University of Wales (Bangor University) and Tropical Agricultural

Research and Higher Education Center (CATIE)

“ASSESSING INTEGRATED WATERSHED MANAGEMENT AND SPATIAL GROUNDWATER VULNERABILITY TO POLLUTION IN PRIORITY WATERSHEDS OF THE YACYRETA DAM IN PARAGUAY”

By

Karim Musálem - Castillejos

A Dissertation for the Degree of Doctor of Philosophy

March 2010

Turrialba, Costa Rica - Bangor, United Kingdom

Form DP-7

CATIE
GRADUATE SCHOOL

DISSERTATION APPROVAL FORM

This dissertation of Karim Musálem Castillejos submitted
Student name

For the degree of ***Doctor of Philosophy*** entitled:
"Assessing integrated watershed management and groundwater vulnerability to pollution in priority watersheds of the Yacyreta dam in Paraguay".

Has been reviewed in final form and approved, as indicated by the signatures and dates given below:

Major Advisor: Dr. Francisco Jiménez Date:

Co-advisor: Dr. Morag McDonald Date:

Committee Members: Dr. Jorge Faustino Date:

Dr. Fergus Sinclair Date:

Department Head: Dr. John W. Beer Date: 15/04/10

Dean, Graduate School: Dr. Glenn Galloway Date: 25-11-2009

To the population of the Mboi Cae and Quiteria Watersheds

To the memory of my father

To my mother and sons

To my wife and family

Acknowledgements

I would like to show my gratitude and appreciation to the following persons and institutions:

Dr. **Francisco Jimenez**, Dr. **Morag Mc Donald**, Dr. **Jorge Faustino**, and Dr. **Fergus Sinclair** for their guidance and help during this research and my postgraduate studies; M. Sc. **Rafaela Laino** for her help applying the DRASTIC model, support during field work and administrative work; Ing. **Juan Estigarribia** for functioning as a contact with the Yacyreta Binational Entity and his continuous support and interest for this research; Ing. **Victoriano Vazquez** for his help organizing the workshops with the Watershed Council and for sharing his views, opinions and information. Dr. **Ian Harris** for his collaboration in GIS procedures and software use.

Dr. **Julio Calvo**, Dr. **Thomas De Luca** and Dr. **Jeffrey Jones,** examiners, for their comments and suggestions to improve this work. Dr. **Glenn Galloway**, Dean of School, for conducting the *viva voce* and for useful recommendations received through his writings.

Mauricio Perayre, **Carlos Basaldua**, **Luis Hauron**, **Victoriano Vázquez**, **Antonio Schapovaloff**, **Andres Taoka**, **Viviana Pacheco**, **Victoria Lopez-Pereira**, **Juan Estigarribia**, **Patricia Peralta**, and **Diosnel Curtido** for their time and help in gathering information of the Watersheds and for sharing their particular views on integrated watershed management in the area; **César Balbuena**,

Eduardo Dose and **Christian Brenes** for their help in GIS data, software and procedures; **Roberto Fleitas** from SENASA for providing indispensable data of wells; **Alicia**, **Nasim, Amira and Miguel Musalem-Castillejos** for their companionship, support, and constructive criticism throughout my research; the **Laino-Guanes** family for their invaluable support during my time in Paraguay; **Tim Pagella**, for his help in revising the research plan and for very useful suggestions.

CATIE staff: **Noily**, **Hannia**, **Martha**, **Aranjid**, **Jeannette**, **Ariadne**, **Alex**, **Carmen**, **Jorge,** and **Alfonso,** for facilitating my time in Turrialba. Colleagues and staff at Bangor: **Sheila**, **Joanna**, **Wojteck**, **Yara** and **Juan** for their support during planning of this research and for facilitating my time in Wales, together with **Pavel Bautista** for his indispensable help in publishing. Alice and Alison for their kindness and help in difficult moments.

CONACYT (**Mexican National Science and Technology Council**) for their full financial support to obtain my Ph. D. Degree; **Yacyreta Binational Entity** for their financial and logistic support during field work and very specially to the **Council of the Mboi Cae and Quiteria Watersheds** for their invaluable support in reaching the objectives of this research.

My gratitude to all.

Contents

Tables

Figures

Abstract

“Assessing Integrated Watershed Management and Spatial Groundwater Vulnerability to Pollution in Priority Watersheds of the Yacyreta Dam in Paraguay”

Karim Musalem. 2009

An in-depth qualitative and quantitative research with an integrated approach to watershed management carried out in Yacyreta Lake in Paraguay is reported. This case study research is based in the Watersheds of the Mboi Cae and Quiteria Rivers, and involves a) assessing the current state of knowledge of the watersheds; b) an analysis to determine socio-environmental conflicts and to propose solutions and strategies from the perspective of the local watershed council c) the determination of achieved integrated watershed management of the watersheds and d) the assessment of spatial aquifer intrinsic vulnerability to pollution. The research is supported by participative social research techniques, workshops, and semi-structured interviews; also, a multi-criteria standard was used to assess integrated watershed management, together with GIS - based models (DRASTIC and GOD) to determine aquifer vulnerability to pollution.

Sources of information and literature review for the study area were organized in a summarized table, identifying available data and previous works carried at the watershed level. Socio-environmental conflicts were identified related to deforestation of riparian forests; also, pollution of soil and water and soil degradation by malpractices in agriculture; health related problems, environmental degradation and problems derived from solid wastes and their insufficient treatment and deposition. The local watershed council was capable of analysing these prioritized conflicts and proposed strategies according to its legal competence. Assessing IWM showed an advancement of 35 % of the total obtainable qualification and a set of critical elements were identified to advance towards IWM. Assessing groundwater vulnerability to pollution resulted in intermediate-high levels of vulnerability (DRASTIC: 56% of the watersheds with values of 140-159; GOD: 95% of the watersheds with values of 0.4 - 0.5), with maximum vulnerability in the lower parts of the watersheds in urban areas and where the flooding of the Yacyreta lake will take place, making it more necessary to consider the threat of urban pollution to the Basalt Aquifer of the Guarani Aquifer System. Several parts of the research were integrated discussing consistency and discrepancy in results.

Keywords: Watershed management certification, socio-environmental conflicts, GIS, DRASTIC, GOD, groundwater vulnerability to pollution, Yacyreta, Encarnacion, Itapua, Mboi Cae River, Quiteria River.

1 Introduction

Integrated watershed management (IWM) takes the sector-based management and study of water to a different level, from a less technocratic to a more holistic, participative, and stakeholder-based approach. IWM seen as an element compatible and within the concept of integrated water resources management (IWRM) considers the watershed as the studying, planning and natural environment unit to achieve IWRM. However complex and challenging, IWM seems as an opportunity to reach the local ability of societies to use water in a rational and sustainable way. According to Ramakrishna (1997) and Jimenez (2004), the interest of working with an IWM approach becomes clearer considering that there is a broad practical and theoretical justification for the use of watersheds as a territorial unit for planning management of natural resources. The same authors consider that there are also increasing investments, interests, knowledge and experiences that are leading to demonstrate, in further years, with concrete examples, the use of this angle to reach sustainable natural resources management.

Dourojeanni (1994) *in* Jimenez (2004) considers that benefits and advantages of using watersheds as a unit for planning and management have been suggested by many authors and are supported by experiences worldwide. The integrated and systemic vision of a watershed leads to two different group of actions: natural resource use for economical growth and those oriented to conservation in order to assure environmental sustainability. IWM angle is also directed to establish processes, rather than specific actions, that would lead to continuous and self-sustained work at a local level.

