

FFTSINT: A TOOL FOR RECURRENCE ANALYSIS OF PEAKS IN THE SPECTRAL ANALYSIS OF DAILY HYDROLOGIC SERIES

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- **ABSTRACT:** This article discusses methodologies for describing fluctuations in flow and in flood levels of aquatic ecosystems. It discusses the role of how significant a recurrence must be for a process to have adaptive value. The available methods for testing periodicities are discussed, together with the limitations where it is assumed that time series are reversible, as in applications of traditional methods for significance testing of peaks. As time series of flows and water levels are irreversible, an alternative method is proposed for testing the significance of periodogram peaks, based on probabilities obtained by generating synthetic series. Given these probabilities, significant frequencies can be identified by filtering and the original series can be reconstructed by means of the inverse Fourier transform. In this process the proportion of total variance remaining in the filtered series can be adjusted, thus simulating signal amplification. The program FFTSint is presented which uses the methodology for generating significant hydrologic series filtered for different levels of significance (α) and for different levels of signal amplification. The methodology was tested using a flow series from the gauging station at Rosário do Sul, on the Rio Santa Maria, Rio Grande do Sul, Brazil.
- **KEYWORDS:** FFT; peaks significance; synthetic series; fitness; hydrologic series; riparian ecology.

1 Introduction

The variable nature of environmental factors through time is recognized as one of the environment's principal characteristics (MARGALEF, 1977; ODUM, 1988; BEGON,

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HARPER & TOWNSEND, 1996; KREBS, 2001). In the case of aquatic ecosystems, variability in flow and flood levels is their main forcing function, determining the temporal and spatial heterogeneity of the river (VANNOTE et al., 1980; NEIFF, 1990; BRETSCHKO, 1995; NEIFF, 1996; MOTTA-MARQUES et al., 1997; POFF et al., 1997; CRUZ et al., 1998; OLIVEIRA, 1998; IRGANG, 1999; WCD, 2000; BENDA et al., 2004; NEIFF et al., 2005).

In the theoretical literature, methods have been proposed for describing patterns of peak events in the behavior of a water body, such as the FITRAS index (frequency, intensity, tension, recurrence, amplitude and seasonality; NEIFF, 1990), the software IHA (RICHTER et al., 1996) and PULSO (NEIFF & NEIFF, 2003). However, this software describe various aspects of the time series considering the fluctuations as a whole, and without any filter allowing an interpretation of which peaks show significant recurrence: in other words, peaks which show a certain degree of regularity giving them adaptive value (usefulness of a trait that can help an organism to survive).

Evolutionary biologists state that the variations in environmental factors, characterized by their amplitude, frequency and predictability, can alter or stop the pattern of species adaptation (FUTUYAMA, 1992; JUNK & WANTZEN, 2004), whilst river ecologists regard predictable peaks as favouring organism adaptation.

Consider a riparian population submitted to a hydrologic regime. Consider also that a hydrologic series may be broken down into two components: one showing a certain degree of predictability and the other random. The question can be asked: does the random component have adaptive value? Since the component is random, it is supposed that probabilities associated with each pulse frequency in a periodogram are equal. Suppose that one particular pulse occurs. Suppose too that this pulse results in a selection process which is beneficial to variety A in the population, which also includes varieties B, C and D. As the random component must present equal probabilities at other frequencies, given that a series is sufficiently long, it is to be expected that other pulses beneficial to varieties B, C and D occur with equal frequency, resulting over the course of time in an equal number of periods favorable to each variety, and therefore an adaptive neutrality.

For the case of a pulse with some degree of predictability, the distribution of probabilities in the periodogram departs significantly from equality. If, in this case, the pulse significantly benefits variety A relative to the others, natural selection will tend to favor this variety, giving rise to more of its offspring and increasing the presence of its genes in the population. Thus, only pulses having a significant recurrence have adaptive value (in the evolutionary or Darwinian sense).

Gutierrez and Almirall (1989) discuss the process of memory construction in biological systems, acting through the influence of mass and energy interchanges on subsequent responses, conditioning structures, differences and local complexities. Maturana and Varela (2001) maintain that environmental perturbations trigger adaptive responses, but it is the system structure which determines the trajectory of the adaptive process. Margalef (2002) states that species evolve and ecosystems succeed each other in a manner showing all the signs of organism activity. The class of these signals would be the result of the coupling between living beings and their inanimate setting, thus forming an exosomatic memory.

Therefore, hypotheses can be formulated regarding the memory of riparian systems when the significant pulses of hydrographs are known. For this, it is necessary to

construct a filter which removes the random contents, leaving the predictable components. This process gives rise to the construction of the significant hydrograph.

Tests to analyse the significance of periodicities can be designed from various standpoints. Salas et al. (1980) present the method using cumulative periodogram ordinates which, in the presence of periodic components associated with the first few harmonics, show a discontinuity in the form of a sharp change in slope in the cumulative curve. The first part, having a steep slope, would represent periodic components and the other part, the random components.

Other traditional approaches are based on the comparison of values of a peak with the values of neighboring frequencies, using the F-test (FISHER, 1929), particularly for simple periodicities, and using the test developed by Siegel (1980) for multiple periodicities. The Siegel test, implemented in packages for time series analysis such as SIGVIEW (<http://www.sigview.com/index.htm>, accessed 04/12/2004), compares the percentage of variance explained by one frequency with the percentages explained by those remaining. Other tests are constructed from the hypothesis of white noise (HAMMER et al., 2003) or red noise (GHIL et al., 2002; VAUGHAN, 2004). The implicit supposition of these tests is that values in the time series are independent (KRÓLAK, 1998).

