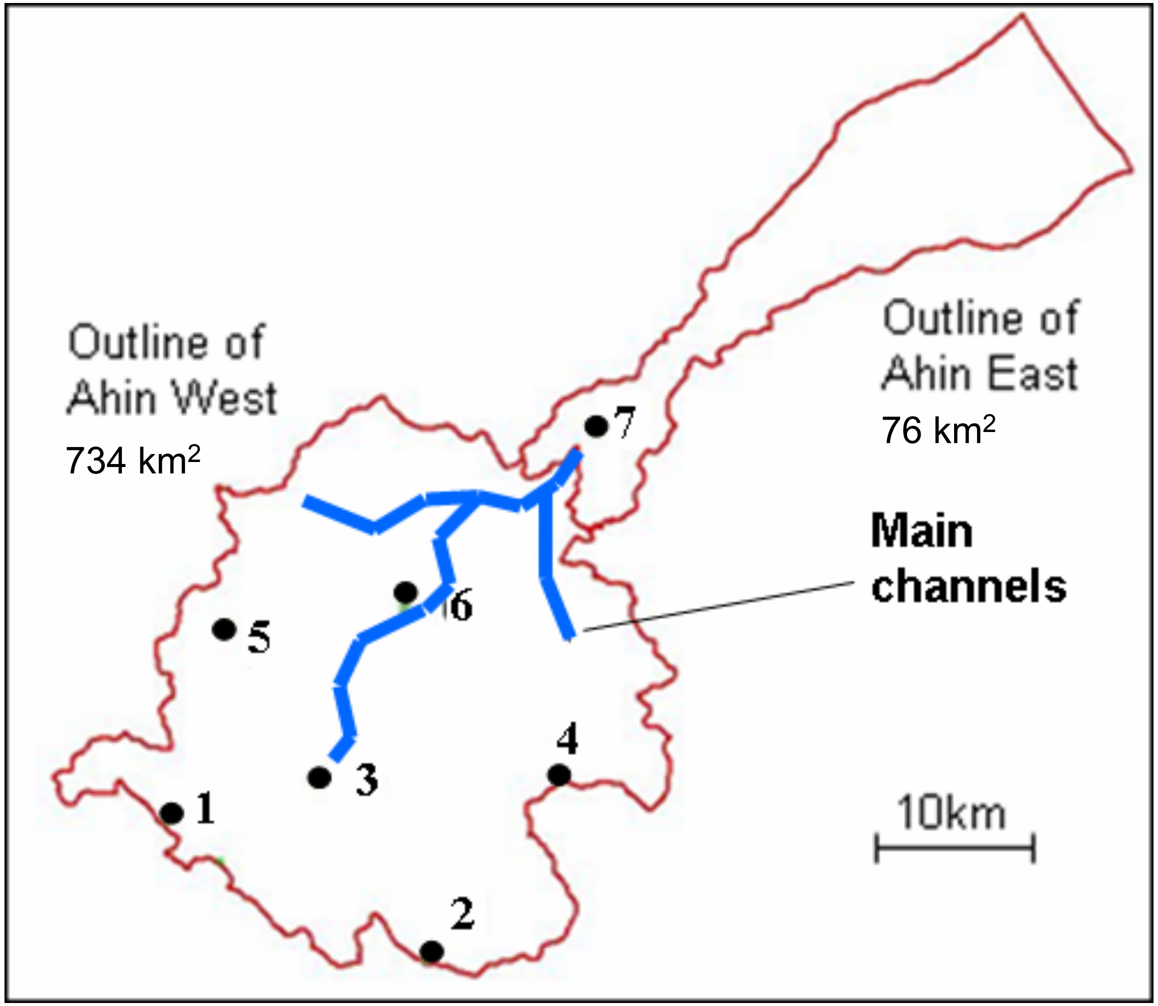
Data support for modelling and analysis is a major issue

II. Modelling the hydrology of arid areas
- 2 Case studies from the Sultanate of Oman

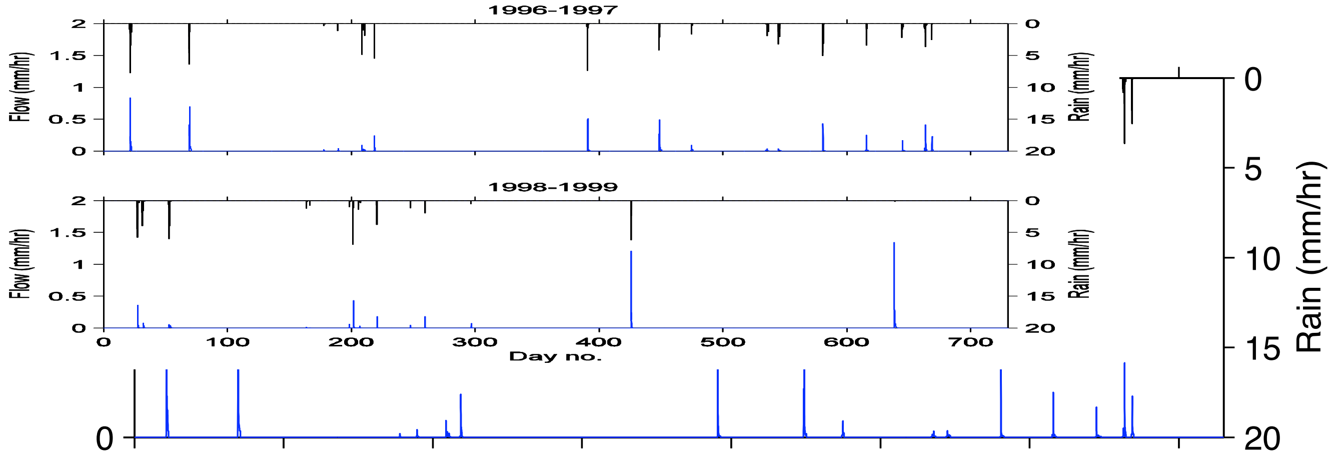
Event modelling for Wadi Ahin using the physics-based KINEROS model

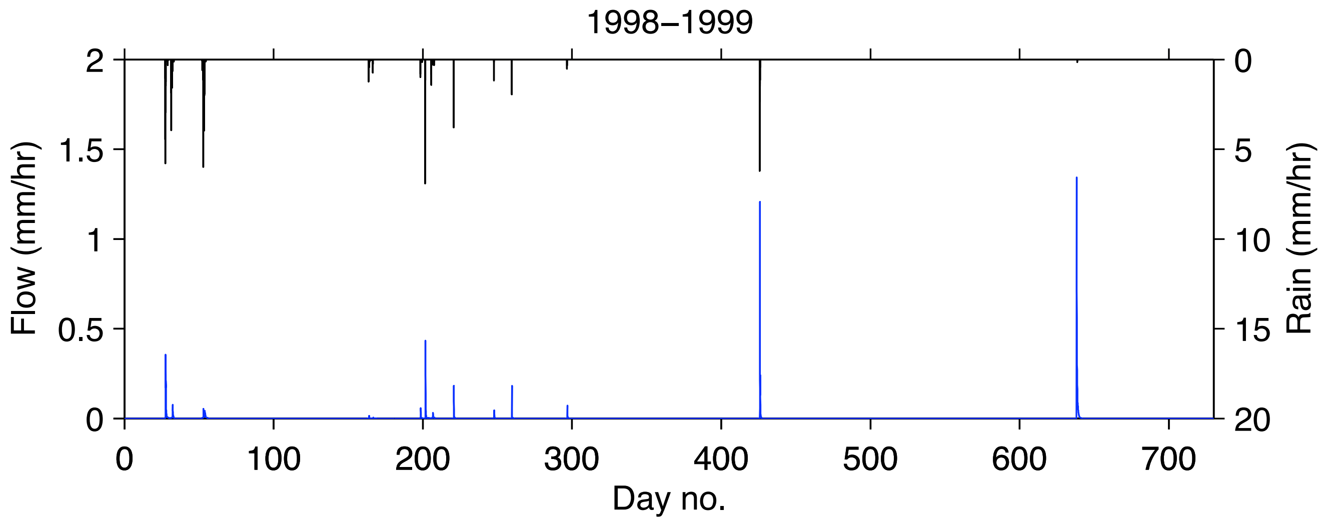
Modelling rainfall-runoff relationships in Wadi Ahin, Sultanate of Oman

