LDAS - TUNISIE

IMPROVEMENT OF WATER RESOURCES MANAGEMENT AND ADAPTATION TO CLIMATE CHANGE – Tunisia

Reconstruction and forecasting of floods in the Medjerda river

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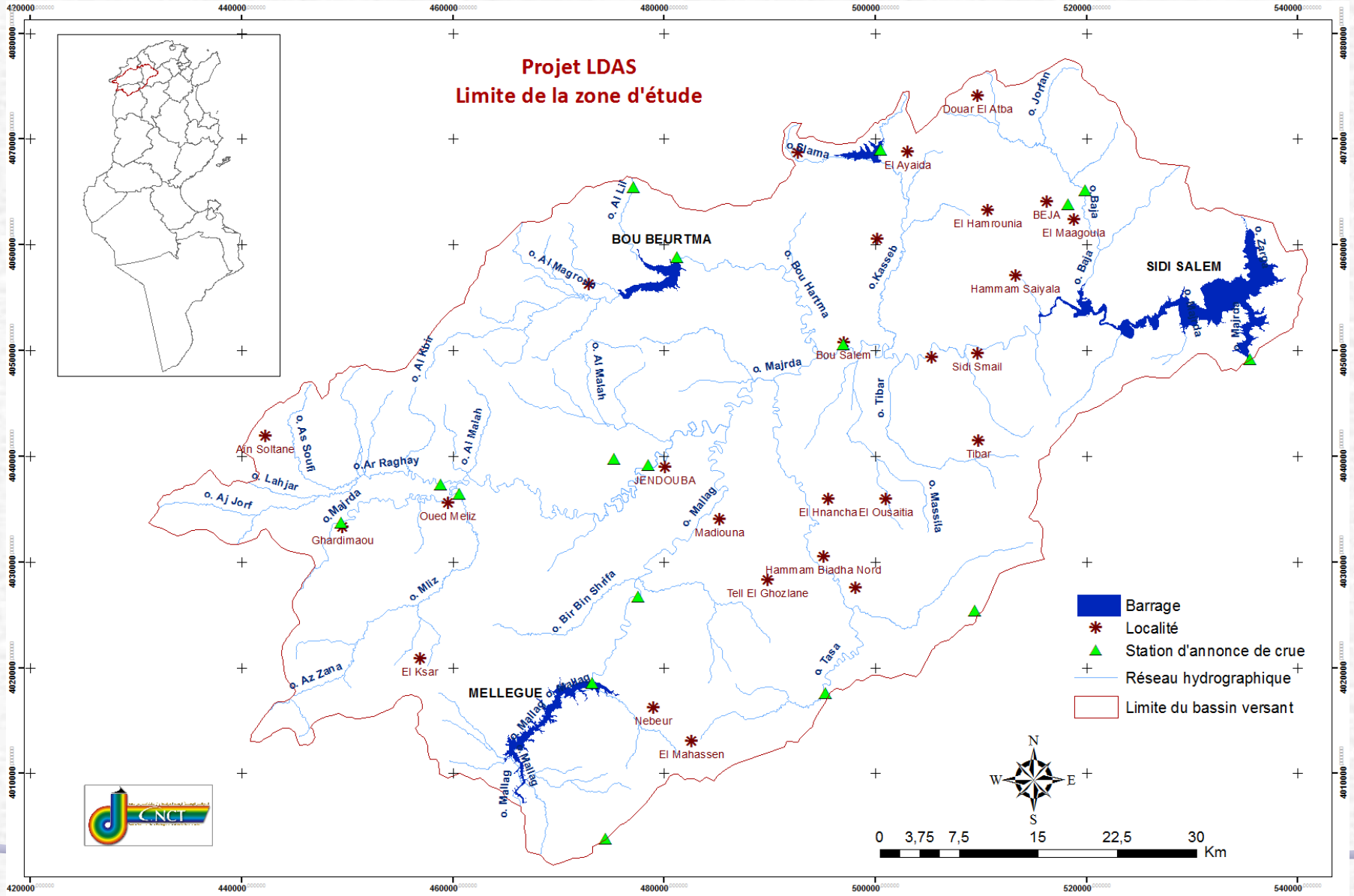
Study area



Projet LDAS
Limite de la zone d'étude
BOU BEURTMA
SIDI SALEM
MELLEGUE
Douar El Atba
El Ayaida
El Hamrounia
BEJA
El Maagoula
Hammam Saiyala
Bou Salem
Sidi Smail
Tibar
JENDOUBA
Oued Meliz
Ghardimaou
Ain Soltane
Madiouna
El Hnancha
El Ousaitia
Hammam Biadha Nord
Tell El Ghozlane
El Ksar
Nebeur
El Mahassen
o. Blama
o. Jorfan
o. Baja
o. Zarg
o. Majrda
o. Al Lil
o. Al Magrou
o. Bou Hartma
o. Kasseb
o. Al Kbir
o. Al Malah
o. Tibar
o. As Soufi
o. Ar Raghay
o. Lahjar
o. Aj Jorf
o. Mallag
o. Massila
o. Mliz
o. Bir Bin Shrifa
o. Az Zana
o. Tasa
Barrage
Localité
Station d'annonce de crue
Réseau hydrographique
Limite du bassin versant
N
S
E
W
0 3,75 7,5 15 22,5 30
Km
420000
440000
460000
480000
500000
520000
540000
4080000
4070000
4060000
4050000
4040000
4030000
4020000
4010000

Physical context

- Average rainfall between 400 and 600 mm/year

Parameters and formula		Medjerda to Ghardimaou	Medjerda to Jendouba	Medjerda to Bou Salem
A (km²)		1490	2424	16 483
P (km)		215	290	754
Kc	$\frac{P}{2\sqrt{A}}$	1,57	1,66	1,67
Alt méd (m)	$H_{50\%}$	800	700	700
D (m)	$H_{5\%} - H_{95\%}$	565	565	565
Ig (m/km) Global Index	D/L	6,2	6,2	6,2
Ds (m) Specific Height difference	$D_s = I_g * \sqrt{A}$	238	238	238
Distance between stations (km)				

- Kc → Form elongated to very elongated,
- Ig, Ds → High relief

Presentation of models

Model of Muskingum : *is a hydrological* ***flow routing model*** *with lumped parameters, which describes the transformation of discharge waves in a river bed using two equations. The first one is the continuity equation (conservation of mass) and the second equation is the relationship between the storage, inflow, and outflow of the reach (the discharge storage equation). These equations are applied within a river reach between two cross sections of a river. The parameters of the* ***model*** *can be estimated by several methods.*

$$Q_v(t+d) = a_1 Q_a(t) + a_2 Q_a(t+d) + a_3 Q_v(t)$$

b. Model of Regression

$$Q_v(t+d) = b_1 Q_a(t+d-\tau_p) + b_2 Q_v(t) + b_3 Q_v(t-d)$$

a_i and b_i are determinated by meansquare method

Evaluation criteria

- The **standard deviation** between the observed and calculated values:

$$S = \sqrt{\frac{\sum_{i=1}^{N}\left(Q_{cal}(i) - Q_{obs}(i)\right)^2}{N}}$$

- **The relative error of peak**:

$$S1 = \frac{Q_{cal\,\max} - Q_{obs\,\max}}{Q_{obs\,\max}}$$

- The **time between peaks of the flow** observed and calculated:

$$tm = \tau_{Qp} - \tau_{Q_o}$$

Observed floods

	Flood	Start	End
1	**03/1973**	1973/3/27 0:00	1973/4/2 12:00
2	**03/1982**		
4	**24-30/12/82**	1982/12/23 0:00	1982/12/30 0:00
5	**15/11/1990**	15/11/1990 13:30	18/11/1990 23:30
6	**13/12/1990**	02:30	16/12/1990 18:30
7	**27/12/1990**	27/12/1990 00:30	27/12/1990 00:30
8	**14/02/1991**	08:30	18/02/1991 07:30
9	**15/03/1991**	18/03/1991 13:30	23/03/1991 02:30
10	**04/01/1995**	02:30	07/01/1995 17:30
11	**06/02/1996**	12:30	11/02/1996 09:30
12	**28/02/1996**	27/02/1996 19:30	03/03/1996 05:30
13	**11/03/1996**	10/03/1996 16:30	14/03/1996 07:30
14	**14/03/1996**	14/03/1996 04:30	18/03/1996 13:30
15	**12/01/1997**	00:30	15/01/1997 11:30
16	**27/12/1997**	27/12/1997 03:30	01/01/1998 02:30
17	**21/01/1998**	20/01/1998 08:30	26/01/1998 06:30
18	**08/11/1999**	00:30	11/11/1999 16:30
19	**25/05/2000**	25/05/2000 19:30	30/05/2000 01:30
20	**11/01/2003**	11/01/2003 5	14/01/2003 23
21	**12/12/2003**	12/12/2003 07	16/12/2003 06
22	**09/02/2005**	09/02/05 00	12/02/05 15
23	**12/04/2009**	12/04/2009 00:00	15/04/2009 21:00

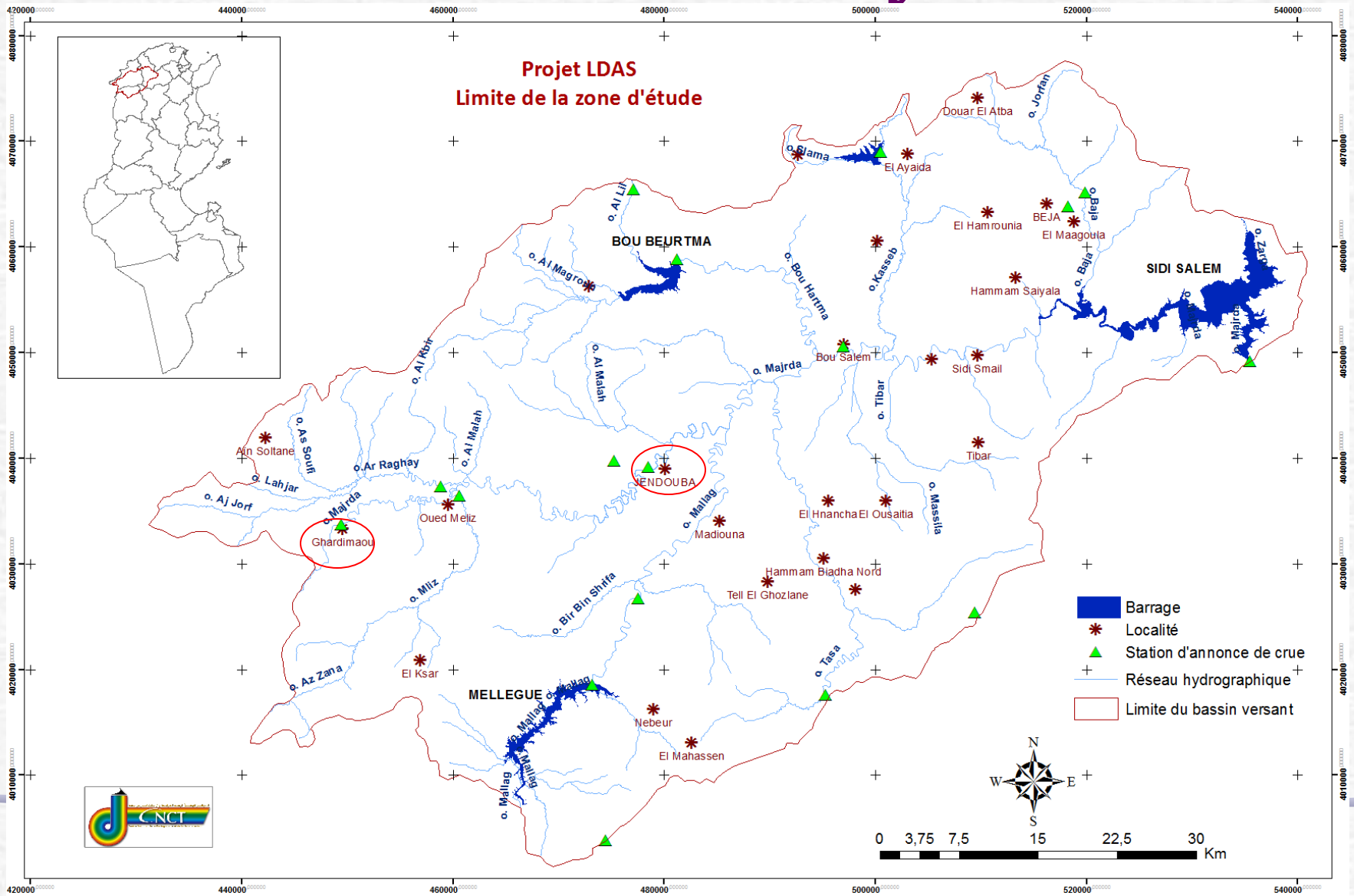
Preliminary Results

14 floods observed and available, 9winter floods, 3 spring floods and 2 autumn floods:

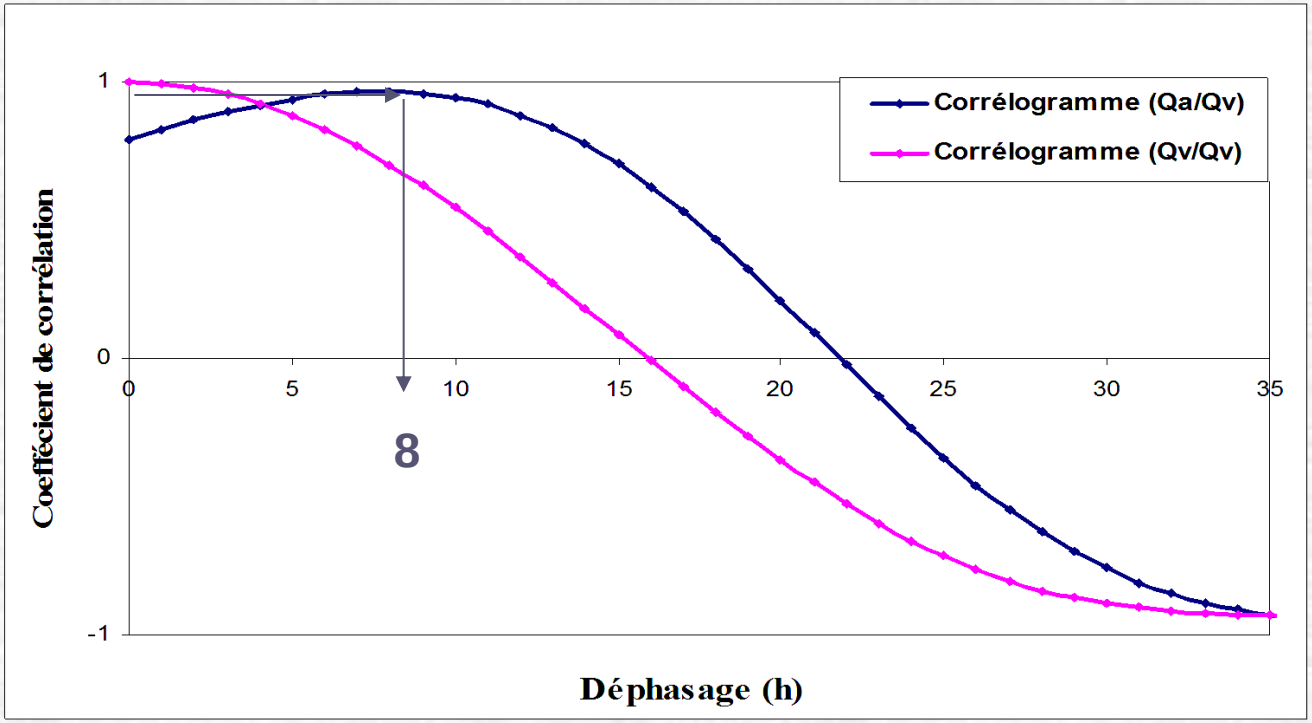
Date of flood	Maximum flow (m3/s) in stations		
	Ghardiamou	Jendouba	Bou Salem
12/11/1990	217,5	375,5	125
13/12/1990	31,2	61,2	114,8
22/12/1990	130,5	229	373,3
14/02/1991	18,8	45,82	89,67
15/03/1991	22,59	423,6	518,2
04/01/1995	57,8	72,85	64,53
06/02/1996	288,1	411,5	530,6
28/02/1996	179,3	225,5	227,8
11/03/1996	26,91	41	44,59
14/03/1996	174,7	186,5	197
12/01/1997	25,18	132	122,3
27/12/1997	164,4	194,2	191,6
21/01/1998	168,7	419,5	419,5
08/11/1999	21,73	128,2	119,5

