2nd International LIFE REWAT Summer School

Digital water management and water-related agroecosystem services: geostatistics, hydroinformatics and groundwater flow numerical modelling

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Scuola Superiore Sant'Anna
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2nd FREEWAT International Workshop

A METHODOLOGY FOR THE INITIAL CHARACTERISATION OF THE RIVER BOUNDARY CONDITION

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Purpose

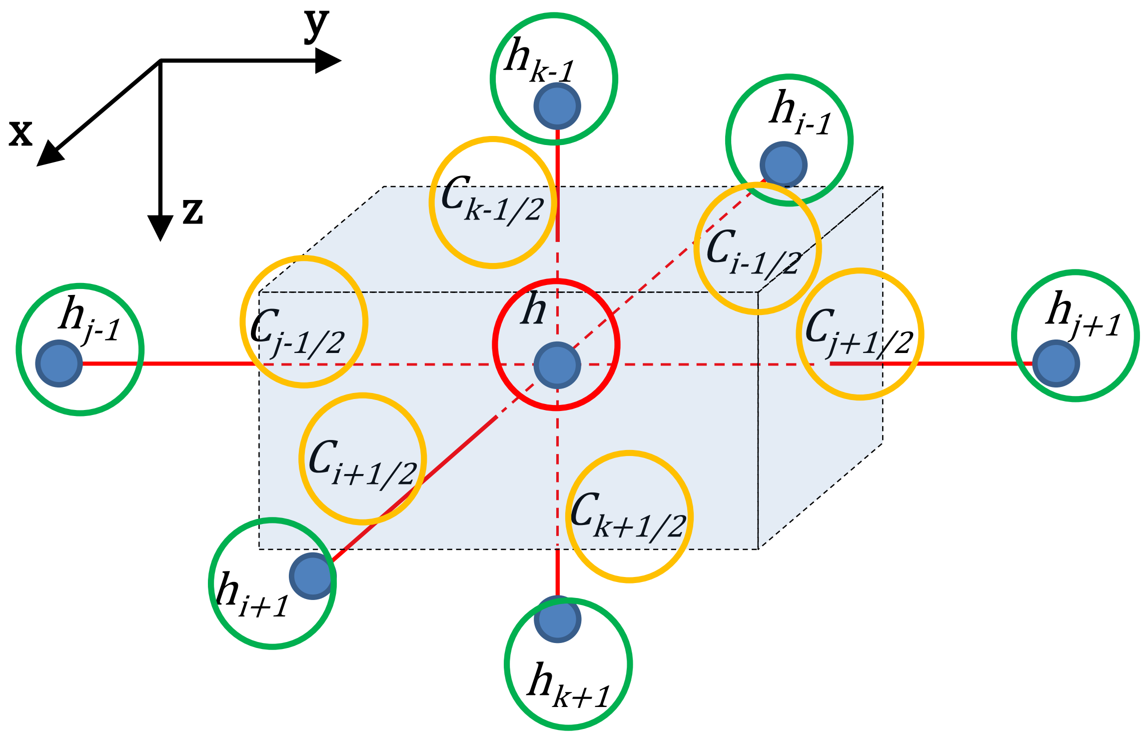
To define the initial parameters of the river boundary condition.

This methodology is mainly applicable when there is not a detailed knowledge of the area to be modelled and yet the river boundary condition must be considered.

It requires the existence of a digital elevation model (DEM).

Finite difference models – Continuity equation

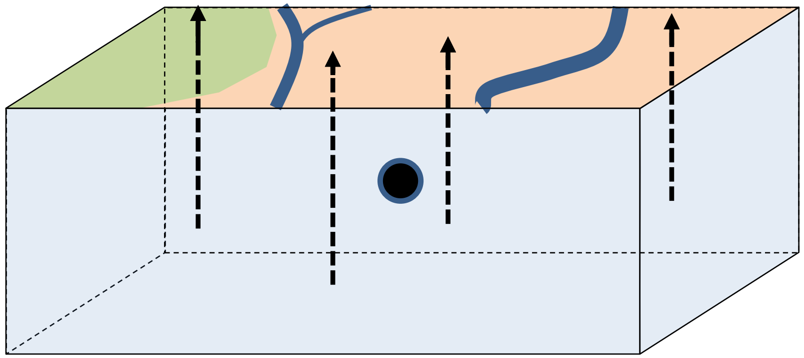
$$C_{j-1/2}\cdot(h_{j-1}-h)+C_{j+1/2}\cdot(h_{j+1}-h)+C_{i-1/2}\cdot(h_{i-1}-h)+C_{i+1/2}\cdot(h_{i+1}-h)$$
$$+C_{k-1/2}\cdot(h_{k-1}-h)+C_{k+1/2}\cdot(h_{k+1}-h)+Q=Ss\,\Delta h/\Delta t\,V$$

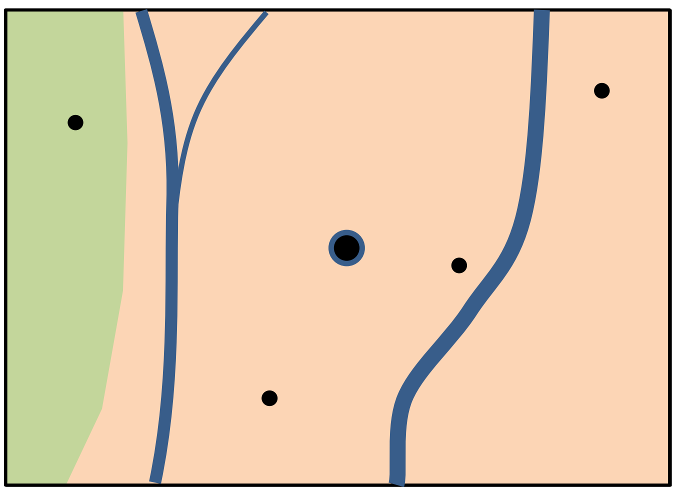


Darcy´s law: Q = K . A . dh / ds >>>> Q = C . dh >>>> C = K . A / ds

Finite difference models – Continuity equation – Q term

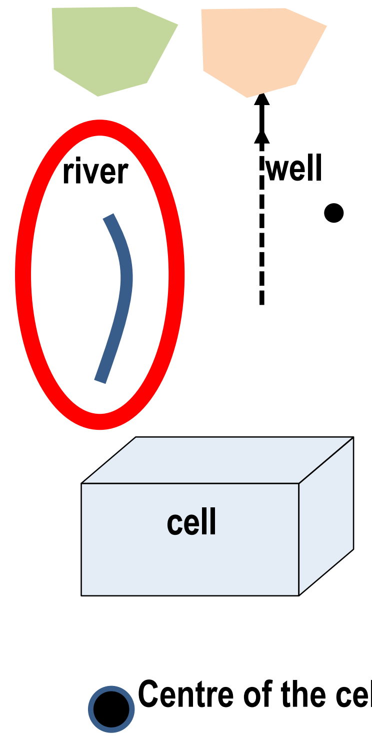
$$C_{j-1/2}.\left(h_{j-1}-h\right)+C_{j+1/2}.\left(h_{j+1}-h\right)+C_{i-1/2}.(h_{i-1}-h)+C_{i+1/2}.(h_{i+1}-h)$$
$$+\,C_{k-1/2}.(h_{k-1}-h)+C_{k+1/2}.(h_{k+1}-h)+\boldsymbol{Q}=\ Ss.\Delta h/\Delta t\,.V$$





Q – Sources and sinks

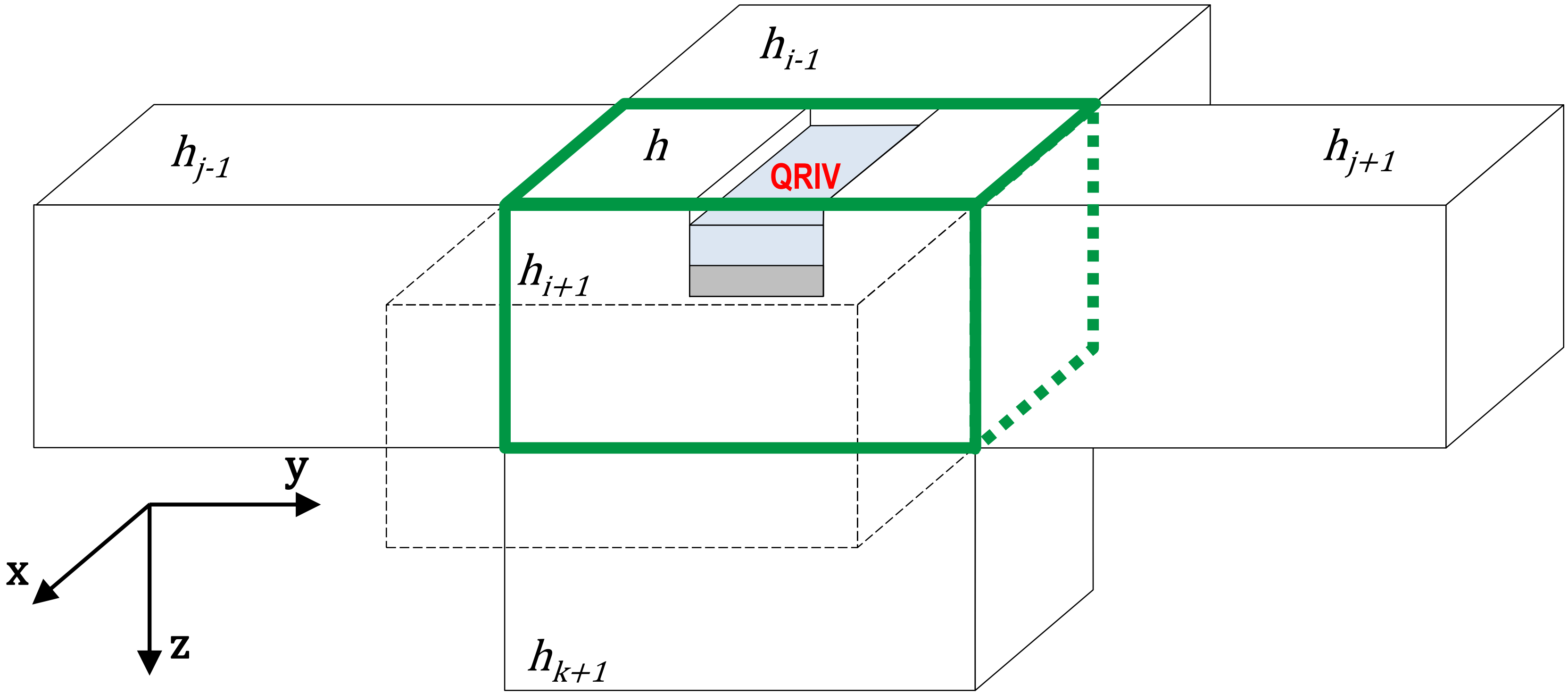
Recharge areas



Finite difference models – Continuity equation – Q term (QRIV)

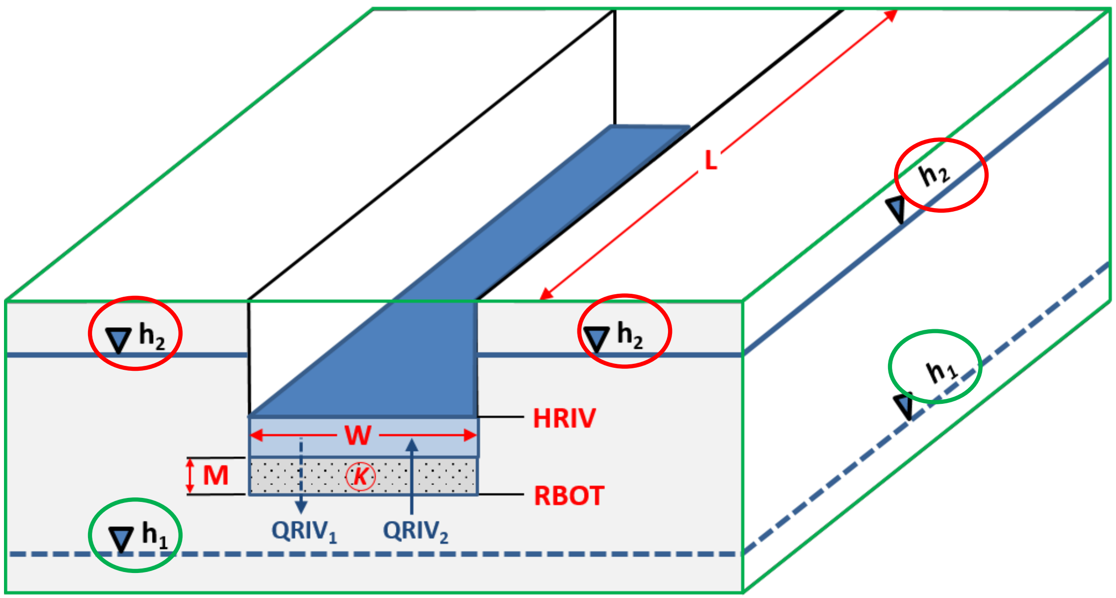
$$C_{j-1/2}.\left(h_{j-1}-h\right)+C_{j+1/2}.\left(h_{j+1}-h\right)+C_{i-1/2}.(h_{i-1}-h)+C_{i+1/2}.(h_{i+1}-h)$$
$$\cancel{+C_{k-1/2}.(h_{k-1}-h)}+C_{k+1/2}.(h_{k+1}-h)+\boldsymbol{Q}RIV = Ss.\Delta h/\Delta t\,.V$$

$QRIV$ – flow rate between the river and the aquifer (L3/T)



Finite difference models – Continuity equation – Q term (QRIV)

$$C_{j-1/2}.(h_{j-1}-h)+C_{j+1/2}.(h_{j+1}-h)+C_{i-1/2}.(h_{i-1}-h)+C_{i+1/2}.(h_{i+1}-h)$$
$$\cancel{+C_{k-1/2}.(h_{k-1}-h)}+C_{k+1/2}.(h_{k+1}-h)+\boldsymbol{Q}RIV = Ss.\Delta h/\Delta t\,.V$$



HRIV – head of the river [L]
RBOT – elevation of the riverbed bottom [L]

(h – hydraulic head of the model cell [L])

K – hydraulic conductivity of the riverbed material [L/T]
L – length of the river [L]
W – width of the river [L]
M – thickness of the riverbed [L]

CRIV – hydraulic conductance (L2/T)

$$CRIV = K \times L \times W \,/\, M$$

QRIV – flow rate between the river and the aquifer (L3/T)

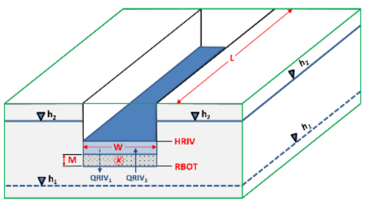
$$QRIV = CRIV \times (HRIV - h), \qquad if\ h > RBOT$$
$$QRIV = CRIV \times (HRIV - RBOT), \qquad if\ h \leq RBOT$$

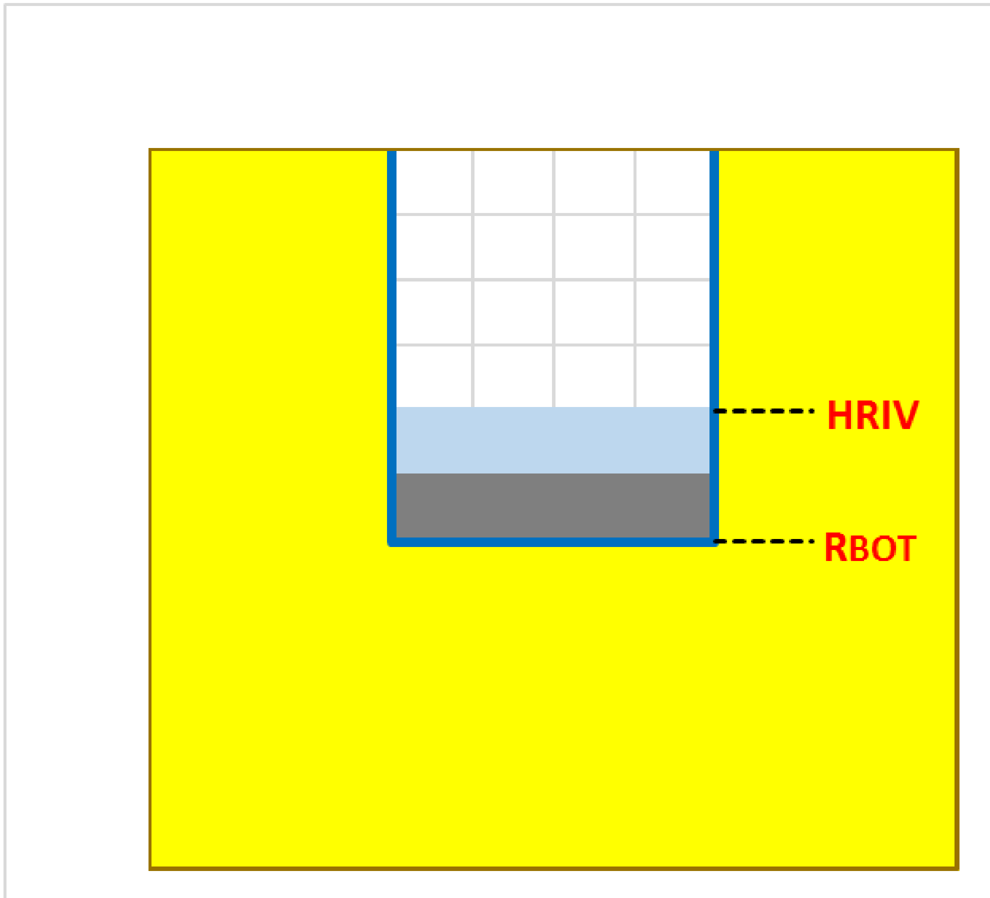
(McDonald and Harbaugh 1988)

Q term (QRIV)

$$QRIV = CRIV \times (HRIV - h), \qquad if\ h > RBOT$$
$$QRIV = CRIV \times (HRIV - RBOT), \qquad if\ h \leq RBOT$$