Wadi Ahin recording raingauge network

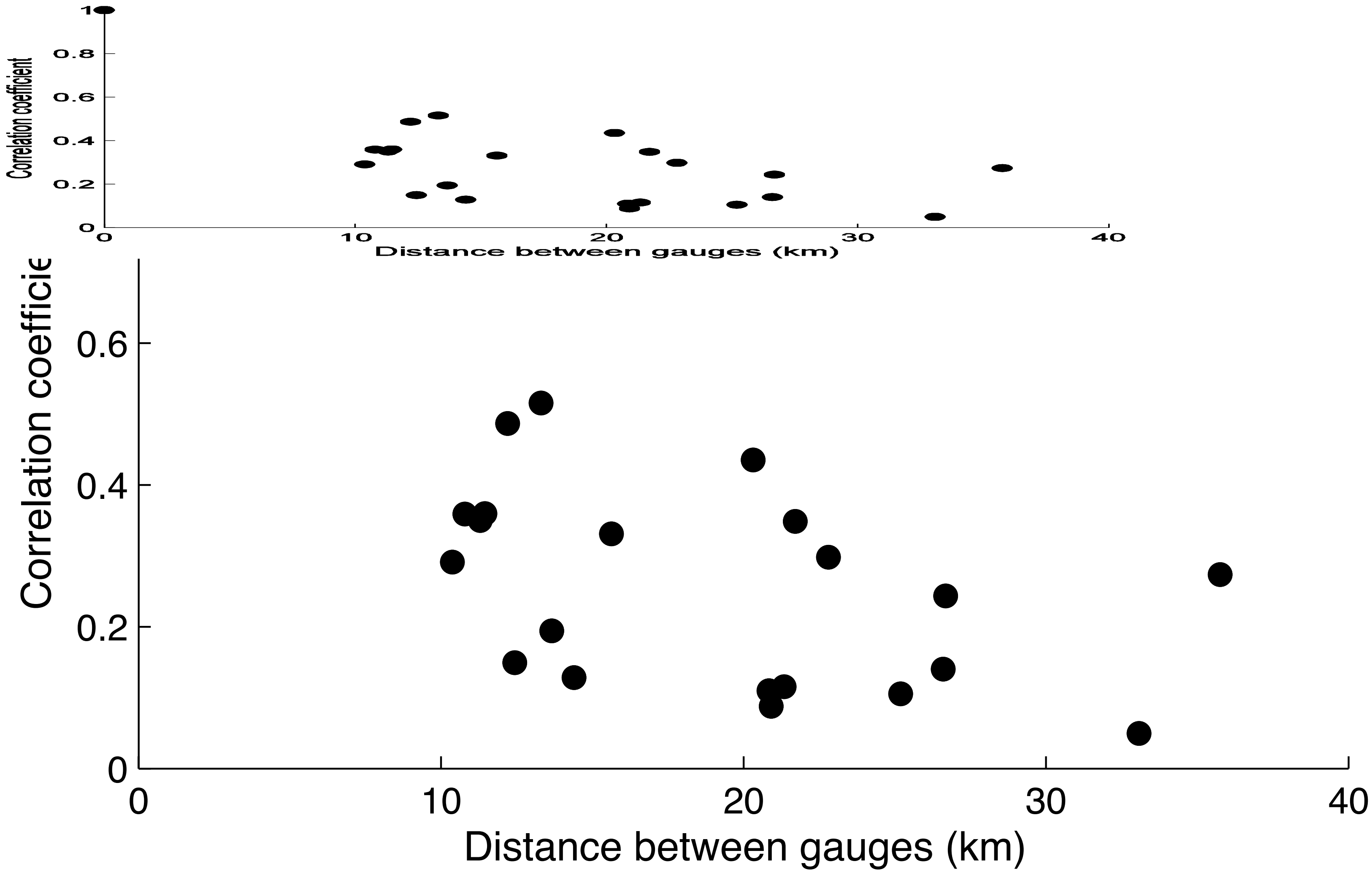


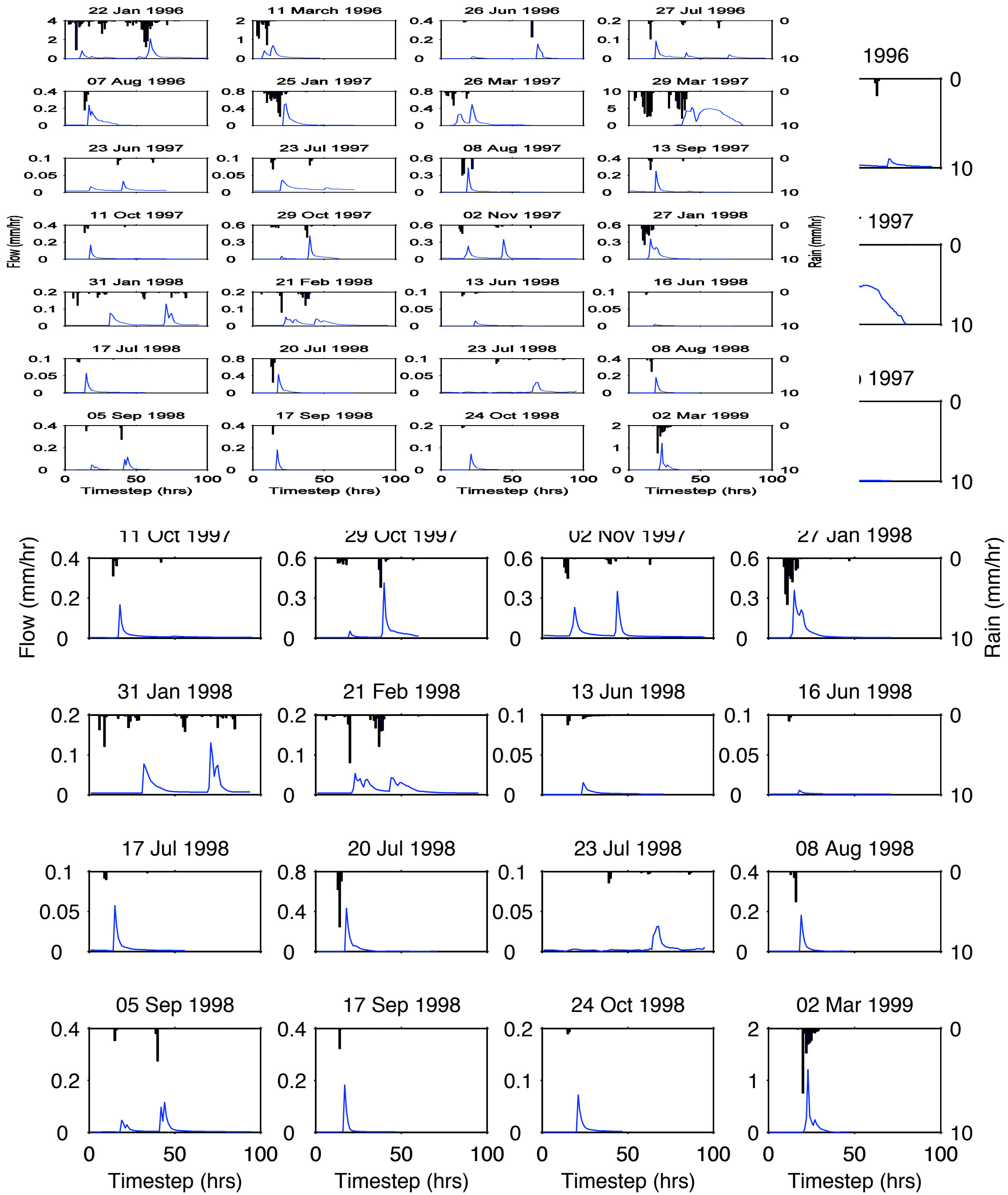
Run-off events, 1996-1999





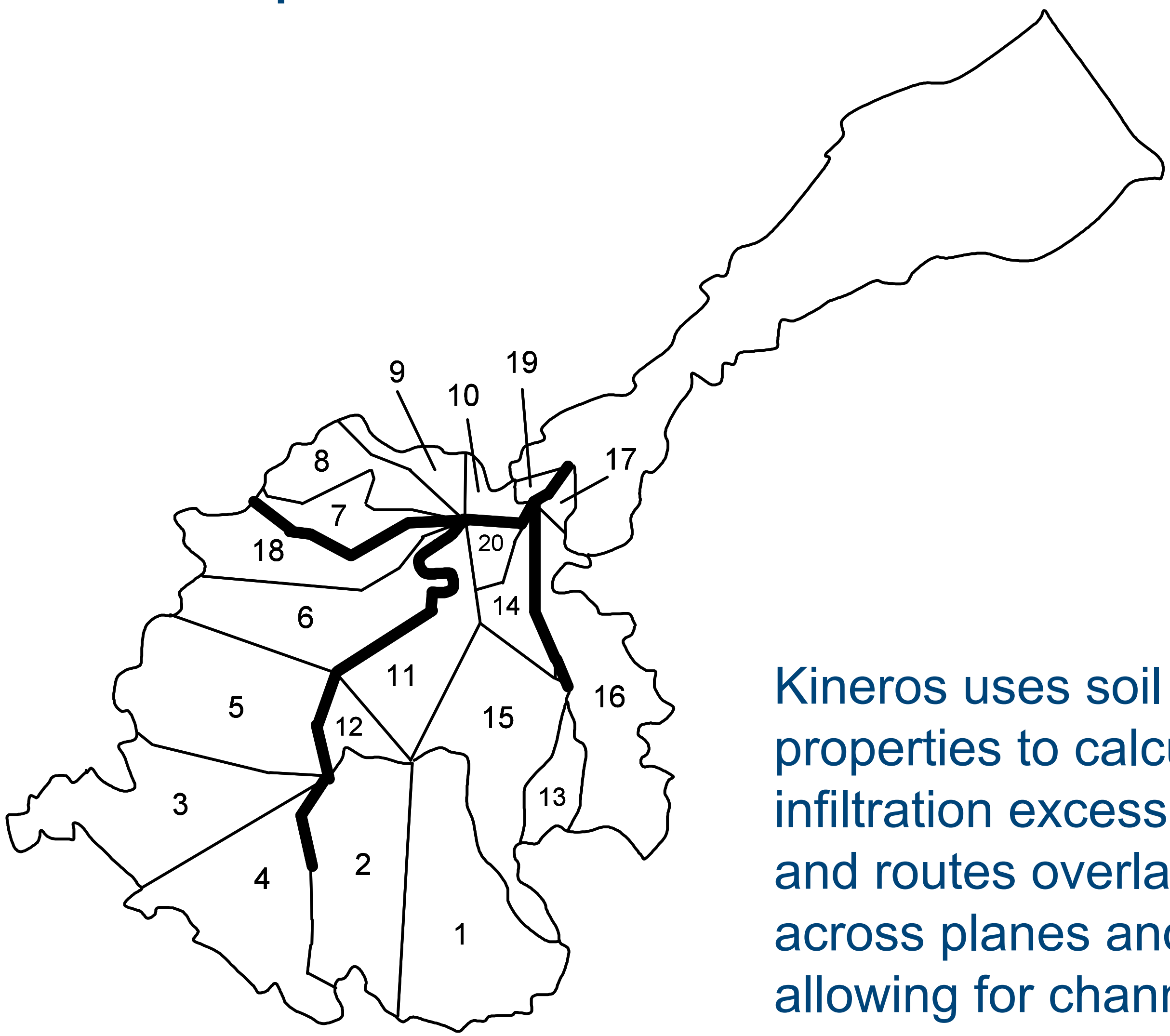
Spatial correlation of hourly rainfall



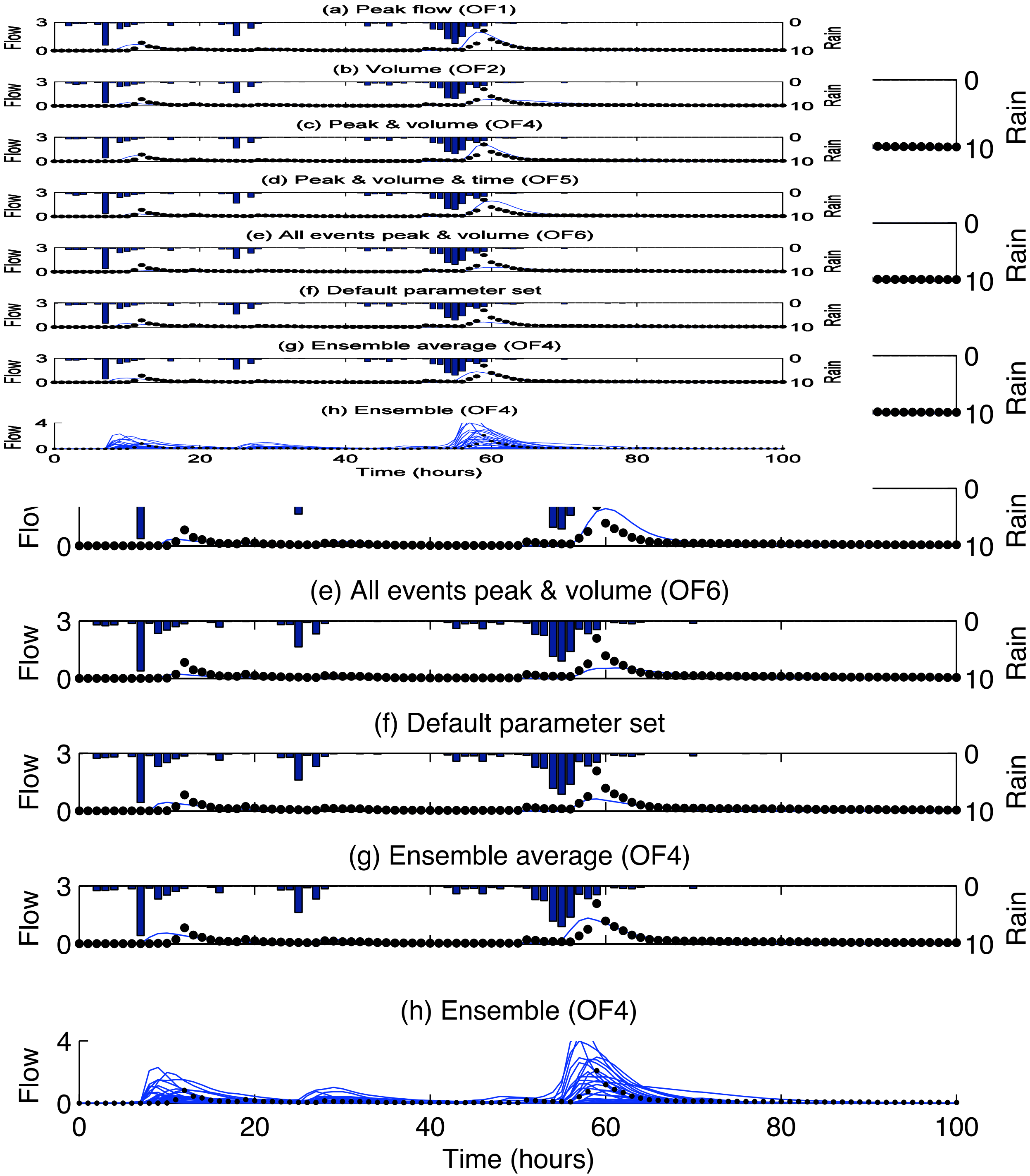


27 runoff events 1996-1999

