SHERIDAN COLLEGE

Environmental Control Program
Environmental Project FLPL 54454

Separated flow approach: measurements for its evaluation

Based on the Fletcher's Creek watershed for the period of March 15 to July 31, 2005

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INTRODUCTION

The first introduction of the approach and its first version without any name was made in 2002 for chlorides concentration and loads assessment based on Etobicoke Creek. The next application of it was made for heavy metals assessment based on the same creek. In the paper titled "Ground water – Climate" relationship revisited" presented at the CWRA 57th annual conference, the main part of the approach, the SimpleBase delineation model, was introduced as the tool for separation of permanent and temporary groundwater discharges into a stream.
In all these cases the adequacy of flow separation by SimpleBase was assumed *a priori*. The objective of this project is to evaluate the adequacy of such separation and based on it method.

THE SEPARATED FLOW APPROACH

The **Separated Flow Approach (SFA)** is the method for daily concentrations, loads and anthropogenic impact and risk assessment of chemicals in river flow broken into the flow components (surface, inter, and base).

Each contaminant has its own pattern for each flow component determined by flow pathway/source, its transportation capacity, and period of year. The total flow concentration (sampled one) is the weighted average of the component's concentrations presented at the moment of sampling depending on their seasonal flow-concentration patterns:

$$Ct = (Qb*Cb + Qi*Ci + Qs*Cs)/Qt$$

Where

Ct, Qt	-	total flow concentration and discharge
Cb, Qb	-	baseflow concentration and discharge
Ci, Qi	-	interflow concentration and discharge
Cs, Qs	-	surface flow concentration and discharge

The approach has several steps, which can be shortly described as following.

1. Separation of total flow into base, inter and surface components provided by SimpleBase model.
2. Associate each available sample with the combination of flow components at the moment of sampling: base, base + inter, or base + inter + surface. It means that total flow at the moment of sampling was equal to baseflow, base + interflow, or base + inter + surface flow.
3. Estimate seasons using 10-days sliding average of air temperature crossing 0, 10 and 20°C (this step will be reconsidered in the result of the project as well).
4. Sort samples of each period by flow component.
5. Starting from baseflow component estimate "concentration - flow" ratios Cb = f(Qb) for each "season" to estimate daily baseflow concentrations between

samples as well as the share of baseflow concentration in “base + inter” and “base + inter + surface” samples.

6. For “base + inter” samples, the Ci concentration can be estimated using the formula Ci = (Ct*Qt – Cb*Qb)/Qi, where Ct and Qt are measured, and Cb and Qb are estimated in the previous step.
7. When Ci for all “base + inter” samples are known, the Ci = f(Qi) function is created for each season and used to estimate interflow concentrations between samples as well as for “base + inter + surface” samples.
8. After obtaining the base and inter shares of “base + inter + surface” samples, the surface concentration can be obtained using formula: Cs = (Qt*Ct –Qb*Cb – Qi*Ci)/Qs. Based on obtained Cs, the Cs = f(Qs) can be created and used for daily assessment.

The idea of the project: during the project period conduct daily measurements of the creek and drained by it groundwater quantity (level, flow) and quality (temperature, pH, TDS and turbidity) parameters in order to obtain Cx = f(Qx) ratios in whole amplitude of each Qx; estimate the total flow parameters using the separated flow approach and compare them with the measured parameters.
Created set of data allows calibrating or evaluating any other model for water quality assessment.
It is obvious, that adequacy of flow separation is the key of the method, and so, the adequacy of the approach practically means the adequacy of the flow separation.

OBJECTIVES OF THE PROJECT

Objectives of the project are:

- ✓ To create the data set for the approach evaluation namely the adequacy of flow separation
- ✓ To figure out what are base-, inter and surface flow components obtained by the SimpleBase model; attempt giving their definitions at least for this particular case
- ✓ To assess the solids transport (TDS +TSS) using SFA
- ✓ Assess the anthropogenic impact quantitatively based on parameters of pristine streams

SIMPLEBASE MODEL

There are several delineation models used in hydrological practice: they are based on fitting the mathematical function to the specific turning points of a hydrograph (Sloto 1994). Their use is limited by BFI estimation and the recession curve parameterization for the hydrological modeling. Existing methods delineate the shallow flow fluctuations from the sharp ones.
The SimpleBase flow delineation spreadsheet model has completely different mechanism and criteria of delineation. The linear function of the groundwater discharge increase during any flux event and the number of fluxes cut by it are the functional parameters of the model.

The SimpleBase model has an irresistibly simple mathematical algorithm and its run has to be started within the low flow period, winter or summer, when the total flow at previous day Q_{t-1} is equal to the base flow Q_{b-1}. If difference between current Q_t and previous day flow Q_{t-1} is bigger than dQ_b (the slope of delineating line or daily increase of the baseflow), the current day baseflow Q_b is equal to $Q_{t-1} + dQ_b$, otherwise $Q_b = Q_t$:
if $Q_t – Q_{t-1} > dQ_b$, $Q_b = Q_{t-1} + dQ_b$, otherwise $Q_b = Q_t$. Interflow increase is described by the linear function as well. The relationship between dQ_b and dQ_i can be identified by the following equation:

$$dQ_i = dQ_b*2^{(K + 0.618)}$$

where
K represents the rate of the flow capacity and baseflow in a river channel before exit to the flood plain and takes the integer values from 2 to 12.
The criterion for sought dQb is the highest number of peak cut.

FLETCHER'S CREEK WATERSHED

The particular interest of this project is concentrated on a stream flow, which is the physical transport medium of water properties drained from the particular area (Fletcher's Creek). The area (15.5 km2) is characterized by its intensive anthropogenic use as heavy urbanized one (the City of Brampton, McLaughlin Rd. above Steeles Ave.). There is some quantitative characterization of the anthropogenic burden on the Creek watershed in Table 1.

Type of land use	Area, km^2	%	Road type	Length, km	Density, km/km^2
Residential area	2.859	18.4			
Industrial area	1.615	10.4	Expressway	0	0.00
Government area	0.765	4.9	Arterial roads	28.57	1.85
Business area	0.174	1.1	Collector roads	27.7	1.79
Green space	9.91	63.9	Local	177.6	11.50
Road area	0.17	1.1			
Total	15.5	100	Total	233.87	15.091
Lawns area	1.4295				
Population	50033				

The information for this table was obtained from the tourist map of MapART Publishing, 2005 (Fig. 1, Appendix). Population estimated very roughly taking the parameters of one household unit as 3.5 peoples per 200 m2. Lawns area is taken as 0.5 of residential and 0.1 of industrial, business and governmental areas. Road width is 0.03, 0.012, and 0.008 km for arterial, collectors, and local roads, respectively. Roads are the main point of the anthropogenic stress in this project because they are the main source of salt in the creek flow. According to information obtained from Al Margues (Region of Peel), the norm of salt put on a road is 130 kg per 1 km of 2-lane road plus 25 L of 23% salt brine for each tonne of crystal salt. Based on that information, the considered drainage area of Fletcher's creek receives 45 tonnes at each salt application.
At the same time the creek valley and stream are the habitats that affect and determine the flowing water quality. During the project period I observed crawfishes and fishes, a leach

and a toad, an otter and nutria, a large turtle (the length of the shell ~30-35 cm plus ~20-25 cm neck and 30 – 35 cm tail), hares, skunks, raccoon's traces (three were killed on surrounding roads), lot of birds and squirrels, mice and rats.

DATA: TOOLS AND MEASUREMENTS

Parameters and tools (Fig. 2, Appendix):

- Water level, velocity, and discharge: a pole and a float on a 10-m string
- Water temperature: spirit glass thermometer
- pH: portable HACH pH meter and lab pH-meter
- Turbidity, NTU and mg/L: sampling, HACH 2100N Turbidimeter
- TDS, g/L: sampling, HACH Conductivity/TDS meter

Daily level measurements

Under the project circumstances it was accepted that daily average water level is equal to the one at the moment of measurements that were done daily around noon (the first source of errors).

The creek water level in the 39-71 cm interval was measured by the graduated plastic pole against the flat stone near the left bank. Accuracy of the level readings is equal to ± 1 cm due to 5 cm graduation. Water level lower than 40 cm was measured against the metal peg maintained in the bottom of the stream near the stone. The parallel measurements were done every time, when level and water transparency allowed this. The datum was accepted as 7 cm lower than the peg height.

The well water level was measured by the graduated string of the bailer. It was measured against the well orifice using the slap sound of the bailer bottom against water surface. The well level was referred to the same datum for simplicity of comparison. The accuracy has to be lower than the one for the creek level.

Daily Flow estimation

Daily flow estimation consists of the following components: daily measurements of water level in the gauging section, the cross-section area estimation for the section, water velocity measurements and discharge calculation, rating curve Q = f(H) obtaining in order to cover 90% of the discharge fluctuation during the project period. Actually, 100% was covered.

