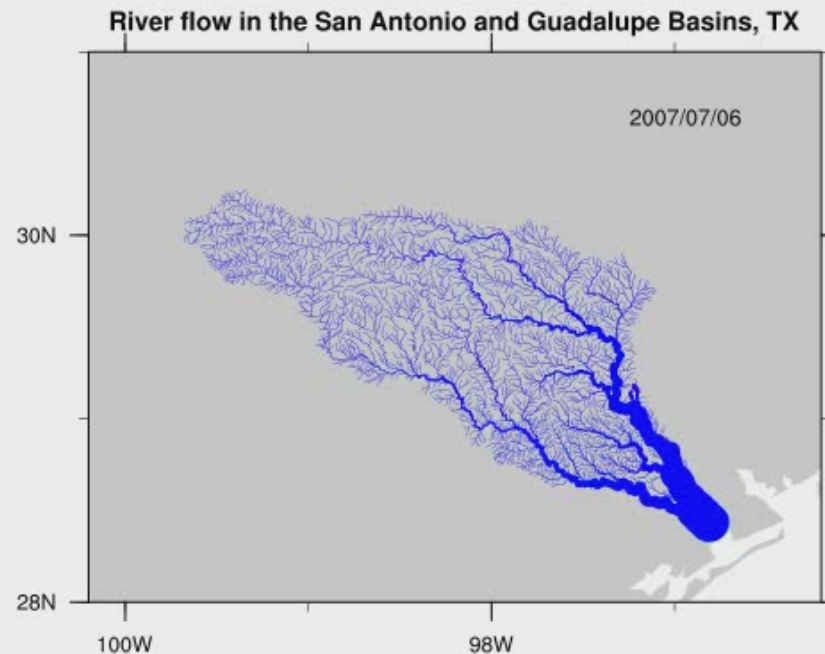


How RAPID works



<http://www.geo.utexas.edu/scientist/david/rapid.htm>

David et al. (2011), Journal of Hydrometeorology, DOI: 10.1175/2011JHM1345.1

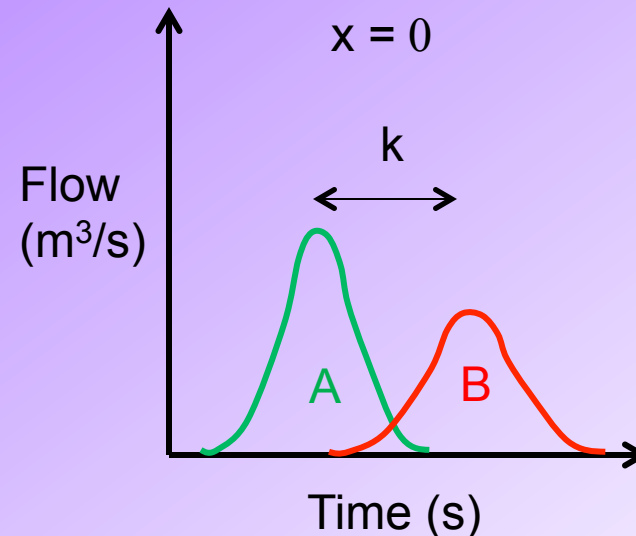
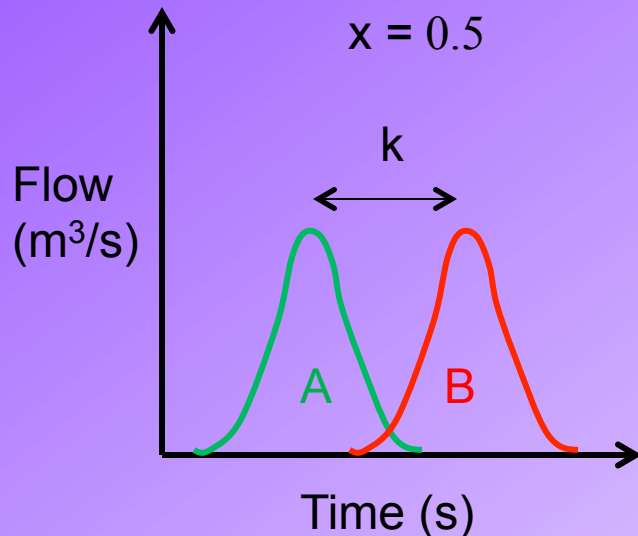
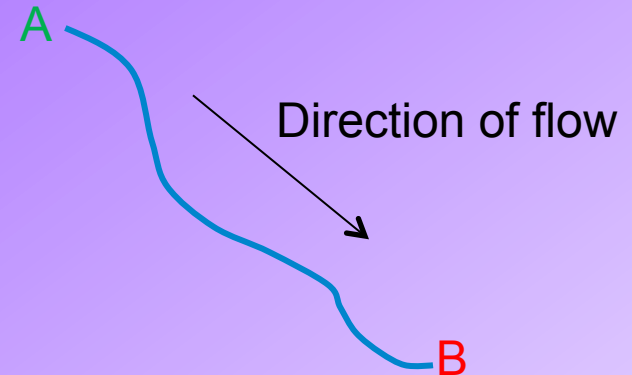
By Cédric H. David
(cedric.david@jpl.nasa.gov)

