Evaluation of the impact of the creation of Artificial Channels on losses and leaks and suspended sediments in the hydrographic basin

Avaliação do impacto da criação de Canais Artificiais sobre a dinâmica das vazões e sedimentos em suspensão em bacia hidrográfica

Evaluación del impacto de la creación de canales artificiales en la dinámica de flujos y sedimentos suspendidos en una cuenca hidrográfica

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Abstract: Multifunctional derivative channels are small artificial passages built to promote various water services from the abstraction of water from natural courses. As the changes that these derivations promote in the hydrological dynamics of the basins are little known, this paper seeks to evaluate the impact of the derivation systems on the flow rate and sediments through the study of hydrogeomorphological scenarios, correlating the variables verified in field. To better understand these issues, we pursued the monitoring of 12 monthly scenarios for flow rates and suspended sediments from 4 derivations, which were chosen from natural channels in the Upper Course of the Rio Dourados basin (Patrocínio-MG / Brazil) .The results show the interference of artificial channels from the diversion structures to the slopes, where the dynamics of displacement of flows and materials are altered, with the formation of artificial base levels generating sediment deposits in the slopes and affecting the production and direction of water on the hydrographic basin. Thus, it was possible to notice that the multifunctional channels promote changes in the hydrogeomorphological interrelationships (forms / processes) of the impacted hydrographic basins. Thus, the need to consider these structures in the approaches related to planning and management of river basins is suggested.

Keywords: artificial open channels; suspended sediments; hydrogeomorphological interactions; interference in the drainage networks, anthropic side bars.

Resumo: Os canais derivados multifuncionais são pequenos condutos artificiais construídos para viabilização de diversos serviços hídricos, a partir da captação de água de cursos naturais. Como são pouco conhecidas as mudanças que essas derivações promovem na dinâmica hidrológica das bacias, este artigo busca avaliar a repercussão dos sistemas de derivação sobre as vazões e sedimentos, por meio do estudo de cenários hidrogeomorfológicos, correlacionando as variáveis verificadas em campo. Dessa forma, foram escolhidas 4 derivações a partir de canais naturais da bacia do Alto Curso do Rio Dourados (Minas Gerais/Brasil) com monitoramento de 12 cenários mensais para vazão e sedimentos em suspensão. Os resultados apresentam as interferências dos canais artificiais desde os barramentos de derivação até às vertentes onde são alteradas as dinâmicas de deslocamento dos fluxos e materiais, com formações de níveis de base artificiais, gerando depósitos de sedimentos nas vertentes e repercutindo na produção e direcionamento da água da bacia hidrográfica. Logo, foi possível perceber, que os canais multifuncionais promovem mudanças nas inter-relações (formas/processos) hidrogeomorfológicas das bacias hidrográficas impactadas. Assim, é sugerida a necessidade de considerar essas estruturas nas abordagens referentes ao planejamento e gestão de bacias hidrográficas.

Palavras-chave: canais abertos artificiais; sedimentos em suspensão; interações hidrogeomorfológicas; interferências nas redes de drenagens; diques marginais antrópicos.

Resumen: Los canales derivados multifuncionales son pequeños conductos artificiales construidos para hacer factibles varios servicios de agua, desde la captura de agua de cursos naturales. Como los cambios que promueven estas derivaciones en la dinámica hidrológica de las cuencas son poco conocidos, este artículo busca evaluar el impacto de los sistemas de derivación en los flujos y sedimentos, a través del estudio de escenarios hidrogeomorfológicos, correlacionando las variables verificadas en el campo. Por lo tanto, se eligieron 4 derivaciones de canales naturales en el curso superior de la cuenca del río Dourados (Minas Gerais / Brasil) con monitoreo de 12 escenarios mensuales de flujo y sedimentos suspendidos. Los resultados muestran la interferencia de canales artificiales desde las barras colectoras de desvío a las pendientes donde se altera la dinámica del desplazamiento de flujos y materiales, con formaciones de nivel de base artificial, generando depósitos de sedimentos en las pendientes y afectando la producción y dirección del agua. cuenca hidrográfica Por lo tanto, fue posible percibir que los canales multifuncionales promueven cambios en las interrelaciones hidrogeomorfológicas (formas / procesos) de las cuencas impactadas. Por lo tanto, se sugiere la necesidad de considerar estas estructuras en los enfoques relacionados con la planificación y el manejo de las cuencas hidrográficas.

Palabras clave: canales abiertos artificiales; sedimentos suspendidos; interacciones hidrogeomorfológicas; interferencia en las redes de drenaje; diques marginales antrópicos

Introduction

In drainage systems, hydrosedimentary analyzes are valid in addressing the distribution of sediments produced, transported and deposited with the intention of subsidizing analyzes on the functioning and management of these environments. (RICHARDS, 1982; SLAYMAKER, 2003) From this perspective, human interventions that impact drainage systems are also treated and can be evaluated from the responses in the river mouth (DIETRICH; DUNNE, 1978; DIETRICH *et al*, 1987; DUIJSINGS , 1987; PHILLIPS *et al*, 2000).

Among possible types of interventions are hydraulic works (SEAR, 1994; LANDWEHR; RHOADS, 2003; ROSGEN, 2006), which promote notable changes in hydrogeomorphological processes, from the sides (MOSLEY; LARONNE, 1982; WALLING; WEBB, 1996), passing through the valley / slope bottom connectivity (JENCSO *et al,* 2009, MUELLER *et al,* 2007) and reaching the preferred water paths (IMAIZUMI *et al,* 2010).

Multifunctional Derivative Channels (CDM) are striking examples of this reality. These conduits, originating from the first irrigation channels, spread around the world and started to serve various activities such as: human and animal consumption, recreation, agriculture, ornamentation, fish farming, among others, and therefore bear perennial flows (SILVA, 2018).

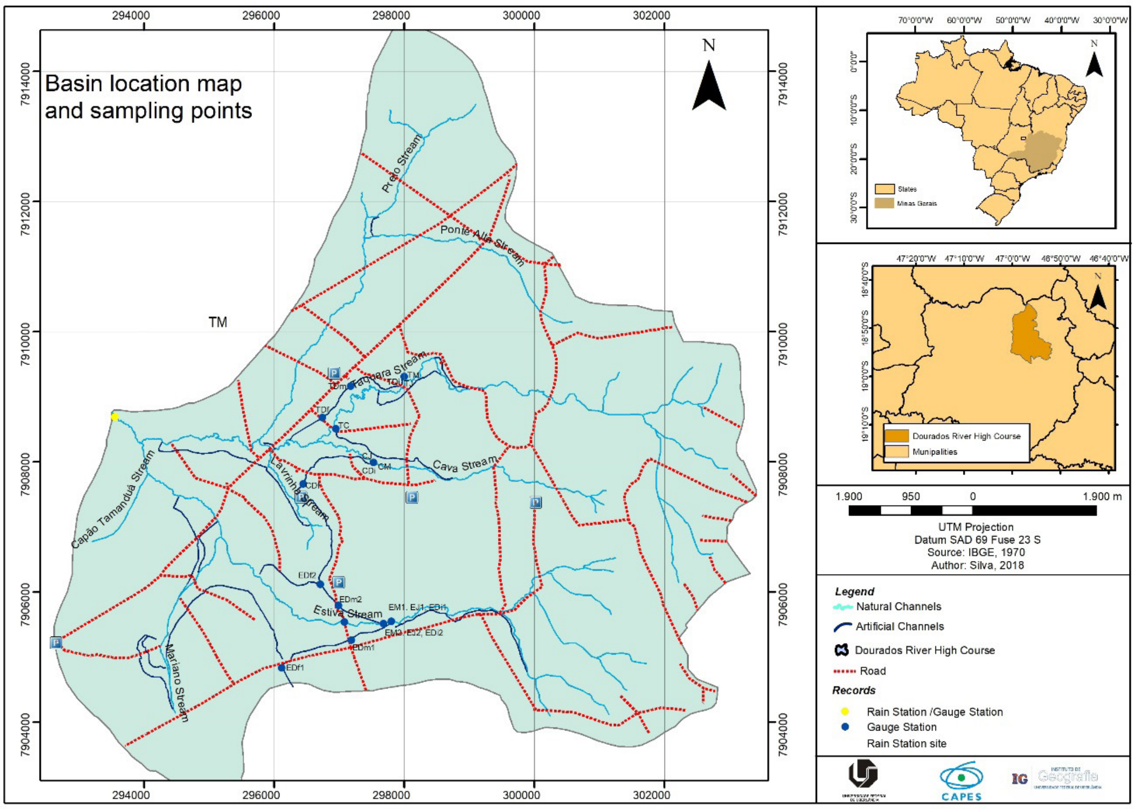
The construction of these small structures produces changes in drainage headwaters, which, however old, common and significant they are, are poorly studied. They can be called Human Topographic Signatures - (ATH) - (TAROLLI and SOFIA, 2016), the derivations are composed of dams, artificial channels and artificial marginal levees. In common, these signatures change the hydrological connectivity, as worked by Croke *et al* (2005) for signatures such as roads and drainage channels.

It is suggested that the derivations systems promote changes in flow rates along the natural channels and trigger the formation of sediment deposits in the slopes. Thus, this study evaluates, through hydrogeomorphological scenarios, the impact of the derivation systems on the discharge and sediment load in a study basin.

