**INFILTRATION IN THE CORGO RIVER BASIN (NORTH OF PORTUGAL): COUPLING WATER
BALANCES WITH RAINFALL-RUNOFF REGRESSIONS ON A MONTHLY BASIS**

Ana Maria Pires Alencão^{1,2} and Fernando António Leal Pacheco^{1,3}

¹ Geology Department, Trás-os-Montes e Alto Douro University, 5000 Vila Real, Portugal

² Centre for Geophysics, Coimbra University, 3000 Coimbra, Portugal

³ Centre for Chemistry, Trás-os-Montes e Alto Douro University, 5000 Vila Real, Portugal

ABSTRACT

A combination of water balances and rainfall-runoff regressions is used to calculate infiltration (I), overland flow (Q_s), base flow (Q_g) and change to the surface water reservoir (Δ_s), on a monthly basis; evapotranspiration from the underground reservoir (ET_m), on an annual basis; and a lag phase of maximum I and maximum Q_g (t_g) within a hydrological year. The water balance equations are written for catchment areas shaped on crystalline rocks and located in temperate climates. The regression lines are fitted to precipitations (P) and river flows (Q_r). The model is tested with the Corgo river hydrographic basin, a small watershed in the Trás-os-Montes and Alto Douro province, north of Portugal. The results are (values in mm y^{-1}): $I = 345.8$, $Q_s = 444.2$, $Q_g = 303.1$, $\Delta_s = 0.5$ (steady state), $ET_m = 42$ and $t_g = 4$ months. They compare favourably with results of other groups, working under similar environmental conditions.

Key words: Water balances, rainfall-runoff regressions, infiltration, base flow.

INTRODUCTION

There are numerous ways for estimating the infiltration of meteoric water into the soil and bedrock. In a recent review, Scanlon et al. (2002) subdivided the available techniques on the basis of three hydrologic sources (or zones) from which the data are obtained, namely surface water, unsaturated zone and saturated zone. Further, within each zone the surveyed methods were classified into physical, tracer or numerical approaches.

The objective of a study plays an important role in determining the appropriate technique for quantifying infiltration, because the goal determines the space and time scales required. In this study, the main purpose was to evaluate groundwater resources at the watershed scale and at time scales of a month to a year, using a method based on easily available data (long-term rainfall, runoff and temperature records). The secondary objective was to obtain input data for subsequent weathering studies. In this context, the assessment of infiltration (or base flow) is vital for the estimation of mineral weathering rates (Pacheco and Van der Weijden, 2002; Van der Weijden and Pacheco, 2003; Pacheco and Alencão, 2005).

The methods based on data from the unsaturated and saturated zones are beyond the scope of this paper, as they are not based on easily available data, and can be found elsewhere (e.g., Belan and Matlock, 1973; Verhagen, 1992; Hendrickx and Walker, 1997; Scanlon et al., 1997; Gee and Hillel, 1998; Zhang, 1998; Cook et al., 1998, 2001). Among the methods based on surface water data (e.g., Lerner, 1997; Ronan et al., 1998; Rosenberry, 2000; Halford and Mayer, 2000), the most adequate technique for this study is the watershed modeling. Recently, Shaw (1994) as well as Beven (2001) summarized the latest findings which represent the state of the art on this subject. From the cited reviews one may distinguish process-oriented models, which conceive the hydrology of a drainage basin as a series of inter linked processes and storages (Dawdy and O'Donnell, 1965; Jonckheere, 1979), but in general use an awesome number of input variables which may result in increasing problems of calibration and therefore be a source of uncertainty (Todini, 1996; Flint et al., 2000, 2002; Ciarapica and Todini, 2002), from conceptual water balance models, which are oriented

towards simpler mathematical formalizations and built on a limited number of parameters.(e.g. Xiong and Guo, 1999).