For obtaining the cross-section area, it was measured two times during the project: the first time March 18 and the second time May 1 till the highest observed so far level 71 cm above datum (~ 201 m a.s.l.) (Fig.3, Appendix).

The water surface velocity was measured in three or one point using a float on a 10 m string. The conversion coefficient to the depth average velocity 0.85 was applied according to WMO No 168. The discharges were calculated using a spreadsheet model developed for the project (Table 1, Appendix). Totally, 50 discharges were measured during the project period (Table 2, Appendix).

Three rating curves were received for the period of March 14 – July 1 (Fig. 4, Appendix).

Daily water quality parameters measurements

Water temperature, pH, samples for TDS and turbidity estimation were made at the same place and time as the water level. This is crucial condition for the analysis of the further results: you do not assume that they are corresponding - you provide the correspondence by simultaneous measurements.
Water temperature is measured by glass thermometer in the plastic protecting container on a string (arranged by the author). The container and string allow measurements by the same instrument in the well as well. This is important in terms of comparison of the results: even there is some systematic error in both measurements, the difference between them illuminates the error.

The pH measurements are made by two instruments: the portable pH meter for measurements in-situ, and the lab pH meter for repeating measurements of pH during analysis of samples. Calibration of both instruments was done against standard buffers of 4, 7, and 10 pH on a pretty regular basis: every two weeks and every time when difference between two meters was more than 0.3.

Grab samples for TDS and turbidity were taken from the centroid of a stream using 250 mL PVE bottle, and PET 0.5 L bailer for the well sampling.
The calibration of the TDS meter and turbidimeter was providing by the lab stuff.

The database updating and initial processing (discharge estimation, hydrograph for each parameters updating, comparison of well and stream graphs) of the obtained data was done daily. Results of measurements in the creek and well are presented on the Table 3 and Fig. 5, 6, Appendix).
Both TDS and turbidity at Fig. 5 clear indicate very close relationship with flow: TDS looks like mirror reflection of hydrograph, turbidity repeats the hydrograph with increasing of its amplitude during low-flow period.
On Fig. 6, Turbidity section, the sharp increase of turbidity before the well dried indicates disturbance of sediments at the bottom of well by bailer during the water sampling.

RESULTS

Flow separation results

Flow separation was done several times during the project. The final result was obtained only with full length of data, when the low-flow data were included. This is a specific of the model: for adequate separation of flood the lowest flow data is needed. Result of delineation of both flow and level hydrographs are presented on fig. 7 a) and b), Appendix.
Quantitative characteristics of separation are the following:
Flow separation: $dQb = 0.003$ m3/s, $dQi = 1.18$ m3/s, $K = 8$
Level separation: $dLb = 0.3$ cm/day, $dLi = 14.7$ cm/day, $K = 5$.
Results of the level hydrograph separation tell us about morphological features of the creek: the highest level reached by Li under K=5 (60 cm) is the elevation of the flood

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plain edge. Creek level increase due to seasonal groundwater increase happens with the ratio of 0.3 cm per day.

Periods estimation

The next step after flow separation is the estimation of sub-periods for single curve Cx = f(Qx).
Before this project development, the criteria for sub-period estimation were the air temperature and different phases of flow regime. For temperature it were dates when its 10-day mean crosses 0, 10 and 20° values indicating the beginning and ends of such events like snow melting, the vegetation growth, full size leaves reaching. For flow regime phases, it was winter and summer low-flow periods, snow-melt and rain floods. This project added one more criterion, which can be easy estimated for any gauged station: water travel time T. It maybe named a residence time of water in a river system as well.

$$T = L*1000/(V*3600),$$

Where
T – travel time, hours;
L - creek length, 14.5 km;
V - stream daily average velocity, m/sec;
3600 - number of seconds in hour.

It is easy to see (Fig. 8, Appendix) that for the low flow period, when flow velocity values are very small, the travel time has very pronounced behavior. It is especially good indicator of periods with strong relationship between Cx and T for each parameter. Based on Cx =f(T) relationship for each parameter, the following periods were estimated:

For TDS assessment:
March 14-27, Mar 28-April 26, Apr 27- May 29, May 30 – June 26, June 27- July 12, July 12 – 31;
For turbidity:
March 14-April 8, April 9 – May 5, May 6 – June 8, June 9 – July 2, July 2-31
For temperature:
March14 – May 7, May 8 – June 1, June2 - July 1, July 2-31.

At first glance it seems to be very hectic, even sporadic. But all three parameters are totally different in terms of their formation and interrelated between each other. Unfortunately, there is no time for thorough analysis of relationships, which has to be done for proper model or approach setting in order to further monitoring optimization. But right now, the main objective is the sufficient data collection for possibility of further analysis, which will be done later, beyond the frame of this project. However, it is necessary to add that chosen periods and parameters behavior during them allowed doing some preliminary conclusions about the stream flow formation and definition of what each flow component is.

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Result of daily parameters assessment

Final results are presented on the fig 9 and table 4(Appendix).
The term average per event needs some explanation; even it seems obvious without ones. Inter and surface flows are temporary events, especially the surface one, which happened only three time for the project period. Averaging of this short event monthly results in very large errors of tits quantitative interpretation (as an example, divide concentrations in the Storm column by 30).
The table provides practical use of the road salt assessment. Let say every winter month (Dec – March) municipality make 5 application of road salt (every 6 days- pretty reasonable frequency). It means 45*5 – 225 tonnes/month *4 months = 900 tonnes per season. Please compare this with the numbers of TDS loads in Table 4.

CONCLUSIONS

Results of the project reveal the high investigative and estimative capacity of the Separated Flow Approach.
The following conclusions were done based on received results (graphical interpretation is given on the fig. 10 (Appendix) :

- Base-flow component of total flow represents the permanent groundwater discharge into river drainage system;
- The long-term elevation limit for this component is estimated for the Fletcher's Creek as an interval from river bottom to the 35 cm from datum
- The interflow component is the most mobile part of creek flow and represent and defined by alluvial deposits within the creek valley (flood plain)
- The limitative capacity of the inter flow, quantitatively estimated by K = 5 for level expression, gives the elevation of flood plain edge
- The interflow can change direction within the flood plain alluvial depositions redirecting excess of water into the deposition storage releasing it later under normal direction of flow

Benefits of the project to continue or restart:

1. gives all-season-patterns of flow quality/quantity relationship
2. gives all seasons daily dataset for any conceptual model evaluation
3. gives transformable within the Lake Ontario watershed patterns for the river flow quantity and quality formation under specific conditions of sub-watershed: till moraine, heavyly urbanized, salt application
4. gives possibility for monitoring optimization: minimal set of data giving similar result in combination with pre-settled model

The Separated Flow Approach as an excellent cost-effective tool for:

- ☐ investigation, assessment and management based on only two **daily measured** parameters: stream flow and air temperature (travel time is the modification of discharge);

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- optimal monitoring: due to flow is one of two main components of the approach, the yearly 7-8 samples set covering flow amplitude by 90% in combination with pre-settled model is enough for adequate assessment of current water quality regime;

- practical education and knowledge: gives fundamental knowledge of flow formation through measurement in a few points: each measurement of any examined parameter is interpreted as a combination of base-, inter-, and surface components representing permanent and temporary ground discharge as well as the surface one.

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APPENDICES

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Fig. 1. The Fletchers Creek watershed (MapART Publisher, 2005, Brampton)