Flood reconstruction

I. Flood reconstruction from Ghardimaou to Jendouba



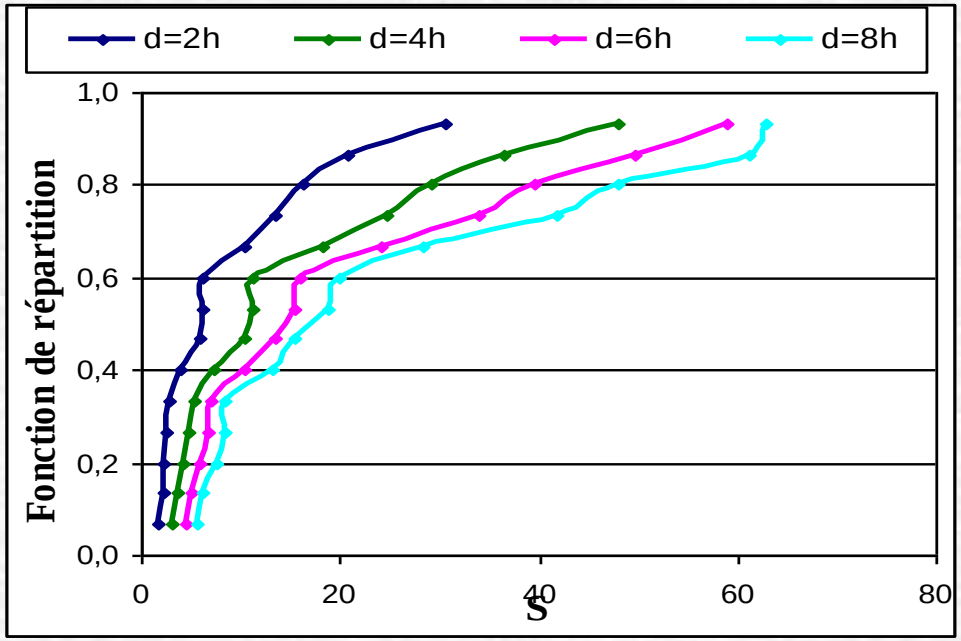
1. Correlogram

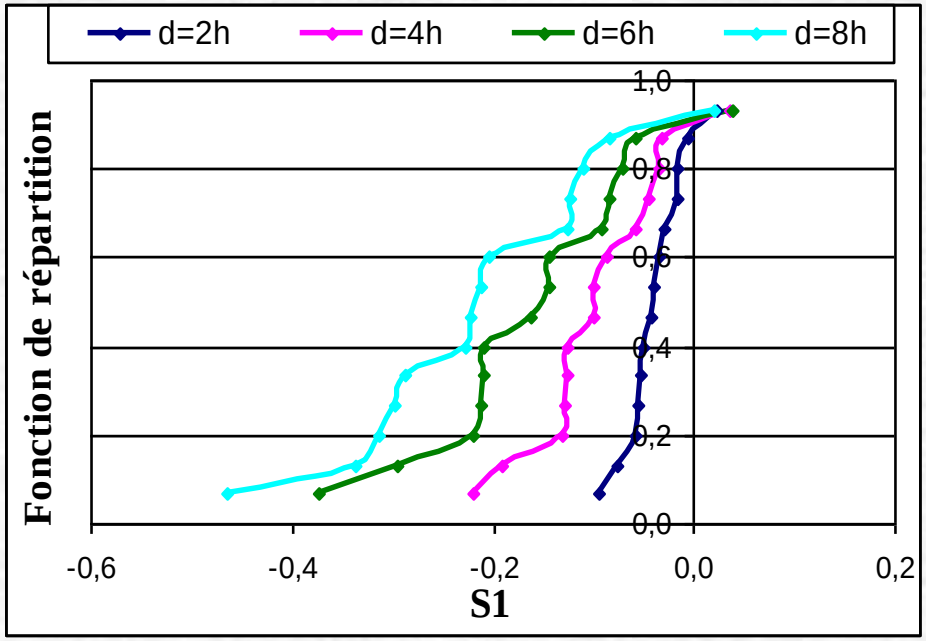


Correlogram of the flood flows of 12/01/1997 on the section Ghardiamou - Jendouba

- The maximum correlation coefficient is 0.96 corresponding to Δt equal to 8 h, which is the propagation time of the flood of 12/01/1997.

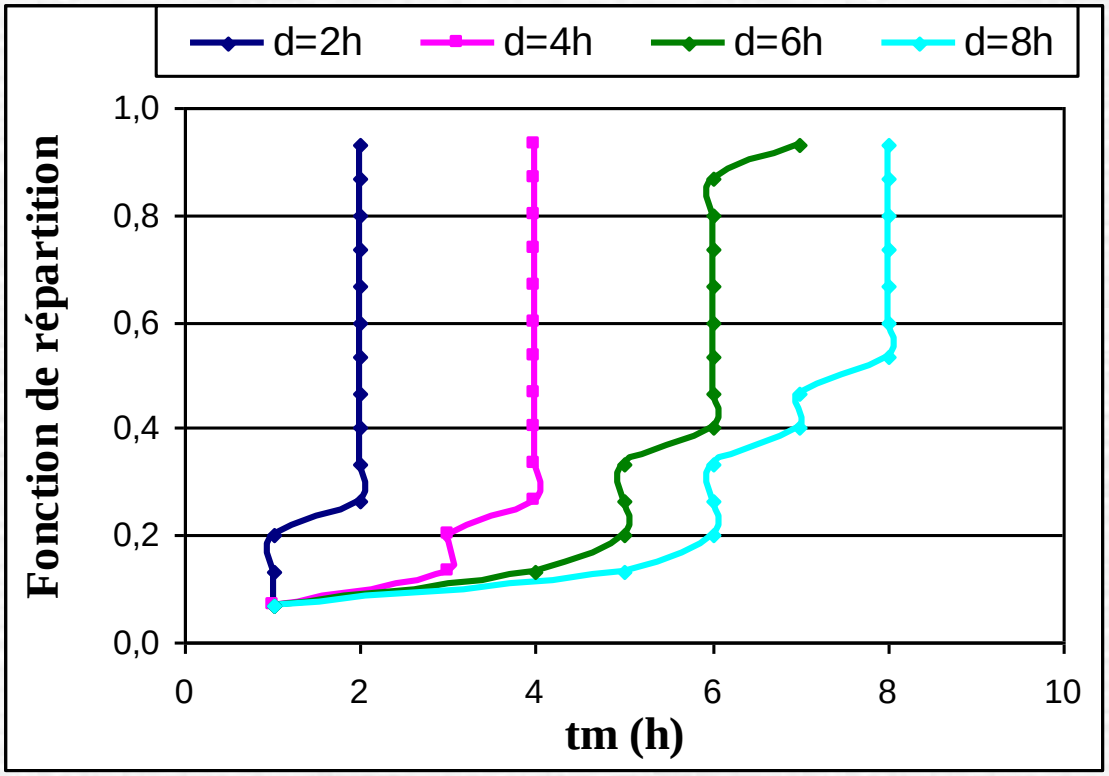
2. Application of Muskingum model





Distribution function of 'S' and 'S1' on the section GHARDIMAOU - Jendouba

- ‘S’ and ‘S1’ increase with reconstruction periods.
- The Muskingum model underestimates the peak discharge.



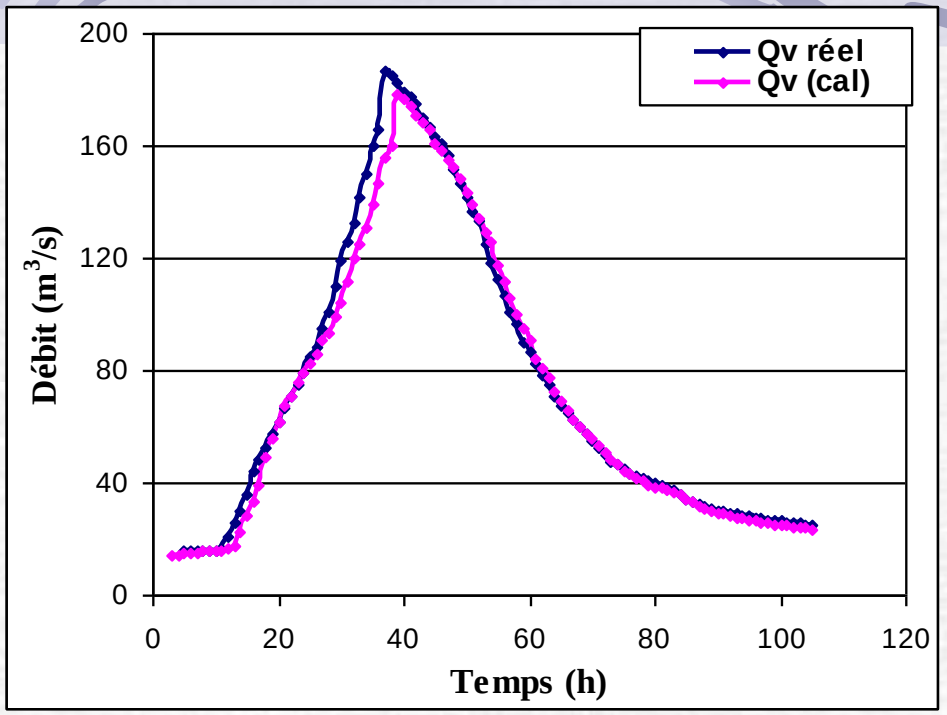
Distribution function 'tm'
on the section Ghardimaou - Jendouba

- By increasing the time step, 'tm' increases,

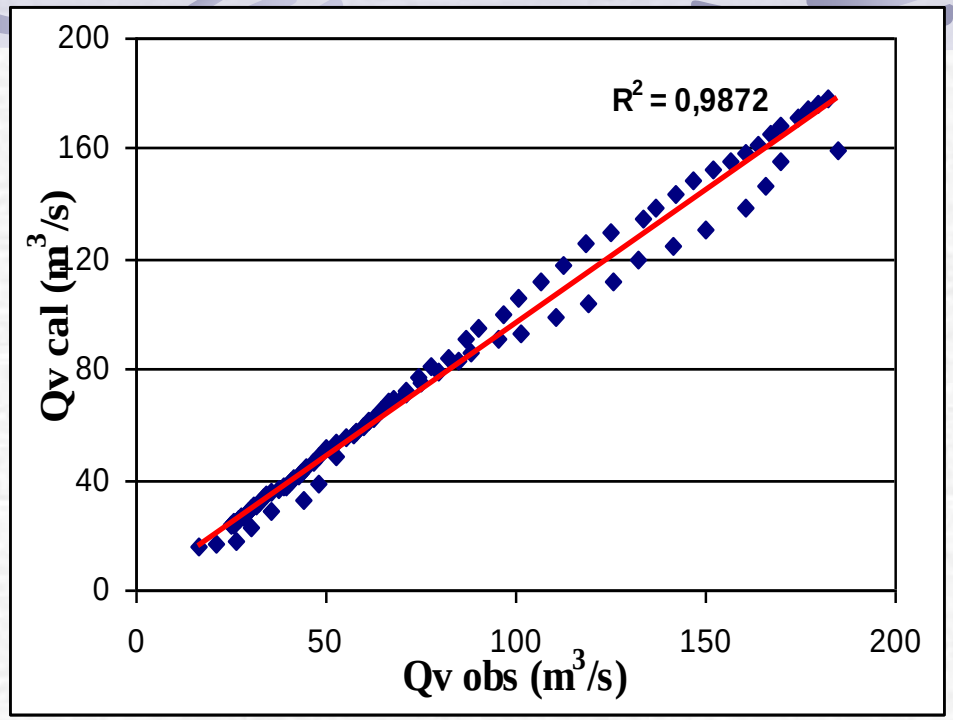
Results of flood reconstruction with Muskingum model (period = 2 hours) on the section Ghardimaou - Jendouba

Flood	Criterion		
	S	S1	tm
12/11/1990	30,697	-0,094	2
13/12/1990	2,636	-0,017	2
22/12/1990	13,450	-0,040	2
14/02/1991	2,171	-0,006	2
15/03/1991	20,841	-0,075	2
04/01/1995	2,891	-0,055	2
06/02/1996	16,270	-0,059	2
28/02/1996	10,291	-0,050	1
11/03/1996	1,641	-0,028	2
14/03/1996	**6,074**	**-0,035**	**2**
12/01/1997	2,145	0,022	1
27/12/1997	5,783	-0,053	1
21/01/1998	3,910	-0,015	2
08/11/1999	6,058	-0,042	2

Flood of 14/03/1996 (time = 2 hours)



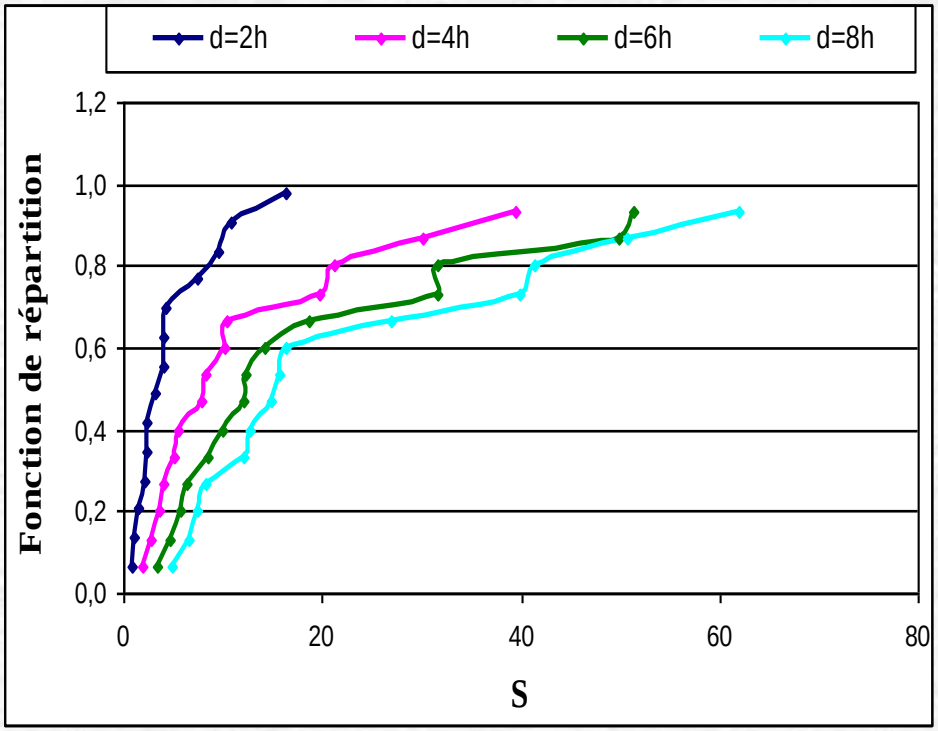
Hydrograms (observed and calculated)

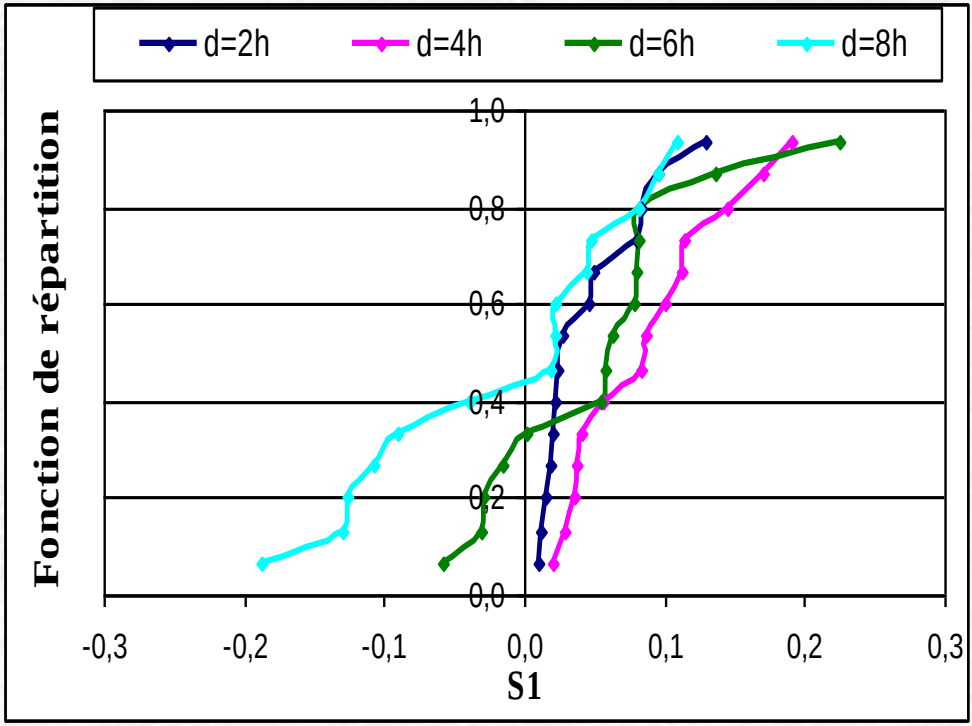


Correlation between flows (observed and calculated)

- the shape of the hydrogram and the peak are reproduced
- Calculated Qmax = -3.5% Qmax observed
- 'Tm' = 2 h,
- The error ranges between 0.001 and 25 m3 / s.

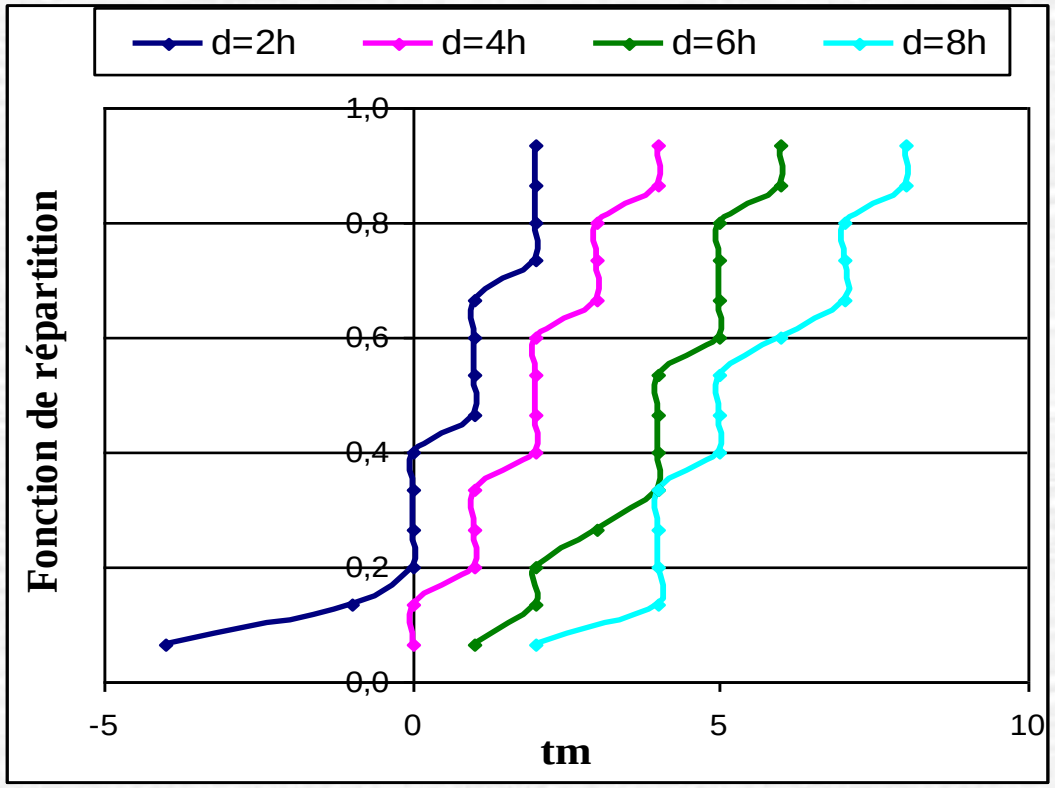
3. Application of Regression model





Distribution of the function 'tm'
on the section Ghardimaou - Jendouba

- ‘S’ increase with reconstruction times.
- S1 'has other positive and negative values,
- The number of negative 'S1' is more important for the period 8 h.