12 Dec 2011, updated 21
Jan 2015

RAPID is based on the Muskingum method

k is a time ($k \geq 0$) related to the celerity of the flow wave

x is a non-dimensional parameter ($0 \leq x \leq 0.5$) related to diffusion of the flow wave



Two types of RAPID runs

- Stream flow computation
 - Computes flow rate based on Muskingum parameters and inflow of water from land and aquifers to river network
- Optimization of parameters
 - Automatically calibrates k and x around some initial values through comparison between computations and observations of stream flow

Types of input for stream flow computations

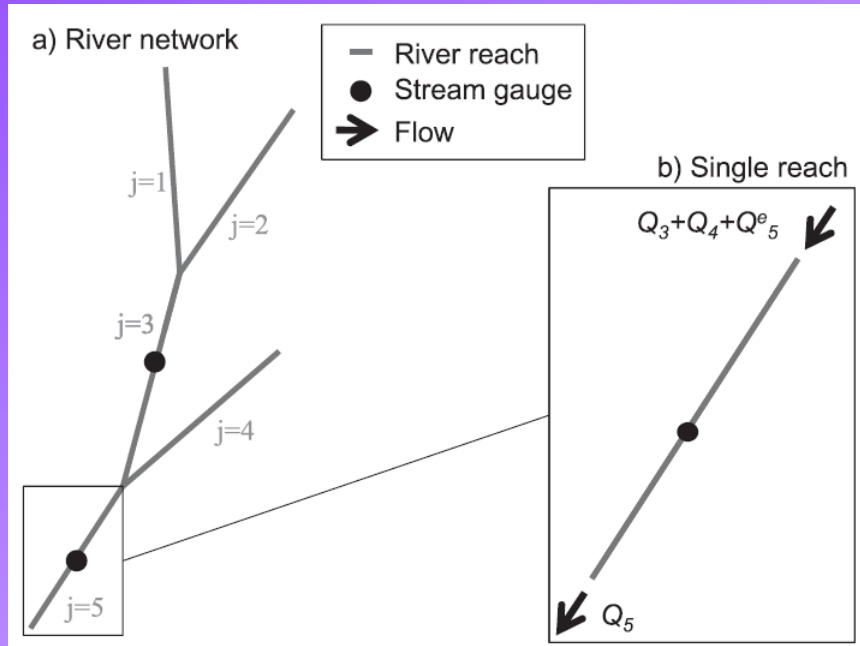
- River network connectivity information
- Inflow of surface and subsurface water to the river network
- Model parameters