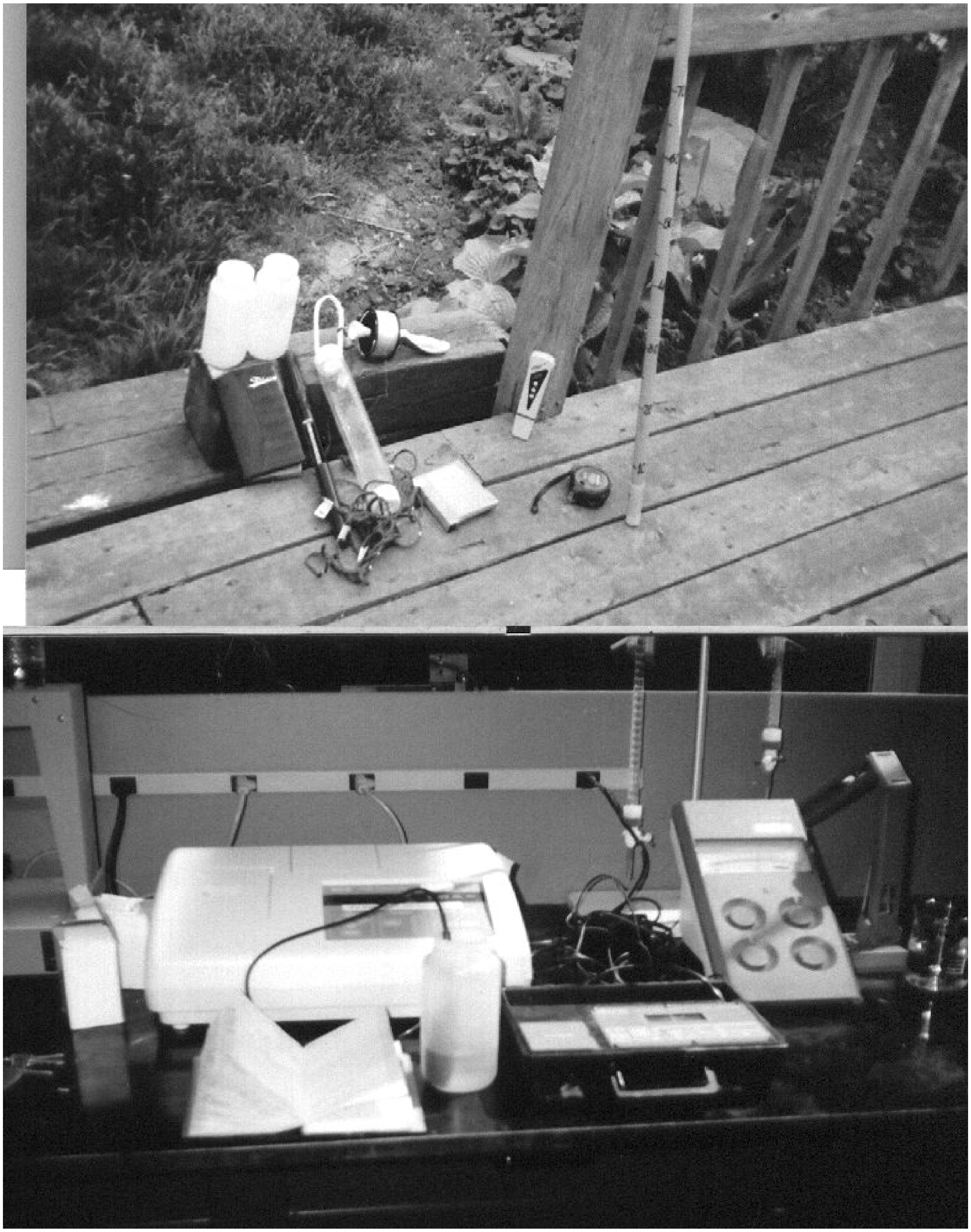

Fig. 2 (a, b). Tools used for measurements, sampling and analysis

a)1- graduated plastic pole; 2 – float of a 10-m string; 3 – portable HACH pH meter; 4 – glass spirit thermometer in protective plastic case; 5 – bailer; 6 – two PVA sampling bottles; 7 – log book; b) 1 – HACH Conductivity/TDS meter; 2 – HACH 2100N Turbidimeter; 3 – lab pH meter; 4 – log book.

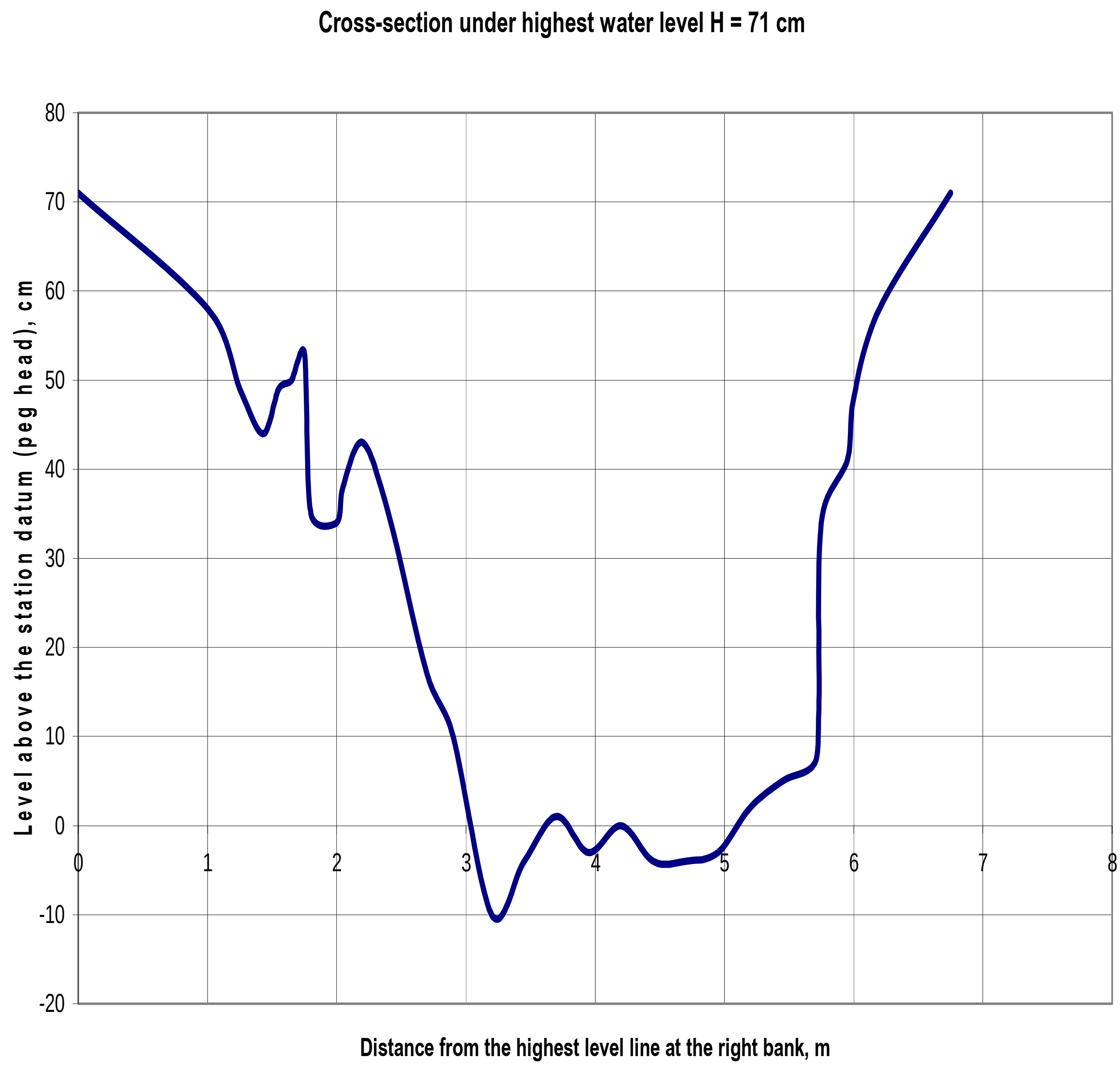

Fig. 3 Cross-section of Fletcher's Creek at the measurement reach

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Table 1. The model for discharge calculation

Date:	**31.07.05**	Start time:	12:00	Finish time:	12:15				
Weather:	Sunny, +1	Start level:	23.5	Finish level:	23.5	F, m2	0.7007	Q, m3/s	0.0272
Point	Distance		Depth, cm			Velocity measurements			
	from zero,m		Reading	Average, cm	Area, m2	Run1/2	V, m/sec	q,m3/s	
R.B.edge	2.4	0	0	0	0	sec	0	0	
1	2.7	0.3	6	3	0.0045		1	4E-05	
2	2.9	0.2	13	9.5	0.019		3.5	0.0006	
3	3.2	0.3	33	23	0.069		6	0.0035	
4	3.45	0.25	27	30	0.075		7	0.0045	
5	3.7	0.25	22	24.5	0.0613		7	0.0036	
6	3.95	0.25	26	24	0.06		7	0.0036	
7	4.2	0.25	23	24.5	0.0613		6	0.0031	
8	4.45	0.25	27	25	0.0625	205	5	0.0027	
9	4.7	0.25	27	27	0.0675		4	0.0023	
10	4.95	0.25	26	26.5	0.0663		3	0.0017	
11	5.2	0.25	21	23.5	0.0588		2	0.001	
12	5.45	0.25	18	19.5	0.0488		1	0.0004	
13	5.7	0.25	16	17	0.0425		0.5	0.0002	
14	5.73	0.03	10	13	0.0039		0.25	8E-06	
L.B. edge	5.75	0.02	0	5	0.0005		0	0	
				Sum:	0.7007		Sum:	0.0272	