Kineros2 catchment discretisation, planes and channels

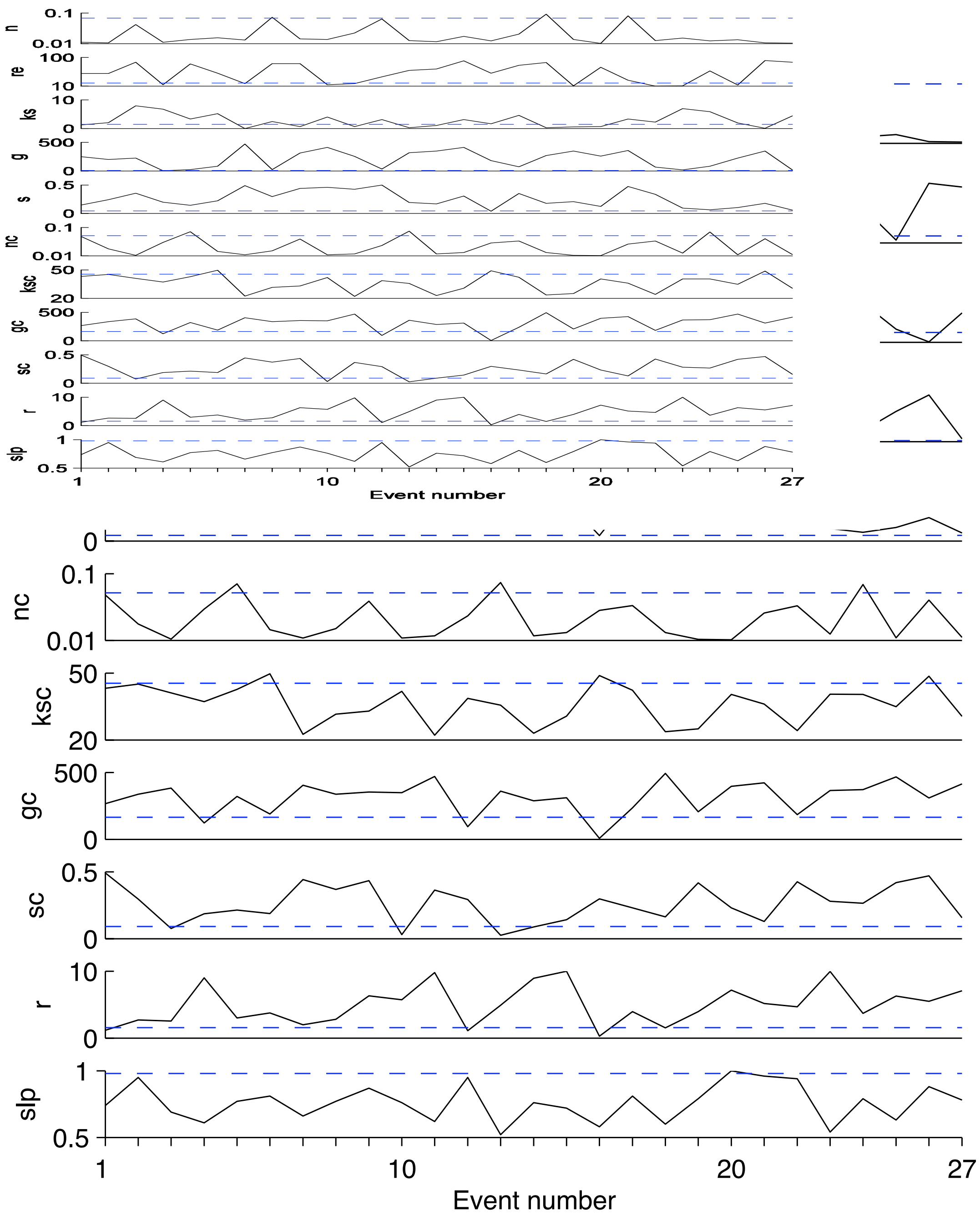


Kineros uses soil physical properties to calculate infiltration excess runoff and routes overland flow across planes and channels, allowing for channel infiltration, based on slope and roughness



