UNIVERSIDADE DO ALGARVE

CATCHMENT INFLUENCES ON THE HYDROLOGICAL FLOWS TO LAKE TERRA ALTA (LINHARES, ES, BRAZIL) AND ECOHYDROLOGY PERSPECTIVES

Mónica Gago González

Dissertação

Master of Science in Ecohydrology – ERASMUS MUNDUS

Trabalho efetuado sob a orientação de:
Universidade do Algarve: Manuela Moreira da Silva
Universidade Federal do Espírito Santo: Gilberto Fonseca Barroso

2015

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Mónica Gago

Fdo Mónica Gago.

Agradecimentos

Agradeço ao programa de Mestrado Erasmus Mundus em Ecohidrologia pela oportunidade de viver esta maravilhosa experiência acadêmica e pessoal.

Agradeço as Universidades do Algarve (UAlg) e Federal do Espírito Santo (UFES) pela oportunidade de desarrolhar a minha dissertação nelas, é em especial à UFES onde trabalhe na obtenção e analises de resultados.

Agradeço ao meu orientador Gilberto Fonseca Barroso por ser um grande professional e uma grande pessoa, fonte de inspiração e apoio que com sua gentileza, paciência, confiança e enormes conhecimentos me motivou primeiro a quer trabalhar neste bonito projeto e segundo a superar as dificuldades e duvidas ao longo deste período.

Agradeço a minha orientadora Manuela Moreira da Silva por ser uma grande professora e pela receptividade com o estudo e a sua gentileza, compressão e paciência especialmente na ultima fase de desenvolvimento do estudo.

Agradeço a todo o pessoal do Lablimno em especial a Fellipe, Fabio, Thayana e Felicidade Pelo auxilio e cooperação na pesquisa e a sua boa companhia.

Agradeço aos Ecohyd (4 life), por ter sido uns grandes companheiros de caminho, poder ter apreendido tanto com eles e de eles nestes dois anos sobre tudo ao nível pessoal, fazendo-me parte da suas vidas e culturas compartilhando muitos momentos especiais juntos.

Agradeço aos grandes amigos que fiz neste caminho e foram a minha família em diferentes lugares do mundo. A Marie e a Nicolai por estar do meu lado em tudo momento, em qualquer lugar do mundo, sendo meus melhores amigos, confidentes e companheiros de viagem literal e emocionalmente. Em Portugal ao meu irmão Arsalan, Katheryna, Amrit, Stavros, Clement, Fabian, pelos tantos momentos de lazer e as risadas compartilhadas. Em Brasil ao Henrique, por fazer-me parte da sua vida e compartilhar sua família e amigos e ter vivido muitos dos momentos e experiências mais inesquecíveis da minha vida junto a ele. A Carol, Leandro e Pedro pela companhia e os bons momentos sempre acompanhados de muita boa musica.

Agradeço a meus e amigos de sempre, por fazer-me querer voltar sempre e brincar como não consegui com ninguém, e a Elvira e Adri que além disso compartilhamos tantas passões e interesses.

Agradeço a meus irmãos e toda minha família pelo apoio e carinho a pesar da distancia, fazendo-me as melhores boas-vindas do mundo.

E agradeço em especial a meus pais, por serem as pessoas mais importantes da minha vida, meu maior apoio, incentivo e inspiração, os que sempre me acompanham, compreendem e ajudam tanto nos momentos de felicidade como de aflição.

Abstract

Lake Terra Alta (LTA) (A= 3.9 km^2; Z_{max}= 22.1.m) is a tropical natural lake located in the State of Espírito Santo (Southeast Brazil) being one of the 90 lakes which form the Lake District of Lower Doce Rover Valley (LDRV). LTA catchment area is 144.7 km^2 and is composed by 8 subbasins and 7 tributaries streams. Its predominant land use is pasturage and smaller dimension cropping and *Eucalyptus* forestry, with no urban areas or industrial activities.

Catchments morphometry and land uses and land cover have implications on the catchments hydromorphological processes, thus influencing hydrological flows to downstream lake. Therefore, hydrological knowledge is necessary to subsidize basin management plans. LTA is under pressure of direct water withdraw for irrigation, as well as water withdraws from the tributary rivers and fluvial damming. Nutrient inputs from catchment natural loads and anthropogenic activities (i.e., agriculture, livestock, forestry). Those pressures may compromise lake ecosystem services that are provided by water quantity and quality. In this regard, an echohydrological approach provide a more concise support for Integrated Lake Basin Management (ILBM), considering the relationships of lake catchment, stakeholders and governance systems.

The main goal of this study is to evaluate the hydrological flows to LTA under an ecohydrological approach, integrating catchment morphometry, hydrography, hydrology, and land use and land cover. Based on a georeferenced database, river discharge measurements and modeling, and hydrochemistry analysis of the tributary streams, loads of nutrients are obtained. Subbasins data are analyzed through multivariate statistical analysis (i.e., PCA) in relation to mentioned catchments features.
The obtained results provide sound information of the influence and relationships of land use and morphometry on the different subbasins. Thus, providing valuable information for the sustainable management of the basin and propose ecohydrologycal responses for inflow nutrient abatement and improve freshwater inputs to lake ecosystem to ensure ecosystem services provided by LTA.

Key words: Morphometry, Land use, Hydrological flows, Integrated Lake Basin Management, Ecohydrology, Ecosystem Services.

Resumo

A Lagoa Terra Alta (LTA) (A= 3.9 km^2; Z_{max}= 22.1.m) e uma lagoa tropical natural localizada no Estado de Espírito Santo (Brasil) sendo uma das 90 lagoas que formam o distrito de Lagoas do Vale do Baixo Rio Doce (LVRD). A área da bacia da LTA e 144.7 km^2 sendo composta por 8 sub-bacias e 7 cursos de água tributários. O uso do solo predominante é o pasto e numa dimensão menor a agricultura e a silvicultura de *Eucalyptus*. Não tem área urbana nem atividade industrial.

A morfometria e usos do solo nas sub-bacias têm implicações nos processos hidrológicos na bacia, influindo os fluxos hidrológicos das lagoas rio abaixo. Por isso o conhecimento hidrológico e necessário para a gestão. LTA tem pressão direita da extração da agua para rega, também na extração nos cursos da água tributários, na construção de barragens e na introdução de nutrientes por fluxos naturais e antropogênicos (agricultura, gado, silvicultura). Essas pressões podem pôr em risco os serviços do ecossistema fornecidos pela qualidade e pela quantidade da água. Em relação, à Eco-hidrología, fornece um apoio mais conciso para a Gestão Integrada da Bacia da Lagoa (ILBM), considerando as relações na bacia da lagoa, as partes interessadas e os sistemas de governança.

O principal objetivo deste trabalho é estudar os fluxos hidrográficos da LTA numa abordagem eco-hidrológica, integrando a morfometria, a hidrografia, a hidrologia e usos do solo. Baseado numa base de dados georreferençados, a vazão medida e modelada dos cursos da água, a analise hidroquímica dos mesmos, os fluxos hidrológicos são estimados. Cada sub-bacia é estudada com estatística multivariada (PCA) em relação às características hidrográficas mencionadas.

Os resultados obtidos fornecem boa informação das influências e relacionamento do uso do solo e a morfologia com as sub-bacias. Assim, fornece informações valiosas para a gestão sustentável da bacia e propor atuações para garantir os serviços do ecossistema fornecidos pela LTA.

Palavras-chave: Morfometria, Uso da terra, Fluxos hidrológicos, Gestão Integrada das Lagoas, Eco-hidrologia, Serviços do ecossistema.

List of abbreviations

A = Watershed area (km2)

a = Cell area (m2)

Au = Basin area

d: cell size (m)

Dd = Drainage density

DE = Difference in elevation

Fs = Stream frequency

If = Infiltration number

L = Length of the flow path

Lb = Watershed length (m) (Farthest distance from watershed ridge to outlet)

Lg = Length of overland flow

Lu − 1 = Total stream length of preceding stream order

Lu = Stream length

N = Number of watershed cells

Np = Number of watershed edge cells

Nu = Number of stream segments

P = Watershed perimeter (km)

Rb = Bifurcation ratio

Rc = Circularity ratio

Re = Elongation ratio

Rf = Form factor

RL = Stream length ratio

S = Slope

π = 3.14

MAMe Q = Mean Annual Measured Discharge (m^3/s)

MDMe Q = Mean Dry Season Measured Discharge (m^3/s)

MWMe Q = Mean Wet Season Measured Discharge (m^3/s)

MAMe Ef Q = Mean Annual Measured Effective Discharge ($m^3/km^2/y$)

MDMe Ef Q = Mean Dry Month Measured Effective Discharge ($m^3/km^2/Aug$)

MWMe Ef Q = Mean Wet Month Measured Effective Discharge ($m^3/Km^2/Nov$)

AMP = Annual mean precipitation(mm)

DP = Driest month precipitation(mm)

WP = Wettest month precipitation(mm)
MAMoQ =Mean Annual Modelled Discharge (m^3/s)
MDMoQ = Mean Dry Season Modelled Discharge (m^3/s)
MWMoQ = Mean Wet Season Modelled Discharge (m^3/s)
MAMoEfQ = Mean Annual Modelled Effective Discharge (m^3/s)
MDMoEfQ = Mean Dry Month Modelled Effective Discharge (m^3/s)
MWM EfQ = Mean Wet Month Modelled Effective Discharge (m^3/s)
MATN = Mean annual Total Nitrogen (μg.L^{-1})
MDTN = Mean Total Nitrogen of the dry month (μg.L^{-1})
MWTN = Mean Total Nitrogen of the wet month (μg.L^{-1})
MATP = Mean annual Total Phosphorous (μg.L^{-1})
MDTP = Mean Total Phosphorous of the dry month (μg.L^{-1})
MWTP = Mean Total Phosphorous of the wet month (μg.L^{-1})
MAETN =Mean Annual Effective Discharge of TN (Kg/km^2/y)
MDETN = Mean Dry Month Effective Discharge of TN (Kg/km^2/y)
MWETN = Mean Wet Month Modelled Effective Discharge of TN (Kg/km^2/y)
MAETP = Mean Annual Effective Discharge of TP(Kg/km^2/y)
MDETP = Mean Dry Month Effective Discharge of TP (Kg/km^2/month)
MWETP = Mean Wet Month Effective Discharge of TP (Kg/km^2/month)

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1. Introduction

In a broad sense, lakes consists essentially of an inland basin or several connected basins containing water (Bragg et al., 2005), which are considered as standing water systems. However, lake basins fed by tributary river flows may show a complex combination of lentic and lotic waters that, in some degree, control the lacustrine hydrodynamics (Ambrosetti et al. 2003), existing then multiple lake hydrological types in function of their physico - chemical characteristics and their relationships with the catchment (Cardille et al., 2004).

Lakes are critical elements of the water cycle and represents the 90 % of liquid freshwater of earth´s surface providing several environmental and socio-economic benefits (ILEC, 2005). This contributions to human well-being that the ecosystems ecosystem structure and function, in combination with other inputs, provide directly or indirectly to people are known as Ecosystem Services (MEA, 2005 ; Burkhard et al., 2012) and lakes as important freshwater bodies furnish a host of services to humanity without ever leaving its natural channel or the aquatic system of which it is a part (Poste and Carpenter, 1997). The analysis of the ecosystem services is important to understand human-environmental systems by the linkages between the natural and the humans systems (Burkhard et al., 2010).

The freshwater services can be divided in broad categories as supply of water for direct use, supply of goods other than water and nonextractive benefits (Poste and Carpenter 1997). Nevertheless a more appropriated classification such as the provided by the Millennium Ecosystem Assessment (MEA, 2005a) refers to provisioning, regulating, provisioning and cultural services. As a broad example, in lakes we can recognize the provisioning services for consumptive use as drinking, domestic and industrial water uses, agriculture, source of aquatic organisms for food as fish, and nonconsumptive uses as transportation or navigation. As cultural services can be find the uses related with recreation and tourism as well as religious meaning and/or personal values as heritage, and the sense of place. The regulatory services are those related with the buffer capacity to maintain the water quality by self-purification capacity or buffer the water flows and its interaction with the land as flood drought mitigation or erosion control. Supporting

services play a key role in nutrient cycling, primary production and food webs (MEA, 2005a).
As the high range of ecosystem services provided encourage the population to enjoy this resources sometimes the excessive use or the bad practices interfere with the ecological integrity of the resource, on this case the water, which means that this ecosystem is not able to provide ecosystem services because is very impacted. Then, the quantification of water and nutrient flows along all the pathways of the hydrological cycle is necessary for the design and selection of effective management strategies required for the aquatic ecosystems integrity and their associated ecosystem services (Jolánkai and Biro 2008).

Lake basin hydromorphology is constituted by morphological features such as area, depth and volume, as well as structure of bottom substrate, and littoral zone (Bragg et al., 2005). In addition, hydrological regime based on the concept of fundamental hydrologic landscape units provides a concise view of a complete hydrologic system consisting of surface runoff, groundwater flow, and the air-water connectivity (Winter, 2001). Thus, the understanding of lake basin morphometry and catchment flows is crucial to the knowledge for lake management in terms water level and volume.

According to Zavoianu (1985) the surface of a drainage basin is the result of a long term process of interaction between flows of matter and energy and the variables which defines the basin behavior towards these flows. And the main elements which characterize a basin are rock type, relief, soil, plant cover and climate. The rock is very important being a support for the other elements and forming the morphometrical features, relief controls the inputs of matter and energy, soil governs the circulation of water by its hydrophysical properties which are decisive for processes of runoff and infiltration and last but not least, vegetation which have a close interdependence with soil have big influence on climatic conditions and hydrological processes. Then the study of those variables is crucial for the understanding of the processes that drives the hydrological flows.

Authors such as Håkanson (2014) and Nõges (2009) highlight that morphometry, which depends on the origin of the lake, drainage basin characteristics and the nature of the surrounding areas, has a key role on lake water quality and ecosystem functional features.

Morphometry of a catchment influence the processes which controls river flows and it main characteristics even determining their flood potential (Withanage et al.,2014). The morphometry can be defined as the measurement and analysis of the configuration of the earth´s surface, shape and landform dimension (Pareta 2011, Withanage et al.,2014). In order to describe the surface drainage networks evolution and behavior many authors as Horton (1945), Strahler (1964), Miller (1953) or Zavoianu (1985) have focused their studies on basin morphology.

For an appropriate morphometry analysis of a basin and estimate the potential of flow intensity and surface runoff of the drainage system is necessary consider areal and linear aspects of the drainage basin and slope. To describe the linear aspects of the drainage network the parameters that should be consider are stream order, stream length, stream number, and bifurcation ratios . On the other hand, the parameters that describe areal aspects of the drainage basin are the basin area, basin perimeter, stream frequency, length of overland flow, drainage density, infiltration number and shape related parameters as the circularity ratio, elongation ratio and form factor (Horton, 1945; Melton, 1957; Miller, 1953; Schumm, 1956; Carlston, 1963; Strahler, 1964; Zavoianu 1985; Romshoo et al., 2012; Magesh et al., 2013).

Nevertheless the water flows may be strongly altered by the interferences on the water cycle due to natural or anthropogenic processes. The vegetation cover is a key factor altering the water flows because of its interrelation with the soil. The presence of forest is decisive factor to reduce peaks of water discharge because of the capacity of the vegetation cover, between other processes, to intercept the rainfall, increase the water infiltration and transpiration, which results on a decrease of the speed and strength at which the water gets to the river, decreasing erosion and reducing the river discharge (Zhou et al., 2010; Birkinshaw et al 2011; Iroumé and Palacios, 2013).

At the same time exposed soils become more vulnerable to erosion increasing runoff , favoring the soil degradation becoming more compacted, impervious and in consequence decreasing the infiltration capacity, generating high runoff and discharge peaks but being unable to maintain a base flow (Konrad & Booth, 2005). Then, the deforestation processes related with changes on land use affects strongly hydrological flows, because more rainfall reach the streams, which increase the discharge, being the agriculture and pasture principal causes of deforestation due to their need of space for their development (Carvalho et al., 2000). When the deforested areas are associated to pasture lands and the presence of cattle, the soil suffers and increased compaction due to the animals weight and lose its infiltration capacity, presenting high runoff and decrease of river discharge on dry periods (Sheatch, and Carlson, 1998). Regarding agriculture practices, water withdraw for irrigation considerably decrease water discharges. However, irrigation itself, the presence of heavy equipment, organic matter losses due to intensification, are some factors related with this land use that promote the degradation and increase runoff and reduce base flows (Vlek et al., 2008). The slope is a parameter that favors erosion processes due to rapid runoff if its values are high (Magesh *et al.,* 2013), then, if those land uses that affect the water cycles by itself are on areas of pronounced slope, the negative impacts are increased.

Other factor that influences the hydrological flows is the construction of dams. In order to provide a water supply for agriculture and pasture, activities that require high quantities of this resource, is necessary the construction of dams for irrigation. Those constructions cause fluvial fragmentation affecting the hydrological regime (Zalewski et al., 1997; Coelho 2008). Commonly the water and sediment flows are altered and the hydrological alteration cause the disruption in the magnitude or timing of natural river flows (Rossemberg et al., 2000). Considering that flow variability is an important characteristic of river systems, with implications for river geomorphology, those changes in turn affects the morphological processes taking place on the stream channel (Puckridge et al., 1998; Brandt 2000). Some examples of the negative impacts of hydrological alteration include: habitat fragmentation, habitat losses, loss of floodplains, riparian zones, and adjacent wetlands, deterioration of irrigated terrestrial environments and associated surface waters and dewatering of rivers, leading to reduced water quality because of dilution problems for point and non–point sources of pollution (Rossemberg et al., 2000).Those effects varies depending on the characteristics of the dam, and on case of irrigation dams use to be associated to a minimum discharge higher than in dams destined to other uses in order to maintain a medium water flow for the irrigation (Coelho 2008).

Small reservoirs for agriculture irrigation may seem to don’t represent a very strong effects on the hydrological flows because maintain a higher environmental flow. However, authors such as Troms e Walker (1993) and Brandt (2000) highlight that when those dams are constructed in series along the river, the effects are enormously amplified and very complex being even possible to be bigger that the impacts of a big dam. This phenomena is called cascade effect and generate enormous hydrological alterations. This kind of model is very common on Brazilian rivers (Barbosa et al., 1999; Coelho 2008).

As it has been shown, catchment land uses have implications for hydromorphologycal processes and therefore lakes respond in a different ways to altered regimes of hydrological flows. These interactions must be considered in sound lake management plans (Nõges, 2009).

But land uses not only affect the water quantity but also the quality. Different authors agree that the alterations on water quality are related with soil and land use interactions (Soranno et al., 2015) because is the water the element which controls the chemical concentration and sediment inputs, as consequence nutrients loads increase in high flow conditions most likely due to runoff from the riverbank soils (Arreghini et al., 2005). Then are the water bodies very vulnerable ecosystems to pollution related with soil disturbances, enhancing the incorporation of suspended or dissolved solids to the water (Malmqvist & Rundle, 2002; Sperling and Chernicharo2005). The principal factor of the decrease on water quality is land use, especially agriculture and pasture, activities which highly contribute to the soil degradation favoring its and accelerating soil erosion, incorporating in that way the nutrients and toxic compounds result of the same activities to the water courses as diffuse pollution (Prato et al.,1989; do Vale et al. 2013)

Agriculture and husbandry for example are necessary for the food production and the economy, nevertheless wastes deposition from agriculture and animal have resulted in environmental changes (Carvalho et al., 2000). When agriculture takes place and the soil is exposed, those waste depositions are lixiviated into the soil causing the wash out of the nutrients of the deeper layers of soil. This loss of nutrients cause soil infertility and generate the need of application of chemical fertilizers. The fertilizers in many situations are not properly applied increasing the nutrient concentrations needed for this activity and as on case of the initial nutrient loss, this excess is conduced to lower areas and generally reach rivers and lakes. (Carvalho et al., 2000). The pasture land that host cattle are as well a source of nutrients for the environment (Gourley et al., 2012). The manure generated by the cows deposited on exposed soils generate a high lixiviation of nutrients intro the soil that as the previous mentioned cause the wash out of the nutrients of the deeper layers of soil which are transported to the closer water bodies. On this case the input of nutrients is continuous and due to the mobility of the animals is widely spread. In addition, if those animals are fed artificially the situation is further aggravated because those animal feed contains nutrients as well (Gourley et al., 2012).

A water use that influences the nutrient loads is the fish farming on floating cages. Håkanson(2005b) summarize that this activities which take place on lakes are a source of phosphorus, nitrogen and organic particles. Those nutrients comes for the faeces of the cultivated fish and the food wastes. Is important to consider that those activities are very intensive which means that the emission of nutrients to aquatic ecosystems may be very high.

The high nutrient loads reaching aquatic ecosystems decrease water quality and may induce eutrophication processes. Eutrophication increases the proliferation of micro and macro algae. When those microalgae blooms takes place the turbidity of the water increase and even generate a thick layer in the surface of the water that do not allow light penetrate and cause the death of aquatic plants settle in the bottom. In addition, those algae had a short life so all this death algae and plant increase the organic matter content in the water. The decomposition of the organic matter is an oxygen consumption process and for this reason when there is eutrophication the oxygen in the water decrease extremely generating even anoxic layers, especially in the bottom, which affects the fauna and the flora of the ecosystem generating the death of organisms and decrease their populations, this result in a loss of biological diversity. Then eutrophication affects the functioning of the system leading loss of biodiversity as well as cause economic and social problems. (Cruzado et al., 2002; Smith, 2003; Withers and Jarvie, 2008, Thornton et al., 2013).

Theoretically a small water inflow from severe eroded areas or with a very intensive land use, should be adequate to reduce allochthonous organic matter and nutrient inputs, and also reduced phytoplankton bloom activity (Wetzand Yoskowitz, 2013).