Table 2. Discharges measured during the project

Date	No	Level, cm	Area, m2	Discharge, m3/s	Date	No	Level, cm	Area, m2	Discharge, m3/s
15.03.05	1	27.5	0.84	0.1	20.04.05	26	26.5	0.81	0.09
18.03.05	2	33	1.01	0.24	22.04.05	27	27	0.83	0.088
19.03.05	3	36	1.13	0.32	24.04.05	28	71	2.83	2.945
20.03.05	4	40	1.28	0.45	25.04.05	29	50	1.71	0.88
21.03.05	5	36	1.13	0.31	26.04.05	30	43	1.4	0.57
22.03.05	6	48	1.61	0.88	29.04.05	31	40	1.28	0.44
24.03.05	7	43	1.4	0.66	01.05.05	32	34	1.04	0.24
25.03.05	8	50	1.71	1.01	04.05.05	33	31	0.95	0.15
26.03.05	9	45	1.48	0.8	08.05.05	34	27.5	0.84	0.102
27.03.05	10	40	1.28	0.48	13.05.05	35	26.5	0.81	0.078
30.03.05	11	45	1.48	0.69	14.05.05	36	31.5	0.97	0.157
31.03.05	12	43	1.4	0.65	16.05.05	37	29	0.89	0.105
01.04.05	13	43	1.4	0.609	19.05.05	38	26.5	0.81	0.063
02.04.05	14	53	1.85	1.63	23.05.05	39	25.5	0.78	0.053
03.04.05	15	58	2.1	2.07	28.05.05	40	25	0.76	0.045
08.04.05	16	35	1.08	0.3	02.06.05	41	24	0.73	0.032
09.04.05	17	33	1.01	0.26	26.06.05	42	23	0.7	0.027
10.04.05	18	32	0.98	0.2	03.07.05	43	23	0.7	0.0281
11.04.05	19	30	0.92	0.15	04.07.05	44	29	0.89	0.106
12.04.05	20	29	0.89	0.12	08.07.05	45	22.5	0.69	0.0263
14.04.05	21	27	0.83	0.101	10.07.05	46	22	0.67	0.0194
15.04.05	22	26	0.79	0.088	12.07.05	47	22	0.67	0.0179
16.04.05	23	25.5	0.78	0.085	21.07.05	48	24.5	0.747	0.0398
18.04.05	24	26	0.79	0.086	30.07.05	49	23.5	0.716	0.031
19.04.05	25	26	0.79	0.083	31.07.05	50	23	0.7	0.027

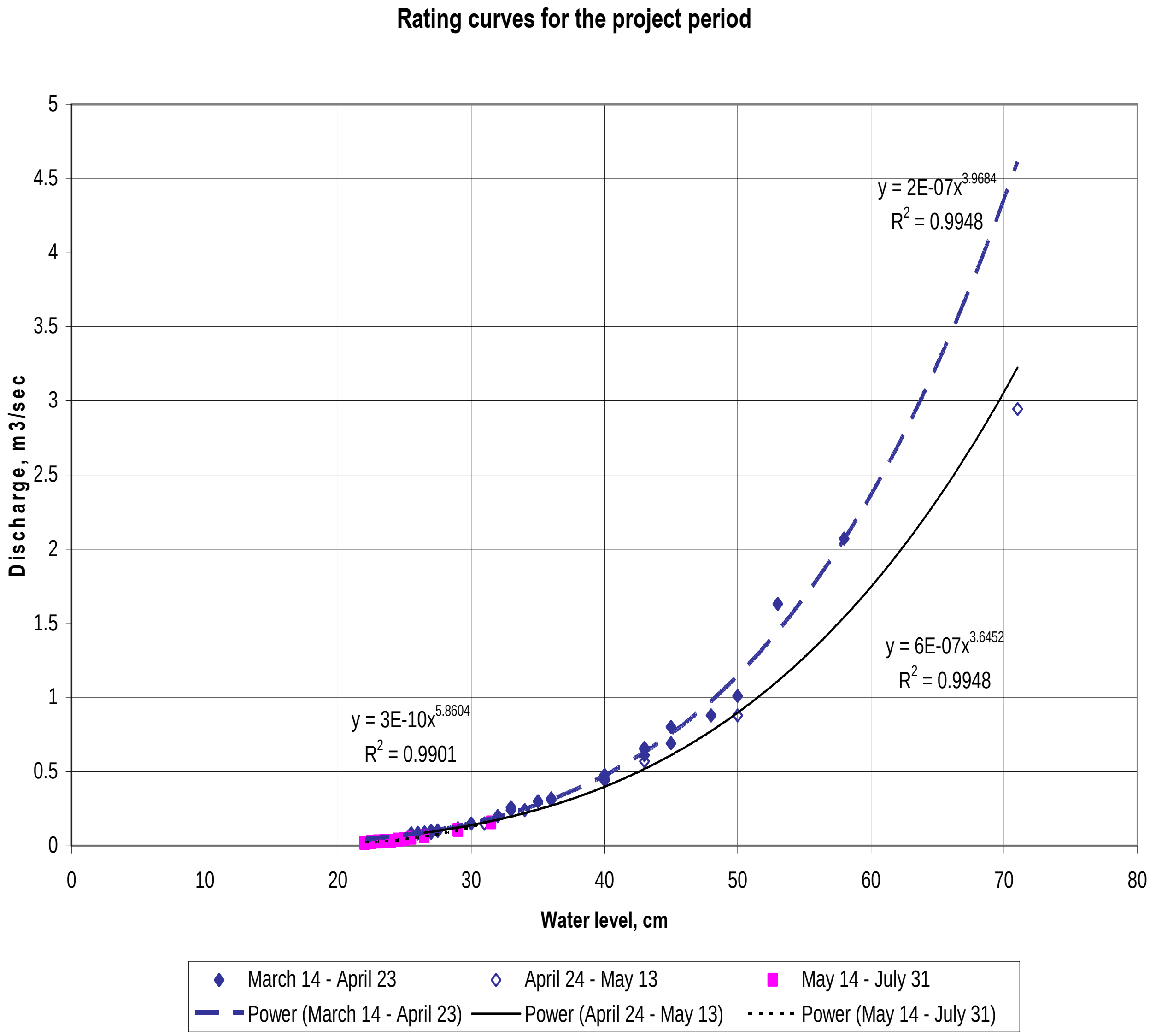

Fig. 4 Rating curves

Table 3. Results of daily measurements

	Level, cm		pH		Turbidity, NFU		TDS, g/L		Temperature, °C	
	well measured	creek above datum	well	creek	well	creek	well	creek	well	creek
14-Mar		29								
15-Mar		27.5								
16-Mar		29								
17-Mar		36								5
18-Mar		33		8.2		23.6		1.68		5.2
19-Mar		36								2
20-Mar		40		7.8						2
21-Mar		36		8.2						4
22-Mar		48		8		46.1		0.69		2.5
23-Mar		50.5		7.8		54.8		0.53		1
24-Mar		43		7.8				1.4		2
25-Mar		50		7.8		26.2		0.62		3.5
26-Mar		45		7.8		46.9		0.61		2
27-Mar		40		8		42.3		0.59		3
28-Mar		42		7.8						2
29-Mar		44		8.2		31.5		0.52		6
30-Mar		45.5		8		43.9		0.5		5
31-Mar		43		8		31.5		0.53		6
01-Apr		43		8.3		26.3		0.6		8.5
02-Apr		53		7.8		72.5		0.5		4.5
03-Apr		58		7.6		57		0.62		2
04-Apr		56		7.7		101		0.515		3
05-Apr		48		8.1		48.3		0.627		5.5
06-Apr		40		8.4						9.5
07-Apr		37		8		16.4		0.78		8
08-Apr		35		8.3		8.63		0.8		8
09-Apr		33		8.4		7.58		0.81		9
10-Apr		32		8.5		6.61		0.89		9
11-Apr		30		8.4		5.95		0.92		8.5
12-Apr		29		8.6		7.29		0.95		9
13-Apr		28		8.6		5.82		0.99		10
14-Apr		27		8.3		5.58		0.958		9
15-Apr		26		8.4		6.05		1.021		9.5
16-Apr		25		8.3		5.68		1.025		10.5
17-Apr		26		8.2		4.25		1.04		11
18-Apr		25		8.1		5.39		1.065		11
19-Apr		26		8.1		4.43		1.086		13
20-Apr		26.5		7.9		5.54		1.065		13
21-Apr		28.5		7.9		17.2		0.865		10.5
22-Apr		27		8.1		5.06		1.045		9
23-Apr		45		7.9		14.7		0.657		8.5
24-Apr		71		7.8		71.5		0.446		7
25-Apr		50		8.1		24.6		0.523		7