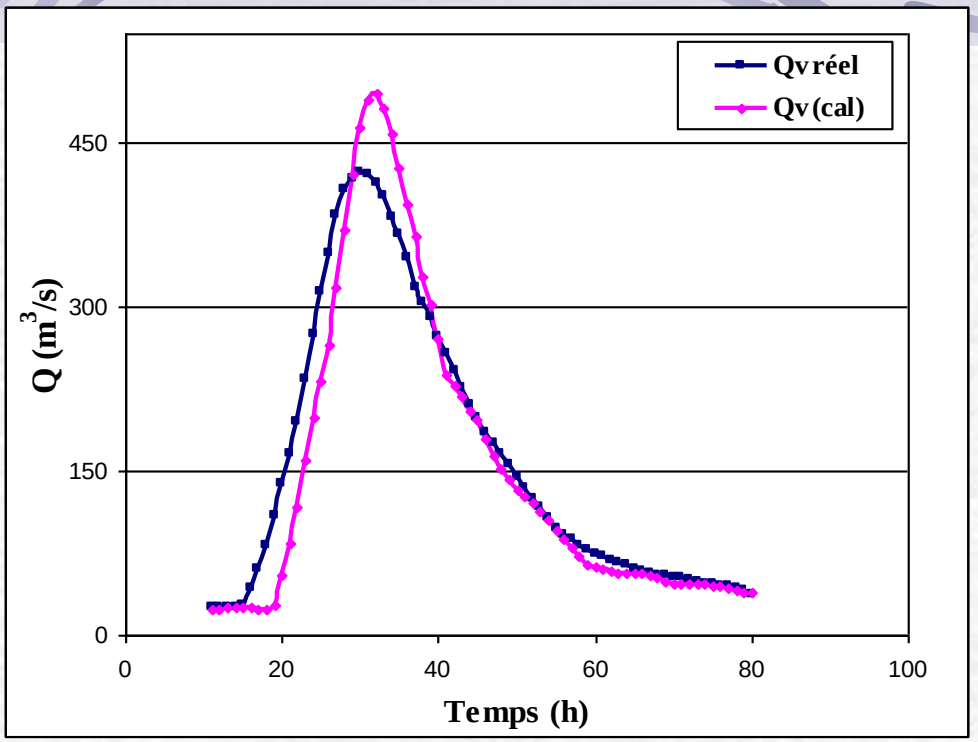
Distribution of the function 'tm'
on the section Ghardimaou - Jendouba

- ‘tm’ increase with the period of reconstruction.

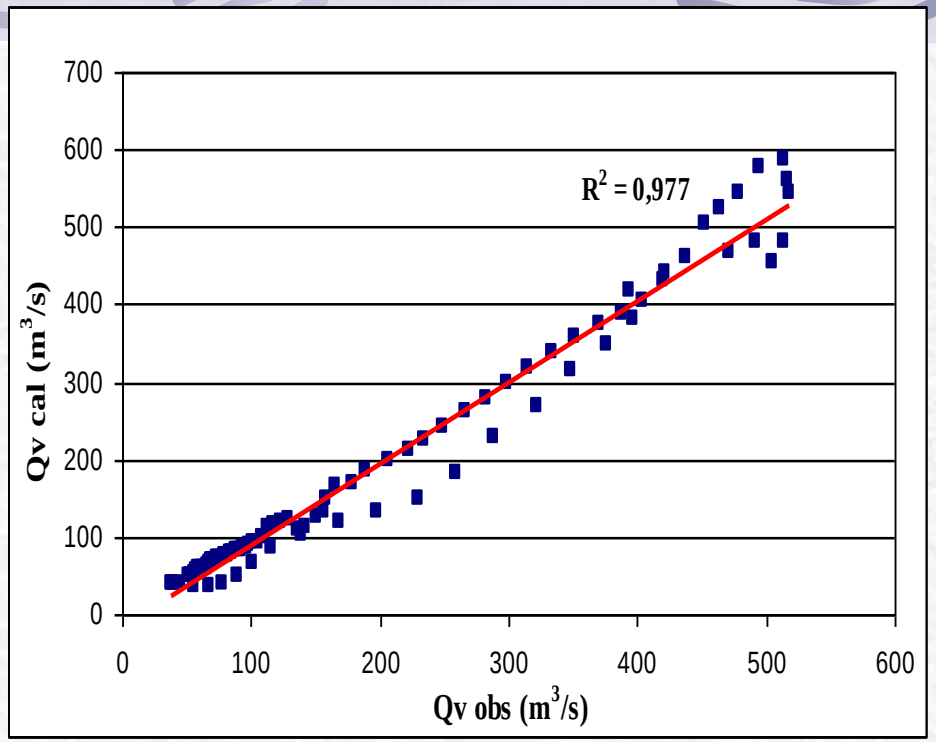
Results of flood reconstruction with Regression model (period= 2 hours) on the section Ghardimaou - Jendouba

Flood	Criterion		
	S	S1	tm
12/11/1990	39,432	0,145	2
13/12/1990	4,046	0,021	4
22/12/1990	19.681	0.191	2
14/02/1991	2,692	0,113	0
15/03/1991	**30,205**	**0,171**	**2**
04/01/1995	3,580	0,035	2
06/02/1996	21,146	0,055	3
28/02/1996	10.361	0.029	1
11/03/1996	2,012	0,084	1
14/03/1996	7,766	0,113	4
12/01/1997	5,475	0,038	3
27/12/1997	8.190	0.087	3
21/01/1998	5,130	0,101	0

Flood of 5/03/1991 for the period of 4 h



Hydrograms (observed and calculated)



Correlation between flows (observed and calculated)

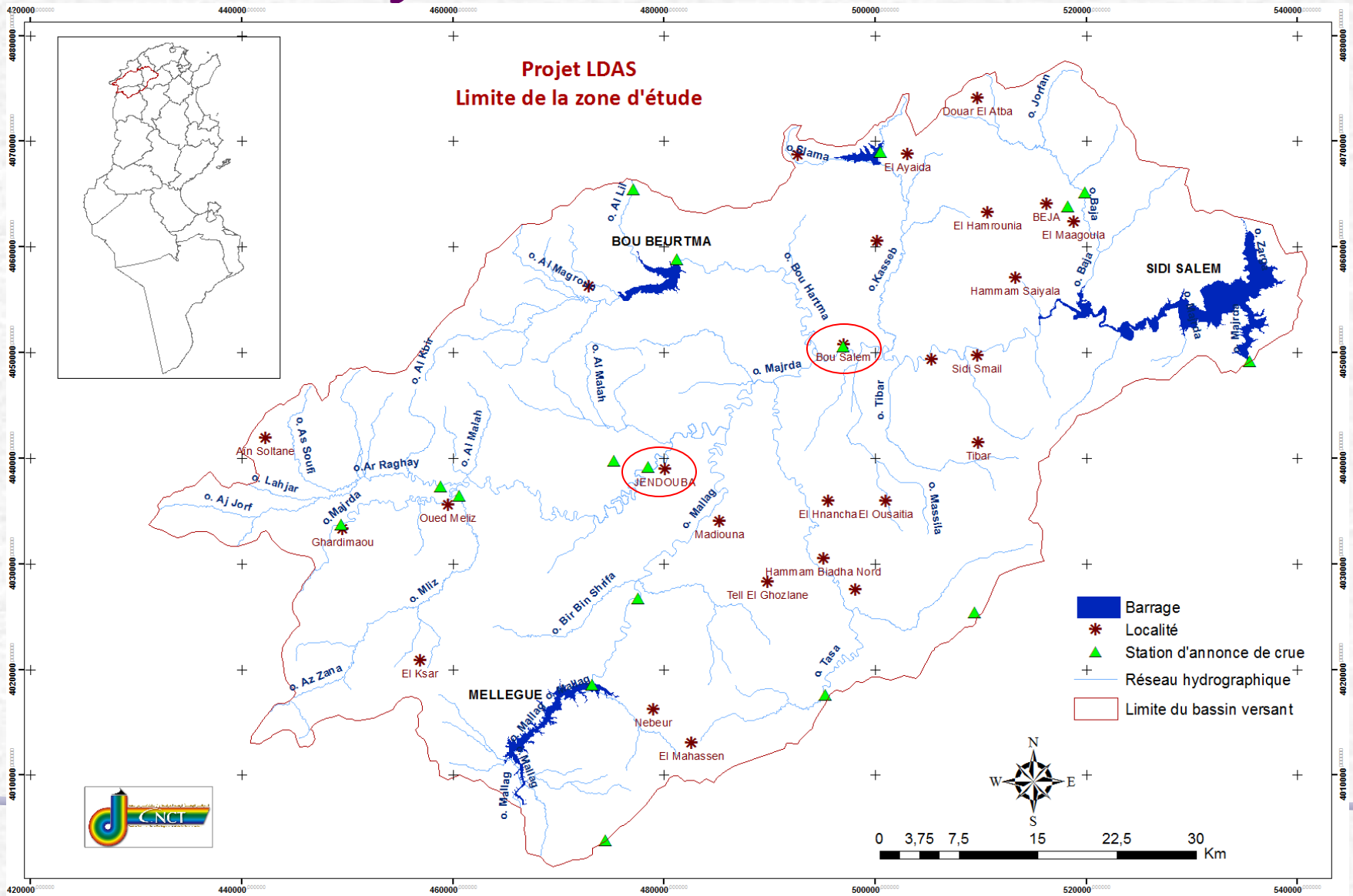
- The shape of the peak flow has become closer,
- Calculated Qmax = **17%** Qmax observed
- 'Tm' = 2 h,
- The error ranges between 0.14 and 84 m3 / s.

Comparison between the results of reconstruction by Muskingum and Regression model on the section of Ghardimaou - Jendouba

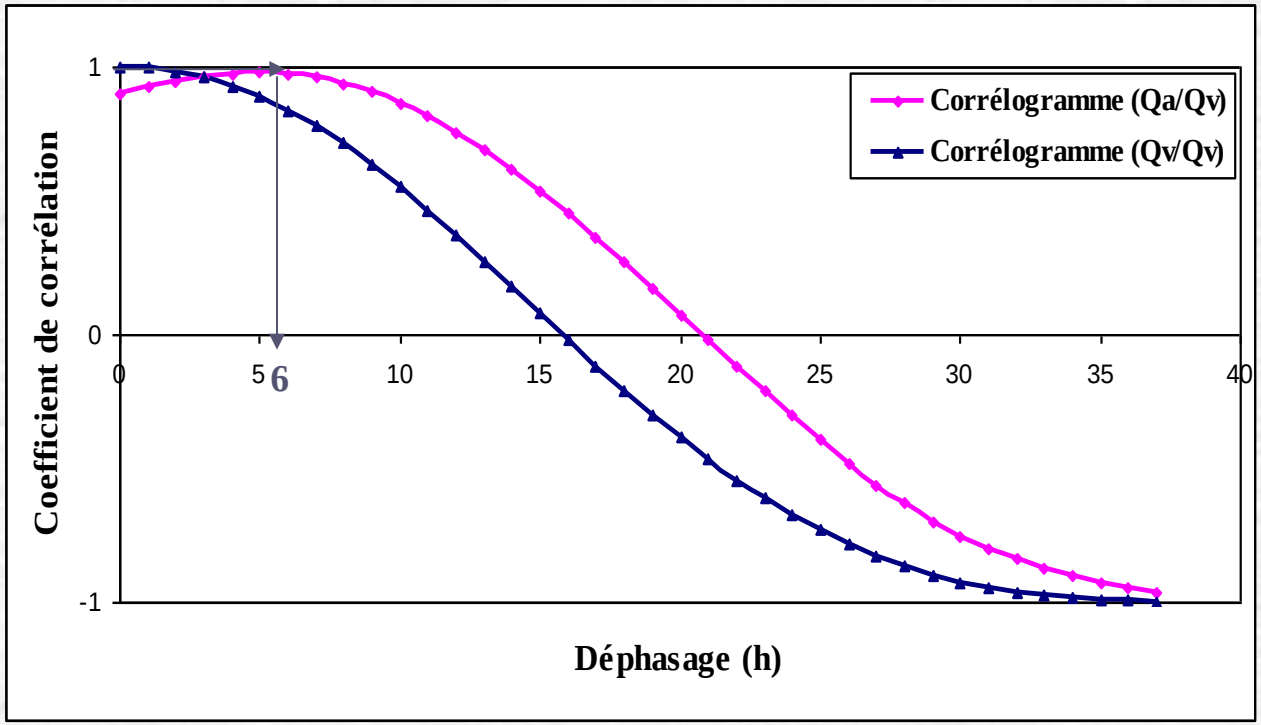
Section	Period (h)	Criterion of evaluation		
		'S'	'S1'	'tm'
Ghardimaou – Jendouba	2	R	M	M
	4	R	R	M
	6	R	R	R
	8	R	R	R

- The Regression model satisfy 'S' for all periods,
- 'S1' is satisfied with Muskingum model for 2h and Regression model for the other periods
- tm is satisfied by Muskingum model for 2 and 4 h and by Regression model for 6 and 8 h,