The main drawback to using the traditional approach is conceptual. According to Salas et al. (1980), a time series is a realization from an infinite population of possible trajectories: in other words, a realization of a stochastic process. Even when a peak is significant in relation to peaks at other frequencies in the same periodogram, this does not tell us about the possible existence of totally random trajectories which can generate peaks of the same magnitude. Manly (1991) describes the use of randomization methods to test the significance of periodogram peaks. However, these randomization methods, as well as autoregressive models, depend on the validity of the assumption that the series is reversible in time. Reversibility necessarily implies symmetry of waves.

Kelman et al. (1983) state that these randomization methods take no account of the marked asymmetry observed in daily time series, particularly in terms of the different physical characteristics existing between the rising and falling limbs of a hydrograph. The rising limb is more associated with phenomena related to precipitation and the generation of surface runoff, whilst the recessions are more related to base flow. These characteristics of daily flow sequences result in time-irreversibility.

Therefore, since the F-test, the Siegel test, and other tests based on whiteness or redness of noise, compare only some peaks in relation to others of the same realization of the stochastic process, or to a synthetic sequence having no physical hydrologic significance (pure white or red noises are not generated in daily hydrologic series) they can mistakenly lead to the conclusion that peaks are significant that in reality are random. The lack of physical significance is also related to the assumption that the time series is reversible, implicit in randomization methods.

Kelman (1980) proposed an algorithm for generating synthetic daily flow sequences which sought to overcome the limitations of time irreversibility by modelling rising limbs and recessions separately.

Kelman (1987) and Mine (1990) describe the use of Second Order Shot Noise (SOSN) models for generating synthetic daily sequences which preserve the mean, standard deviation, and serial and cross correlations of the historic daily series. This is achieved by producing pulses of random height with a Poisson distribution, superposed on

an exponential equation fitted to the recessions. In this paper, we discuss an approach using an algorithm to test the statistical significance of hydrologic pulses, starting from a spectral analysis of daily hydrologic series and of daily synthetic sequences, leading to the significant hydrograph: that is, to the reconstructed series obtained by filtering undertaken in frequency space, based on significant peaks.

2 Materials and methods

Type in contents Spectral analysis by means of the fast Fourier transform (FFT), is one of the most widely-used methods for describing periodicities that are present in time series (LEGENDRE and LEGENDRE, 1998). As it concerns a reversible process, the Fourier transform can be used to represent a time series either in the time or the frequency domains. This property can be used for data filtering (PRESS et al., 1992).

Given that a time series of daily flows contains periodic components superimposed on random components, the FFT can be used to transform a series in the time domain (a time series) into the frequency domain (the power spectrum, or the amount of variance in flows contained in each frequency), and can be filtered in this domain, from which a filtered series in the time domain can be derived. To do this, the first step is a procedure for generating synthetic daily sequences (using algorithms that have hydrologic meaning). From these generated sequences, FFTs are obtained for testing for periodicities at various significance levels. Having defined the significance, values found to be non-significant can be eliminated in the frequency domain and the inverse transformation is effected, so as to obtain a representation in the time domain with the random components filtered out (the significant hydrograph). The process is illustrated in Figure 1.

The core of the proposed approach lies in the test of hypotheses about the significance of peaks in the power spectrum (at all frequencies) in the series of daily flows. In this test, acceptance of the null hypothesis implies that the values of the power spectrum (variance) at a given frequency are generated by chance. If this hypothesis is true, the amount of variation in the time series that is explained by a periodicity with the given frequency indicated in the power spectrum, when compared with the values obtained from the synthetic sequences obtained using models such as SOSN (Mine, 1990) and DIANA (Kelman et al., 1983), will rarely be greater than the value of the original series. When this comparison is made between the original series and 999 synthetic sequences, for example, we can count the number of times the power function of the synthetic sequences resulted in a power function equal to or greater than that of the original series. This procedure yields a probability. If the power function of the synthetic sequences exceeded or equalled the power function of the original series 35 times in 1000 (999 synthetic series plus the original series) the probability associated with this hypothesis is 0.035. If the significance level of the test was set at $\alpha = 0.05$, the null hypothesis will be rejected, and the periodic component in the time series is considered to be significant (non-random). If the significance level of the test was set at 0.01, the null hypothesis would be accepted and we would conclude that periodicity expressed at that frequency does not differ from periodicities that occur by chance.

From a statistical viewpoint, a value of α can be taken based on the traditional values such as 0.05 and 0.01.

Nevertheless, the question can be asked: what is the hydro-ecological interpretation of this significance?

Given that self-organizing systems generally have responses based on limiting values, it can be expected that some value of α represents a boundary beyond which the system begins to show adaptive responses. In other words, from the point of view of flow periodicity, at what level of probability are riparian systems able to incorporate patterns of variability into their structure and increase their stability? The answer to this question lies beyond the scope of this article, since it involves the development of specific methodology. From the point of view of constructing an instrument to put the approach into practice, this question reduces to the possibility of filtering the original series with significance taken case by case.

Having defined the value of α , a value of zero can be given to non-significant frequencies, and we can proceed to the inverse transformation that gives a representation in the time domain, with the random components eliminated.

2.1 The program FFTSint

From inspection of Figure 1, the algorithm can be divided into three phases: one consisting of the generation of synthetic daily sequences, one in which periodicities are tested, and a phase in which the significant hydrograph is generated.

For the first phase, commercial software exist that deal with flood risk analysis and evaluation of operating rules for hydroelectric installations, using models such as DIANA and SOSN. However no packages were found for use at the second and third phases of the proposed algorithm. To fill this gap, the program FFTSint was developed.