In this paper, a monthly water balance model is introduced. Relative to comparable algorithms (a review is provided by Xu and Singh, 1998), the distinctive feature of our method is the coupling of regression equations between rainfall and river flow with water-balance equations, for solving for unknown components of the water balance (e.g. infiltration and base flow). Further, infiltration (input to the underground reservoir) and base flow (output) are determined separately on a monthly basis, which enables the calculation of a lag phase of maximum infiltration and maximum base flow. This approach may provide an effective tool to the hydrologist who is seeking for ways of evaluating groundwater resources in temperate climates. The object of this study is the Corgo river basin, a small watershed in Trás-os-Montes and Alto Douro, north Portugal.

WATER BALANCES AND RAINFALL-RUNOFF REGRESSIONS

Premises

The method developed in this study estimates components of the water-balance equation by combining this equation with rainfall-runoff regressions on a monthly basis. The spatial scale is the watershed scale, the time scales are the month–year scales. The algorithm is applicable to any region of temperate climate, with cold-wet and warm-dry seasons. The cold-wet season is a period of water surplus, i.e. a period with precipitation (P) in excess of potential evapotranspiration (ETP) that usually goes from autumn to early spring. The warm-dry season has $ETP > P$ and runs from late spring to summer. In any case, the river basins must be shaped on massifs of crystalline rocks with a limited coverage by alluvial aquifers. The underground trajectory of precipitation water inside the basins must start in the top soil, where it can feed evapotranspiration or proceed throughout the saprolite and rock fractures, ultimately ending up in the river as base flow.

The water balance

Figure 1 depicts the main components of the water balance at the watershed scale. In such system, the surface (Δ_s) and underground (Δ_g) water reservoirs are in permanent change. The source of water to the catchment is rainfall (P), which is partially lost as direct evaporation (E_p) or overland flow (Q_s), before entering the underground reservoir as infiltration (I). Part of the infiltrated water returns to the atmosphere as evapotranspiration (ET_m), while the other part emerges as base flow (Q_g), after a period of underground flow, or remains in storage. The net infiltration ($R = I - ET_m$) is termed groundwater recharge. The measured river flow, also known as runoff (Q_r), accounts for the surface plus groundwater contributions, to which direct evaporation from the river channel (E_r) and changes to the surface water reservoir (Δ_s) may have to be deduced. The water balance model considered in this study can be summarized by the following equations:

$$\text{River flow balance: } Q_r = Q_s + Q_g - E_r - \Delta_s \quad (1a)$$

$$\text{Overland flow balance: } Q_s = P - E_p - I \quad (1b)$$

$$\text{Underground reservoir balance: } \Delta_g = I - ET_m - Q_g \quad (1c)$$

It should be noted that Equations 1a–c ignore any man's influences, such as abstractions from groundwater and rivers, or discharges such as sewage and industrial effluents, but in many small watersheds throughout the world these influences are localized and not comparable to the system's natural inputs and outputs.

Rainfall-runoff regressions

The derivation of relationships between the rainfall over a catchment area and the resulting flow in a river is very much dependent on the time scale being considered. For short durations (hours) the complex interrelationship between rainfall and runoff is not easily defined, but as the time period lengthens the connection becomes simpler, until, on an annual basis, a straight-line correlation may easily be obtained (Shaw, 1994). At monthly scale, the rainfall-runoff relationships may also be represented by a linear regression, that can be combined with Equations 1a–c for determining the unknown components of the water balance.

The cold-wet season - In general, the cold-wet season in a temperate climate is a period of water surplus, which means that rainfall (P) largely exceeds the potential evapotranspiration (ETP). The fate of excess water is infiltration and overland flow (Figure 1). During this coldest period the assumption of little transpiration is reasonable. The vegetation may actively be taking water for transpiration from the root zone, but $E_p \gg ET_m$. On the other hand, although evaporation from the river channel occurs always as long as there is potential evapotranspiration, the channel area is just a minor portion of the watershed, and therefore $E_p \gg E_r$. The assumptions made were adopted by numerous other authors (Xu and Singh, 2004) and imply that during the cold-wet season $ETP \approx E_p$ (and therefore that $ET_m = E_r \approx 0$). Based on these assumptions, Equations 1a,b may be rewritten as follows:

$$Q_r = Q_s + Q_g - \Delta_s \quad (2a)$$

$$Q_s = P - ETP - I \quad (2b)$$

This set has two equations and four unknowns (Q_s , Q_g , Δ_s and I) and is therefore undetermined. By coupling Equations 2a,b with linear regressions between Q_r and P , on a monthly basis, it is possible to solve the undetermination.