II. Flood reconstruction from Jendouba to Bou Salem



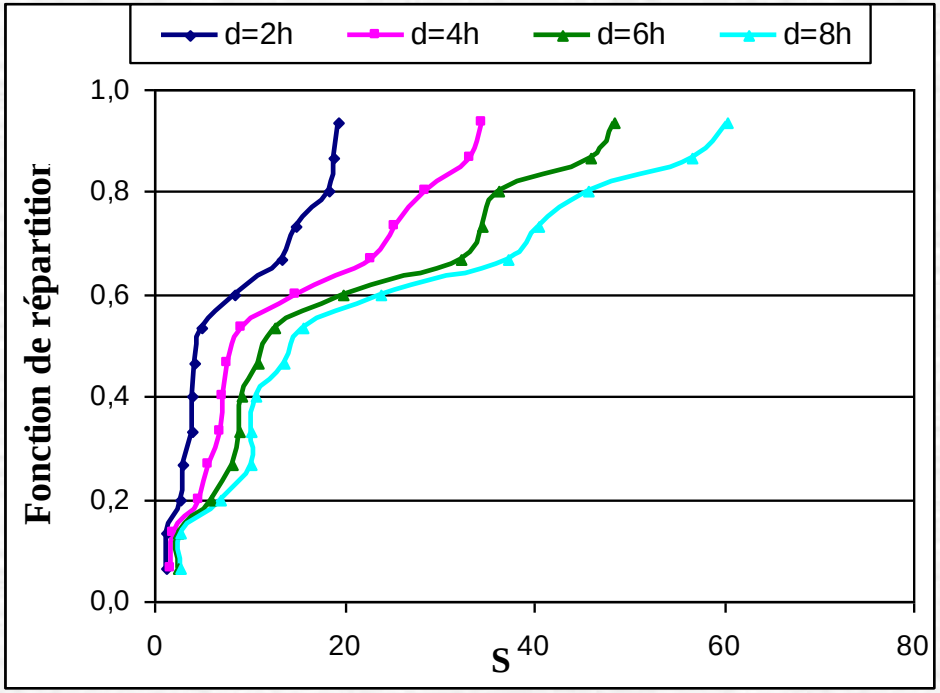
1. Correlogram

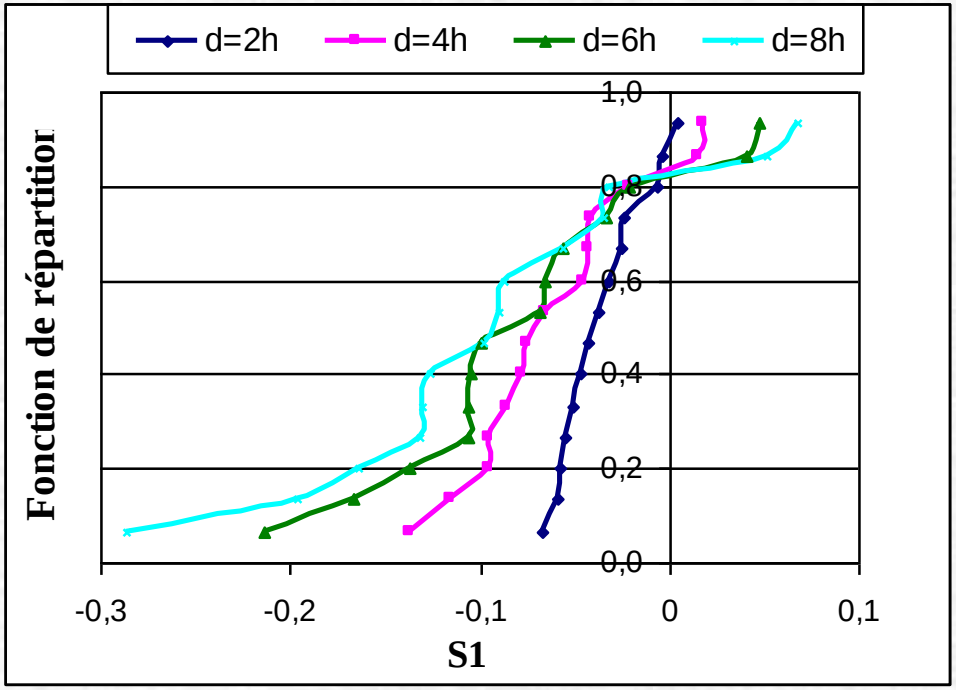


Correlogram of the flood flows of 12/01/1997 on the section Jendouba- Bousalem

- The maximum correlation coefficient is 0.979 corresponding to Δt equal to 6 h

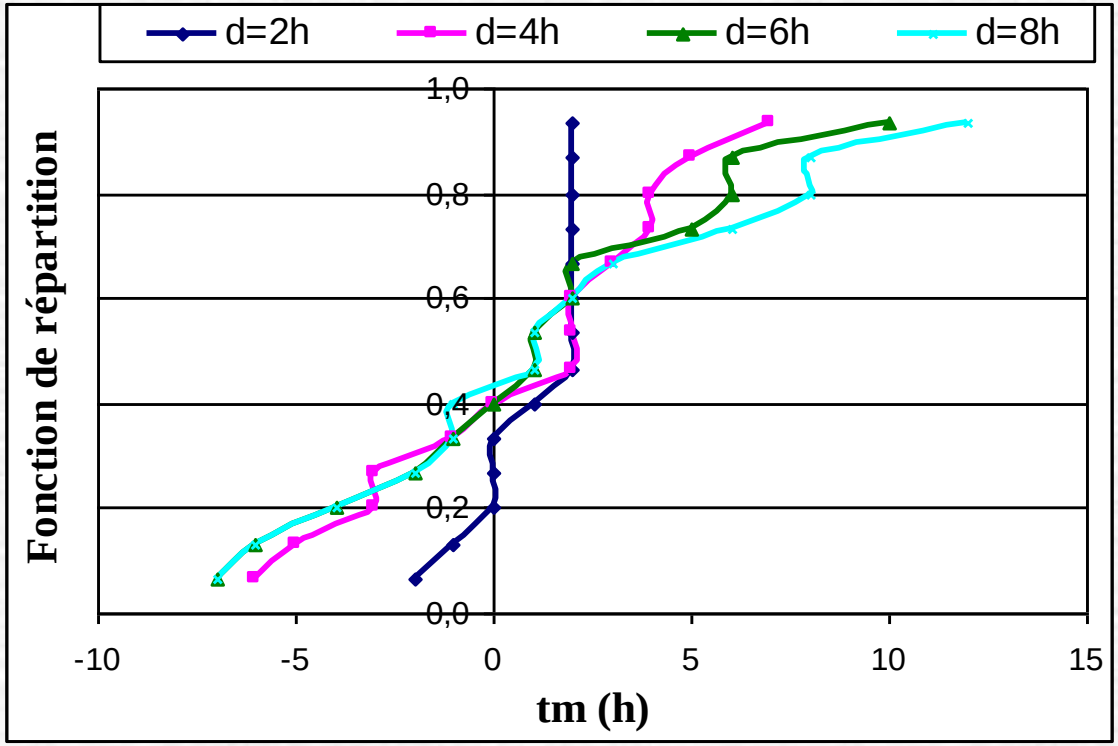
2. Applications of Muskingum model





Distribution function of 'S' and 'S1' on the section Jendouba - Bousalem

- ‘S’ increase with reconstruction period.
- S1 increase when the period increase.



Distribution of the function 'tm'

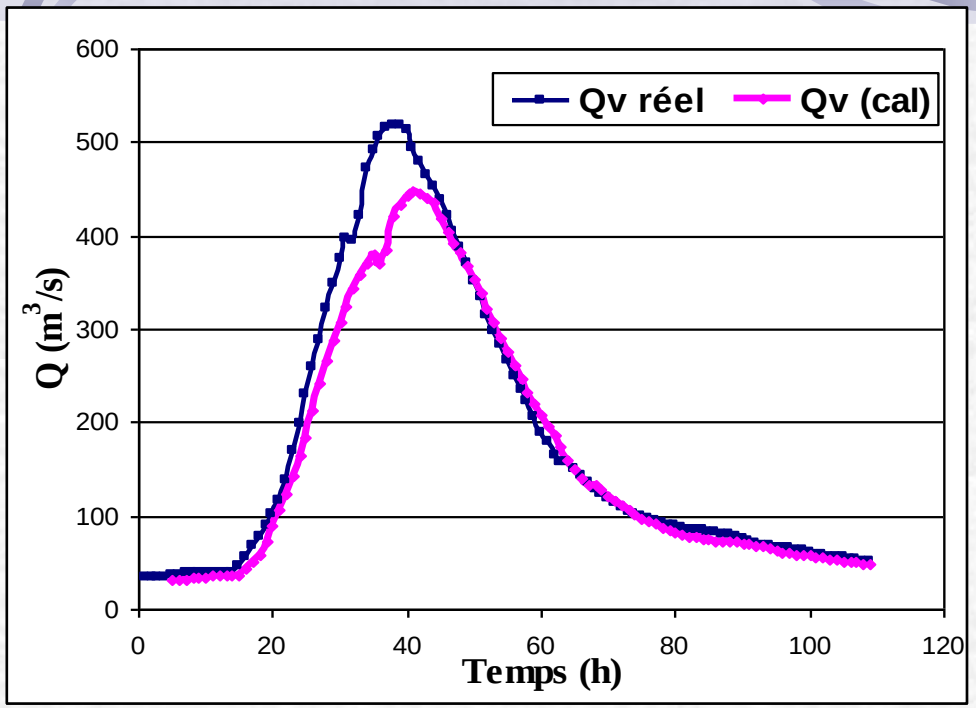
on the section Jendouba – Bou Salem with Regression model

flows peak are reproduced in delay phase from 1 to 12 h and in advance phase from 1 to 7 h.

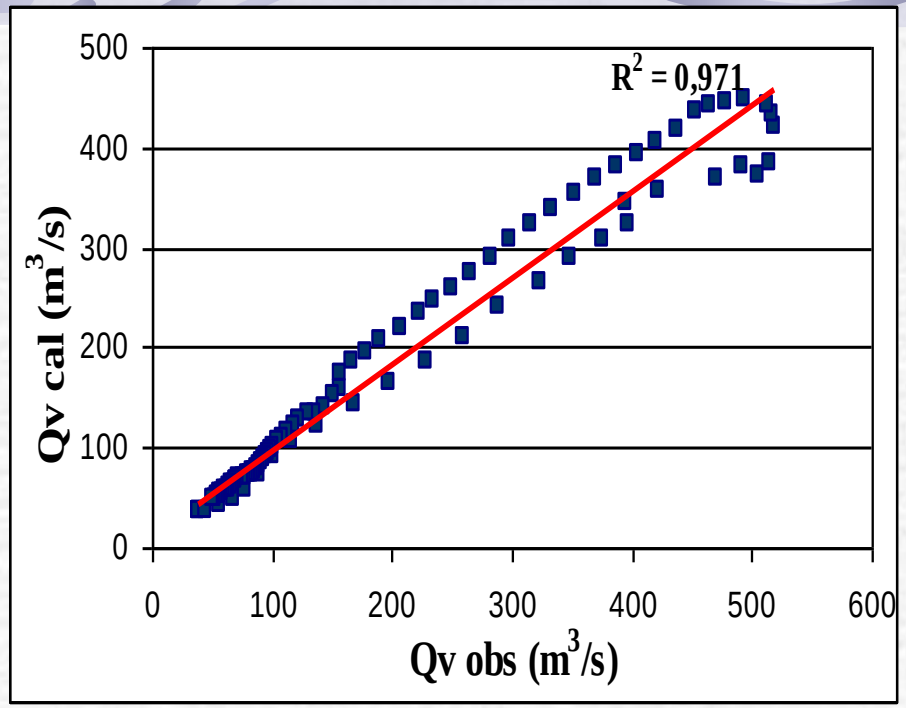
Results of flood reconstruction with Muskingum model (period= 2 hours) on the section Jendouba – Bou Salem

Flood	Criterion		
	S	S1	tm
12/11/1990	28.461	0.015	2
13/12/1990	7.579	-0.078	7
22/12/1990	22.890	-0.042	4
14/02/1991	5.689	-0.046	4
15/03/1991	**33.178**	**-0.137**	**3**
04/01/1995	1.861	1.861	0
06/02/1996	34.494	-0.116	5
28/02/1996	14.843	-0.086	-6
11/03/1996	1.972	-0.041	-1
14/03/1996	9.219	-0.095	2
12/01/1997	4.635	-0.075	2
27/12/1997	7.114	-0.065	-3
21/01/1998	25.359	0.017	-5
08/01/1999	6.975	-0.096	-3

Flood of 15/03/1991 for period = 4 h



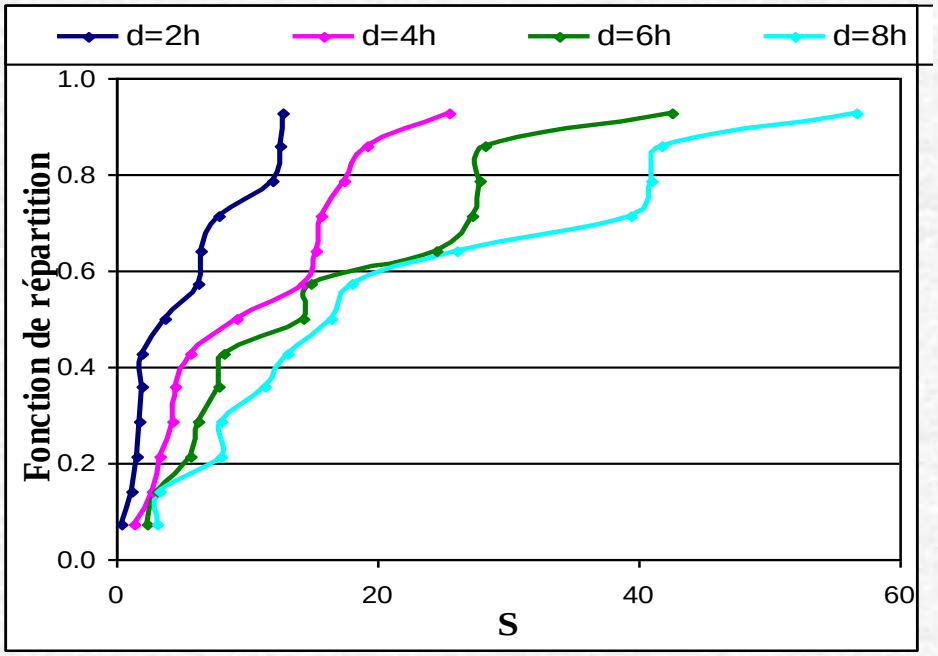
Hydrographs observed and calculated

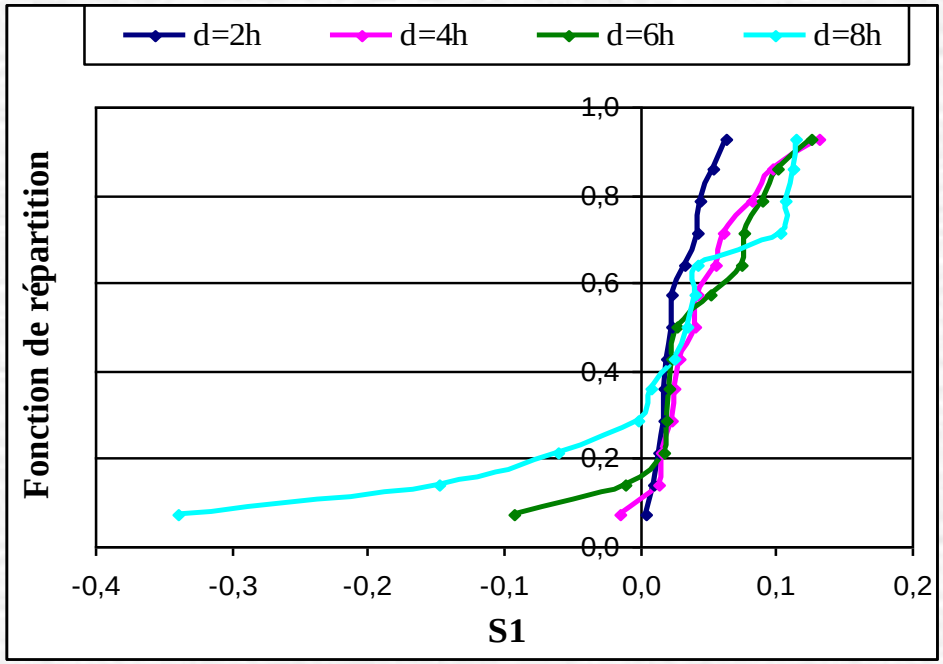


Correlation between flows observed and calculated

- ‘tm’ = 4 h,
- Qmax calculated = - 19 % Qmax observed,
- the error varies between 0,38 and 134 m^3/s.

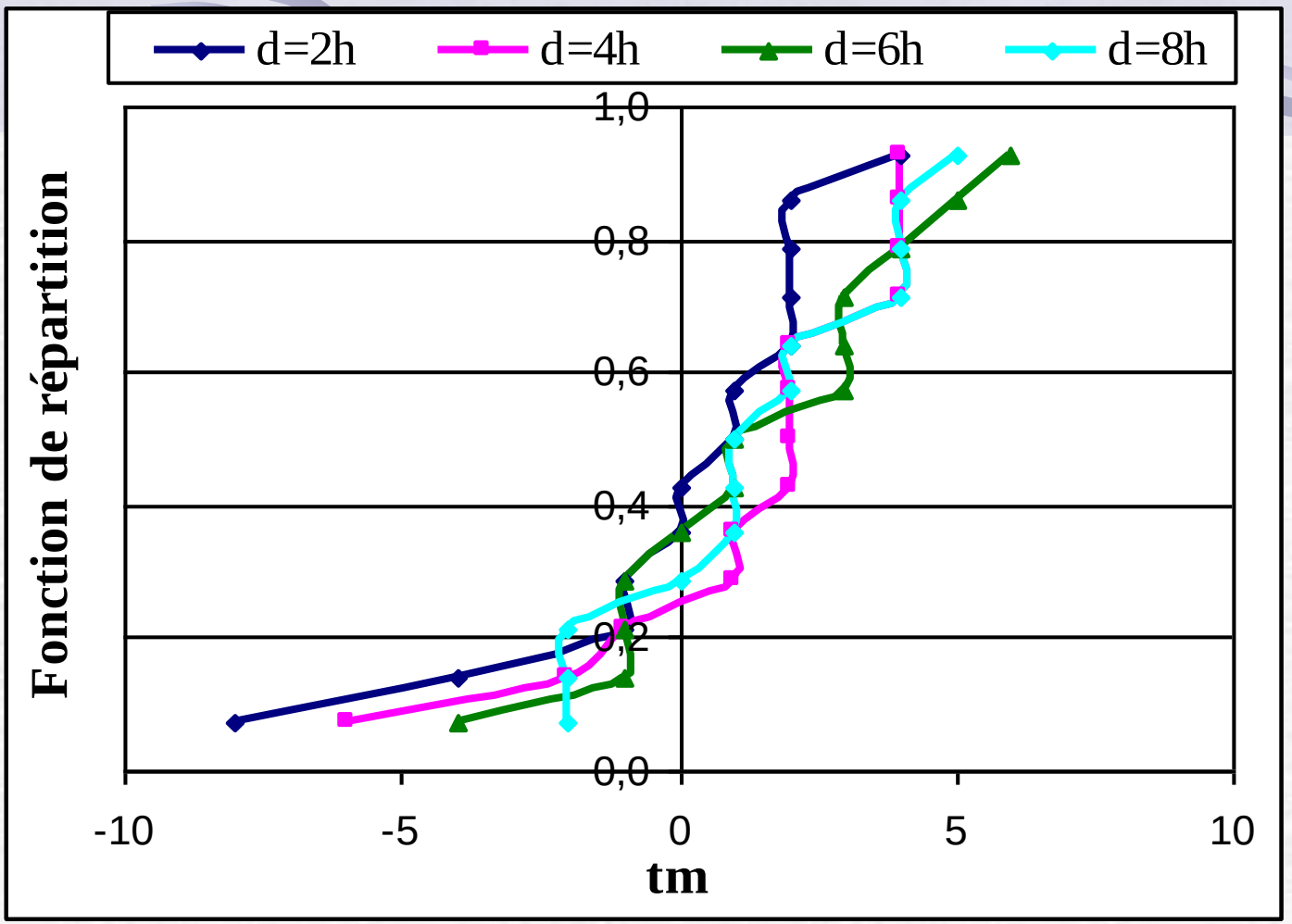
3. Application of Regression model





Distribution of the function 'tm'
on the section Jendouba – Bou Salem

- ‘S’ increase with the reconstruction period.
- average values of |S1| increase with period.