The program was written in Delphi 5.0. Currently the source code is available at: <<https://drive.google.com/file/d/0BwxsogEEmGrnazJGWUY0dGJscW8/view?usp=sharing> (file FFT.pas)>.

FFT is an algorithm for calculating the discrete Fourier transform (DFT), defined as:

$$H_n = \sum_{k=0}^{N-1} h_k e^{2\pi i k n / N} \quad (1)$$

where H_n is the discrete Fourier transform, h_k is the value of the variable being studied in the time domain of order k , N is the length of the series, n is the number of intervals in the frequency domain and i is equal to $\sqrt{-1}$. The values of k and n vary over interval between 0 to $N-1$.

The transformation given in (eq. 1) is reversible, so that the constituent elements of the series in the time domain can be found from H_n :

$$h_k = \frac{1}{N} \sum_{n=0}^{N-1} H_n e^{-2\pi i k n / N} \quad (2)$$

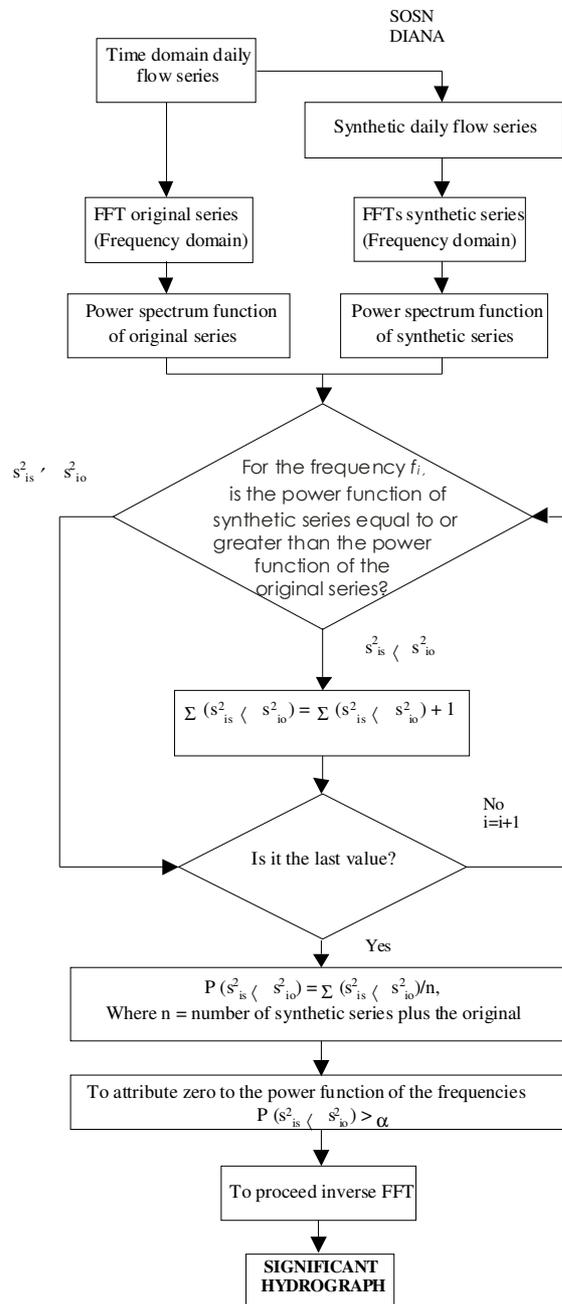


Figure 1 - Procedure for computing the significant hydrograph.

Using the complex representation, values for the magnitude (power function, or “power”) (eq. 3) and phase (eq. 4) can be obtained (Bourke, 1993; Smith, 1999). Thus:

$$\text{Magnitude} = \|H_n\| = \sqrt{(h_{real})^2 + (h_{imag})^2}, \quad (3)$$

$$\text{Phase} = \Phi_n = \arctan\left(\frac{h_{imag}}{h_{real}}\right). \quad (4)$$

The initial step in a time series analysis using FFTSint involves opening an input file containing a matrix in which each row is a time series, the first row being the original series. The program proceeds with FFT, showing the values in a table within a window. This shows the raw data of the original time series, the frequencies between 0 and 0.5 cycles/day; the real and imaginary parts of the FFT, and the power function (“power”). A window at the side shows these results graphically.

Amongst the options for running the FFT, the program must be told whether the length of the series is to be determined by cutting off some values, or by adding zeroes to the end of the series. According to Bloomfield (apud MEKO, 2005), the second option is preferred, since it does not discard any information contained in the series, and does not significantly alter the interpretation of the spectral analysis.

After opening the file with the original and synthetic series, FFTSint reads and notes the number of synthetic sequences, and the number of elements in each series in the Status block. If there are days missing from the original series, the missing values are represented by an asterisk (*). As the series is read, missing values are filled by linear interpolation. From this unbroken series, the program calculates the real and imaginary parts of the FFT and the power function. In the way that the program is written, results can be shown on the computer screen, or the computed graphs and tables saved in a file for subsequent analysis.

The Probability Matrix gives for each frequency in the original series the probabilities of the powers of the synthetic series at that frequency which are greater than the power in the original series. Only after calculating the probability matrix is it possible to proceed to the next step of filtering the Probability Matrix. The algorithm for filtering the “Probability Matrix” selects the frequencies whose associated probabilities are less than or equal to the fraction entered in the field indicated for the filter (the significance level α). Thus, a smaller fraction means a smaller number of selected frequencies. This step can be repeated for various values of α , and results can be shown on the screen or written to file for later analysis. Only after filtering the Probability Matrix is the algorithm used which inverts the FFT to give the frequencies that remain after the filtering process.