Model cell with a river



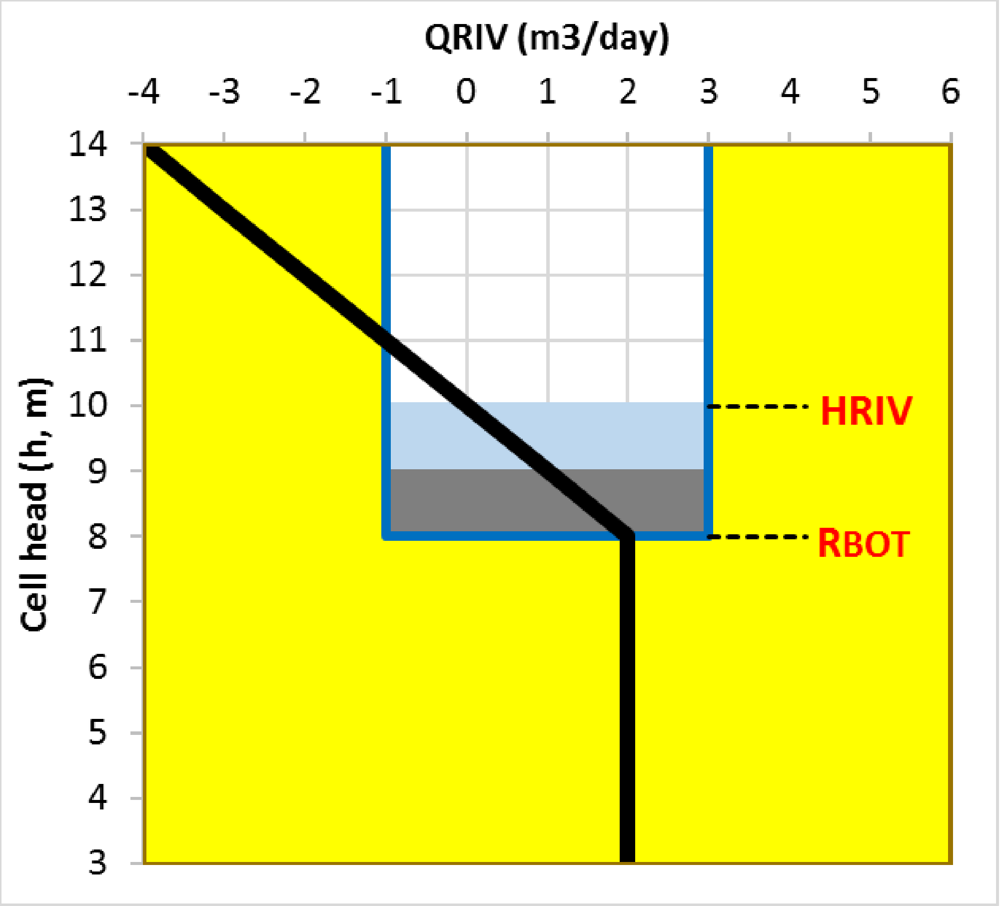


Q term (QRIV)

$$QRIV = CRIV \times (HRIV - h), \qquad if\ h > RBOT$$
$$QRIV = CRIV \times (HRIV - RBOT), \qquad if\ h \leq RBOT$$

Model cell with a river

$HRIV = 10$ m
$RBOT = 8$ m
$CRIV = 1\ m^2/d$



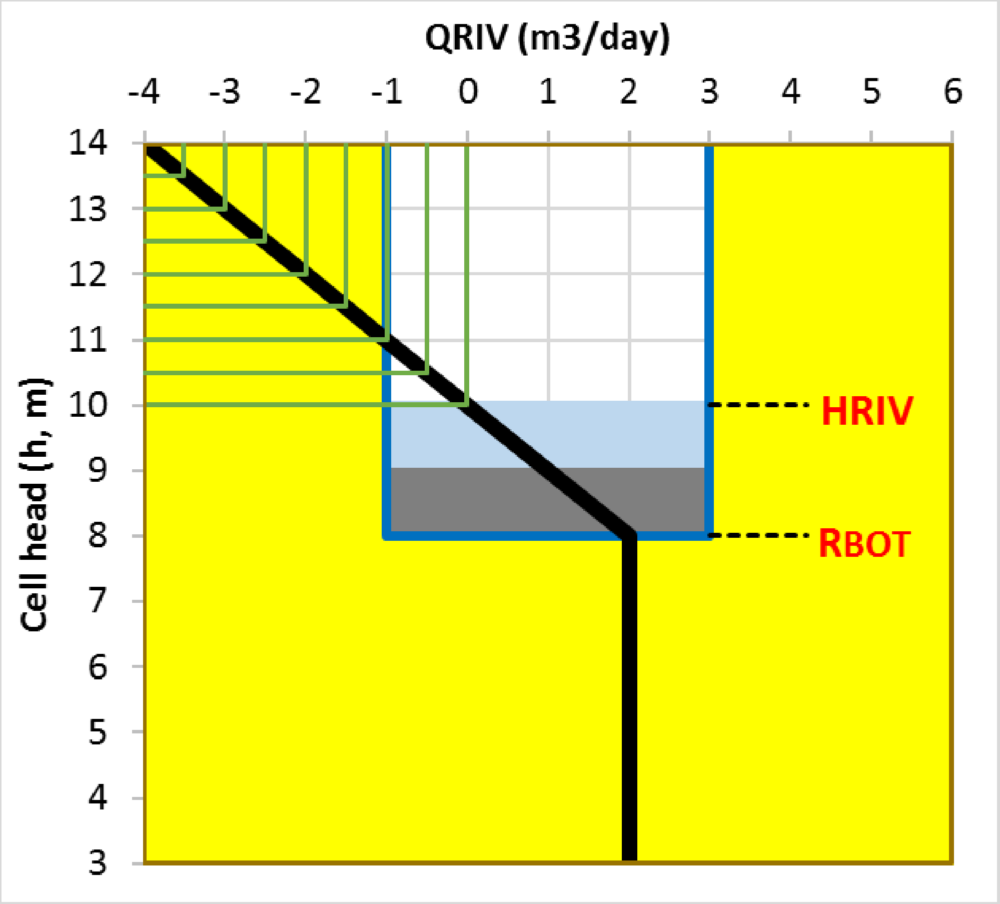
Q term (QRIV)

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \le RBOT$$

Model cell with a river

$HRIV = 10$ m
$RBOT = 8$ m
$CRIV = 1\ m^2/d$



h > HRIV

QRIV is negative → the aquifer discharges to the river (from 4 m3/day)

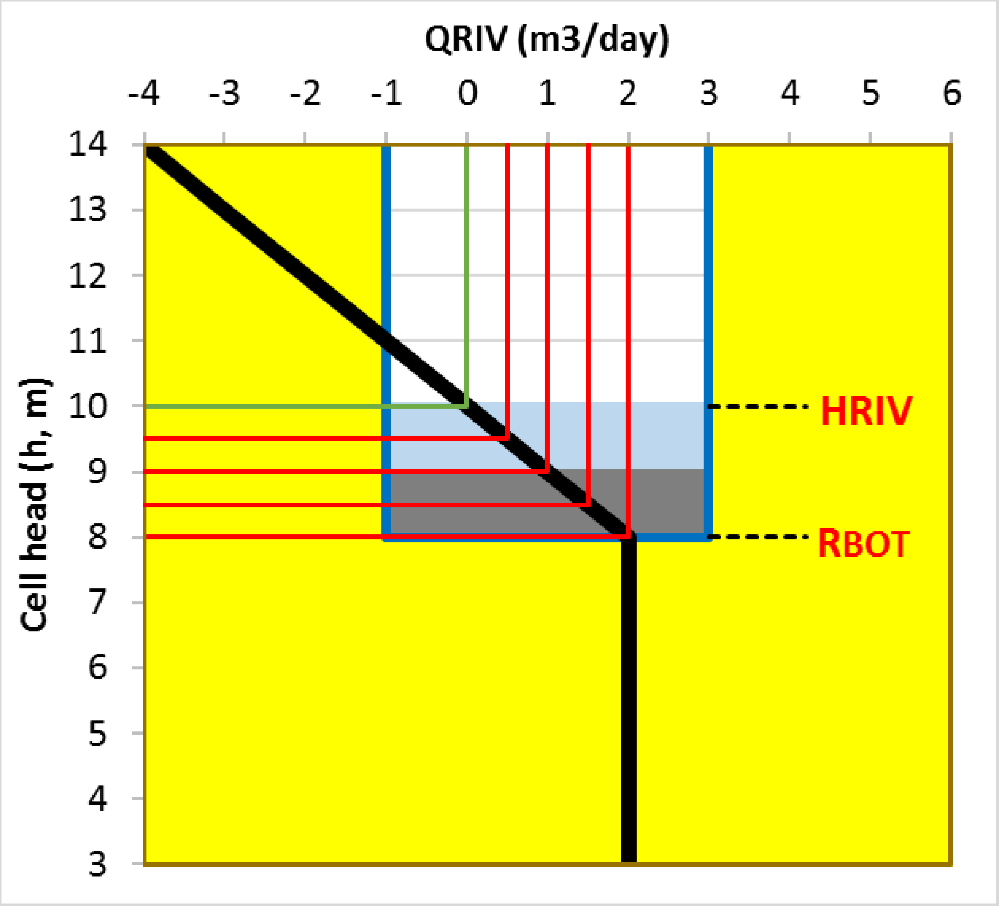
Q term (QRIV)

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

Model cell with a river

$HRIV = 10$ m
$RBOT = 8$ m
$CRIV = 1\ m^2/d$



HRIV > h > RBOT

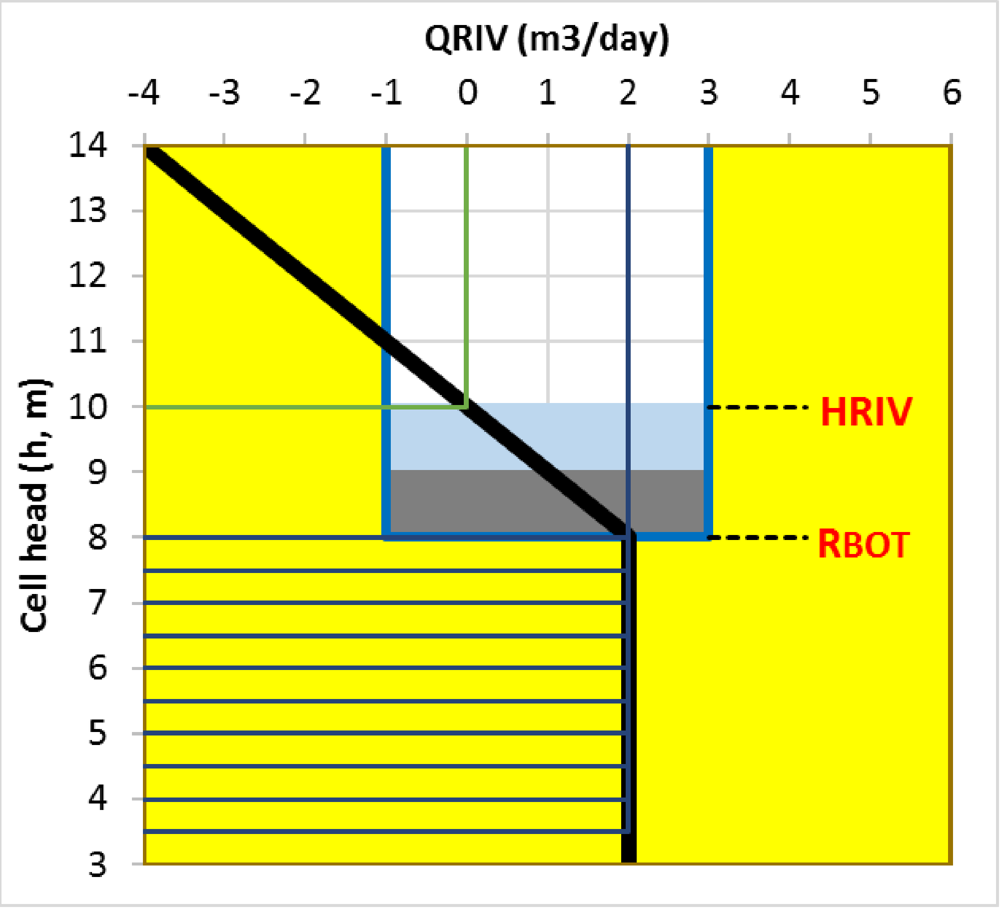
QRIV is positive → the river recharges the aquifer in an increasing rate (up to 2 m3/day)

Q term (QRIV)

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$
$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

Model cell with a river

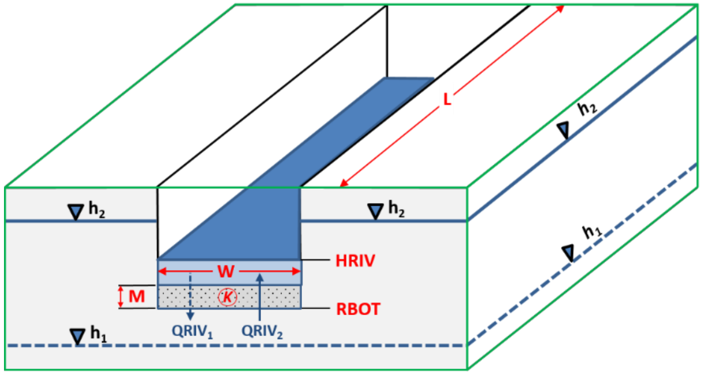
$HRIV = 10$ m
$RBOT = 8$ m
$CRIV = 1\ m^2/d$



h < RBOT

QRIV is positive → the river recharges the aquifer at a constant rate (2 m3/day)

Assign the river boundary condition to a model developed with the FREEWAT platform



In FREEWAT the river boundary condition requires the assignment of three parameters:

CRIV
HRIV
RBOT

CRIV is a lumped parameter calculated using K**,** L**,** W **and** M

Procedures will be partially demonstrated using the FREEWAT platform plugin and QGIS commands.

Assign the river boundary condition to a model developed with the FREEWAT platform

RIV text file in MODFLOW-2005 (simplified)

1980	953					Max number of river reaches, Flag and unit number
1980	0					Nr of reaches active during current stress period, Nr of parameters in use in the current stress period
1	282	36	2.12271e1	8.72201e2	2.07271e1	
1	283	37	2.22068e1	8.80703e2	2.17068e1	For each reach cell
1	281	37	2.38138e1	9.38881e2	2.3771e1	[LAYER, ROW, COLUMN, STAGE, COND, RBOT]
…..						….

(Harbaugh 2005; https://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/index.html?lpf.htm)

RIV model data object table in FREEWAT

riv_layer_riv :: Features total: 34, filtered: 34, selected: 0

	PKUID	ID	ROW	COL	layer	segment	length	stage_1	rbot_1	cond_1	stage_2	rbot_2	cond_2
1	1	0	20	1	1	1	75.2795282472	0	-5	0.000501863521...	0	-5	0.000501863521...
2	2	0	20	2	1	1	100.300344097	0	-5	0.000668668960...	0	-5	0.000668668960...
3	3	0	20	3	1	1	100.300344097	0	-5	0.000668668960...	0	-5	0.000668668960...
4	4	0	20	4	1	1	100.300344097	0	-5	0.000668668960...	0	-5	0.000668668960...
5	5	0	20	5	1	1	100.13776637	0	-5	0.000667585109...	0	-5	0.000667585109...
6	6	0	19	5	1	1	4.93407108373	0	-5	3.28938072248e...	0	-5	3.28938072248e...
7	7	0	19	6	1	1	105.657774458	0	-5	0.000704385163...	0	-5	0.000704385163...
8	8	0	19	7	1	1	105.657774458	0	-5	0.000704385163...	0	-5	0.000704385163...
9	9	0	19	8	1	1	104.546611254	0	-5	0.000696977408...	0	-5	0.000696977408...
10	10	0	19	9	1	1	1.97538606987	0	-5	1.31692404658e...	0	-5	1.31692404658e...