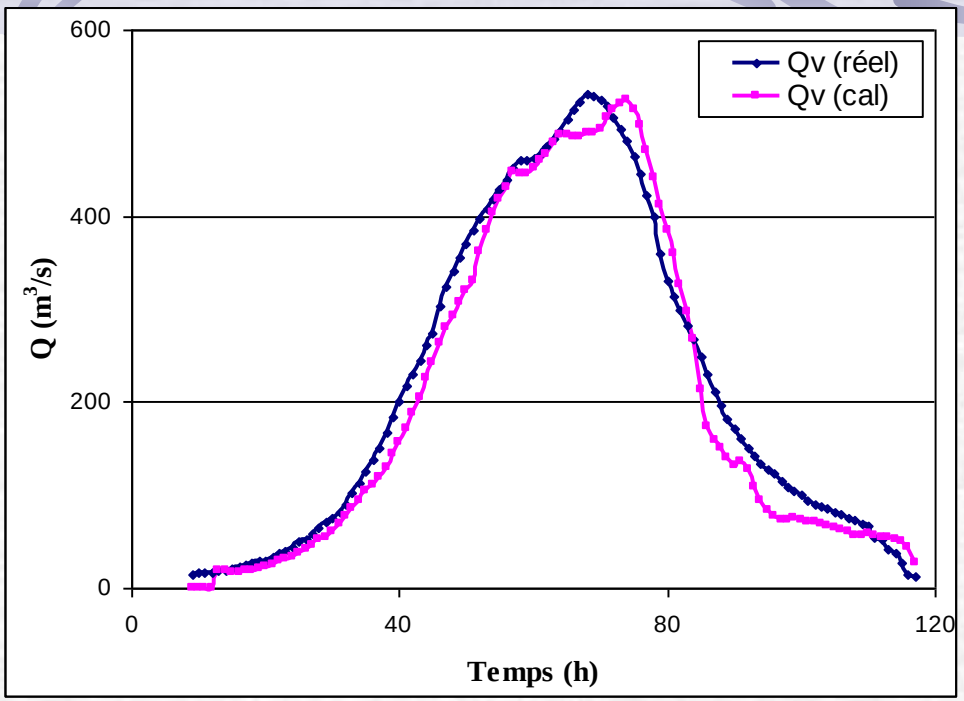
Distribution of the function 'tm'
on the section Jendouba – Bou Salem

- ‘tm’ varies between - 8 et 6 h,

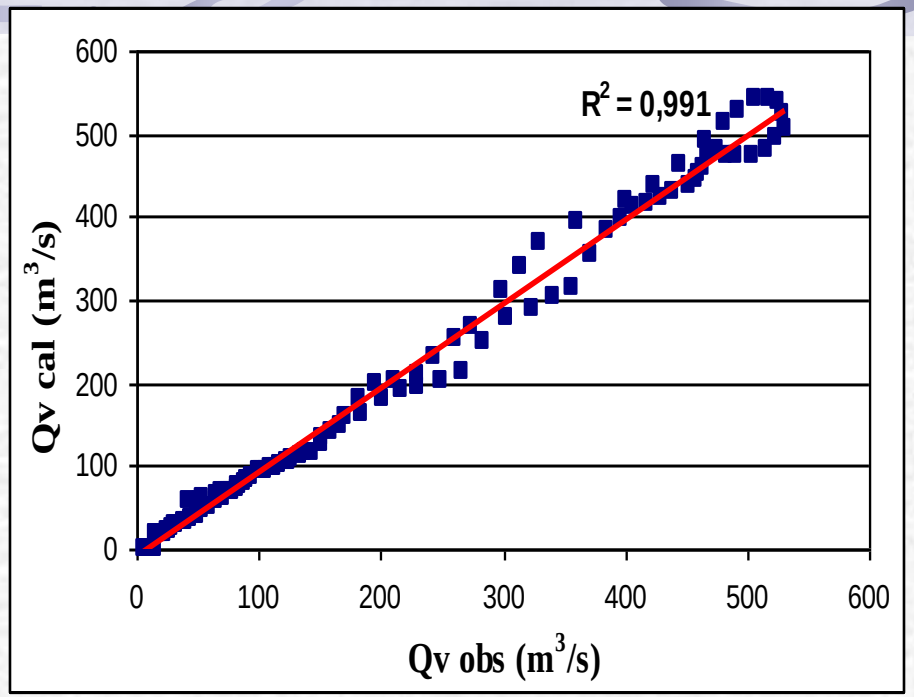
Results of flood reconstruction with Regression model (period= 4 hours) on the section Jendouba – Bou Salem

Flood	Criterion		
	S	S1	tm
12/11/1990	24.463	0.077	4
13/12/1990	5.687	0.024	-1
22/12/1990	28.210	0.021	3
14/02/1991	2.258	0.125	1
15/03/1991	42.534	0.074	3
04/01/1995	3.225	0.053	1
06/02/1996	**27.762**	**-0.010**	**6**
28/02/1996	14.240	0.020	0
11/03/1996	14.862	-0.460	4
14/03/1996	14.934	-0.092	5
12/01/1997	8.227	0.102	3
27/12/1997	7.790	0.017	-1
21/01/1998	27.208	0.090	-4
08/01/1999	6.366	0.026	-1

Flood of 06/02/1996 for period = 6 h



Hydrograph observed and calculated



Correlation between flows observed and calculated

- the shape of the hydrograph is almost reproduced
- 'Tm' = 6 h
- Qmax Calculated = - 1% Qmax observed
- The error varies between 0.64 and 55.7 m3 / s

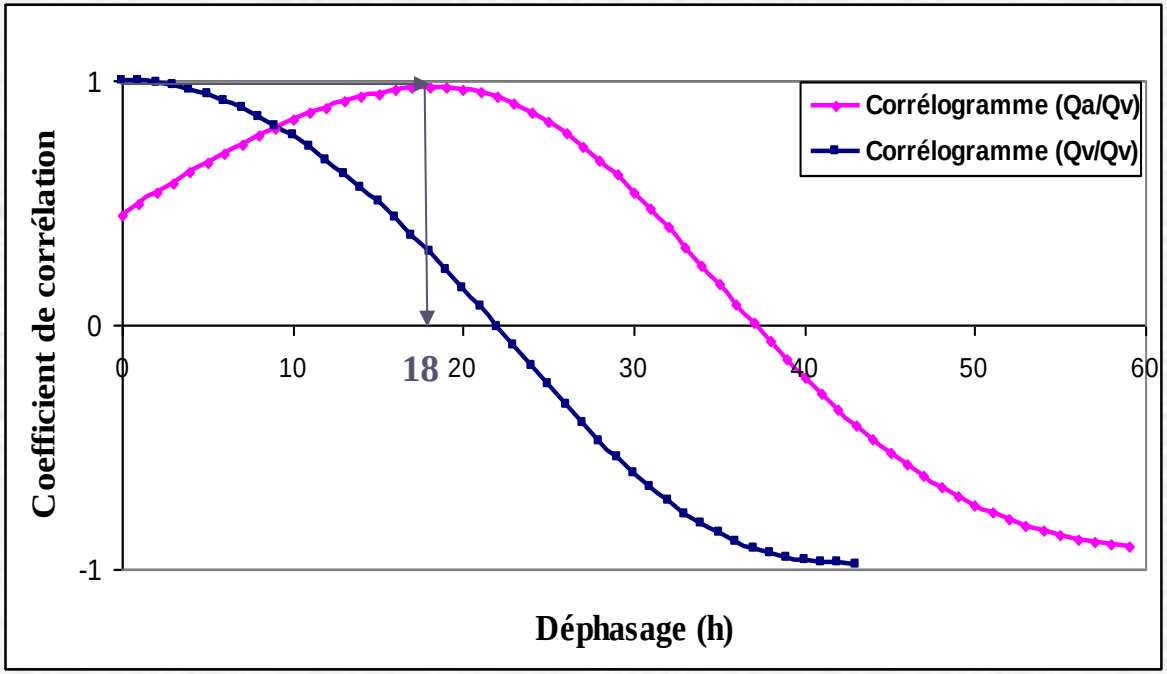
Comparison between the results of reconstruction with Muskingum and Regression models on the section Jendouba - Bousalem

Section	Time (h)	Evaluation Criteria		
		'S'	'S1'	'tm'
Jendouba – Bou Salem	2	R	R	M
	4	R	R	M
	6	R	R	M
	8	R	R	M

- The Regression model satisfied 'S' et 'S1',
- 'tm' is satisfied by the Regression model .

III. Flood reconstruction from Ghardimaou to Bou Salem

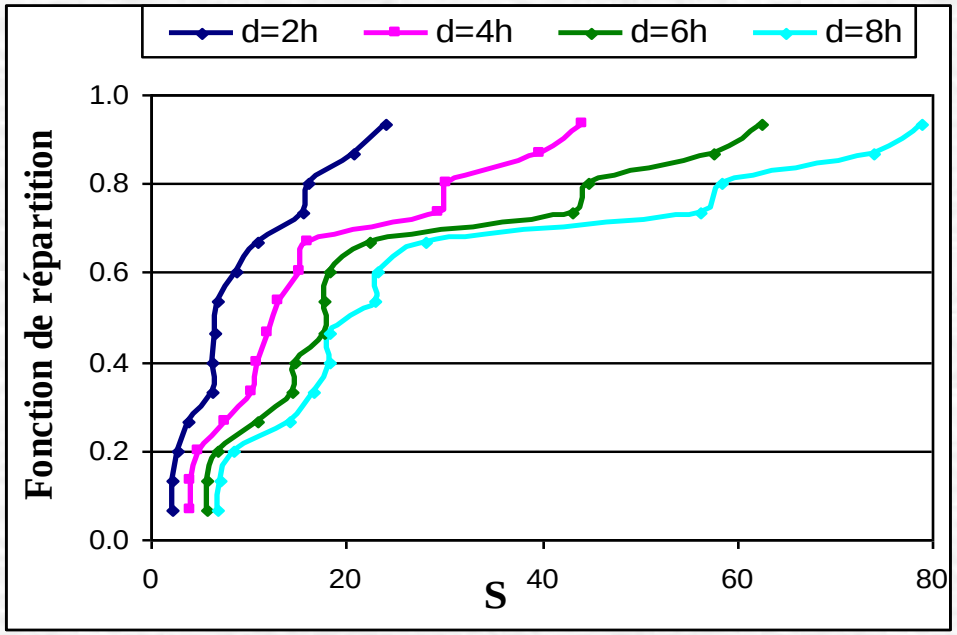
1. Correlogram

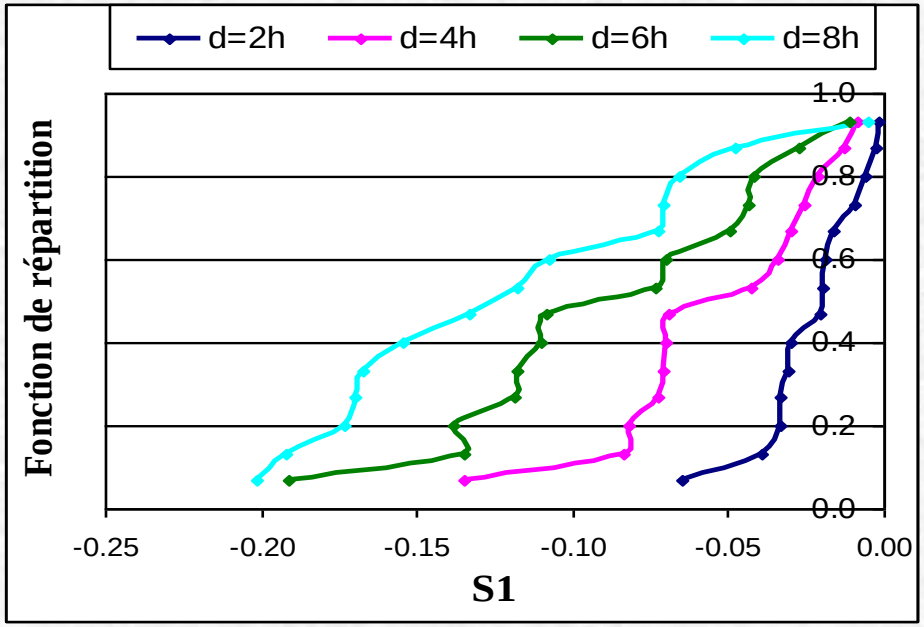


Correlogram of the flood of 08/11/1999
In the section Ghardimaou - Jendouba

The maximum correlation coefficient is 0.972 corresponding to a phase shift of 18 h.

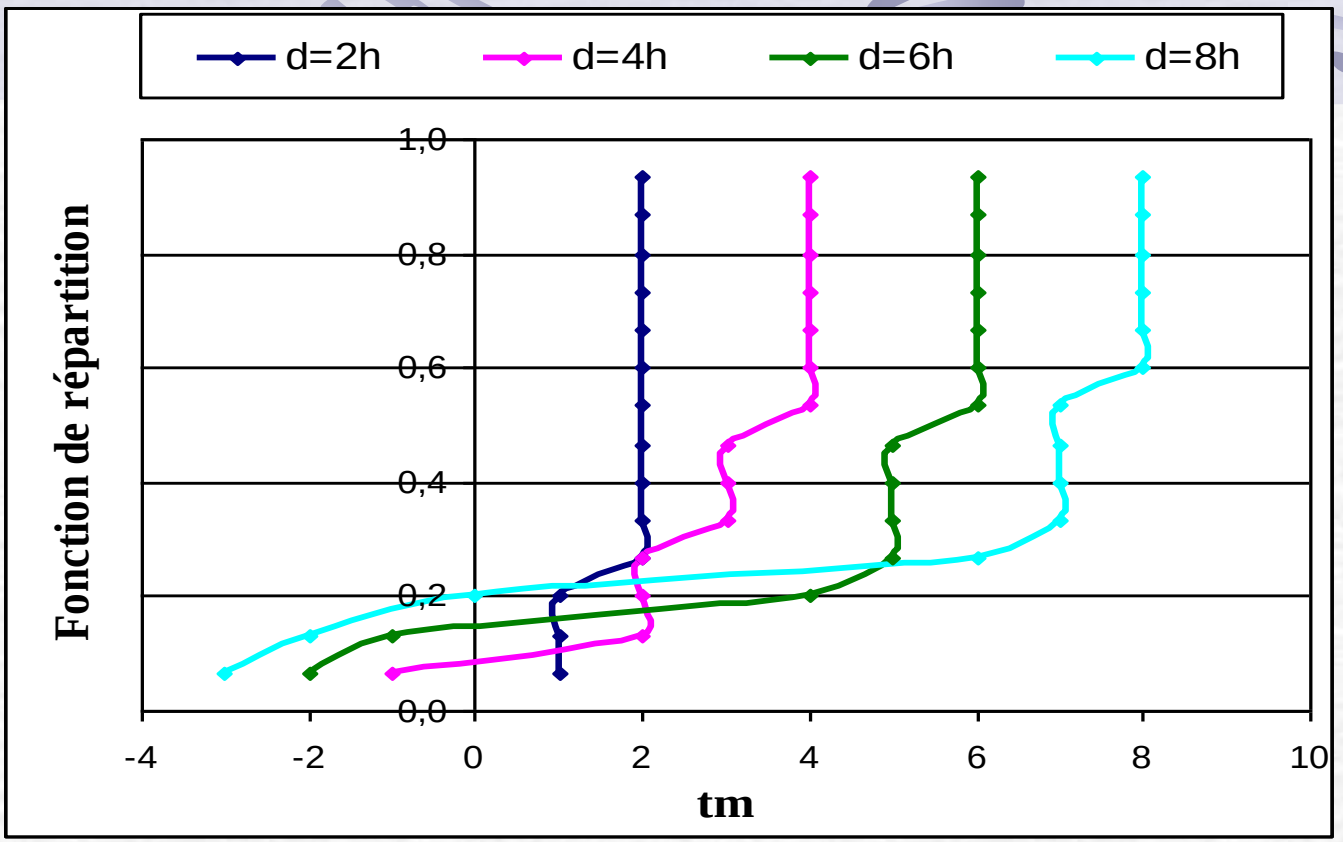
2. Application of Muskingum model





Distribution fonction of 'S' and 'S1' in the section Ghardimaou– Bou Salem

- 'S' and 'S1' increases with the time of reconstitution.



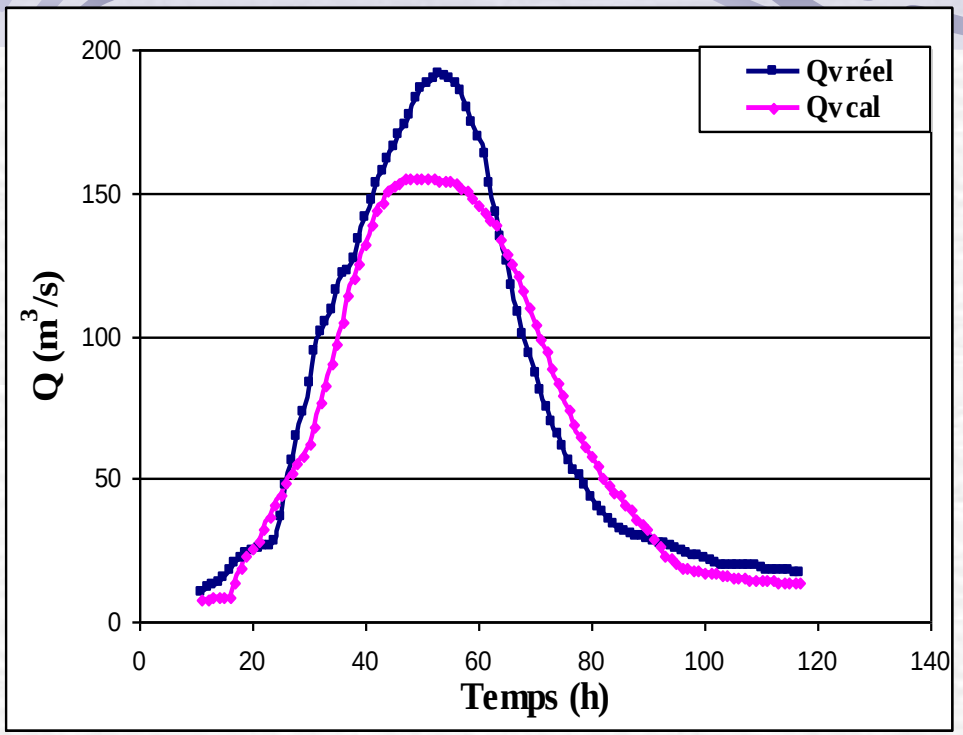
Distribution fonction of tm in the section Ghardimaou– Bousalem with Muskingum model

- For the same sign, 'tm' increases with the time of reconstruction.