Study area

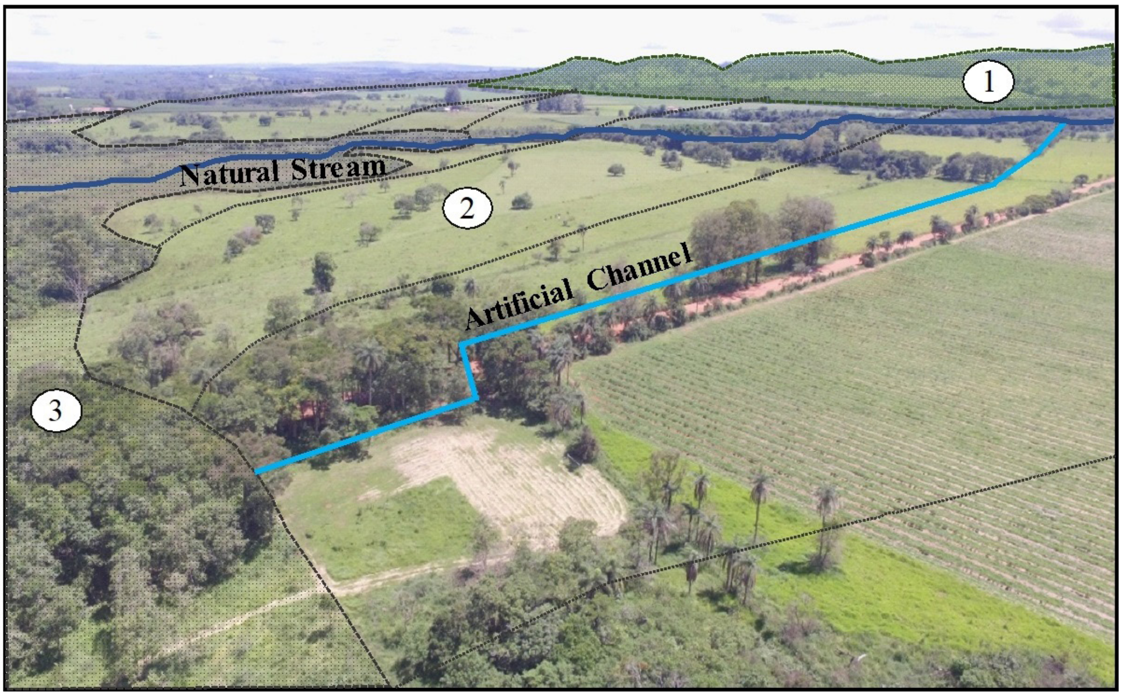
For instrumentation of this research, the hydrographic basin of the upper course of the Dourados River (48 km²) was chosen. This area is marked by the presence of artificial channels interacting with natural streams and anthropic elements (Figure 1). It is also advantageous that this basin was systematically studied (Silva and Allan Silva 2012; Silva, Silva and Assunção, 2013, Veloso e Silva 2013, Silva and Rodrigues 2015, 2016) and monitored by the National Water Agency (**Rain Gauge** e Fluvial Gauge Station at Charqueada Site) and Silva (2018) for land use and land occupation, precipitation, flow rates, environmental changes and othr aspects of hydrogeomorphology.

Figure 1 - Location map and sampling points



The geomorphological context of the area are influenced by intrusion system(CASSETI, 1981), with fluvial terraces that develop between more hilly sectors (quartzite monoclinic ridges), a favorable setting for the development of the natural drainage network, where 8 streams support 16 branches (Figure 2) . This water availability, from the tropical climate with two well-defined seasons, makes it possible to assess the relationships between natural, artificial channels and users (SILVA, 2014). In this sense, the fact that the basin is a mosaic between ancient forms of occupation and the advance of agricultural modernization, contributes to the observation of multifunctional artificial channels, maintained by different technical maintenance efforts, ranging from hoes to excavators.

Figure 2 - Landscape diversity of the study basin. In the image, it is possible to notice the difference between higher sectors in the form of high hills (1), around 1200 meters above sea level, on quartzitic rocks, followed by lower areas in the form of low hills (2), between 1000 and 900 meters, with sandy materials forming river terraces and (3) alluvial plains, below 900 meters.



Throughout the basin, sand are predominant in terrain surface, from weathered sedimentary and metamorphic rocks, inserted on the context of evolution of the landforms at the Serra Negra Dome structure. Therefore, naturally the streams carry these sandy materials, which, in the presence of artificial channels, are redirected to the slopes and also deposited in it.

Materials and procedures

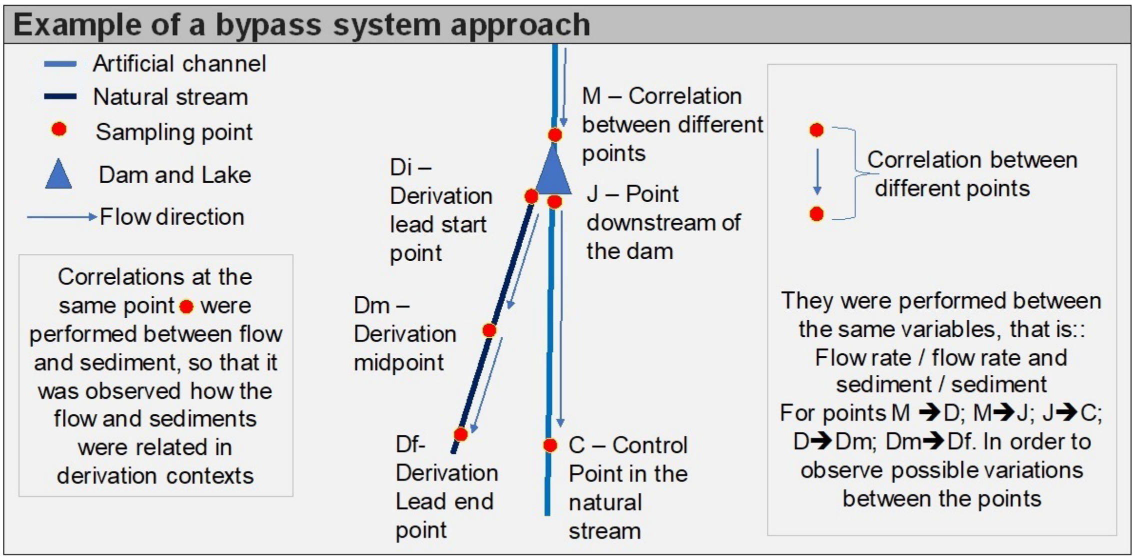
For the study basin, provisional monitoring was applied as Lord *et al* (2009) indicating 12 hydrogeomorphological scenarios of precipitation, flow and sediments in the 2015/2016 hydrological year. The survey of scenarios is advantageous, as seen in Sidle and Onda (2004), Zabaleta *et al* (2007), Ibarra (2012) and Confessor and Rodrigues (2018) because they use provisional instruments and enable analyzes of certain hydrogeomorphological contexts.

Precipitation was monitored with six pluviometers as directed by the Agencia Nacional de Águas (ANA, 2011). Four artificial channels derived from three natural streams were monitored, and Figure 3 reveals the position of the cross sections in which monitoring data was acquired and correlations were promoted. The definition of these channels and their morphologies allow to observe the effects of HTA's, represented by marginal grooves and dikes, present in the dynamics of the slope at the bottom of the valley. The flow was measured according to the methodology of CETESB (2011) with fluviometric micromolinet (Global Water BC 1200 - graduated rod) to obtain speeds, using Equation (1).

(1) $Q = V \times A$

Q being the discharge (m^3 / s), V the speed (m / s) and A the wet section area (m^2).

Figure 3 - Distribution and location of the sample points and indication of the correlations performed. The scheme presents a natural course, which after the insertion of a dam starts to derive part of its flow to an artificial channel. Thus, the points chosen for monitoring show the flow behavior and amount of sediments before and after the dam (in the natural channel) and at the beginning, middle and end points of the artificial channel.



In order to better understand the approach in the channels, it is necessary to consider that before each acronym, presented in Figure 3, a letter will be included that indicates which natural channel is receiving a derivation (Chart 1). Thus, T will be used for the derivation of the Taquara stream, C for the Cava stream and E for the Estiva stream, which has two derivations.

Chart 1 - Example of naming configuration for sampling points in the cross sections applied in this study

Derivation in the Taquara Stream	
TM	Upstream point of the bypass dam in the Taquara stream
TJ	Point downstream of the bypass dam in the Taquara stream
TC	Control point in the Taquara stream
Tdi	Derivation start point in the Taquara stream
TDm	Bypass midpoint in the Taquara stream
TDf	Derivation end point in the Taquara stream

For suspended sediments, samples were collected at the same discharge measurement points, using 1000 ml plastic bottles. Thus, three samplings were performed at each cross section, following the methodology established by Carvalho (2008). In the laboratory, the operational procedures established for the Laboratory of Geomorphology and Soil Erosion (LAGES, IG-UFU) were obeyed, available in Santos and Rodrigues (2019). Thus, the Concentration of Suspended Sediments (CSS) and the Solid Cargo Transported in the section (QSS) were plotted for analysis of each derivation. Linear correlations were also used, with Pearson's coefficient, to perceive the intensity with which indicators were related, given by Equation 2.