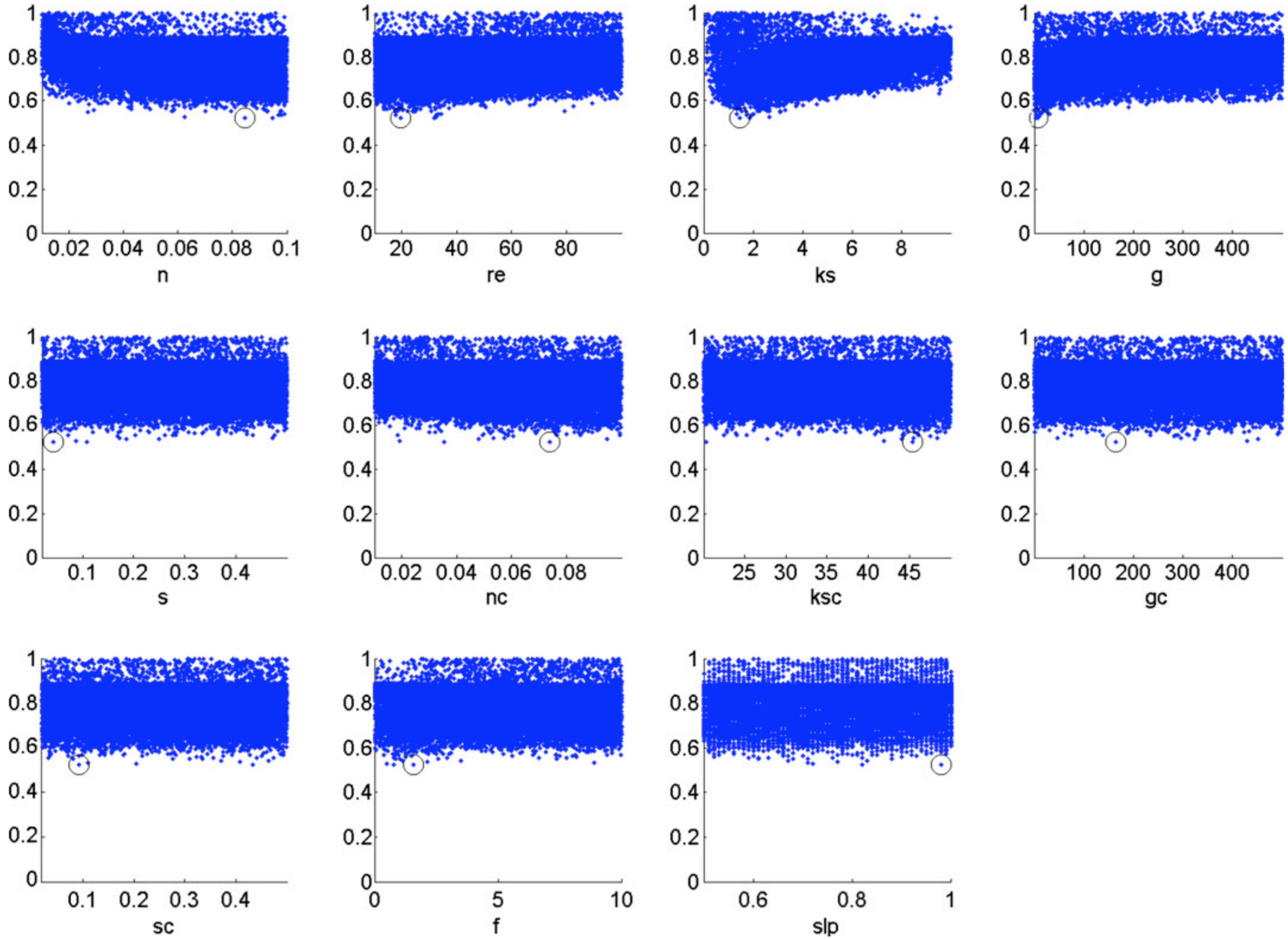
Example of calibration and validation results, 22 January 1996.