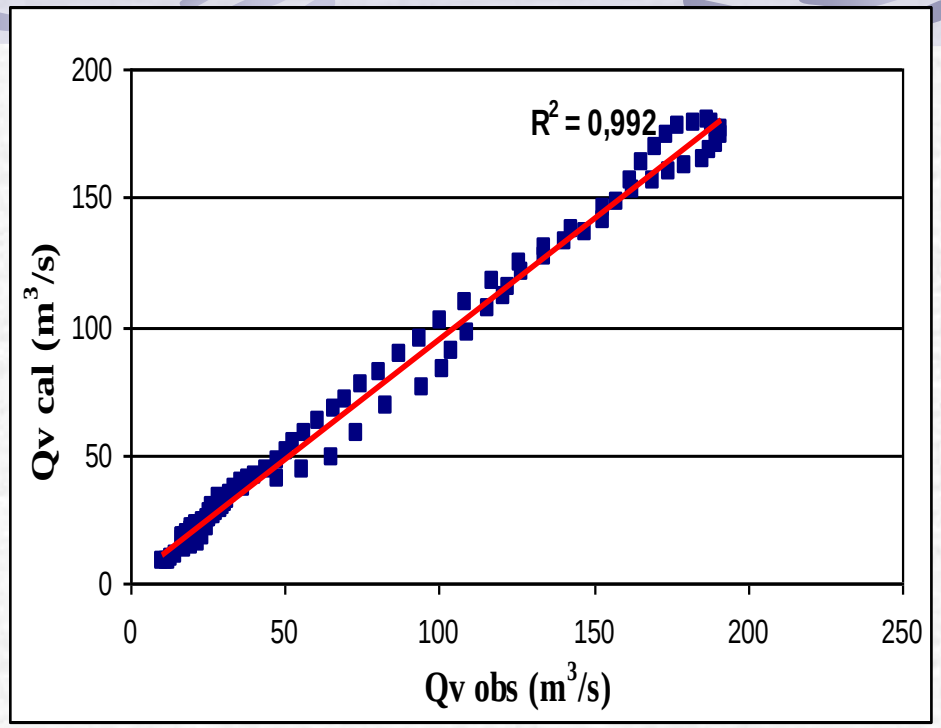
Results of flood reconstruction with Muskingum model (period = 6 hours) on the section Ghardimaou – Bou Salem

Flood	Criterion		
	S	S1	tm
12/11/1990	17.802	-0.011	-1
13/12/1990	14.624	-0.044	6
22/12/1990	43.138	-0.050	6
14/02/1991	10.950	-0.028	5
15/03/1991	62.631	-0.138	6
04/01/1995	3.225	0.053	1
06/02/1996	57.647	-0.118	6
28/02/1996	22.463	-0.117	4
11/03/1996	5.705	-0.073	6
14/03/1996	18.362	-0.110	6
12/01/1997	6.760	-0.108	6
27/12/1997	**14.440**	**-0.191**	**-2**
21/01/1998	44.731	-0.042	5
08/01/1999	17.824	-0.070	5

Flood of 27/12/1997 for period = 6 h



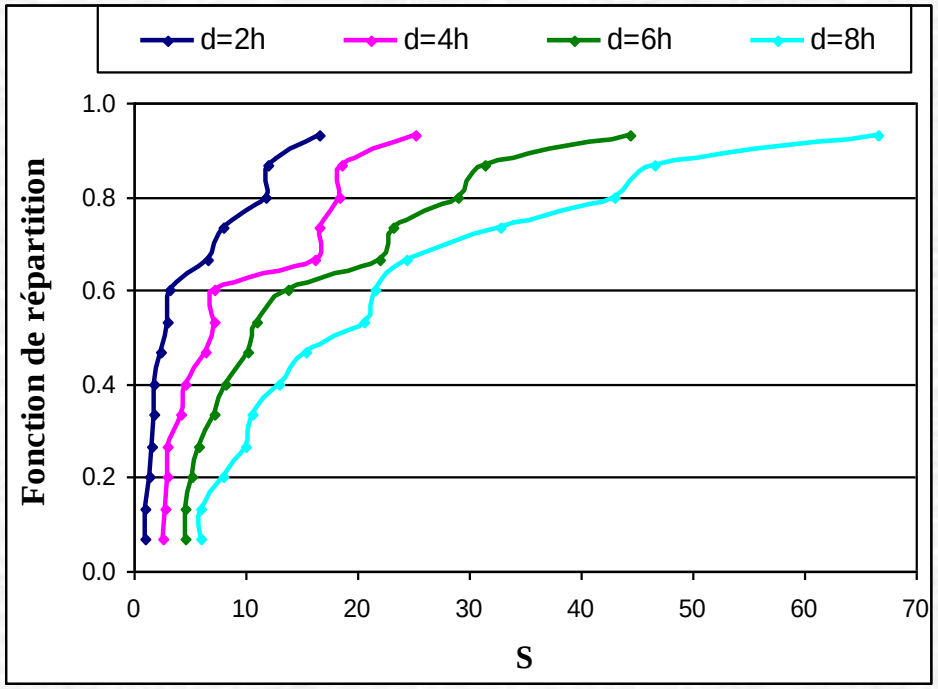
Hydrograph observed and calculated

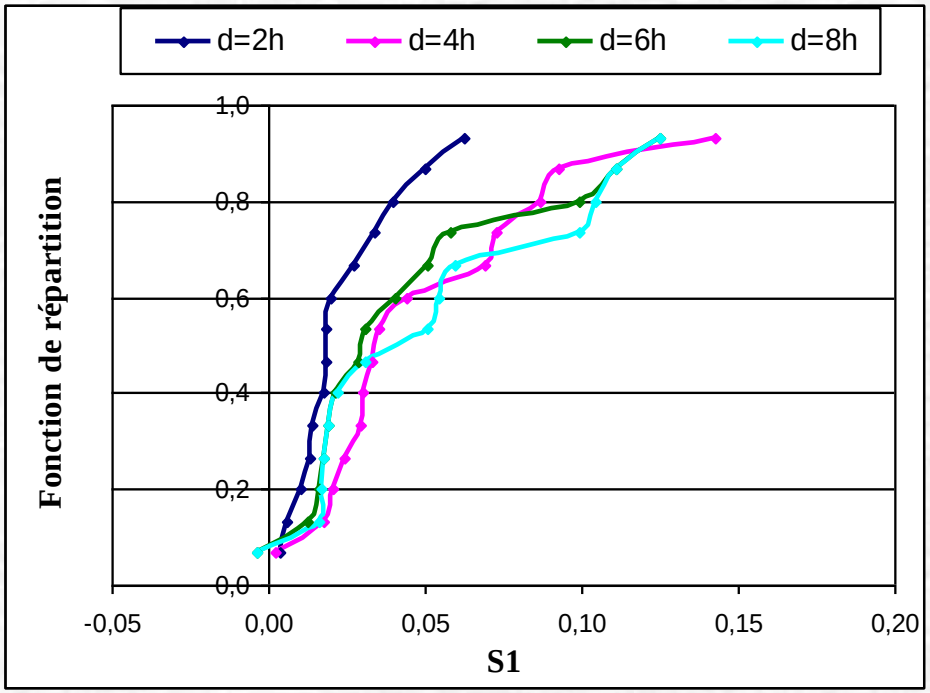


Hydrograph observed and calculated

- peak shape became spread,
- 'Tm' = 2 h,
- Calculated Qmax = - 19% Qmax observe
- the error varies between 0.6 and 37.4 m3 / s.

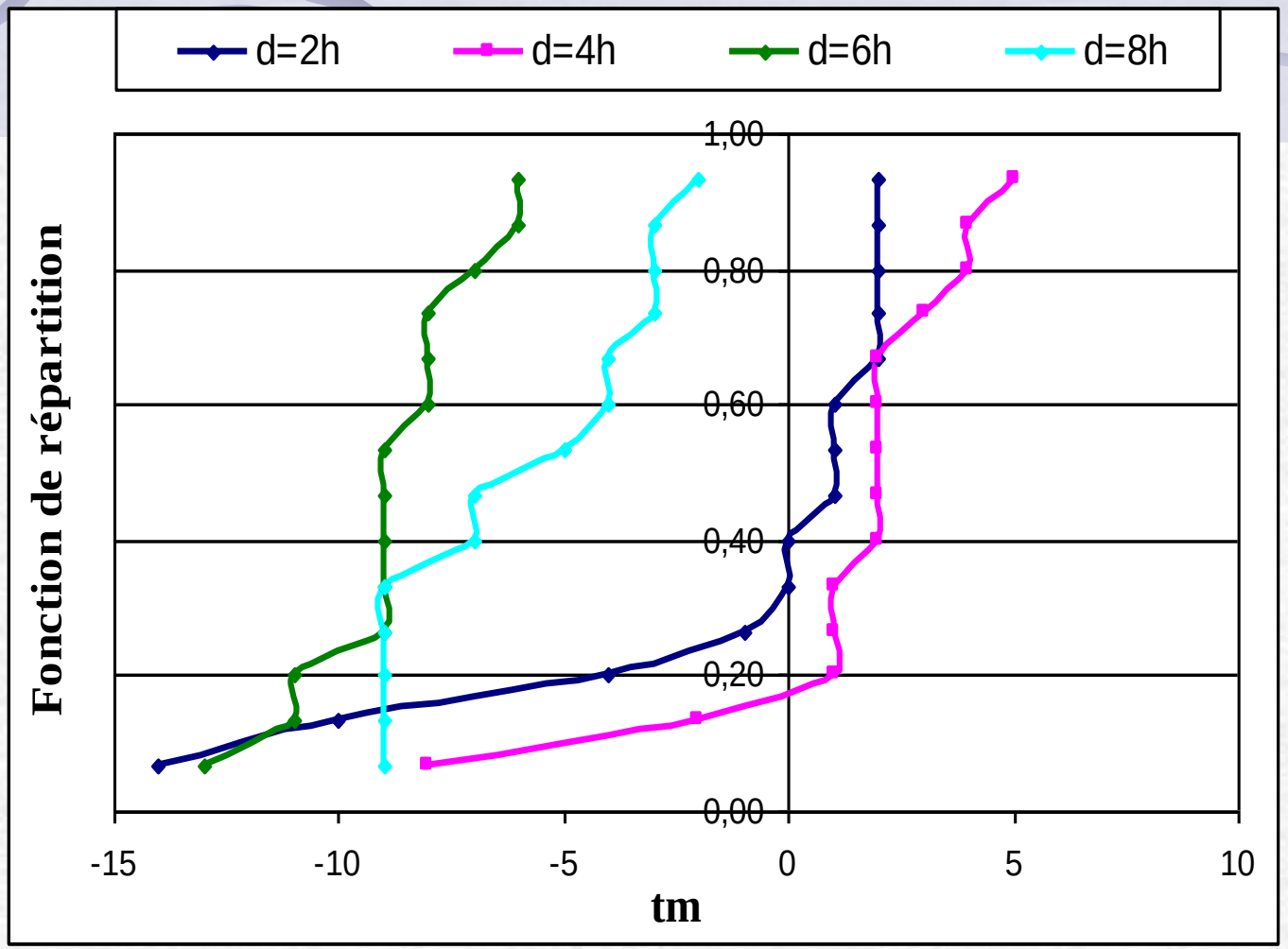
3. Application of Regression model





Distribution fonction of ‘S’ and ‘S1’ in the section Ghardimaou– Bousalem with Regression model

- ‘S’ increase with reconstruction time.
- the lowest values of 'S1' are found for periods of 2 h.



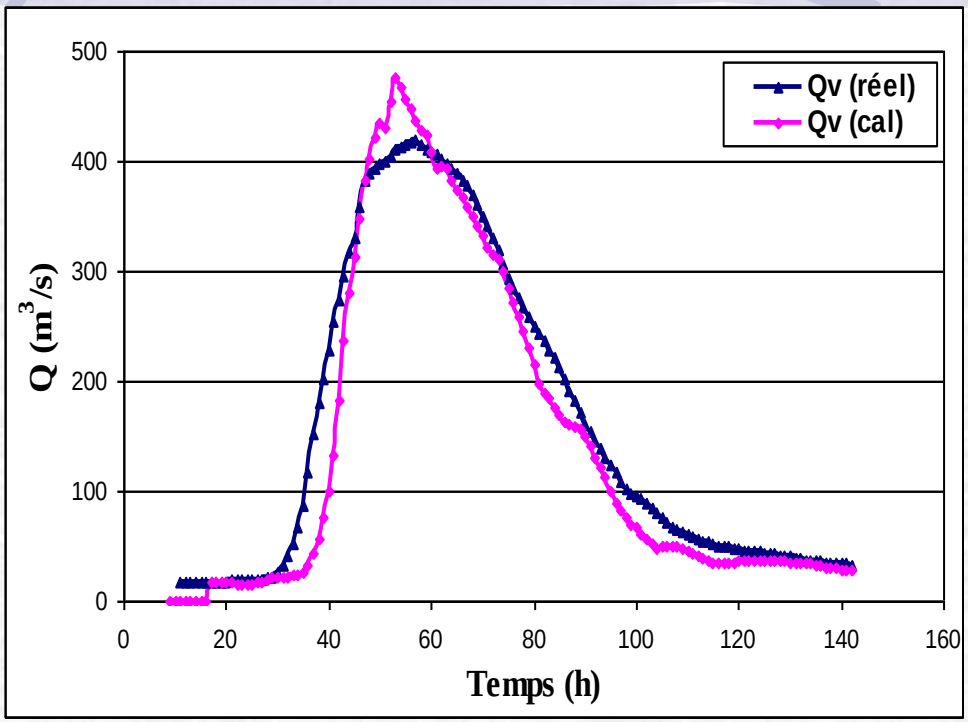
Distribution fonction of‘tm’ in the section de Ghardimaou – Bousalem with Regression model

- ‘tm’ varies between -14 et 5 h,

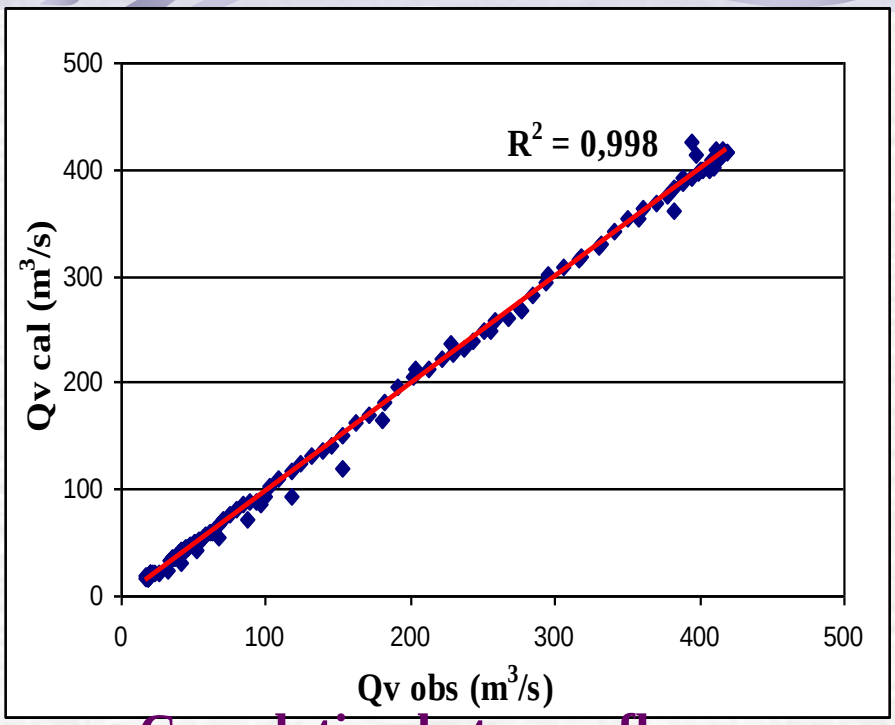
Results of flood reconstruction with Regression model (period = 8 hours) on the section Ghardimaou – Bousalem

Flood	Criterion		
	S	S1	tm
12/11/1990	24.470	0.084	6
13/12/1990	8.022	0.038	1
22/12/1990	43.073	0.010	5
14/02/1991	10.533	0.125	3
15/03/1991	66.510	0.076	4
04/01/1995	6.000	-0.001	6
06/02/1996	46.628	-0.030	8
28/02/1996	21.615	-0.013	1
11/03/1996	6.058	0.050	7
14/03/1996	15.494	0.011	3
12/01/1997	10.009	0.064	6
27/12/1997	20.662	0.030	-5
21/01/1998	**32.803**	**0.136**	**-4**
08/01/1999	12.942	0.026	5

Flood of 21/01/1998 (period = 8 h)



Hydrograph observed and calculated



Correlation between flows observed and calculated

- peak shape is not reproduced,
- ‘tm’ = - 4 h,
- Qmax calculated = 13,5 % Qmax observed,
- Error varies between 0,022 and 10 m^3/s.