The correlation between lake morphometry, hydrochemistry and biota have been study since last century and several studies have shown correlation between the morphometric parameters and productivity of the lakes because of the regulation of general physical, biological and chemical lake processes (Carpenter 1983; Håkanson, 2005b). Due to the role of morphological parameters such as lake form and size, morphology influence in processes as diffusion, resuspension or bioturbation, which affect the rate of nutrient recycling from sediment to water regulating the primary production, which, in turn, regulate secondary production (Carpenter 1983; Håkanson, 2005a, 2005b). From lake catchment, transport processes regulate, in some extent, abiotic state variables and lake processes (Håkanson, 2005) such water, inorganic and organic material fluxes through river runoff, influence water chemistry, hydrodynamic, light penetration, climate, biogeochemical cycles and food-web structure (Nõges, 2009). Then, it is essential the study of the morphometry of the tributary basins that drain the water into the lake.

The environmental quality of a watershed is a major issue of concern especially when they host anthropogenic activities (Danelon et al., 2012). As we have seen lakes are under continuous environmental pressures that disturb the natural balance of the watershed, altering its structure and functioning, consequently they are strongly impacted, a sound management is crucial in order to foster lake ecosystem services to human well-being. The required quality of water is directly influenced by the water use, nevertheless it is necessary to consider that water bodies are usually associated to multiple uses, which are required to satisfy diverse quality criteria (Sperling and Chernicharo2005). On a catchment where the water is used for irrigation, animal supply, aquaculture, recreation, transport and of course is essential for the preservation of the aquatic life present in the ecosystem, therefore the water should be free from chemical substances and organisms harmful for the health of the soil and plantations, animals, humans and the species (Sperling and Chernicharo2005).

The problems that affect the functioning of a watershed should be analyzed in a systemic way instead of punctually because a bad management of the entire basin triggers the punctual negative situations (Odum 1971). In this regard, the Integrated Lake Basin Management - ILBM seems to be a concise approach considering the relationships of lake catchment, stakeholders and governance systems. According to ILEC (2007), six pillars for a good lake basin management are required: the presence of institutions to manage the lake and its basin for the benefit of all lake basin resource uses; policies to govern people's use of lake resources and their impacts on lakes; involvement of the stakeholders; use of the best technological possibilities available; the knowledge both of a traditional and scientific nature is valuable; and sustainable finances to fund all of the above activities are essential. These constitute the essential components of basin governance about which ILBM can provide the overall framework for application. Nevertheless ILEC (2007) recognizes that for the success of the integrated management is necessary the basin approach, technology should be applied, if stakeholders are not involved fully understanding their role on the problems the strategy of management will nut success, the long term commitment is essential because the processes on lakes require their time, the long term monitoring is necessary and understand that Lake Basin Management is a continuing process.

In another hand, more focused on the environmental aspects, ILBM is an interesting approach because it gives importance to the ecosystem features to face an environmental problem. Considering that the occurrence and management of lake problems are influenced by three characteristics: integrating nature, which indicate that inputs as well as their related problems are shared throughout the lake; long water retention time which indicate that a lake is able to absorb large inputs, but also once is degraded it can take a very long time to be recover; and complex response ecosystem dynamics which indicated that lakes do not always respond to changes in a linear way, so the problems need to be anticipated as far in advance as possible through scientific studies and environmental monitoring to unravel the complex processes and their implications (ILEC, 2007).

For the present study, the application of the ILBM is an important reference because on the Lake Terra Alta – LTA watershed (Southeast Brazil) there are no evidences of a concise management plan that ensure the ecosystem services that LTA provides to the community. As on this basin there are no previous studies of the catchment, develop a study which involve the integrative principles of the ILBM where the importance of the basin approach is a major pillar, could be useful for water managers and create a precedent to develop this management approach.

On a catchment such as LTA, the unbalance between ecosystem services and functioning and the inefficient and inequitable use of water by stakeholders may leads into a water scarcity in both quantity and quality. On LTA catchment where the water is used for irrigation, animal supply, aquaculture, recreation and transport the maintenance of a good water quality and quantity is crucial. As we have seen in the bibliography those land uses are determinant for the quality of the hydrological flows, being at the same time strongly influenced by the morphometry of the basin. On case of LTA watershed the first step to achieve an integrated management is the study of the hydrological flows in terms of quantity and quality considering the different aspects that, based on the bibliography, influence them. Those parameters are morphometry, hydrology and land use, being focused on different subbasins that provide the water to the Lake Terra Alta. Then, the objective is to provide good information to the managers to detect the possible environmental problems that are taking place on the basin and the potential impacts that may take place. For this reason, the study is developed under an ecohydrological approach, where important to promote the integration of areas of the science to have a more holistic vision which increases the quality of the information. This approach is enhanced by the ILBM which promotes the information exchange with the basin managers , local communities and decision makers to achieve a better management and thus ensure ecosystem services.

To solve problems in a more sustainable way or mitigate future problems, the application of an interdisciplinary science like Ecohydrology which quantifies and explains the relationship between hydrological processes and biotic dynamic at a catchment scale (Zalewski et. al. 2004). Ecohydrology fulfils the two fundamental conditions of successful strategic action according to decision-making theory: elimination of threats and amplification of chances (Zalewski et. al. 1997). For this reason in necessary understand the biotic and abiotic properties and processes of the ecosystem, to use them as a management tool and increase the carrying capacity, resistance and resilience of the own ecosystem to be able to be adapted to human impacts.

2. Study goals

The main goal of this study is to evaluate the influence of morphometry, hydrography and land use of the Lake Terra Alta catchment on the hydrological flows in terms of quantity and quality. The better understanding of those factors will contribute to a more integrated and efficient basin management strategies capable of restore, minimize and avoid the negative impacts related with the natural or human induced environmental changes that take place on the basin favoring the sustainability of the ecosystem services provided by this watershed.

In order to reach this goal it is crucial to reach specific goals to obtain a better understanding of the watershed through the study of those variables individually and develop an integrated analysis. In consequence, the specific goals of this study are:

- The generation of a georeferenced database through geographic information systems.
- Analyze the morphometrical characteristics of the basin.
- Analyze the water discharges (measured and modelled).
- Analyze the nutrient loads (N and P).
- Analysis of the previous factors by a multivariate statistical method to know the relationships between them and the role that represents on each subbasin. In order to know the more determinant factor for each subbasins, is possible to acts specifically to minimize the risk of changes in the hydrological flows as well as solve the already existing problems.
- Propose a decision tree for the factors influencing hydrological flows in order to provide a tool that facilitates the first stages of the management of the basin.

Is important to consider that an important component of the hydrological cycle as is the groundwater, was not analyzed on the present study due to the total absence of groundwater studies on the area and the impossibility to develop them. At the same time, was not possible to consider the geological framework for the morphological characterization of the subbasins of the study area for the same reason, due the absence of detailed geological information of the study area.

3. Study area

The study area of this study is situated in the southeast coast of Brazil, in the state of Espirito Santo. Being one of the 90 lakes which form the Lower Doce River Valley (LDRV) Lake District, which has an area of 165 km^2 (Barroso *et al*, 2012), Lake Terra Alta (LTA) is a tropical natural lake located in the municipality of Linhares, at the north of the State of Espírito Santo (Figure 3.1).

LTA catchment, has an area of 144.7 km^2 and is composed by 8 subbasins and 7 tributaries streams (Figure 3.2). The Lake area is 3.9 km^2, with a volume of 3,534,8831.06 m^3 (0.03 km^3). The maximum depth is 22.1 m and its mean depth 9.04 m (Barroso *et al*, 2012). The lake presents a warm monomictic pattern with thermal stratification on the warm and rainy season, from October to April, and mixing during the dry and cold season, June to September (Venturini, 2015). The retention time based on mean annual discharge of tributary streams is 1.6 years (Barroso et al., 2014), a considerable low value that indicate higher capability of the lake to recover after a disturbance (Ambrosetti, 2002; ILEC 2007)

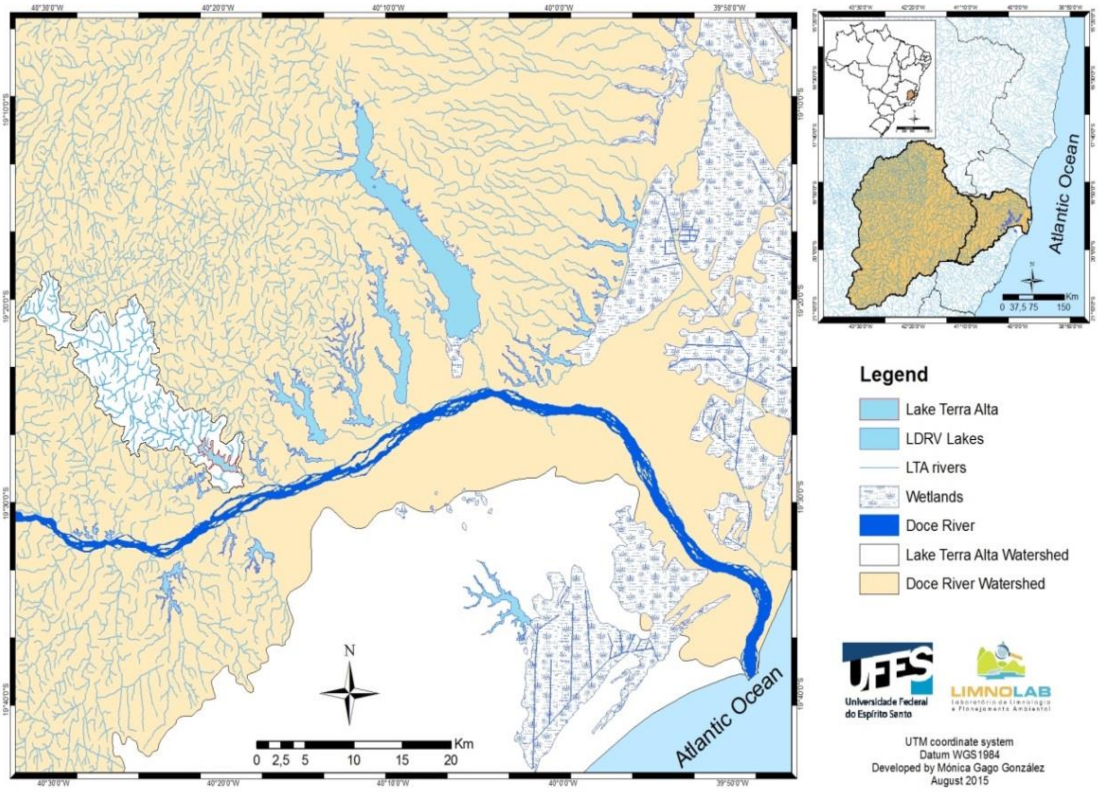


Figure 3.1. Location of Lake Terra Alta watershed on the Lower Doce River Valley.

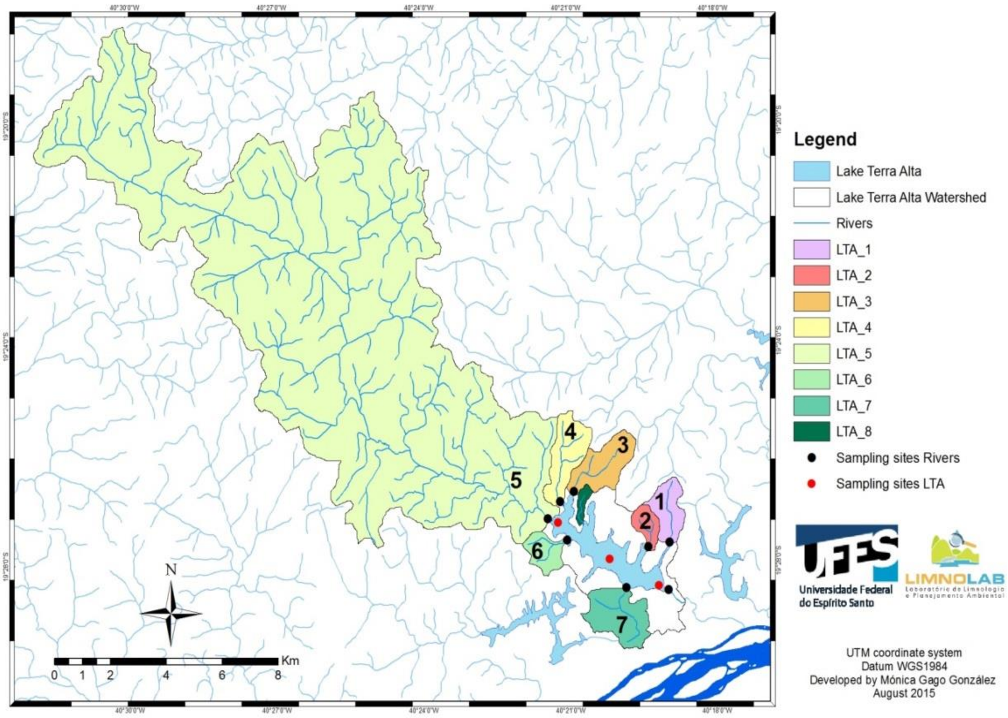


Figure 3.2. Subbasins of LakLTA watershed.

Figure 3.3. Perspective of LTA

Figure 3.4. Perspective of LTA

Based on Köppen climate classes by, the climate on the municipality of Linhares is Aw, a tropical humid climate characterized by a dry winter and maximum rainfall during the summer (Nóbrega *et al.*, 2008)). Considering historical data of 66 years of 13 meteorological stations (Figure 3.5), the regional mean monthly rainfall is higher than 100 mm meanwhile the dry months showed a regional mean monthly rainfall smaller than 50 mm (Barroso et al. 2014). Then, the wet and warm period, comprising the months between October and March, has a mean monthly rainfall of 167,6 mm and a mean temperature of 24,8 ºC . Meanwhile, the dry and mild cold period, comprise the months between April and September and the mean monthly rainfall is 46,1 mm and the mean air temperature 21,9 ºC. According the historical trend, August is consider the driest month and December the wettest month.

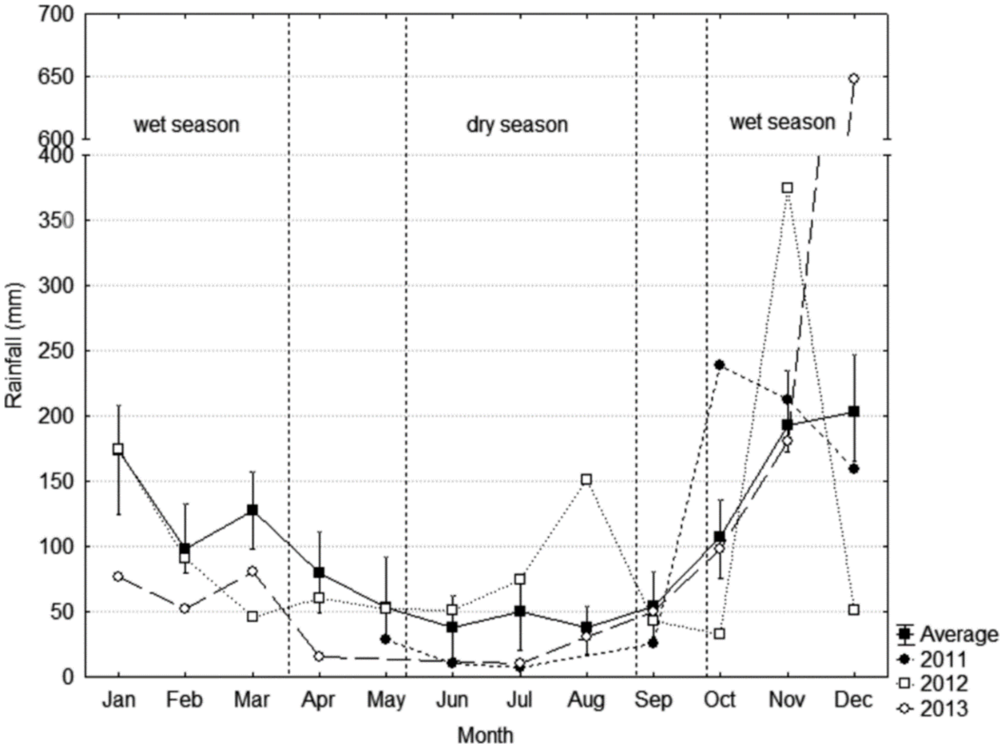


Figure 3.5. Regional mean monthly rainfall (1947 to 2013) and monthly rainfall for 2011 and 2013 (Barroso et al., 2014).

The LDRV Lake District is divided between lakes located in natural dammed alluvial valleys and lakes located on the coastal plain (Martin et al., 1996). According with LTA is inserted in the Barreiras Formation Tertiary Period (Figure 3.6.). The Tertiary plateau is represented by continental deposits divided by subpararel hydrographic network that are drained by small water courses flowing on big valleys of flat bottom silted up with Quaternary sediments. The upper part of its catchment is in the area dominated by Precambrian crystalline rocks drained by a dense dendritic hydrographic net, which presents an uneven relief (Martin et al., 1996).

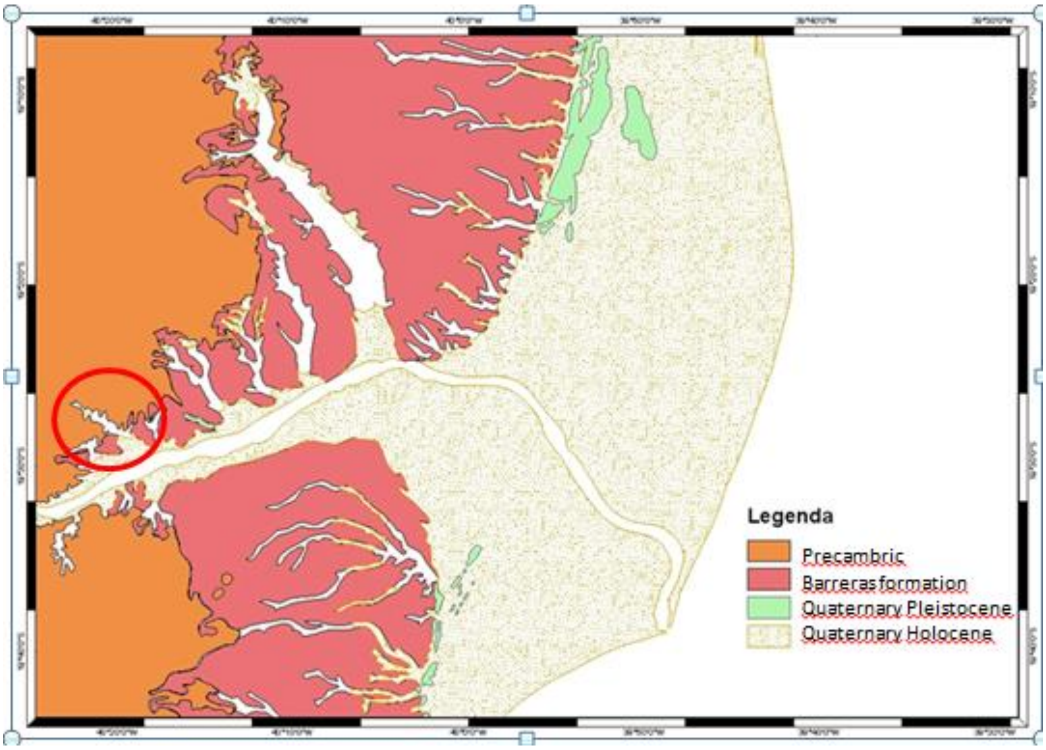


Figure 3.6. Geomorphological Figure of LDRV. (Modified Limnolab)

According to the land use of the basin can be consider than the main economic activity is husbandry followed by the agriculture and *Eucalyptus* forestry. Without considering the natural forest which represents around 36 % of the basin, LTA catchment land use (Table 3.1) is predominantly pastureland, representing approximately a 31 % of the basin. In smaller dimension agriculture with 18% of the basin and a 10% of *Eucalyptus* forestry. LTA watershed has no urban area or industrial activities.

It is important to mention that the lake host an intensive fish farming facility (Figures 3.7 and 3.8) on floating cages with *Tilapia* with a production around 15,000 kg of fishes per month.

Table 3.1. Land use on LTA watershed.(Barroso *et al* 2013)

Land use	Area (km²)	% of the basin
Forest	52,2	36
Pasture land	45,2	31
Agriculture	26,5	18
Foestry	14,0	10
Rock	10,8	3
Urban	0,001	0

Figure.3.7. Fish farming facility with floating cages.

Figure 3.8. Fish farming facility

In order to provide water for those activities, 33 small irrigation reservoirs were identified in the watershed. Direct lake water withdraw for irrigation, as well as water withdraws from the tributary rivers and fluvial damming represents a pressure for the LTA hydrology, as well as the nutrient inputs from watershed natural loads and anthropogenic activities as agriculture, livestock, forestry and from fish farming which also stress lake trophic state. Those pressures may compromise lake ecosystem services that are provided by water quantity and quality.

4. Materials and Methods

4.1 Georeferenced database

A georeferenced database was elaborated with the software ArcGIS 10.1 ESRI® in order to provide the basic information of the hydromorphology of study area as well as the land uses. The coordinate system and datum are UTM and WGS 1984.

A Digital Elevation Model (DEM) of 30 m resolution was used to delimitate LTA subbasins ArcGISwith ArcGIS Hydrology modelling. Once the subbasins were delimitated, the polygons were edited in order to obtain an effective drainage area of the tributary streams, excluding those areas where the water was draining directly to the lake and not through streams.

The river delimitation for the LTA basin and the respective subbasins was done clipping over a hydrography Figure of LDR watershed.

Land use was as well delimited for the entire basin and subbasins in the same way that the previous one based on a Land use Figure of 2010.

4.2 Basin morphometry

Different parameters as watershed area, basin perimeter, basin length, slope, stream number, stream order, stream length, drainage density, stream frecquency, bifurcation ratio, length of overland flow, form factor, circularity ratio, elongation ratio and infiltration number, has been analyzed with the objective to evaluate the watershed morphometry.