Taking into account also wider information in the field, the Food and Agriculture Organization of the United Nations, European Observatory of Mountain Forests, International Centre for Integrated Mountain Development and Red Latinoamericana de Cooperación Técnica en Manejo de Cuencas Hidrográficas (2006), undertook a major large-scale assessment and global review of the current status and future trends of integrated and participatory watershed management, recognizing that "Since the 1990's, integrated and participatory watershed management has been seen as a promising approach for conserving water, land and biodiversity, enhancing local livelihoods and supporting broader sustainable development processes at the river basin levels."

On the other hand, however, it has also been pointed out by Blomquist and Schlager (2005), that IWM can sometimes be difficult, specially if dealing with political issues, and that "Fundamental political considerations are inherent in water resources management, however, and are unavoidable even if the desire for watershed-scale decision-making bodies were realized”. IWM accepts and recognizes possible political difficulties of the approach. It also lies on the premise of this particular focus not being a “straitjacket” (Jimenez: personal communication), while recognizing the angle as a possible option suitable to the particular conditions in a particular watershed, and the already existing legal and political framework.

There is also a link amongst stakeholders and IWM: Gerasidi, Apostolaki, Manoli, Assimacopoulos and Vlachos (2009) consider after a study in Greece that “Stakeholder involvement is recognised as an important factor in the successful implementation of water management plans” and also that: “Involving stakeholders enables, first, a better understanding of different parties that have an interest in water management problems; second, the process can articulate more clearly the context of agreements and disagreements; and finally it can also significantly contribute to conflict management or conflict resolution.” Integrated watershed management and its approach consider indefectibly the involvement of stakeholders in the management of water resources at the watershed level.

The conformation of water committees (or watershed decision bodies, watershed committees) at local levels is also considered an element of joining and articulating the different institutions when IWM, seen as the cornerstone of IWRM, is sought. The importance of water committees, not only comprises objectives of watershed management in a given moment, but their importance has also been identified as one of possible strategies to respond to global climate change. As put by

Bergkamp, Orlando and Burton (2003) “Adapting to climate change adds a new global dimension to the need for improved water management (…). Many deficiencies in the current management of water resources need to be addressed, this does not mean that the concern about climate change can be delayed or put off. On the contrary, climate change should serve to reinforce calls for improved water management”. Work carried out by Hardy and Koontz (2009) in USA, comparing the differences in organizational watershed partnerships describes the importance of mixed partnerships (citizens and government), in making national policies to be applied at the local level, pointing out the importance of watershed decision bodies to the flow of national to local policies.

According to Global Water Partnership and works by Sadoff and Muller (2009) “While there is growing confidence about model predictions of changing temperatures and rainfall, the impact of these changes on water availability from rivers, lakes and underground sources is poorly understood. Changes in aridity will have a substantial impact on both surface water runoff and groundwater recharge as will changes in the timing and intensity of rainfall”. It is this uncertainty that also strengthens the importance of water committees at the watershed level; groundwater will also become even more important as uncertainty in rainfall and aridity make groundwater a buffering factor for impacts caused by climate change.

Using these previous considerations, the present research combines the elements of IWM as a theoretical framework; together with the use of methodologies based on GIS and social research methodologies to assess IWM and groundwater vulnerability to pollution in a study case in Paraguay. This research studies the IWM process already taking place in the area and sees it as a challenge undertaken by the local population. Reports by United Nations Educational Scientific and Cultural Organization (UNESCO) (2006) consider the importance of presenting case studies regarding water resources, strengthening the “accuracy of the big picture on the basis of snapshots of water in the field. In the global strategy to improve the overall quality of water resources, local actions often present the starting point of the most fruitful efforts (…). Case studies aim to provide a snapshot of those efforts while showing the significance of the decisions taken at local, sub-national and national levels”. This research reports on a case study of two watersheds in Paraguay, considering that “Local-level actions and on-the-ground insights are the starting point of the global strategy to improve the overall quality and quantity of the World’s water resources. Lessons learned —successes and failures — are invaluable sources of information and, if properly shared, will help solving some of the world’s most pressing freshwater-related problems”. The justification of the methodologies and approach, together with the selection of the watersheds lies in the following Sections.

2 Literature review and justification

2.1 Why the Mboi Cae and Quiteria Rivers?

Two watersheds were selected as study areas for this research, mainly because of the following reasons[1]:

a) **Water elevation** caused by the filling of the Yacyreta dam will affect the lower areas of the Mboi Cae and Quiteria Watersheds. The area to be

1 A description of the main characteristics of the watersheds is presented in Section 3.

permanently flooded affects the city of Encarnacion, capital of Itapua Department. Construction and civil works, bridges, streets, and coastal barriers are being built currently in the area in preparation for water elevation. YBE (Yacyreta Binational Entity) has concentrated most of its work in preparation to water level change of the reservoir to the lower floodable parts of these two watersheds, both socially and in infrastructure, however social demands by affected population have not been met entirely and opposition to the finalization of the project occurs presently.

b) **A conformation of a watershed council** took place during the elaboration of this research. As an experience, it made these two watersheds as one of the first in Paraguay to have such a committee. Also parallel works and interest in IWM have taken place in the area. At first, the lack of information and lack of advancement in the process of IWM triggered this study, now, a few years later, interest has also become the need to document what has been taking place in the watersheds. The Mboi Cae and Quiteria Watershed Council works not only with the problematic water level rise in the lower areas of the basins, but also in the whole area of the watersheds.

c) **The presence of the Guarani Aquifer System**. The Mboi Cae and Quiteria Watersheds are also located in an area corresponding to one of the largest aquifers of the world, with importance at the local, national and international level, this, combined with intensive agriculture has raised questions about pollution. Soil aptitude for agriculture is considered as one of the best in the

Country, also, some soil conservation and efficient use of chemicals is being adopted by some local farmers

Information for Mboi Cae and Quiteria Watersheds was very limited, most of the records were outdated and they did not tend to view the whole area of the drainage basins, but usually only focus on the populated areas of Encarnacion (PY). On the other hand, there was no GIS constructed of the whole area of the watersheds by Yacyreta or other institutions consulted at beginning of the research. Some information on urban areas was available but maps were done years ago and were presented on printed forms, without digital or geographical reference or projection.

2.2 Why to determine “state of knowledge”?

Different aspects of the Mboi Cae and Quiteria Watersheds changed regarding availability of information and as well as local processes during this research. New information was produced and made available, not only from this work, but from other studies being carried out in the area coincidently also using a watershed angle. At the beginning of this research, little or nothing was known of the watersheds, delimitations were not found in any previous study, boundaries were not clear and generally speaking information was very scarce. By the end of this research, a consultancy by a third group, financed by YBE gathered and generated plenty of information approaching a characterization. A joint council for both watersheds was installed during this period, as a result of a combined effort in the area by multiple institutions and persons as well as a corresponding legal framework at the national level. Studies were made regarding soil analysis and a newer publication at the regional level covering historical aspects produced even more information.

Again, when this study was initiated there was very little advancement towards IWM, now, after two years, a lot of information and inter-institutional processes have taken place, including the present work. However, it is important to notice that most of this information is available only at the local level; almost none of it will be found outside the hydro-electrical power plant technicians and the Mboi Cae and Quiteria Watershed Council. It was of interest for this study to document in a synthesised manner the available information of the watersheds.