Comparison between the results of reconstruction with Muskingum and Regression models on the section Ghardimaou – Bousalem

Section	Period (h)	Evaluation criteria		
		‘S’	‘S1’	‘tm’
Ghardimaou – Bousalem	2	R	M	M
	4	R	R	R
	6	R	R	M
	8	R	R	M

- ‘S 'is satisfied by the regression model for all time,
- 'S1' is satisfied by the Muskingum model for 2h and Regression model for the rest
- 'tm' is satisfied by the regression model for 2 h and the Muskingum model for 4, 6 and 8 h

Flood reconstruction of Bou Salem

The reconstruction of flood of Bou Salem is better:

- **by 'S':**

from GHARDIMAOU flood with the regression model,

- **by 'S1‘:**

✓ for periods 2 and 8 h, from GHARDIMAOU flood with the regression model,

✓for periods 4 and 6 h, from Jendouba flood with the regression model,

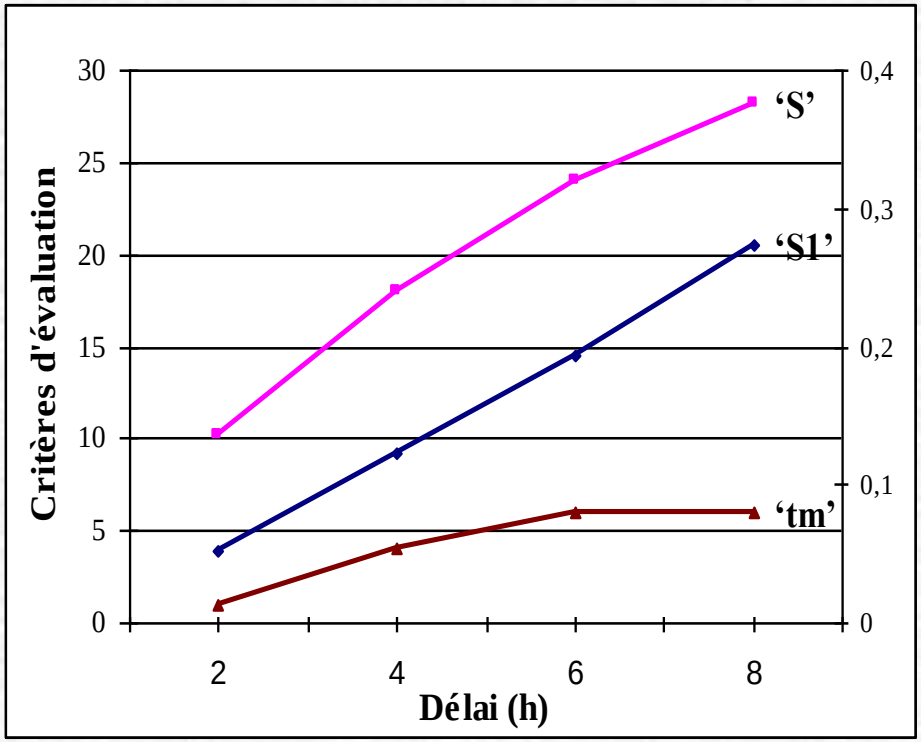
- **by 'tm':**

from Jendouba flood with the Muskingum model.

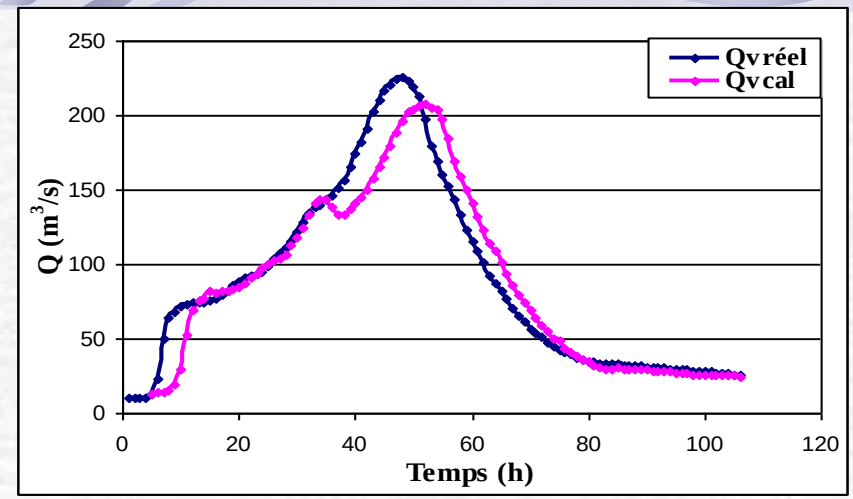
Flood Forecasting

IV. Flood forecasting from Ghardimaou to Jendouba

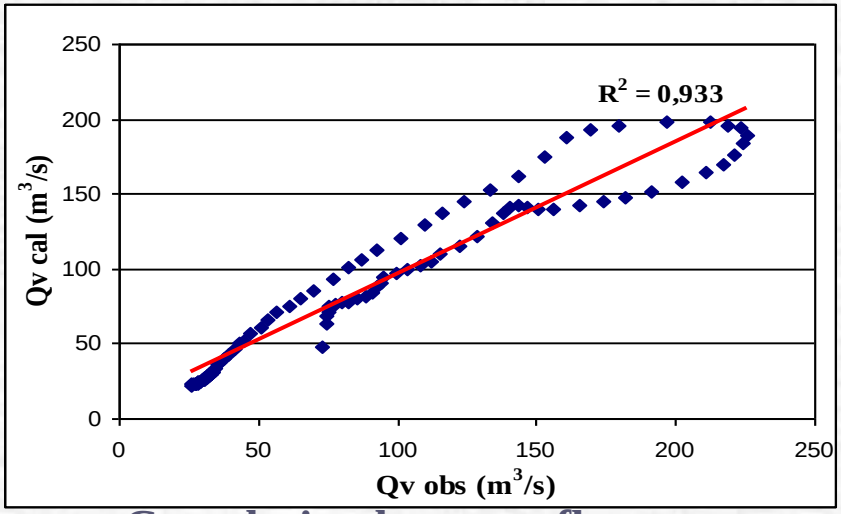
1. With Muskingumodel



Change in assessment criteria of 28/02/1996 flood forecasting with the Muskingum model



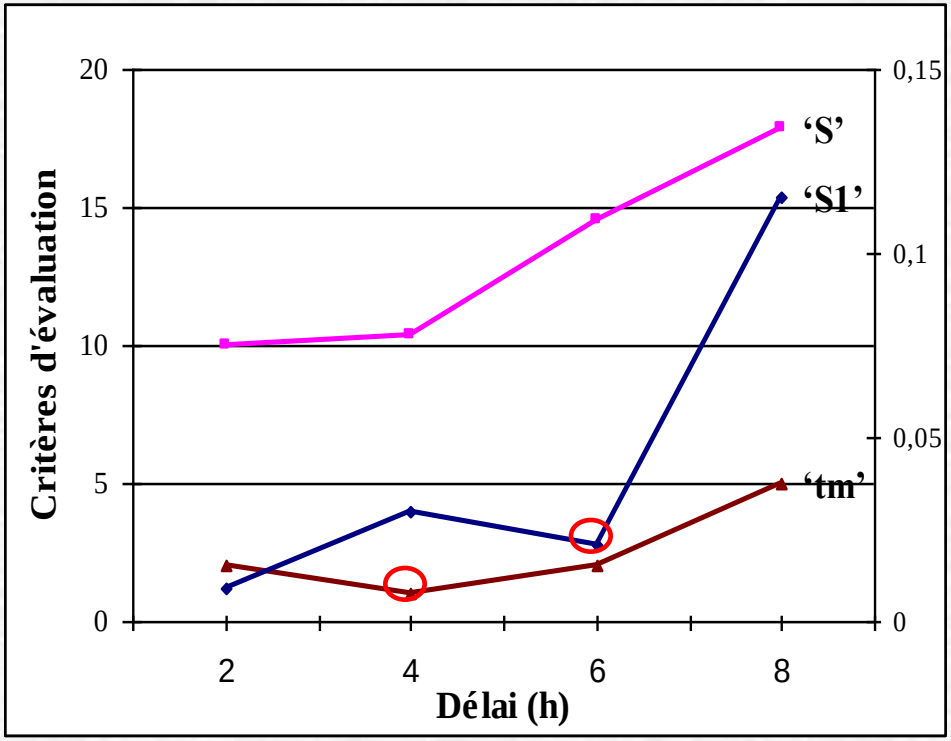
Hydrograph observed & simulated at 4h

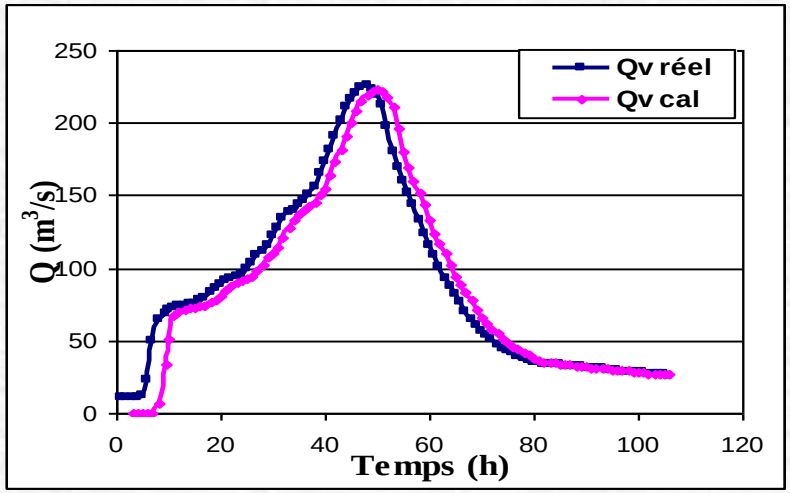


Correlation between flows observed & simulated

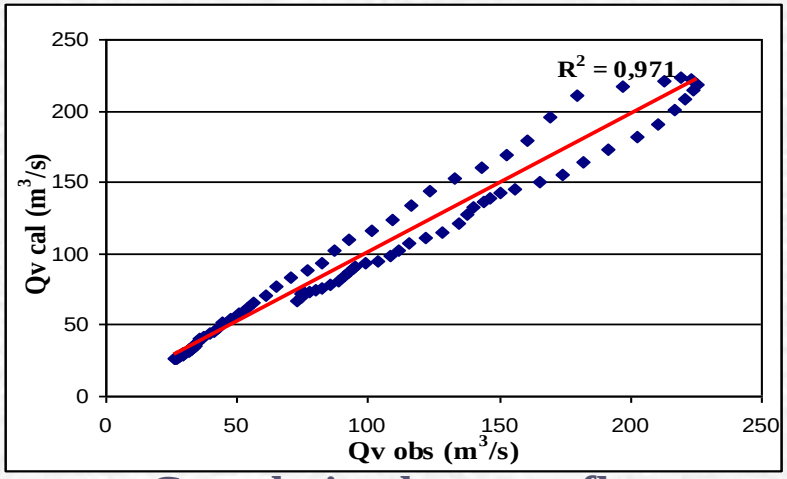
- 'S', 'S1' & 'tm' increase with the time of forecast.

2. With Regression model





Hydrograph observed & simulated at 2h



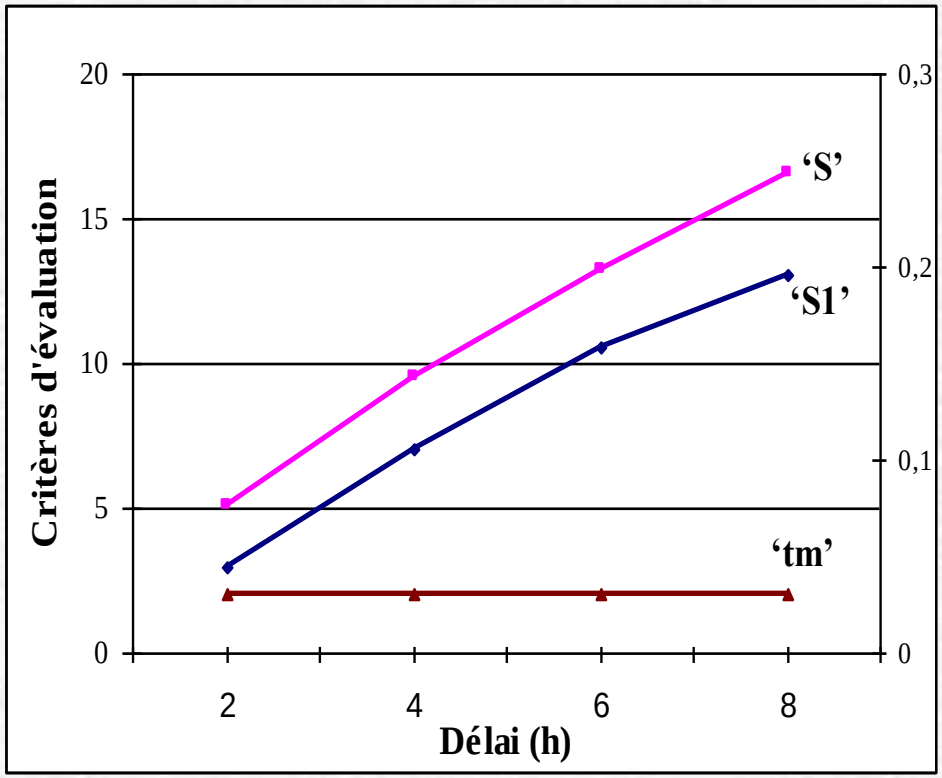
Correlation between flows observed & simulated

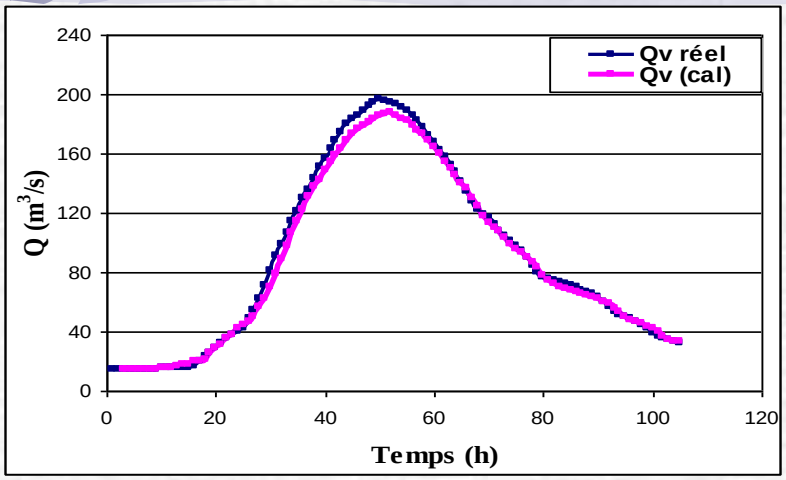
Change in assessment criteria of 28/02/1996flood forecasting with the Regression model

- 'S' increase with forecasting time.
- 'S1' & 'tm' varie with time.

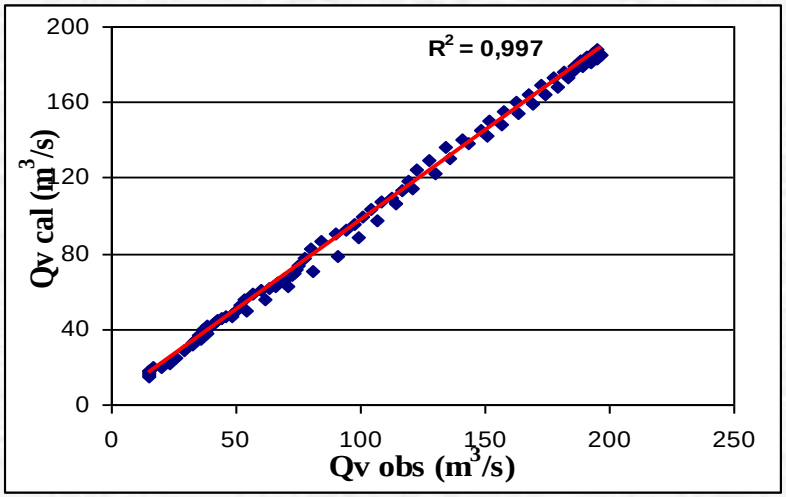
V. Flood forecasting from Jendouba to Bou Salem

1. With Muskingum model





Hydrograph observed & estimated at 2 h

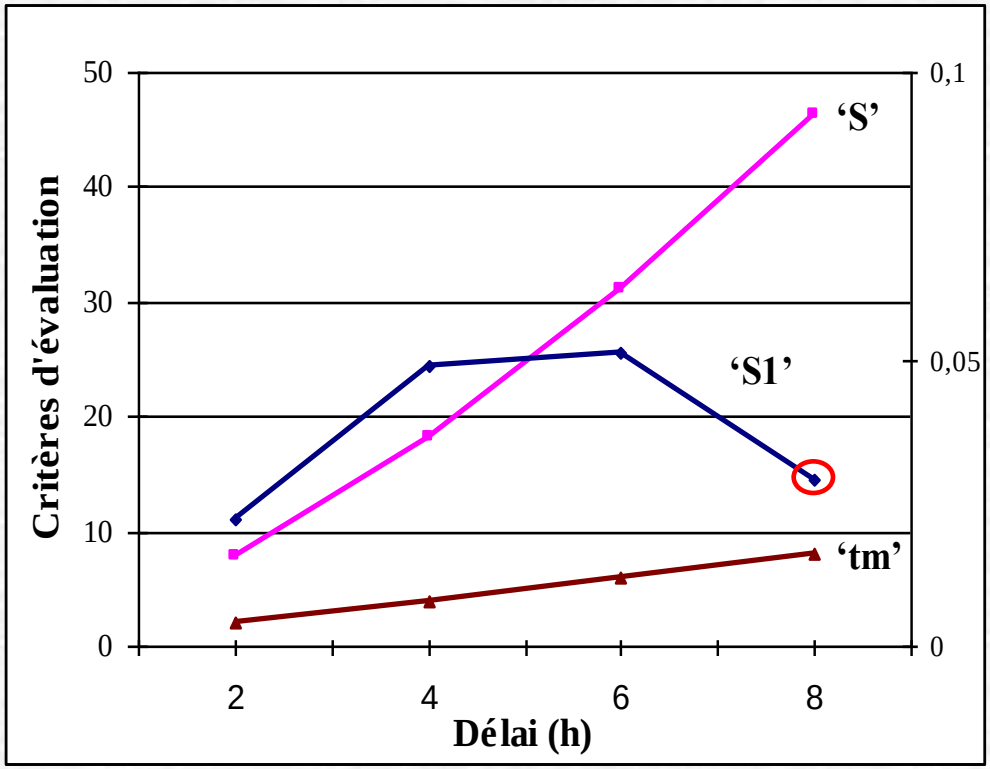


Correlation between flows observed & simulated

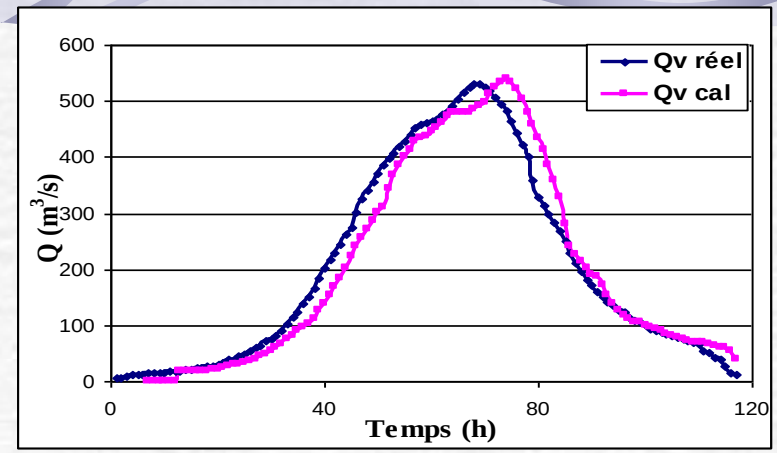
Change in assessment criteria of 14/03/1996 flood forecasting

- 'S' & 'S1' increase with forecasting time,
- 'tm' is constant at 2 h every time .