Show All Features

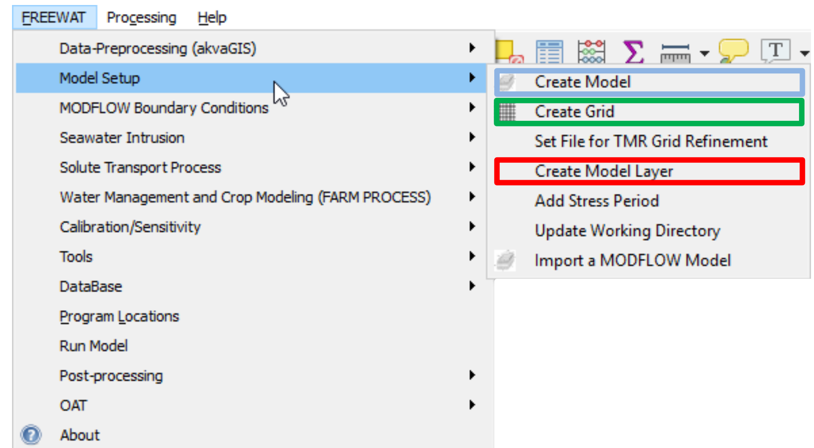
(de Filippis et al. 2019)

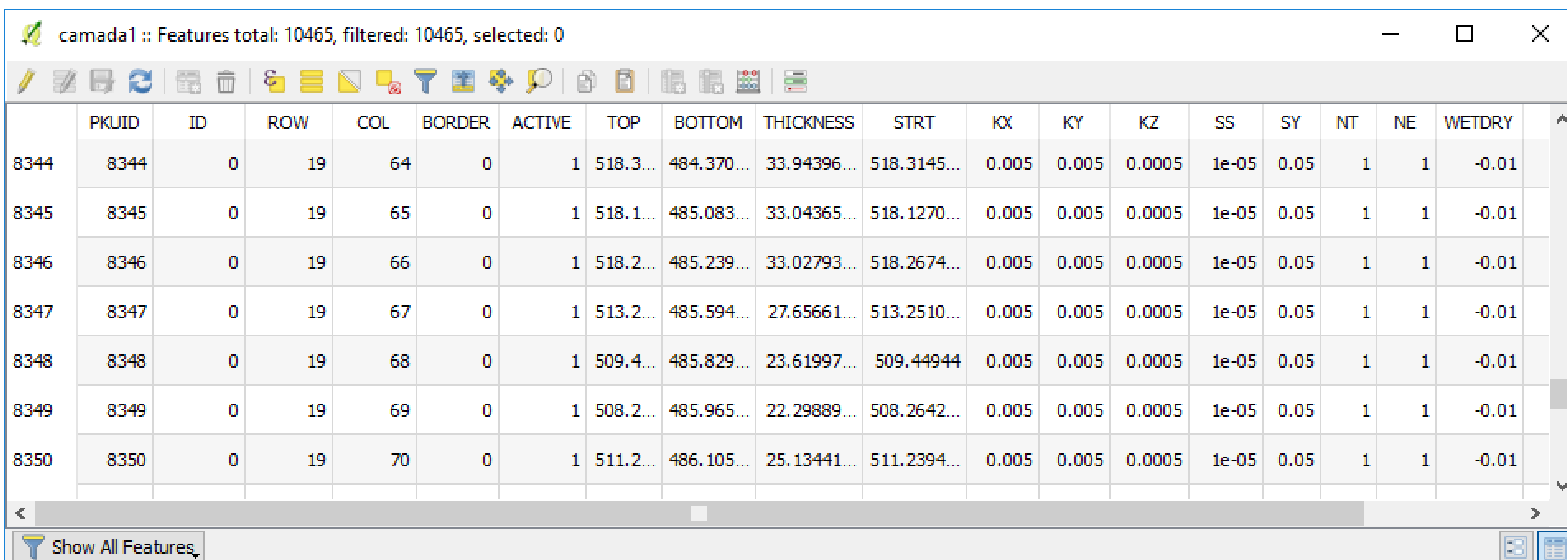
The model grid (layer 1 of the model)

Use the Model Setup | Create Model, Create Grid and Create Model Layer to generate the first layer of the model (“camada1”).

In the presented example the model grid is square, 200 m side, rotated 26.4º to West, and **the river boundary condition values will be assigned to the 1st layer**.

Assign the field properties for this first model layer, namely, ACTIVE, TOP, BOTTOM, THICKNESS, STRT, KX, KY, KZ, SS, SY, NT, NE and WETDRY




camada1 :: Features total: 10465, filtered: 10465, selected: 0

	PKUID	ID	ROW	COL	BORDER	ACTIVE	TOP	BOTTOM	THICKNESS	STRT	KX	KY	KZ	SS	SY	NT	NE	WETDRY
8344	8344	0	19	64	0	1	518.3...	484.370...	33.94396...	518.3145...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8345	8345	0	19	65	0	1	518.1...	485.083...	33.04365...	518.1270...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8346	8346	0	19	66	0	1	518.2...	485.239...	33.02793...	518.2674...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8347	8347	0	19	67	0	1	513.2...	485.594...	27.65661...	513.2510...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8348	8348	0	19	68	0	1	509.4...	485.829...	23.61997...	509.44944	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8349	8349	0	19	69	0	1	508.2...	485.965...	22.29889...	508.2642...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8350	8350	0	19	70	0	1	511.2...	486.105...	25.13441...	511.2394...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01

Show All Features

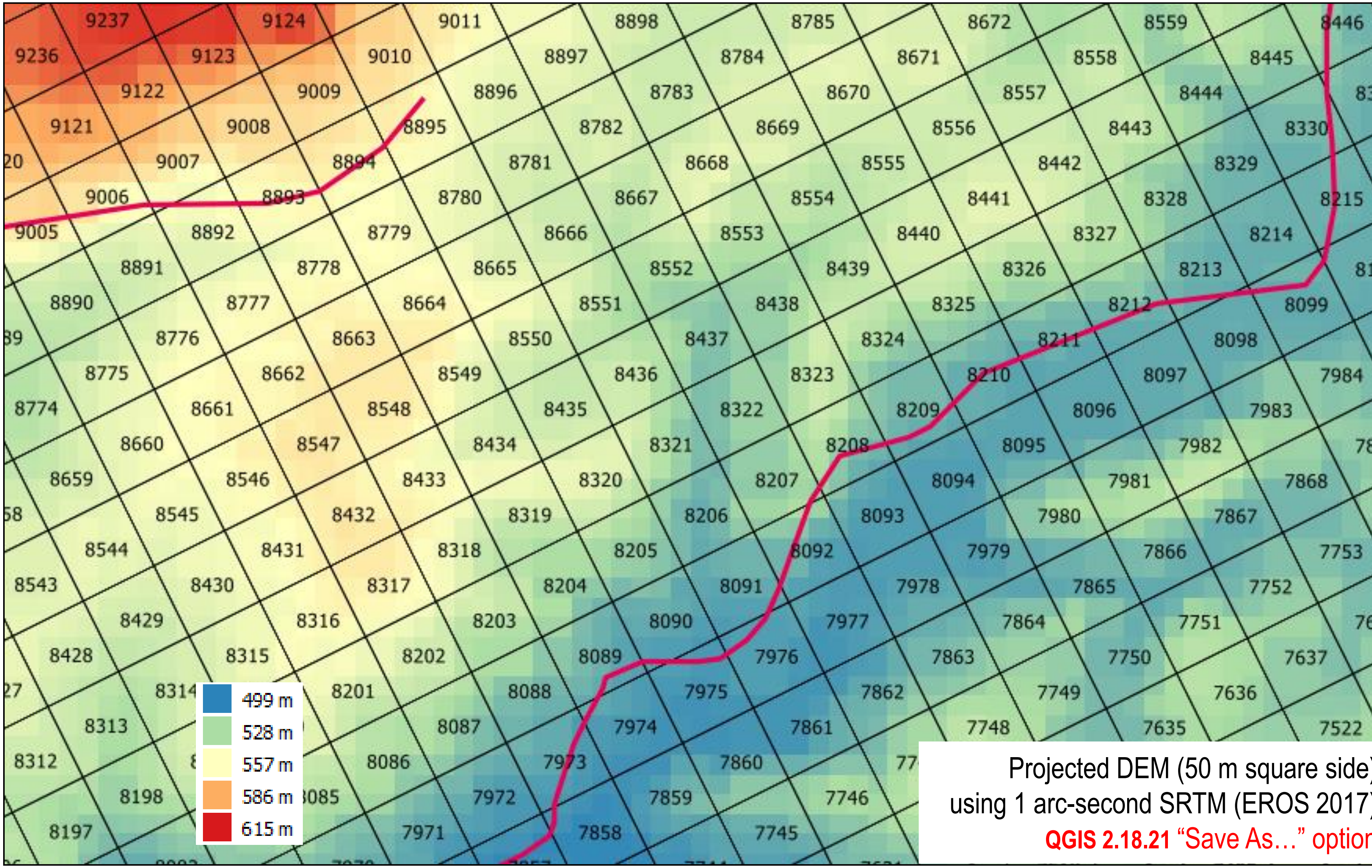
Goto Slide 37

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers

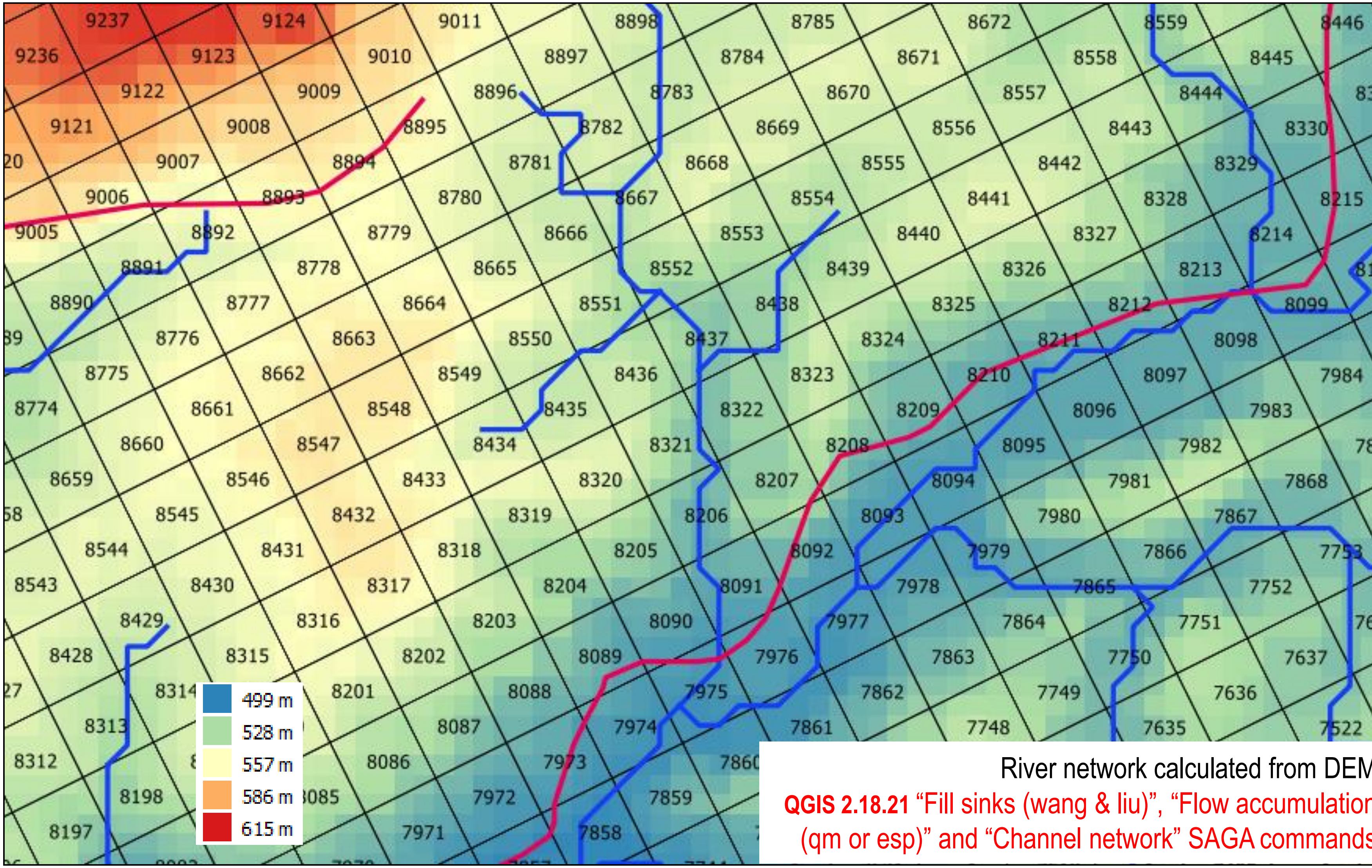
Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers + DEM



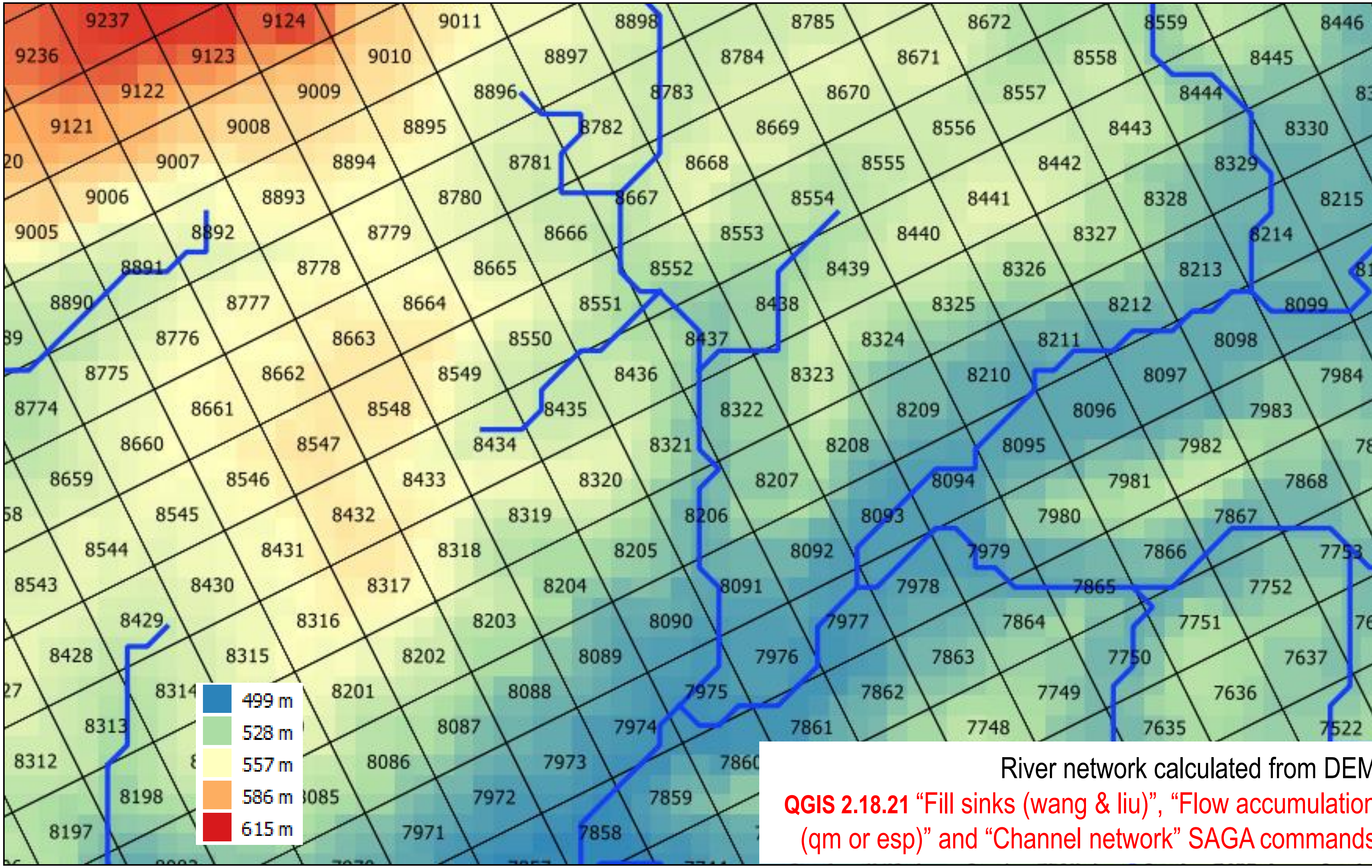
Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers + DEM (+ rivers recalculated with DEM)



Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM



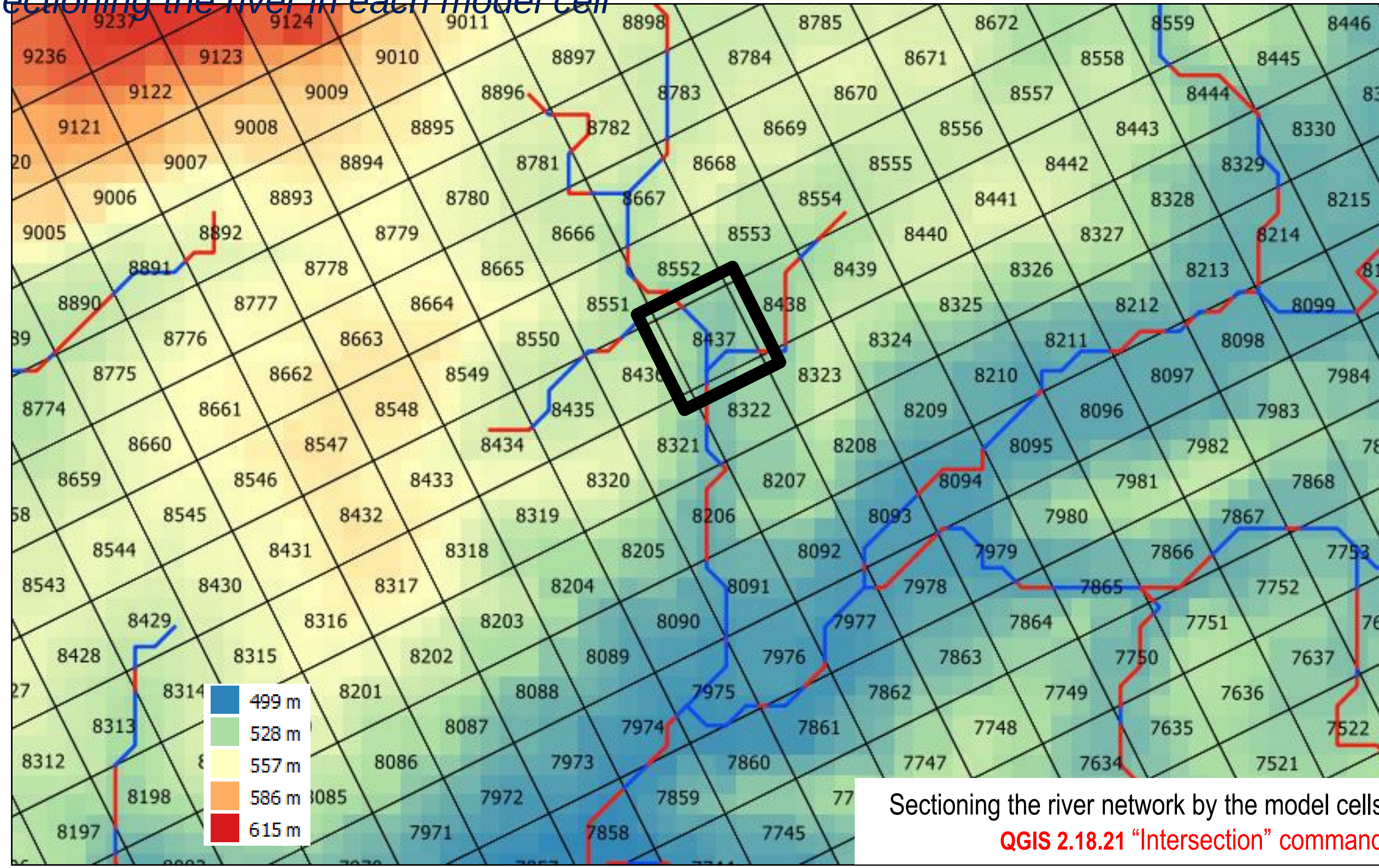
River network calculated from DEM

QGIS 2.18.21 "Fill sinks (wang & liu)", "Flow accumulation (qm or esp)" and "Channel network" SAGA commands