2.3 Why to assess integrated watershed management?

Heathcoate (1997) recognizes the importance of an integrated approach towards watershed management, stating the "Importance of embracing a less technocratic view of *earlier generations* taking into account the contribution of a variety of disciplines and viewpoints in the development of stronger water management strategies". Heathcoate observes, based in analysis and case studies, the need for IWM, as it becomes clearer that: "It maybe social and economic forces, rather than technical considerations, that result in a successful watershed planning effort". In Heathcoate's words about the end product, a watershed plan: "Must reflect the current societal consensus about value of water resources, about responsibilities, and social attitudes, and about the community's vision of an ideal watershed state. Integrated watershed management is, therefore, a journey, not a destination."

Considering that YBE has created and worked different programs regarding environmental and social issues and that it has a 17 year period investing and developing programs with a local impact, seeking social acceptance by local stakeholders; it was of interest for this research to gather information that led to the assessment of the IWM level in the Watersheds of the Mboi Cae and Quitera Rivers, as well as the local perception by rural stakeholders of environmental and social development programs. This study applied an IWM standard in a particular condition where there have been actions taken and existing processes towards reaching good natural resources management in the past years, more evidently through the conformation of the Joint Mboi Cae – Quiteria Watershed Council in 2007.

The standard to "certify" (also used: evaluate or determine) IWM was created in CATIE, Costa Rica, and is still on a trial phase, it was built as a tool to help determine the advancement regarding integrated management of a watershed in countries in tropical areas of America. It presents a series of criteria and indicators to evaluate IWM and was subject of a Master's thesis by the author in Musalem (2005). It was developed through interviews held in institutions, universities, and NGO's mainly in Honduras, Costa Rica and Mexico. In the present work, the need to understand the level of IWM achieved after environmental and social programs were carried out by YBE and mainly the conformation of a watershed council in proximity watersheds (priority pilot watersheds) to the Yacyreta Reservoir by using this IWM standard is considered as justification. The application of this standard provides also with another example of its use and is considered helpful to contribute with knowledge about the standard, lessons learnt or adaptation needs of the indicators. This case study pretends to give information for the Watersheds and at the same time to strengthen the standard itself.

Work carried out by Sullivan and Meigh (2007) describes the need of a holistic tool and of using an integrated index tool together with the importance of an indicator approach for a more effective water policy-making. In their study, a water poverty index was developed, used, and tried out, showing that integrated indicators, “Despite their imperfections, provide a useful and easy to use tool for policy making and management in the water sector”. Tools like the one presented by Sullivan*, et al.* (2007) combine biophysical, social, economic and environmental data, in a similar way, the IWM standard used to determine IWM for the Mboi Cae and Quiteria Watersheds seeks an integration of different aspects as well as data triangulation.

2.4 The Yacyreta Dam, an element of conflict?

Entities that manage and operate hydro-electrical power plants (HPP’s) usually deal with environmental issues by demand of local populations, governments or other environment-related non-governmental organizations (NGOs). These issues are most of the times dealt by the entities through the instrumentation of programs regarding social awareness, land use, soil and water conservation, biodiversity conservation, wildlife refugees and the dedication of funds as a payment for the environmental impact occurring during and after installation of the dam. On the other hand, assurance of an optimal water quality is expected as possible in order to allow the longest time of proper functioning of the HPP and its energy producing benefits. In all, entities managing HPP usually have a major responsibility in dealing with environmental issues, derived both from social pressure as well as for the own maintenance of the power plant infrastructure.

Besides just specific environmental programs, HPP’s managing entities usually also run social development programs that benefit local population inside the area of influence of the reservoir. This is mostly an approach towards local population so that a positive influence is perceived, thus, creating a proper social environment of mutual help and institutional recognition. In some cases, these social development programs are intended to fund the construction of schools, bridges, streets, or paved roads, amongst other needs, not at all necessarily related to natural resources management. It then turns out a HPP usually becomes an institution with a high level of involvement for development at a local scale, perceived either negatively or positively by local and non-local population; such is the case of the Yacyreta Binational Entity (YBE) in South America.

The YBE is administered jointly by bordering countries Paraguay and Argentina; it is in charge of one of the biggest energy producing facilities in South America located in one of the largest watersheds in the world. The Parana River Watershed is of an approximate 2,5 million sq km according to data from Revenga, Murray, Abramovitz and Hammond (1998). At least an approximate one third of this area is correspondent to the drainage basin leading to the Yacyreta Reservoir (Figure 1). The YBE on the Paraguayan side has limited environmental and social programs and influence on smaller proximity areas selecting only several smaller priority watersheds. From these, two watersheds, Quiteria and Mboi Cae have been suggested as pilot areas to start IWM works, thus, leading to particular interest of research in them and particularly focusing the present work.

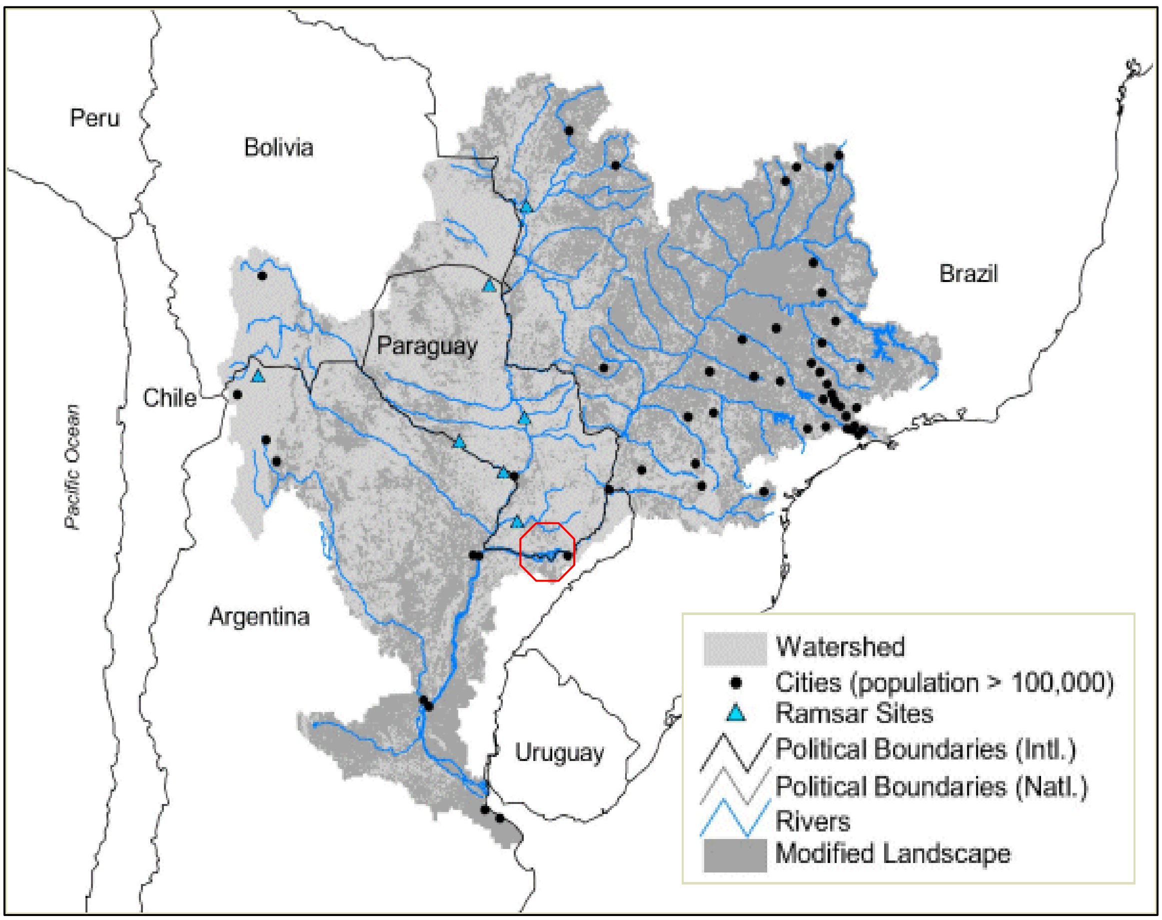


Figure 1. Parana River Watershed (2,582,672 sq km); red circle marks approximate location of Yacyreta (dam and reservoir) and Mboi Cae and Quiteria Rivers. Cities within red circle correspond to Encarnacion and Posadas, border cities in Paraguay and Argentina. Data and map source: Revenga*, et al.* (1998).