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} = \frac{\mathrm{cov}(X,Y)}{\sqrt{\mathrm{var}(X) \cdot \mathrm{var}(Y)}} \quad (2)$$

P = Pearson's coefficient, in which x1, x2..xn and y1, y2..yn are the measured values of both variables to be correlated in order to observe whether the behavior of one is influenced by the other

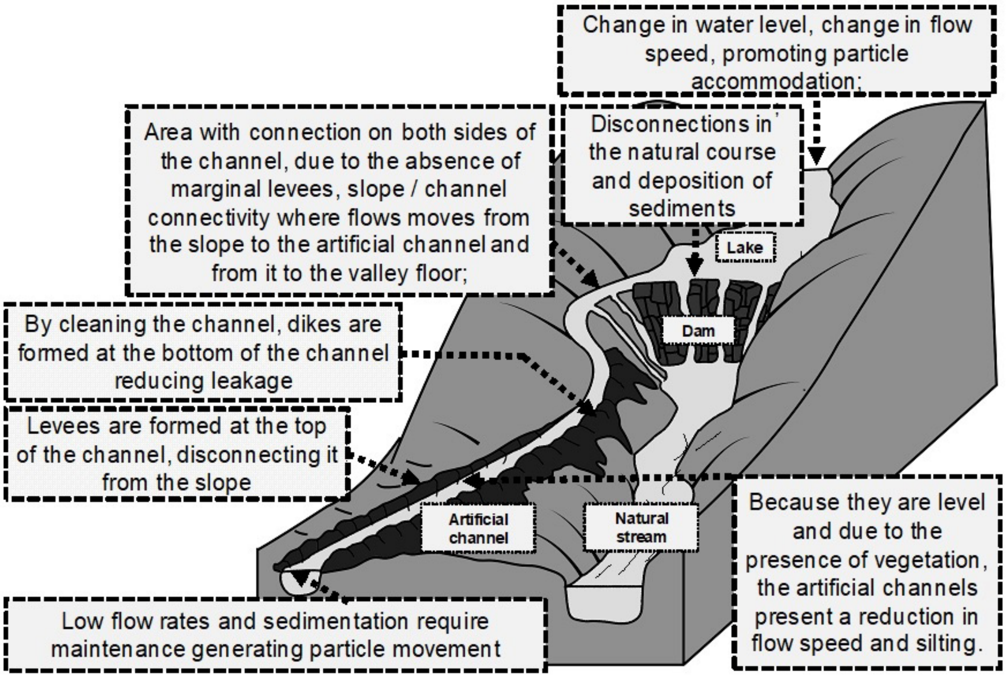
For these correlations, the scale proposed by Milone and Angelini (1995) was used to define the intensity of these relationships. The data obtained allowed to establish flow analysis (between two cross sections), suspended sediments (also between two sections) and flow and sediments (on the same section).

Results and discussions

The derivation system starts from dams built to raise the water level in the channel, which will be partially transposed by the slope through artificial channels. Therefore, many of them are opened directly on the surface with the development of vegetation inside. Thus, the flows in the ducts vary according to the volume of water directed from the natural channel, evaporation, evapotranspiration, leaks, infiltrations and human demanded consumption.

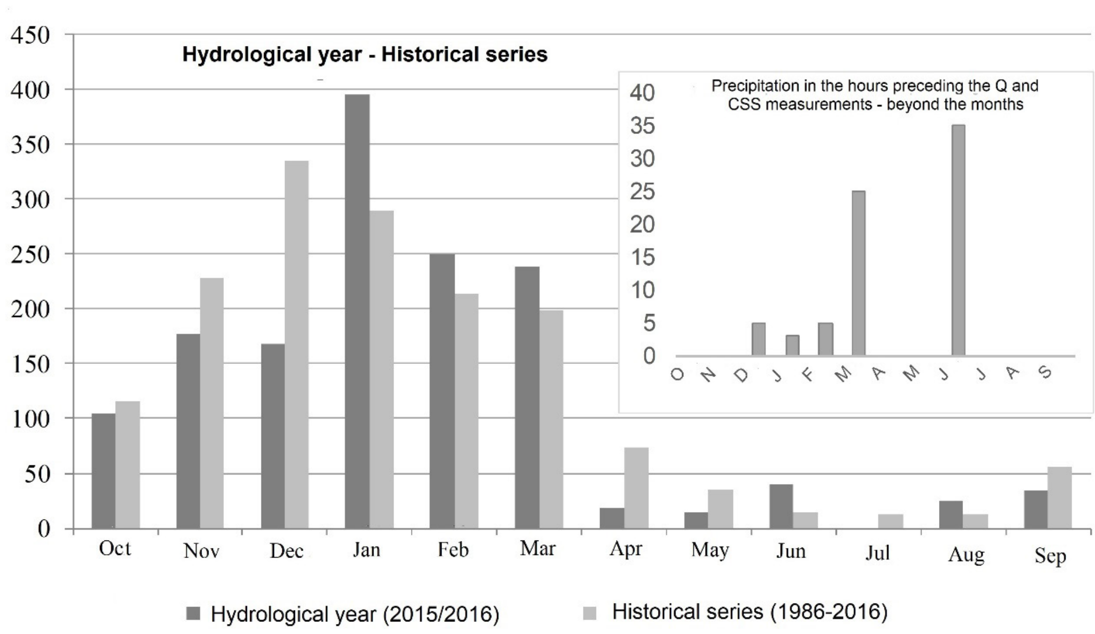
When these channels are obstructed by vegetation and sediments, maintenance takes place with withdrawals and marginal levees are formed. The derivation systems, therefore, play a role in accommodating materials inside de ducts and next to the levees that force the accommodation of materials that were transported on the slopes. As a result, anthropic marginal levees are constructed that hinder the connection between natural slopes and artificial slopes as so as with the channels (Figure 4). Otherwise, when the dykes are absent, the flows on the slopes can connect to the duts.

Figure 4 - Scheme of a derivation and influential structures in the hydrosedimentary dynamics



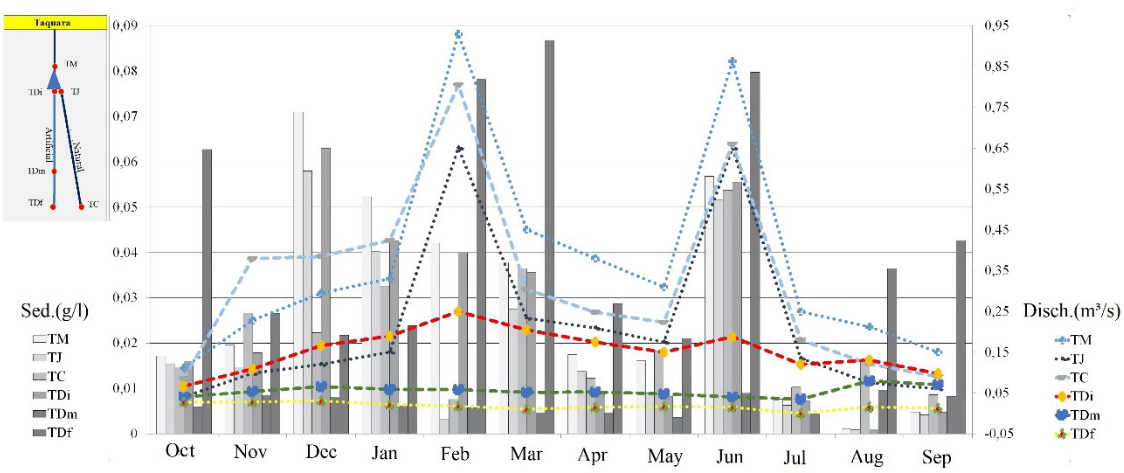
These empirical findings are reinforced and better understood by studying the flows and sediment loads along the basin. To do so, initially, the effect of precipitation is considered (Graph 1) when assessing the behavior of the indicators along the natural and artificial channels.

Graph 1 - Precipitation - hydrological year 2015/2016 and the 24 hours prior to the field collections. Charqueada Rain Gauge Station and field monitoring

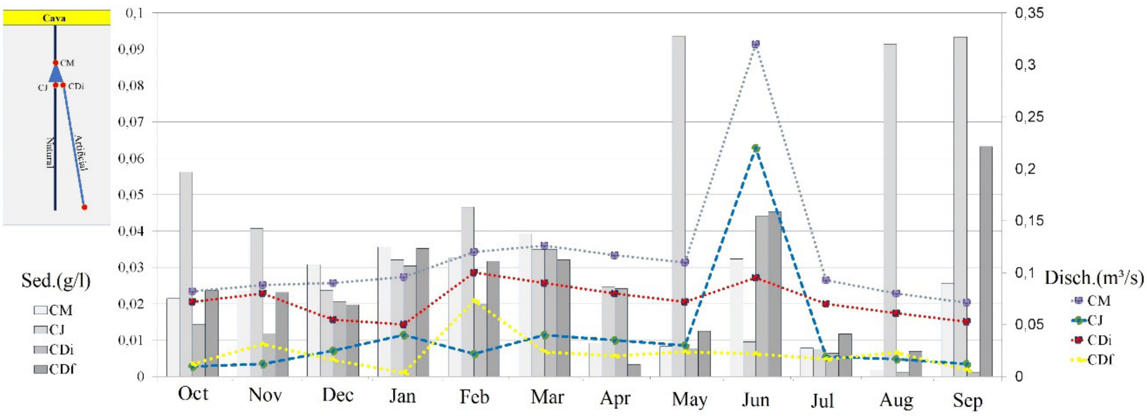


Since the flow and transport of materials are linked to the hydrological dynamics (COOKE and DOORNKAMP, 1975), the Discharge (Q) and the Suspended Sediment Load (CSS) are associated in the monitored episodes and shown in graphs 2 to 5.