Bars - rainfall;
Dots – observed flow
Lines - simulated flow

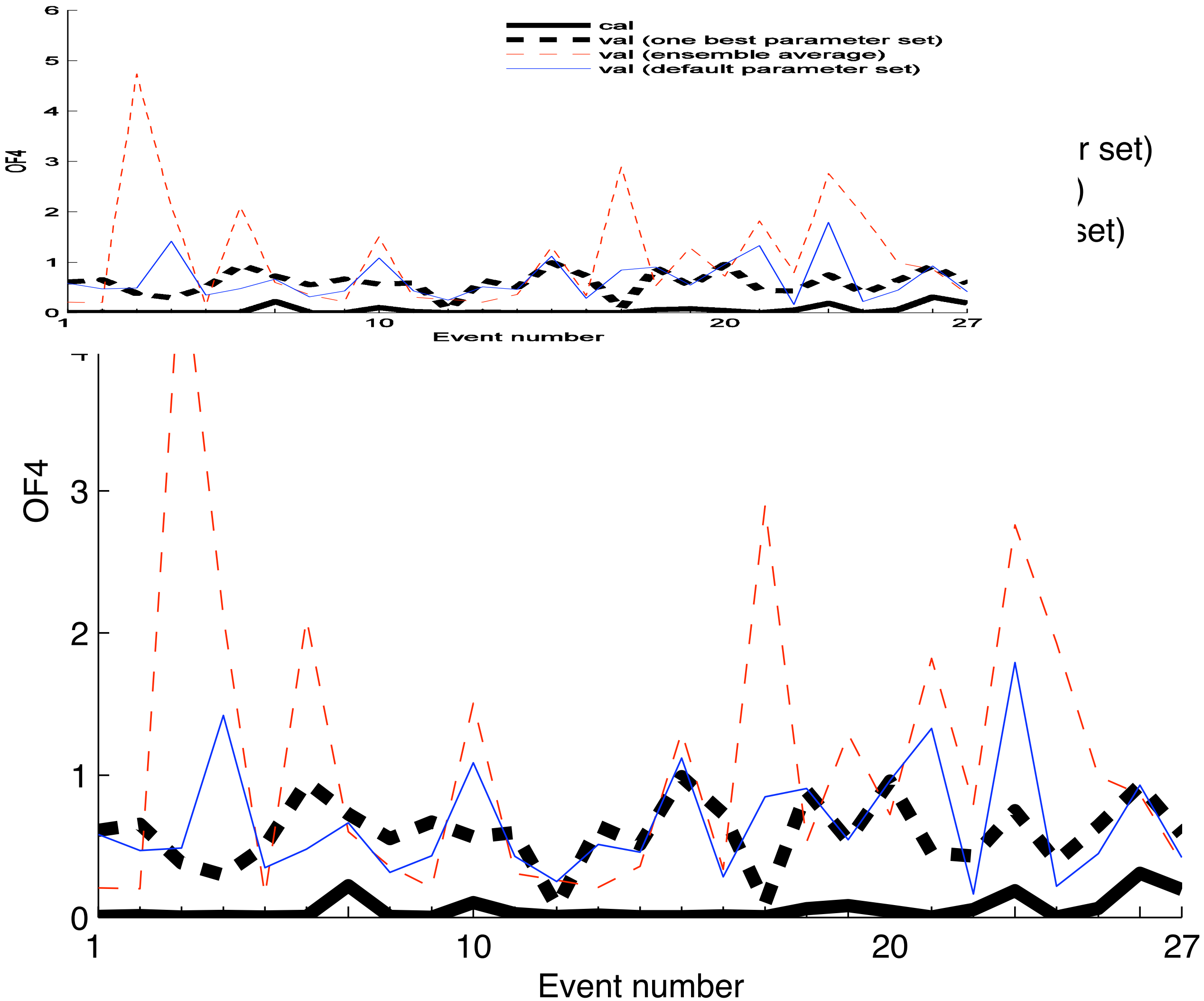


Variation of optimum parameter values (OF4) over the 27 events

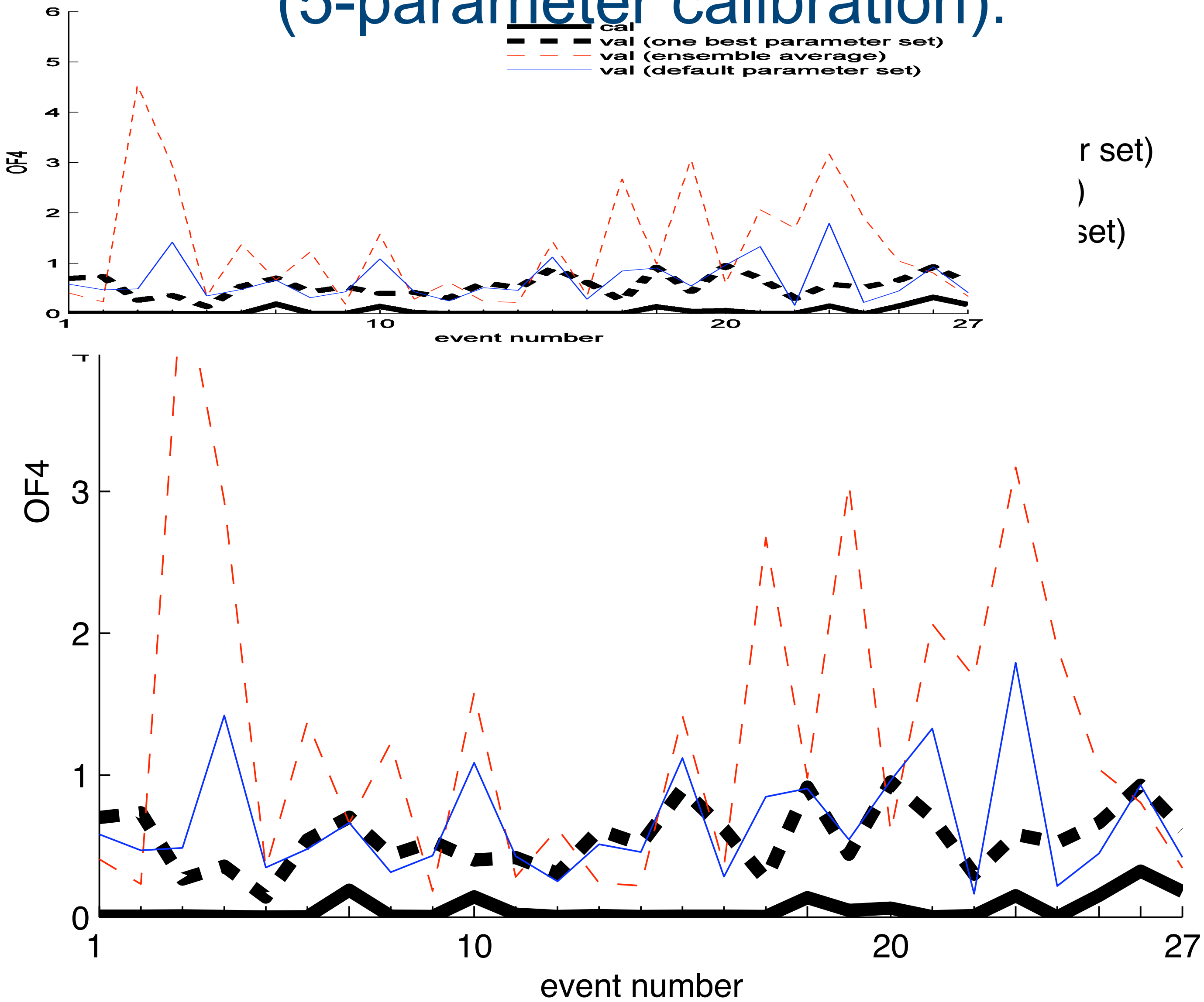
Parameter identifiability
- dotty plots of parameter values against OF6



Performance (OF4) in calibration and validation using different strategies, for each of the 27 events (11-parameter calibration)

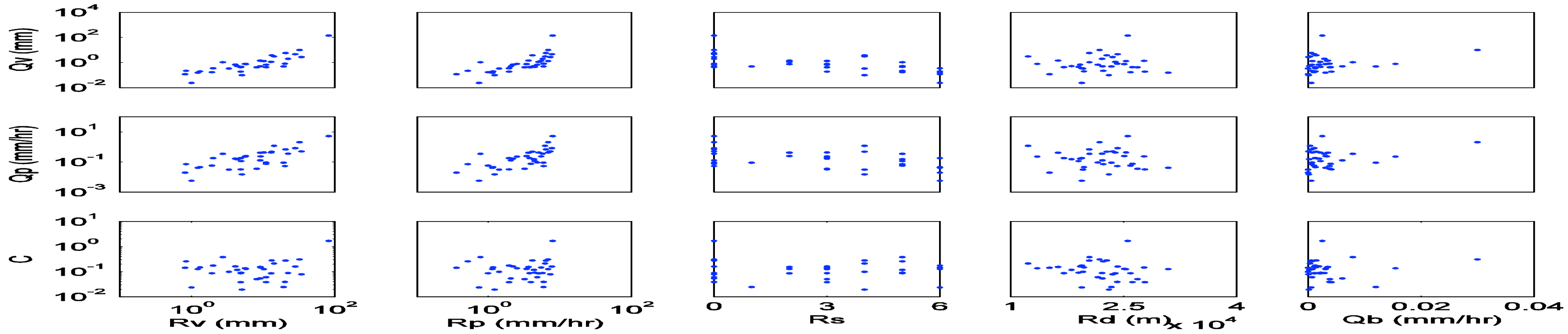


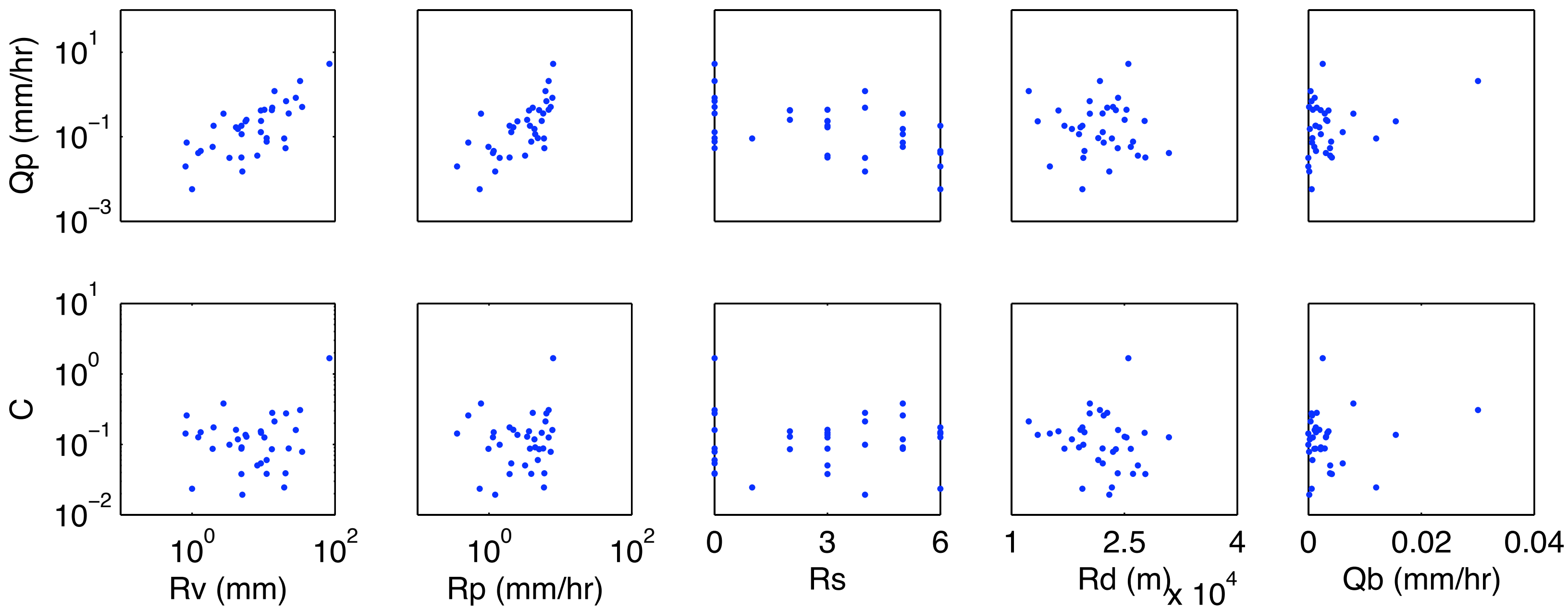
Performance (OF4) in calibration and validation using different strategies, for each of the 27 events (5-parameter calibration).