The Yacyreta dam is a major infrastructure work and is a primary source of electrical energy of Paraguay and Argentina. For its initial operation, in September 1994, it was necessary to dam the Parana River, giving rise to the formation of an artificial lake of 1600 sq km in surface. According to Meichtry, Llano and Martens (2006), the dam is located 70 km west of Posadas (Argentina) and Encarnacion (Paraguay); 300 km southeast of Asuncion and 1000 km north of Buenos Aires (27°28' S; 56°44' W). Yacyreta has two spillways, one constructed in the main stream of the Parana River, composed of 18 floodgates, and the other installed in the Aña-Cua stream, with 16 radial floodgates. A central station was constructed, equipped with 20 Kaplan vertical axis turbines of an installed power generation capacity of 3100 MW, a spillway and one sluice of navigation. Table 1 and Table 2 show general information about the dam, watershed, river and the reservoir. General information of the dam was obtained from the YBE webpage available at www.eby.gov.py, and the Argentinean Secretariat of Energy www.energia.gov.ar accessed in April 2007.

An issue in this area is a 5 meter water elevation of the Yacyreta reservoir. This elevation was planned since the construction of the dam and is taking place as this thesis is being published. Removal of population (mainly downtown commercial) and total infrastructure works was expected **before** the water level change took place (Table 3) however local demands are that this has not been accomplished. The fourth Paraguayan director since this study began is now taking office and is seeking for a solution with local formal and informal businesspeople affected by the water elevation: www.eby.gov.py.

Table 1. General information about the watershed, the river and the reservoir in the Yacyreta Hidroelectrical Power Plant, Argentina and Paraguay. Source: YBE.

Parana Watershed	Units	
Area (as reported by Yacyreta)	sq Km	970,000
Mean rainfall	mm	1,500
Maximum rainfall area in the watershed	mm	2,500
River		
Mean volume of water	m^3/s	12,000
Maximum daily registered volume of water (1905)	m^3/s	53,000
Minimum registered volume of water (1944)	m^3/s	2,900
Design volume	m^3/s	95,000
Construction volume (Rec. 50 years)	m^3/s	44,000
Reservoir		
Normal maximum level	sq m	83
Surface (at final water level – 83 m)	sq Km	1,600
Volume (at final water level – 83 m)	Hm^3	21,000
Maximum maximorum level	m	84.5

Table 2. Capacity of energy production of the Yacyreta Dam for current and future water level. Source: Argentinean Secretariat of Energy.

Capacity	
Annual mean energy (current 78 m water level)	11,500 GWh
Installed Power (current 78 m water level)	2,100 MW
Annual mean energy (at 83 m water level)	20,000 GWh
Installed Power (at 83 m water level)	3,100 MW

Table 3. Estimated number of families. affected by the construction and filling of the Yacyreta Dam to its current water level (78 m) and its future final water level (83 m above sea level), According to Yacyreta Binational Entity.

Families	Paraguay		Argentina		Total	
	78 m	83 m	78 m	83 m	78 m	83 m
Urban	157	3,923	1,981	7,041	2,138	10,964
Rural	326	796	31	224	357	1,020
Total	483	4,719	2,012	7,265	2,465	11,984

Figure 2 shows the projected sequence of change in water level in the area of the City of Encarnacion, Yacyreta Reservoir – Parana River. The two subject watersheds of this study will be directly affected by this change in water level in a permanent way. YBE has until now taken actions towards preparing for this event, both socially and environmentally in urban areas.

Figure 2. Sequence of approximate flooding of the Yacyreta reservoir in the area of the cities of Encarnacion and Posadas. From left to right: 1) Parana River at original level; 2) current level at 78 m; and 3) expected level of 83 m. Mboi Cae and Quiteria Rivers visible only partially at their junction with the reservoir. Source of Image and drawing: YBE no ref.

Much has been said and speculated at the national level about different impacts, conflicts and social and environmental impacts happening during the installation of a large dam such as Yacyreta. Some methodologies, such as the ones used by Tilt, Braun and He (2009) in China and South Africa, use a social impact analysis to understand how large dams affect populations at various levels. Tilt*, et al.* (2009) achieve an important insight of the cultural, economic, productive and social impacts of large dams. On the other hand due to the magnitude of the Yacyreta project, understanding it in a complete context requires a wider analysis that could not fit our particular concentrated interest in the pilot Mboi Cae and Quiteria Watersheds and the possible reach of this study. However, it was of interest, and derived from work in Paraguay, consultation, interviews, and mainly mass media reports pointing out the negative impact of the project, that lead to construct a workshop that could help identify the most important socio-environmental conflicts, as a perception from the local point of view, and also to understand to what level the Yacyreta Dam is perceived as a negative impact in the subject watersheds. It is important to stand out that this study does not at all intend minimizing (or maximizing) the effect of the Yacyreta Dam, but concentrates not only in the lower floodable part of the watersheds, but also on the entire watersheds, putting in perspective this particular situation with other environmental and social conflicts in the whole area of the subject watersheds.

Given the conditions and combination of factors happening in the area, such as the creation of a watershed council, the filling of the dam, the intensive productive agriculture, and in general all conditions specified in the Section 3 about the area of study, it was a of interest to gather knowledge on the main socio-environmental conflicts and to offer possible solutions from the perspective of the recently created watershed council. This part of the study is a response to the particular combinations and characteristics of the area and the watersheds, and the new possibility opened by the creation of a local water decision body, still adapting to its capacities, and possibilities. The methodology used for this section of the study is qualitative rather than quantitative and is supported by considerations by Patton (1990), Kirby, Kidd, Koubel, Barter, Hope, Kirton, Madry, Manning and Triggs (2000). Specifically, qualitative research is used on the basis that "the logic and power of purposeful sampling lies in selecting information-rich cases for study in depth (…) from which one can learn a great deal about issues of central importance to the purpose of the research", leading to an in-depth qualitative study.

Socio-environmental conflict is understood for this study as a social condition or combination of conditions affecting negatively or impacting negatively in the environment, generating pollution, degradation or affections, this includes any social activities that generate negative impacts on the natural environment, but also those that are derived from a degraded natural environment that can affect human activities negatively. According to literature from Africa Peace Forum, Center for Conflict Resolution, Consortium of Humanitarian Agencies, Forum on Early Warning and Early Response, International Alert and Saferworld (2004): “conflict analysis is the systematic study of the profile, causes, actors, and dynamics of conflict; and is directed to help development, humanitarian and peace building organisations to gain a better understanding of the context in which they work and their role in that context”. Although the present study is basically a fraction of a wholesome conflict analysis, it was intended for multiple reasons in this study: Firstly, to generate information for triangulation with the IWM standard and some of its indicators, secondly, to provide with a clearer perspective for the members of the Mboi Cae and Quiteria Watershed Council of the current problematic in the area, providing a prioritization of conflicts and helping to focus on possible solutions from their capacities and legal framework. Hopefully, the complete work here presented will be taken by this Council to reach a better understanding of the Watersheds of the Mboi Cae and Quiteria Rivers, and serve as a support for decision-making and continuation of works locally.