RAPID solves a vector-matrix version of the Muskingum method

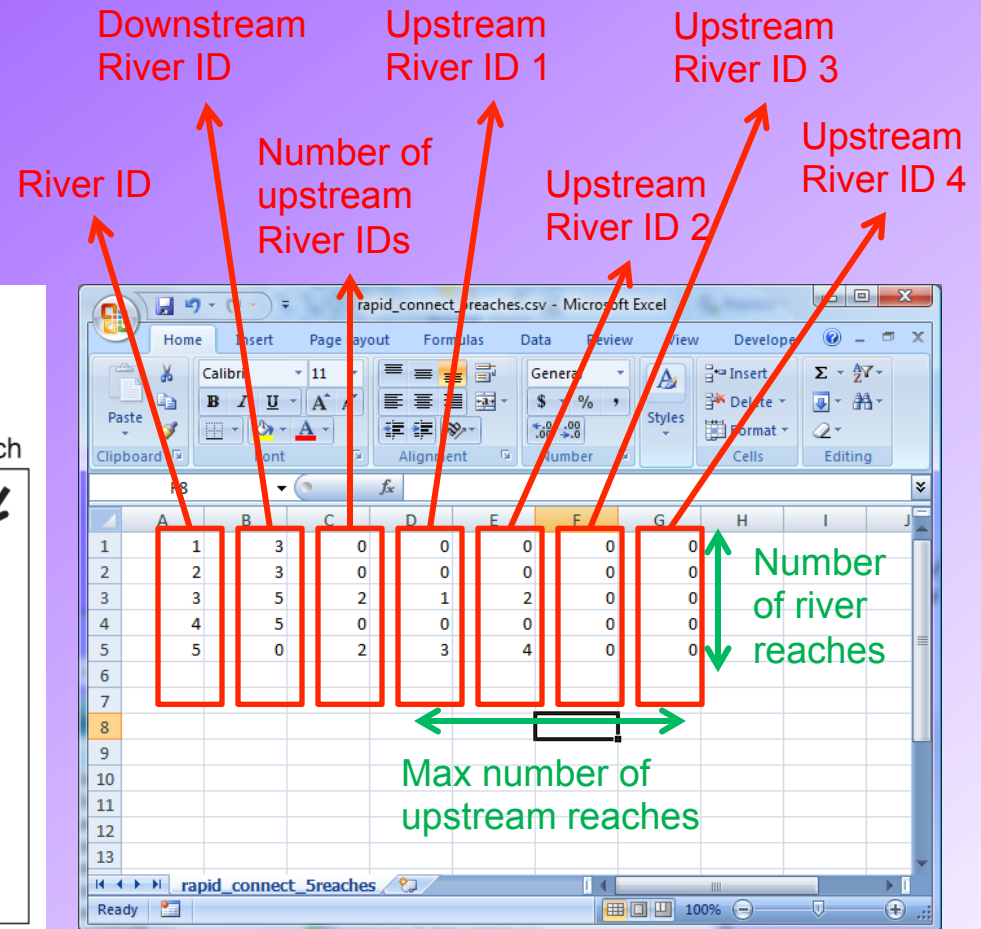
$$(\mathbf{I} - \mathbf{C}_1 \cdot \mathbf{N}) \cdot \mathbf{Q}(t + \Delta t) = \mathbf{C}_1 \cdot \mathbf{Q}^e(t) + \mathbf{C}_2 \cdot [\mathbf{N} \cdot \mathbf{Q}(t) + \mathbf{Q}^e(t)] + \mathbf{C}_3 \cdot \mathbf{Q}(t)$$

I	Identity matrix
N	Network matrix, computed based on network connectivity information
Q^e	Vector of flow rates from outside the network into upstream of each river reach
C₁, C₂, C₃	Parameter matrices, computed based on the values of k and x
Q	Vector of flow rates at the outlet of each river reach (output of RAPID)

River network connectivity (1/2)