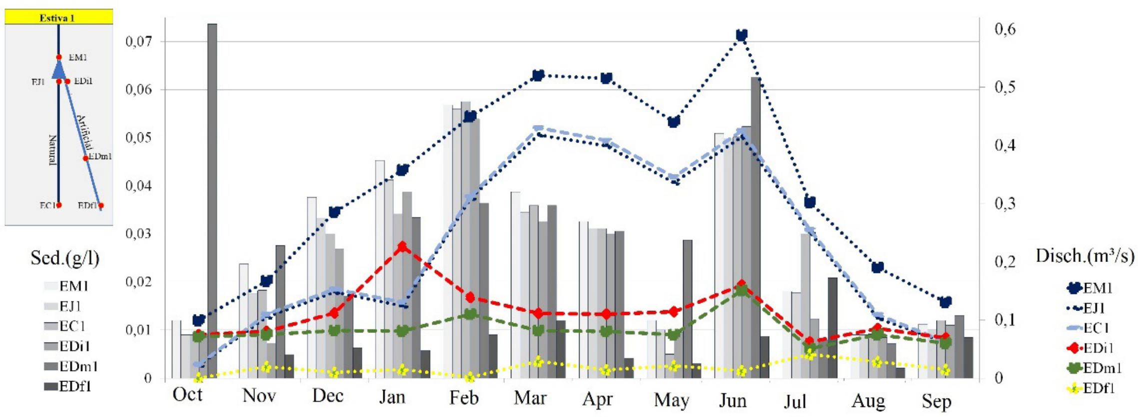
Graph 2 - Taquara Stream - Variation of CSS and Q



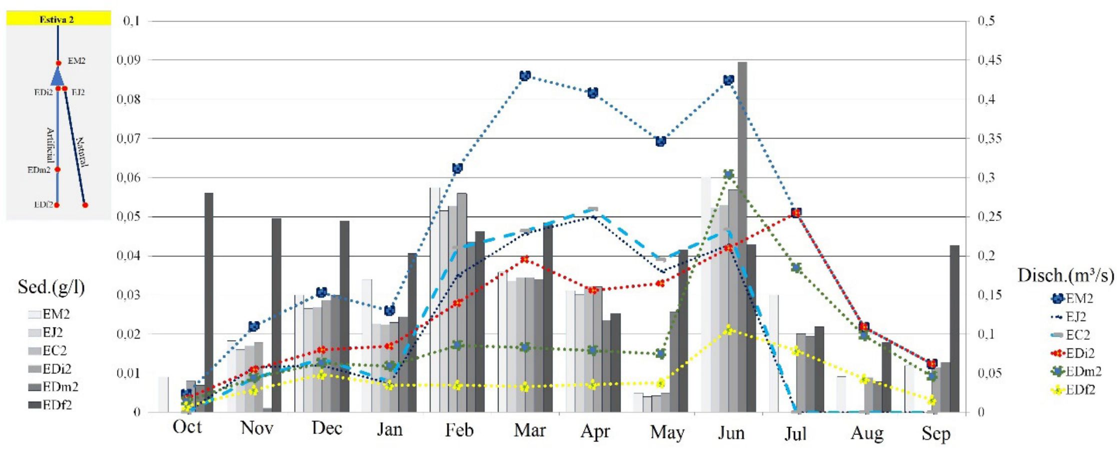
Graph 3 - Cava Stream- Variation of CSS and Q



Graph 4 - Estiva Stream, Derivação 1 - Variation of CSS and Q



Graph 5 - Estiva Stream, Derivation n. 2 - Variation of CSS and Q

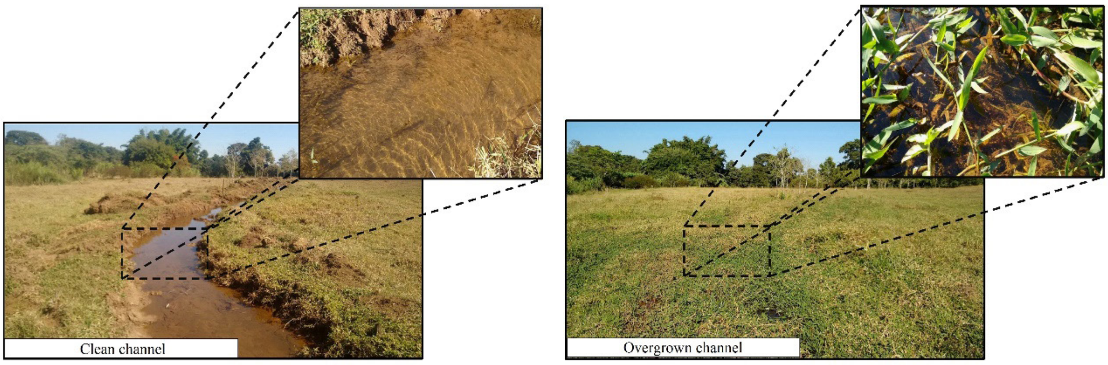


These results show that the highest flow values are contained in the valley floor which, thanks to the already presented connection between the slope and channel (MIRUS 2007; CUNHA *et al* 2013), ends up driving most of the flow (part is retained in the dynamics of derivation) towards the exutory. The discharge variation in the valley floor is also valid for the lower flows, when the users of artificial channels, increases the uptake pressure on the natural courses, precisely in the dry season (from April to September), as observed in Graph 1. In contrast, in the artificial channels discharges vary less, since they are contained by the limited capacity of these conduts (Graphs 2 to 5).

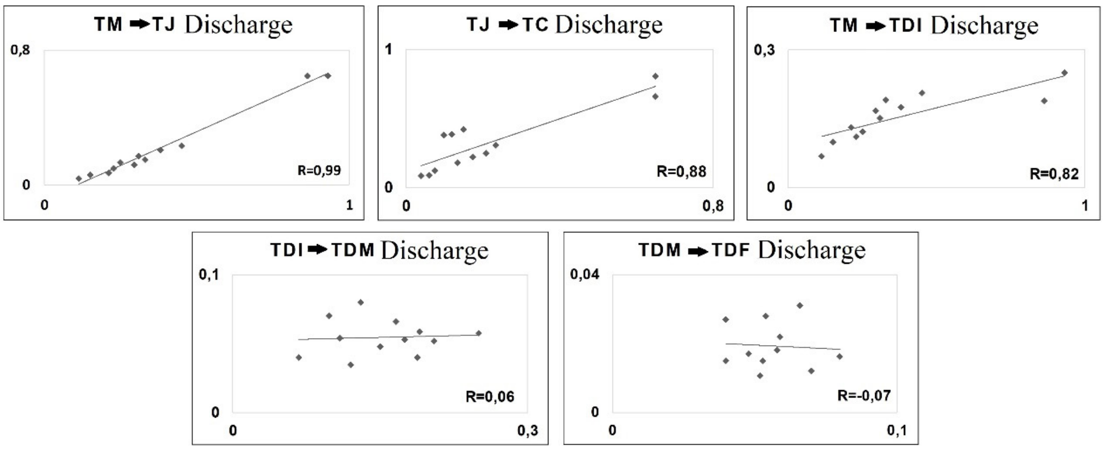
In the scenarios presented, mainly in the natural channels, there are behavioral affinities between flows and sediments. In the artificial channels, the presence of obstacles and the hydraulic configuration itself can contribute to different responses in these indicators. This issue is observed mainly with regard to the behavior of the flow and sedimentary deposition, as seen in other structures in Lawrence and Atkinson (1998), Infante and Segerer (2010) and Gutierrez (2013). Thus, the sediments that tend to varies according to the flow in the natural channels, in the artificial channels, are more subordinated to the low speeds of the flows, the presence of vegetation and the actions of cleaning and removing particles, as seen in the final stretches of the derivations (Figure 5).

To reinforce the considerations about the behaviors in the derived and natural channels, correlations were still made with the same indicators, but at different points (Charts 6 to 9). In these notes the correlations with higher values suggest few changes between two connected cross sections.

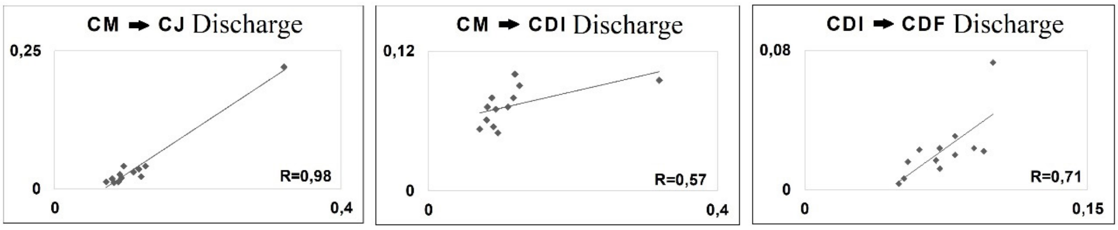
Figure 5 - Artificial channel in two moments: after cleaning and removing the sediments and in vegetated condition with sediments being fixed on the vegetation stems