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

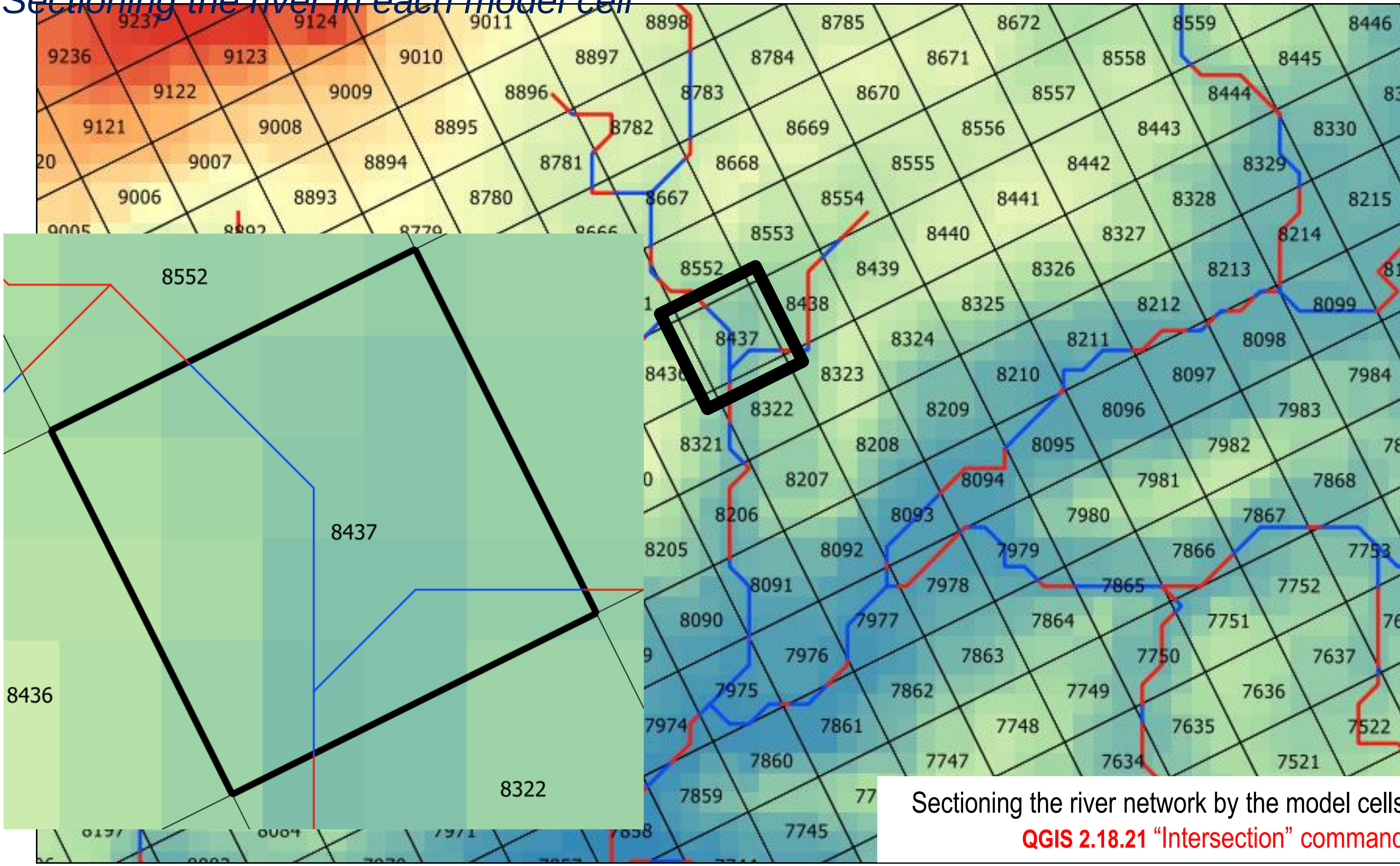
Sectioning the river in each model cell



Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

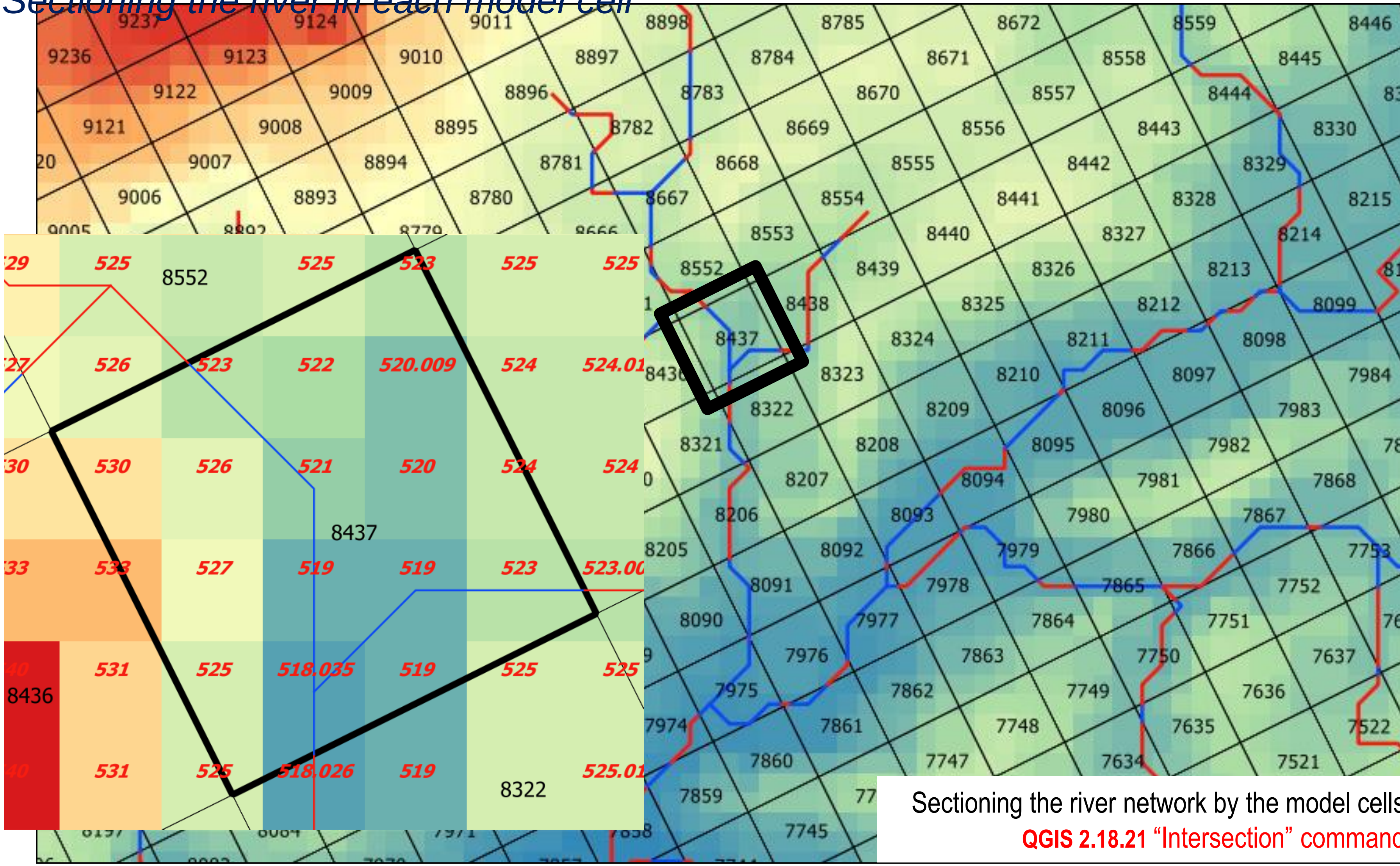
Sectioning the river in each model cell



Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

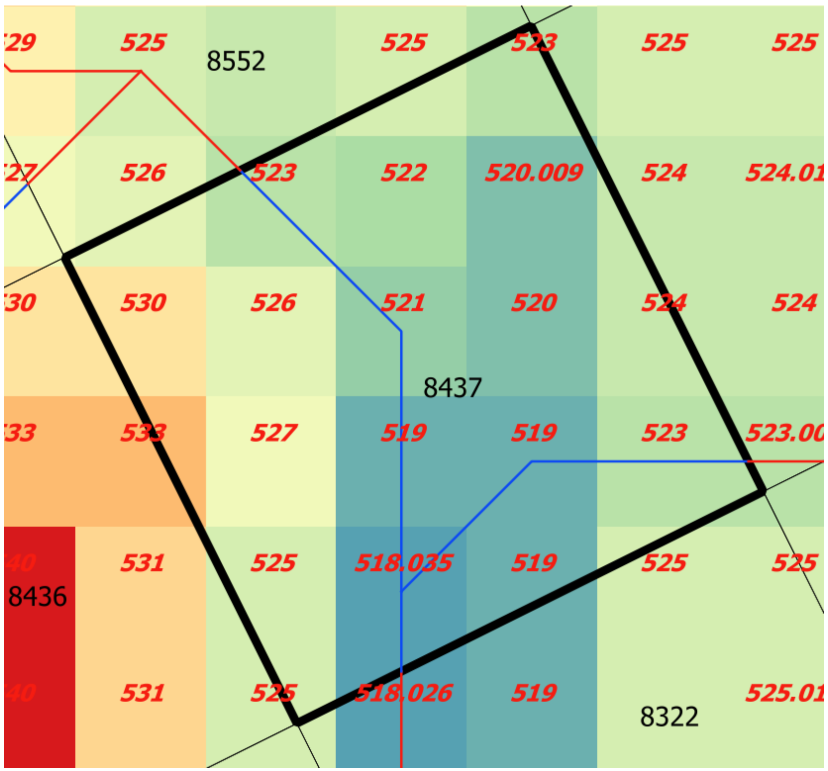
Sectioning the river in each model cell



Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments



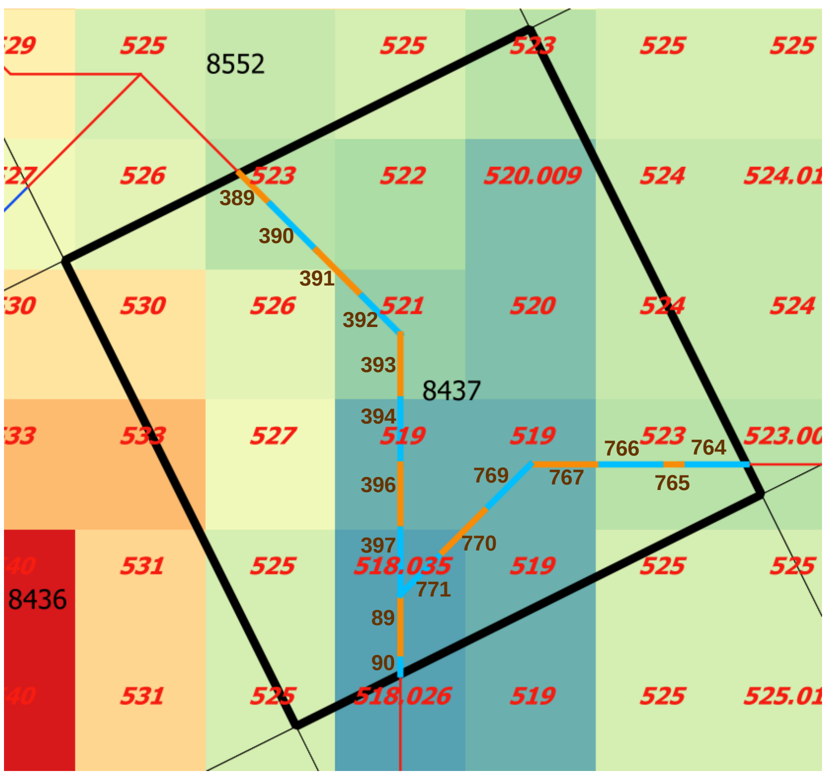
Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Determine the length of each segment

PKUID	ID	LENGTH
8437	390	25
8437	764	25
8437	765	8.189833
8437	766	25
8437	389	16.81009
8437	391	25
8437	392	20.71068
8437	393	25
8437	394	25
8437	396	25
8437	767	25
8437	769	25
8437	397	25
8437	770	25
8437	771	20.71068
8437	89	25
8437	90	5.715815



Segment length = 25 m

Subdividing the river in segments

QGIS 2.18.21 "Densify geometries given an interval" + "Explode lines" tools

Calculate the length of each segment

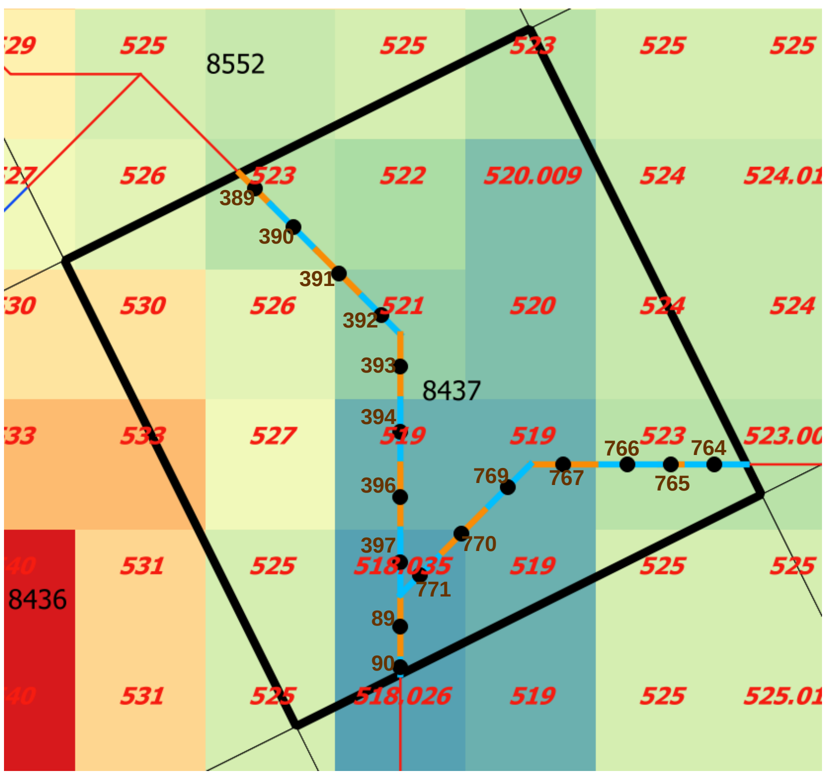
QGIS 2.18.21 Add field LENGTH to the table, calculate field LENGTH = $length and ID = $id. Delete records with LENGTH = 0

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Determine the central point in each segment



MEAN_X	MEAN_Y	UID
473233.839	9144216.161	390.0
473395.690	9144125.000	764.0
473379.095	9144125.000	765.0
473362.500	9144125.000	766.0
473219.057	9144230.943	389.0
473251.517	9144198.484	391.0
473267.678	9144182.322	392.0
473275.000	9144162.500	393.0
473275.000	9144137.500	394.0
473275.000	9144112.500	396.0
473337.500	9144125.000	767.0
473316.161	9144116.161	769.0
473275.000	9144087.500	397.0
473298.484	9144098.484	770.0
473282.322	9144082.322	771.0
473275.000	9144062.500	89.0
473275.000	9144047.142	90.0

Central point of each segment

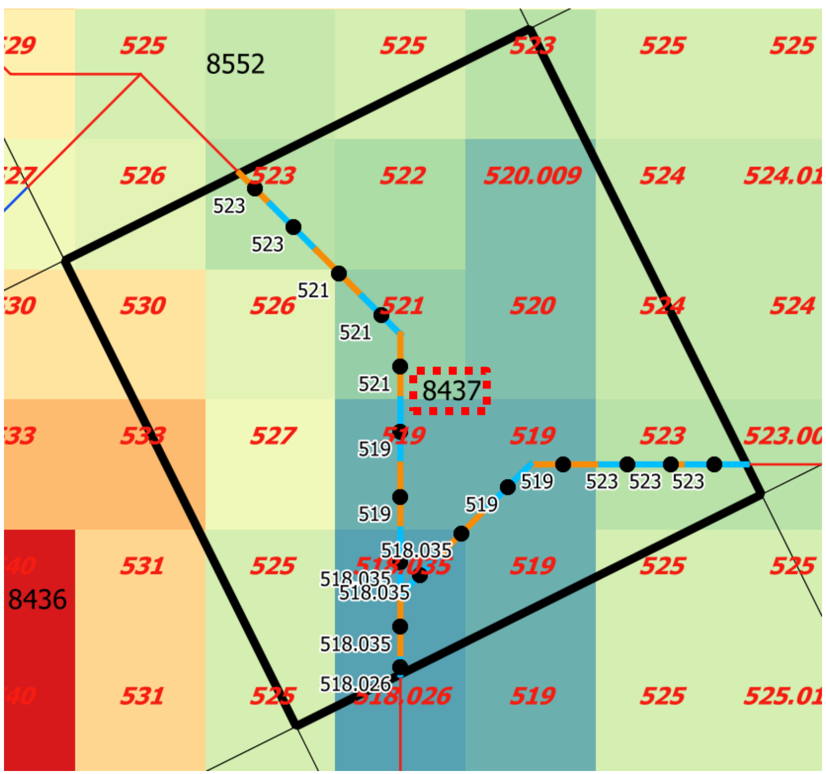
QGIS 2.18.21 "Mean coordinate(s)" tool

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Determine the central point in each segment – get elevation value