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26-Apr		43		8.1		15		0.61		7
27-Apr		60		8		48.1		0.452		9
28-Apr		47		8.3		35		0.442		8
29-Apr	-70	40	8.2	8.4	2.6	13.68	0.269	0.585		9
30-Apr	-67	37	8.2	8.3	2.54	7.64	0.274	0.622		10
01-May	-90	34	7.9	8.4	2.45	4.82	0.266	0.676		8
02-May	-98	32	8.2	8.7	2.28	4.41	0.265	0.693		8
03-May	-98	33	8	8.4	2.41	6.44	0.288	0.745		7.5
04-May	-103	31	8	8.7	2.29	4.82	0.351	0.782		8
05-May	-104	30	8	8.9	2.42	3.65	0.41	0.787		10
06-May	-108	29	7.9	8.2	2.11	4.9	0.374	0.746		11
07-May	-111	28.5	7.7	8.1	1.87	4.77	0.712	0.832		12
08-May	-116	27	7.5	8.1	1.91	4.89	0.717	0.859	7	14
09-May	-122	28	8	8	1.95	4.43	0.896	0.914	7	15
10-May	-128	27	8	7.9	1.95	4.74	0.725	0.866	7	15
11-May	-130	27	7.8	8.1	1.93	5.13	0.857	0.938	7	18
12-May	-128	27	7.5	8.2	1.4	5.59	1.28	0.974	7	12
13-May	-120	26.5	7.7	8	1.59	4.4	1.041	0.984	7	11
14-May	-121	31.5	7.6	7.7	1.54	22.2	1.067	0.67	8	11
15-May	-120	31	7.3	7.8	1.3	5.17	1.113	0.735	8	12
16-May	-126	29	7.3	7.9	1.21	5.85	1.187	0.785	8	10
17-May	-128	27.5	7.4	8	1.31	4.02	1.135	0.857	8	10
18-May	-129	27	7.4	8	1.2	3.63	1.25	0.879	8	9.5
19-May	-129	26.5	7.1	8.1	0.683	3.66	1.475	0.895	8	12
20-May	-130	26.5	7.3	8	1.43	4.37	1.352	0.925	8	13
21-May	-131	26	7.3	7.9	0.698	4.23	1.426	0.945	8	13.5
22-May	-135	25	7.3	7.9	1.16	5.92	1.39	0.96	8	14
23-May	-136	25.5	7.3	7.9	0.855	5.99	1.5	0.969	8	13
24-May	-138	27	7.4	7.9	0.889	5.34	1.55	0.991	8	12
25-May	-139	25.5	7.3	7.8	0.882	6.79	1.567	0.96	8	12.5
26-May	-140	25.5	7.3	7.9	0.782	5.74	1.572	0.984	8	14
27-May	-141	25	7.4	7.9	0.815	7.92	1.58	0.951	8	15
28-May	-144	25	7.4	7.9	0.793	5.48	1.597	0.983	8	14.5
29-May	-148	25	7.4	7.9	1.05	5.47	1.577	0.978	8.5	14.5
30-May	-150	28	7.3	7.7	0.959	11.4	1.57	0.747	8.5	14.5
31-May	-151	26	7.2	7.7	0.785	8.64	1.635	0.67	8.5	14.5
01-Jun	-152	24.5	7.3	7.7	0.705	7.79	1.634	0.782	8.5	15.5
02-Jun	-155	24	7.1	7.7	0.418	7.39	1.662	0.837	8.75	17
03-Jun	-155	24	7.2	7.7	0.552	7.77	1.656	0.895	9	17
04-Jun	-153	24.5	7.3	7.7	1.06	9.89	1.663	0.925	9	17
05-Jun	-157	24	7.1	7.6	1.03	9.25	1.67	0.949	9	17.5
06-Jun	-160	24	7.1	7.7	0.814	8.14	1.667	0.949	9	19.5
07-Jun	-161	23.5	7	7.6	0.804	9.72	1.645	0.955	10	19.5
08-Jun	-163	23.5	7	7.5	0.971	7.11	1.67	0.975	10	19.5
09-Jun	-166	24	7	7.6	0.946	9.14	1.68	0.946	10	20
10-Jun	-170	26	7	7.6	0.833	16.3	1.8	0.833	10	21.5
11-Jun	-168	23.5	7.3	7.6	1.32	6.88	1.7	0.835	10	21.5
12-Jun	-172	23.5	7.3	7.7	1.19	6.89	1.69	0.817	10	23
13-Jun	-170	23.5	7.5	7.7	1.18	7.8	1.69	0.904	10.5	22
14-Jun	-167	43	7.2	7.6	1.68	65.4	1.71	0.49	10.5	23

15-Jun	-160	45	7	7.4	0.446	66.3	1.72	0.431	10.5	21
16-Jun	-165	36	6.9	7.6	0.764	30.8	1.725	0.509	11	18
17-Jun	-167	31	6.9	7.5	1.1	15.9	1.727	0.595	11	17
18-Jun	-169	28	6.8	7.5	1.07	10.3	1.741	0.66	11	16.5
19-Jun	-172	26	6.8	7.5	0.921	7.89	1.705	0.762	11	16
20-Jun	-171	25.5	6.8	7.5	4.08	11.6	1.66	0.76	11	15
21-Jun	-175	25	6.9	7.5	2.75	14.4	1.738	0.798	11	17
22-Jun	-177	25	6.9	7.5	3.19	15	1.73	0.808	11.5	18.5
23-Jun	-178	24	6.7	7.4	4.24	12	1.778	0.73	11.5	16.5
24-Jun	-178	23.5	7	7.6	2.73	13.8	1.725	0.785	11.5	18
25-Jun	-181	23.5	7.3	7.6	5.65	11.2	1.81	0.835	11.5	20.5
26-Jun	-184	23	7.3	7.7	16.1	12.9	1.85	0.85	11.5	20
27-Jun	-185	23	7	7.7	2.3	12.4	1.87	0.863	12	20.5
28-Jun	-191	23	7.1	7.7	14.3	12	1.85	0.854	12	21.5
29-Jun	-194	23.5	7	7.6	7.06	10.3	1.936	0.859	12	21.5
30-Jun	-195	23.5	7	7.6	25.7	8.33	2.03	0.87	12	21.5
01-Jul	-196	23	7	7.7	113	6.85	2.04	0.87	12	22
02-Jul	-205	23	-	7.7	-	8.41	-	0.879		17.5
03-Jul	-206	23	-	7.8	-	13.2	-	0.881		18
04-Jul	-207	29	-	7.7	-	19.6	-	0.872		18.5
05-Jul	-208	23.5	-	7.9	-	12	-	0.778		20
06-Jul	-208	24	-	7.9	-	16.2	-	0.506		19
07-Jul	-208	23	-	7.8	-	12.8	-	0.84		19.5
08-Jul	-208	22.5	-	7.7	-	9.31	-	0.78		19.5
09-Jul	-208	22.5	-	7.8	-	11.9	-	0.77		19
10-Jul	-208	22	-	7.7	-	8.03	-	0.769		19
11-Jul	-208	22	-	7.6	-	6.88	-	0.851		21
12-Jul	-208	22	-	7.8	-	8.47	-	0.751		22
13-Jul	-208	25	-	7.8	-	9.13	-	0.877		22
14-Jul	-208	35	-	7.6	-	36	-	0.25		25
15-Jul	-208	26	-	7.6	-	19.1	-	0.388		23.5
16-Jul	-208	23	-	7.5	-	7.2	-	0.382		23
17-Jul	-208	49	-	7.6	-	171	-	0.2		22.5
18-Jul	-208	34	-	7.7	-	44.9	-	0.336		24
19-Jul	-208	30.5	-	7.6	-	26.4	-	0.399		24
20-Jul	-208	26.5	-	7.7	-	23.6	-	0.425		21
21-Jul	-208	24.5	-	7.8	-	18.2	-	0.551		22.5
22-Jul	-208	27	-	7.6	-	71.9	-	0.197		22
23-Jul	-208	23.5	-	7.8	-	13.9	-	0.66		20.5
24-Jul	-208	23	-	7.7	-	8.36	-	0.635		20
25-Jul	-208	23	-	7.7	-	8.83	-	0.68		20.5
26-Jul	-208	27	-	7.7	-	14.9	-	0.633		20.5
27-Jul	-208	31	-	7.6	-	43	-	0.371		19.5
28-Jul	-208	25	-	7.7	-	17	-	0.475		18
29-Jul	-208	23.5	-	7.8	-	13.6	-	0.576		18
30-Jul	-208	23.5	-	7.8	-	16.9	-	0.617		18.5
31-Jul	-208	23	-	7.8	-	11.7	-	0.605		18.5