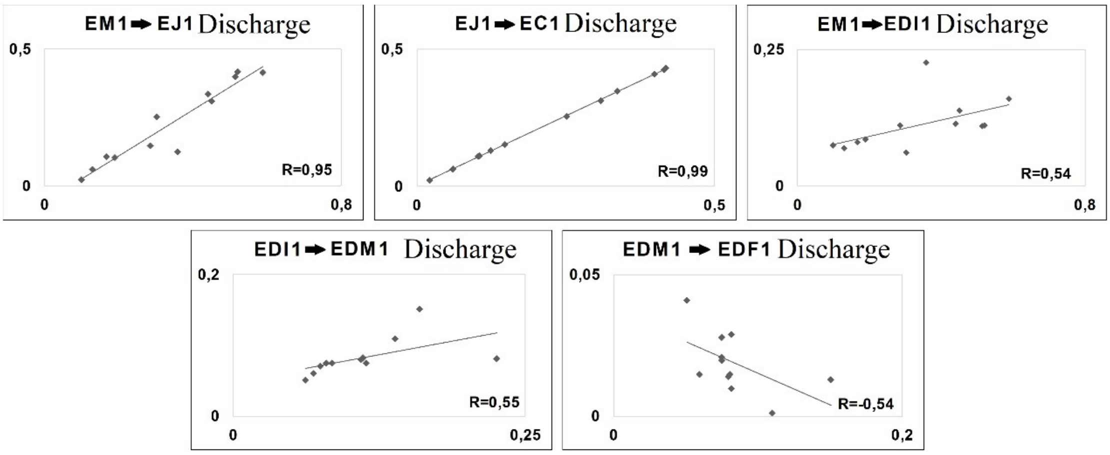
Graph 6 - Correlations of flows between cross sections of the Taquara stream derivation



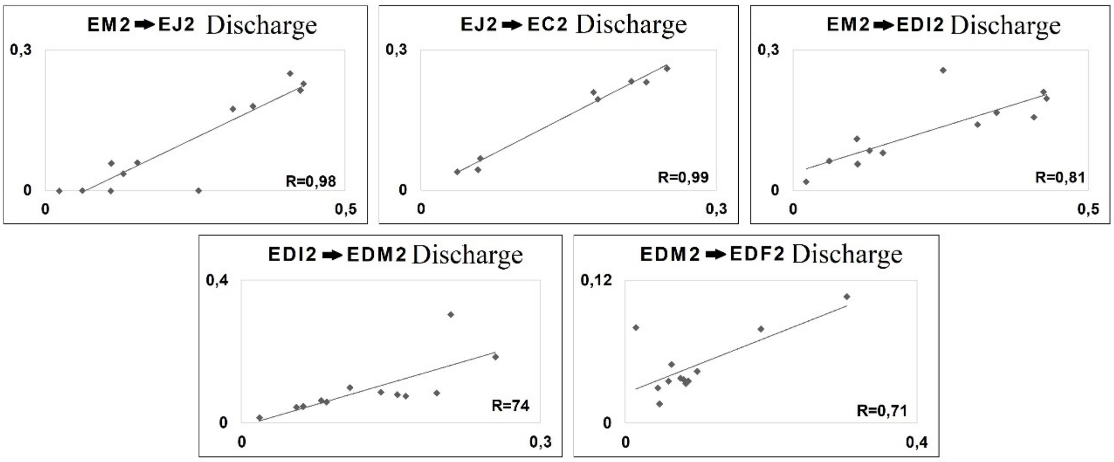
Graph 7 - Correlations of flows between cross sections of the Cava stream derivation



Graph 8 - Correlations of flows between cross sections of derivation 1 of the Estiva stream



Graph 9 - Correlations of flows between cross sections of derivation 2 of the Estiva stream



The correlations, as will be presented below, were shown to be good to excellent in the natural channels and higher in comparison to those observed in the artificial channels, in which negative correlations were also observed.

• Strong positive correlations between the sampling points of the natural channels: in the dynamics of the valley floor, especially in the floods, when the channels accommodate the flows and the discharges have repercussions in the downstream points. These are the cases between points upstream and downstream of the dams (TM and TJ with R = 0.99, CM and CJ with R = 0.98, EM1 and EJ1 with R = 0.95 and EM2 and EJ2 with R = 0, 97), and downstream of the dams with the control points (TJ and TC with R = 0.88, EJ1 and EC1 with R = 0.99 and EJ2 and EC2 with R = 0.99);

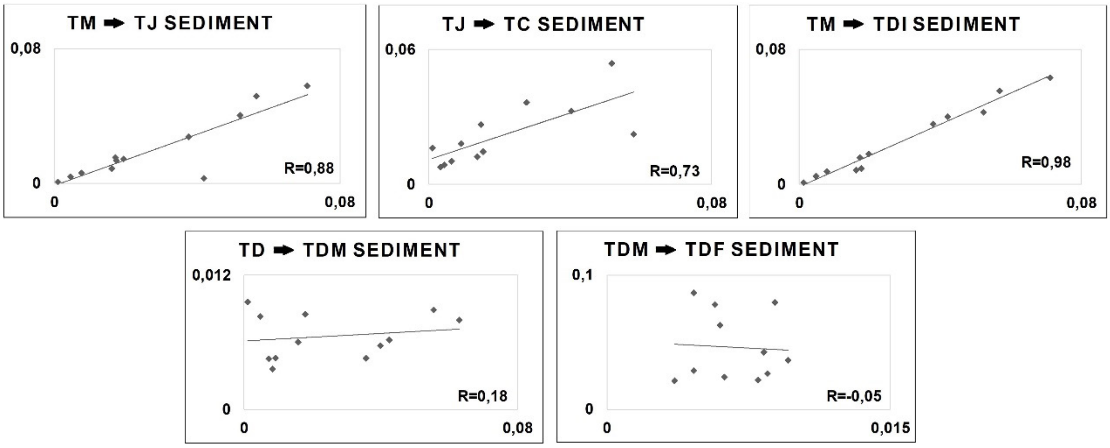
• Positive correlations between the natural channel and the beginning of the derivation: the previous argument is reinforced when CM and CDi are analyzed with R = 0.57, EM1 and EDi1 with R = 0.54. In the rainy season the values in the natural channels continue to rise, while in the derivations they stabilize after the limit of the cross section that overflows by the slope. In the dry season, the flow rates are reduced at the natural channel and efforts of the users try to mitigate this fall in the artificial ones (widening the intake). However, these same efforts created two scenarios with higher correlations in TM and TDi with R = 0.80 and EM2 and EDi2 with R = 0.81. In this case, the channels were so deepened, and the levee were consequently elevated, that their catchment capacity is more tolerable to the increase in the natural flow.

• Positive correlations along the derivations: given the regular shape of the artificial channels, flows are conducted without major oscillations, seen in CDi and CDf (R = 0.71), EDi1 and EDm1 (R = 0.54) EDi2 and EDm2 (R = 0.71). In the segments in question, maintenance, consumption losses, evaporation, evapotranspiration, infiltration and leaks are responsible for changing the flow rates and mitigate the correlations. Among the stretches studied, the greatest example of this process is between TDi and TDm with greater flow variation along the channel and R = 0.06.

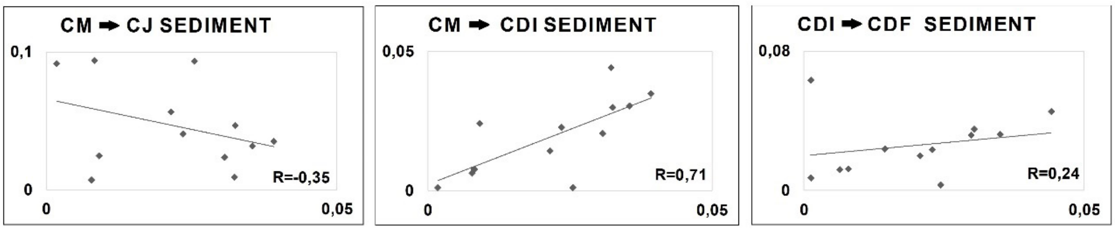
• Cases with negative correlations: TDm and TDf (R = -0.07) show a negative correlation given the flow deviations between points and maintenance activities, so even though the discharge rises in TDm it can decrease in TDf. EDm1 and EDf1 (R = -0.54) occurs in the context of wetlands formed by the leakage of the channel damaged due to domestic animals actions.

These procedures were applied to the Suspended Sediments transported, and the graphs from 10 to 13 presents the results obtained.

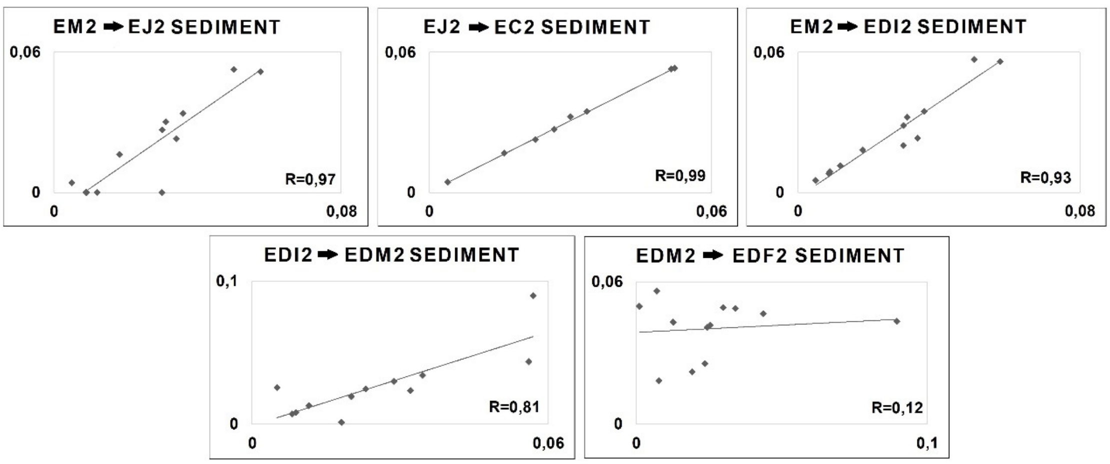
Graphs 10 - Correlations of suspended sediments between cross sections of the Taquara stream derivation



Graph 11 - Correlations of suspended sediments between cross sections of the Cava stream derivation.