MEAN_X	MEAN_Y	UID	ID	Z
473233.839	9144216.161	390.0	390	523
473395.690	9144125.000	764.0	764	523
473379.095	9144125.000	765.0	765	523
473362.500	9144125.000	766.0	766	523
473219.057	9144230.943	389.0	389	523
473251.517	9144198.484	391.0	391	521
473267.678	9144182.322	392.0	392	521
473275.000	9144162.500	393.0	393	521
473275.000	9144137.500	394.0	394	519
473275.000	9144112.500	396.0	396	519
473337.500	9144125.000	767.0	767	519
473316.161	9144116.161	769.0	769	519
473275.000	9144087.500	397.0	397	518.0349
473298.484	9144098.484	770.0	770	518.0349
473282.322	9144082.322	771.0	771	518.0349
473275.000	9144062.500	89.0	89	518.0349
473275.000	9144047.142	90.0	90	518.0262

Get elevation value from the DEM

QGIS 2.18.21 Create and fill field ID = to_real("UID") + "Add raster values to points" SAGA command

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Link tables

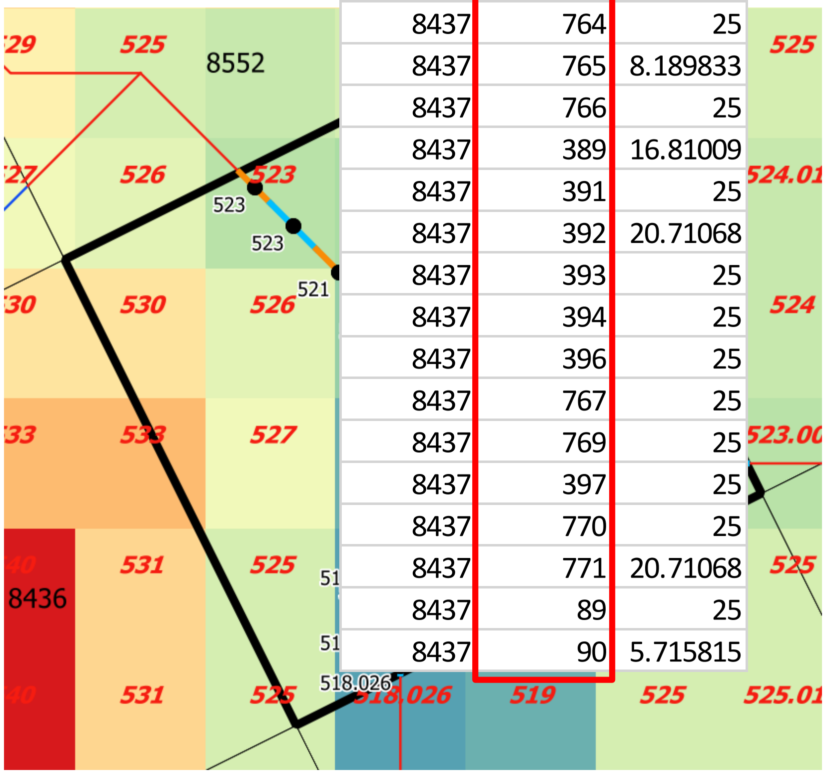


Table of the segments

PKUID	ID	LENGTH
8437	390	25
8437	764	25
8437	765	8.189833
8437	766	25
8437	389	16.81009
8437	391	25
8437	392	20.71068
8437	393	25
8437	394	25
8437	396	25
8437	767	25
8437	769	25
8437	397	25
8437	770	25
8437	771	20.71068
8437	89	25
8437	90	5.715815

Table of the central points of the segments

MEAN_X	MEAN_Y	UID	ID	Z
473233.839	9144216.161	390.0	390	523
473395.690	9144125.000	764.0	764	523
473379.095	9144125.000	765.0	765	523
473362.500	9144125.000	766.0	766	523
473219.057	9144230.943	389.0	389	523
473251.517	9144198.484	391.0	391	521
473267.678	9144182.322	392.0	392	521
473275.000	9144162.500	393.0	393	521
473275.000	9144137.500	394.0	394	519
473275.000	9144112.500	396.0	396	519
473337.500	9144125.000	767.0	767	519
473316.161	9144116.161	769.0	769	519
473275.000	9144087.500	397.0	397	518.0349
473298.484	9144098.484	770.0	770	518.0349
473282.322	9144082.322	771.0	771	518.0349
473275.000	9144062.500	89.0	89	518.0349
473275.000	9144047.142	90.0	90	518.0262

Link tables using the common field ID

QGIS 2.18.21 Properties | Joins | Add vector join

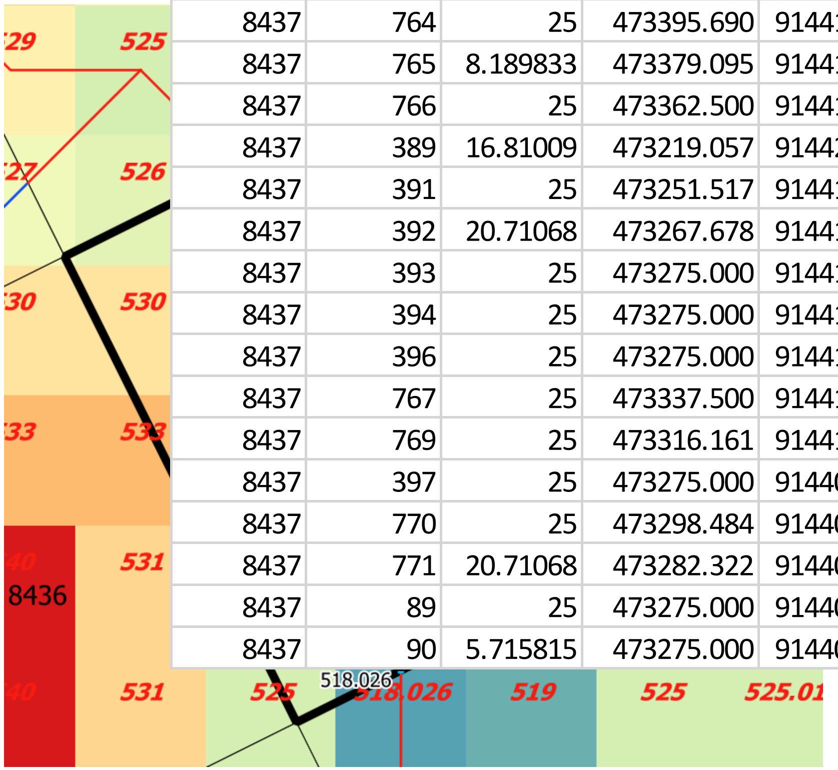
Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Link tables

PKUID	ID	LENGTH	MEAN_X	MEAN_Y	UID	Z	Z1
8437	390	25	473233.839	9144216.161	390.0	523	523
8437	764	25	473395.690	9144125.000	764.0	523	523
8437	765	8.189833	473379.095	9144125.000	765.0	523	523
8437	766	25	473362.500	9144125.000	766.0	523	523
8437	389	16.81009	473219.057	9144230.943	389.0	523	523
8437	391	25	473251.517	9144198.484	391.0	521	521
8437	392	20.71068	473267.678	9144182.322	392.0	521	521
8437	393	25	473275.000	9144162.500	393.0	521	521
8437	394	25	473275.000	9144137.500	394.0	519	519
8437	396	25	473275.000	9144112.500	396.0	519	519
8437	767	25	473337.500	9144125.000	767.0	519	519
8437	769	25	473316.161	9144116.161	769.0	519	519
8437	397	25	473275.000	9144087.500	397.0	518.0349	518.0349
8437	770	25	473298.484	9144098.484	770.0	518.0349	518.0349
8437	771	20.71068	473282.322	9144082.322	771.0	518.0349	518.0349
8437	89	25	473275.000	9144062.500	89.0	518.0349	518.0349
8437	90	5.715815	473275.000	9144047.142	90.0	518.0262	518.0262



Add new field

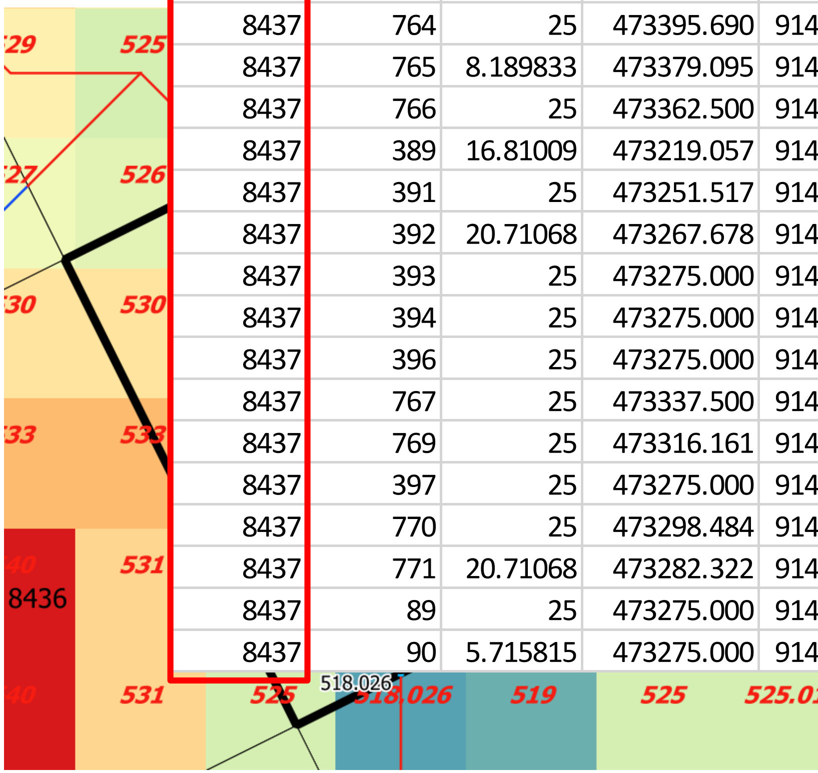
QGIS 2.18.21 Add field Z1 and calculate Z1 = Z

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Calculate the statistics for each model cell



PKUID	ID	LENGTH	MEAN_X	MEAN_Y	UID	Z	Z1
8437	390	25	473233.839	9144216.161	390.0	523	523
8437	764	25	473395.690	9144125.000	764.0	523	523
8437	765	8.189833	473379.095	9144125.000	765.0	523	523
8437	766	25	473362.500	9144125.000	766.0	523	523
8437	389	16.81009	473219.057	9144230.943	389.0	523	523
8437	391	25	473251.517	9144198.484	391.0	521	521
8437	392	20.71068	473267.678	9144182.322	392.0	521	521
8437	393	25	473275.000	9144162.500	393.0	521	521
8437	394	25	473275.000	9144137.500	394.0	519	519
8437	396	25	473275.000	9144112.500	396.0	519	519
8437	767	25	473337.500	9144125.000	767.0	519	519
8437	769	25	473316.161	9144116.161	769.0	519	519
8437	397	25	473275.000	9144087.500	397.0	518.0349	518.0349
8437	770	25	473298.484	9144098.484	770.0	518.0349	518.0349
8437	771	20.71068	473282.322	9144082.322	771.0	518.0349	518.0349
8437	89	25	473275.000	9144062.500	89.0	518.0349	518.0349
8437	90	5.715815	473275.000	9144047.142	90.0	518.0262	518.0262

PKUID	8437
SUM_LENGTH	372.1371
MIN_Z	518.0262
MEAN_Z1	520.245

SUM_LENGTH = complete length of the river in the cell

MIN_Z = lowest elevation value of the river in the cell

MEAN_Z1 = average elevation value of the river in the cell

Calculate statistics

QGIS 2.18.21 "Dissolve with stats" plugin

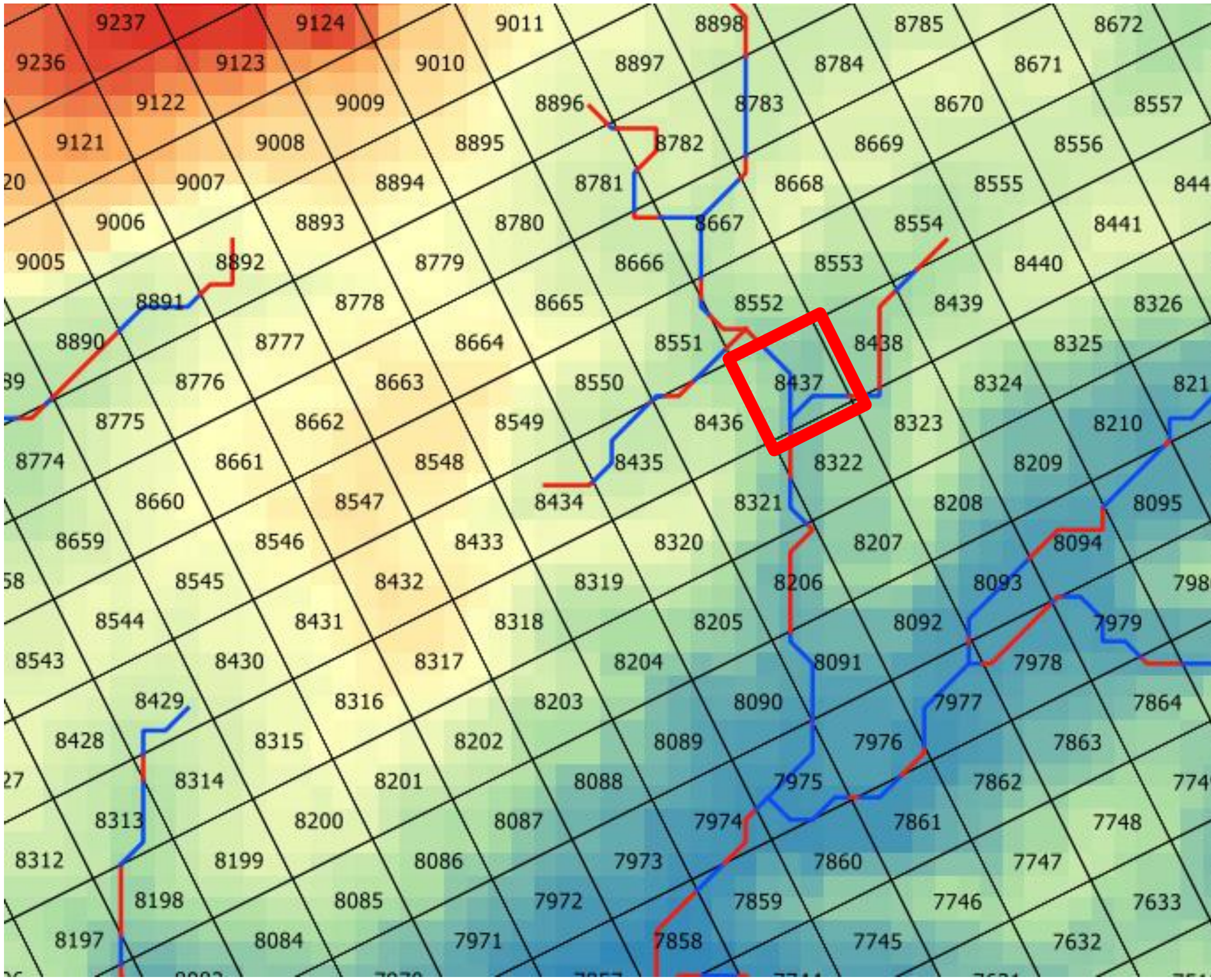
Sum LENGTH, Min Z, Mean Z1

Characterisation of the head of the river (HRIV) and river length (L)

Model grid + rivers recalculated with DEM + DEM + cell detail

Subdividing the river in each model cell into segments

Calculate the statistics for each model cell



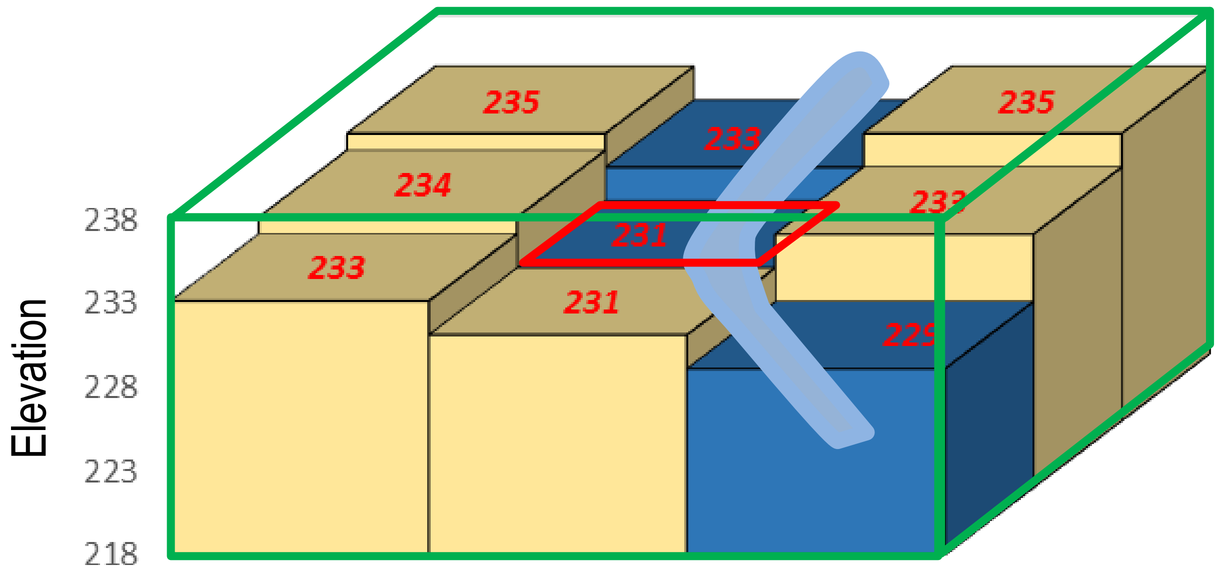
PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
8321	119.8592	516	517.3362
8322	100.5289	518.0087	518.0192
8323	56.6815	523.0087	523.0145
8434	111.8225	542	542.6049
8435	231.6169	536	538.008
8436	88.0528	531	533.4
8437	372.1371	518.0262	520.245
8438	263.9904	523.0087	524.544
8439	65.0933	526.0123	527.3416
8551	175.0350	527	530.8
8552	253.0660	523	527.4615
8554	93.1770	530	530.75
8666	75.9640	540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041