2.5 Is the Guarani Aquifer System vulnerable to pollution?

Another feature of the Mboi Cae and Quiteria Watersheds is that they are also located in the Guarani Aquifer System. It has been suggested that most of the population living in this area is almost absolutely supplied by underground water from the Guarani Aquifer System. This comes to notice by works from Fariña, Vassolo, Cabral, Vera and Jara (2004), Cabral (2005) and Foster, Kemper, Garduño, Hirata and Nanni (2006) and institutions working in the area and specifically in the Guarani Aquifer. It has also been suggested that the intensive agriculture and soybean production in the area may lead to a pollution of this water resource.

In the book World Agriculture and the Environment by Clay (2004), a dedicated section to the summarization of the expansion of soybean production and the possible concerns related to the intensive heavily mechanized production, notes four major environmental impacts: conversion of natural habitats, soil erosion, use of pesticides and herbicides and use of genetically modified seeds. As it has been noticed by Clay “Soybean production has been clearly associated with the degradation of soil by the uses of agrochemicals and is considered a major source of freshwater and groundwater contamination”. Since the main productive activity in the watersheds is soybean and wheat production (Section 3). The two elements in combination: Guarani Aquifer System and soybean production have been taken as subject of interest for this study.

According to the BGR (The Federal Institute for Geosciences and Natural Resources) and work carried out by Oporto and Vassolo (2003) and Fariña*, et al.* (2004) the Guarani Aquifer is probably one of the largest groundwater reservoirs of the planet. It is located in South America between 12° and 35° latitude south and 47° and 65° longitude west. It is estimated that this aquifer system contains a reserve of 45,000 cubic km of water. Cabral (2005) informs that the it covers an area of approximated 1.2 million sq km (surface greater than the one than Spain, together with France and Portugal occupy in Europe) of which 840,000 sq km belong to Brazil, 225,500 sq km to Argentina, 71,700 sq km to Paraguay (it represents 18% of the territory) and 58,500 sq km to Uruguay. According to Fariña*, et al.* (2004), it is located in the eastern side of Paraguay, having formed a strip that extends from North to South, along the Parana River

An estimated 80% of the potable water supply in Paraguay is made from underground water; showing also the importance of this resource for the socioeconomic development of the area. Cabral (2005) estimates that 38% of the population of Paraguay lives on the Guarani Aquifer System and is supplied by its waters and that conditions in the area, specifically intensive agriculture and urban wastes are or will be risking water quality of the Guarani Aquifer. This study plans to understand how vulnerable it is to become polluted in this area using two different models used widely as reported in the forthcoming literature.

Aller, Bennett, Lehr, Petty and Hacket (1987) developed a standardized system for evaluating intrinsic groundwater pollution potential using hydrogeology settings;

this methodology called DRASTIC has been since then used in multiple studies, research and case studies (see further review). The acronym DRASTIC corresponds to the initials of seven base maps or parameters of the model. A description of the model and its parameters is found in Section 6.4. In the same year, Foster, Hirata, Gomez, D'Elia and Paris (2002) published a guide for groundwater quality protection, which includes in detail a developed methodology for aquifer vulnerability to pollution aliased GOD (available publication for this research was of year 2002, original methodology published in 1987), considering three parameters for the model. GOD model is described in Section 6.5. Both models have been used in different hydro-geological conditions, generating a wide experience in their use, some of which are reported next:

Shahid (2000) used DRASTIC to determine aquifer vulnerability to pollution in and around Midnapur-Kharagpur towns, West Bengal, India. The result of the study shows that 50 percent of the area is highly vulnerable to industrial and municipal pollutants and more than 81 percent of the area is highly vulnerable to pesticide pollutants. Shahid's results identify areas near the Kasai River as more susceptible to pollutants, suggesting a need for proper management approaches to be adopted to provide a long term pollution free groundwater supply in the area.

Chowdhury, Iqbal and Szabo (2003) presented a case study in Chippewa Creek Watershed in Ohio using DRASTIC within an evaluation of groundwater resource, identifying more vulnerable areas to pollution. Another experience by Ceballos and Avila (2004) applied the DRASTIC methodology in karsts geology in the Yucatan

Peninsula in Mexico. The study found high and extreme vulnerability values in almost all the Peninsula. The authors also initially intended to apply GOD methodology, however finally decided on DRASTIC methodology which provided a wider range of values, due to the higher level of parameters, and the very homogeneous characteristics of the Yucatan Peninsula.

Some adaptations have been made to the DRASTIC model in correspondence to very particular conditions, such as karsts conditions, Cucchi, Forti and Zini (2004) used SINTACS "In order to fit DRASTIC in the hydro-geologic, climatic and impact settings that are typical of the Italian territory and of the Mediterranean basin". According to Trevisan, Padovani and Capri (n/a), the Research Group for Defence against Hydrogeologic Disaster (GNDCI) of the Italian National Research Council (CNR) created a new model called SINTACS (Civita and De Maio, 1997 in Trevisan, *et al.* (n/a)). The acronym refers to the Italian name of the parameters considered. Such adaptations of the DRASTIC model have not been found so far for the study area of this work and its particular conditions.

Gogu and Dassargues (2000) undertook a review of vulnerability assessment and mapping methods that included DRASTIC, GOD, SINTACS and others, considering that "The concept of groundwater vulnerability is a useful tool for environmental planning and decision-making (…) and that applying different methods to the same zone and using the same data showed that the relatively simple methods could provide similar results to the complex ones." In the same idea, Agüero and Pujol (2002) compared the GOD and DRASTIC models in Costa

Rica. Considering both models, differences about the methods were made regarding use, data collection and simplicity of the models. Agüero and Pujol found similar vulnerability values with both models, and showed capable of determining intrinsic vulnerability in a similar manner. As well as other authors, a series of recommendations are made if a deeper study of specific pollutants is required. The study by Agüero*, et al.* (2002) can be considered an example of what is pretended to achieve with the present study of the Watersheds of the Mboi Cae and Quiteria Rivers, however in totally different geological conditions.

In CATIE, several researchers have used aquifer vulnerability analysis to support wider investigations related to vulnerability, water resources, or watershed management. Vignola (2005) used the DRASTIC model in order to strengthen decisional instruments for water provisioning systems in El Salvador, specifically as a characterizing tool of the different susceptibilities to pollution. Laino (2005) applied the same model in a study in Paraguay, as a tool to determine management of water resources in a rural watershed and to strengthen knowledge of the implications for the environmental management of the Guarani Aquifer. Also in the same year, Obando (2005), applied the DRASTIC method in an in-depth groundwater vulnerability analysis in a watershed in Nicaragua, while Watler (2008) used GOD model in a water resources vulnerability analysis in a watershed in Costa Rica, Watler used GOD specifically for groundwater, while using other methodologies for superficial water.