All parameters were calculated for the entire LTA basin, as well as for each of the 7 subbasins according to different authors.

- *Watershed Area A (km^2); Watershed Perimeter P (km ; Watershed length L_b (m)*

The total area of the basins, their perimeter and the length between the mouth and the outflow were obtained by ArcGIS (ArcGIS 10.1 ESRI®) basic geometry tools.

-*Slope S (%)*

Slope is an important parameter to be analyzed in morphometry, because determines the inclination of the terrain (Magesh et al., 2013). Slope is strongly related with runoff, the higher slopes rapid runoff and may result in soil losses. On this study this parameter was calculated in two different ways.

As it was mentioned before, a slope Figure was created with ArcGIS in order to obtain the slope classes in percentage of our study area according to the Brazilian Soil Agency (Table 4.1).

Table 4.1: Slope classification (%) (Embrapa, 1979).

Slope (%)	Classes
0-3	Flat
3-8	Smothly undulated
8-20	Undulated
20-45	Strongly undulated
45-75	Mountainous
>75	Strongly mountainous

The second way, in order to obtain the mean slope of the basins was calculated following the Romshoo et al., 2012 equation (**1**) :

$$S = D_c/L \quad \textbf{(1)}$$

where,

De is the difference in elevation

L is the length of the flow path

- *Stream order (U)*

The primary step in drainage-basin analysis is to designate stream orders, which is a dimensionless property to hierarchically codify fluvial systems (Horton, 1945). Following the Strahler method (1964) that slightly modifies the Horton´s (1945) which organizes hierarchically the tributaries, stream order was obtained by ArcGIS 10.1 ESRI®. Due to the small size of the basin and number of streams it was possible to do it by hand, selecting the streams and classifying them. The procedure starts from the finger-tip tributaries designated as order 1. If two of those channels connect, they form an order 2 channel segment, which if joins other Order 2 will form an Order 3 tributary and so on, resulting that the highest order stream is the main channel where all discharges of the other streams are leaded. Thus, stream order increase as total number of streams decreases (Magesh et al., 2013). Greater discharge and velocity of the flow are coupled with higher stream order (Romshoo et al., 2012)

- *Stream number (Nu)*

Horton (1945) defined it as the number of channels that can be found in a stream order, and is proportional to the channel dimension and size of the watershed. In general, on higher stream order there is a decrease on the stream number and lower stream number indicates higher infiltration and permeability (Romshoo et al., 2012; Magesh et al., 2013)

The stream number was obtained after the Stream order classification from ArcGIS 10.1 ESRI®; it was counted on the attribute table as the number of streams belonging to each order.

- *Stream length (Lu)*

Stream length shows the scale of the components on the drainage network (Strahler 1964). In general, stream length decrease when the stream order increase and the first order presents the maximum total length of stream segments (Magesh et al., 2013).

With the tool, calculate geometry of ArcGIS 10.1 ESRI®, the length of the selected river was calculated.

- *Drainage density (Dd)*

Dd was calculated according to Hortons (1945) **(2)** and represents the total stream length Lu per unit of area of the basin A.

$$Dd = \Sigma Lu/A \quad \mathbf{(2)}$$

where,

Lu is the stream length

A is the area of the watershed

Drainage density (Dd) is an important property of a river network being an indicator of the land form (Strahler 1964; Moglen 1998). This geomorphic property is strongly linked with hydrological processes as infiltration or overland flows, and thus, influence their interactions and resulting processes as runoff (Moglen 1998). Different authors as Horton (1945) and Carlston (1963) highlight the importance of permeability and thus infiltration to determine drainage density. The higher drainage density is related with mountainous watersheds with impermeable materials and sparse vegetation that results in lower infiltration capacity and in consequence, a relatively rapid hydrological response to rainfall events. Meanwhile, low drainage density number shows poorly drained basins with slower hydrologic response due to a higher infiltration capacity associated with a good vegetation cover and permeable subsurface materials in low relief areas (Romshoo et al., 2012; Melton 1957).

In general terms the size of drainage units decrease proportionately when drainage density number increase (Strahler 1964).

- *Stream frequency (Fs)*

The equation (**3**) from Horton (1945) defines the Stream frequency (Fs), where Nu is the number of stream segments and A is the basin area. This parameter is related to permeability, infiltration capacity and relief of watersheds (Montgomery and Dietrich 1989; Romshoo et al., 2012).

$$Fs = \Sigma\, Nu/A \qquad \textbf{(3)}$$

where,
Nu is the number of stream segments
A is the area of the watershed

-*Bifurcation ratio (Rb)*

According to Schumm (1956) equation **(4)** , the Bifurcation ratio depends on the stream number, defining a ratio between the stream number of an order (Nu) and the stream number of the next higher stream order (Nu+1). This parameter contribute to the understanding of the branching pattern of a drainage network (Magesh et al., 2013), being an useful number to define the form of the drainage basin, specially due to its stability because in general is representative in different environments or regions with the exception of areas or high geologic controls (Strahler 1964).

$$Rb = (Nu) / (Nu + 1) \quad \textbf{(4)}$$

where,

Nu is the number of stream segments

This parameter indicates the vulnerability of the basin for flooding if it presents a high value (Romshoo et al., 2012). The mean bifurcation ratio ranges between 3 and 5 if there is not strong influence of the geological characteristics of the drainage network, and low values indicates poor structural disturbances and higher permeability of the terrain (Magesh et al., 2013) meanwhile higher values are related with well-dissected, hilly drainage basins (Horton 1945).

-Length of overland flow (Lg)

The length of overland flow determine the distance that the rainwater need to reach a definite stream channel and can be calculated with the equation of Horton (1945) (**5**) and in most cases it is approximately the half to reciprocal of the Drainage density. Horton describes this parameter as one of the most important variables that influence the drainage basin development in hydrologic and physiographic terms being an important variable on which runoff and flood processes depend (Zavoianu 1985; Romshoo et al., 2012).

$$Lg = 1/(Dd*2) \quad \textbf{(5)}$$

where,

Dd is the drainage density

Higher values indicate higher distances and lower values shorter distances before to reach the stream channels (Magesh et al., 2013).

-Form factor (Rf)

The Form Factor is one of the most relevant shape related parameters in the morphology. The equation proposed by Horton (1945) **(6)** define the Form factor, where its related the area of the basin (A) and its length, represented by Lb, the farthest distance from watershed ridge to outlet.

$$Rf = (A) / (Lb + 1)^2 \quad \textbf{(6)}$$

where,

Lb is the farthest distance from watershed ridge to outlet or watershed length (m)

A is the area of the watershed

Form factor values closer to 1.0 represent circular basins and as longer and narrower the basin is, its form factor value is decreasing due to their higher lengths (Magesh et al., 2013).

-Elongation ratio (Re)

This parameter measure the shape of the basin of the river linking the diameter of circle with the area and the maximum length of the basin (Magesh et al., 2013) and is calculated by the Schumm (1956) equation **(7).**

$$Re = (2/\pi) \sqrt{} (A / Lb)^2 \quad \textbf{(7)}$$

where,

Lb is the farthest distance from watershed ridge to outlet or watershed length (m)

A is the area of the watershed

More circular basins seems to be more efficient in the runoff discharge due to a lower concentration time, they are representatives of lower reliefs and their Re values are closer to 1.0. Meanwhile elongated basins with higher relief are closer 0.6 values (Magesh et al., 2013). The results of the elongation ratio should be similar to the form factor (Strahler 1964).

-Circularity ratio (Rc)

Circularity ratio influences the hydrological response of the watersheds as basin-shaped (Romshoo et al., 2012). This shape related parameter was defined by Miller (1953) as a ratio of the area of the basin and the area of a circle. Is an indicator of the dendritic stage of a watershed and the stage of the life cycle of the tributary basins (Magesh et al., 2013). This parameter was calculated with the equation **(8)**

$$Rc = 4\pi A/ (P)^2 \quad \textbf{(8)}$$

where,

A is the area of the watershed

P is the perimeter of the watershed

-Infiltration number (If)

To describe the infiltration capacity of the basin the equation proposed by Romshoo (2012) was used **(9)**. This number is inversely proportional to the infiltration capacity (Romshoo et al., 2012)

$$If = Dd \times Fs \qquad \mathbf{(9)}$$

where,

Dd is the drainage density

Fs is the stream frequency

4.3 In situ discharge measurements

Stream discharge measurements were taken between 2012 and 2013 in 7 sampling events: 4 during dry season and 3 during wet season for the seven LTA. Stream discharge measurements (m^3/s) were taken on the outfall of all 7 LTA tributary streams with a SonTek FlowTracker Acoustic Doppler Velocimeter – ADV .

4.4 Hydrological modeling

This section presents a hydrological modeling based on conversion of rainfall on river discharge, discounting potential evapotranspiration according to Molisani et al. (2006) and Molisani et al., (2007). Rainfall data are based on regional historical records of rainfall (i.e., 30 years) of 21 meteorological stations. Mean annual rainfall and mean values for the dry and wet months, August and December, respectively, were interpolated (Spline with 0.2 weight on 6 neighbors) in a GIS environment for the LDRV. The continuous surface model (i.e., raster file) of regional rainfall was than clipped to the boundaries of LTA watershed. Evapotranspiration rates based on air temperature at every 100 m elevation were adiabatically corrected.

Acording to Kjerfve (1990), the equation **10** show that discharge is directly dependent on precipitation, area, and the runoff ratio (Δf /r)

$$Q = \iint r * (\Delta f / r) * dA \qquad \textbf{(10)}$$

where:

Q is the discharge (m^3/s)

r is the precipitation (mm/y)

A is the area of the watershed (km^2)

Δf /r is the runoff ratio

The runoff ratio is in turn dependent of the potential evotranporation (E_0) and precipitation (r), it can be calculated with the equation of Schreiber (1904) (11**)** and represents the fraction of precipitation, which drains into the rivers as a runoff (Molisani 2006).

$$\Delta f / r = e^{-E0/r} \qquad \textbf{(11)}$$

where:

Δf /r is the runoff ratio

E_0 is the potential evotranporation (cm/year)

To calculate the runnoff ratio is necessary the previous calculation of the potential evotranporation (E_0 cm/year) **(12) ,** which depends on the solar radiation intensity, which is turns means that depends on the absolute air temperature. Is described by Holland (2001) (Molisani 2006).

$$E_0 = 1.0\times10^9 \times e^{-4620/T} \qquad \textbf{(12)}$$

where:

E_0 is the potential evotranporation (cm/year)

T is the absolute air temperature expressed in Kelvin (K)

To sum it all up now that the process is described, to calculate the discharge we need the precipitation which has been calculated previously with the interpolation method and air temperature. On this case temperature measurements were not available, so a reference temperature value from the adjacent area is necessary and its correction adiabatically by

-0,97ºC per 100m of elevation increase (List, 1966). The rainfall data was converted to obtain the precipitation rate.

The obtained discharges were transformed in Effective Discharge **(13)** multiplying by a time unit and divided by the area of the basin. In case of annual mean was multiplied by 365 days obtaining and Effective discharge in $m^3/km^2/year$ meanwhile for the dry and wet month was multiplied by 31 days obtaining $m^3/km^2/month$ because the wet and dry months have 31 days each. Through this transformation the results can be compared between the basins because the influence of the total area is excluded.

$$Qe = Q*time / A \qquad \textbf{(13)}$$

where:
Qe is the effective discharge
Q is the direct discharge
A is the area of the watershed

On case of the In situ discharge measurements, the transformation to Effective discharge follows the same procedure, but for wet/dry month was necessary to select them from the sampling dates. According to Figure 3.5 and the sampling dates for the wet month was consider November 2012 and August 2013 for the dry. Then, was necessary consider that August has 31 days but November only 30 when the calculations of effective discharge are done.

4.6 Hydrochemistry analysis

N and P flows were based on concentrations of stream water samples, taken between 2012 and 2013 on 7 sampling events, three during the dry season (< 50mm/yr) and four on wet season (> 100mm/yr), at the outfall of the 7 LTA tributary streams. For total N and P, samples were frozen without filtration, whereas for dissolved inorganic nitrogen (DIN) and phosphorus (PID) samples were filtered (Whatmann fiber glass 934AH) in the field right after sampling and stored on 100 mL polypropylene flasks. All samples were frozen immediately. The analysis was carried out at UFES' LimnoLab located in Goiabeiras campus through spectrophotometry (UV/VIS).

Total fractions of N and P were digested (Figure 4.1.) on persulfate solution according to Valderrama (1981), a method which shows good reliability and allow the storage of the sample till the analysis. The simultaneous oxidation depends on the difference of pH during the digestion due to a boric acid-sodium hydroxide system, starting the reaction in an alkaline medium, which allows the oxidation of the nitrogen, and progressively decreasing the pH till obtain an acidic environment for the phosphorous oxidation.

Figure 4.1 Autoclave of Limnolab (UFES)

PT was analyzed after the digestion through a colorimetric method according to Carmouze (1994). The absorbances were measured in a spectrophotometer on four 1 cm glass cells at a wave length of 885 nm. The absorbances obtained were corrected with the value of the blanks and applied to the regression curve to obtain the final concentration.

For nitrogen were just analyzed nitrite (NO_2^-) and nitrate (NO_3^-) because it was not possible the quantification of ammonia and organic nitrogen, therefore is important to consider that when in the present study we refer to TN we are only considering nitrites and nitrates. Nitrite was determined according to Grasshoff *et al.* (1999) method, where nitrite is quantified by spectrophotometry (Figure 4.2) of the azo dye resulting from the reaction of nitrite with an aromatic amine which leads to the formation of a diazonium compound which couple with a second amine. The absorbances obtained were corrected with the value of the blanks and applied to a regression curve to obtain the final concentration of nitrite. This methodology was followed although there are no saltwater samples, due to the analytical limitations.

For nitrate determination was used the Cd column method (Figure 4.3) according to Carmouze (1994) which consists in the reduction of nitrate to nitrite. The yield of the reduction is very sensitive and highly dependent on the metal used (i.e., Cd) in the reduction and the activity of the metals surface as well as pH. If the previous variables are not the appropriated, it will result in a partial reduction, which results in too low nitrate values (Grasshoff *et al.*1999). The resulting nitrite was quantified by the method described above.

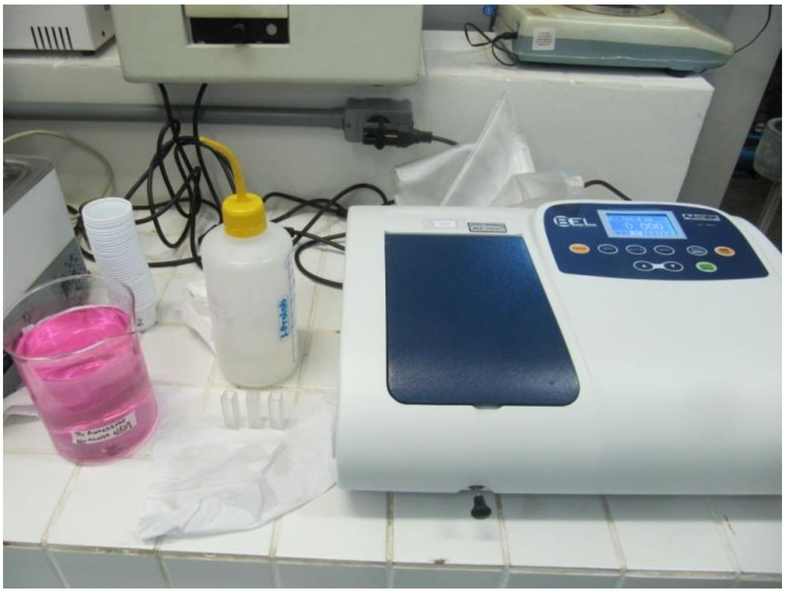


Figure 4.2. Spectophotometry. Limnolab. (UFES)

Figure 4.3. Cd column reduction method. Limnolab. (UFES)

N and P flows were computed, based on the concept of Wagner (2009) of point source load computation according to the equation **(14),**

$$C_{day} = C*Q*86400 \qquad \textbf{(14)}$$

Where,

C_{day} is load or flow (g/day)

C is the concentration (g/m^3)

Q is the instantaneous discharge (m^3/s)

86,400 seconds per day.

This equation was modified (15) to obtain the load or flow of nutrients on yearly base for the annual mean (nutrient/year) or monthly base for wet and dry month (nutrient/month). The concentration of nutrients (C) was multiplied by the specific discharge for each measurement of each subbasin (Q) to obtain the average of the subbasin, which finally was multiplied by 86400 seconds/day and by 365 days on case the annual mean and 31 days for the wet and dry month, being all the process consequently adapted with the convenient unit conversion to obtain kg/year or kg/month.

$$Tnutrient/year = C*Q*86400*365 \qquad \textbf{(15)}$$

$$Tnutrient/month = C*Q*86400*31$$

Where,

Tnutrient is the total load of TN or TP

C is the concentration (g/m^3)

Q is the instantaneous discharge (m^3/s)

As well as for the water discharge, the nutrient load was converted into TN and TP effective discharge (TNED and TPED) **(16)** dividing the load by the area of each subbasin (A). This is useful in order to standardize the flows regarding the area of subbasins.

$$TNED \text{ and } TPED = Tnutrientyear/A \qquad \textbf{(16)}$$

Where,

Tnutrient is the total load of TN or TP

TNED /TPED are the TN and TP effective discharges

C is the concentration (g/m^3)

Q is the instantaneous discharge (m^3/s)

4.7 Statistical analysis:

In order to whether know the interaction between water quality, hydromorphological variables and land use can be recovered as statistically significant covariance patterns was used the Principal component analysis (PCA).

-Multivariate analysis, Principal Component Analysis (PCA).

The multivariate analysis consists in the representation of scattered variables and cases in a multidimensional diagram with as many axes as descriptors in the study. Nevertheless, as is not possible to represent more than two or three dimensions on paper, those diagrams are represented onto bivariate graphs whose axes are of special interest, specifically chosen to represent the variability of the data set in a space of reduced dimensionality (Legendre and Legendre, 1998).

Principal component analysis PCA is one of those methods of ordination in reduced space which allows the identification of the most important components that explain nearly all of the variances of the system, providing a shortened description with few significant indices that reflect the most relevant processes (Petersen et al., 2001; Ouyang, 2005). The PCA, project those representative features into two-dimensional axes independent between them, and even reducing the data complexity, the relationships between the variables are mainly maintained (Janžekovič and Novak, 2012). The number of the components is the same than the variables, nevertheless a component is formed by all the variables (Ouyang, 2005). Legendre and Legendre (1998) argue that the number of observations cannot be smaller than the number of descriptors to obtain a statistical valid estimation of the dispersion matrix, nevertheless other studies have shown that regardless the number of observations and descriptors PCA could be applied (Ouyang, 2005).

On this study the PCA analysis was runned with the Multi Variate Statistical Package software MVSP 3.2, where the data were log10 transformed and centered and only axis 1 and 2 reported.

-Cluster analysis

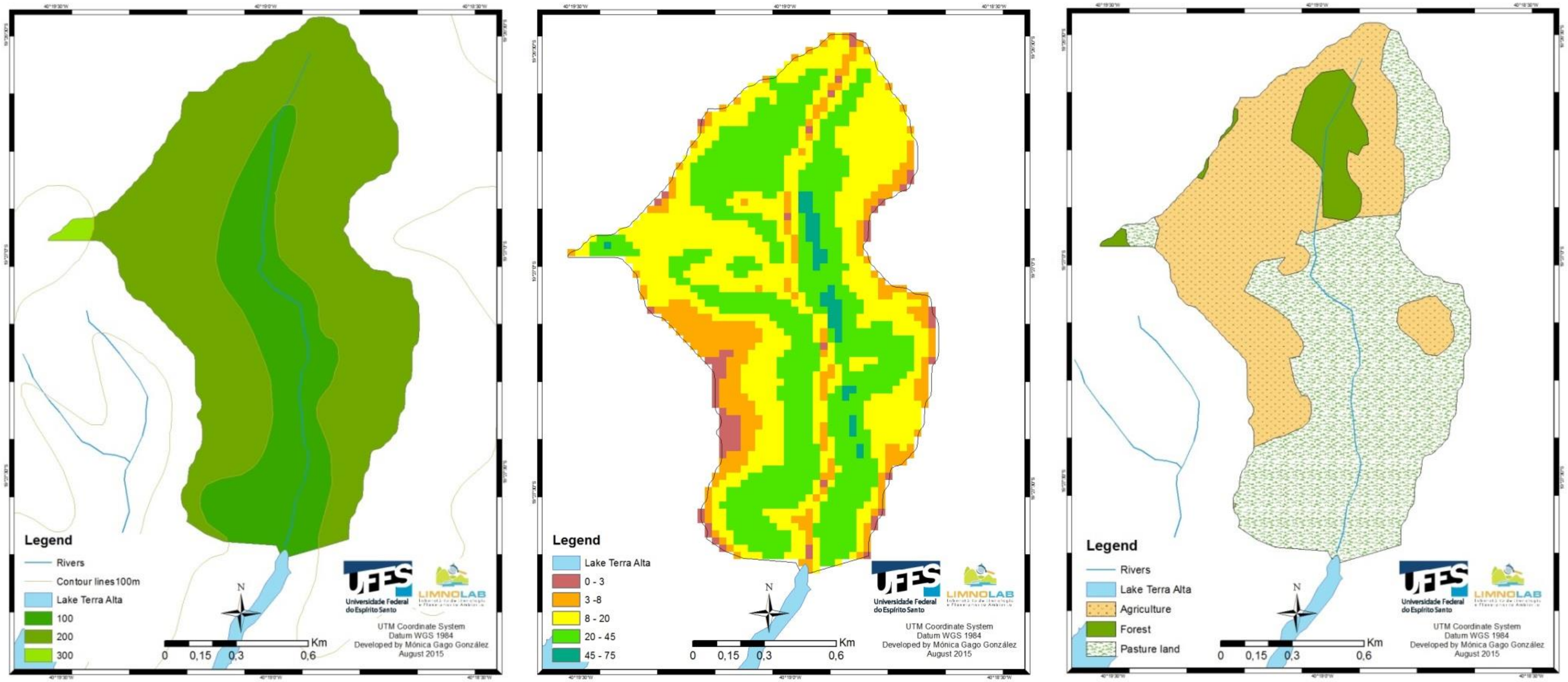
This analysis consists on the partition of our set of objects or descriptors in two or more subsets, the clusters, through pre-established rules of agglomeration or division (Legendre and Legendre, 1998).