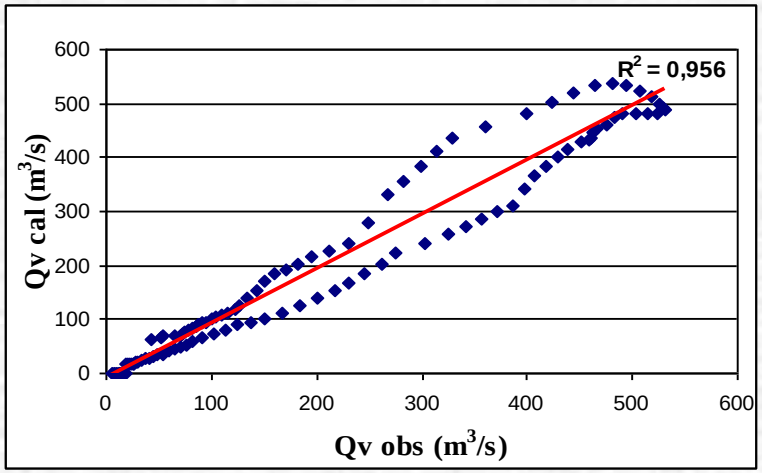
2. With regression model



Variation des critères d'évaluation de prévision de la crue de 06/02/1996



Hydrograph observed & estimated at 6 h

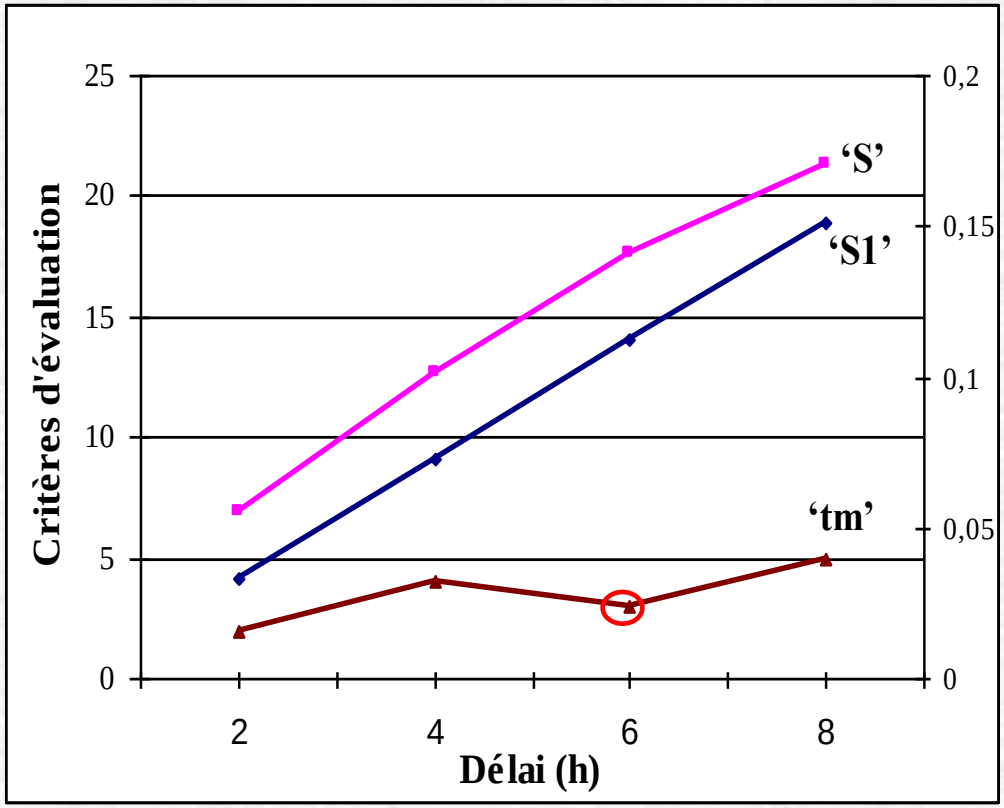


Correlation between flows observed & simulated

- 'S' and 'tm' increase with forecasting time.
- 'S1' varies with time.

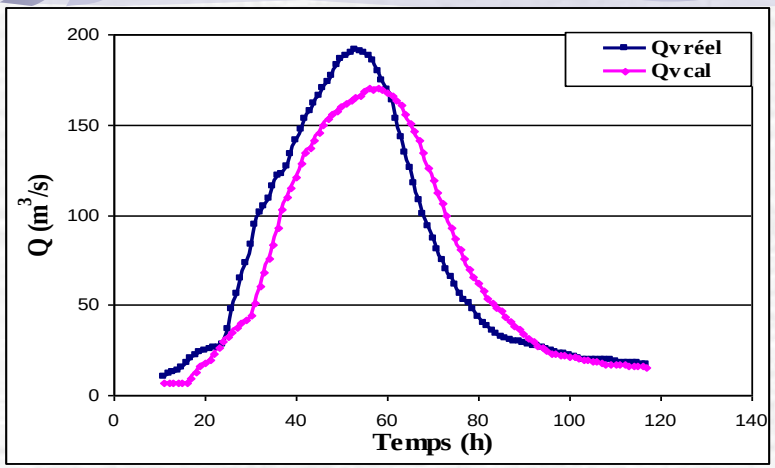
V. Flood forecasting
From Ghardimaou to Bou Salem

1. With Muskingum model

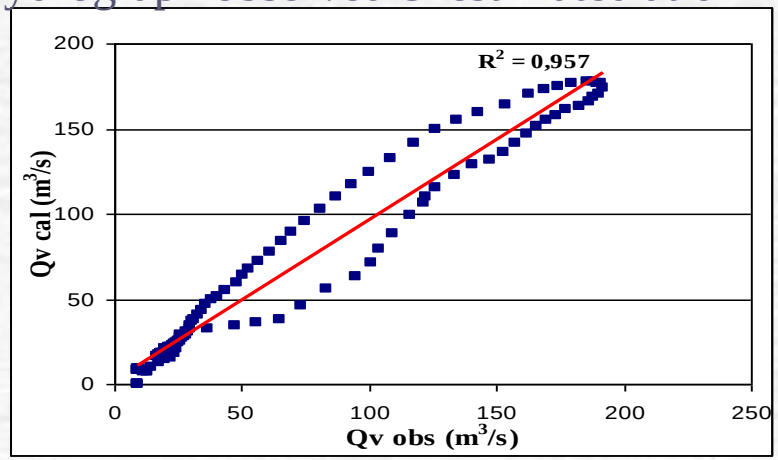


Change in assessment criteria of 28/02/1996 flood forecasting

- 'S' and 'tm' increase with forecasting time.
- 'S1' varies with time.

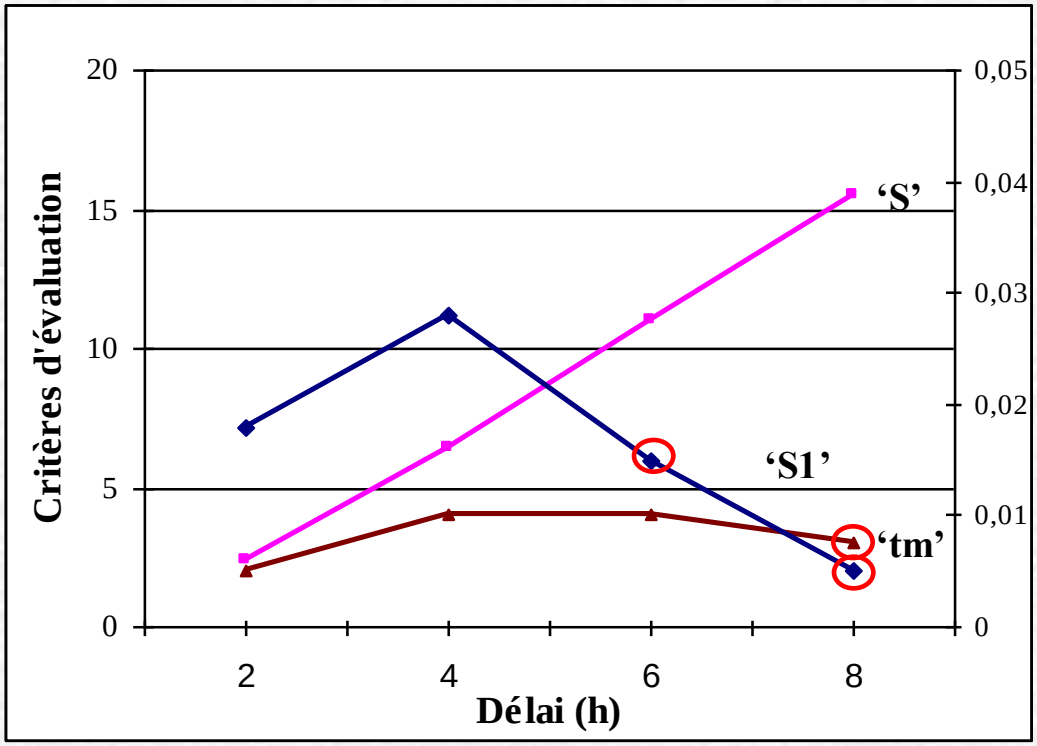


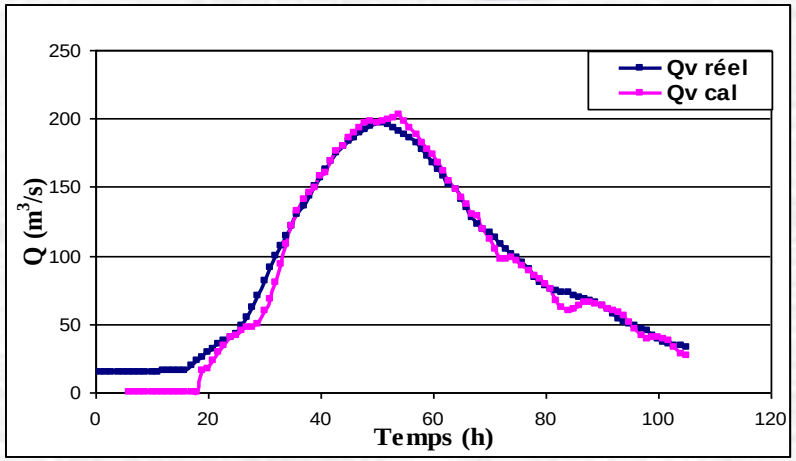
Hydrograph observed & estimated at 6 h



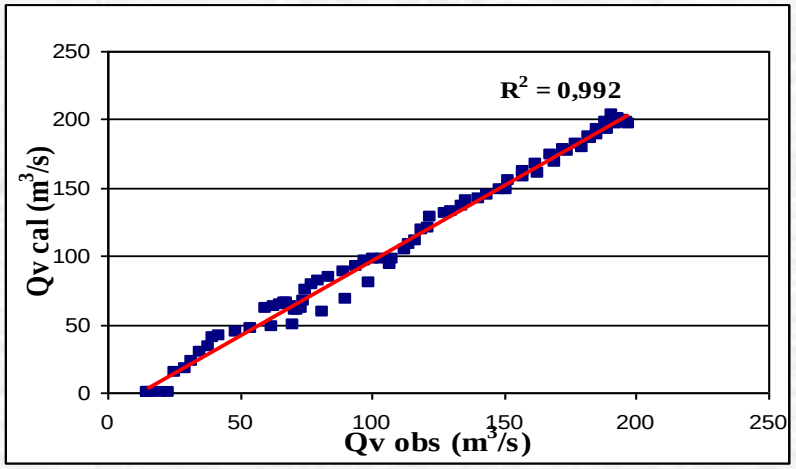
Correlation between flows observed & simulated

2. With regression model





Hydrograph observed & estimated at 4 h



Correlation between flows observed & simulated

Change in assessment criteria of 06/02/1996 flood forecasting

- 'S' increase with forecasting time.
- 'S1' ' and 'tm' varie with time.

Conclusion

336 operations of reconstruction and **3 operations of forecasting** floods in primary stations of Medjerda in the upstream of Sidi Salem dam :

- **Results of reconstruction**

Section	Period (h)	Evaluation criteria		
		'S'	'S1'	'tm'
Ghardimaou – Jendouba	2	R	M	M
	4	R	R	M
	6	R	R	R
	8	R	R	R
Jendouba – Bou Salem	2	R	R	M
	4	R	R	M
	6	R	R	M
	8	R	R	M
Ghardimaou – Bou Salem	2	R	M	M
	4	R	R	R
	6	R	R	M
	8	R	R	M

➢ Forecasting results

Application of Muskingum model:

- 'S' and the relative error of peak 'S1' increases with the time of preparation of the three sections,
- 'tm' varies from one section to the other depending on the time of forecast.

Application of Regression model :

- 'S' increases with the time on the three sections.
- 'S1' and 'tm' are variable by the effect of propagation time.

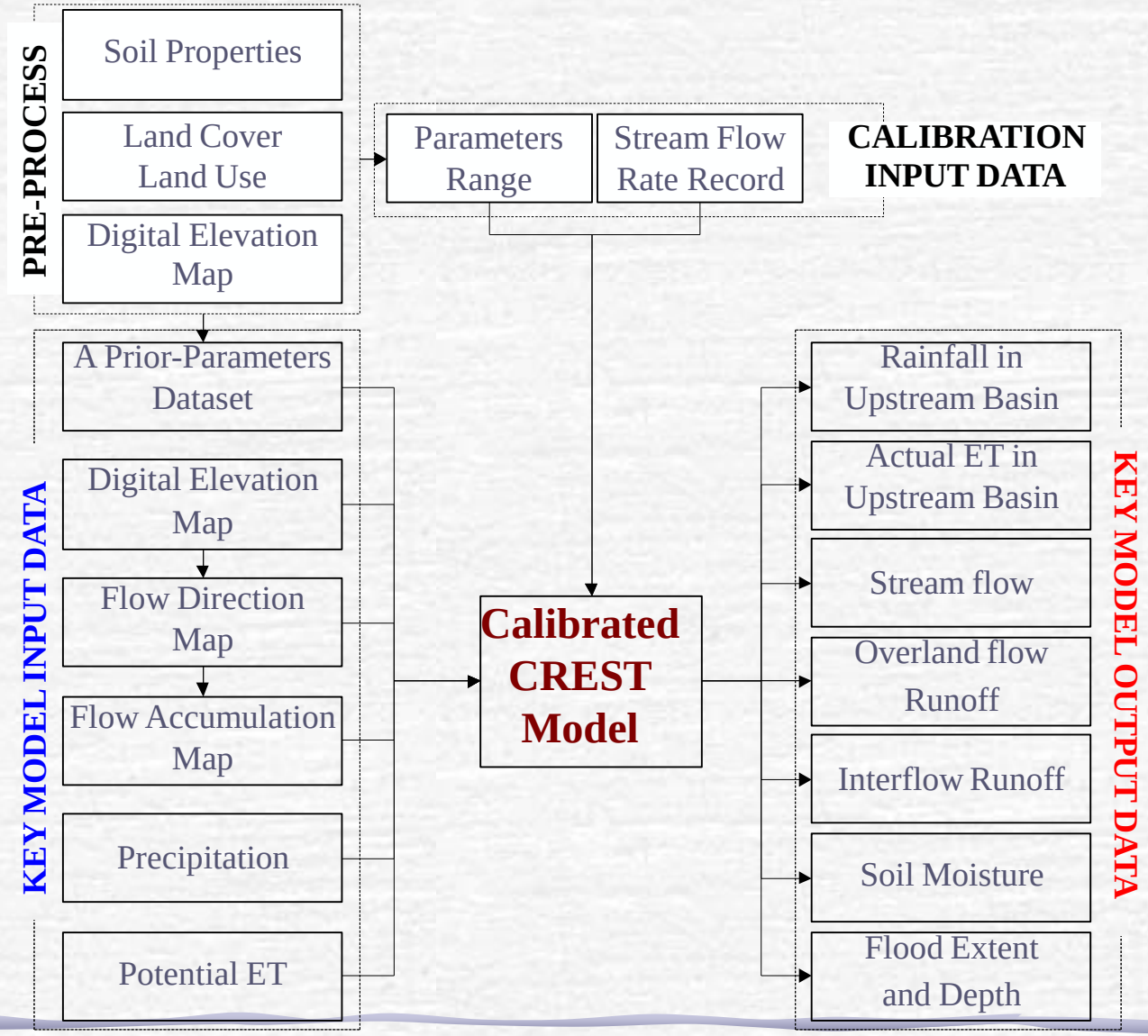
Needs & perspectives

- Develop models for flood forecasting in near real time in the main stations of the river Medjerda (upstream Sidi Salem dam) to contribute to the management system and flood warning administered by the Water Resources Department (DGRE).
- Adaptive models of flood propagation
- Integration of information extracted from satellite images.

In-situ data & validation process

Topic	Development institution	partners	Implementation institution
Floods Mapping and Modeling	CNCT	INM DGRE Universities/INAT	DGRE

In-situ data & validation process



Thank you
for your attention