There are real and imaginary components associated with each filtered Probability Matrix value. The inverse FFT of this series which has been filtered in the frequency domain leads to a series from which random components have been eliminated, given the significance level (“ α ”) (Figure 2).

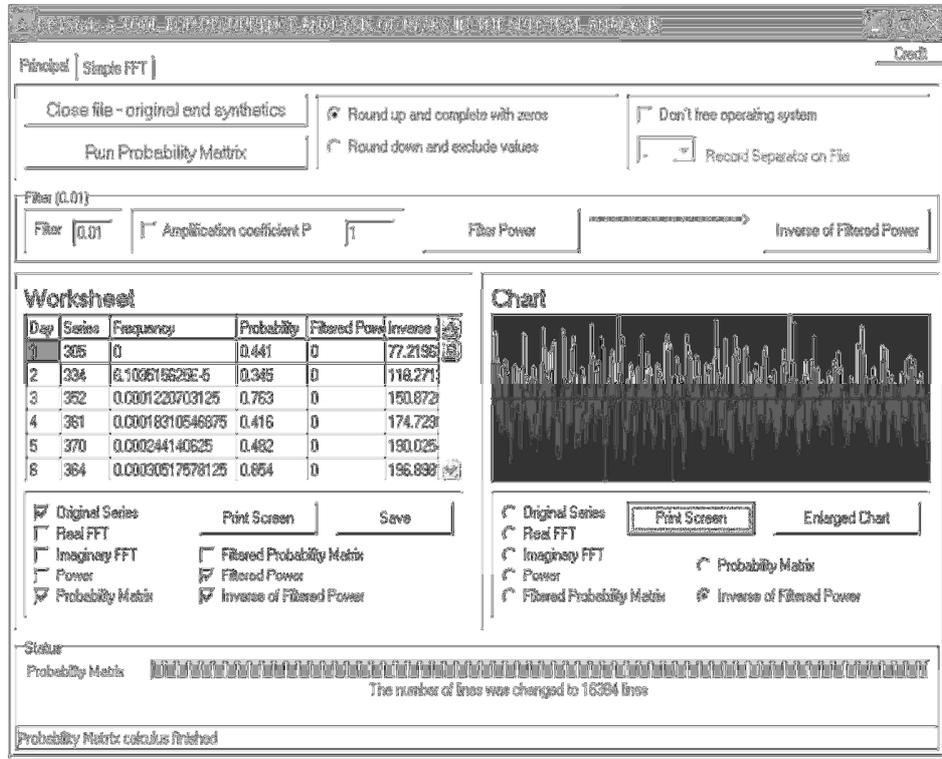


Figure 2 - Layout of the graphical interface of FFTSint after processing the inverse FFT of the filtered Probability Matrix.

One test option, used in this study, allows a filtering to be included which increases the magnitude of significant frequencies. The idea is based on the intuitive perception that the brain is capable of amplifying the magnitude of certain sounds, even in the presence of noise, when somebody is concentrated to hear it. The procedure includes a redistribution proportional to the total variation, or of one proportion to itself (P, value between 0 and 1), expressed in the power spectrum of the original series between significant frequencies at a given α . The equation for this distribution is given by a very simple rule (eq. 5).

$$\|H_n\|_{\text{amplified}} = \frac{\|H_n\|_{\text{filtered}} P \left(\sum_{k=0}^{N-1} \|H_n\|_{\text{original}} \right)}{\sum_{k=0}^{N-1} \|H_n\|_{\text{filtered}}} \quad (5)$$

This procedure alters the values of real and imaginary components at each frequency. To calculate values of the real and imaginary components, a system of

equations is used that involves the equations (3) and (4), in which the phase is held constant. Indeed, there are two equations and two unknowns.

3 Results and discussion

To implement the test this approach, a series of daily flows was used from the flow gauging station at Rosário do Sul, in the municipality of Rosário do Sul, Rio Grande do Sul, Brazil (Table 1). The series has 12268 values of daily flow in m³/s, for the period 01/06/1967 to 31/12/2000.

Table 1 - General physiographic and hydrographic data for the gauging station Rosário do Sul

Gauge station		Rosário do Sul
Mean pulse amplitude (days)*		59.94
Mean period (days)**		41.17
Gauge station UTM coordinates (Zone 21S, SAD69 datum)	UTM X ("Easting")	700546
	UTM Y ("Northing")	6652596
Recession coefficients	Surface flow	0.17138
	Subsurface flow	0.06647
Water course	Name	Rio Santa Maria
Drainage area	km ²	12101.97

* Mean pulse amplitude between two flood periods (one pulse involves a flood phase and a phase of separation in relation to the river; Neiff & Neiff, 2003) taking the over-bank level equal to the mean long-term level.

** Calculation based on the power spectrum (FFT).

Using the data presented in Table 1, synthetic sequences (999) were generated using the SOSN model (MINE, 1990), so that the stochastic process had 1000 occurrences. These 1000 series were processed using FFTSint so as to obtain a filtered series (eq. 2) for each of the following values of α : 0.5; 0.4; 0.3; 0.2; 0.1; 0.05 and 0.01. The purpose was to explore the influence of this parameter on filtering the series (sensitivity analysis). Figure 3 shows one year of the original series together with the filtered series.

It can be seen that a pattern exists in the pulse amplitudes. There is a fall-off in amplitude as the significance of the filtering process increases. On the other hand, there is a smoothing of the filtered hydrograph at high significance levels ($\alpha = 0.01$).