The subbasins of LTA catchment are the descriptors that we want organize, for this proposal the method of cluster selected is the hierarchically where according to Legendre and Legendre (1998) the two more similar descriptors are cluster and then the rest of the descriptors clump into groups which at the same time are aggregate to other groups as the similarities diminish. The easiest way of interpretation of this analysis is graphical representation, a Dendogram. The cluster analysis was run with the MultiVariate Statistical Package software MVSP 3.2, where the data were log10 transformed.

5. Results

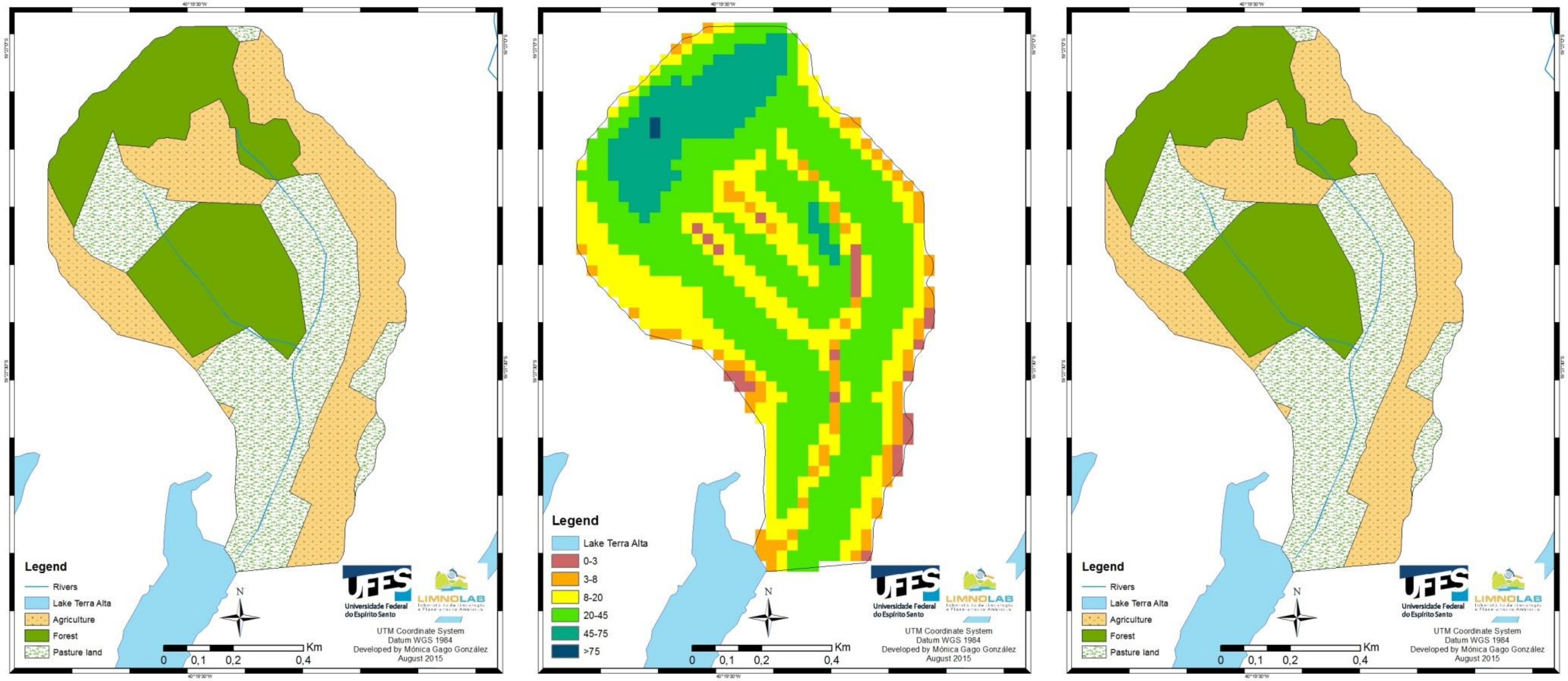
5.1 Georeferenced database

The resulting Figures of the georeferenced data base are presented by subbasin grouped in sets of three, where the first represents the altimetry classes each 100 m elevation, the second one represents the land use and the third one, the slope according the Embrapa 1979 soil classification. B1 is represented on Figure 5.1. , B2 on Figure 5.2. , B3 on Figure 5.3. , B4 on Figure 5.4. , B5 on Figure 5.5. , B6 on Figure 5.6. and B7 on Figure 5.7.



a) **b)** **c)**

Figure 5.1. Subbasin B1 elevation (a), slope (b) and land use/land cover (c).

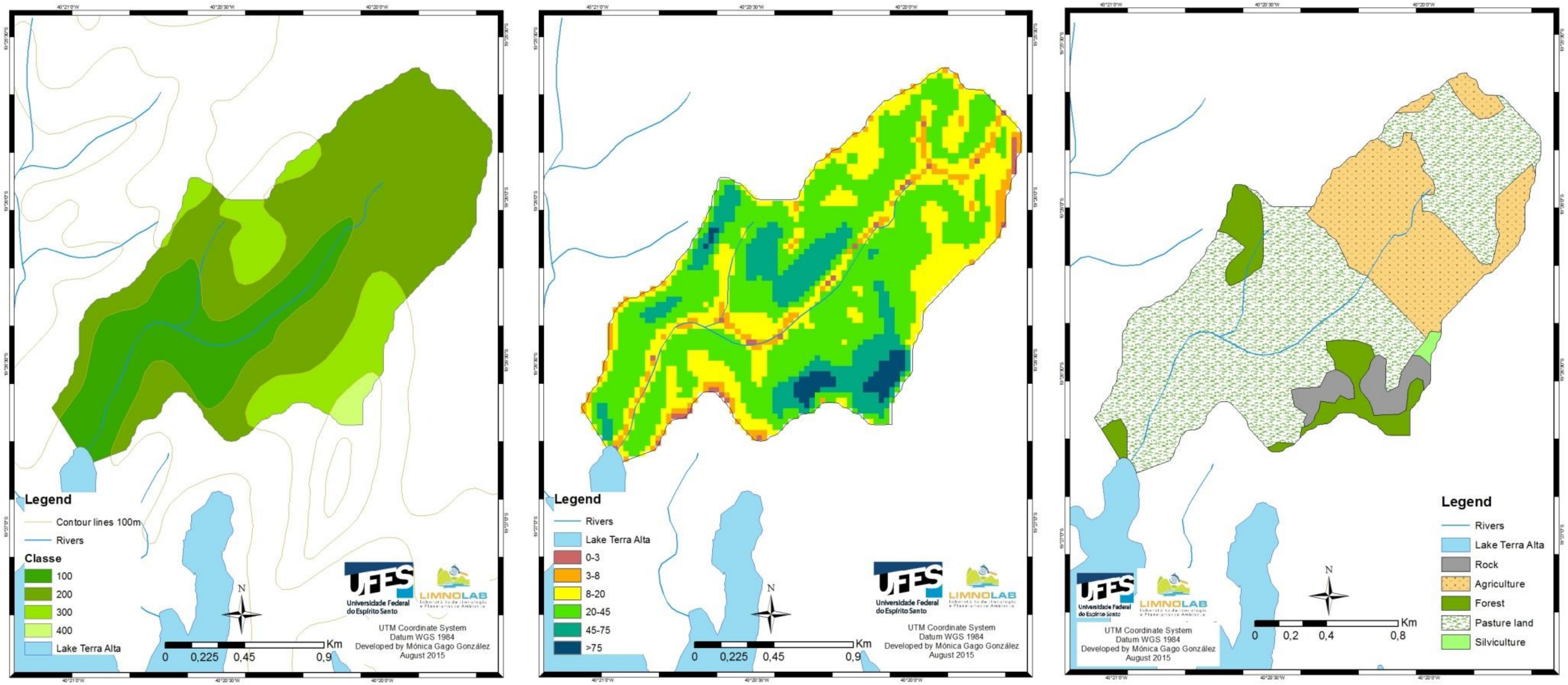


a)

b)

c)

Figure 5.2. Subbasin B2 elevation (a), slope (b) and land use/land cover (c).

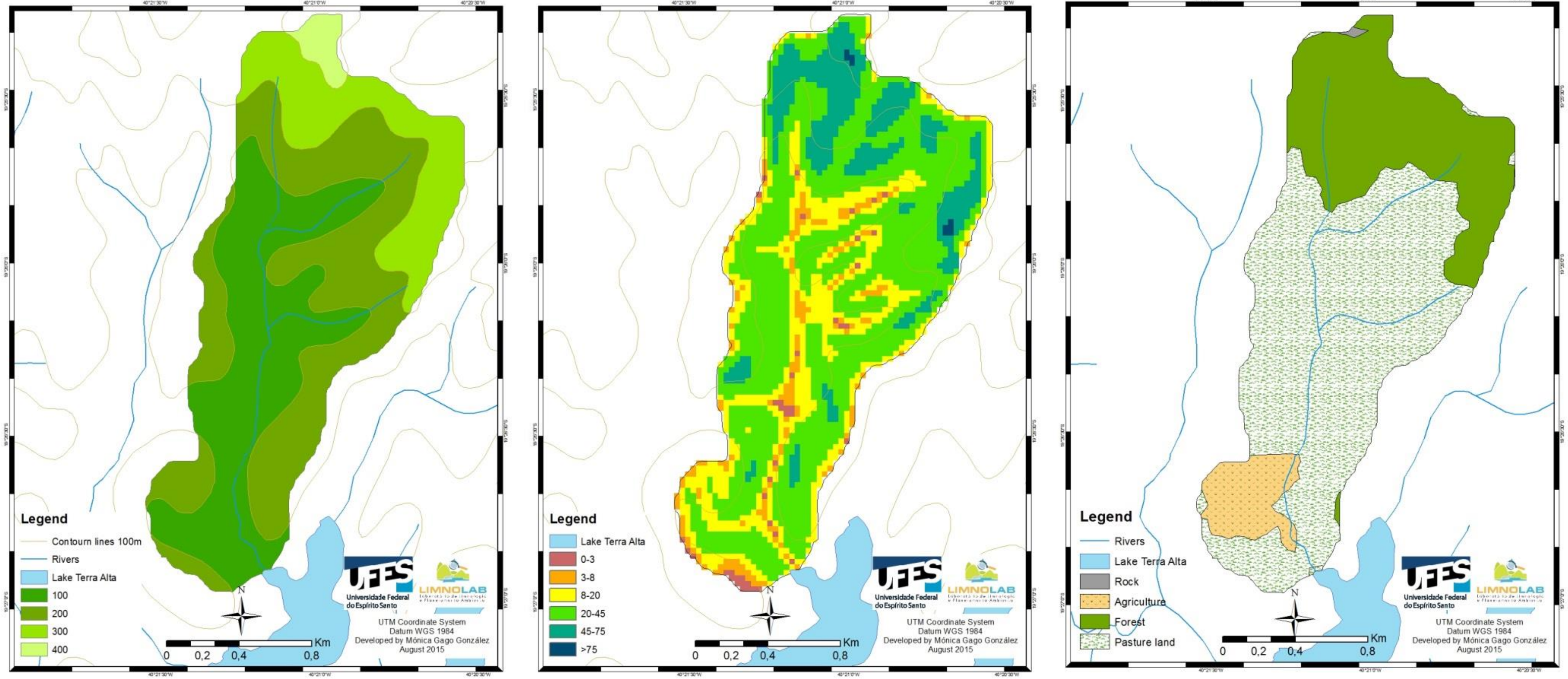


a)

b)

c)

Figure 5.3. Subbasin B3 elevation (a), slope (b) and land use/land cover (c).



a)

b)

c)

Figure 5.4. Subbasin B4 elevation (a), slope (b) and land use/land cover (c).

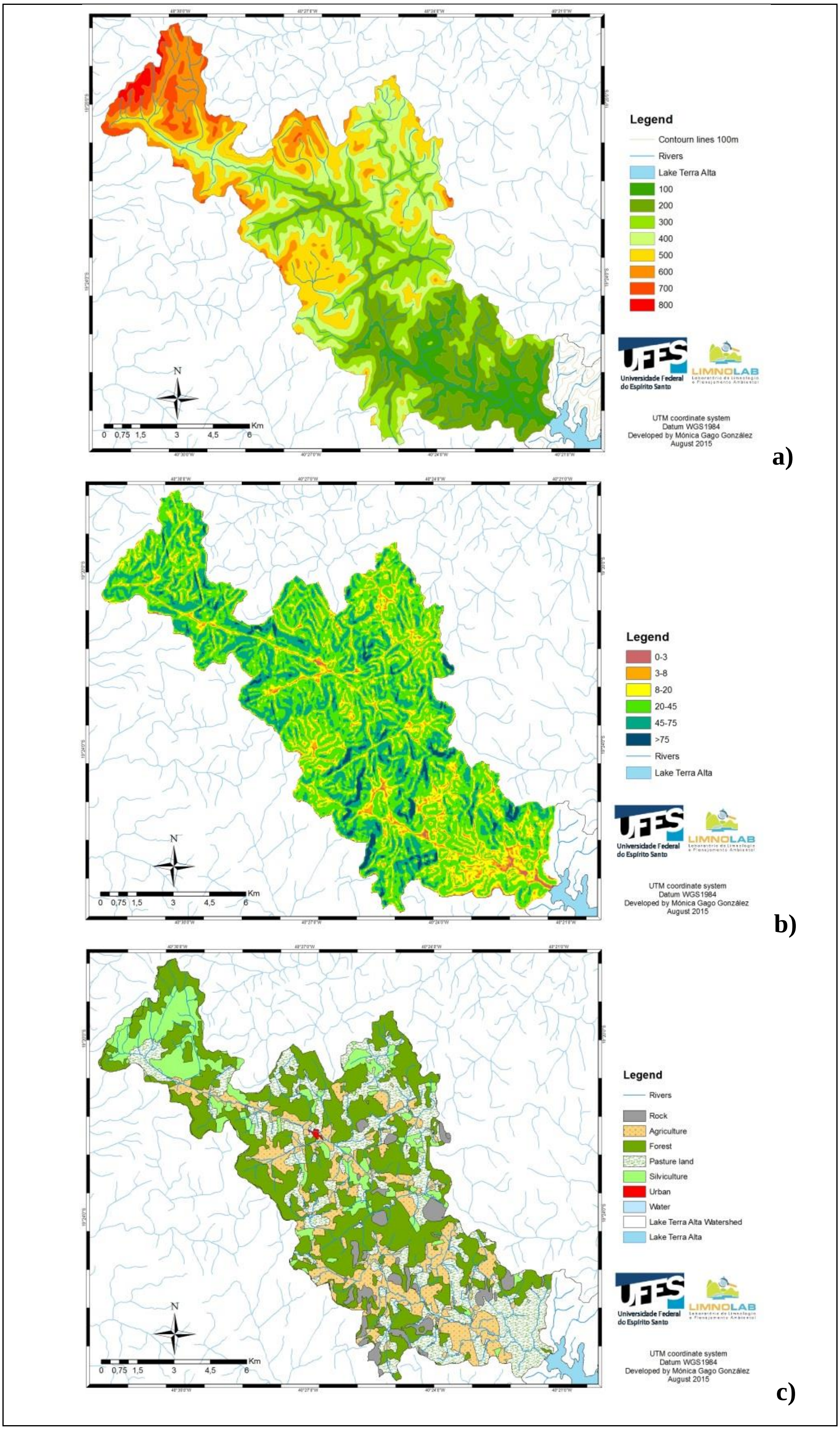
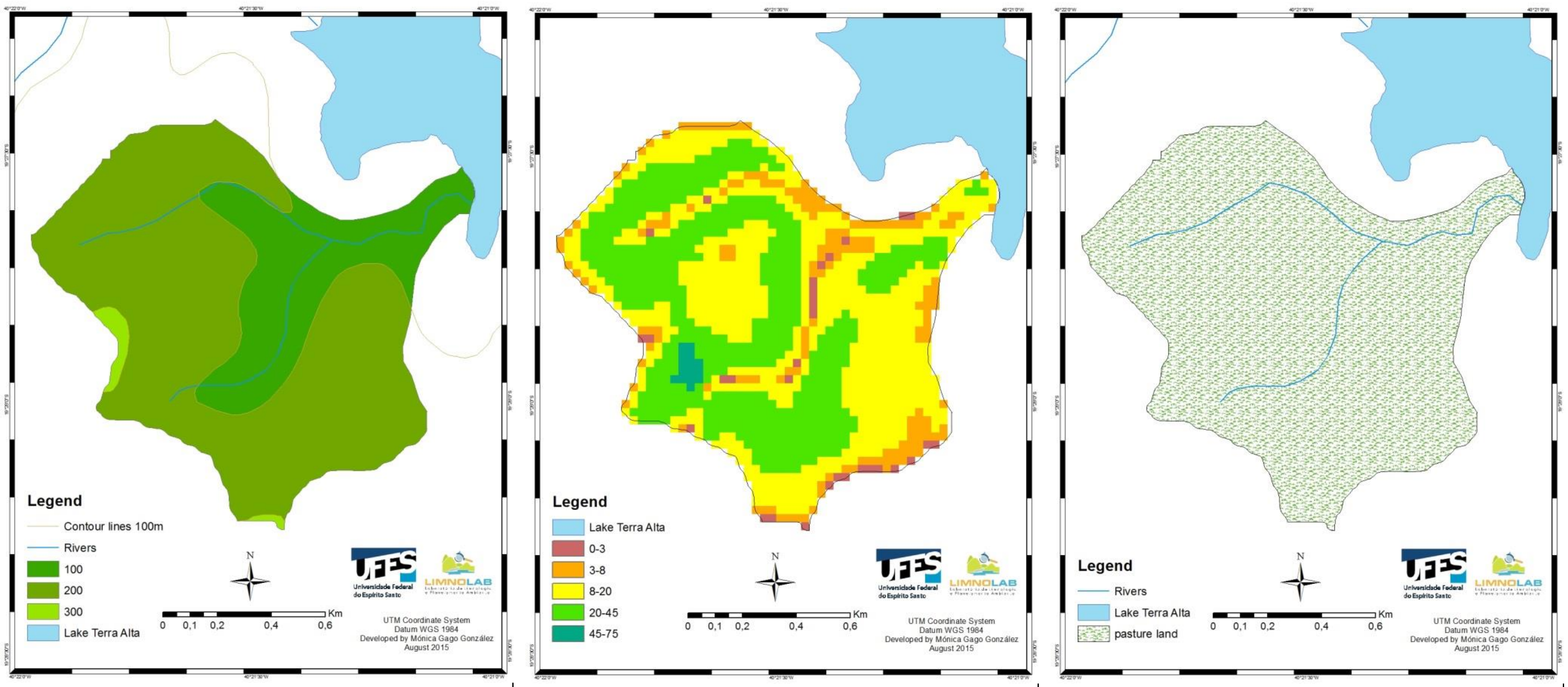
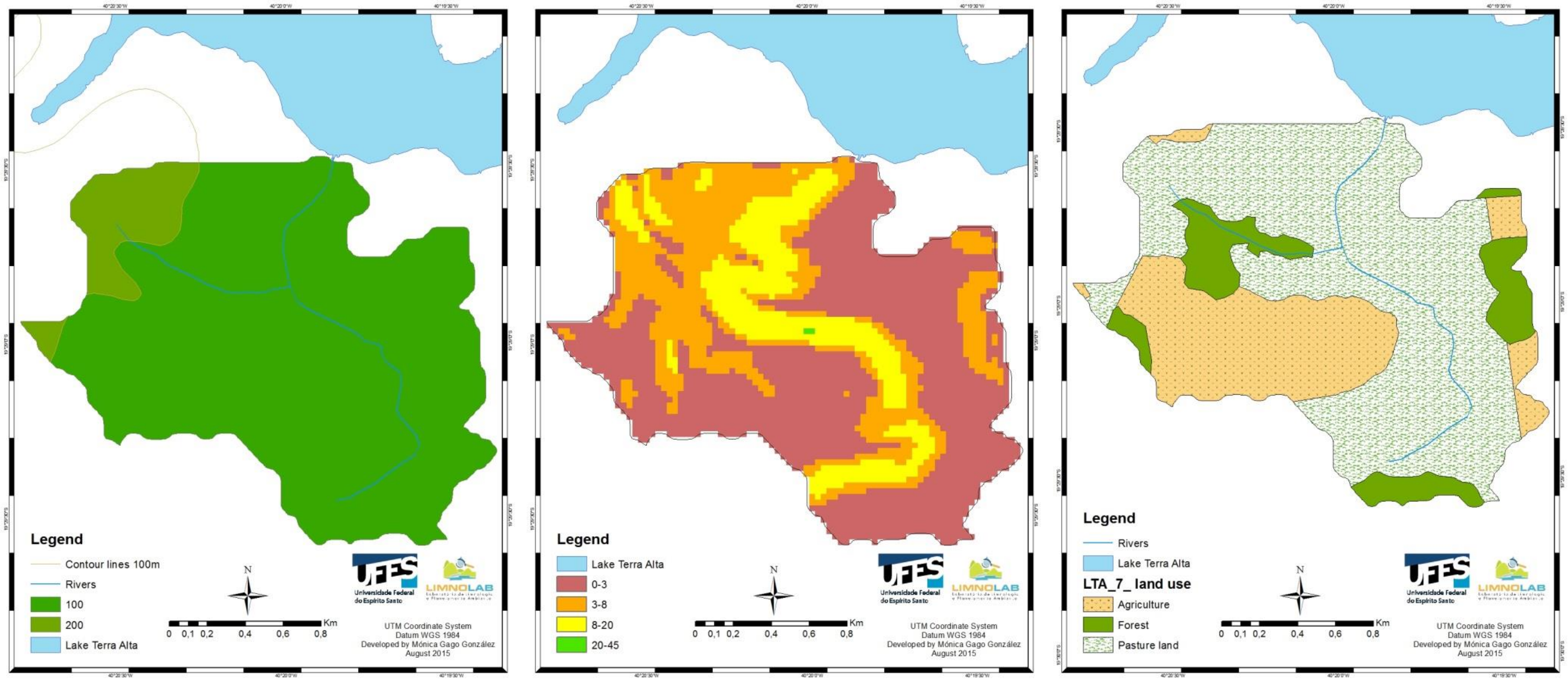


Figure 5.5. Subbasin B5 elevation (a), slope (b) and land use/land cover (c).



a) b) c)

Figure 5.6. Subbasin B6 elevation (a), slope (b) and land use/land cover (c).



a) b) c)

Figure 5.7. Subbasin B7 elevation (a), slope (b) and land use/land cover (c).