Graph 13 - Correlations of suspended sediments between cross sections of derivation 2 of the Estiva stream



For the charts of CSS correlations, the same styles between the strongest correlations in the natural channels as compared to the artificial ones, are observed and discussed below:

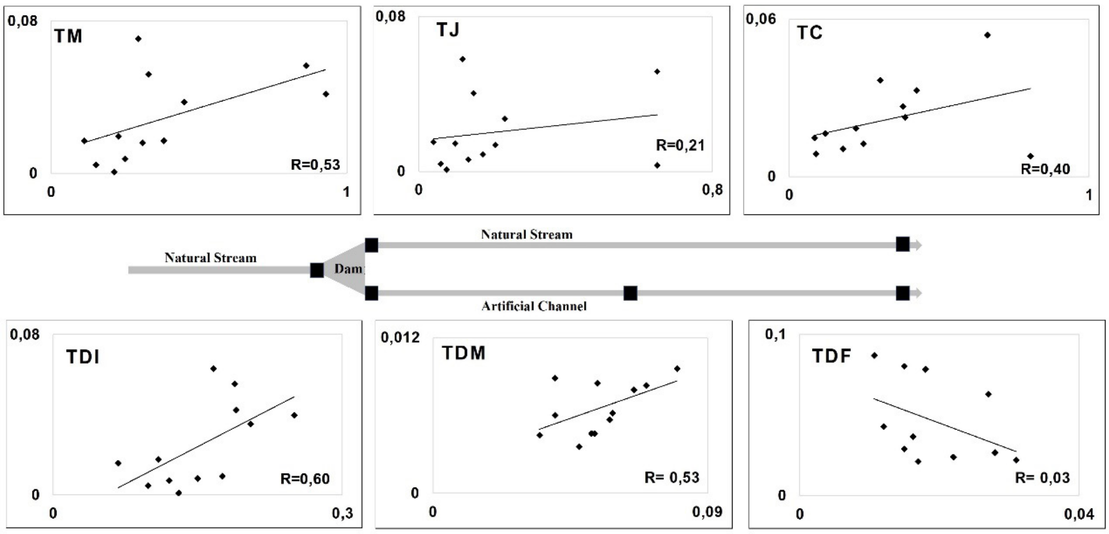
• High positive correlations: were mainly identified at the derivation points that conjugate the natural channel, upstream and downstream of the derivation dam, and the beginning of the artificial channel (TM and TDi with 0.98, TM and TJ with 0.88 , CM and CDi with 0.71, EM1 and EDi1 with 0.95, EM1 and EJ1 with 0.99, EM2 and EDi2 with 0.93 and EM2 and EJ2 with 0.97). These values suggest that the dams have a small capacity to change the sediment load transport.

• Positive correlations found along the artificial channels: The mobility and accommodation of sediments between TDi and TDm (0.18), CDi and CDf (0.24), EDi1 and EDm1 (0.36) and EDm2 and EDF2 (0, 12) vary according to maintenance, growth of vegetation and reduction of flows. The segment entre EDi2 and EDm2 presents a behavior similar to the beginning of diversion (R = 0.81), which suggests less deposition, as the channel is well excavated and with few obstacles facilitating the flow of the sediment;

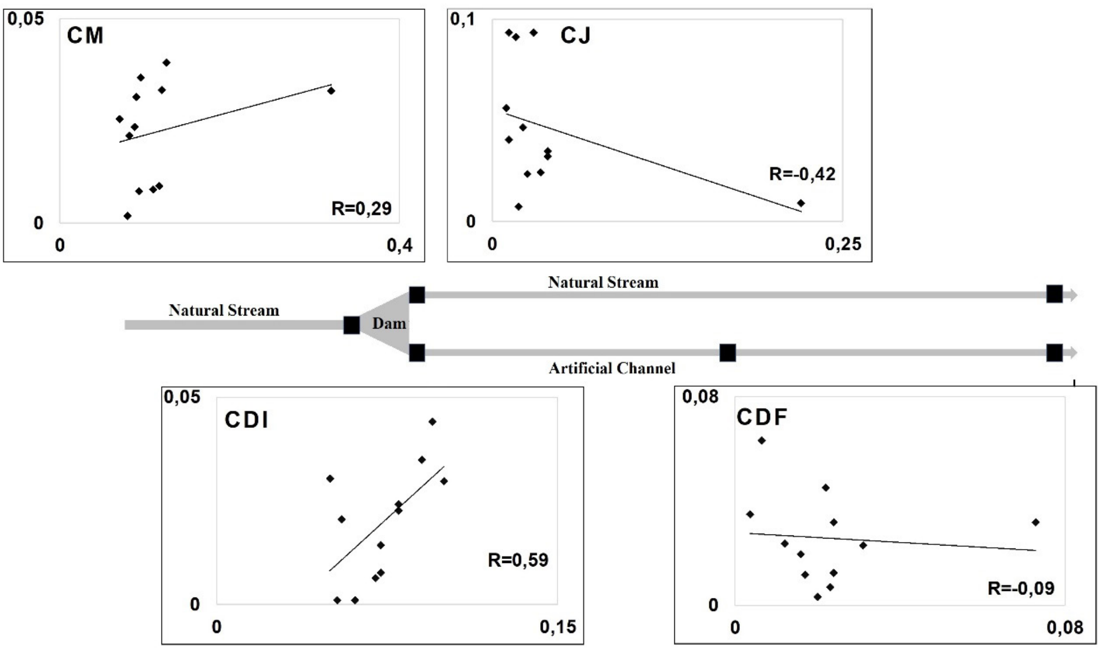
• Negative correlations: occurred in TDm and TDf (-0.05), CM / CJ (-0.35) and EDm1 and EDm1 (-0.10), suggesting that human interventions, such as channel reforms, deviations and interaction with domestic animals, can prevent one point from regularly influencing another.

As the analysis progresses, it appears that both the variations (over time and space) and the correlations of discharges (Q) and the concentration of suspended sediments (CSS) are stronger in the natural channels. In artificial ones, human action trying to prevent them from being obstructed by vegetation and sediments ends up generating more complex and often difficult behaviors to be correlated. There is also the possibility of observing the behavior of these channels by analyzing the correlation between Q and CSS, in the same cross section, in order to observe the influence of channels, dams and other forms in the dynamics of these drainage systems. Charts 14 to 17 are responsible for presenting possible proximity and discrepancies in each cross section for the two indicators. The correlations, which are markedly weaker in this type of conjugation, will be discussed and compared between different cross sections, seeking to identify the smallest, largest and what are the meanings of these indications.

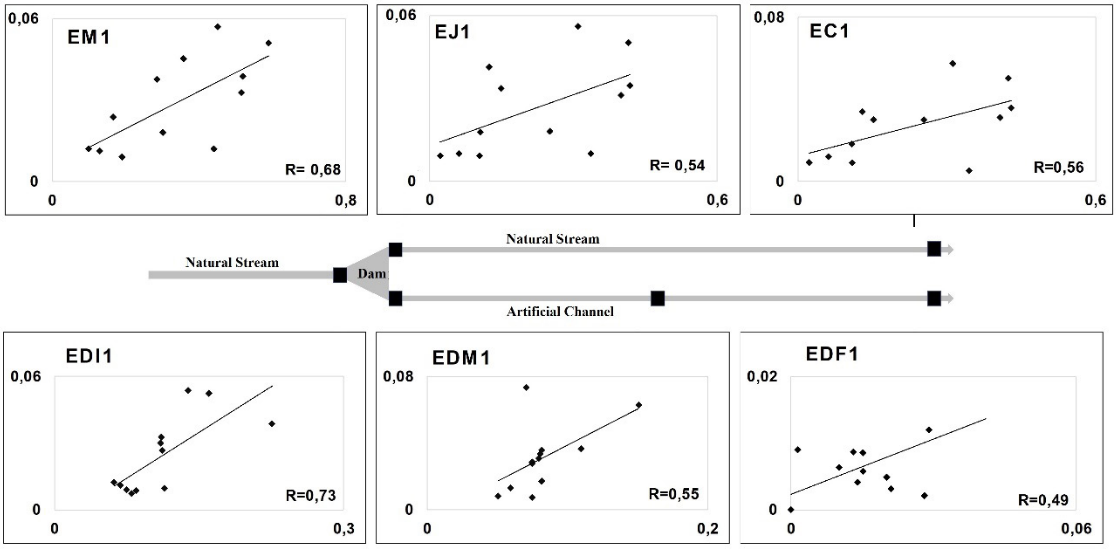
Graph 14 - Taquara Stream - Correlations between CSS and Flow.