Calculate statistics

QGIS 2.18.21 “Dissolve with stats” plugin

Sum LENGTH, Min Z, Mean Z1

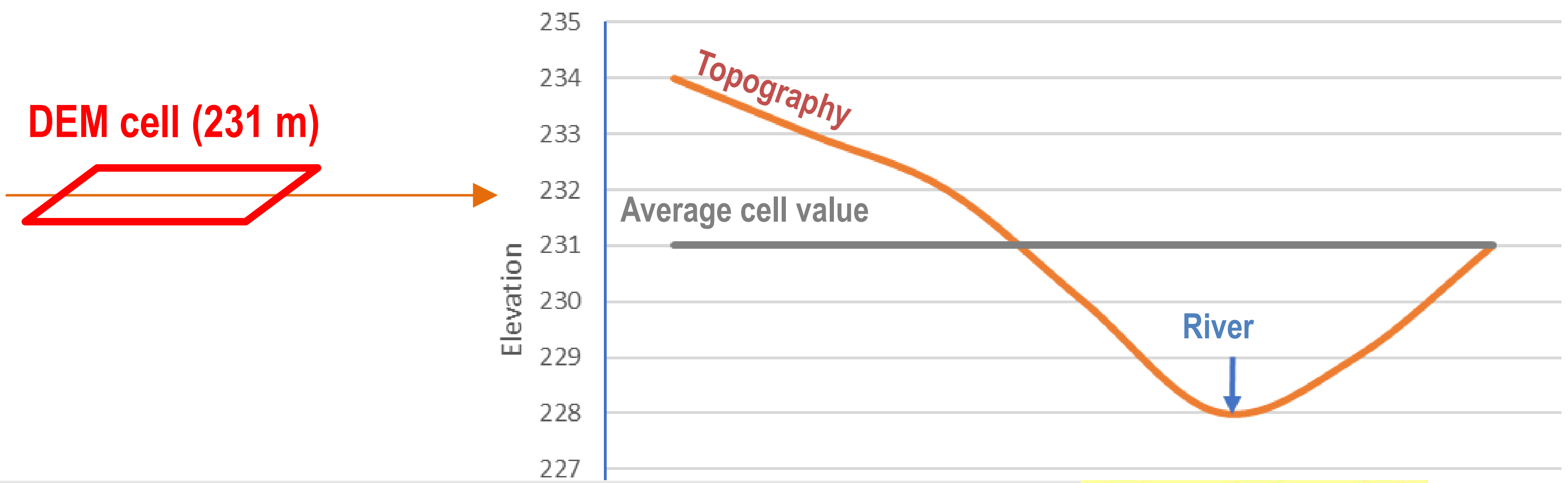
Computation of the parameters of the river boundary condition



9 cells of the DEM

1 cell model average elevation: 232.67 m

DEM cell (231 m)

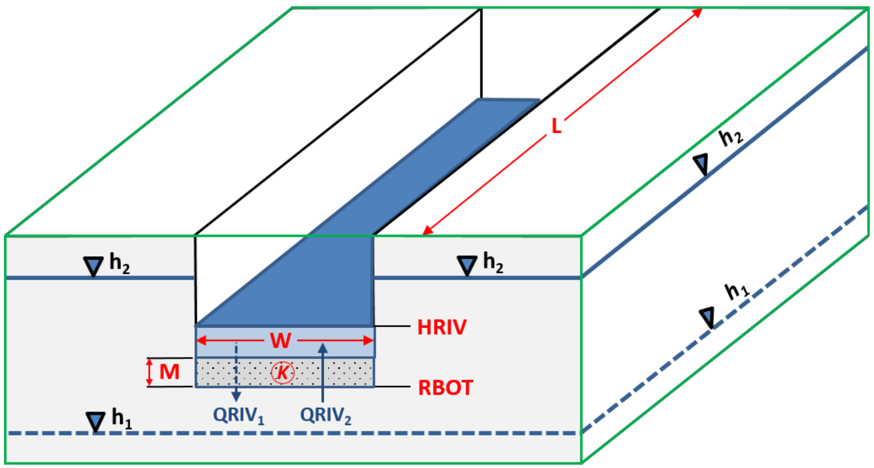


Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

$$CRIV = L \times W \times K / M$$



PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
8321	119.8592	516	517.3362
8322	100.5289	518.0087	518.0192
8323	56.6815	523.0087	523.0145
8434	111.8225	542	542.6049
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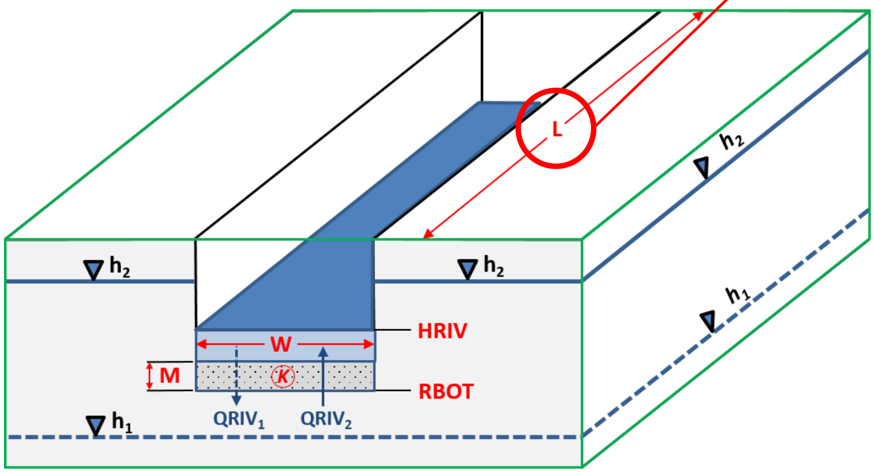
8436	88.0528	531	533.4
8437	372.1371	518.0262	520.245
8438	263.9904	523.0087	524.544
8439	65.0933	526.0123	527.3416
8551	175.0350	527	530.8
8552	253.0660	523	527.4615
8554	93.1770	530	530.75
8666	75.9640	540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041
8781	119.1627	540.0087	542.5787
8782	199.2968	542.0087	543.4497
8783	223.4074	540.0123	540.0312

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

$$CRIV = \boxed{L} \times W \times K / M$$



PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
8321	119.8592	516	517.3362
8322	100.5289	518.0087	518.0192
8323	56.6815	523.0087	523.0145
8434	111.8225	542	542.6049
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8439	65.0933	526.0123	527.3416
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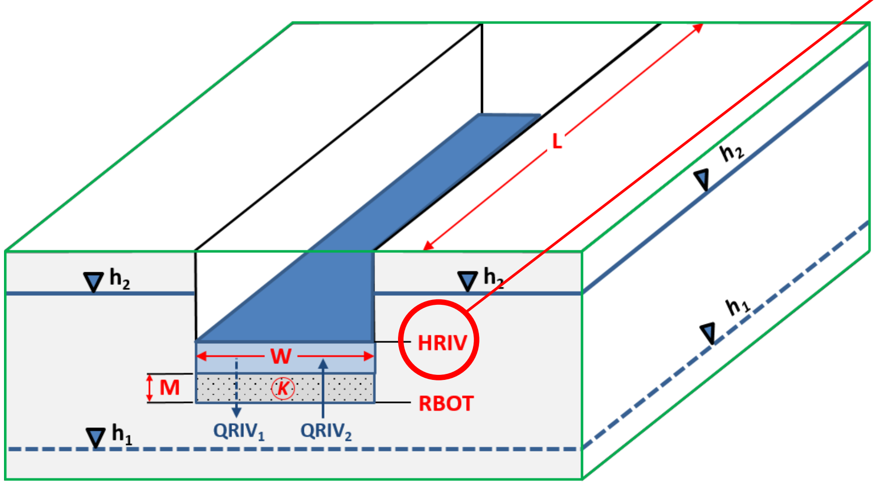
8552	253.0660	523	527.4615
8554	93.1770	530	530.75
8666	75.9640	540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041
8781	119.1627	540.0087	542.5787
8782	199.2968	542.0087	543.4497
8783	223.4074	540.0123	540.0312

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (\boxed{HRIV} - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (\boxed{HRIV} - RBOT), \quad if\ h \leq RBOT$$

$$CRIV = L \times W \times K / M$$



PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
8321	119.8592	516	517.3362
8322	100.5289	518.0087	518.0192
8323	56.6815	523.0087	523.0145
8434	111.8225	542	542.6049
8435	231.6169	536	538.008
8436	88.0528	531	533.4
843[illegible]	[illegible]	[illegible]	[illegible]
8438	263.9904	523.0087	524.544
8439	65.0933	526.0123	527.3416
8551	175.0350	527	530.8
8552	253.0660	523	527.4615
8554	93.1770	530	530.75
8666	75.9640	540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041
8781	119.1627	540.0087	542.5787
8782	199.2968	542.0087	543.4497
8783	223.4074	540.0123	540.0312

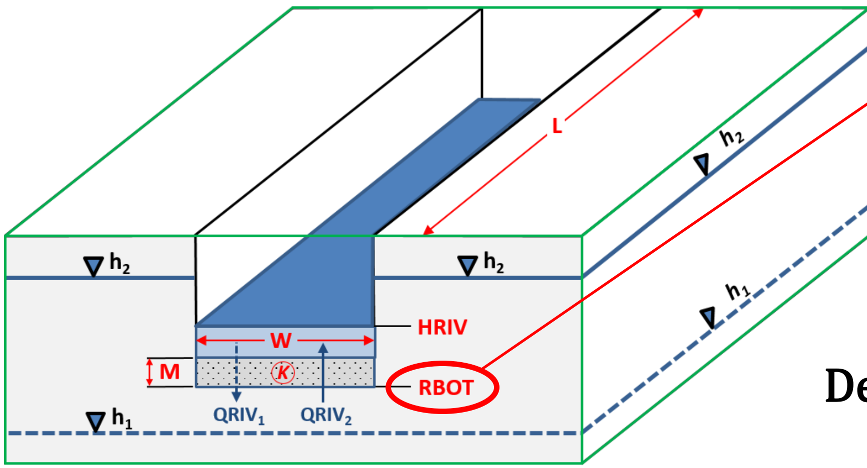
$$HRIV = ([MIN\_Z]+[MEAN\_Z1]) / 2$$

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - \boxed{RBOT}), \quad if\ h \leq RBOT$$

$$CRIV = L \times W \times K / M$$



$$\boxed{RBOT = HRIV - \text{depth to the river bottom}}$$

Depth to the river bottom

Data from bathymetry and riverbed thickness

Relation with river stage (HRIV)

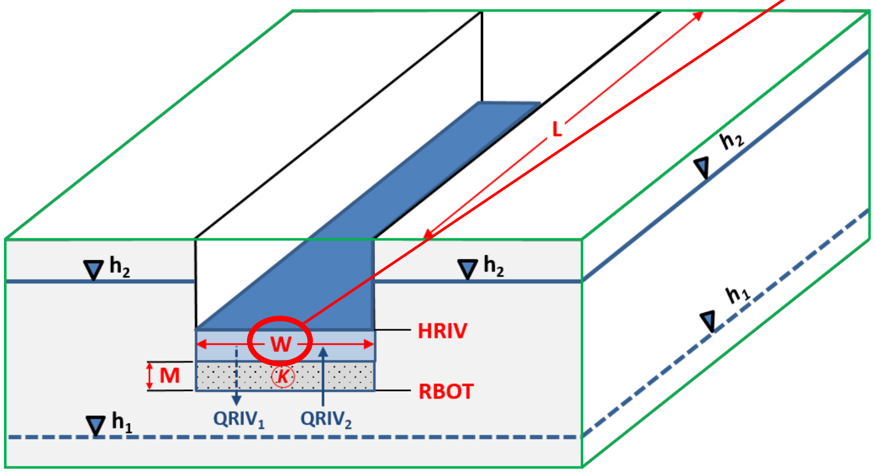
River stage (m)	**0 – 2**	**2 – 10**	**10 – 20**	**> 20**
Depth of the river bottom (m)	5	3	2	1

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

$$CRIV = L \times \boxed{W} \times K / M$$



Width of the river

Field information

Cartography or image observation

Relation with river stage (HRIV)

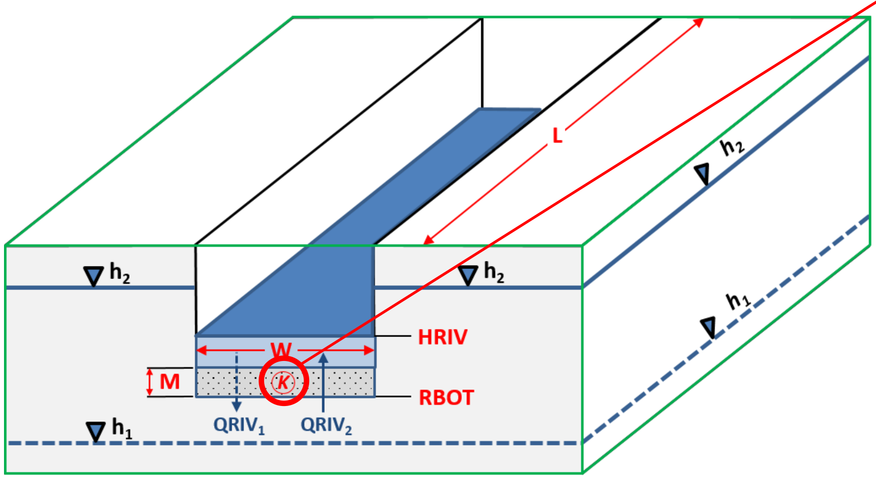
River stage (m)	0 – 1	1 – 2	2 – 10	10 – 50	> 50
Width of the river (m)	100	50	10	5	1

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \qquad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \qquad if\ h \leq RBOT$$

$$CRIV = L \times W \times \boxed{K} / M$$



Hydraulic conductivity of the riverbed material

Available information of the riverbed material

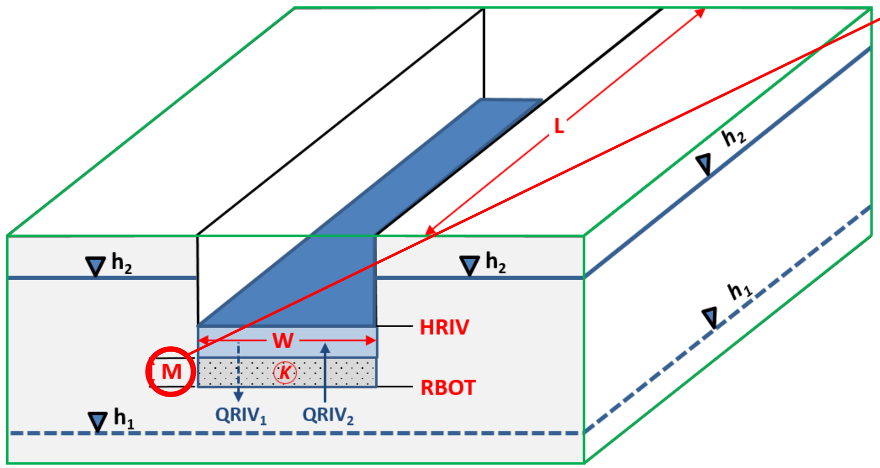
Vertical K of the numerical model cell (KZ)

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \quad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \quad if\ h \leq RBOT$$

$$CRIV = L \times W \times K \,/\, \boxed{M}$$



Thickness of the riverbed

?