5.2 Basin morphometry

On this section the all the obtained numerical results of the morphological parameters are presented on Table 5.1.

-*Watershed Area A* (km^2)

The entire watershed of LTA has an area of 144 km^2. B5 is the biggest subbasin with an area of 122.5 km^2. The other subbasins have much smaller values. being presented in decreasing order B7 (3.32 km^2). B4 (2.88 km^2). B3 (2.83km^2). B1 (1.89 km^2). B6 (1.39 km^2) and the smaller one. B2 (0.98 km^2)

-*Watershed Perimeter P(km)*

The perimeter follow the same trend as the area, ranging in decreasing order from B5 followed by B7, B4, B3, B1, B6, till B2 being their respective values 87.41km , 8.94 km, 8.48 km, 8.22km , 6.66km, 5.54km, 4.31km.

-*Watershed length* L_b *(km)*

On the watershed length we can observe some variations in the order compared with area a perimeter due to the shape of the basins. From the entire basin of LTA (27.71 km) the subbasin B5 (22.45km) still being the one with higher value, nevertheless B7 is not anymore the next higher value, ranging now from B4 (3.09km), B3 (2.92km), B1 (2.24 km), B7 (2.04km), B6 (1.59km) , till B2 (1.53km) which still maintain the smallest values.

-*Slope S (%)*

According the Silva et al., 2010 equation (**1**), the values of the slope are as follow: LTA 34.06%, B1 22.92%, B2 34.92%, B3 32.66%, B4 38.07%, B5 35.93%, B6 23.77%, B7 4.91%. Where B4 presents the highest slope followed by B5, B2, B3, B6, B1 and finally B7. The subbasin is consider strongly undulated according the Embrapa (1979) (**Table**) classification, and its subbasins as well, with the exception of the B7 which presents a much smaller value and is considered smoothly undulated.

For a more detailed vision of the slope distribution the representation of the slope for each subbasin in classes according to Embrapa(1979) soil classification was exposed on the previous section 3.1 results of georeferenced database, concretely on Figures 5.1., 5.2., 5.3., 5.4, 5.5., 5.6., and 5.7.

- *Stream order (U)*

LTA have 4 stream orders as we can see on the Figure 5.8**.** , but we can only find those 4 orders in the subbasin B5. Meanwhile B2, B3, B4, B6 and B7 presents 2 orders and only B1 have 1 order.

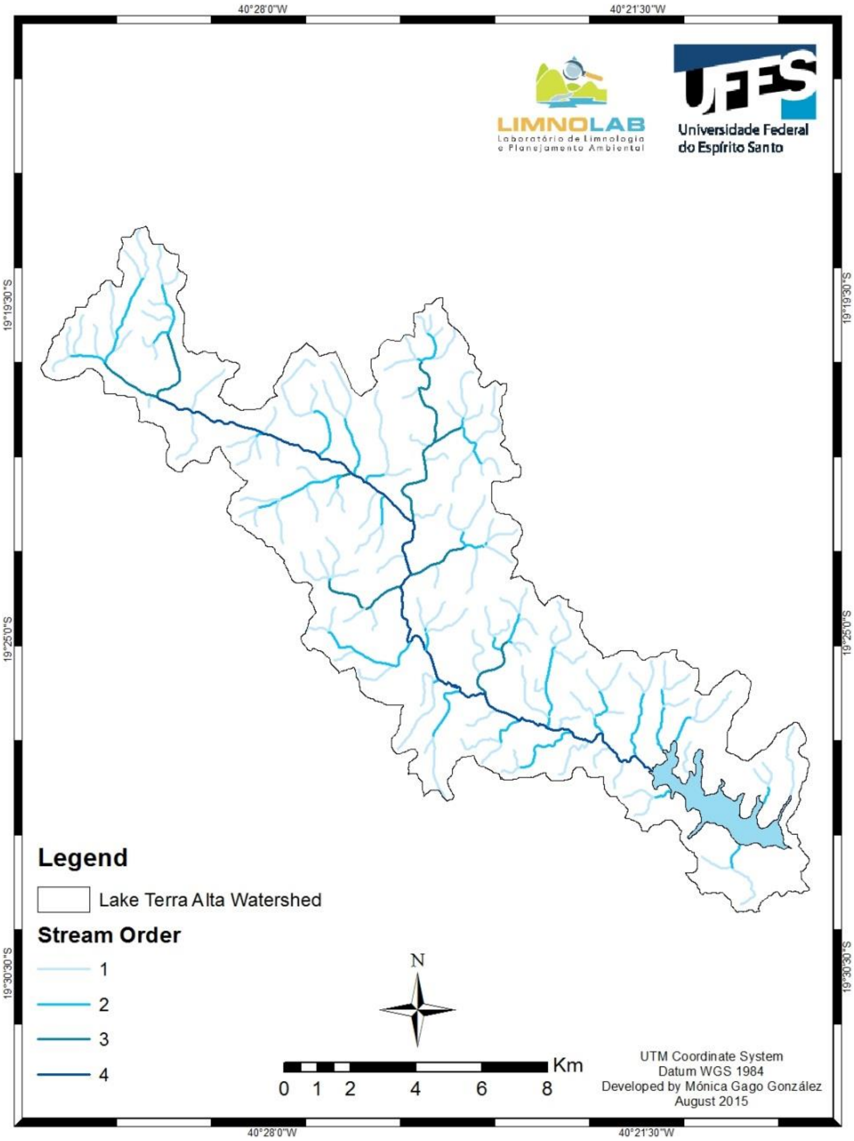


Figure 5.8. Stream order on LTA watershed.

- *Stream number (Nu)*

LTA has a total of 236 streams, and is the B5 the subbasins which contribute more to this number because presents 217 streams. The other subbasins are much less complex, B4 have 5 streams, B2, B3, B6 and B7 have 3 streams and B1 only have 1 stream.

- *Stream length (Lu)*

LTA catchment has a total stream length of 218.13 km of which 132.48 km correspond to order 1. 42.61km to order 2, 19.02km to order 3 and 24.02 km to order 4. B1 has 2.23 km of stream length, all pertaining to 1st order stream. B2 has a total of 2.05 km being 1.49 km correspondent to order 1 and 0.56 km to order 2. B3 has a total of 3.33 km, 2.37 km corresponding to order 1 and 0.96 km to order 2. For B4 the stream length for order 1 is 2.73 km and for order 2 is 1.98 km from the 4.71 km of the total subbasin. The subbasin B5 has a total stream length of 198.5 km of which 117.76 km correspond to order 1, 37.7 km to order 2, 19.02 km to order 3 and 24.02 km to order 4. B6 has a total of 2.63 km being 2 km correspondent to order 1 and 0.63 km to order 2. And for B7 the total is 3.55 km from which 2.79 km are order 1 and 0.76 km are order 2.

- *Drainage density (Dd)*

For the LTA watershed the drainage density is 1.51. The results for its subbasins varies between 1 and 2, being B2 the subbasin with higher drainage density (2.09) , followed by B6 (1.89), B4 (1.64), B5 (1.62), B1 (1.18), B3 (1.18), B7 (1.07).

- *Stream frequency (Fs)*

On the case of stream frequency, 1.64 is the value for the all LTA basin. For B1, B2, B3, B4, B5, B6 and B7 are stream frequency is respectively 0.53, 3.07, 1.06, 1.74, 1.77, 2.15, and 0.90.

-*Bifurcation ratio (Rb)*

The mean bifurcation ratio for LTA is 1,96. For B5 is 1.85, nevertheless for the rest of subbasins the result is based in an unique value because they have only 2 streams order. Thus, for B2, B3, B6 and B7 the bifurcation ratio is 2, and for B4 is 1.5. In case of B1, as only has 1 stream order was not possible to obtain the bifurcation ratio. Those low values indicate for all subbasins poor structural disturbances and higher permeability of the terrain according Magesh et al., 2013.

-Length of overland flow (Lg)

For LTA basin the length of overland flow is 0.33. For B1, B2, B3, B4, B5, B6 and B7 the values 0.42 , 0.24, 0.42, 0.31, 0.31, 0.27 and 0.47 respectively.

-Form factor (Rf)

The form factor of LTA is 0.17 . The values for the subbasins are 0.18 for B1 and B3, 0.15 for B2, 0.17 for B4, 0.22 for B5, 0.21 for B6, and 0.36 for B7

-Elongation ratio (Re)

Values for elongation ratio in LTA and B1, B2 B3 B4, B5, B6 and B7 are 0.28, 0.39, 0.41, 0.37, 0.35, 0.31, 0.47, and 0.57 respectively.

-Circularity ratio (Rc)

LTA has a very small value of circularity ratio, 0.1. For this parameter the values are less uniform along the subbasins, being the biggest one B2 with 0.66, followed by B6 with 0.57, B1 and B3 0.53, B7 with 0.52, B4 with 0.5 and B5 with 0,2.

-Infiltration number (If)

The infiltration number for LTA is 2.47. This value varies considerably for one basin to another being B2 the basin with 6,42, the higher infiltration number followed by B6 with 4.06, B5 with 2.87, B4 with 2.85, B3 with 1.25, B7 with 0.97 and B1 with 0.63.

Table 5.1. Results of the morphometric parameters for the seven subbasins of LTA catchment where: watershed area (A) in km^2; watershed perimeter (P) in km; watershed length Lb; slope (S) in %; stream length (Lu); stream number (Nu); Drainage density (Dd); Stream frequency (Fs); Bifurcation ratio (Rb); Length of overland flow (Lg); Form fator (Rf); Elongation ratio (Re); Circularity ratio (Rc); Infiltration number (If)

	A (km^2)	P (km)	S (%)	Lb (km)	U	Nu	Σ Nu	Lu (km)	Σ lu (km)	RL	Dd	Fs	Rb	Rbm	Lg	Re	Rf	Rc	If
B1	1.89	6.66	22.92	2.24	1	1	1	2.23	2.23	-	1.18	0.53	-		0.42	0.39	0.18	6.66	0.63
B2	0.98	4.31	34.92	1.53	1	2	3	1.49	2.05	-	2.09	3.07	2.00	2.00	0.24	0.41	0.15	12.84	6.42
					2	1		0.56		0.38			-						
B3	2.83	8.22	32.66	2.92	1	2	3	2.37	3.33	-	1.18	1.06	2.00	2.00	0.42	0.37	0.18	4.44	1.25
					2	1		0.96		0.41			-						
B4	2.88	8.48	38.07	3.09	1	3	5	2.73	4.71	-	1.64	1.74	1.50	1.50	0.31	0.35	0.17	4.37	2.85
					2	2		1.98		0.73			-						
B5	122.51	87.41	35.93	22.45	1	109	217	117.76	198.50	-	1.62	1.77	1.88	1.85	0.31	0.31	0.22	0.10	2.87
					2	58		37.70		0.32			3.05						
					3	19		19.02		0.50			0.61						
					4	31		24.02		1.26			-						
B6	1.39	5.54	23.77	1.59	1	2	3	2.00	2.63	-	1.89	2.15	2.00	2.00	0.27	0.47	0.21	9.01	4.06
					2	1		0.63		0.32			-						
B7	3.32	8.94	4.91	2.04	1	2	3	2.79	3.55	-	1.07	0.90	2.00	2.00	0.47	0.57	0.36	3.78	0.97
					2	1		0.76		0.27			-						

5.3 In situ discharge measurements

Results of the measured discharge are represented on Table 5.2 the is presented for the annual mean as well as for the dry and wet seasons. The mean annual measured discharge on the subbasins of LTA is on average 0.6781 m³/s, being the biggest subbasin B5, which contribute with the with higher discharge of 0.588 m³/s. B7 the next subbasin in area follows with 0.155 m³/s and progressively decreasing we find B3 with 0.011 m³/s, B4 and B6 with 0.006 m³/s and B1 and B2,the smallest subbasins with the smallest discharge, 0.004 m³/s.

On the dry season B5 still contribute with the highest discharge of 0.2508 m³/s, followed by B7 with 0.0217 m³/s, B3 with 0.0088 m³/s, B6 with 0.0036 m³/s, B2 with 0.003 m³/s and B1 with 0.0003 m³/s. During the wet season B5 continues having the highest discharge with 0.633 m³/s. But now is followed by B3 with 0.024 m³/s, B4 with 0.011 m³/s, B6 and B1 with 0.006 m³/s, B2 with 0.005 m³/s, and B7 with 0.004 m³/s is the subbasin with the smallest discharge.

Table 5.2. *In situ* discharges of LTA subbasins. Where: MAMe Q (Mean Annual Measured Discharge)(m³/s); MDMe Q(m³/s)(Mean Dry Season Measured Discharge), MWMe Q(m³/s)(Mean Wet Season Measured Discharge)

Subbasin	Area (km²)	MAMe Q(m³/s)	MDMe Q(m³/s)	MWMe Q(m³/s)
B1	1.89	0.004	0.0003	0.006
B2	0.98	0.004	0.0030	0.005
B3	2.83	0.011	0.0088	0.024
B4	2.88	0.006	0.0062	0.011
B5	122	0.588	0.2508	0.633
B6	1.39	0.006	0.0036	0.006
B7	3.32	0.155	0.0217	0.004

Table 5.3. *In situ* effective discharges of LTA catchment subbasins. Where: MAMe Ef Q(m^3/km^2/y) (Mean Annual Measured Effective Discharge); MDMe Ef Q(m^3/km^2/Aug)(Mean Dry Month Measured Effective Discharge), MWMe Ef Q(m^3/Km^2/Nov) (Mean Wet Month Measured Effective Discharge)

Subbasin	Area (km^2)	MAMe Ef Q(m^3/km^2/y)	MDMe Ef Q(m^3/km^2/Aug)	MWMe Ef Q(m^3/Km^2/Nov)
B1	1,89	74370	425	7954
B2	0,98	138372	8199	13753
B3	2,83	120508	8328	21981
B4	2,88	71018	5766	10080
B5	122	151272	5483	13401
B6	1,39	133857	6936	11747
B7	3,32	1475162	17506	3279

When the effective discharge is calculated and thus, the total area is ignored obtaining the discharge per km^2, the results change considerably as we can observe in Table 5.3. where the exact results are presented.

For the annual mean Mean Annual Measured Effective Discharge (MAMe Ef Q) B7 has more than 1475000 m^3/km^2/y being the subbasin with higher discharge, followed by B5,the biggest subbasin contributing more than 151000 m^3/km^2/y. B2,the smallest subbasin, has more than 138000 m^3/km^2/y, B6 more than 133000 m^3/km^2/y, B3 more than 120000 m^3/km^2/y, B1 more than 74000 m^3/km^2/y and B4 with around 71000 m^3/km^2/y.

On the driest month (August) B7 has now the biggest discharge with 17500 m^3/km^2/y, followed by B3 and B2 with more than 8000 m^3/km^2/y, B6 with almost 7000 m^3/km^2/y, B4 with almost 6000 m^3/km^2/y, B5 with almost 5500 m^3/km^2/y and B1 with the smallest discharge with only 425 m^3/km^2/y.

Regarding the wettest month (November), B3 with almost 22000 m^3/km^2/y has the highest discharge. B2 which is the smallest subbasin is the one with higher discharge with more than 13700 m^3/km^2/y and is followed by B5 with 13400 m^3/km^2/y, B6 with more than 11700 m³/km²/y, B4 with 10000 m³/km²/y, B1 with almost 8000 m³/km²/y and B7 with more than 3200 m³/km²/y.

3.4 Rainfall model.

The results of the rainfall model represented on Map 3.9. that use the same color scale for the three periods, shows that during wet and dry season the rainfall is more homogenous along the subbasin, meanwhile, for the annual mean the rainfall distribution is not uniform, registering the highest values of precipitation on the north of the LTA catchment and in smaller degree in the southern part surrounding the lake.

The maximum precipitation modelled is over 1100 mm and the minimum is 21mm. The results obtained on average for the altimetry classes are presented on Table 5.4. , ranging from 726mm to 1115mm for the annual mean, from 26mm to 36mm on the driest month, and from 152mm to 214mm for the wettest month. On the three periods the lowest altimetry classes have the lowest precipitations, which are increasing progressively till their maximum values on the highest altitudes.

Table 5.4. LTA catchment average modelled precipitation (mm) for the Annual mean (AMP), the driest month (DP) and the wettest month (WP).

Classes	AMP (mm)	DP(mm)	WP(mm)
0-100	736	26.52	152
100-200	726	25.53	155
200-300	778	26.69	166
300-400	854	29.05	177
400-500	882	29.90	181
500-600	1016	34.01	200
600-700	1083	35.89	209
700-800	1115	36.62	214

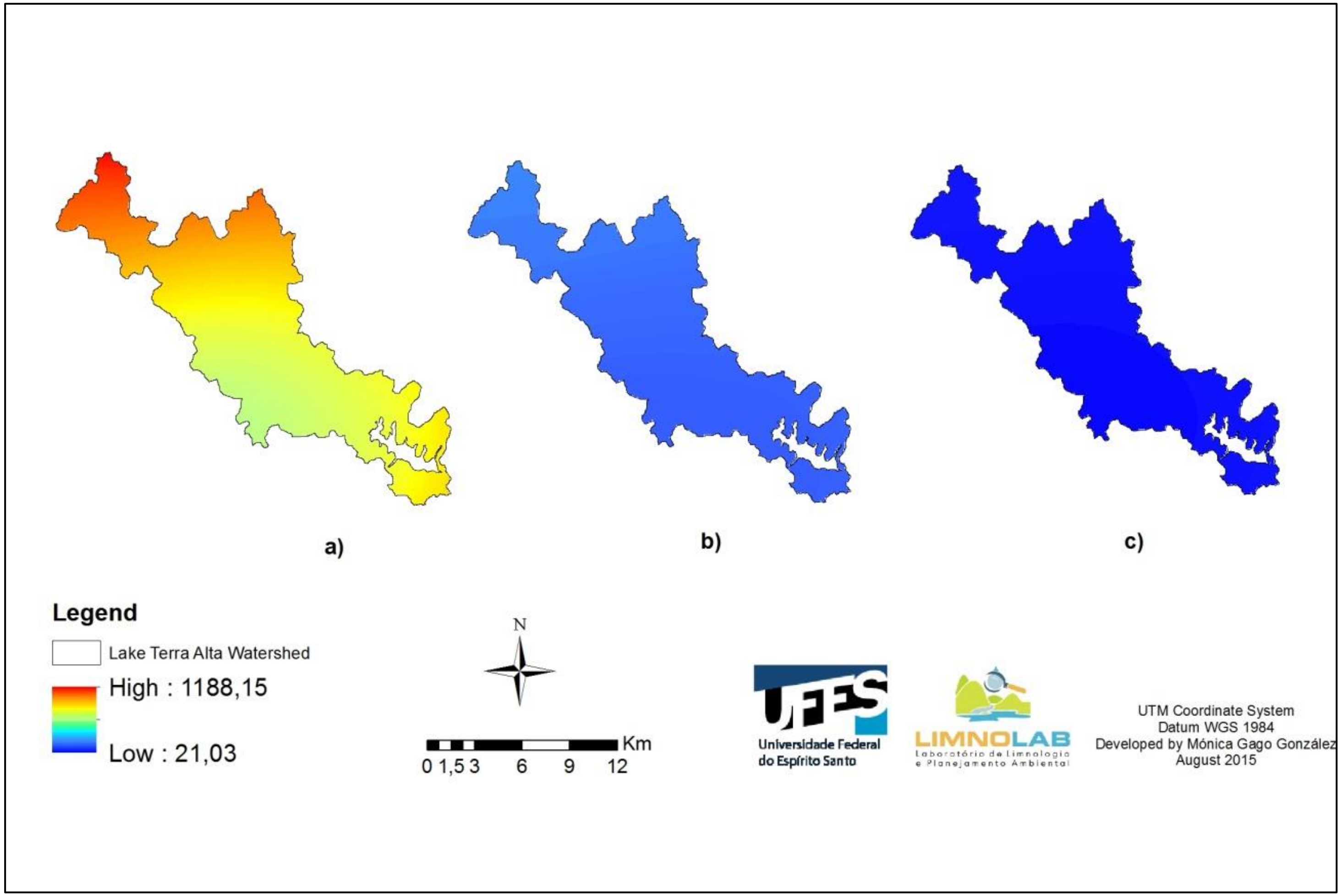


Figure 5.9. Rainfall model for LTA catchment, where a) annual mean, b) wettest month (December) and c) driest month (August).