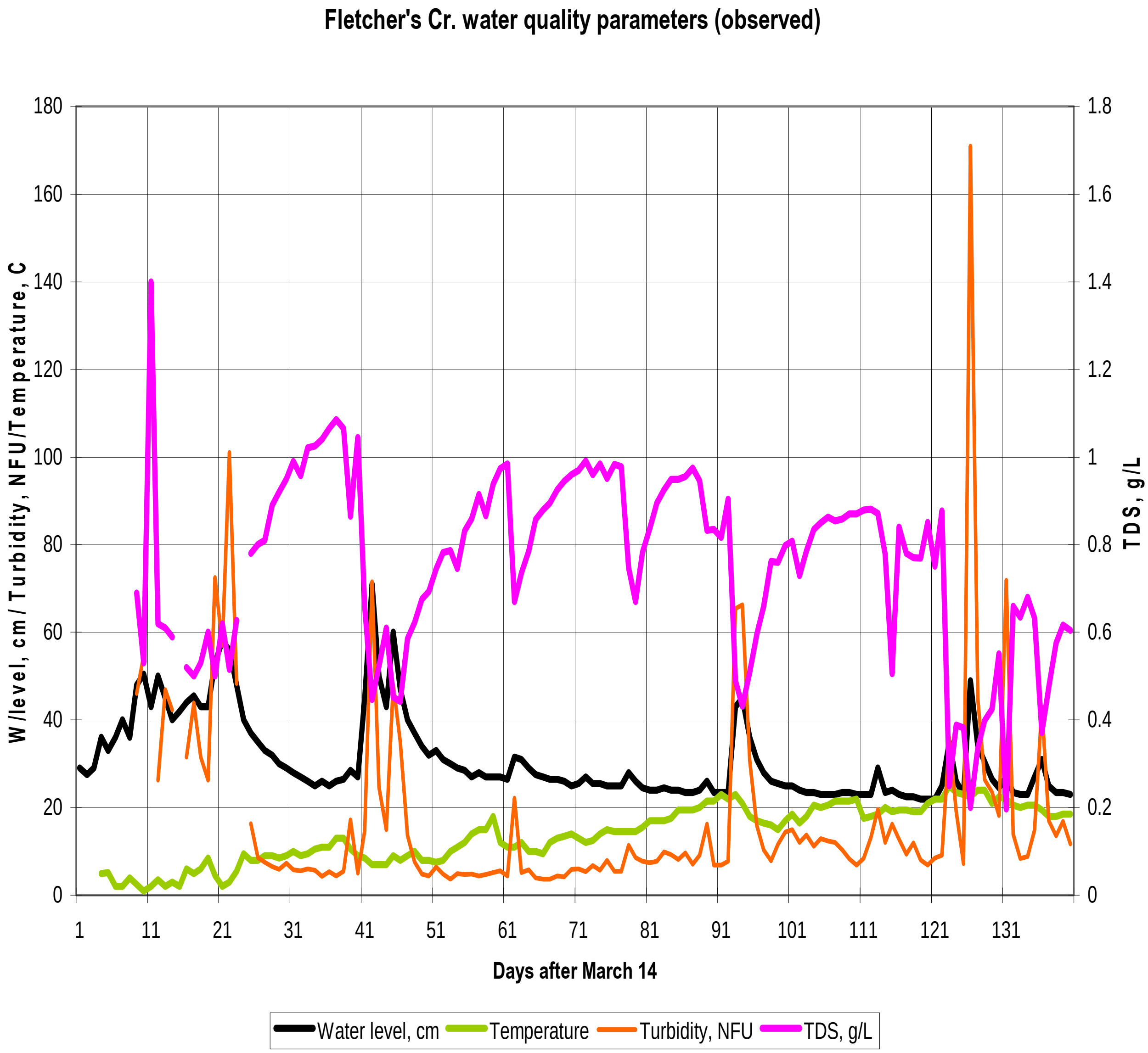

Fig. 5 Results of the creek water daily measurements

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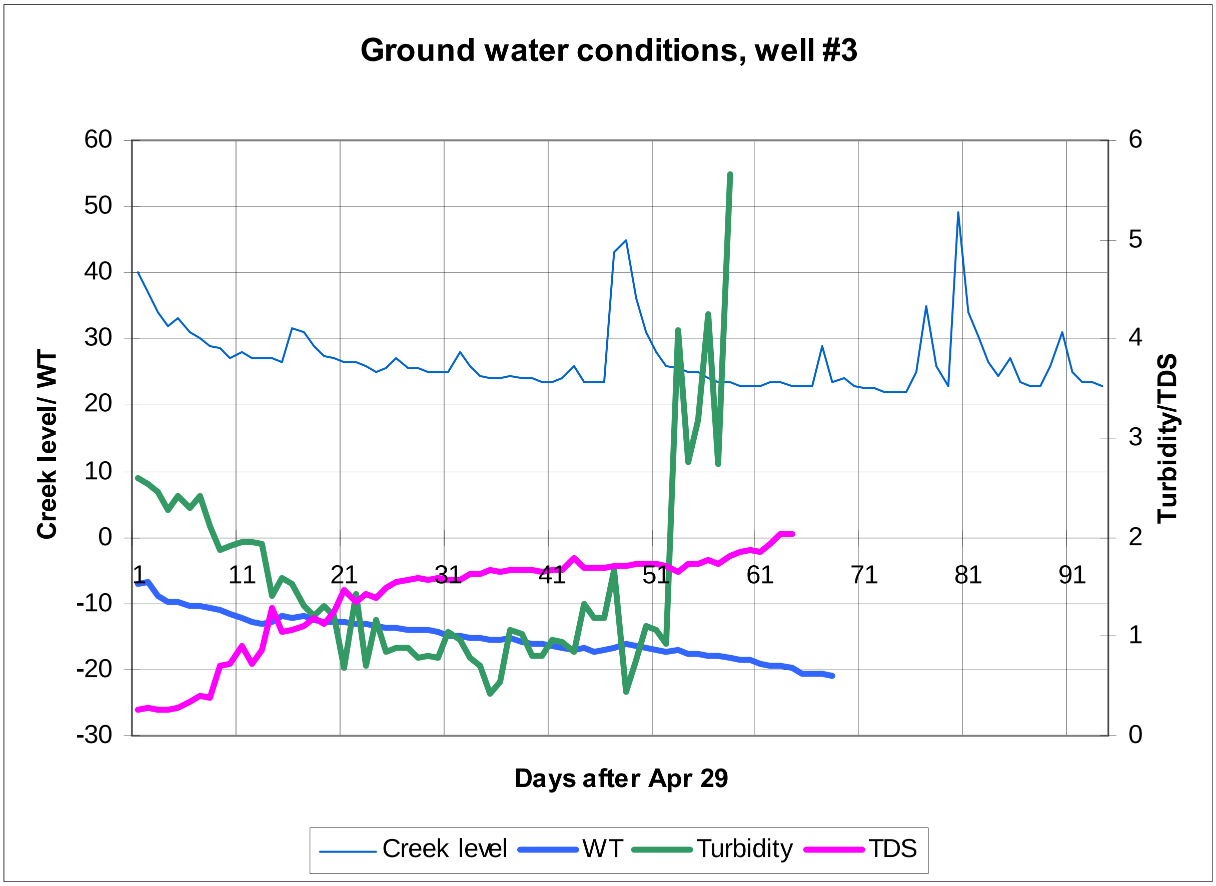
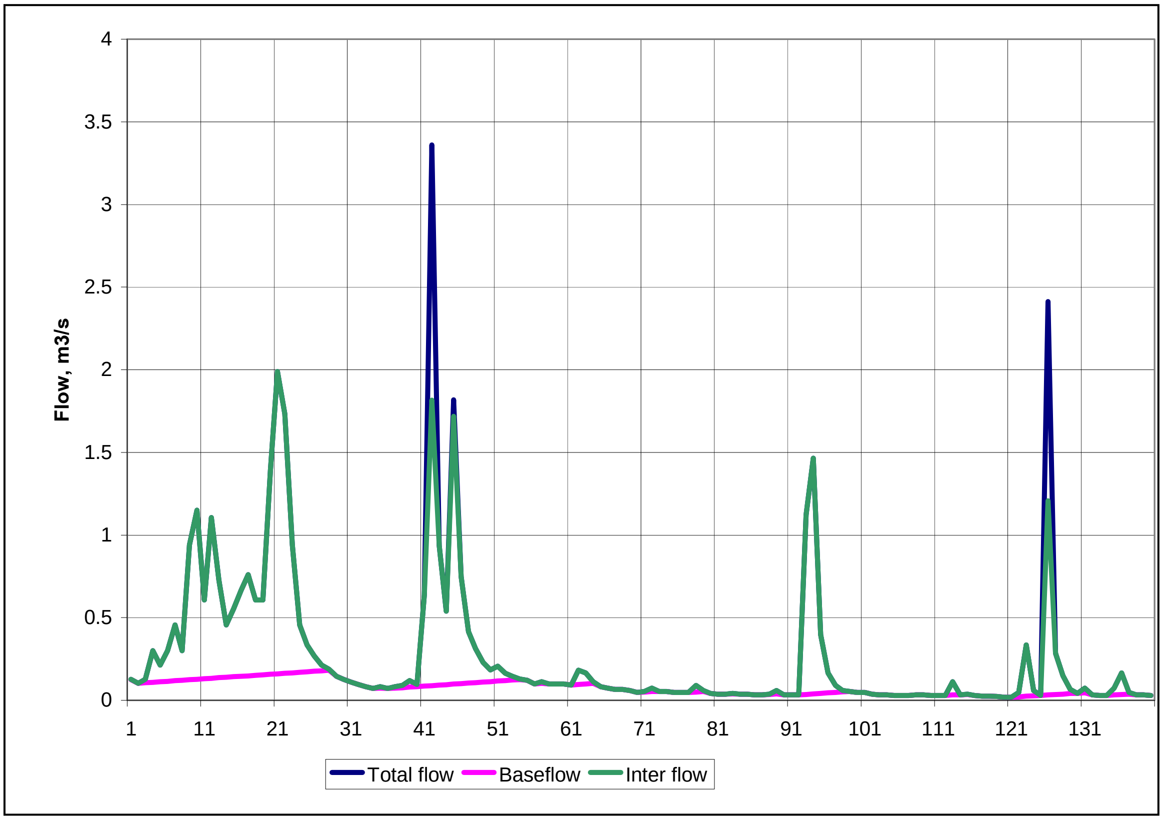