Works by Laino (2005), Obando (2005) and Vignola (2005), while applying the same model to assess groundwater vulnerability to pollution, are distinct in the way of obtaining the necessary information and data to use the model, depending on previous studies in the areas. When precise data was not found by the authors, it was estimated by using other available information based in literature review and experts considerations. This three examples show how the application of the model can vary in difficulty of application and intensity of work for the researcher, mainly depending on how precise data is available or wanted, and also how the application of the model is used in different contexts and for different objectives. Following this previous studies, the present work intends to use the results of the DRASTIC and GOD models as a knowledge tool for the Mboi Cae and Quiteria Watershed Council. At the same time, an opportunity to compare these two models in the same area allows a triangulation of the results and the use of the models. Within this research, both models serve the purpose of obtaining information in response to concerns about aquifer pollution and eventually as a decision tool for management at the watershed scale. To understand how the change of water level of the Yacyreta Reservoir could affect aquifer vulnerability to pollution, a future worst case scenario was used changing values in the DRASTIC model. Also changing values on net recharge assumed as an effect of climate change in the area allowed predicting how climate change could affect the vulnerability of pollution to the aquifer in the subject watersheds.

The following Section presents general information about the Watersheds in a concentrated literature review and is seen as indispensable to understand the background situation where this study takes place, also giving an insight of the general aspects, biophysical and socio-economical characteristics, some of which also justify the objectives of the research and help understand the works carried in this study.

3 Area of study

3.1 General aspects

The Watersheds of the Mboi Cae and Quiteria Rivers are located in Paraguay, inside La Plata River Watershed in South America (Literature Review: Figure 1). Figure 3 shows the location of both Watersheds inside the Itapua Department in Paraguay.

The Watersheds of the Mboi Cae and Quiteria Rivers cover part of 5 and 7 different municipalities respectively, all of them in Itapua Department. Political division at the Municipality level is illustrated in Figure 4 and Figure 5.

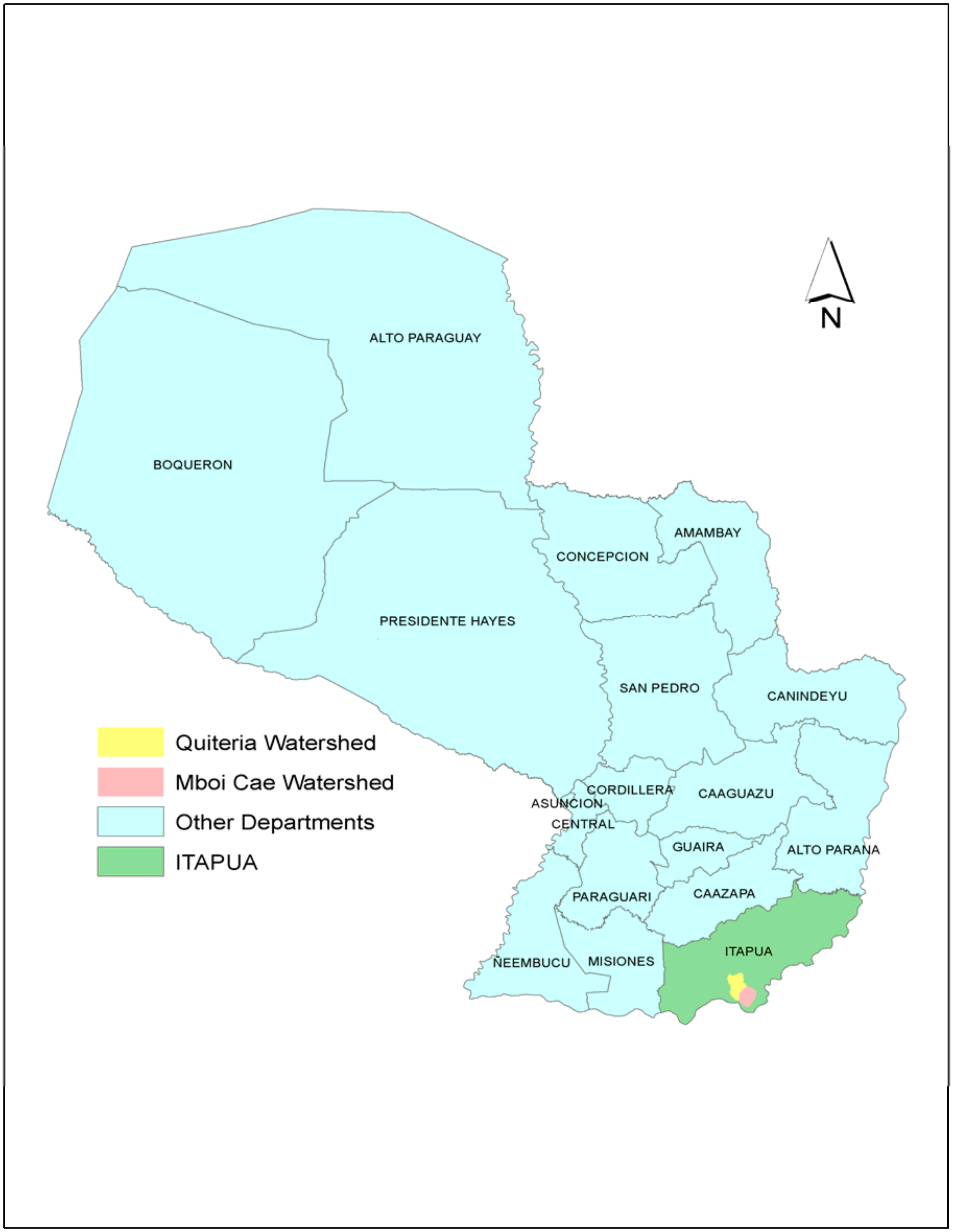


Figure 3. Location of the Mboi Cae and Quiteria Watersheds in Paraguay and Itapua Department. Source: Paraguay Departments Map and watershed delimitation by author using Digital Elevation Model.