Event analysis

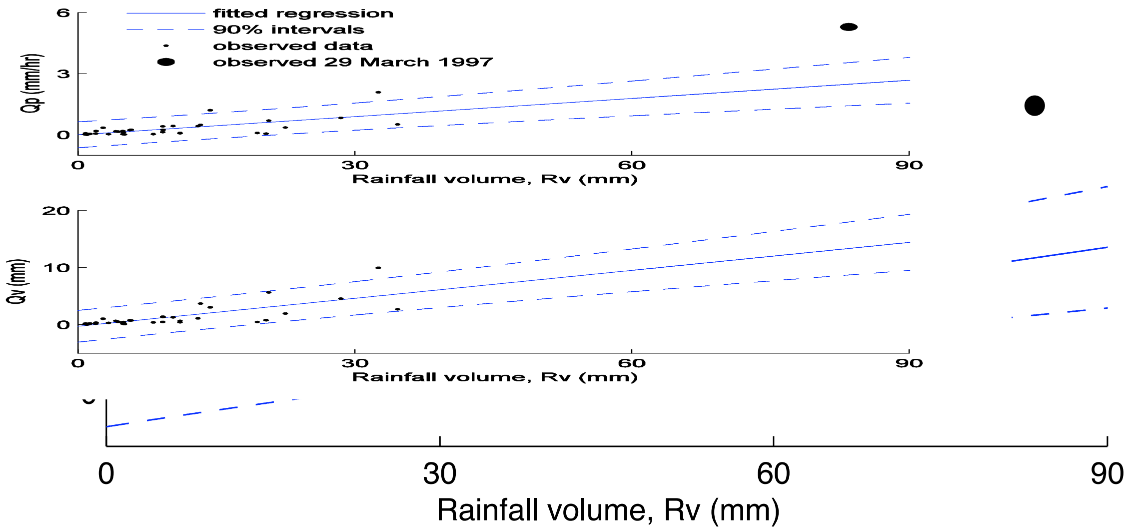
dependence of flow volume (Qv), flow peak (Qp) and runoff coefficient (C) on rainfall volume (Rv), rainfall peak intensity (Rp), rainfall spatial variability (Rs), distance weighted rainfall (Rd) and baseflow (Qb) (antecedent wetness)