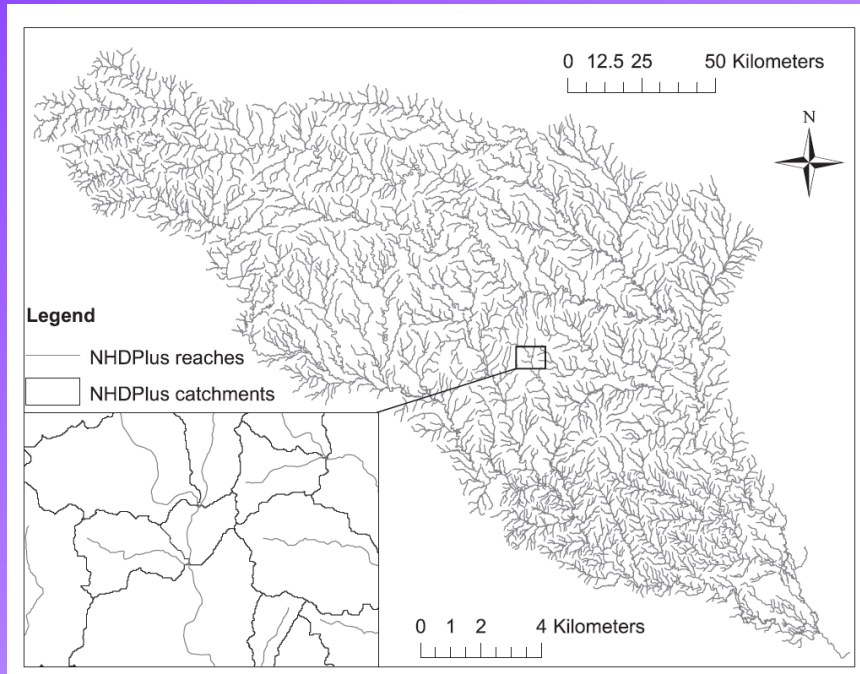


From David et al. 2011 (JHM)



Time-independent, .csv file

River network connectivity (2/2)



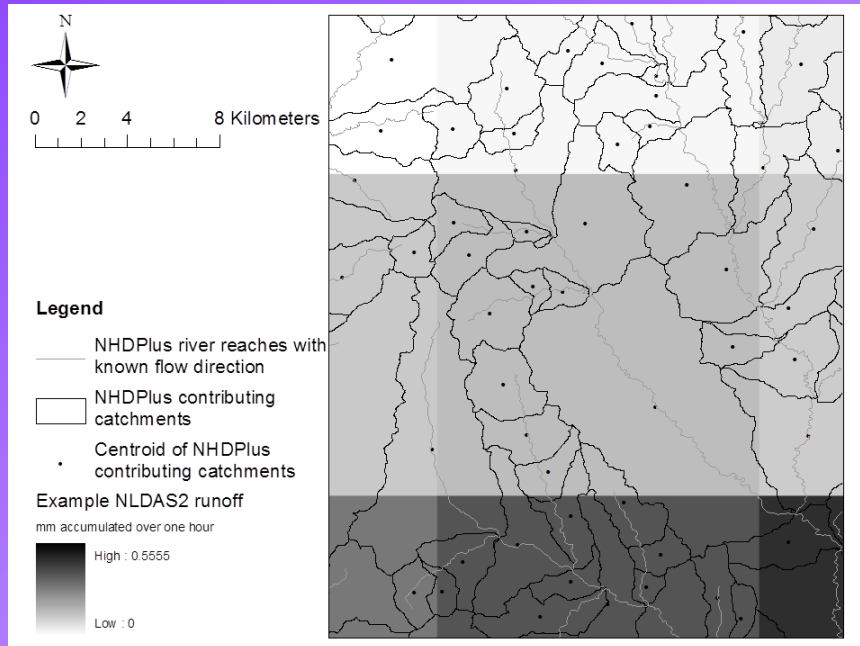
rapid_connect_San_Guad.csv - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J
1	1619571	1620045	0	0	0	0	0			
2	1619573	1619583	0	0	0	0	0			
3	1619575	1619583	0	0	0	0	0			
4	1619577	1619579	1	1620045	0	0	0			
5	1619579	1619595	1	1619577	0	0	0			
6	1619581	1619595	1	3589578	0	0	0			
7	1619583	1619585	2	1619573	1619575	0	0			
8	1619585	1619593	2	1619583	1619587	0	0			
9	1619587	1619585	2	1619589	1619597	0	0			
10	1619589	1619587	0	0	0	0	0			
11	1619591	1619593	0	0	0	0	0			
12	1619593	1619601	2	1619585	1619591	0	0			
13	1619595	1619597	2	1619579	1619581	0	0			

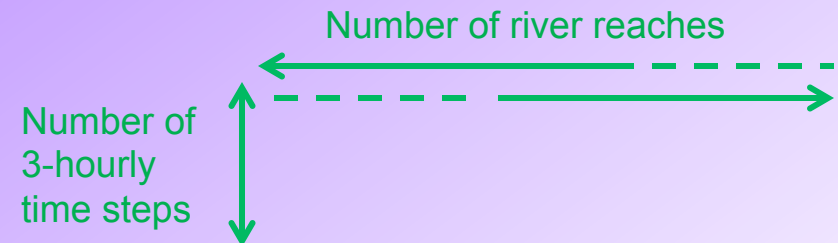
rapid_connect_San_Guad

From David et al. 2011 (JHM)