This result demonstrates that significant periodic components act more about the pulses of lower amplitude than on pulses of high amplitude. Thus, the random component would be more associated with high amplitude pulses. From the point of view of stability of systems, the periodic components, that allow the incorporation of information of system perturbation regime, would be more associated with low amplitude disturbances, whereas the random components associated with the more high amplitude disturbances result in displacement of the system from its stability region stability (in the sense of MARGALEF, 1977), suggesting a successional dynamic in which the opportunist character is more important than adaptations resulting from recurring phenomena with predictable form.

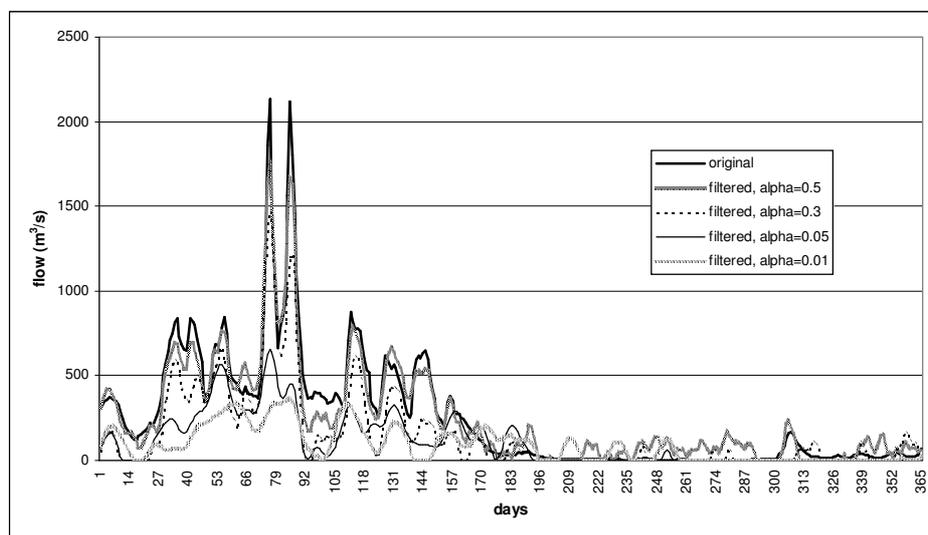


Figure 3 - Original and filtered series for the flow gauging station at Rosário do Sul, RS, Brasil, first 365 days.

The trends identified in the means and standard deviations show a limit at $\alpha = 0.5$ (Figure 4), which defines a sharp change in behavior. Here, the means and deviations were calculated using the filtered series of the negative elements (negative flows are artifacts created by the FFT inverse: only zero and positive components of the resultant series have physical meaning). In the interval of α between 1.0 and 0.5, where randomness predominates, the mean remains quite stable (significance of $F = 0.319$ for the regression coefficient, $r^2 = 0.24$, indicating that the regression coefficient does not differ significantly from zero), while the standard deviation falls quite smoothly (significance of $F = 0.005$, $r^2 = 0.89$). For α between 0.5 and 0.01, the standard deviation changes, decreasing strongly in mean and standard deviation (significant, respectively, with significance of $F = 0.0033$ and 0.0011 and $r^2 = 0.91$ and 0.95). The rate of decline in the means, measured by the regression coefficient (134.52), was 3.1 times smaller than the rate of decline shown by the regression of standard deviation on α (regression coefficient = 418.42; significance of $F = 0.001085$; $r^2 = 0.95$).

The decline in variability can be expressed in terms of variation in squared deviations (square of the difference between the flow value in the original series and its equivalent in the filtered series) as α decrease (Figure 5).

It is seen that the relationship is highly significant (significance of $F = 0.0000028$), demonstrating the predictability in the relation between the periodic and random components as the significance changes. The squared deviation represents the squared difference between the significant periodic component for a given α , and the original series (which represents the sum of both periodic and random components). Thus, the deviation gives the square of the random component. It is seen that the relation between

the squared deviations and α is direct, which means that filtering with high significance increases the sum of total errors as compared with filtering with low significance.

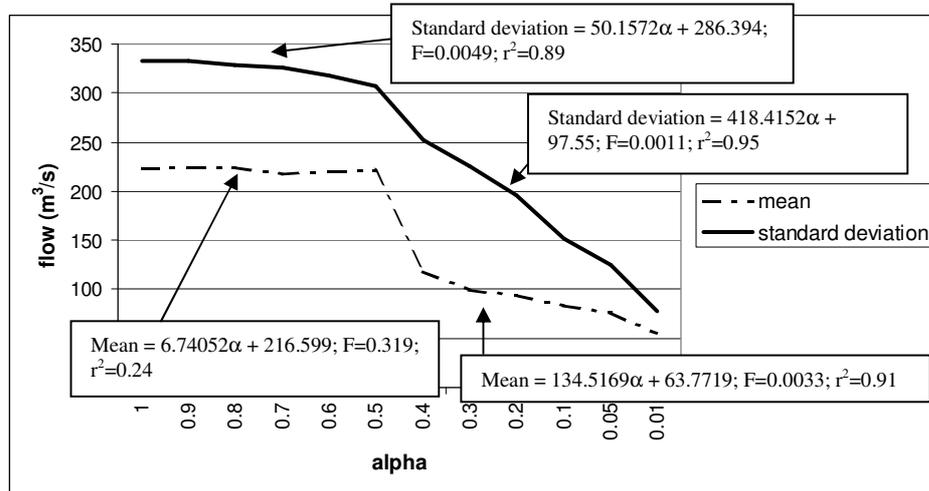


Figure 4 - Mean and standard deviation of original and filtered time series of daily flow at the gauging station Rosário do Sul, RS, Brazil.