Fig. 6 Groundwater measurement results



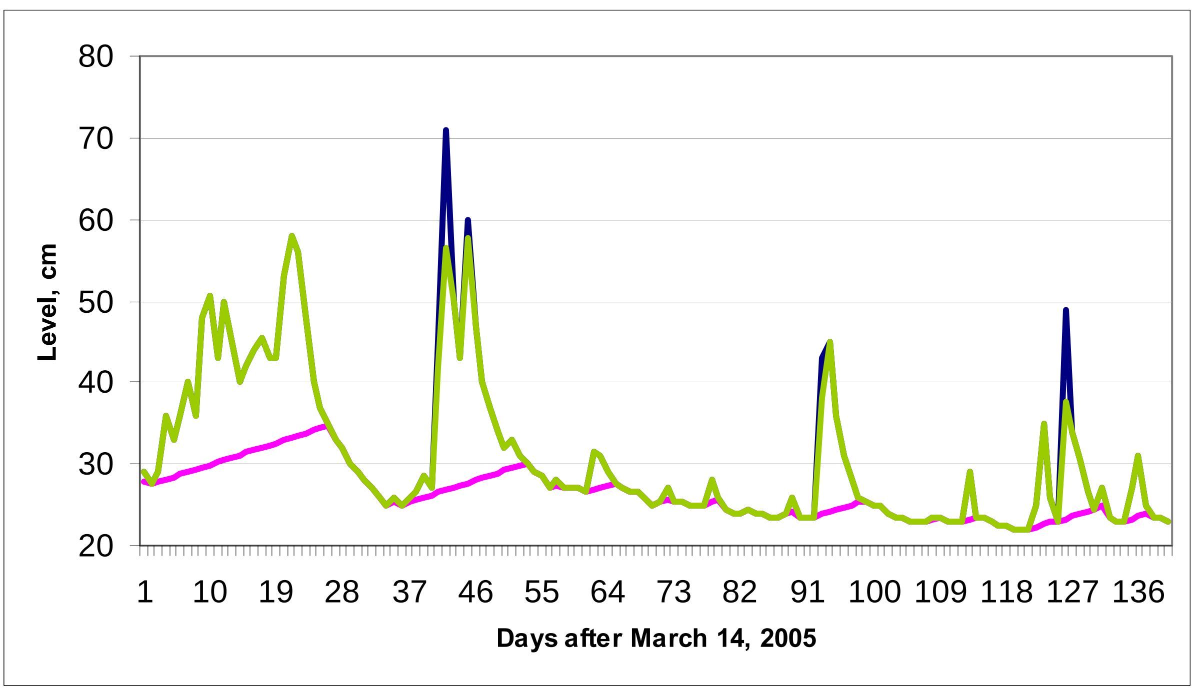


Fig. 7. Flow (above) and level hydrographs of the Fletcher's Creek.

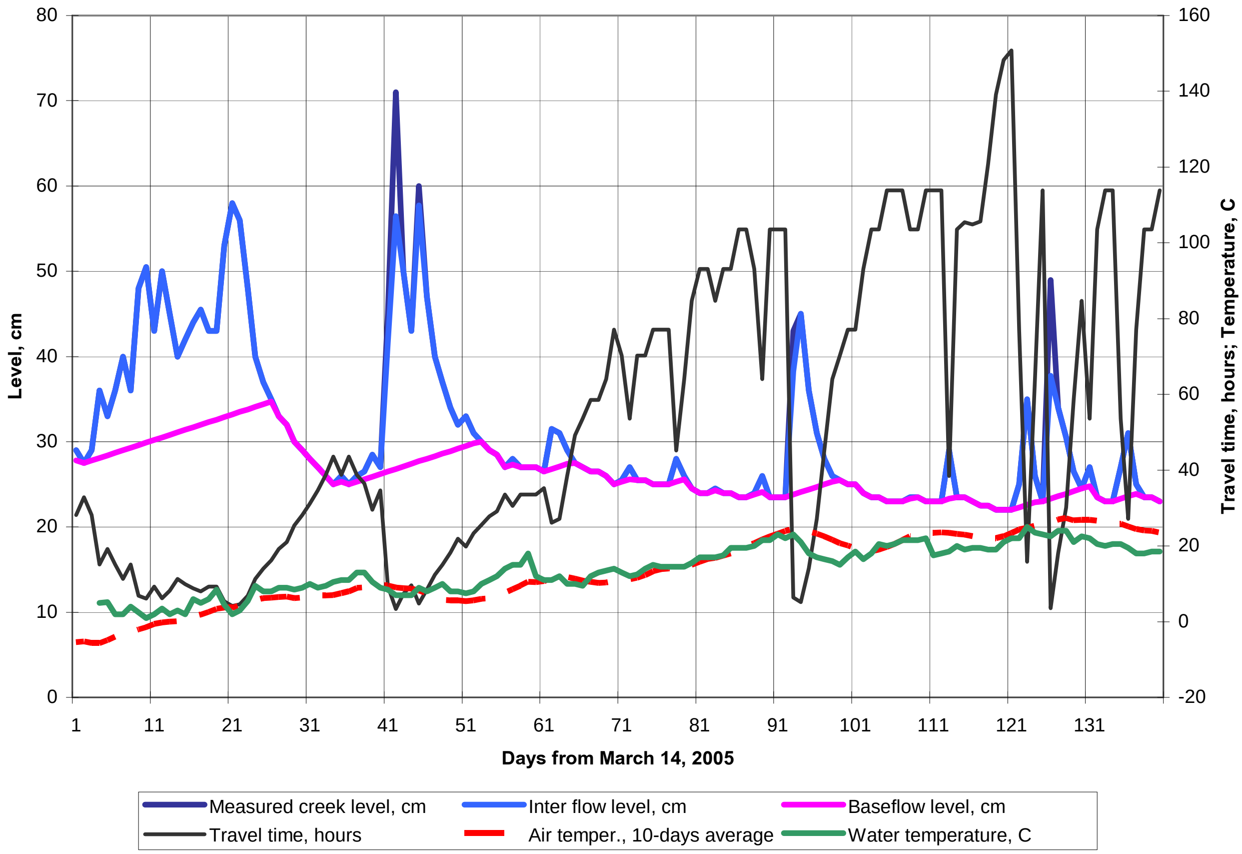
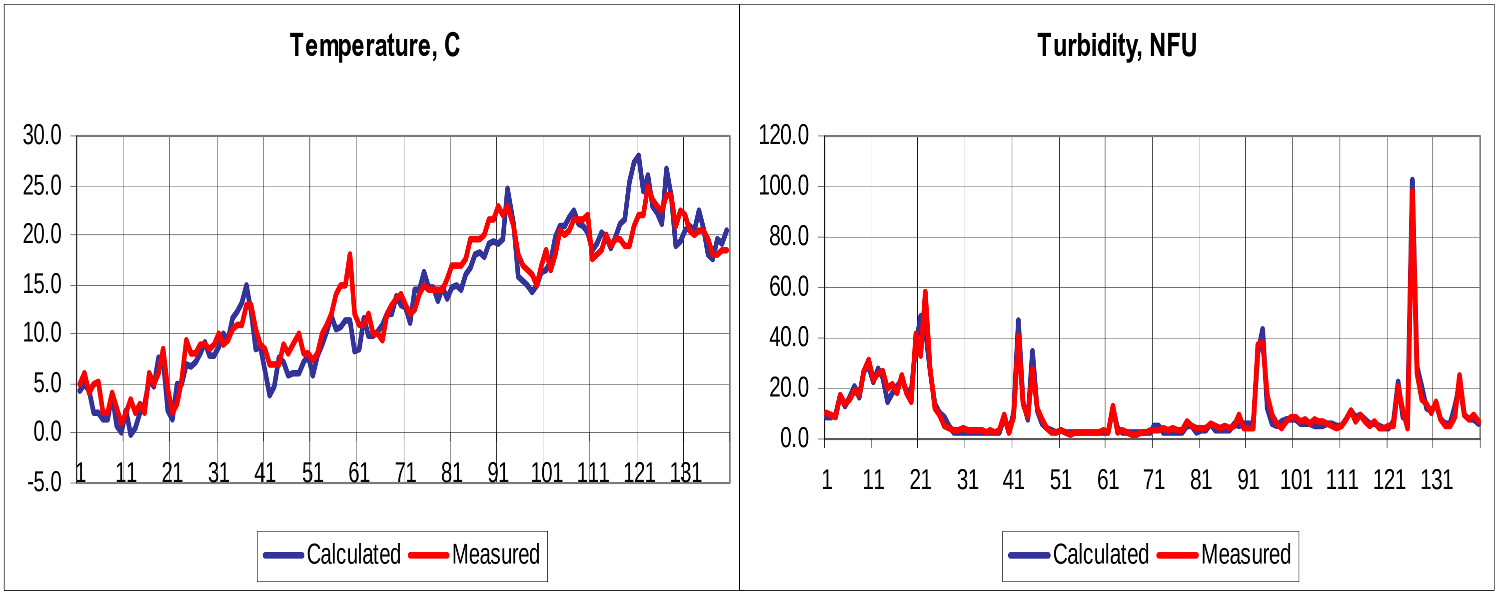
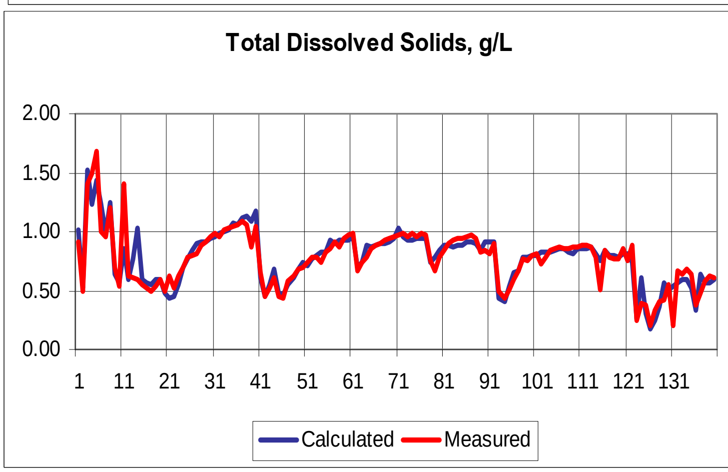