Inflow of surface and subsurface water to the river network



```
netcdf m3_riv_San_Guad_2004_2007_cst {  
  dimensions:  
    Time = UNLIMITED ; // (11686 currently)  
    COMID = 5175 ;  
  variables:  
    float m3_riv(Time, COMID) ;  
  data:  
  
  m3_riv =  
    2.526759, 6.137938, 41.08073, 0.5575362, 0, 0, 6.703924, 0, 1.129583,  
    3.62081, 3.479724, 0, 2.021173, 2.695687, 9.142337, 7.479404, 15.38157,  
    8.39207, 2.95332, 3.413808, 0.8832929, 0.7860029, 1.529658, 8.792186, 0,  
    2.567003, 1.833389, 2.430393, 25.02393, 5.862353, 19.34686, 14.74761, 0,  
    11.71766, 0.8861017, 10.14037, 2.581038, 10.21363, 18.73453, 6.782395,  
    2.190305, 4.037749, 11.81774, 1.059521, 1.791464, 11.27044, 21.42298, 0,  
    1.407341, 3.601853, 3.335725, 21.6604, 14.01184, 11.35658, 0, 1.47073,  
    1.133804, 13.0413, 1.288851, 8.71509, 4.377013, 22.01137, 22.8595,  
    3.860107, 8.06075, 8.480346, 8.134371, 7.060644, 7.85318, 0.5882702,  
    12.49716, 1.421477, 7.115898, 37.74683, 33.57643, 16.3294, 26.10514,  
    34.84179, 11.33458, 6.059221, 19.37656, 0.04671912, 0, 0, 0.8073183,  
    0.1978648, 0.2678824, 3.395122, 4.5281, 21.60848, 0, 0, 8.216671, 0,  
    0.6018223, 0, 0.1581878, 0, 0.03851565, 0, 0, 0, 0.1849627, 0, 0,  
    0.4224799, 0.618562, 0, 430.6951, 486.1809, 1044.173, 387.0211, 165.783,
```



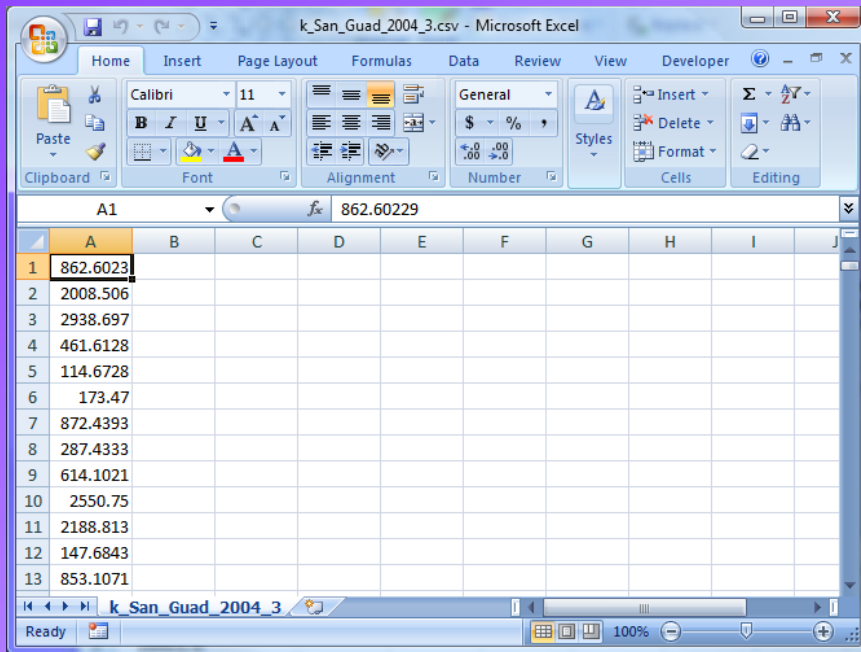
Time-dependent, .nc file

There are 1460 days between 2004/01/01 and 2007/12/30, i.e.