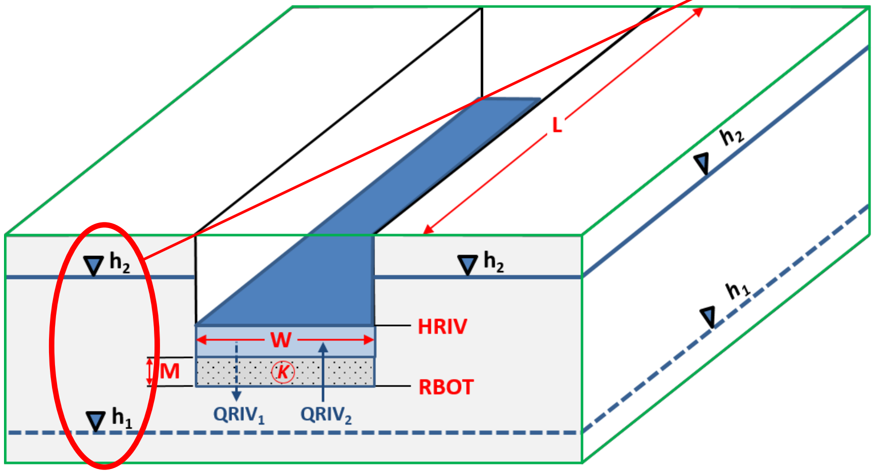
1 m >>>>>> calibration

Computation of the parameters of the river boundary condition

$$QRIV = CRIV \times (HRIV - h), \qquad if\ h > RBOT$$

$$QRIV = CRIV \times (HRIV - RBOT), \qquad if\ h \leq RBOT$$

$$CRIV = L \times W \times K / M$$

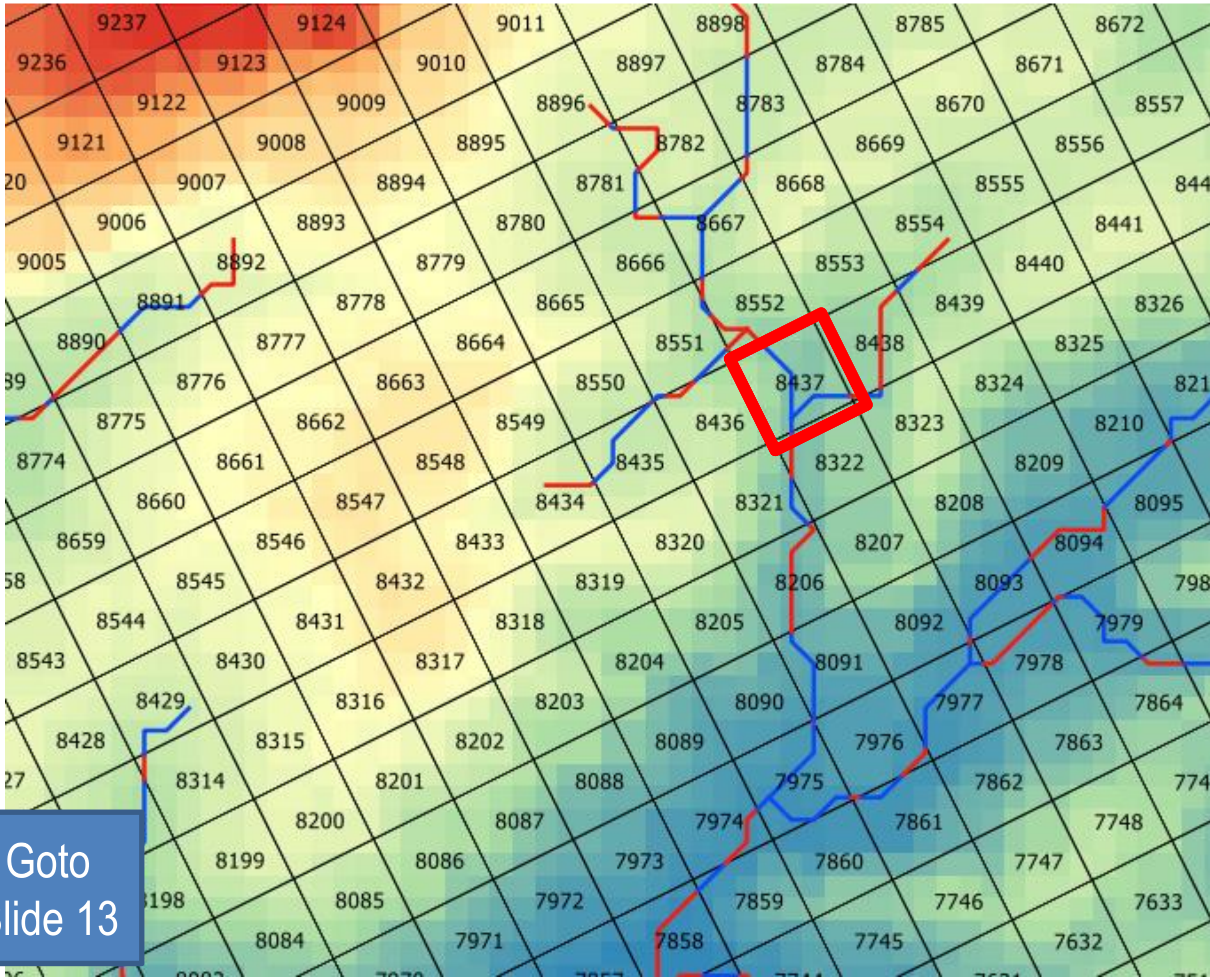


Cell hydraulic head

Calculated by the model

Assigning the values to each cell of the model

Link tables Layer 1 of the model with the statistics for each model cell



Goto Slide 13

Table with the statistics for each model cell

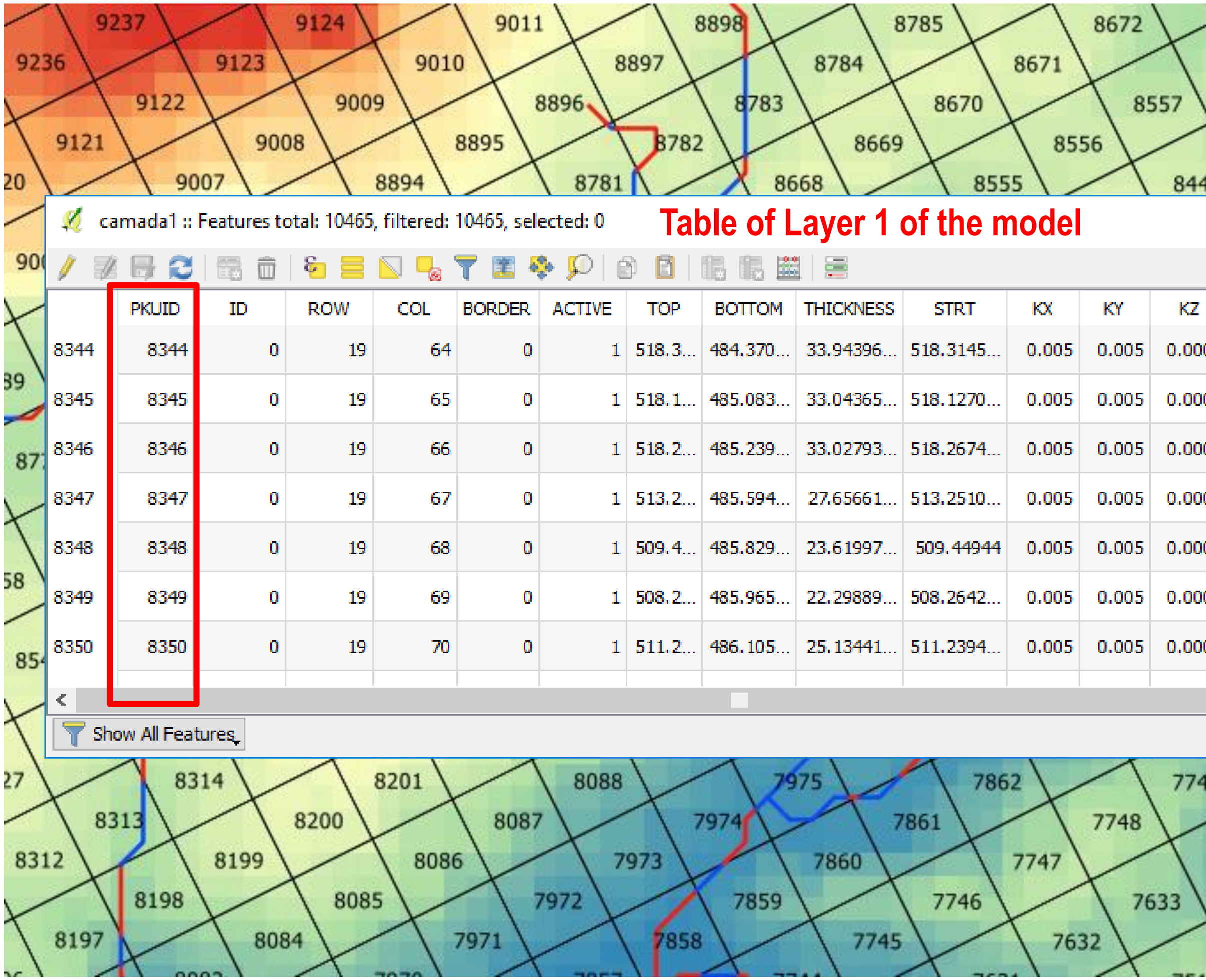
PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
8321	119.8592	516	517.3362
8322	100.5289	518.0087	518.0192
8323	56.6815	523.0087	523.0145
8434	111.8225	542	542.6049
8435	231.6169	536	538.008
8436	88.0528	531	533.4
8437	372.1371	518.0262	520.245
8438	263.9904	523.0087	524.544
8439	65.0933	526.0123	527.3416
8551	175.0350	527	530.8
8552	253.0660	523	527.4615
8554	93.1770	530	530.75
8666	75.9640	540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041

Link tables using the common field PKUID

QGIS 2.18.21 Properties | Joins | Add vector join

Assigning the values to each cell of the model

Link tables Layer 1 of the model with the statistics for each model cell



camada1 :: Features total: 10465, filtered: 10465, selected: 0

Table of Layer 1 of the model

	PKUID	ID	ROW	COL	BORDER	ACTIVE	TOP	BOTTOM	THICKNESS	STRT	KX	KY	KZ	SS	SY	NT	NE	WETDRY
8344	8344	0	19	64	0	1	518.3...	484.370...	33.94396...	518.3145...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8345	8345	0	19	65	0	1	518.1...	485.083...	33.04365...	518.1270...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8346	8346	0	19	66	0	1	518.2...	485.239...	33.02793...	518.2674...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8347	8347	0	19	67	0	1	513.2...	485.594...	27.65661...	513.2510...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8348	8348	0	19	68	0	1	509.4...	485.829...	23.61997...	509.44944	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8349	8349	0	19	69	0	1	508.2...	485.965...	22.29889...	508.2642...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01
8350	8350	0	19	70	0	1	511.2...	486.105...	25.13441...	511.2394...	0.005	0.005	0.0005	1e-05	0.05	1	1	-0.01

Show All Features

Table with the statistics for each model cell

PKUID	SUM_LENGTH	MIN_Z	MEAN_Z1
8091	219.2297	506.0087	509.2009
8092	15.8166	507.0211	507.0211
8093	230.0325	507.0211	507.652
8206	267.8480	512	513.7529
		516	517.3362
		.0087	518.0192
		.0087	523.0145
		542	542.6049
		536	538.008
		531	533.4
		.0262	520.245
		.0087	524.544
		.0123	527.3416
		527	530.8
		523	527.4615
		530	530.75
		540	540.0044
8667	349.3819	533	536.1283
8668	54.5476	540	540.0041

Link tables using the common field PKUID
QGIS 2.18.21 Properties | Joins | Add vector join

Assigning the values to each cell of the model

Save the linked shape as a new shape (or Table), Create and fill the new fields

PKUID	ROW	COL	ACTIVE	TOP	BOTTOM	THICKNESS	KX	KY	KZ	SUM_LENGTH	MIN_Z	MEAN_Z1
8323	19	43	1	533.88	491.13	42.75	0.15	0.15	0.015	56.68	523.01	523.01
8434	18	39	1	548.19	501.84	46.35	0.15	0.15	0.015	111.82	542.00	542.60
8435	18	40	1	540.36	499.69	40.67	0.15	0.15	0.015	231.62	536.00	538.01
8436	18	41	1	536.06	496.70	39.36	0.15	0.15	0.015	88.05	531.00	533.40
8437	18	42	1	522.44	495.59	26.85	0.15	0.15	0.015	372.14	518.03	520.25
8438	18	43	1	526.56	496.52	30.04	0.15	0.15	0.015	263.99	523.01	524.54
8439	18	44	1	534.50	497.86	36.64	0.15	0.15	0.015	65.09	526.01	527.34
8551	17	41	1	537.00	502.46	34.54	0.15	0.15	0.015	175.03	527.00	530.80
8552	17	42	1	531.56	500.75	30.81	0.15	0.15	0.015	253.07	523.00	527.46
8554	17	44	1	535.50	502.39	33.11	0.15	0.15	0.015	93.18	530.00	530.75

Table of Layer 1 of the model

Table with the statistics for each model cell

Save the linked table:
QGIS 2.18.21 "Save As…" option

Assigning the values to each cell of the model

Save the linked shape as a new shape (or Table), Create and fill the new fields

New fields

PKUID	ROW	COL	ACTIVE	TOP	BOTTOM	THICKNESS	KX	KY	KZ	SUM_LENGTH	MIN_Z	MEAN_Z1	HRIV	CRIV	RBOT
8323	19	43	1	533.88	491.13	42.75	0.15	0.15	0.015	56.68	523.01	523.01	523.01	0.85	522.01
8434	18	39	1	548.19	501.84	46.35	0.15	0.15	0.015	111.82	542.00	542.60	542.30	1.68	541.30
8435	18	40	1	540.36	499.69	40.67	0.15	0.15	0.015	231.62	536.00	538.01	537.00	3.47	536.00
8436	18	41	1	536.06	496.70	39.36	0.15	0.15	0.015	88.05	531.00	533.40	532.20	1.32	531.20
8437	18	42	1	522.44	495.59	26.85	0.15	0.15	0.015	372.14	518.03	520.25	519.14	5.58	518.14
8438	18	43	1	526.56	496.52	30.04	0.15	0.15	0.015	263.99	523.01	524.54	523.78	3.96	522.78
8439	18	44	1	534.50	497.86	36.64	0.15	0.15	0.015	65.09	526.01	527.34	526.68	0.98	525.68
8551	17	41	1	537.00	502.46	34.54	0.15	0.15	0.015	175.03	527.00	530.80	528.90	2.63	527.90
8552	17	42	1	531.56	500.75	30.81	0.15	0.15	0.015	253.07	523.00	527.46	525.23	3.80	524.23
8554	17	44	1	535.50	502.39	33.11	0.15	0.15	0.015	93.18	530.00	530.75	530.38	1.40	529.38

HRIV = if(("MIN_Z"+"MEAN_Z")/2>"TOP"-0.5,"TOP"-0.5,**("MIN_Z"+"MEAN_Z")/2**)

HRIV = if("HRIV"< "BOTTOM",IF("BOTTOM" + 0.5 < "TOP", "BOTTOM" + 0.5, ("TOP"+"BOTTOM")/2), "HRIV")

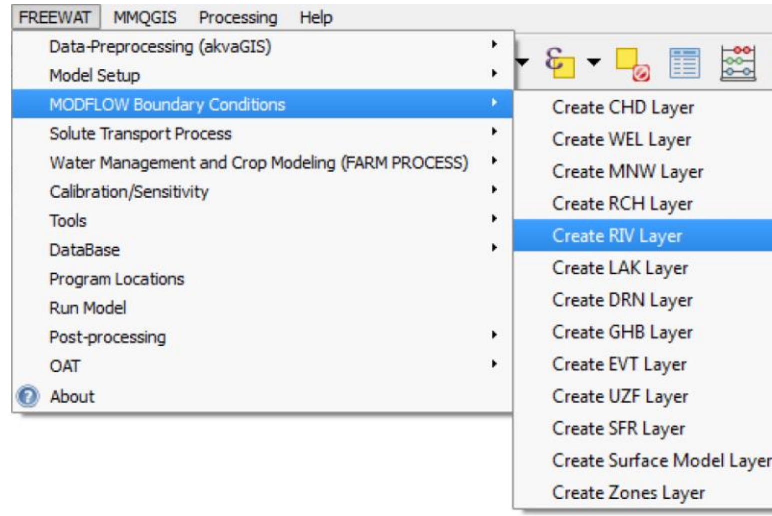
CRIV = "SUM_LENGTH" * "KZ" * if("HRIV" <= 1, 100, if("HRIV" <= 2, 50, if("HRIV" <= 10, 10, if("HRIV" <= 50, 5, 1))))

RBOT = "HRIV"-if("HRIV" <= 2, min(5, "HRIV"-"BOTTOM"), if("HRIV" <= 10, min(3, "HRIV"-"BOTTOM"), if("HRIV" <= 20, min(2, "HRIV"-"BOTTOM"), min(1, "HRIV"-"BOTTOM"))))

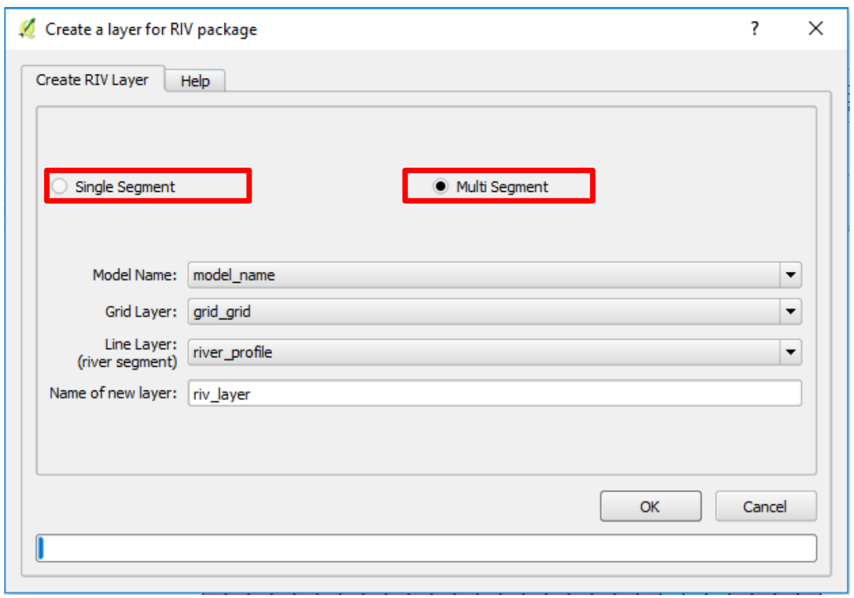
Add new field

QGIS 2.18.21 Add fields HRIV, CRIV, RBOT and calculate them

Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform



Two options to create the layer for the RIV package:



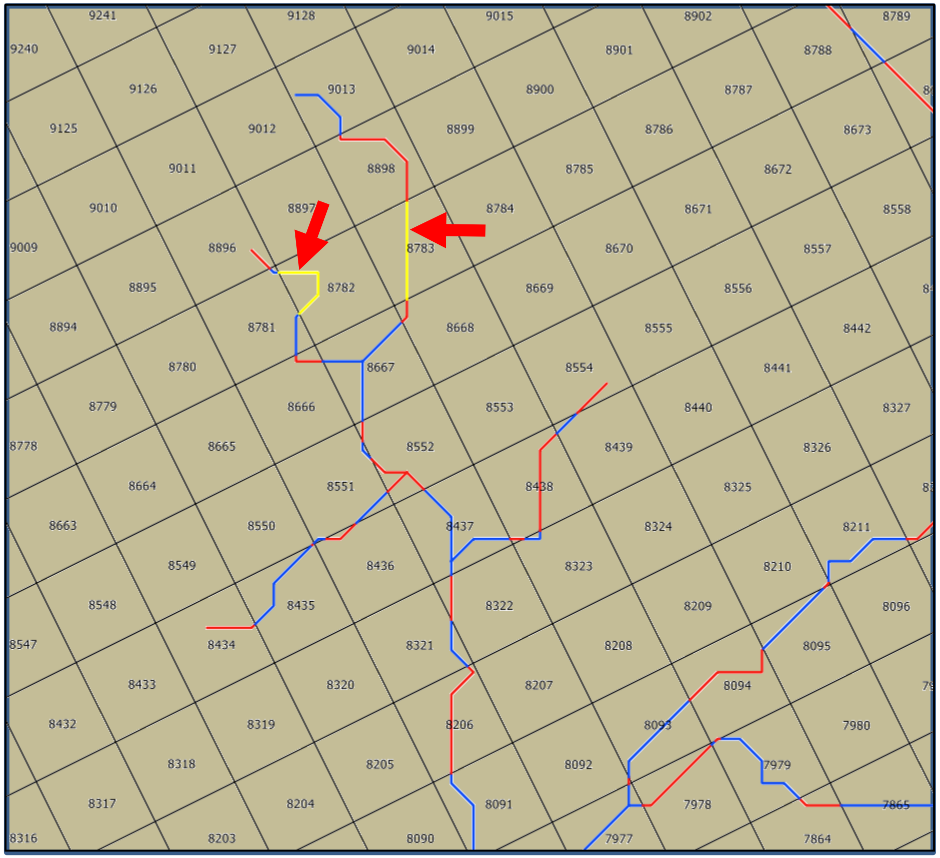
At the moment none of these two options allows an easy way to input the data produced using the presented methodology.