First, the overland flow may be expressed as a proportion of the effective rainfall ($P-ETP$):

$$Q_s = b \times (P - ETP) \quad (3)$$

where b is the constant of proportionality. Subsequently Equation 2a may be rearranged as:

$$Q_r = Q_g - b \times ETP + b \times P - \Delta_s \quad (4)$$

If Q_g and ETP are assumed relatively constant for a given month, although Q_g is expected to change within a year in response to the emptying/refilling of the underground reservoir and ETP due to temperature variations, then Equation 4 may be rewritten as follows:

$$Q_r = a + b \times P - \Delta_s \quad (5a)$$

where

$$a = Q_g - b \times ETP \approx \text{constant for a given month} \quad (5b)$$

In a plot Q_r versus P , $\underline{a}$ will be the intercept-y of a least squares fitting, $\underline{b}$ the corresponding slope, and Δ_s the median deviation of the scatter points with regard to the straight-line. Additional scatter to the Q_r versus P plots may be introduced by measurements errors, which should be eliminated prior to any least squares fitting. Figure 2 shows a typical Q_r versus P plot for a month X in the cold-wet season. The thick line is the least squares fitting. The large crosses are points of the thick line, meaning that all overland flow of month X contributed to the measured river flow of that month. Contrarily, the filled circles and the open circles are plotted above and below the thick line, respectively. In the first case (filled circles) the river flows of month X are greater than the least squares predictions; hence the excess flows had to come from the surface water reservoir leading to $\delta_s < 0$. In the second case (open circles) the river flows are smaller than the predictions, so part of the overland flow was necessarily added to the surface water reservoir ($\delta_s > 0$). During the cold-wet season, more years are expected with $\delta_s > 0$ than with $\delta_s < 0$, because during this season the water levels in the rivers rise, and Median (δ_s) = $\Delta_s > 0$ is expected.

In summary, four consecutive steps are necessary to estimate Q_s , Q_g , Δ_s and I , in Equations 2a,b:

Step 1 – For each month, rainfall (P) has to be plotted against river flow (Q_r) on a bilinear diagram.

For the present case study P and Q_r listed in Appendices A and B were used.

Step 2 – Points that markedly correspond to measurement errors should be removed.

Step 3 – The other scatter points have to be fitted using the least squares method, in order to estimate the values of parameters $\underline{a}$ and $\underline{b}$.

Step 4 – Using medians, Q_s (Equation 3), Q_g (Equation 5b), Δ_s (Equation 5a) and I (Equation 2b) may be determined. The use of medians (instead of means) is justified because precipitation, the source for the above mentioned water balance components, is distributed irregularly in time and therefore requires a more robust estimate of its central tendency value.

The warm-dry season - Usually, the warm-dry season is a period of water deficit ($P < ETP$). During this period, most rainfall is consumed by direct evaporation from interception, and therefore only a negligible portion of P is converted into overland flow (i.e. $Q_s \approx 0$) or infiltration ($I \approx 0$).

River flows are of almost exclusive underground origin, and for that reason plots of Q_r versus P usually give points around straight-lines of low slope ($b \approx 0$). Similarly to the cold-wet season, Figure 3 illustrates the typical relationship between Q_r and P for a month in the warm-dry season. Equations for the warm-dry season are derived readily from those of the cold-wet season, taking into account the current assumptions ($Q_s = 0$ and $I = 0$) and the usual observations ($b \approx 0$). Equation 5b can be rewritten as:

$$Q_g \approx a \quad (6a)$$

and Equation 5a as:

$$\Delta_s \approx a - Q_r \quad (6b)$$

Contrarily to the cold-wet season, $\Delta_s < 0$ is expected, in agreement with the lowering of river water levels.