$1460 \times 24 / 3 = 11686$ 3-hourly time steps

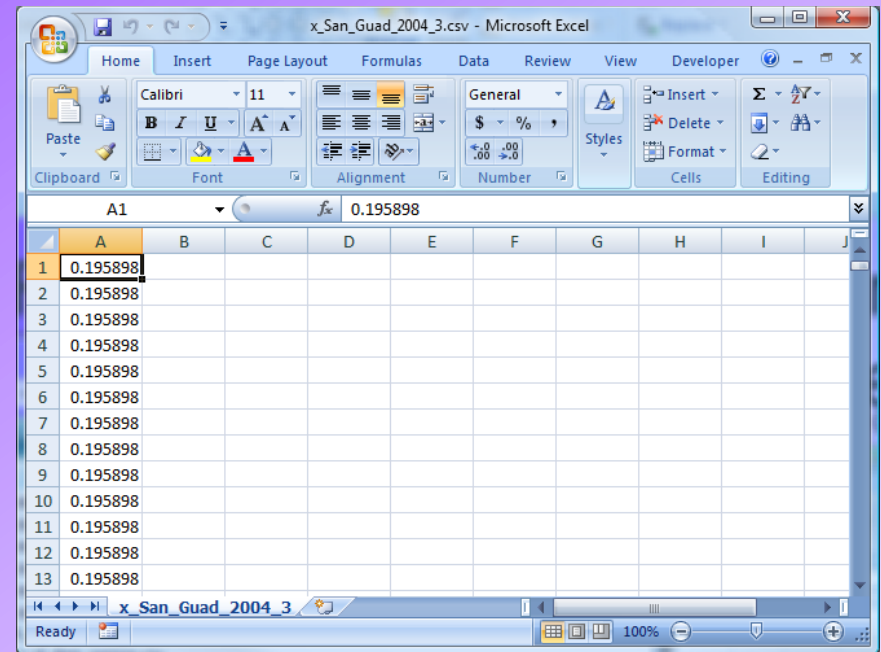
Treated as entering upstream of each river reach

Model parameters



	A	B	C	D	E	F	G	H	I	J
1	862.6023									
2	2008.506									
3	2938.697									
4	461.6128									
5	114.6728									
6	173.47									
7	872.4393									
8	287.4333									
9	614.1021									
10	2550.75									
11	2188.813									
12	147.6843									
13	853.1071									

k_j



	A	B	C	D	E	F	G	H	I	J
1	0.195898									
2	0.195898									
3	0.195898									
4	0.195898									
5	0.195898									
6	0.195898									
7	0.195898									
8	0.195898									
9	0.195898									
10	0.195898									
11	0.195898									
12	0.195898									
13	0.195898									

x_j

Time-independent, .csv files

Types of input for optimization of parameters

- River network connectivity information (same as previously)
- Inflow of surface and subsurface water to the river network (same)
- Some estimation of model parameters (different)
- Observations of stream flow on the river network (new)

RAPID uses the inverse method for optimization

$$\phi(\mathbf{k}, \mathbf{x}) = \sum_{t=t_o}^{t=t_f} \left[\left(\frac{\bar{\mathbf{Q}}(t) - \mathbf{Q}^g(t)}{f} \right)^T \cdot \mathbf{G} \cdot \left(\frac{\bar{\mathbf{Q}}(t) - \mathbf{Q}^g(t)}{f} \right) \right]$$