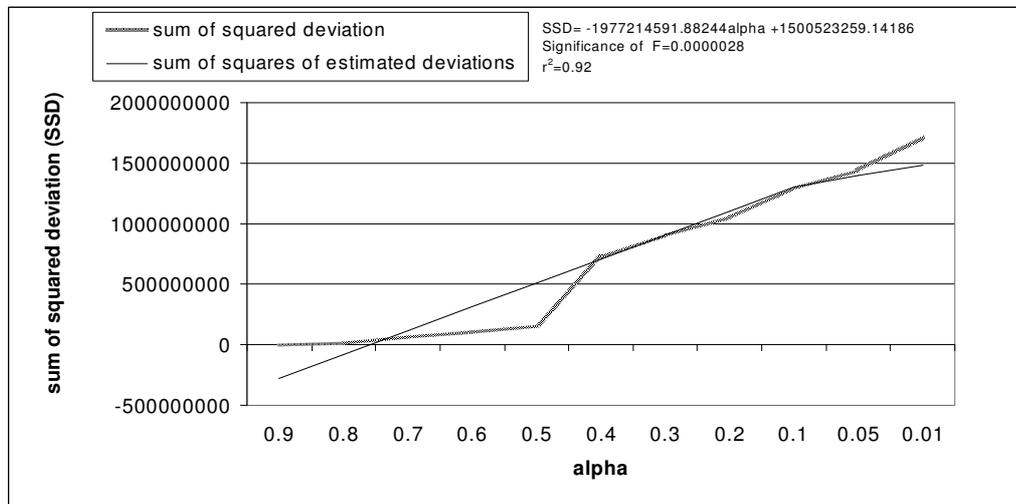


Figure 5 - Regression of the sum of squared deviations between the original and filtered series for the gauging station at Rosário do Sul, RS, Brazil.

This result is consistent with what is to be expected, since the more significant the filter (the smaller the α), the smaller is the amplitude of the filtered series and, therefore, the greater the residual. This means that the filtering process is analogous to a process of

wave lamination. Hence, the result shows a predictably inverse relation between the significance of the filter and the proportion of noise in the composition of the time series of flow. If the filter is very rigorous, the quantity of variation not explained by periodicity will be greater, which implies that there exists a significance level which optimizes the balance between periodic and random components, manifested in the biota as a balance between succession and adaptation. It would be possible to tune this fit by using plant functions as indicator variables of adaptive mechanisms (PILLAR & SOSINSKI Jr., 2003; CARLUCCI et al., 2012).

This possibility has been tested in some research and projects with objective to prescribe streamflows in diverse types of rivers: lowland rivers (CRUZ, 2005) and highland rivers (UFSM, 2006a, 2006b, 2006c). Cruz (2005) demonstrated that in a river with great floodplain, the plant functional characters are distributed throughout the transversal section of the river with bigger adjustments for the periodic components in lower levels and for the random components in the highest levels. Based in these results, the author considered a methodology of streamflow prescription that uses the filtered hydrograph for lower levels and the original hydrograph (that it includes random and periodic components) for the highest levels, using software IHA (RICHTER et al., 1996) and PULSE (NEIFF & NEIFF, 2003) to characterize the pulse regimen to be kept in the river. The Water Resources Research Group of the UFSM (Federal University of Santa Maria) has developed methodology to prescribe streamflows for reduced flows handles of hydreletric powerplants (the stretch of reduced flows between the dam and the release of turbine discharge). Differently of the lowland rivers, the studied highland rivers show a longitudinal partition of pulses, with random or periodic predominance in different stretches of river, having been used the FFTSint to characterize the dominant regimen and to prescribe the streamflow tension fringe to be kept in the reduced flows handles, overlapping this fringe on the minimum flows necessary to keep the water quality in accordance with legal requirements. This approach is being evaluated by the environmental protection agency of the Rio Grande do Sul (FEPAM).

The sensitivity analysis of the signal amplification process of signals at significant frequencies was measured by the variation, for the same α , in the value of the ratio (P) between the sum of the power functions of the original series and the equivalent sum of the powers for the significant frequencies (filtered series). The following values of P were tested: 1.0; 0.9; 0.8; 0.7; 0.6; 0.5; 0.4; 0.3; 0.2; 0.1; 0.05 and 0.01. Figure 6 shows the effect of varying P on the filtered series when $\alpha = 0.05$.

The same graph is shown in Figure 7 for a filtering significance of 0.01. It is seen that for equal values of P, the lower α results in a higher value for the flows in the filtered series. This can be interpreted as follows. As α decreases, the number of frequencies eliminated in the filtering process increases. Thus the total variance that must be redistributed amongst a smaller number of significant frequencies is greater, resulting in a greater amplitude, given that the frequency and phase were not modified in the filtering process. In other words, the result agrees with what was expected. The behavior of the mean and standard deviation was shown to be equal for the two significance levels presented.