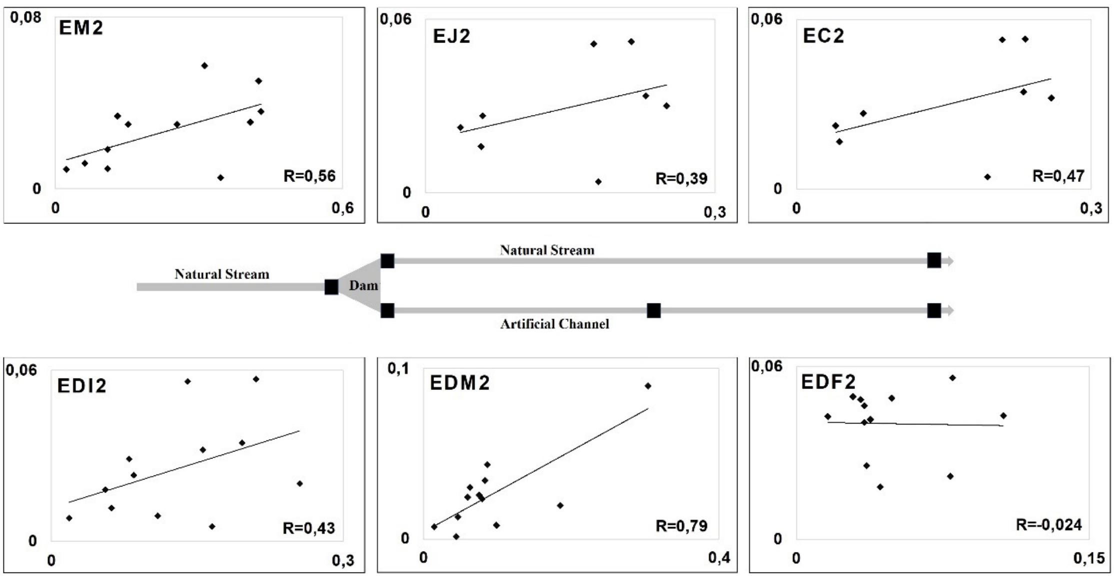
Graph 15 - Cava Stream - Correlations between CSS and Flow.



Graph 16 - Estiva Stream 1 - Correlations between CSS and Flow.



Graph 17 - Estiva Derivation 2– Correlations between CSS and Flow



As seen in the graphs, it is complex to relate flows and sediments, since the studied environments have different profiles of land use and land occupation. Presenting within the statistical approach of Milone and Argelini (1995), weak correlations. As suggested by Imaizumi *et al* (2010), the sediment input is mainly connected to runoff to channel processes. These degrees of connectivity (CROKE and MOCKLER, 2005), are very diverse and permeated by human topographic signatures, such as: roads, ditches, collecting gutters, artificial channels, drains and natural elements such as: interfluve, slopes, valley bottoms, natural channels, vegetation, soil types, among others.

These conditions (different land uses and occupations) were observed in the sectors preceding TM, EM1 and EM2 (Graphs 14, 16 and 17), which present the correlation values of 0.53, 0.68 and 0.52 respectively, although not high , among the largest found. The wooded stretches (in this basin predominant in the spring areas), as suggested by Sidle and Onda (2004), soften these surface displacements, prevailing the hydraulic dynamics in the channel.

The presence of obstacles, such as buses, can produce lower correlations when compared to stretches before buses. This condition as seen in graph 14 with TJ (R = 0.21), Graph 16 in EJ1 (R = 0.54) and in Graph 17 with EJ2 (R = 0.39) where only part of the flow passes with reduced sedimentary charge, diverted or retained in the derivation process. Then, in the control points of the natural channels, the correlations are slightly higher, as in TC (R = 0.40), EC1 (R = 0.56) and EC2 (R = 0.47). For this condition it is possible that, in the natural channel section, the correlations between CSS and Q are strengthened given the dynamics between streams and natural courses.

At point CJ (Graph 15), the values for CSS differ (R = -0.42), from other points downstream, due to the difficulty of purification related to the increase in organic matter (vegetation, especially the invasive Hedychium coronarium) and the drop in discharge, a factor that even compromises water quality and ecosystem viability (SVENDSEN et al, 2009). Therefore, it is considered that the Q and CSS values, downstream of the dams, are closely linked to the potential capture at the beginning of the derivation (as in TJ with R = 0.21). Intake, in turn, is conditioned by the performance of users, who define maintenance against leaks, sedimentation and growth of vegetation, and Q and CSS can can occurs normally

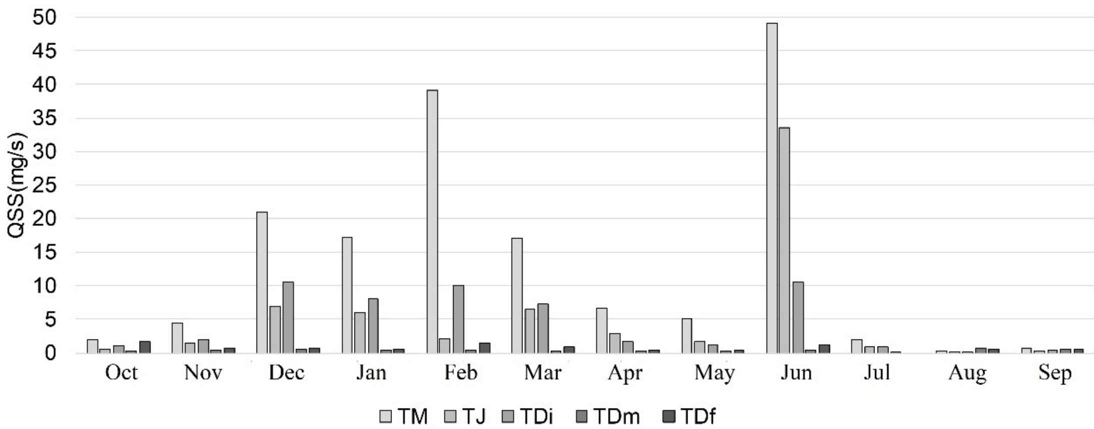
(SILVA, 2018). Thus, for certain derivations, such as TDi (R = 0.60), CDi (R = 0.59) and EDi1 (R = 0.73), they have similar behaviors, still influenced by the dynamics of the natural course, before the dam , and maintaining the profile of cross section.

In the mean derivation points, as seen in graphs 14 and 16, TDm (R = 0.53) and EDm1 (R = 0.55) correlations are observed (compared to the start of the derivations). In open channels, as noted by Greene and Knox (2014), the reduction of transport energy, whether due to the configuration of the channel or vegetation, allows deposition. Therefore, if at the beginning the derivations behaved influenced by the natural channels and their variations, now, at the midpoint, the flows are more stable and siltation prevails. The conditions of the section preceding the point EDm2 (Graph 17), arboreal and shaded, that inhibits the growth of vegetation inside the channel, produced a higher correlation value (R = 0.79), given the ease of sediments displacement in the absence of significant obstacles.

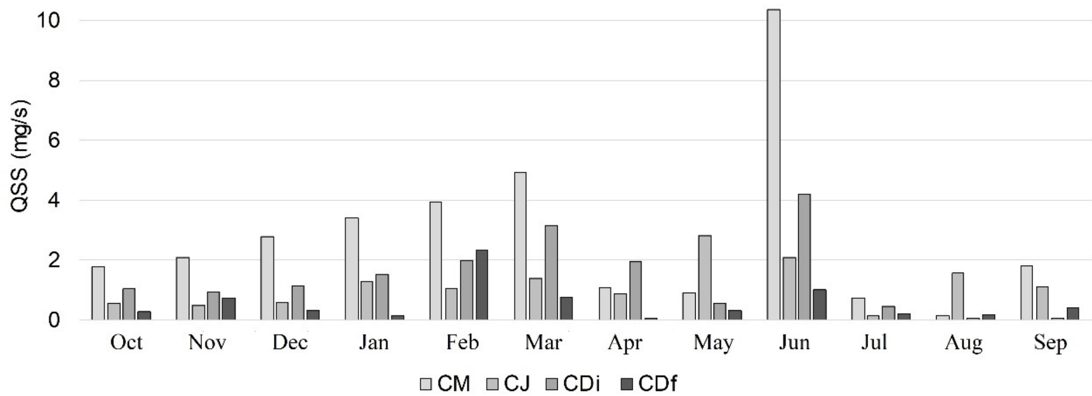
In the final stretches of the derivations with constant maintenance, sediment remobilization occurs, even though the flow rates are low. As a result, the cross sections showed negative correlations, as seen in graph 14 in TDF (R = -0.03), graph 15 in CDF (R = -0.09) and in graph 17 with EDF2 (R = -0, 02). This condition is also observed in larger transposition works, in which sediment removals are constantly necessary to guarantee the flow, as exposed by Hawley *et al* (2013). The cross section EDf1 (Graph 16) is distinguished by the positive correlation (R = 0.49), given the maintenance, in this case the discharge and sediments are reduced. The only exception for EDf1 comes from maintenance in July, an exceptional opportunity to understand the dynamics of cleaning the channels.

The correlations between flow and suspended sediments suggest that the values of these variables change from one point to another, due to reduced flow, accommodation or remobilization of sediments. To better observe these processes, Charts 18 to 21 show the solid transported load (QSS). This approach matters, as stated by López-Tarazón *et al* (2011), since the sediment concentrations can be high even at low flows, an issue seen in some cases in this study.