5.5 Flow estimation

The discharges calculated from the rainfall model developed previously are represented on Table 5.5. where is evident a considerable decrease in magnitude compared with measured ones. Starting with the mean annual modelled discharge follows the same trend than the measured discharge. B5 has the highest discharge with 0,320 m³/s, wich if followed in decreasing order by B3 and B7 with 0.004 m³/s, B1 and B4 with 0.003 m³/s and B2 and B6 with 0.001 m³/s.

For the dry season the B5 with 0.006 m³/s still has the highest discharge, being followed by B7 and B1 with 0.00006 m³/s, B3 with 0.00005 m³/s, B2 and B4 with 0.00003 m³/s and B6 with 0.00001 m³/s. Those results show that the trend of the discharged obtained in situ is not maintained.

In case of the wet season the same situation is faced, changing not only the magnitude of the value but the trend as well, being B5 the highest with 2.9 m³/s, followed by B3, B4 and B7 with 0.05 m³/s, B1 with 0.03 m³/s, and B2 and B6 with 0.02 m³/s.

Table 5.5. Modelled discharges of LTA catchment subbasins. Where: MAMo Q (Mean Annual Modelled Discharge)(m³/s); MDMo Q(m³/s)(Mean Dry Season Modelled Discharge), MWMo Q(m³/s)(Mean Wet Season Modelled Discharge.

Subbasin	Area (km²)	MAMo Q(m³/s)	MDMo Q(m³/s)	MWMo Q(m³/s)
B1	1.89	0.003	0.00006	0.03
B2	0.98	0.001	0.00003	0.02
B3	2.83	0.004	0.00005	0.05
B4	2.88	0.003	0.00003	0.05
B5	122	0.302	0.00614	2.94
B6	1.39	0.001	0.00001	0.02
B7	3.32	0.004	0.00006	0.05

The modelled effective discharges (Table 5.6.) of the annual mean shows difference with the ones measured in situ, being B5 the highest with more than 77600 m³/km²/y, followed B1 with 52100 m³/km²/y, B2 with more than 46600 m³/km²/y, B3 with 42000 m³/km²/y, B7 with more than 41100 m³/km²/y, B4 with more than 36500 m³/km²/y and B6 with almost 30200 m³/km²/y.

For the dry month B5 still having the highest discharge with 134 m³/km²/Aug, is followed by B1 with 79 m³/km²/Aug, B2 with 73 m³/km²/Aug, B7 with 46 m³/km²/Aug, B3 with 42 m³/km²/Aug, B4 with 29 m³/km²/Aug and B6 with 20 m³/km²/Aug. Regarding the wet month B5 with more than 64000 m³/Km²/Nov shows the highest discharge, and the rest of the subbasins presents much less variation: B1 almost 47000 m³/Km²/Nov, B3 more than 45400 m³/Km²/Nov , B2 with more than 45100 m³/Km²/Nov,B4 with 44400 m³/Km²/Nov, B7 around 41500 m³/Km²/Nov, and B6 with more than 40800 m³/Km²/Nov.

Table 5.6. Modelled effective discharges of LTA catchment subbasins. Where: MAMo EfQ (Mean Annual Modelled Effective Discharge)(m³/s); MDMo Ef Q(m³/s)(Mean Dry Month Modelled Effective Discharge), MWMo Ef Q(m³/s)(Mean Wet Month Modelled Effective Discharge)

Subbasin	Area (km²)	MAMo Ef Q(m³/km²/y)	MDMo Ef Q(m³/km²/Aug)	MWMo Ef Q(m³/Km²/Nov)
B1	1.89	52119	79.26	46913
B2	0.98	46606	73.35	45113
B3	2.83	42002	42.92	45463
B4	2.88	36554	29.54	44401
B5	122	77640	134	64313
B6	1.39	30180	20.73	40850
B7	3.32	41123	46.34	41549

3.6 Hydrochemistry analysis

The results of the TN and TP concentrations obtained for the LTA catchment subbasins are presented on Table 5.7. and for the effective discharge of TN and TP on Table 5.8. In both cases the values are ranked in the order of most relevant to least relevant contribution to the stream.

For Mean annual Total Nitrogen (MATN) presents concentrations of 1246.82 μg·L^{-1} in B5, 950.9 μg·L^{-1} in B4, 922.82 μg·L^{-1} in B1, 848.36 in B3 μg·L^{-1}, 667.78 μg·L^{-1} in B7, 578.7 μg·L^{-1} in B2 and 493.01 μg·L^{-1} in B6.

During the dry season the concentrations (MDTN) were 1096.64 μg·L^{-1} in B5, 851.19 μg·L^{-1} in B4, 743.54 μg·L^{-1} in B1, 576.48 μg·L^{-1} in B2, 504.02 μg·L^{-1} in B3, 438.47 μg·L^{-1} in B7 and 208.71 μg·L^{-1} in B6.

The concentrations during wet season (MWTN) were equal to 1447.08 μg.L^{-1} in B5, 1307.48 μg.L^{-1} in B3, 1161.86 μg.L^{-1} in B1, 1083.85 μg.L^{-1} in B4,973.51 μg.L^{-1} in B7, 872.07 μg.L^{-1} in B6 and 581.88 μg.L^{-1}in B2.

The concentrations of the Mean annual Total Phosphorous (MATP) are equal to 577.27 μg·L^{-1} in B3, 310.53 μg·L^{-1} in B7, 256.17 μg·L^{-1} in B2, 209.56 μg·L^{-1} in B2 , 188.04 μg·L^{-1} in B6, 147.37 μg·L^{-1} in B1 and 124,42 μg·L^{-1} in B5.

During the dry season the MDTP were 620.21 μg·L^{-1} in B3, 435.54 μg·L^{-1} in B7, 291.12 μg·L^{-1} in B4, 279.21 μg·L^{-1} in B2, 271.09 μg·L^{-1} in B6, 241.25μg·L^{-1} in B1 and 166.42 μg·L^{-1} in B5.

The concentrations during wet season (MWTP) were 520 μg.L^{-1} in B3, 225.35 μg.L^{-1} in B2, 143.84 μg.L^{-1} in B7, 77.31 μg.L^{-1} in B6, 68.42 μg.L^{-1} in B5, 44.38 μg.L^{-1} in B4 and 22.19 μg.L^{-1}in B1.

Table 5.7. LTA subbasins nutrient concentration in (μg.L^{-1}) of LTA subbasins. Where, MATN is Mean annual Total Nitrogen, MDTN is the Mean Total Nitrogen of the dry month, MWTN is the Mean Total Nitrogen of the wet month, MATP is Mean annual Total Phosphorous, MDTP is the Mean Total Phosphorous of the dry month and MWTP is the Mean Total Phosphorous of the wet month.

Subbasin	MATN (μg.L^{-1})	MDTN (μg.L^{-1})	MWTN (μg.L^{-1})	MATP (μg.L^{-1})	MDTP (μg.L^{-1})	MWTP (μg.L^{-1})
B1	922	743	1161	147	241	22.19
B2	578	576	581	256	279	225
B3	848	504	1307	577	620	520
B4	950	851	1083	209	291	44.38
B5	1246	1096	1447	124	166	68.42
B6	493	208	872	188	271	77.31
B7	667	438	973	310	435	143

Table 5.8. Nutrient loads of LTA catchment subbasins. Where: MAETN (Mean Annual Effective Discharge of TN)(Kg/km^2/y); MDETN(Kg/km^2/y)(Mean Dry Month Effective Discharge of TN), MWETN (Kg/km^2/y)(Mean Wet Month Modelled Effective Discharge of TN); MAETP (Mean Annual Effective Discharge of TP)(Kg/km^2/y); MDETP(Kg/km^2/month)(Mean Dry Month Effective Discharge of TP), MWETP (Kg/km^2/month) (Mean Wet Month Effective Discharge of TP)

Subbasin	MAETN (Kg/km^2/y)	MDETN (Kg/km^2/Aug)	MWETN (Kg/km^2/Nov)	MAETP (Kg/km^2/y)	MDETP (Kg/km^2/Aug)	MWETP (Kg/km^2/Nov)
B1	1146	0.45	13.11	183	0.15	0.25
B2	2580	12.94	21.89	1142	6.27	8.48
B3	1140	3.98	27.23	775	4.89	10.83
B4	740	4.57	10.18	163	1.56	0.42
B5	48.55	0.13	0.42	4.85	0.02	0.02
B6	1492	2.78	19.68	569	3.61	1.74
B7	9356	6.19	2.58	4350	6.15	0.38

For the annual mean of TN effective discharge B7 is the subbasin with higher contribution with 9356 Kg/km^2/y, and B2, the smallest subbasin, the next in nutrient input with 2580 Kg/km^2/y. B6 contributes with 1492 Kg/km^2/y, followed by B1 and B3 with 1146 and 1140 Kg/km^2/y respectively, B4 with 740 Kg/km^2/y and the B5, with only 48 Kg/km^2/y.

On the dry month is B2 which higher TN contribute with 12.94 Kg/km^2/Aug, followed by B7 with 6.19 Kg/km^2/Aug, B4 with 4.57 Kg/km^2/Aug, B3 with 3.98 Kg/km^2/Aug, B6 with 2.78 Kg/km^2/Aug, B1 with 0.45 and B5 with 0.13 Kg/km^2/Aug.

For the wet month the TN discharge is considerably higher than in the dry month. B3 contributes with 27.23 Kg/km^2/Nov, followed by B2 with 21.89 Kg/km^2/Nov, B6 with 19.68 Kg/km^2/Nov, B1 with 13.11 Kg/km^2/Nov, B4 with 10.18 Kg/km^2/Nov, B7 with 2.58 Kg/km^2/Nov, and finally B5 with 0.42 Kg/km^2/Nov.

TP mean annual effective discharge has shown that B7 with 43500 Kg/km^2/y is the subbasin that more TP with a considerable difference, followed by B2 with 1142 Kg/km^2/y, B3 with 775 Kg/km^2/y, B6 with 569 Kg/km^2/y, B1 with 183 Kg/km^2/y, B4 with 163 and B5 with only 4,85 Kg/km^2/y.

For the dry month the highest TP effective discharge in Kg/km^2/Aug ,is 6.27 on B2, 6.15 on B7, 4.89 on B3, 3.61 on B3, 1.56 on B4, 0.15 on B1 and 0.02 on B5.

The wet month TP effective discharge in Kg/km^2/Nov ,is 10.83 on B3, 8.48 on B2,1.74 on B6, 0.42 on B4, 0.38 on B7, 0.25 on B1 and 0.02 on B5.

5.7 Statistical analysis

For the PCA and cluster analysis only some variables were selected (Table 5.9.) and introduced on the MVSP 3.2 considering that are the most representative. Those parameters were the Slope , Drainage density , Stream frequency , Length of overland flow , Form factor , Elongation ratio , Circularity ratio , Infiltration number , Mean annual effective discharge, Mean annual effective Total nitrogen and Mean annual effective Total phosphorous, agriculture, pasture and forest.

-PCA analysis.

For the PCA and cluster analysis only some variables were selected (Table 5.9.) and introduced on the MVSP 3.2 considering that are the most representative. Those parameters were the Slope , Drainage density , Stream frequency , Length of overland flow , Form factor , Elongation ratio , Circularity ratio , Infiltration number , Mean annual effective discharge, Mean annual effective Total nitrogen and Mean annual effective Total phosphorous, agriculture, pasture and forest.

-PCA analysis.

The results of PCA analysis of variables and cases can be seen on Tables 5.10, 5.11. 5.12. and are graphically represented on the biplot (Figure 5.1)

Table 5.10. Representability of the two components of PCA analysis for the selected variables of LTA catchment.

	Axis 1	Axis 2
Eigenvalues	6.359	3.66
Percentage	45.424	26.141
Cum. Percentage	45.424	71.566

Table 5.10 show that components 1 and 2 explain the 71.56 % of the variance, and their relative contributions are 45.4 and 26.1 %, respectively.

For the hidromorphological variables and land use, in component one (Table.5.11.), the relative contribution was 0.36 for S, 0.29 for Dd, 0.26 for Fs, -0.31 for Lg, -0.32 for Re, -0.3 for Rf, -0.13 for Rc, 0.27 for If, -0.07 for agriculture, -0.2 for Pasture, 0.16 for forest, -0.29 for MAED, -0.29 for MAETN and -0.27 for MAETP.

For component 2 (Table 5.11.), was -0.009 for S, 0.31 for Dd and Fs, -0.28 for Lg, 0.25 for Re, -0.08 for Rf, 0.37 for Rc, 0.27 for If, -0.3 for agriculture, 0.29 for Pasture, -0.24 for forest, 0.003 for MAED, 0.28 for MAETN and 0.3 for MAETP.

Table 5.11. PCA analysis results of the morphological parameters.

PCA variables	Axis 1	Axis 2
S(%)	0.363	-0.009
Dd	0.299	0.31
Fs	0.261	0.312
Lg	-0.317	-0.286
Re	-0.322	0.249
Rf	-0.3	-0.081
Rc	-0.134	0.378
If	0.274	0.319
Agric	-0.077	-0.313
Past	-0.2	0.291
For	0.168	-0.241
MAED	-0.29	0.003
MAETN	-0.296	0.282
MAETP	-0.279	0.302

For the cases (Table 5.12.), the relative contribution of component one was -0.4 for B1, 0.77 for B2, -0.27 for B3, 0.63 for B4, 1.14 for B5, 0.06 for B6 and -1.94 for B7. And for component 2 was -0.61 for B1, 0.73 for B2, -0.3 for B3,-0.09 for B4, -1.05 for B5, 1.22 for B6 and 0.08 for B7.

Table 5.12. PCA analysis results of the seven subbasins of LTA.

PCA cases	Axis 1	Axis 2
B1	-0,405	-0,619
B2	0,776	0,739
B3	-0,275	-0,303
B4	0,637	0,099
B5	1,149	-1,057
B6	0,064	1,226
B7	-1,946	-0,085

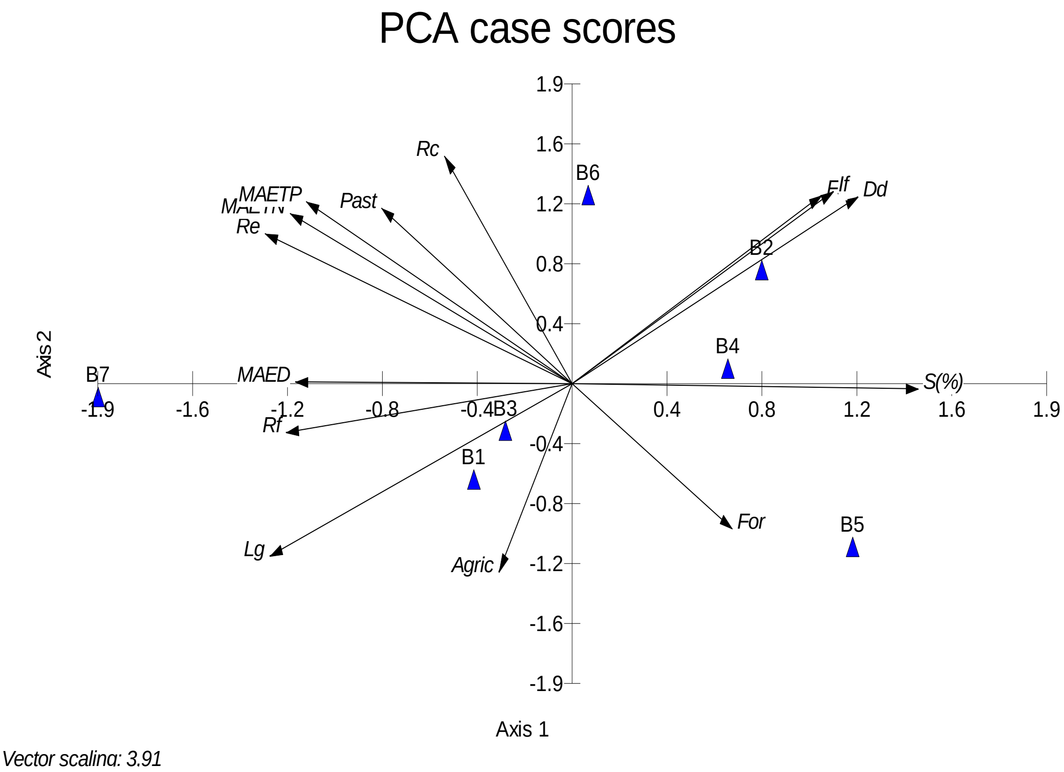


Figure 5.1. Biplot of the PCA analysis of LTA subbasins and the morphometric parameters: Slope (S); Stream length (Lu); Stream number (Nu); Drainage density (Dd); Stream frequency (Fs); Length of overland flow (Lg); Form factor (Rf); Elongation ratio (Re); Circularity ratio (Rc); Infiltration number (If), Mean annual effective discharge(MAED), Mean annual effective Total nitrogen (MAETN) and Mean annual effective Total phosphorous (MAETP) and % of Pasture, Agriculture and Forest.

-Cluster analysis

The introduction of the same variables on MVSP 3.2 gave as a result of the Cluster analysis on a dendogram (Figure 5.2.), where B1 and B3 shows the highest similarities between them meanwhile the rest of the basins are attached individually to this first cluster. Is B4 the first attached, then B2 with a bit more similarity, and B6, B7 and B5 are the next subbasins showing a decrease on similarity each time higher.

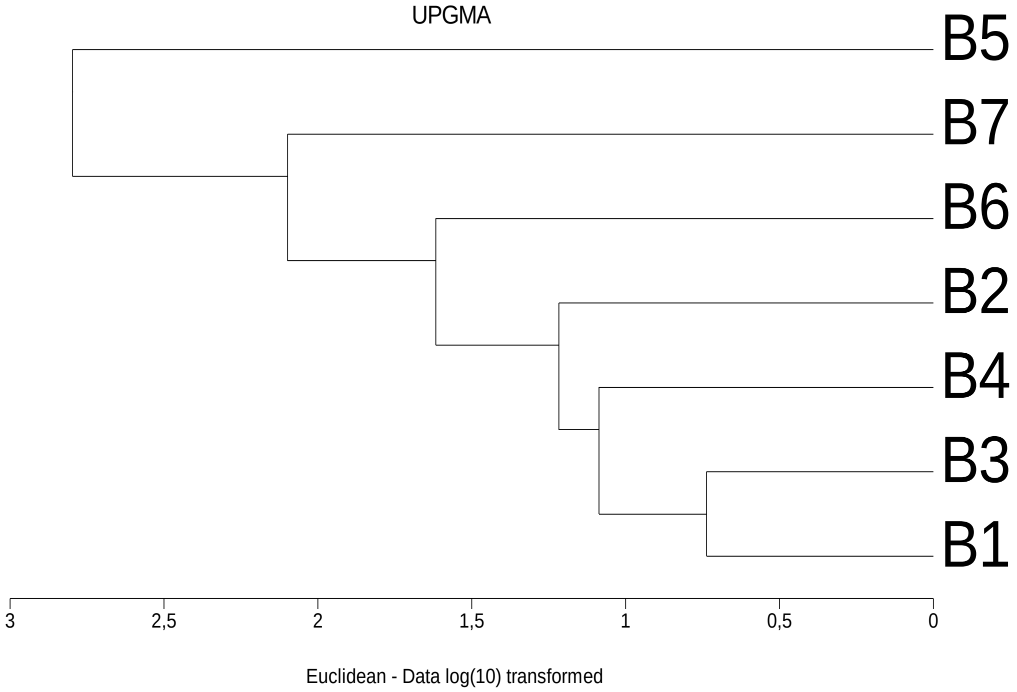


Figure 5.2. Dendogram obtained of the cluster analysis for the seven subbasins of LTA catchment.

Table 5.9. Variables of LTA catchment selected for multivariate statistical analysis: Slope (S); Stream length (Lu); Stream number (Nu); Drainage density (Dd); Stream frequency (Fs); Length of overland flow (Lg); Form factor (Rf); Elongation ratio (Re); Circularity ratio (Rc); Infiltration number (If), Mean annual effective discharge(MAED), Mean annual effective Total nitrogen (MAETN) and Mean annual effective Total phosphorous (MAETP), Pasture, Agriculture and Forest.

	S (%)	Dd	Fs	Lg	Re	Rf	Rc	If	Agric (%)	Past (%)	For (%)	MAED	MAETN	MAETP
B1	22.92	1.18	0.53	0.42	0.39	0.18	0.53	0.63	39.72	53.29	6.87	74370	1146	183
B2	34.92	2.09	3.07	0.24	0.41	0.15	0.66	6.42	33.96	34.16	31.75	138372	2580	1142
B3	32.66	1.18	1.06	0.42	0.37	0.18	0.53	1.25	24.55	62.43	8.10	120508	1140	775
B4	38.07	1.64	1.74	0.31	0.35	0.17	0.50	2.85	6.99	61.25	31.45	71018	740	163
B5	35.93	1.62	1.77	0.31	0.31	0.22	0.20	2.87	17.97	26.09	39.71	151272	48.55	4.85
B6	23.77	1.89	2.15	0.27	0.47	0.21	0.57	4.06	1.00	100	1.00	133857	1492	569
B7	4.91	1.07	0.90	0.47	0.57	0.36	0.52	0.97	25.70	62.31	12.00	1475162	9356	4350

6. Discussion

6.1 Discussion of the results

The maps obtained for the georeferenced data base are powerful tools, because they show key factors as land use and slope. The increase of the nutrient loads is associated with farming activities as well as runoff processes, which are influenced to a great extent by the basin slope (Arreghini et al., 2005; Vendramini et al., 2007). Then, is recommended the combined analysis for a better basin management because land use and slope and their relationship influence the water quality and quantity.

The water bodies are very vulnerable ecosystems to pollution and soil disturbances that results from the land use that introduce compounds into the water and degrade the soil enhancing the incorporation of suspended or dissolved solids to the water (Malmqvist & Rundle, 2002; Sperling and Chernicharo, 2005).The land uses registered by Barroso *et al*., (2013) for LTA watershed presents a 36% of natural forest, land cover that is associated with low discharges because of the rainfall interception by the trees and a priory don’t represent a big source of nutrients.