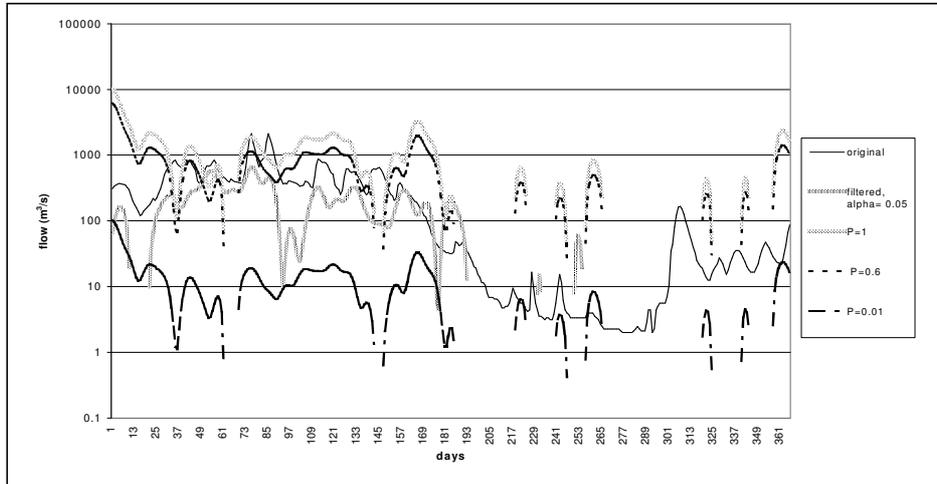


Figure 6 - Effect of the ratio of the sum of the power function in the original series to that of the filtered series (signal amplification), taking $\alpha = 0.05$.

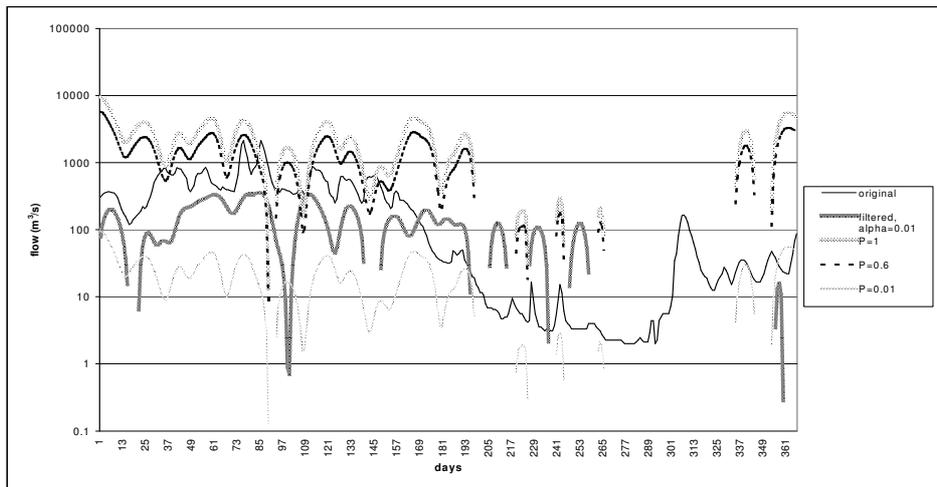


Figure 7 - Effect of the ratio of the sum of the power function in the original series to that of the filtered series (signal amplification), taking $\alpha = 0.01$.

The Figure 8 shows, the mean for $\alpha = 0.05$ stays almost constant as P varies, whilst the standard deviation increases linearly with P.

Figure 9 shows the same pattern for $\alpha = 0.01$. Another important characteristic is that the period is preserved during the process of signal amplification, irrespective of the significance level of the filter used.

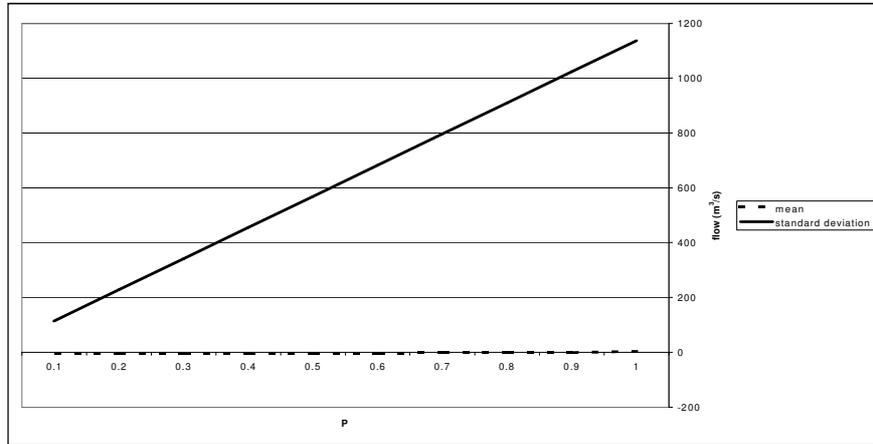


Figure 8 - Effect of the ratio between the sum of the power function of the original and filtered series (signal amplification) on the mean and standard deviation, taking $\alpha = 0.05$.

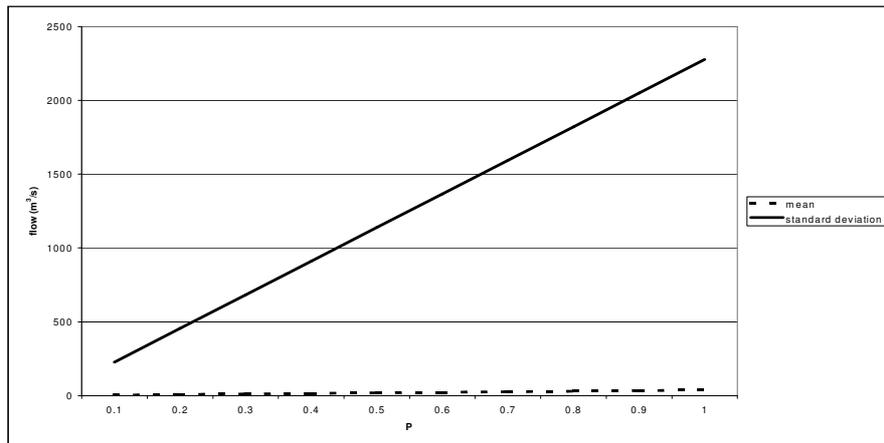


Figure 9 - Effect of the ratio between the sum of the power function of the original and filtered series (signal amplification) on the mean and standard deviation, taking $\alpha = 0.01$.