This happens because there are cells where more than one stream may occur.

Later the option "Multi Segment" will be used to prepare the layer for the RIV package, but first some preparation procedures must be carried out.

Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform

To avoid an error message, select any two segments of the river from the initial river layer. **These two segments must be unique in the cell.**



Save these two segments in a new shapefile (e.g. name TwoRivers.shp)

Save the two rivers shapefile

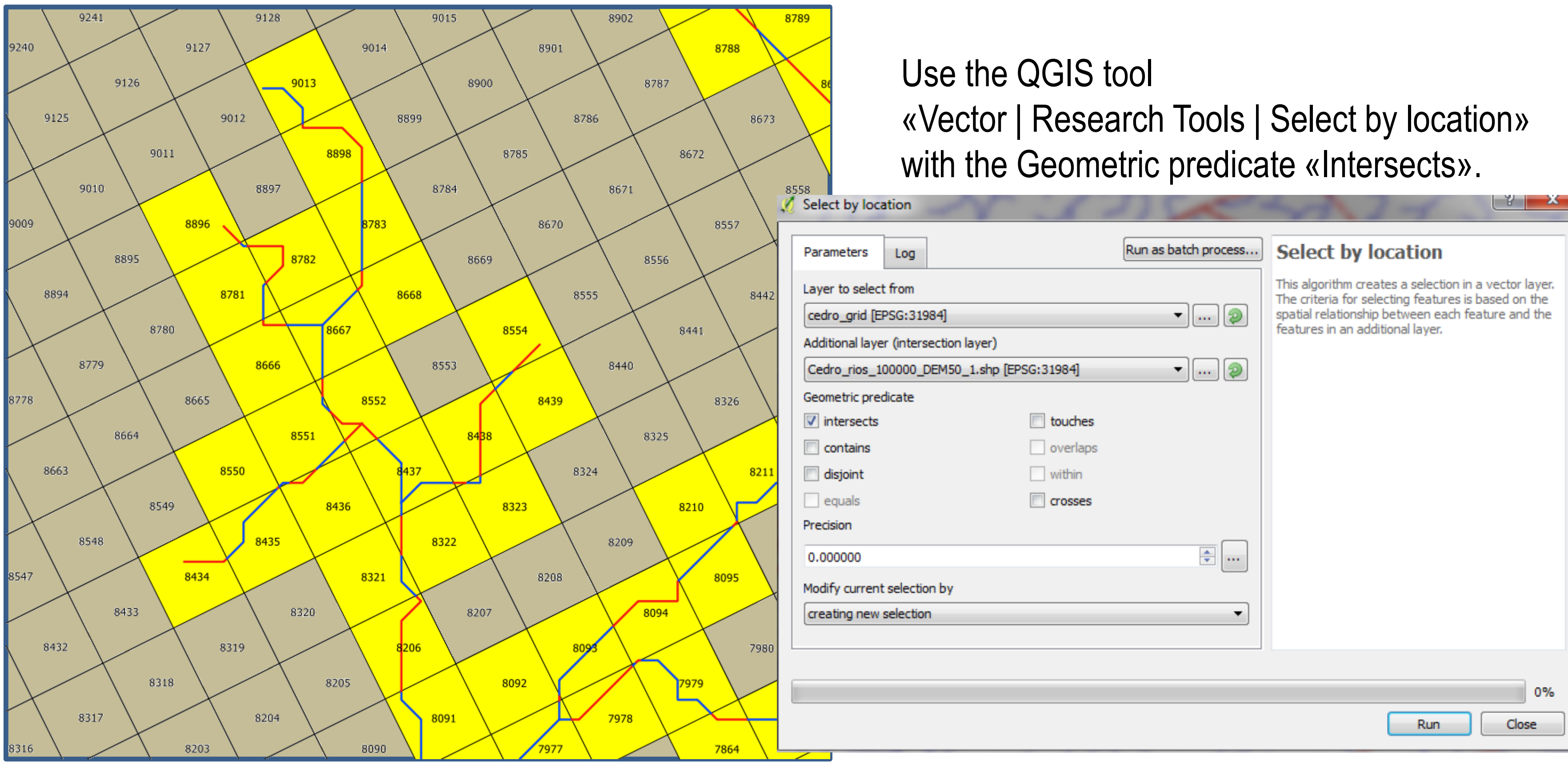
QGIS 2.18.21 Select the river layer in the QGIS "Layers Panel", click with the mouse right button, and select "Save As…"

"Save only selected features" option activated.

Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform

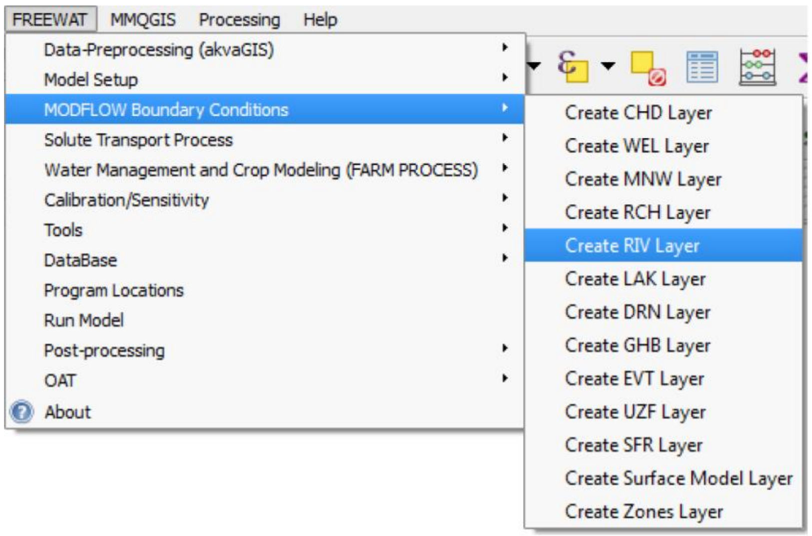
Now select all the cells from the **grid** model data object (MDO – this is the MDO produced when the model was generated under the Model Setup | Create Grid option)

Use the QGIS tool «Vector | Research Tools | Select by location» with the Geometric predicate «Intersects».

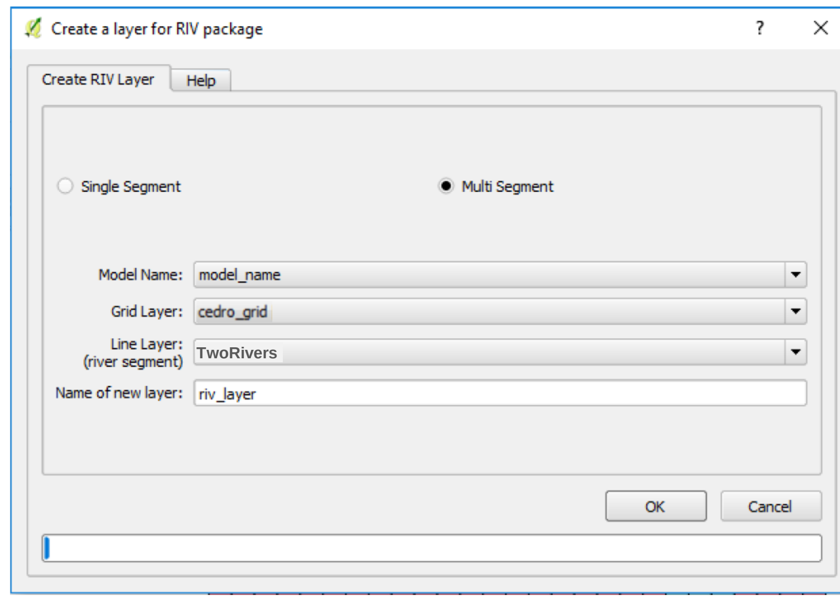


Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform

Finally, select in FREEWAT the “Create RIV Layer” option:



Select the “Multi Segment” option:



The RIV riv_layer MDO is produced but only those cells of the RIV MDO corresponding to the TwoRiver.shp are filled with values in the MDO. The remaining cells will have “None” values.

Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform

Join the river layer (riv_layer) MDO:

~~PKUID~~	ID	ROW	COL	layer	segment	length	stage_1	rbot_1	cond_1
~~1538~~	0	19	43	1	1				
~~1565~~	0	18	39	1	1				
~~1566~~	0	18	40	1	1				
~~1567~~	0	18	41	1	1				
~~1568~~	0	18	42	1	1				
~~1569~~	0	18	43	1	1				
~~1570~~	0	18	44	1	1				
~~1598~~	0	17	41	1	1				
~~1599~~	0	17	42	1	1				
~~1600~~	0	17	44	1	1				

With the shape/table containing the river boundary condition parameters:

~~PKUID~~	ROW	COL	ACTIVE	TOP	BOTTOM	THICKNESS	KX	KY	KZ	SUM_LENGTH	MIN_Z	MEAN_Z1	HRIV	CRIV	RBOT
~~832[illegible]~~	19	43	1	533.88	491.13	42.75	0.15	0.15	0.015	56.68	523.01	523.01	523.01	0.85	522.01
~~8434~~	18	39	1	548.19	501.84	46.35	0.15	0.15	0.015	111.82	542.00	542.60	542.30	1.68	541.30
~~8435~~	18	40	1	540.36	499.69	40.67	0.15	0.15	0.015	231.62	536.00	538.01	537.00	3.47	536.00
~~8436~~	18	41	1	536.06	496.70	39.36	0.15	0.15	0.015	88.05	531.00	533.40	532.20	1.32	531.20
~~8437~~	18	42	1	522.44	495.59	26.85	0.15	0.15	0.015	372.14	518.03	520.25	519.14	5.58	518.14
~~8438~~	18	43	1	526.56	496.52	30.04	0.15	0.15	0.015	263.99	523.01	524.54	523.78	3.96	522.78
~~8439~~	18	44	1	534.50	497.86	36.64	0.15	0.15	0.015	65.09	526.01	527.34	526.68	0.98	525.68
~~8551~~	17	41	1	537.00	502.46	34.54	0.15	0.15	0.015	175.03	527.00	530.80	528.90	2.63	527.90
~~8552~~	17	42	1	531.56	500.75	30.81	0.15	0.15	0.015	253.07	523.00	527.46	525.23	3.80	524.23
~~8554~~	17	44	1	535.50	502.39	33.11	0.15	0.15	0.015	93.18	530.00	530.75	530.38	1.40	529.38

Note that the **PKUID** does not refer to the same cell in the tables.

Assign the river boundary condition parameters to the RIV model data object in the FREEWAT platform

Join the river layer (riv_layer) MDO:

PKUID	ID	ROW	COL	layer	segment	length	stage_1	rbot_1	cond_1	ROWCOL
153[illegible]	0	19	43	1	1	56.68146	523.0116	522.0116	4.25111	19043
15[illegible]5	0	18	39	1	1	111.8225	542.3025	541.3025	8.386688	18039
1[illegible]66	0	18	40	1	1	231.6169	537.004	536.004	17.37127	18040
[illegible]567	0	18	41	1	1	88.05281	532.2	531.2	6.603961	18041
1568	0	18	42	1	1	372.1371	519.1356	518.1356	27.91028	18042
[illegible]569	0	18	43	1	1	263.9904	523.7764	522.7764	19.79928	18043
1[illegible]70	0	18	44	1	1	65.09335	526.6769	525.6769	4.882001	18044
15[illegible]8	0	17	41	1	1	175.035	528.9	527.9	13.12762	17041
159[illegible]	0	17	42	1	1	253.066	525.2308	524.2308	18.97995	17042
160[illegible]	0	17	44	1	1	93.17695	530.375	529.375	6.988272	17044

With the shape/table containing the river boundary condition parameters:

PKUID	ROW	COL	ACTIVE	TOP	BOTTOM	THICKNESS	KX	KY	KZ	SUM_LENGTH	MIN_Z	MEAN_Z1	HRIV	CRIV	RBOT	ROWCOL
832[illegible]	19	43	1	533.88	491.13	42.75	0.15	0.15	0.015	56.68	523.01	523.01	523.01	0.85	522.01	19043
84[illegible]4	18	39	1	548.19	501.84	46.35	0.15	0.15	0.015	111.82	542.00	542.60	542.30	1.68	541.30	18039
84[illegible]5	18	40	1	540.36	499.69	40.67	0.15	0.15	0.015	231.62	536.00	538.01	537.00	3.47	536.00	18040
[illegible]36	18	41	1	536.06	496.70	39.36	0.15	0.15	0.015	88.05	531.00	533.40	532.20	1.32	531.20	18041
[illegible]437	18	42	1	522.44	495.59	26.85	0.15	0.15	0.015	372.14	518.03	520.25	519.14	5.58	518.14	18042
[illegible]38	18	43	1	526.56	496.52	30.04	0.15	0.15	0.015	263.99	523.01	524.54	523.78	3.96	522.78	18043
84[illegible]9	18	44	1	534.50	497.86	36.64	0.15	0.15	0.015	65.09	526.01	527.34	526.68	0.98	525.68	18044
85[illegible]1	17	41	1	537.00	502.46	34.54	0.15	0.15	0.015	175.03	527.00	530.80	528.90	2.63	527.90	17041
855[illegible]	17	42	1	531.56	500.75	30.81	0.15	0.15	0.015	253.07	523.00	527.46	525.23	3.80	524.23	17042
8554	17	44	1	535.50	502.39	33.11	0.15	0.15	0.015	93.18	530.00	530.75	530.38	1.40	529.38	17044

Note that the **PKUID** does not refer to the same cell in the tables.
Create a new **ROWCOL** virtual field (integer) in each table and compute ROWCOL = "ROW" * 1000 + "COL“.

Summary (1/2)

a) Prepare the model grid (each cell is identified by its PKUID) using FREEWAT.

b) Prepare the DEM raster file using QGIS

c) Prepare the streams' shapefile (it may advantageous to produce it from the DEM) using QGIS

d) Section the streams' shapefile by the limits of the model grid by intersecting the streams' shapefile with the model grid using QGIS (preserve the PKUID of the model grid in the line output)

e) Divide each stream section in segments using a predetermined interval (variable LEN_SEG) and compute the length of each segment (field LENGTH) using QGIS (preserve the PKUID)

f) Calculate a point shapefile with the central point of each segment using QGIS (preserve the PKUID)

g) Overlap the point shapefile with the DEM and get the elevation at each central point using QGIS

h) Calculate the statistics of the mean (field Z_MEAN) and minimum elevation (field Z_MIN), and the total length of the segments (field SUM_LENGTH) for each model (identified by its PKUID) using QGIS

Summary (2/2)

i) Calculate for each model cell the parameters required to define the RIV BC (HRIV, RBOT and CRIV) dependent on the computed values (HRIV and L) and the other assumptions (for K, W, RBOTTOM, M) using QGIS

j) Select two independent sections of the river in the streams shapefile and save them as a new shapefile using QGIS

k) Select all the cells of the model grid that are intersected by the streams shapefile using QGIS

l) Create the River Model Data Object (each cell with the river is identified by its own PKUID) using FREEWAT.

m) Create a common field (ROWCOL) to link the tables containing each model cell parameters required to define the RIV BC and the new River MDO using QGIS

n) Fill the fields of the River MDO using QGIS

…

o) The river boundary condition is finished. Its parameters may later be changed during the calibration process

Summary – variables that can be changed

The raster size

The river network extension (if it has been produced using the DEM)

The predetermined interval of the length of the line sections (variable LEN_SEG = 25 m).

The way to compute:

- → HRIV – (Z_MIN + Z_MEAN) / 2
- → RBOT – dependent on HRIV by creating a table
- → W – dependent on HRIV by creating a table
- → K – equal to Kz from the model cell
- → M – assumed 1

may all be subject to a different analysis

Conclusions

A methodology was presented that allows the characterisation of the parameters required for the river boundary condition, namely the head of the river (HRIV) and the length of the river (L).

Approaches to characterise the remaining parameters (RBOT, K, W and M) were also suggested.

The overall methodology can be used with DEMs of different sizes. However better results will be obtained if a relation of at least 9 DEM cells to 1 numerical model cell exists.

One of the advantages of these procedures is that they allow, using base information usually available (the DEM) to make a first characterisation of the river boundary condition, in a consistent and reproducible way, which can be used as a starting point for the model calibration.

This is also important if there is a change in the model geometry, by enlarging or refining areas, which would imply a change in the parameters HRIV, L, RBOT. In this case, the river boundary condition can be easily recalculated.

The major steps of the methodology can be programmed to provide an automatized procedure to calculate the boundary condition parameters and be included in the FREEWAT plugin (Help needed here!)

The same approach may be applied if the river network is modelled with the DRAIN boundary condition.

The formulas or relational tables presented to characterise each parameter may be adapted (for instance not using the mean value of the average river stage and the minimum river stage to quantify HRIV, or the presented relational table between HRIV and W).

References

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