ET_m is an important water-balance component during the warm-dry period, but standing solely on P , Q_r and ETP records it is not possible to estimate ET_m on a monthly basis. Nevertheless, if the underground reservoir is assumed to be in steady-state on an annual basis (annual $\Delta g = 0$), then the annual ET_m can be calculated on that basis using Equation 1c ($ET_m = I - Q_g$).

STUDY AREA

The hydrographic basin of Corgo river is located near Vila Real (north of Portugal) and has an area of approximately 290 km² (Figure 4). Altitudes vary between 60 m in the mouth and 1360 m in the spring. For a river that is approximately 40 km long, this represents an average riverbed slope of 3.2%.

The Corgo river is an affluent of the Douro river and runs mostly along a large-scale tectonic depression, the so-called Penacova–Régua–Verin fault. The geology of the basin is characterized by Paleozoic metasediments that were intruded by Hercynian granites and covered locally by Quaternary deposits (Sousa, 1982; Matos, 1991). Major soil types are luvisols (53 %), anthrosols (22 %) and leptosols (9 %), with thicknesses that usually do not exceed 80 cm. Land use is dominated by forests (pine, oak, eucalyptus) intermixed with agricultural areas. In the highlands,

the earth surface is covered mostly by spontaneous vegetation, while in the tectonic valleys there is a predominance of agriculture.

The region is characterized by a cold-wet period running from October to May, succeeded by a warm-dry period lasting from July to August. Although they vary considerably in their temperatures and precipitations, the months of June and September can be included in a warm-wet period (Figure 5). The river flows reflect the climatic conditions, with the periods of high and low runoff coinciding with the cold-wet and warm-dry seasons, respectively.

Precipitation and river flow data

Representative precipitation data were computed for a drainage area inside the Corgo river basin from the records of 7 meteorological stations (Figure 6) using the Thiessen polygons method. For the period 1960/61–1984/85, results are summarized in Appendix A. River flow data of the same period were obtained at the Ermida hydrometric station (Figure 6) and are compiled in Appendix B.

RESULTS AND DISCUSSION

Q_r versus P regressions and error analysis

Using the data in Appendices A and B, Q_r versus P scatter plots were drawn for all months in a year and the corresponding least squares fittings were calculated (Table 1). Prior to the calculation of these fittings, some markedly anomalous points (e.g., associated with measurement errors in Q_r and/or P) were removed from the plots; in total 17 out of 300 points (5.6%). The cold-wet period ($P-ETP > 0$) includes all months from October to May, the warm-dry period ($P-ETP < 0$) the remaining months. As expected, the scatter points fit to straight-lines of high slope for the months in the cold-wet period (median $b = 0.50$) and to straight-lines of low slope for the months in the warm-dry period (median $b = 0.12$). The associated coefficients of determination (r^2) are 0.8 and 0.3, respectively.

Water balances

The water balance components were calculated on a monthly basis, using medians of precipitation (P), river flow (Q_r) and potential evapotranspiration (ETP), in combination with the $\underline{a}$ and $\underline{b}$

coefficients deduced from the Q_r versus P regressions (Table 1). The P and Q_r medians were determined from data in Appendices A and B, the ETP medians by the Thornthwaite method, using long-term average temperatures as given in INMG (1991).

The calculated components of the water balance (Q_g , Q_s , Δ_s , I) are also shown in Table 1. On a yearly basis, infiltration approaches $I = 346$ mm and base flow $Q_g = 303$ mm. Assuming that the underground reservoir is in steady-state on a yearly basis ($\Delta_g = 0$), then the difference between I and Q_g (43 mm) is the annual ET_m (Equation 1c). This value is consistent with the 75 mm obtained by Alenção (1998) for a nearby basin.