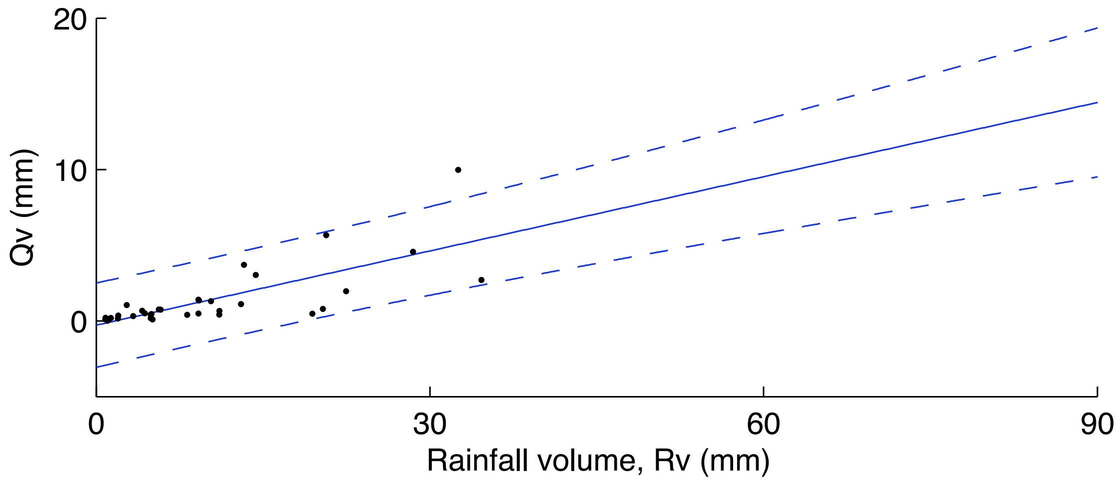
Regression models,

observed data and 90% confidence intervals



$$Q_p = -0.00514 + 0.0315R_v$$

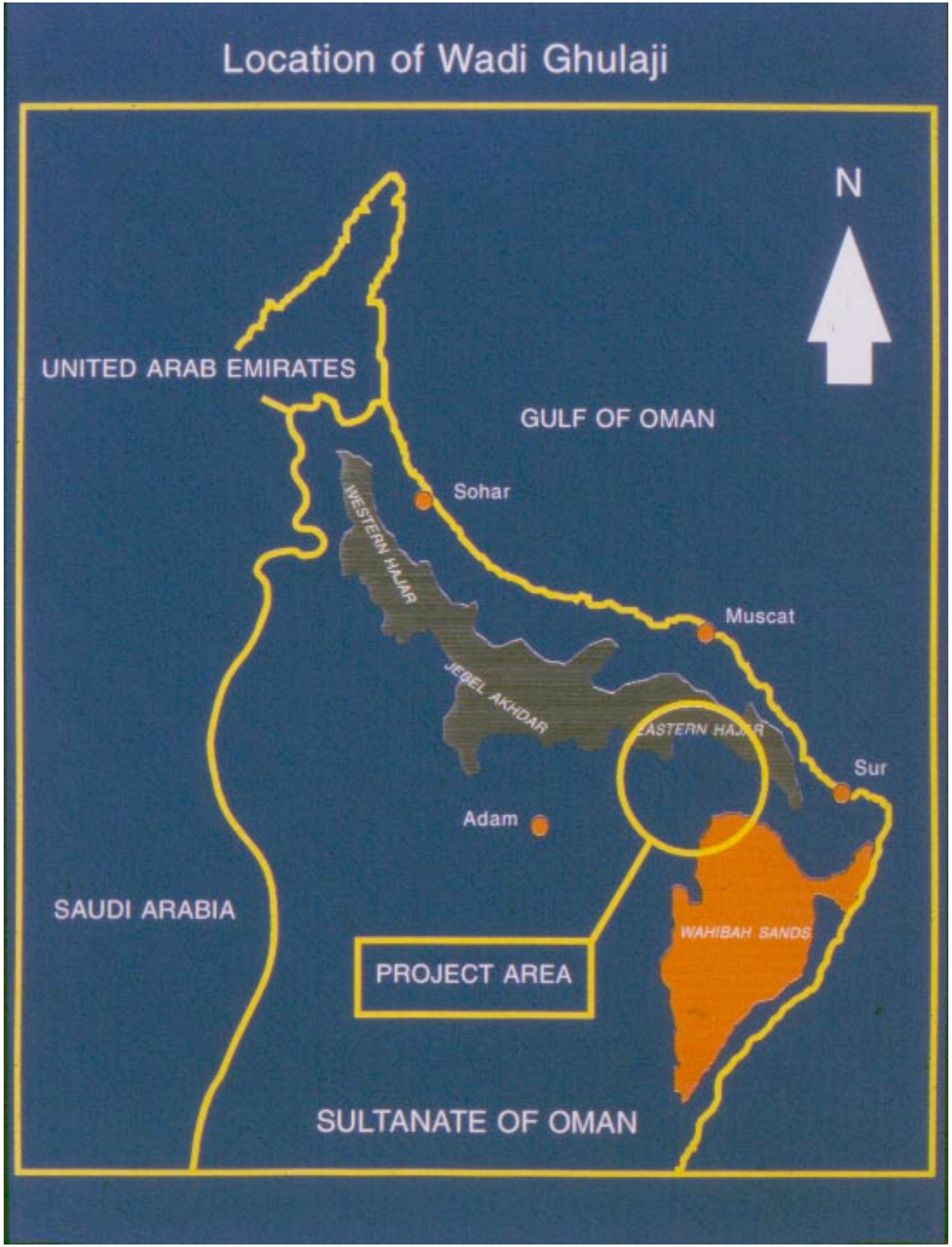
$R^2 = 0.49$



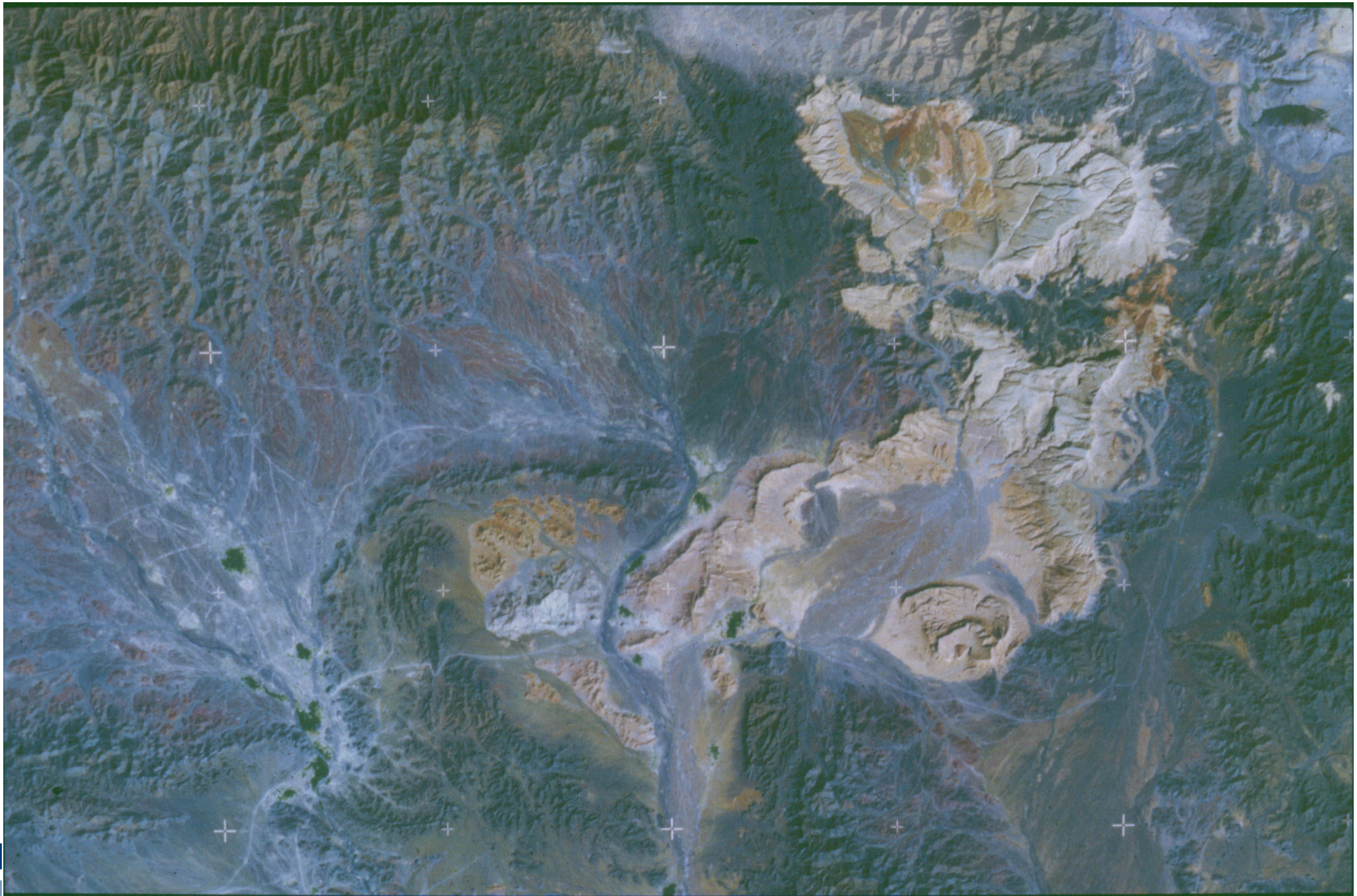
$$Q_v = -0.283 + 0.172R_v$$

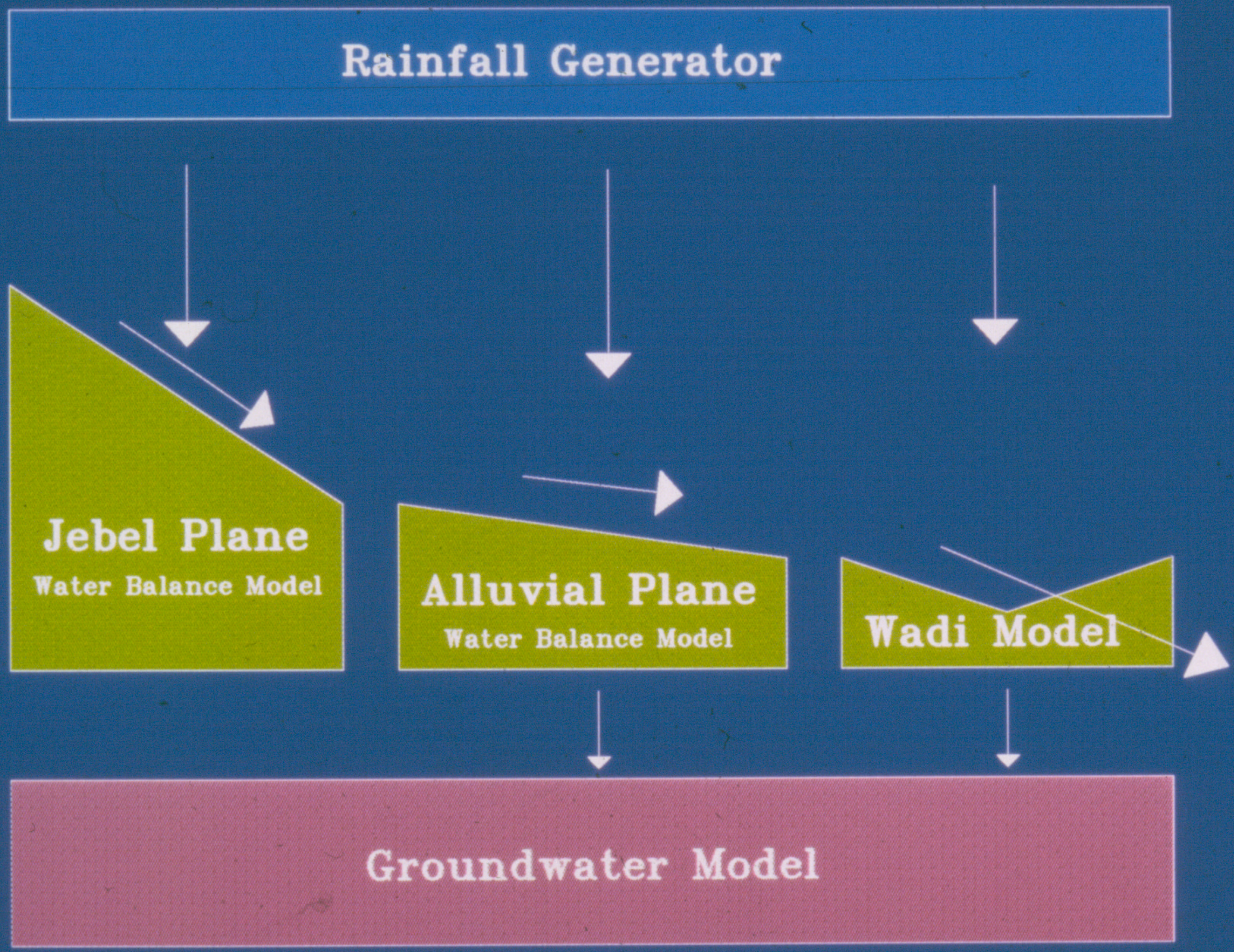
$R^2 = 0.60$

Continuous modelling, Wadi Ghulaji - evaluation of recharge dam performance

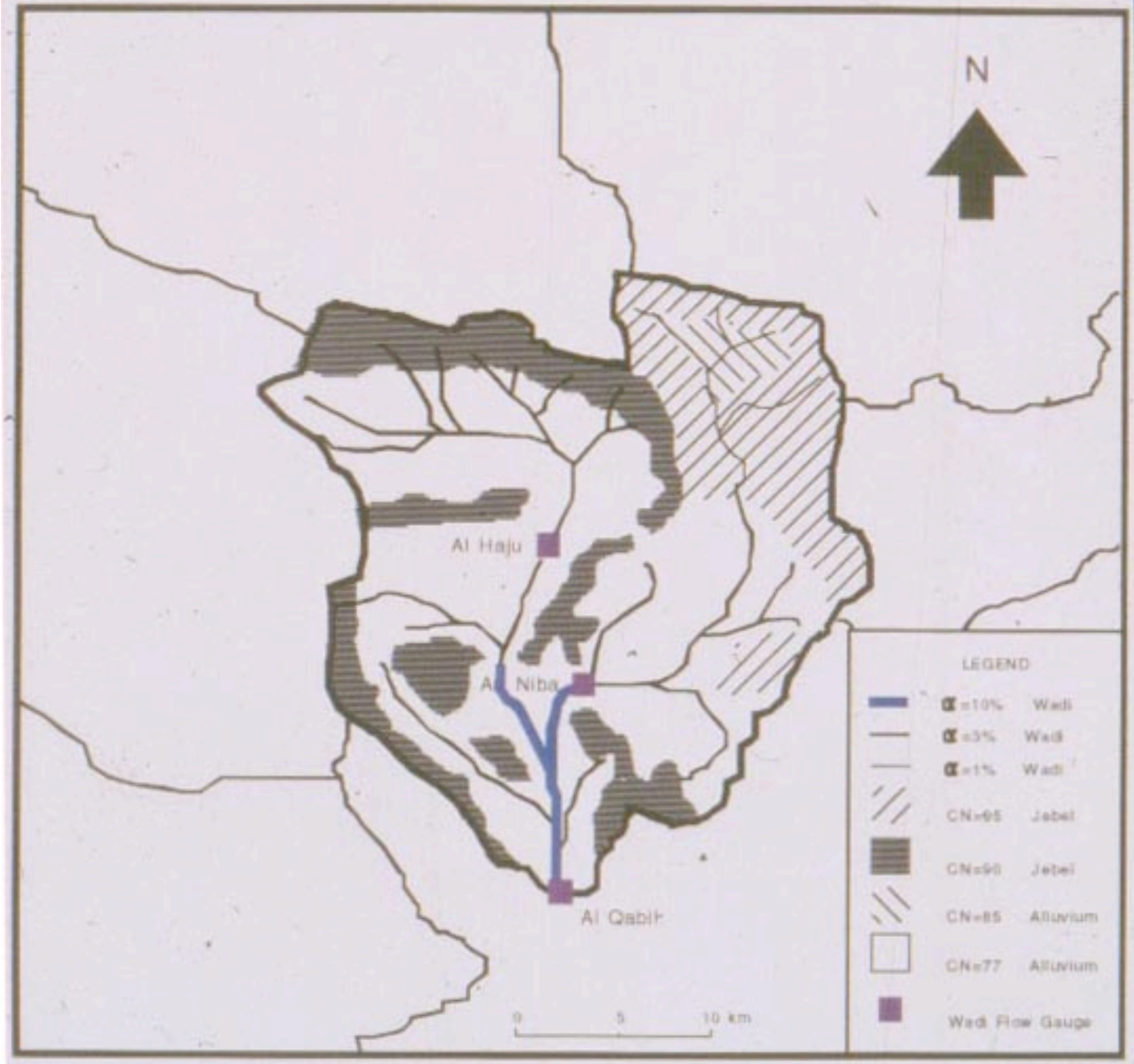

Location of Wadi Ghulaji
N
UNITED ARAB EMIRATES
GULF OF OMAN
Sohar
WESTERN HAJAR
Muscat
JEBEL AKHDAR
EASTERN HAJAR
Sur
Adam
SAUDI ARABIA
WAHIBAH SANDS
PROJECT AREA
SULTANATE OF OMAN


D
E
A
B
C

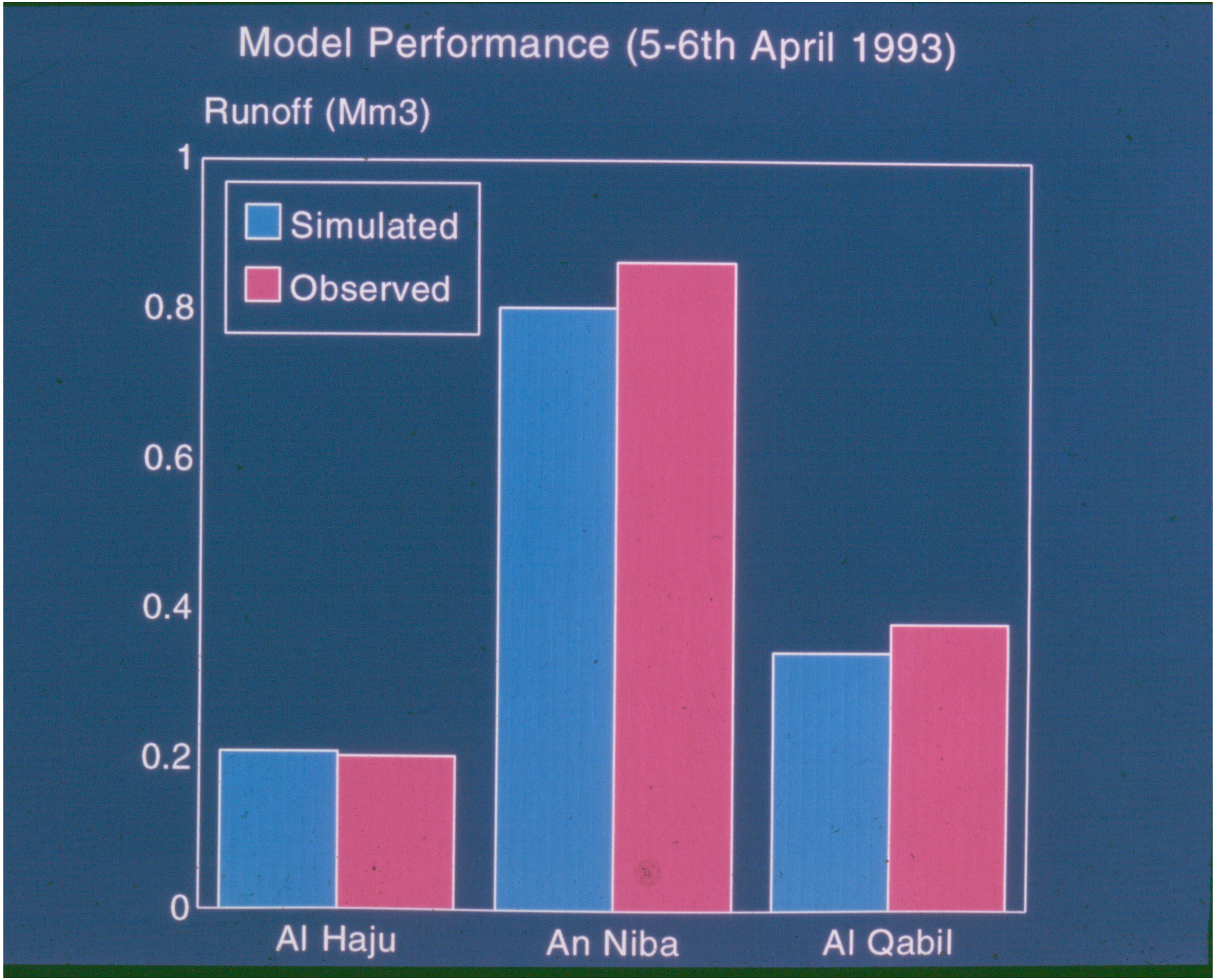




Schematic of the Wadi Ghulaji Water Resource Model



Distributed Calibrated Parameters


Model Performance (5-6th April 1993)
Runoff (Mm3)
1
0.8
0.6
0.4
0.2
0
Simulated
Observed
Al Haju
An Niba
Al Qabil

Annual catchment water balance (mm), simulated scenarios

Scenario	Rainfall	Evaporation	Groundwater recharge	Runoff	%Runoff
Wet	88	71	12.8	4.0	4.6
Average	87	72	11.2	3.5	4.0
Dry	53	45	5.5	1.7	3.2

Conclusions (1)

- Spatial variability of hydrological response can be a dominant influence in arid areas; for effective groundwater recharge management the spatial variability of recharge processes must be understood
- Distributed (or semi-distributed) rainfall–runoff models provide the capability to represent rainfall and runoff processes in a spatially distributed manner. In principle they can represent spatial variability of rainfall and transmission losses
- For water resource management problems, modelling can be a useful tool in exploring scenarios and management options – answering ‘what-if’ questions
- Models can also provide a framework for integrated data assimilation and improved understanding

Conclusions (2)

- The Wadi Ahin application illustrates that data sets typically used for distributed (or semi-distributed) rainfall–runoff modelling in arid regions cannot provide accurate reproduction of observed response across multiple events