This homogeneity of behavior in signal amplification with filters of different significance simplifies the procedure for testing the “perception” capacity exhibited by organisms of a riparian ecosystem (one might test the relationship between series filtered with different P and the distribution of functional traits with respect to flood levels, e.g.), since both α and P can be varied without affecting the behavior of means and standard deviations.

Figure 10 shows the decomposition of the flow series into its periodic and random components. It is seen that negative flows, where flows in the original series were close to zero, are compensated by positive symmetric residuals. In parts of the hydrograph where

the filtered series is negative, all the flow in the original series is explained by random fluctuation.

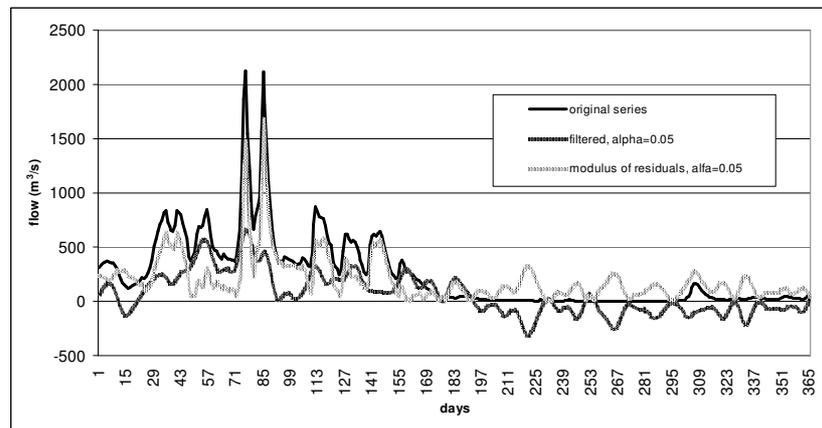


Figure 10 - Decomposition of the series of daily flows at Rosário do Sul, RS, Brazil, into its periodic components (filtered series) and random components (modulus of the residuals), first 365 days, taking $\alpha = 0.05$.

Conclusions

FFTSint is a tool for exploring the partitioning of a time series of daily flows into two series for a given level of significance: the filtered series, which represents the significant periodic components, and a series of residuals, which represents the random components. This analogy can be applied to the paradigms in the theory of ecological systems and can be extended to the analysis of responses by riparian systems. As the two series are associated with different system mechanisms (the periodic series allows information to be incorporated into the system structure, and a high degree of system resistance, whilst the random series is associated with the resilience mechanisms of the system, or its capacity to return to a meta-stable state after strong perturbation), it is expected that this tool will provide a series of tests of the relationship existing between periodicity, resistance and resilience of ecosystems.

The test options, including the possibility of using various levels of significance, allow the user to test the relation between periodic and random components in the pulses and their relation to system properties. Thus for any given system the level of significance can be identified which allows a system to respond in terms of adaptive mechanisms to the periodic components, and in terms of successional mechanisms for the random components.

It also allows a test of whether there is amplified system response. The program allows the user to analyse the amplification for various proportions of total variance in the original series. This is because a system can show various degrees of “perception”, such that its response can be amplified by a factor that is unknown a priori. Also by allowing this proportion to vary, the approach allows analyses to be undertaken which identify the degree of signal amplification being displayed in the system structure.

Some of the possible applications of the proposed filtering approach are the analysis of gradients in flood plains, studies relating to residual or ecological flow, planning of monitoring programs (defining the smallest sampling period), definition of restrictions in reservoir operating rules, and others. Characterization of hydrologic pulses, decomposed into their periodic and random components, can be undertaken, after the treatment here proposed, using packages such as IHA (RICHTER et al., 1996) and PULSO (NEIFF & NEIFF, 2003).

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CRUZ, R. C., PORTO, M. L., SILVEIRA, G. L., CRUZ, J. C., PEREIRA, R. D. FFTSint: um Instrumento para Análise de Recorrência de Pulsos em Análise Espectral de Séries Hidrológicas Diárias. *Rev. Bras. Biom.* São Paulo, v.33, n.4, p.426-444, 2015.

- *RESUMO: Este artigo discute metodologias para descrever flutuações em vazões e cotas de ecossistemas aquáticos. Discute o papel que recorrências significativas devem ter para o processo ter valor adaptativo. Os métodos disponíveis para testar periodicidades são discutidos, assim como as limitações devidas ao pressuposto de reversibilidade das séries temporais, como ocorre nos métodos tradicionais para teste de significância de picos. Como as séries temporais de vazões e cotas de inundação são irreversíveis, é proposto um método alternativo para testar a significância de picos no periodograma, baseado em probabilidades obtidas por geração de séries sintéticas. Dadas estas probabilidades, frequências significativas podem ser identificadas por filtragem e a série original pode ser reconstruída por meio da transformação inversa de Fourier. Neste processo, a proporção da variância total remanescente na série filtrada pode ser ajustada, simulando uma amplificação de sinal. O programa FFTSint é apresentado. Este usa a metodologia para gerar séries hidrológicas filtradas significantes para diferentes níveis de significância (α) e para diferentes níveis de amplificação do sinal. A metodologia foi testada usando uma série de vazões da estação fluviométrica Rosário do Sul, no rio Santa Maria, Rio Grande do Sul, Brasil.*
- *PALAVRAS-CHAVE: FFT; significância de picos; séries sintéticas; adaptação; séries hidrológicas; ecologia de áreas ribeirinhas.*

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