Seasonal variations of water balance components

The calculated infiltrations (I), surface and base flows (Q_s , Q_g), and changes to the surface water reservoir (Δ_s), for each month in a year, are shown in Figure 7 (source data taken from Table 1). As expected, infiltration occurs during the cold-wet season, especially in the period

November–January, and generally speaking is out of phase with the base flow, which is more important in the period March–May. The lag phase of maximum I and maximum Q_g is $t_g = 4$ months.

From October to January infiltration increases rapidly, while the base flows are kept relatively low (except in January), meaning that the underground reservoir is being replenished ($\Delta_g > 0$).

Eventually, some saturation occurs in January, which would explain the decrease in I during February. In response to a refill of the underground reservoir, the base flows increase rapidly from January till March, and stay high till May. In February and upcoming months $I < Q_g$. Consequently, $\Delta_g < 0$ and infiltration may increase again, which occurs in March. The period March–June is characterized by a progressive decrease in infiltration, caused by a decline in the rainfall. For the same time span there is a progressive decrease in the base flow, which is related to the normal emptying of the underground reservoir. Finally, from July to September, infiltration remains at the zero level and base flows are reduced to residual values.

The accumulated change to the surface water reservoir is represented in Figure 7 by the thick line. During the cold-wet season, $\Delta_s > 0$ and therefore the accumulated Δ_s grows gradually till reaching a value close to 26 mm in May. This result is consistent with the normal rise of the river's water level during the winter and spring seasons. From June on $\Delta_s < 0$ and so the accumulated Δ_s drops down till a residual value of 0.5 in September; the highest drop (22 mm) occurring in the first month of the warm-dry period (June). In the period October–January, the accumulated Δ_s grows in phase with Q_s and Q_g , continues rising in the period February–May notwithstanding the drop in Q_s observed after January, and drops down in June in phase with Q_g , suggesting that the river's water level is more sensitive to the changes in Q_g .

Application of the model to a nearby catchment for comparison of results

Comparison of I, R and Q_g with the results obtained by other groups

Maxey and Eakin (1950), working in Nevada, USA, developed an empirical step function whereby the annual R is set to percentages of the annual P ranging from 0 % (for $P < 203$ mm) to 25 % (for $P > 507$ mm). Although slightly modified ($R = 0$ was set to $P < 100$ mm), the step function of Maxey and Eakin (1950) was also used by Hevesi and Flint (1998), with consistent results. In the Corgo river basin, $P = 1202$ mm and therefore $R = 0.25 \times P$, in keeping with the above mentioned step functions. With the model introduced in this study it was found that $R = 303$ mm, or $R = 0.252 \times P$, which is acceptable.

Using the Kille method (Kille, 1970), Mihálik and Kajan (1990) found Q_g (annual) = 195 mm for P (annual) = 1078 mm (thus, $Q_g = 0.18 \times P$). Our results compare modestly with this but match those of Gurtz et al. (1990) that found Q_g (annual) = 237 mm by continuous hydrograph separation, meaning that $Q_g = 0.25 \times P$ for P (annual) = 931 mm.

In a study carried out in France, Cosandey and Didon-Lescot (1990) calculated infiltration in the context of flood analysis, and found I (annual) = 294.4 mm for a P (annual) = 1900 mm ($I = 0.15 \times P$). This deviates from our result ($I = 0.29 \times P$) but a reason exists for the discrepancy: at the La

Latte basin (south of the Lozère mountain) precipitation is rather irregular, with some events producing large amounts of rain in short periods of time (e.g. 400 mm in 48 hours). This does not occur in the Corgo basin. However, the discrepancy may also be due to a scale effect (the Latte basin is very much smaller than the Corgo basin).