G

Gauge matrix

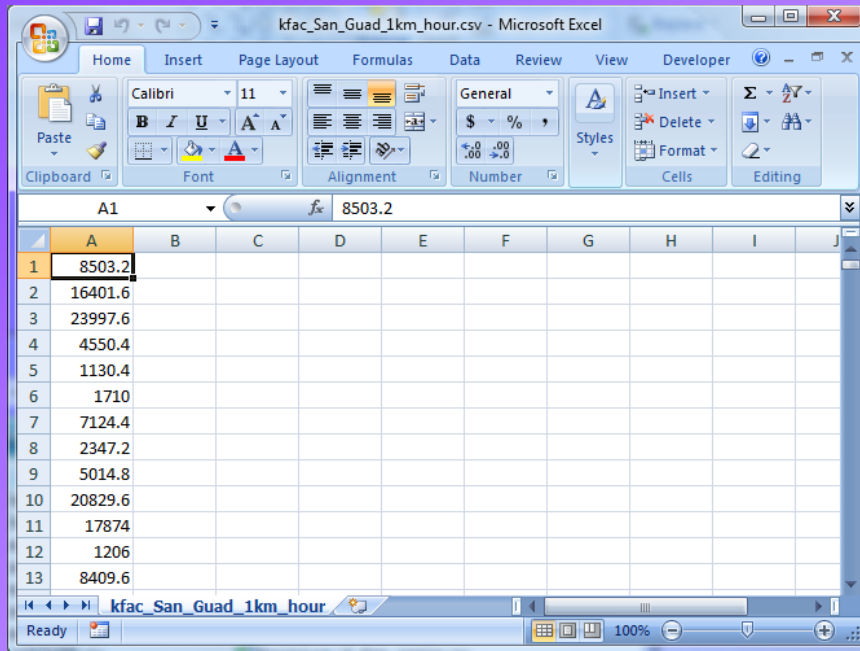
Q^g

Observed daily stream flow

$\bar{\mathbf{Q}}$

Vector of daily flow rates at the outlet of each river reach
(output of RAPID)

First guess of model parameters in optimization mode



	A	B	C	D	E	F	G	H	I	J
1	8503.2									
2	16401.6									
3	23997.6									
4	4550.4									
5	1130.4									
6	1710									
7	7124.4									
8	2347.2									
9	5014.8									
10	20829.6									
11	17874									
12	1206									
13	8409.6									

RAPID looks for λ^k and λ^x that minimize the cost function

$$k_j = \lambda^k \cdot k_j^{fac}$$

$$x_j = \lambda^x \cdot 0.1$$

k_j^{fac} estimated based on
length of river reach and
on celerity of flow wave

Time-independent, .csv file

Observations of stream flow on the river network

List of river IDs where gauges are located

Observations in m^3/s

	A	B	C	D	E	F	G	H	I	J
1	1619595									
2	1619649									
3	1620031									
4	1622713									
5	1622763									
6	1623207									
7	1630223									
8	1631023									
9	1631087									
10	1631099									
11	1631387									
12	1631587									
13	1637447									

Number of river gauges

Time-independent, .csv file

	A	B	C	D	E	F	G	H	I	J
1	3.14317	10.27902	4.389111	21.97387	0.220871	0.368119	1.104357	0.396436	0.018689	4.41
2	3.256437	10.2507	4.389111	21.80397	0.158574	0.396436	1.104357	0.396436	0.02237	4.38
3	3.284754	10.0808	4.389111	21.83229	0.150079	0.424753	1.104357	0.396436	0.024919	4.36
4	3.284754	10.02416	4.389111	21.71902	0.118931	0.424753	1.104357	0.368119	0.026618	4.30
5	3.284754	9.939213	4.389111	21.74734	0.107604	0.396436	1.07604	0.339802	0.021804	4.41
6	3.228121	9.882579	4.389111	21.5208	0.101941	0.396436	1.019406	0.339802	0.021238	4.44
7	3.114853	9.910896	4.389111	21.43585	0.099109	0.368119	1.019406	0.339802	0.018972	4.44
8	3.114853	9.910896	4.389111	20.75625	0.107604	0.368119	1.047723	0.368119	0.017556	4.53
9	3.114853	9.882579	4.389111	23.5313	0.116099	0.311485	1.07604	0.396436	0.019822	4.47
10	3.114853	9.882579	4.389111	21.20932	0.116099	0.271842	1.047723	0.368119	0.022087	4.44
11	3.114853	9.882579	4.389111	21.37922	0.116099	0.266178	1.019406	0.368119	0.017273	4.41
12	3.086536	9.825946	4.389111	21.3509	0.127426	0.266178	1.189308	0.368119	0.014442	4.41
13	2.973269	9.854263	4.389111	21.32259	0.135921	0.263347	1.217624	0.424753	0.015857	4.41

Number of river gauges

Number of daily observations

Time-dependent, .csv file

Further information

RAPID website: <http://rapid-hub.org/>

RAPID source code: <https://github.com/c-h-david/rapid/>