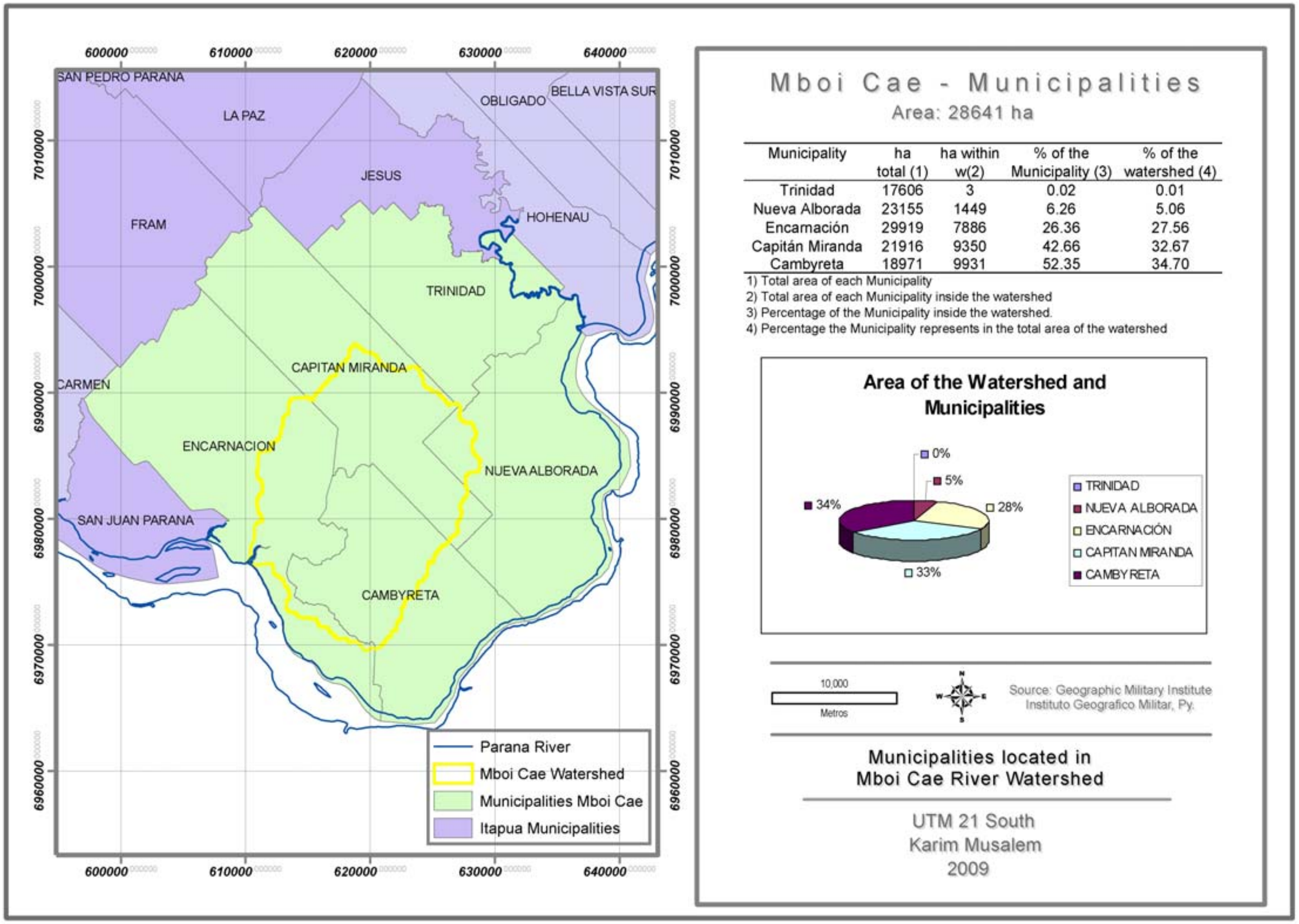


Figure 4. Watershed of the Mboi Cae River and Municipalities. Source: Paraguay political division map and watershed delimitation and calculations by the author.

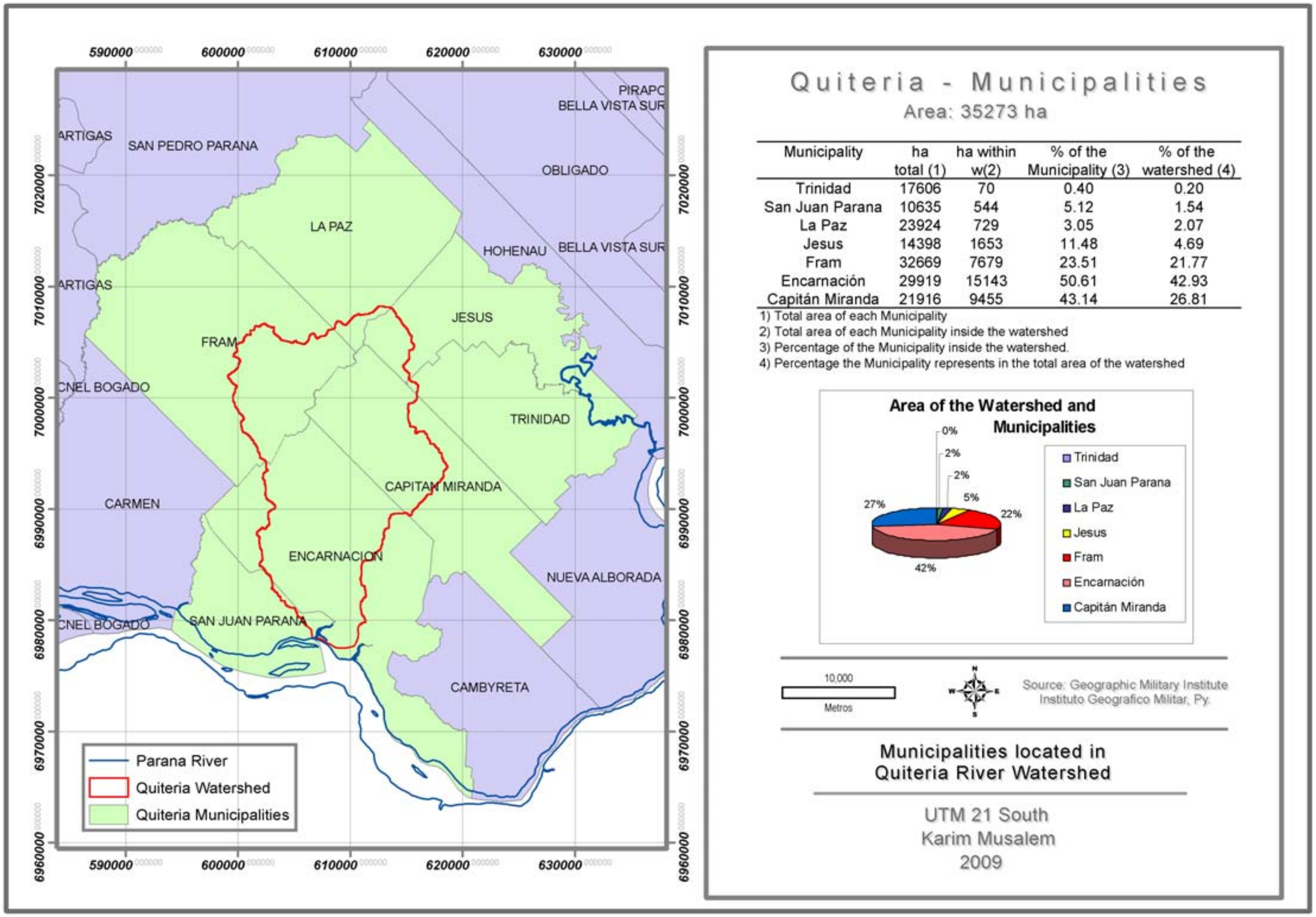


Figure 5. Watershed of the Quiteria River and Municipalities. Source: Paraguay political division map watershed delimitation and calculations by the Author.

3.2 Morphometry

Figure 6 shows the delimitation of the subject watersheds, selected as priority watersheds of the Yacyreta Dam. Mboi Cae River Watershed is of approximately 28641 ha with a total perimeter of 96 Km. Quiteria River Watershed has an approximate 35 273 ha with a total perimeter of 125 Km.