CONCLUSIONS

The model presented in this study is simple but effective. Based on a limited amount of data (precipitation and runoff records and average potential evapotranspiration) and on the link between precipitation and runoff, the method is able to discriminate among most terms of a water balance at the catchment scale. Additionally, because the method estimates infiltration and base flow in separate and on a monthly basis, the lag phase of maximum infiltration and maximum base flow is also evaluated.

ACKNOWLEDGEMENTS

This study has been supported by the Sapiens project POCTI/40772/CTA/2001.

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TABLE 1

Legend: Input data for the water balance (columns below the "Data" heading), results of the least squares fittings (columns under the heading "Least Squares Regressions") and calculated components of the water balance (columns under the heading "Water Balances").

Month	Data			Least Squares Regressions				P-ETP	Water Balances			
	P	Q _r	ETP	Anomalous Years	a	b	r ²		Q _g	Q _s	Δ _s	I
Oct	96.9	13.5	61.8	1,2,17,22	-4.96	0.20	0.80	35.1	7.4	7.0	0.9	28.0
Nov	125.8	41.7	27.4	17,25	0.15	0.34	0.80	98.4	9.5	33.4	1.2	64.9
Dec	180.7	116.9	17.5		2.69	0.65	0.91	163.2	14.1	106.1	3.3	57.1
Jan	218.6	159.4	17.9	5	22.55	0.66	0.69	200.7	34.4	132.4	7.4	68.2
Feb	148.1	127.7	18.3		25.51	0.72	0.73	129.8	38.7	93.4	4.4	36.3
Mar	121.4	96.2	35.2	3,4,9,18,19	50.68	0.42	0.75	86.2	65.5	36.2	5.5	50.0
Apr	111.5	88.1	49.9		40.57	0.44	0.62	61.6	62.5	27.1	1.5	34.5
May	92.1	60.6	76.8		10.73	0.56	0.79	15.3	53.7	8.6	1.7	6.7
Jun	44.9	33.1	105.0	14	10.78	0.43	0.48	-60.1	10.8	0.0	-22.4	0.0
Jul	9.0	5.7	133.4	14	3.96	0.19	0.28	-124.4	4.0	0.0	-1.7	0.0
Aug	9.9	1.4	120.7	11,13,14	1.46	0.01	0.01	-110.8	1.5	0.0	0.0	0.0
Sep	43.0	2.5	90.6		1.17	0.04	0.37	-47.6	1.2	0.0	-1.3	0.0
Total	1201.7	746.8	754.5						303.1	444.2	0.5	345.8

P – median precipitation after excluding the anomalous years; Q_r – median river flow after excluding the anomalous years; ETP – potential evapotranspiration; a, b – intercept-y and slope of the regression line; r² – associated coefficient of determination; Q_g – base flow; Q_s – overland flow; Δ_s – change to the surface water reservoir; I – infiltration. All columns under the "Data" and "Water Balances" headings are in mm. Numbers under the heading "Anomalous Years" are in agreement with the Nr codes in Appendices A and B.

FIGURE 1

Caption: The water balance at the catchment scale. Symbols (units are in mm): P – precipitation; E_r – evaporation from the river channel; ET_m – evapotranspiration from the soil and organic compartments; E_p – direct evaporation; I – infiltration; Q_s – overland flow; Q_g – base flow; Q_r – river flow.

FIGURE 2

Caption: Schematic representation of a typical Q_r versus P regression for a month in the cold-wet period. Symbols (units in mm, except for b that is dimensionless): P – precipitation; Q_r – river flow; Q_g – base flow; Q_s – overland flow; ETP – potential evapotranspiration; δ_s – change to the surface water reservoir in a particular year; a and b – intercept-y and slope of the regression line.

FIGURE 3

Caption: Schematic representation of a typical Q_r *versus* P regression for a month in the warm-dry period. Symbols (units in mm): P – precipitation; Q_r – river flow; Q_g – base flow; δ_s – change to the surface water reservoir in a particular year; a – intercept-y of the regression line.