The rest of the basin is occupied by semi natural systems, with 31% of pastureland, 18% of agriculture and 10% of *Eucalyptus* forestry. The agriculture and cattle are considered as an important source of nutrients because of the use of fertilizers and the animal manure respectively (Carvalho et al., 2000, Gourley et al., 2012). In addition they are associated with the soil degradation, which in turns favors runoff and the nutrient losses into the streams (El-Hassanin et al., 1993; Carvalho et al., 2000; Koulouri and Giourga 2007; Qadir 2014).

The slope is a very important factor affecting soil erosion intensity (Morgan, 1986 ; Fox and Rorke, 1999). The average slope of the basin is strongly undulated, considering that steep slopes are related with the increase of runoff and thus, soil losses, the negative impacts of the land uses may be enhanced (El-Hassanin et al., 1993; Kosmas, 1995; Fox and Rorke, 1999; Koulouri and Giourga 2007). This reveals the need of a bigger effort on management because those characteristics may alter the hydrological cycles of the basin. If land use and slope, variables which alters the hydrological cycles are analyzed combined with rainfall, discharge, and sediments and nutrient loads the understanding of the ecosystem increase and is easier to prevent and mitigate negative impacts related with the environmental changes.

The morphometric parameters selected for the statistical analysis of LTA subbasins are similar to the Lake Nova watershed according to (Amorim 2015), which is interesting due to the difficulty to compare the LTA subbasins with other studies because of the big difference on climate and size. The similarities of the Lake Nova watershed, being part as well to the LDRV Lake District, due to its proximity to LTA make of this study a good reference to compare the obtained data.

Is important to analyze the basin shape because the way in which floods are formed and move depend on it (Zavoianu, 1985). According to Zavoianu 1985, the rounded basins are more prone to floods because they can travel with more velocity, this lead to an increase on the erosion and transport capacities and in consequence the suspended load is greater and the geomorphology of the basin change faster. Then, elongated basins favors a diminution of floods because tributaries flow into the main stream at greater intervals of time and space and have higher capacity to distribute runoff (Zavoianu, 1985; Pareta 2011,2012; Romshoo et al., 2012; Meraj et al., 2015).

Re, Rf and Rc are the shape related parameters which defines the form of the basin. The shape related parameter of LTA subbasins are (Table 5.9): for Rf maximum and minimum values are respectively 0,15 in B2 and 0,36 in B7, the maximum and minimum Values for Re are respectively 0,47 in B1 and 0,28 in B7 and for Rc the maximum and minimum values are respectively in 0,66 in B2 and 0,2 in B5.

Drainage density (Dd), infiltration number (If), stream frequency (Fs) are properties linked with the hydrological response of a drainage basin based on the infiltration capacity of the watershed, which is influenced by the permeability and relief (Horton, 1945; Strahler 1964; Melton 1957; Zavoianu 1985; Moglen 1998; Pareta 2011,2012; Romshoo et al., 2012; Meraj et al., 2015).

The Dd values obtained for the LTA subbasins (Table 5.9) varies between 1 and 2. Different authors agrees that drainage density varies from 0,5 km/km^2 to 3,5 km/km^2. The basins with higher values are more prone to erosion because they are better drained, associated with impermeable materials, lower infiltration capacity and in consequence, a relatively rapid hydrological response to rainfall events.(Horton 1945; Carlston 1963; Moglen 1998; Almeida et al., 2009; Romshoo et al., 2012). Then subbasins, which present medium low values, are prone to runoff processes.

Fs is related to permeability and infiltration capacity of watersheds (Montgomery and Dietrich 1989). In general low values are associate to soil erosion and are also associated with low stream quantity and capacity of generation of new ones , wich is the situation od LTA subbasins (Table 5.9).

The range of Values of If on LTA subbasins is very wide (Table 5.9), and in consequence this parameter is highly dependent of the subbasin. This value is inversely proportional to the infiltration capacity (Romshoo et al., 2012), the higher values shows lower infiltration capacity which is associated with early discharge peaks, thus, higher runoff which in last term is associated to soil degradation.

To analyze the water flows were obtained in situ measurements of discharge and modelled discharge to calculate after effective discharges where the water flow is not dependent of the size of the subbasins.

The in situ discharge measurements results show that for the seven subbasins of LTA watershed the mean annual measured discharge is 0.67 m³/s, a high value compared with the result of Amorim (2015) where the mean annual discharge of the three subbasins of Lake Nova which conforms a much bigger watershed is 0.54 m³/s.

Mean annual measured discharge shows that the biggest subbasin, B5, compared with the other subbasins (Table 5.2.), contributes with sharply higher discharge (0.588 m³/s) and the smaller subbasin, B2, with the smallest discharge (0.004 m³/s). On the dry season B5 still contribute with the highest discharge of 0.2508 m³/s, but B1 shows the smallest with 0.0003 m³/s. And during the wet season B5 continues having the highest discharge with 0.633 m³/s and B7 with 0.004 m³/s is the subbasin with the smallest discharge. The magnitude of the discharges during the wet season where the higher ones for the tree periods of time for all subbasins except for B7, this may be caused for the presence of the outflow of a lake adjacent to B7 which presents a source of water even on the dry periods, however there were no visual connection and was not considered on this study. For the three periods the biggest subbasin presents the higher discharges, then, was interesting avoid the size factor and calculate the effective discharge.

The results of the effective discharge have shown the importance of small subbasins on LTA catchment. The results of Table 5.3. showed that B5, almost 120 km² bigger than the rest of subbasins, presented the biggest discharge with a very important difference on magnitude with regard to the others, nevertheless once the effective discharge was obtained the changes were considerable and the biggest subbasin wasn't any more the one with the biggest discharge. For the annual mean effective discharge, B7 with 1475162 m³/km²/y is the highest, meanwhile B5, even having the second higher discharge, is much smaller with only 151272 m³/km²/y. Is important to mention that this discharge that is closely followed by B2, the smallest subbasin with 138372 m³/km²/y. On the driest month (August) B7 has now the biggest discharge with 17500 m³/km²/y and B1 with the smallest discharge with only 425 m³/km²/y. During the wettest month (November), B3 with almost 22000 m³/km²/y has the highest discharge and B7 the smaller with more than 3200 m³/km²/y. As well as for direct discharges the wet period presents bigger discharge than during the dry period, except for subbasin B7, nevertheless, the discharges during the mean annual are the ones with bigger magnitude while for the direct ones were on the wet period.

The results of modeled discharges (Table 5.5) are based on a rainfall model (Table 5.4) where the altimetry class is an important factor for the precipitation, precipitation which increases simultaneously with the elevation of the area. The magnitude of the precipitation is much higher for the annual mean than for the wet period.

The mean annual modelled discharge follows the same trend than the measured discharge where B5, the biggest subbasin B5 has the highest discharge (0.320 m³/s) and B2, the smallest subbasin together with B6 only have 0.001 m³/s. For the dry season the B5 with 0.006 m³/s still has the highest discharge and B6 with 0.00001 m³/s the smallest, and in case of the wet season the same situation is faced, changing not only the magnitude of the value but the trend as well, being B5 the highest with 2.9 m³/s, and B6 the lowest with 0.02 m³/s.

In other hand, the modelled effective discharges (Table 5.6.) of the annual mean shows difference with the ones measured in situ, being B5 which more contribute, with more than 77600 m³/km²/y, and B6 the subbasin with less contribution with almost 30200 m³/km²/y. For the dry month B5 still having the highest discharge with 134 m³/km²/Aug, and B6 the smallest with 20 m³/km²/Aug. Regarding the wet month B5 with more than 64000 m³/Km²/Nov shows the highest discharge and B6 with more than 40800 m³/Km²/Nov the lowest. The magnitudes of the discharge were also bigger for the wet period than on dry period for all subbasins meanwhile for the measured that was valid for all subbasins with the exception of B7.In contrast with the measured effective discharges the magnitude of mean annual discharge are not bigger than on wet period for all the subbasins, being higher on wet period for B3, B4, B6 and B7.

The comparison between the measured in situ discharge and the modelled obtained with the rainfall model shows a considerable difference. The results obtained with the modeled discharges are clearly not in line with the trends of the measured discharges, and the magnitudes of the values of the modelled discharge are smaller. It was expected that the measured discharges were smaller than the modelled ones due to the natural or anthropogenic factors of water loss, especially due to water extraction for land uses like irrigation that requires high quantities of water. Nevertheless, in situ discharges are significantly higher than the modelled, same situation than in the study of Amorim (2015) where a similar rainfall discharge model showed the same situation. There are many factors that may affect, as the rainfall intensity and timing, but this factor affects as well the measured ones. The influence of the groundwater may be a determinant factor for those differences, because the contribution of the groundwater is present on the *in situ* discharge but unfortunately we can´t quantify it, nevertheless the modelled discharges are only based on rainfall data which may be an important reason why the magnitudes are so different and much smaller. Dams presence may influence those differences as well because the dams generate variations on hydrological regime, occasioning the disruption in the magnitude or timing of natural river flows and in consequence processes taking place on the stream channel as erosion processes and sediment transport with repercussion on the structure and function of the water bodies (Zalewski et al., 1997; Puckridge et al., 1998; Brandt 2000; Rossemberg et al., 2000; Coelho 2008). Even the small dams for irrigation that could represent a very strong effects on the hydrological flows individually, when are constructed in series along the river produce de denominated cascade effect, amplifying enormously the complexity and magnitude on the impacts on the hydrological flows (Troms e Walker, 1993; Brandt, 2000; Coelho, 2008). Considering that on LTA catchment are 33 small dams, the fluvial fragmentation due to the small impoundments along the streams could be the factor that explains this situation.

The seasonality between modelled and measured was different as well, because if the trend of all subbasin is that the higher discharges are registered on wet periods, the modelled didn't consider the exception that takes place on B7 which has bigger discharge on dry period than on wet period.

In consequence, due to those considerable differences obtained between the modelled discharges and the in situ ones, we consider that this model is not representative enough and can't be applied with accuracy to the study area, even if the methodology followed to develop the rainfall model and the discharge calculations showed that the results obtained were reliable in studies as Vicente-Serrano (2003).

As was mentioned before, different authors agree that the alterations on water quality which generate impacts on the aquatic ecosystems, are related with the direct input of nutrients which derivate from the land uses as agriculture and cattle and at the same time, the interaction between those land uses and their influence in soil degradation which as well enhance the nutrient inputs because promote the incorporation of suspended or dissolved solids to the water (Prato et al.,1989; Downing et al., 1999; Carvalho et al., 2000; Malmqvist & Rundle, 2002; Arreghini et al., 2005 Sperling and Chernicharo2005 Santos 2005; Gourley et al., 2012; do Vale et al. 2013).

Regarding the nutrient concentration results (Table 5.7.), the Mean annual Total Nitrogen presents highest concentrations in B5 (1246.82 $\mu g \cdot L^{-1}$), and the lowest in B6 (493.01 $\mu g \cdot L^{-1}$). During the dry season, with 851.19 $\mu g \cdot L^{-1}$ B5 has the highest and B6 the lowest with 208.71 $\mu g \cdot L^{-1}$. During wet season with 1447.08 $\mu g . L^{-1}$, B5 continues showing the highest but now has B2 the lowest with 581.88 μg.L^{-1}. The TN concentration during the wet season was higher than in the dry period for all subbasins, being even higher than in the annual mean.

The concentrations of the Mean annual Total Phosphorous (Table 5.7.) presents some differences with TN, having as the higher concentration 577.27 μg·L^{-1} in B3, and the lowest in B5 (124.42 μg·L^{-1}.). 620.21 μg·L^{-1} in B3, and 166.42 μg·L^{-1} in B5. For dry season the higher and lower concentrations were respectively 520 μg.L^{-1} as well in B3, and 22.19 μg.L^{-1}in B1. The TP concentration during the dry season was higher than in the wet period for all subbasins, being even higher than in the annual mean.

Comparing the results with a lake of the same lake district (LDRV) registered on the study of Amorim (2015), the higher concentrations of TN and TP in lake Nova were registered during the dry and cold periods meanwhile in lake Terra Alta the concentrations of TP are higher during the dry cold period but for the TN is during the we period where the higher concentrations have been registered. The concentrations of TN of Lake nova ranged between 279 μg·L^{-1} and 1646,4 μg·L^{-1} on dry season, between 198 μg·L^{-1} and 1059 μg·L^{-1} on wet season, between 20μg·L^{-1} and 44μg·L^{-1} on dry period and between 13μg·L^{-1} and 164μg·L^{-1} on wet period. Then, concentrations of the nutrients of the LTA subbasins are in general higher than on the subbasins of Lake Nova with the exception of TN on the dry season.

According to the Brazilian law nº 357 de 17/03/2005 (CONAMA 2005) for water quality , in fresh water of class 2 the maximum concentrations of TP the maximum concentration is 100 μg·L^{-1}. The values of LTA subbasins exceed the TP maximum concentration during the dry period in all subbasins and during the wet period on subbasins B2, B3 and B7, then special attention should be put on those subbasins. However, there is not a maximum value stabilized for TN , being only proposed a maximum value for TN when the competent environmental authority determines that the nitrogen is the limiting factor for eutrophication, then the maximum value is 2180μg·L^{-1}(Siqueire et al., 2012).

For the annual mean of TN effective discharge (Table 5.8.) B7 is the subbasin with higher contribution with 9356 Kg/km^{2}/y, and B2, the smallest subbasin, the next in nutrient input with 2580 Kg/km^2/y. B5 presents only 48 Kg/km^2/y. On the dry month is B2 which higher TN contribute with 12.94 Kg/km^2/Aug, and B5 contribute the less with 0.13 Kg/km^2/Aug. For the wet month B3 contributes with 27.23 Kg/km^2/Nov and B5 with 0.42 Kg/km^2/Nov being the subbasins with respectively higher and lower loads. The TN effective discharge during the wet season was higher than in the dry period for all subbasins, however was much higher for the annual mean.

TP mean annual effective discharge (Table 5.8.) has shown that B7 with 43500 Kg/km^2/y is the subbasin that more TP contributes and with only 4.85 Kg/km^2/y, the less. For the dry month the highest TP effective discharge is 6.27 Kg/km^2/Aug on B2, and the lower is 0.02 Kg/km^2/Aug on B5. The wet month a highest contribution is 10.83 on B3, and the lowest 0.02 Kg/km^2/Nov on B5.
The seasonality on the TP effective discharge is not so clear as for TN e because TPeffective discharge was higher during the dry period than during the wet on B4, B6, B7, higher on wet period for B1, B2, B3 and equal on B5.on the three cases the annual mean was higher than the season with higher discharge.

Is important to highlight that the trend of TN and TP match on the two subbasins regarding the subbasins with more contribution of nutrients during the annual mean, being B2 and B7 in the and B4 and B5 the subbasins with the smallest contribution. The nutrients effective discharge from B2 is surprisingly high, being the second in importance for the annual mean, being the smallest subbasin with only 0,98 km2 . In contrast, the biggest subbasin B5 has shown the smallest Tnutrients effective discharge. This fact is necessary to be considered by the managers.

The PCA analysis (Table 5.11) showed a very strong correlation between Dd, If, and Fs in both axis, being the most evident relationship on the biplot (Figure 5.1). B2 is located very close to them on the diagram, fact that corroborates the results of the calculations where B2 has the highest values of those parameters.

The values of the Form factor(Rf) elongation ratio (Re)and circularity ratio (Rc) are the three more representative parameter of basin shape (Majed 2009). On LTA subbasins agree with their low values , which means that are more elongated subbasins. The more elongated basins are associated with low peak discharges being less prone to floods

(Christofoletti, 1981; Romshoo et al., 2012; Magesh et al., 2013). Those parameters show correlation on the PCA(Table 5.11), having Re more correlation on axis 1 with Rf and on axis 2 with Rc.

Re and Rc agree on the two more elongated subbasins being B4 and B5 and B6 as the second more circular, but Rc considers B2 as the most circular instead of B7.

Rc, is related with the stream frequency, geology, land use and slope of the basin according Kaur et al. 2014. This definition consider the shape of the basin but at the same time the soil structure being a transitional parameter between the two main groups of parameters that we differentiate on the PCA analysis, matching with its location on the biplot (Figure 5.1), closer to Re and at the same time correlated by axis 2 with Dd, If and Fs.

On the other hand, according to Strahler 1964 the results of Re and Rf should be similar, nevertheless on the LTA subbasins there are some relevant differences on the results that may cause this lack of correlation on the PCA. B7 is the most circular for both parameters (Table 5.9), B1,B3 and B4 are on the same position, and B6 is almost at the same place being consider one of the more circular, nevertheless there are divergences with the most elongated, where for Re is B5 and for Rf is B2, subbasin that visually on the (Figure 5.2) does not match with the results.

Continuing with Rf and Re is observed an interrelation with Length of overland flow (Lg) having similar values on axis 1. On axis 2, are Rf and Re are more related between them and both presents good correlation with mean annual effective discharge(MAED) on the axis 1 of the PCA (Table 5.11), specially Rf. Lg, that showed less correlation with the previous parameters, depends on the slope and is influenced by the land use and type of cultivation (Zavoianu 1985). The correlation with slope on the PCA is not evident but forestry and agriculture show some correlations respect the axis 2, specially with agriculture.

Medium high slopes favors erosion processes due to rapid runoff (Magesh *et al.*, 2013) We can observe this relationship on the biplot (Figure 5.1) because slope is considerably well related with Dd, Fs and If, parameters which influence the runoff.

and the LTA subbasins are considered in general strongly undulated according to Embrapa 1979 classification. That means that this factor may be decisive on specific subbasins for water and nutrient flows.

The increase of the nutrient loads is associated with farming activities as well as runoff processes, which are influenced to a great extent by the basin shape (Arreghini et al., 2005; Vendramini et al., 2007). The biplot (Figure 5.1) shows a considerably high correlation between Re, TN and TP discharge (MAETN/MAETP) and pasture lands (past), and in lesser extent with MAED, Rc and Rf. The MAED and Rf shows bigger correlation between them on both axis of the PCA as we mentioned above, but the values of axis 1 correlate those parameters considerably with Re and nutrient loads.

To sum all the information generated, most of it present on the statistical analysis, the comparison of the results of the morphometric parameters, land use and hydrological flows between subbasins will help to distinguish the variables that more influence the water quantity and quality for each subbasin and in relation with the others..

PCA and cluster analysis (Figures 5.1. and 5.2.) agree on the correlation between B1 and B3 even if B3 is twice as large as B1, for this reason is interesting analyze them together. The results of the basin shape are the same for both subbasins revealing that are considerably elongated according to their values of Rc, Re and Rf, which indicated that are less prone to floods. The Dd, Fs and If values are small compared with other subbasins thus, according to different authors (Horton 1945, Strahler 1964; Montgomery and Dietrich 1989; Romshoo *et al.,* 2012). The lower values indicates that permeability of the substratum is higher, increasing and infiltration capacity, characteristics that show that there is lower availability of water to flow into the stream and are less prone to erosion, which may be related with the fact that are subbasins with low discharge. Nevertheless B1 effective discharge is much smaller. Considering that the morphometric parameters are very similar (Table 5.9), the low discharge may be more pronounced for the water withdraw for irrigation in two subbasins where agriculture is important in magnitude, especially for B1 where the agriculture is a 15 % higher and the discharge much lower. In addition B3 has a bigger stream order that generally involve higher discharge (Romshoo *et al.,* 2012). The higher slope and length of overland flow also favors the higher discharge and erosion processes transporting more sediments and nutrients to the streams. We can forget as well the contribution of the groundwater on the discharge that may vary significantly between subbasins, on this case being higher on B3, unfortunately there are not studies on this regard to contrast this hypothesis. The nutrient input is medium low compared with other subbasins (Table 5.9) for effective discharge, which on this case cannot be attributed to the dilution processes mentioned by Bowes et al., 2008 because of the low discharge, particularly on B1. However for TN they have almost the same contribution, and is on TP where the difference increase being on B3 notably higher. On this point is important remember that the concentration of B3 was very high, being over the limits that the Brazilian environmental criteria and regulations (CONAMA), which should be consider for management actions. The high values of TN for B1don´t seem to be result of the transport of the nutrients by the water because the discharge is low and is not very prone to erosion. Then, the high input seems to be more related with bad practices of the agricultural activities which are very water consuming which can be one main driver of the low discharge on B1, promote soil degradation and the wash out of nutrients from soils and their flow to the streams with the water of irrigation, and the use of fertilizer in higher concentrations that the required. Then, we could assume that land use, concretely agriculture is a principal factor determining hydrological flows on B1. Meanwhile, on B3 where the discharge is slightly higher than in B1 with very similar morphological parameters, land use seems to be determinant. In one hand more than the 60% of the basin is pasture land, activity that does not require water withdraw from the stream. In other hand its phosphorous discharge is much higher than on B1 meanwhile the nitrogen is almost the same, then, the phosphorous provided by the cattle manure of a land use much more extended and less balanced with agriculture on B3 may be the responsible of the high concentration of TP which even exceed the environmental law limit.