Fig. 8 Combined graph of the creek separated level hydrograph, temperature and travel time.





Correlation coefficients:

Temperature: **R = 0.962**
TDS: **R = 0.91**
Turbidity: **R = 0.977**

Fig. 9. Results comparison between measured and obtained by the SFA daily parameters

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Table 4. Monthly summaries for solids (TDS, turbidity TSS and TDS+TSS)

	Concentration, mg/L			TDS+TSS	Loads, tonne			TDS+TSS
	Base	Inter*	Storm*	Total	Base	Inter	Storm	Total
Mar	623	2615	0	905	124.2	514.4	0.0	638.7
Apr	988	744	792	796	289.7	539.0	78.3	907.0
May	891	883	0	870	194.9	31.7	0.0	226.6
Jun	859	744	0	810	82.8	122.6	0.0	205.3
Jul	633	528	650	630	50.6	55.2	37.8	143.6

* - average of events, not monthly

	Concentration, mg/L			TSS	Loads, tonne			TSS
	Base	Inter*	Storm*	Total	Base	Inter	Storm	Total
Mar	8.6	23.0	0.0	18.7	1698	16537	0	18235
Apr	4.3	18.0	123.8	13.0	1522	34146	10718	46387
May	2.6	11.3	0.0	3.4	579	406	0	985
Jun	5.7	19.3	0.0	7.9	560	9237	0	9797
Jul	7.6	20.6	250.0	13.0	651	8895	14523	24070

* - average of events, not monthly

	Concentration, g/L			TDS	Loads, tonne			TDS
	Base	Inter	Storm	Total	Base	Inter	Storm	Total
Mar	0.614	2.6	0.0	0.886	122.5	497.9	0.0	620.4
Apr	0.985	0.7	0.7	0.783	288.2	504.9	67.5	860.7
May	0.885	0.9	0.0	0.866	194.3	31.3	0.0	225.6
Jun	0.853	0.7	0.0	0.803	82.2	113.3	0.0	195.5
Jul	0.626	0.5	0.4	0.617	50.0	46.3	23.2	119.5

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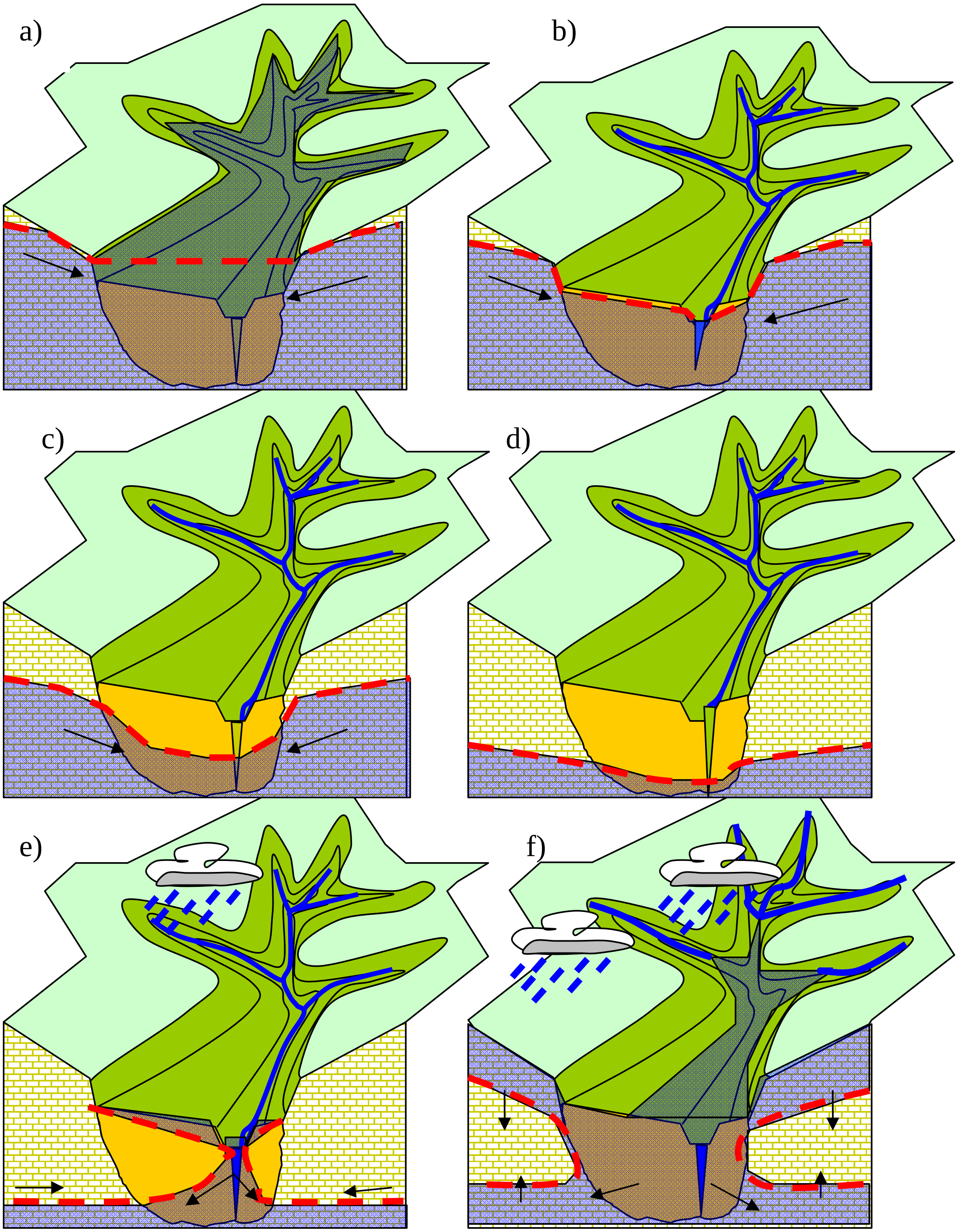

Fig. 10. Visual interpretation of flow components interaction in the flow formation process (based of the Fletcher's Creek project results).