FIGURE 4

Caption: Location and land use of the Corgo river hydrographic basin.

FIGURE 5

Caption: Strahler diagram of the Corgo river hydrographic basin. Precipitation and temperature averages were computed from long-term records (1951–80) as given in INMG (1991).

FIGURE 6

Caption: Topography and drainage pattern within the Corgo river basin. Location of the hydrometric station and of meteorological stations used to calculate precipitation averages. Boundary lines: of the Corgo basin (dash-dot line); of the drainage area upstream the hydrometric station (dashed line).

FIGURE 7

Caption: Seasonal variation of infiltration, surface and base flow, and accumulated Δ_s .

APPENDIX A

Nr	Year	Month											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	60/61	465.8	406.9	271.6	259.5	90.4	16.3	288.8	137.2	46.0	99.5	6.5	29.4
2	61/62	206.8	217.4	496.7	224.2	33.0	392.0	161.2	57.1	30.5	31.4	1.0	51.4
3	62/63	68.8	96.9	86.6	424.7	601.7	281.1	190.4	50.1	116.0	2.8	4.2	35.5
4	63/64	96.8	717.2	380.4	18.2	393.6	340.4	83.7	36.6	115.7	19.3	9.1	43.0
5	64/65	160.7	15.8	94.5	327.0	74.6	325.6	16.6	28.5	31.0	6.2	3.0	201.9
6	65/66	173.3	352.3	336.4	527.4	613.8	1.2	370.8	33.6	103.2	1.3	39.6	43.9
7	66/67	274.5	179.7	66.3	132.1	190.8	146.9	37.8	216.1	10.1	0.1	27.4	54.8
8	67/68	76.8	125.8	27.6	8.4	385.8	91.9	209.0	125.9	13.1	0.8	47.6	121.8
9	68/69	117.6	236.9	303.0	312.5	257.8	470.2	114.0	199.6	69.6	9.8	0.3	119.3
10	69/70	44.4	158.0	93.7	501.4	79.1	30.9	24.0	206.0	67.6	7.7	17.3	7.2
11	70/71	8.5	253.1	41.4	321.7	41.2	113.8	123.9	178.8	141.6	78.7	31.1	4.5
12	71/72	66.8	32.3	55.0	207.6	431.6	168.7	31.6	64.9	25.5	38.2	5.8	62.1
13	72/73	154.9	124.2	207.7	213.3	27.4	25.6	58.6	184.4	35.9	37.7	12.0	44.0
14	73/74	136.3	30.6	101.0	382.6	236.7	54.7	23.1	86.0	262.3	2.7	1.1	33.9
15	74/75	5.9	197.4	37.4	226.1	147.9	204.5	35.2	36.5	7.7	1.5	12.7	142.9
16	75/76	96.9	99.0	59.2	73.2	76.6	71.9	63.6	9.6	38.8	33.1	79.2	95.9
17	76/77	265.5	130.3	283.2	378.1	445.4	129.0	74.0	65.4	74.7	13.7	34.2	27.1
18	77/78	170.8	99.0	352.3	223.8	477.8	160.6	168.1	91.9	66.2	3.6	0.0	11.6
19	78/79	42.7	47.4	743.9	204.9	478.5	236.9	164.0	94.0	4.3	19.7	1.1	10.9
20	79/80	276.4	77.8	180.7	125.8	113.6	138.3	54.5	115.5	43.8	14.4	10.8	32.9
21	80/81	62.3	112.2	50.4	2.4	92.8	158.6	129.5	117.1	21.6	7.9	8.8	121.9
22	81/82	144.4	0.0	589.6	120.3	83.7	7.1	56.1	49.1	47.7	8.2	18.7	108.6
23	82/83	118.2	195.3	216.2	15.5	148.1	23.4	367.2	299.4	42.7	15.3	41.9	7.5
24	83/84	47.1	199.0	290.4	187.6	35.9	192.7	111.5	106.3	91.3	7.9	30.5	40.6
25	84/85	212.9	382.8	125.2	273.5	277.3	133.2	124.4	92.1	57.4	8.0	1.0	7.3

Legend: Monthly precipitation (P in mm) at the Corgo river hydrographic basin, covering the period 1960/61–1984/85. Source data retrieved from DGRAH (1986).