- The limitations imposed by relatively sparse observations of rainfall are of particular concern, as well as the need for calibration of key surface and subsurface parameters
- Careful consideration is needed of the potential benefits to justify the effort and expense of this modelling approach
- Much research is needed to critically evaluate model performance for arid area applications
- Future progress probably requires stochastic modelling of spatial rainfall
- Improved data is a key requirement for improved modelling and management

Some further reading:

- Wheater, H.S., Sorooshian, S. and Sharma KD (Eds.) (2008) Hydrological modelling in arid and semi-arid areas. Cambridge University Press. 195pp.
- Wagener, T., Wheater, H.S. and Gupta, H.V. (2004) Rainfall-Runoff Modelling in Gauged and Ungauged Cathments, Imperial College Press, 306pp.

- McIntyre, N., Al-Qurashi, A., Wheater, H.S. (2007) Regression analysis of rainfall-runoff data from an arid catchment in Oman. Hydrological Sciences Journal, Vol 52, no. 6, 1103-1118, December.
- Al-Qurashi, A., McIntyre, N., Wheater, H., Unkrich, C. (2008) Application of the Kineros2 rainfall-runoff model to an arid catchment in Oman. Journal of Hydrology, 355, 91-105.

And for more information on water resources in arid areas, data and modelling tools visit http://www.g-wadi.org

Some recent work on rainfall modelling

- Yang, C., Chandler, R.E., Isham, V.S. and Wheater, H.S. (2005) Spatial-temporal rainfall simulation using generalized linear models. Water Resources Research, Vol. 41, W11415, doi 10.1029/2004 WR003739.
- Kenabatho P.K, McIntyre N.R., Wheater H.S. (2008) Application of generalised linear models for rainfall simulations in semi arid areas: A case study from the Upper Limpopo basin in north east Botswana. Proc. 10th BHS National Hydrology Symposium, Exeter, September.
- Mirshahi B., Onof C. J., Wheater H.S. (2008) Spatial-temporal daily rainfall simulation for a semi-arid area in Iran: a preliminary evaluation of generalised linear models. Proc. 10th BHS National Hydrology Symposium, Exeter, September.