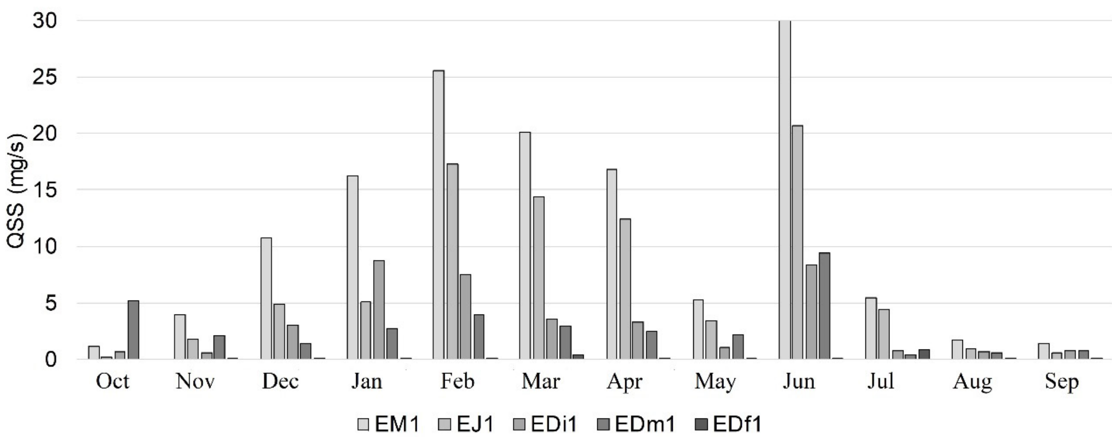
Graph 18 - Transported solid cargo (QSS) - Taquara Stream



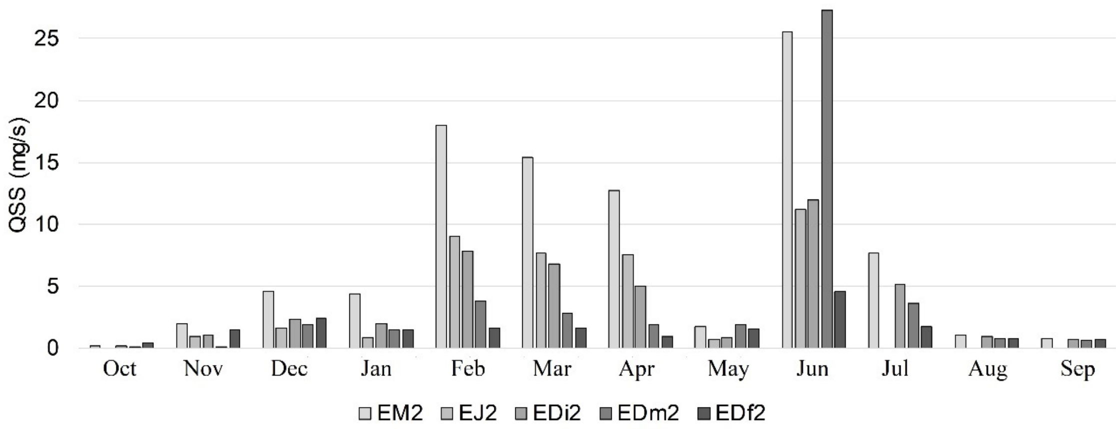
Graph 19 - Transported solid cargo (QSS) - Cava Stream.



Graph 20 - Transported solid cargo (QSS) - Estiva Stream 1



Graph 21 - Transported solid cargo (QSS) - Estiva Stream 2



Following the flow, generally the highest values of QSS are in the natural channels, upstream of the derivations, and then decrease in the dams, divisions and losses in the flows, as well as artificial channels conducive to deposition. The dmas, for example, in addition to dividing the sediment flows and load between two directions, even retain 13% between EM1 and EJ1 and 22% of the sedimentary material between TM and TJ. In the case of the Cava stream, the decomposing organic matter at the CJ point masks the values retained in the dam.

It is also necessary to consider maintenance, when the levels of sediment available for transportation increase in contrast to the reduction in the volume of water in the channel. This indication is seen in the higher values in TDf than TDm, in CDf than CDi and EDf2 on EDm2. As these increases occur even during the drought period, it is seen that they do not refer to the connections with the slopes, but in the interventions within the conduits themselves.

In summary, Table 1 shows the potential for water displacement within the basin and how the transposition implies altering the hydrological dynamics. In the measurement carried out in the dry season, the percentages deviated are high, with a channel having its flow rates suppressed, which reflects in the reduction of the minimum flow rates in the basin's outflow.

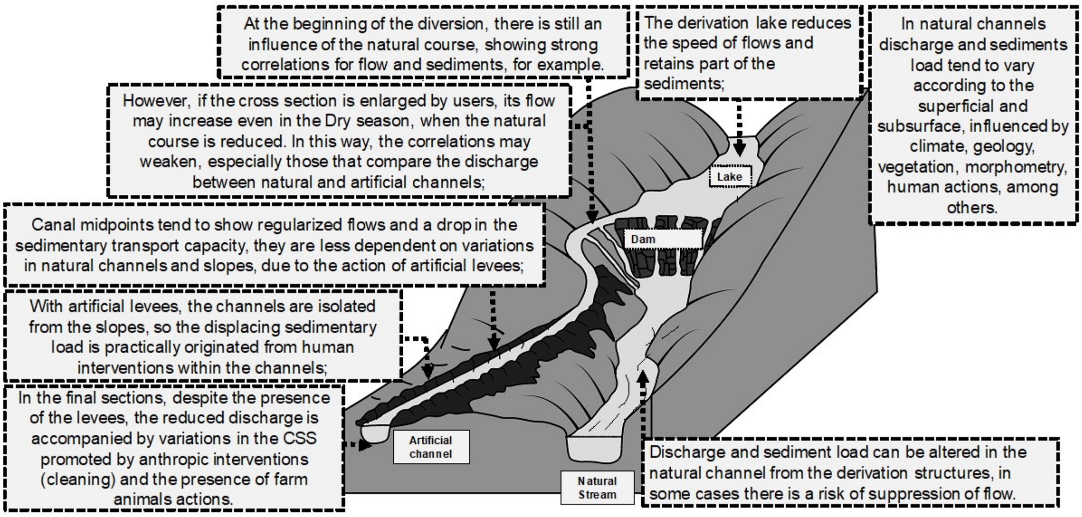
Table 1 - Percentages of water derived from sampling in the rainy and dry seasons (hydrological year 2015/2016)

Derivation	jan/16	sep/2016
Estiva Stream 1	64%	23%
Estiva Stream 2	63%	100%
Cava Stream	58%	79%
Taquara Stream	55%	42%

In this basin, Silva (2014) showed that the predominant occupation profile until the early 1990s was traditional, with agriculture and maintenance of artificial channels using rudimentary techniques and tools (use of hoes, for example). Therefore, the derived channels were smaller, given the rudimentary management techniques, with the return of flows to the natural courses since the anthropic levees were smaller. However, from the insertion of new means of maintenance with machinery (SILVA, 2018), the levees grew, reducing the concentration capacity of this basin, at the same time that maintenance was abandoned in the final stretches of the derivations, slowing the return of flows to natural channels.

Figure 6 summarizes the main factors observed in the derivation systems, showing themselves to be consonant with other research. In Terajima *et al* (1997), for example, studies on drainage heads, related to the removal, transport and sedimentation of materials, are valid to analyze the hydrogeomorphic processes. Dunne (1982), on the other hand, when evaluating dozens of hydrographic basins, attested how the human role in sedimentary and hydrological responses is preponderant, as shown now in the context of these channels..

Figure 6 - Synthesis of the hydrosedimentary behavior of a hydrographic basin with artificial open channels based on the correlations and conditions of land use over a hydrological year



Final remarks

The scenario-based approach allowed to describe the behaviors of the flows and sediments, confirming that the derivations systems promote changes in the flows, with suppressions that can be total, including repercussions on the sedimentary material, along the natural channels. The graphs, of the studied realities, can be translated in the following points:

• While the largest flow variations occur in the natural channels, which hold the volumes directed to them by the configuration of the valley floor, the artificial channels tend to have stabilized flow depending on their shape and the frequency of maintenance;

• In the natural channels the dams and wells (point elements) are responsible for the accommodation of particles, while in the artificial channels it is the vegetation and the low slope that promote the decay of particles in the water column along the entire channel (longitudinal elements);

• Therefore, the dissipation of the energy from the flows is greater in the artificial channels, with deposition prevailing in contrast to the tendency of movement of the particles in the natural channels;

• Hydrosedimentary graphs and correlation studies show the potential of anthropic action in altering hydrological dynamics, and the creation of its own dynamics in artificial channels, as well as in the direction of sediments, especially by redirecting flows and loads to the slopes;

• In the artificial channels, along the slopes, depositions of sediments are promoted, the cleaning of these materials generates marginal levees that impact the displacement of surface waters along the slope towards the valley floor;

• Thus, the changes initially proposed are to redirect the flows, as they generate repercussions both in the forms (slopes and valley bottoms), as well as in the processes linked to them, a testament to the hydrogeomorphological impact that these practices promote.

Therefore, it is necessary to consider that many channels are still being built or altered without taking into account the impacts they produce. The perception of these impacts, evidenced in this study, suggests that environments with artificial open channels need attention to promote understanding of problems, especially with regard to the impacts of the HTA's built for the derivations (such as dams and channels), or resulting from them (marginal dikes, preferential paths promoted by leaks and deposition areas). These efforts to understand the evolution of landscapes, such as those presented in this study, should provide means for the management of these areas.

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Contribution statement

All authors offered substantial scientific and intellectual contributions to the study. The tasks of conception and design of the study, preparation and writing of the manuscript, as well as critical review were developed in a group. The first author Renato Emanuel Silva was especially responsible for the creation and organization of the research, carried out fieldwork, wrote and revised the article. The second author Sílvio Carlos Rodrigues, guided the research, revised and translated the article.

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