APPENDIX B

Nr	Year	Month											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	60/61	165.5	88.9	192.2	191.4	87.7	42.1	98.3	60.6	28.8	8.1	2.0	1.2
2	61/62	8.9	55.2	251.1	232.5	47.4	191.7	144.5	40.1	13.5	2.9	0.8	0.3
3	62/63	1.0	3.4	10.4	129.6	262.4	360.0	142.6	46.4	46.6	6.4	1.9	1.8
4	63/64	4.2	261.3	207.1	59.9	191.2	373.6	84.6	37.4	38.9	6.1	1.5	1.0
5	64/65	13.5	7.9	12.5	85.7	67.0	202.6	45.7	23.2	6.6	0.4	0.0	11.0
6	65/66	32.4	174.2	235.6	416.5	537.3	90.5	226.7	54.3	38.0	4.9	0.6	0.0
7	66/67	40.4	91.9	48.8	70.0	127.7	101.8	38.6	99.7	26.9	4.6	1.0	0.0
8	67/68	0.3	30.3	14.9	12.5	152.7	84.3	102.5	101.3	17.9	2.7	0.8	13.1
9	68/69	15.0	116.4	262.5	257.5	203.9	371.3	105.6	148.1	63.9	14.8	2.1	10.5
10	69/70	12.5	41.3	43.7	398.5	122.6	52.2	34.2	84.3	33.4	5.3	1.6	1.5
11	70/71	1.7	31.1	32.7	198.4	79.5	104.0	79.5	99.4	112.7	46.2	16.1	5.7
12	71/72	9.8	7.7	12.7	89.1	345.4	157.8	50.2	41.7	14.2	4.5	0.8	3.9
13	72/73	21.2	58.1	116.9	204.3	54.5	32.6	23.8	98.0	39.5	12.3	5.1	5.7
14	73/74	23.9	17.1	35.0	222.9	237.7	71.3	43.3	50.0	99.2	40.8	4.7	6.0
15	74/75	4.9	41.7	28.8	96.7	123.0	166.9	48.1	31.1	12.6	1.8	0.3	3.8
16	75/76	16.9	32.3	47.8	30.9	67.5	52.2	40.6	19.6	4.2	2.9	1.4	3.2
17	76/77	131.4	143.9	244.3	354.8	456.0	154.0	98.1	48.2	35.0	11.0	3.8	2.8
18	77/78	40.5	48.7	275.6	189.1	425.8	224.5	88.1	86.8	32.8	10.5	3.0	2.5
19	78/79	2.4	4.8	473.0	251.9	570.1	376.4	210.8	67.4	31.4	6.8	2.0	1.5
20	79/80	64.8	61.0	99.8	127.7	128.7	104.1	78.4	87.0	33.5	6.6	2.6	2.4
21	80/81	10.4	41.3	28.7	20.0	24.7	80.6	112.5	81.7	29.4	5.0	0.5	5.3
22	81/82	83.5	9.7	383.4	78.5	78.6	52.5	33.0	18.0	7.2	0.9	0.1	0.8
23	82/83	21.7	81.8	170.5	69.8	69.8	55.0	177.9	230.0	55.5	7.9	3.4	2.2
24	83/84	3.6	55.8	235.4	83.6	83.6	111.6	123.4	90.2	64.3	8.9	3.1	3.0
25	84/85	47.9	280.0	176.1	338.5	338.5	144.8	140.3	47.6	38.9	4.2	1.1	0.9

Legend: Monthly river flows (Q_r in mm), measured at the Ermida hydrometric station (Figure 6) during the period 1960/61–1984/85. Source data retrieved from www.inag.pt.