According to the results showed on **table**. B4, presents high values of slope, this agree with the very evident correlation on the PCA(Tables 5.11. and 5.12.) The results (Table 5.9) show as well that is the second more elongated subbasin but its relation on the PCA with the shape related parameters is not very strong. In other hand, the medium high values of Dd, Fs and If , which shows more correlation on the biplot (Figure 5.1)., are characteristics that show low infiltration capacity and vulnerability to erosion processes that favors the sediment and nutrient inputs to the streams, which could be enhanced due to the steep slope. Nevertheless the value for the annual discharge is very low compared with other subbasins. Being pasture the main land use, agriculture has a small presence on the basin, fact which dismiss the water withdraw for irrigation as a decisive factor for the low discharge values. The considerably high presence of forest located in the upper part of the basin, where is more prone to erosion due to the higher slopes (Figure 5.4.) , may be a decisive factor to reduce the water discharge because of the capacity of the vegetation cover, between other processes, to intercept the rainfall, increase the water infiltration, and transpiration, which results on a decrease of the speed and strength at which the water gets to the river, decreasing erosion and reducing the river discharge (Zhou et al., 2010; Birkinshaw et al., 2011; Iroumé and Palacios, 2013) . This low discharge related with the high presence of natural vegetation may be reason why B4 presents very low nutrient effective discharge compared with other subbasins because the reduced transport of sediments and nutrients into the stream.

According to the cluster analysis (Figure 5.2.) B5 is the subbasin less related with the others that conforms LTA catchment, nevertheless the results of the morphometric parameters (Table 5.9) are very similar to B4, insinuating a medium-big river discharge due to the low infiltration capacity and vulnerability to erosion because it has medium high values of Dd, Fs and If and high values of slope. Contrary to B4, B5 discharge match up with higher values of discharge, which is expected for a basin with those morphometric characteristics, having very high effective discharge. Is important to consider that B5 has the highest stream order, which is associated with greater discharges (Romshoo *et al.*, 2012) and as we mentioned before the contribution of the groundwater on the discharge, on this case increasing it, unfortunately there are not studies on this regard to contrast this hypothesis.. As on case of B4 the effective discharge of nutrients is low, on this case, could be related with dilution processes and the strong influence of vegetation cover. Being the natural forest a 40% of the basin use and silviculture a 11% and mostly associated with high slope areas (Figure 5.5.) the erosive processes that transport sediment and nutrients can be buffered. The influence of the groundwater could be as well very important on the nutrient loads. On B5 then, the water discharge is greatly associated with the morphometry parameters, nevertheless, the nutrient loads is not so clearly dependent on morphometry but is more with land use.

On the case of subbasin B2, the very high values of Dd, If and Fs , insinuates a quite rapid hydrological response and a low infiltration capacity. The relief of B2 is relatively high being one of the biggest slopes compared with the other subbasins, characteristic that favors runoff and increase the effects of the high hydrological response indicated by the previous morphometric parameters. The PCA analysis shows a very good correlation of slope, those parameters and the basin for axis one (Tables 5.11 and 5.12). Those characteristics are evident on the high discharge, being the third subbasin with more effective discharge. Even if as on case of B4 maintains a considerable area of forest located on the areas of higher slopes (Figure 5.2.), seems that vegetation cover don’t have the same relevance reducing river discharge. Agriculture and pasture land represents more than the 30% of the basin each one (Table 5.9), those land uses itself favor soil degradation which leads to erosion processes increasing water and nutrient flows, as well as the nutrient input related with the presence of manure and fertilizers use (Carvalho et al., 2000) and as a result of those characteristics, compared with the other subbasins B2 is the second subbasin with more contribution of effective TN and TP, being interesting highlight the strong correlation presented on the Biplot (Figure 5.1). In addition, the concentrations of TP exceed greatly the environmental law limit(Table 5.7) , and as on case of B3 may be related with the input of manure by cattle, because even if the agriculture and pasture, are balanced in percentage of occupation, on the biplot (Figure 5.1.) can be observed that the correlation of pasture and TP is much higher than for agriculture. As a result of all those characteristics we could conclude that the morphometric parameters as well as cattle farming seem to be key factors controlling B2 hydrological flows.

Continuing with subbasin B6 wich is well correlated with B2 on the biplot and the cluster (Figures 5.1. and 5.2.) can be observed their similarities with big hydromorphological parameters which favors higher discharges, being B6 as well a less elongated subbasin with low slope, and slightly smaller values of Dd, If and Fs on B6 compared with B2. Those characteristics influence B6 to have considerably high discharge being the next subbasin with more effective discharge after B2. This high discharge strongly related with morphometry parameters could be the decisive factor influencing the medium high discharge of nutrients present on B6 compared with other subbasins. The fact that the land use is exclusively pasture on this area should be consider and may be the reason why the nutrients loads are although noticeably smaller (Table 5.9), especially for TN effective discharge than B2 where agriculture is present.

B7 presents very high values of shape related morphometric parameters (Table 5.9) suggesting a more circular basin which as authors as Zavoianu, 1985, Pareta 2011,2012; Romshoo et al., 2012, Meraj et al., 2015 recognize that are more prone to flood. At the same time PCA analysis (Figure 5.1.) shows that is very correlated with basin shape parameters. The lowest slopes and very low values of Dd, Fs, and If, all characteristics of well drained basin, with permeable soil and good infiltration, circumstances associated to lower runoff and slower hydrological response. However B7 presents the higher effective discharge compared with other subbasins which could be associated with the close presence of the outflow of a adjacent lake and their groundwater connection. With the nutrient loads is as well the basin with notably highest values , situation that is evidenced on the PCA analysis (Figure 5.1., Table 5.9) where is much correlated with water and nutrient loads. At the same time, is well correlated with pasture that is the predominant land use and provably the variable responsible of the very high concentration of TP that as well as B2 and B3 excess the law limits (Table 5.8). This land use may be also related with the increased discharges because increase soil erosion.

On this case it would have been useful use the rainfall Figures developed for this subbasin in order to know if the higher discharge of water and nutrients was related with big and strong rainfall, but as results weren’t satisfactory, we will assume that should be directly related with land use, considering that the use of the pasture lands is quite intensive in number of cows and degrade enormously the soil increasing sharply the soil compaction and erosion.

6.2 Ecohydrological perspectives

To achieve a sustainable use of the water resources is necessary a more integrated approach (Omedas et al 2011) based in a better governance, the policy making and control has to be based in stakeholders participation and education, all supported by the new scientific knowledge to reach a good ecological estate of the water the resources as well as a good socio-economic status.

Ecohydrology creates a new background for the assessment and management of freshwater resources and accelerates the implementation of an idea relating to sustainable development, because it fulfils the two fundamental conditions of successful strategic action according to decision-making theory: elimination of threats and amplification of chances (Zalewski et. al. 1997). Ecohydrology quantifies and explains the relationship between hydrological processes and biotic dynamic at a catchment scale (Zalewski et. al. 2004). For this reason in necessary understand the biotic and abiotic properties and processes of the ecosystem, to use them as a management tool and increase the carrying capacity, resistance and resilience of the own ecosystem to be able to be adapted to human impacts (UNESCO-IHP, UNEP-IETC. 2004). In addition, the socio-economic dimension, is complicated when the main ecosystem service provided by the ecosystem is the provisioning of water for food production, so is necessary apply a management which find a sustainable equilibrium between the water resources and the economy. A well-managed policy with the ecohydrological approach also could confront this situation because try to find an easier solution based in the buffer capacity of the ecosystem.

The use of a decision tree could represent a useful tool for the first stages of an integrated watershed plan because represents a good resource for an easy understanding of the principal factors which affect the ecosystem integrity, on case of LTA watershed the hydrological flows in quantity and quality. Some examples of decision trees reference for aquatic ecosystems are the Rawson (1939) diagram explaining the principal factors which determine the quantity and distribution of the biological community, nutrient cycling and general lake productivity, which was modified afterwards by Cole (1994); the Richardson (1996) about eutrophication effects or the Reynolds (1992) related with the phosphorous presence on lakes.

This kind of resource is important for basin managers with inadequate and or insufficient scientific knowledge to face a concrete problem. In regard, will help managers and decision makers to develop a general study, as the one that is developed on this thesis, and with its results identify the subbasins which need priority

intervention. Once the priorities are defined a deeper study of this subbasin may be developed in order to create and specific action plan, on this way time and economic resources can be minimized. But decision trees are also a powerful tool for the integration of all the stakeholders in the process, making them actively partakers and make them understand the processes taking place and balance the different needs to obtain a water resources management sustainable in all the dimensions. Then is an optimum source for environmental education of local communities.
For the cases as of LTA watershed, where the objective is to know the factors affecting the hydrological flows in quantity and quality, the following decision tree is proposed (Figure 6.1.).

For LTA watershed morphometry and land use are the key drivers of environmental degradation, both affecting the soil integrity and nutrient inputs. In consequence the mitigation and restoration measures should be focus on soil protection and nutrient reduction.

A first step should be an environmental education program where show and apply different sustainable agricultural practices as ecological agriculture to avoid the use of pesticides and fertilizers to avoid the nutrient inputs, crop rotations and association of crops, scientific irrigation calculating evapotranspiration to avoid salinization and soil degradation, creation of farmers cooperatives and facilitation of the relationships between the agricultural activities as the use of the animal manure coming from close farms and lands, appropriated techniques of fertilization even if is coming for an animal source. A wide range of good practices widely spread and well know relatively easy to teach and apply.

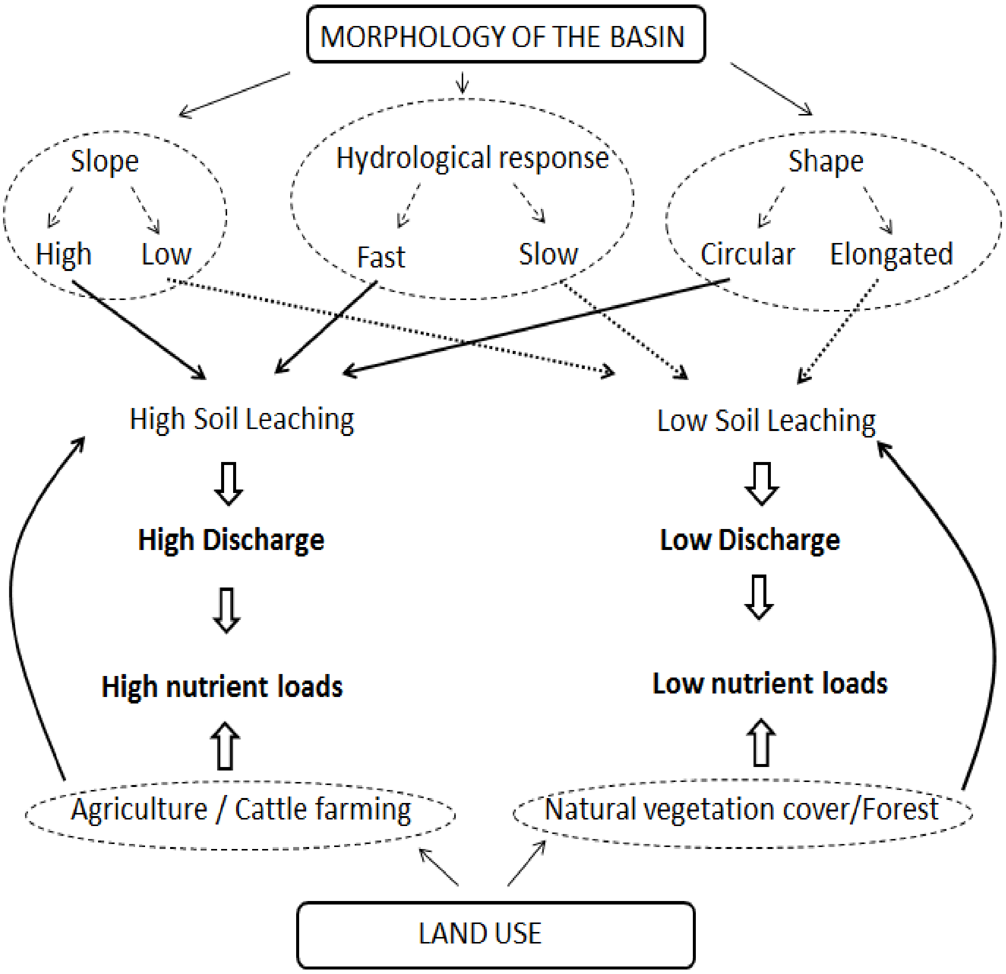


Figure 6.1. Decision tree for hydrological flows determination.

In other hand exists many other measures more complex that requires a deeper scientific knowledge on the field of phytotechnology or green engineering.

To reduce the impact of nutrients is very recommended the preservation of the ecotones, areas that consists on belts of permanent vegetation including herbs, grasses, shrubs, or trees adjacent to the aquatic ecosystems, creating then a land/water buffer zones that remove or trap nonpoint source pollutants (Schiemer and Zalewski, 1991; Mander et al., 1997; Mandera et al., 2005; Passeport et al., 2013). Phosphorous and nitrogen are effectively reduced on those areas because plants assimilate those compounds, microbiological processes as denitrification which reduce nitrogen removal are stimulated, sorption of phosphorous through the soil decreasing its availability and favors river bank stabilization allowing sedimentation processes and in consequence reducing runoff and nutrient (Lowrance et al., 1984; Vought et al., 1995; Syversen, 2005; Hoffmann et al., 2009; Raty et al., 2010; Parn et al., 2012) The construction or restoration of ecotones in LTA watershed is then the principal objective. Below are exposed two techniques related with the buffer zones with very satisfactory results in nutrient removal.

Bioengineering favors the nitrogen removing with denitrification barriers like Walls constructed vertically underground for groundwaters and run off. Beds immersed in small streams, drainage systems or at the outflow from a point source, and Layers to support septic tank drainage fields or under irrigated top soils, all constructed with materials rich in carbon, can change the polluting forms of N into non pernicious N that pass to the atmosphere, being very effective decreasing in some cases even in a 70%. (Bednarek et al., 2014). Also similar barriers based on limestone have been constructed to reduce phosphorus levels through absorption by the barrier showing good effectiveness, reducing concentrations in the groundwater by 58% (Kiedrzyńska et al., 2008) Those kinds of barriers are even more effective against the nutrient pollution if are integrated and coordinated with the construction of buffer zones, or artificial wetlands

The next ecohydrological measure is as well related with the buffer zones or artificial wetlands because takes place on the water. Technology developed by Teuro Higa during the 1970´s at the University of Ryukyus, Japan (Namsivayam et al.2011) denominated The Effective Microorganisms (EM) is based in a multi-culture of coexisting anaerobic and aerobic beneficial microorganisms (Moyo et al.) non-genetically modified, containing Lactic acid bacteria, Photosynthetic bacteria and Yeasts in a solution (Rashid and West, 2007), in which each group of microbes plays a different role. Meanwhile, lactic acid bacteria promote the fast breakdown of organic substances, yeast produce many active agents as amino acids and polysaccharides that will become the feed for other microorganisms, and the Photosynthetic bacteria play a special role in nutrient cycles, especially Nitrogen and Carbon.

Originally it was developed to enhance microbiological communities in soils but have been shown that EM can have many different applications in the field of agriculture with success, and in recent years have been apply in different systems of water treatment (Rashid and West, 2007). The effectiveness is the key of success of this technique is based in the synergic effect of these tree groups of microorganisms and their adaptability to work in broad range of conditions, their capability to displace by competitive exclusion other microorganisms as pathogens. This technique has shown good results not only in the removal of BOD, COD, TSS, but also in nitrogen and phosphorous, being a very good alternative to deal with eutrophication processes in the water bodies. In Poland, a study was carried out with a probiotic technology based in the EM in ponds. After the previous treatment of sewage water in a constructed wetland system with willow vegetation filter with subsurface horizontal flow, the study of Jóźwiakowski et al., (2009) has shown a significant drop in total nitrogen by 56.9% and total phosphorous by 77.6%.

EM are especially effective combined with Duckweed in nutrient removal, both treatment together show more efficiency reducing nutrients, with reduction rates of NH4 by 86% and total P by 99% (Rashid and West 2007).

In conclusion those techniques are very effective but there is a plenty of options (phytotechnology, biotechnology and biomanipulation, ecohydrologycal engineering) that offers the possibility to adapt the technique to the problem. Putting an especial effort in the restoration or creation of riparian corridors is recommended because they act as buffer zones for nutrient retention and bank stabilization increasers.

7. Conclusions

The present study considers morphometry, hydrography and land use of the catchment with the objective to understand how they affect the hydrological flows of the LTA watershed in order to achieve a more integrated and efficient basin management favoring the sustainability of the ecosystem services provided by this watershed.

The results obtained reveals that morphometry is responsible of the water discharge in most of the subbasins, but at the same time, land uses interfere as well on the hydromorphological characteristics increasing soil vulnerability as in case of agriculture and pasture or buffering it as in case of the natural forest. Land uses especially agriculture influence as well discharge reducing water availability due to water extraction. Is on nutrient load where the land use is the main driver, increasing nutrient inputs with agriculture and pasture wastes or buffering those inputs into the water with natural vegetation. Nevertheless, further studies are necessary to complement this information and obtain more accurate one. A runoff potential analysis including a sediment transport study will be very important to increase the knowledge of erosion processes. Will be important as well a better knowledge of the state of the riparian corridors of the rivers and an assessment of the wetland areas.

The use of GIS, is indispensable to obtain accurate basic information of the subbasins in terms of morphology, hydrology and land use but in a simplified, faster and cheap way. Those make of GIS in an important tool to be applied on integrated management of a watershed.

The comparison of discharge and effective discharge, as well as nutrient concentration and effective nutrient discharge, have shown that neglect the size of the basin gives a different perspective of the water flows. The subbasins play a different role than for direct discharge measurements, where their potential to generate environmental changes goes unnoticed. This study have shown the relevance of small subbasins which apparently didn’t play an important role influencing discharge and nutrient concentration but once calculated, the effective discharges have shown that may present strong environmental pressures that compromise quality and or quantity of hydrological flows. Thus, those calculations may be crucial for managers to define priority activities.

The rainfall discharge model was not applicable to LTA due to the big differences in magnitude and trends of discharge that maintain with the measured ones. However, especially the rainfall distribution Figures being used in conjunction with slope and land use Figures, could have provide powerful information to understand the better the more vulnerable areas of each subbasin, thus facilitating the management decisions.

The importance of the basin approach proposed by the ILBM is essential for the understanding of water and nutrient flows. This is especially obvious for basins where the results are more ambiguous as on case of B7 where a broader analysis which includes the adjacent basin could have explain better the water flows.

Multivariate statistical analysis is very good to understand better the relationships between variables in an accurate but at the same time intuitive way thanks to its graphical representation. PCA analysis is especially useful on subbasins where only the results of the parameters don't show clear evidences or can't explain concrete differences. As an example the case of B1 and B3 differences, B2 and B6 and B7 all regarding the land use, being essential for the identification of the land use that more contribute to water discharge stimulated by soil erosion as well as the kind of land use that explains the high presence of a concrete nutrient.

On subbasins B1 and B3 the land use, concretely agriculture seems to be determinant to decrease water discharge due to water extraction for irrigation and a source of nutrients into the streams. Their differences in land use determine the kind of land use that is more influent of the presence or the excess of a nutrient, on this case Agriculture and TN are more related in B1 and Cattle and TP in B3.

On B4 the land use, concretely forest seem to be the decisive to buffer discharge, especially erosive process on vulnerable areas, buffering as well the input of nutrient into the river.

For B5 the presence of forest seems to be as well a key factor to buffer the nutrient inputs, nevertheless are the morphometric parameters which unquestionably controls the river discharge. For this subbasin the cascade effect derived of small irrigation dams constructed in series should be deeply study.

On B2 and B6 are the morphometric parameters the main drivers of river discharge and inconsequence the transport of nutrients, nevertheless the land use may favor as well the quantity of water decreasing the quality of the soil and increasing the loads of nutrients resulting from agriculture on case of B2 and pasture on B6. However for B2 the cattle farming seems to be the determinant factor for the high values of phosphorous concentration.

On case of B7 the measured discharge is the opposite to the expected discharge associated with the morphometric parameters pointing out pasture as the key driver of water quantity and quality due to soil degradation and input of nutrients. Nevertheless as we have mention previously and adjacent lake watershed could have strong influences on the river discharge.

For those reasons B7, B2 and B6 and B3 are subbasins which more negatively could affect to LTA due to their nutrient loads. Those subbasins seems to be especially vulnerable to impacts, concretely on B2 and B6 the morphometry parameters that influence the high hydrological response are decisive for water flows. In addition, for the tree subbasins, cattle farming looks as a key driver of environmental degradation. Nevertheless more studies should be developed in order to understand better the system loads, especially geology and groundwater variables which influence in high extent the hydrological cycles in quantity and quality. On the other hand, the information provided by this study may be a reference. Then, according to the obtained results, the first management actions should be focus on those subbasins promoting better practices on cattle ranching and soil restoration. Is suggested a deeper study of the estate of the river banks which are areas very sensitive to soil destruction especially when the cattle needs to access to the river to drink as well as other areas of the watershed vulnerable to erosion. Identify the most relevant areas source of diffuse pollution with a well-planned monitoring program is also one of the first actions developed by the environmental managers.

In consequence apply measures to mitigate and prevent environmental problems consequents with the principles of Ecohydrology that increase the resistance and resilience of the ecosystem are the most appropriated. The use of a decision tree as the proposed is a useful tool for the basin managers to know the principal factors which affect hydrological flows in quantity and quality helping them to develop a general study as the present and identify the subbasins which need priority intervention. Once the priorities are defined a deeper study of this subbasin may be developed in order to create and specific action plan, on this way time and economic resources can be minimized.

The implementation of green engineering to increase soil quality and stabilize areas prone to soil losses, a transition to agricultural and cattle farming techniques more efficient which reduce nutrient inputs and soil degradation, biotechnology,… are some of the measures recommended on section 5 of the present study to follow the ecohydrological approach. Used individually or combined, seems to be the most appropriated to mitigate impacts and restore impacted areas on LTA watershed and thus, ensure the ecosystem services of LTA and its catchment.

We can conclude that the methodology followed allows a good first approach for the understanding of the processes taking place on the LTA watershed influencing the water quantity and quality. Allows to generate first hypothesis of the environmental integrity of each subbasin compared with the others and how it may affect to the entire basin, being an useful scientific resource for the environmental managers an authorities to take decisions and implement the most appropriated integrated lake basin management plan.

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