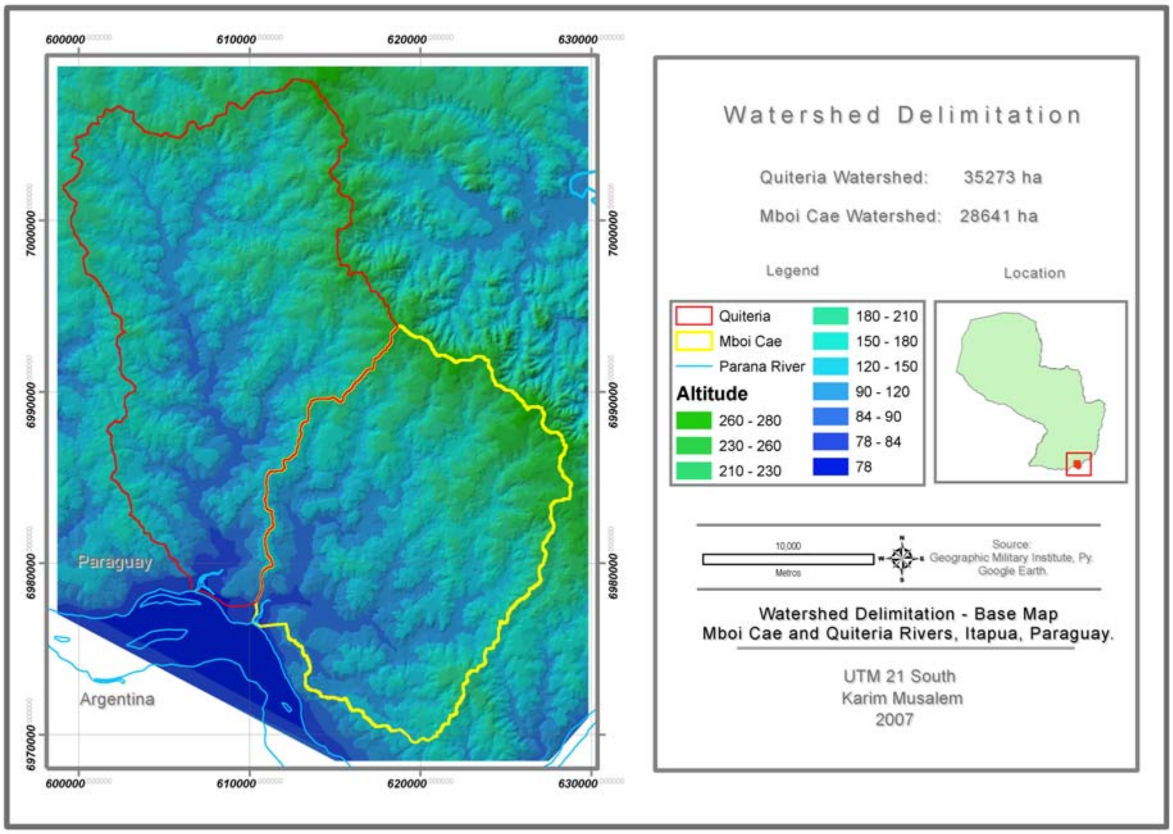


Figure 6. Base map of Mboi Cae and Quiteria River Watersheds and altitude. Source: watershed delimitation by Author using DEM; altitude obtained from contour lines from IGM, height measurements with GPS and Google Earth.

According to estimations by Global Consultores (2008) both watersheds have a total area of 640 sq Km, of which approximately 41 sq Km (6% of the total) is urban and 599 sq Km rural. Once the filling of the dam is completed at a level of 84 m (meters above the sea level), an approximate 1930 ha will be covered with water, reducing dry land to approximately 621 sq Km. Advancing the wetlands inside the mouth of the Mboi Cae and Quiteria Rivers. Measurements by the author using GIS shows that elevations in the Mboi Cae Watershed go from 78 to 280 m in some areas of the water divide (Figure 7), with a 202 m difference in a maximum longitude of 20.9 Km. Elevations of the Quiteria Watershed go from 78 to 270 m. in some areas of the water divide, with a 192 meter difference in a 30.8 Km maximum longitude.

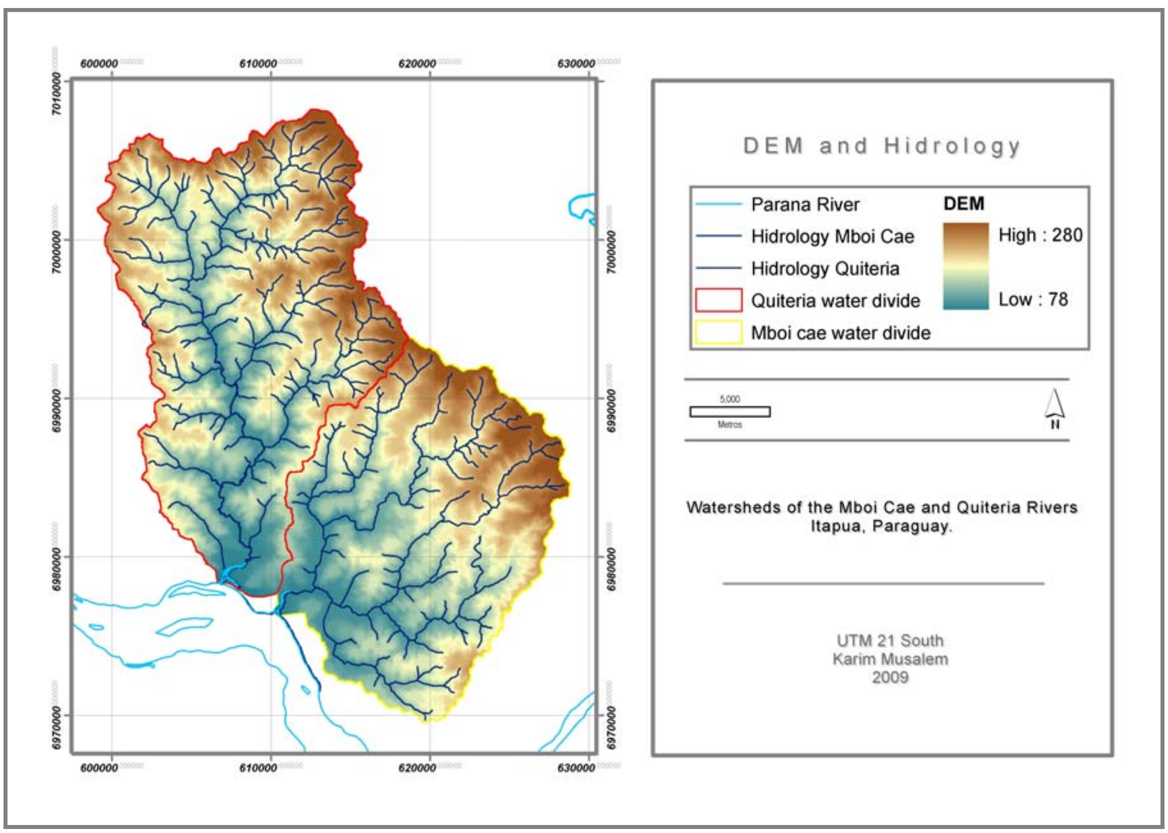


Figure 7. Digital elevation model (DEM) and hydrology in the study area. Watersheds of Mboi Cae and Quiteria Rivers, Paraguay.

3.3 Hydrology

Table 4 summarizes information on hydrology as determined by Global Consultores (2008). Measurements reported by this consultancy group were in revision. The final document was not available despite a formal solicitude made to the YBE.

Table 4. Hydrological characteristics available for the Watersheds of Mboi Cae and Quiteria Rivers, Itapua, Paraguay.

	Mboi Cae	Quiteria
Number of tributaries	104	172
Area of the watershed	290 sq Km	350 sq Km
Longitude of Tributaries	165,028 m	323,088 m
Hydrographical density Number of tributaries / Area of the watershed	0.36	0.49
Drainage density Total longitude of tributaries / Area of the watershed	569	923
Flow /year	174,000,000 m^3/year	210,000,000 m^3/year
Average flow	5.52 m^3/s	6.66 m^3/s
Specific flow	19.03 litres/s/sq Km	19.03 litres/s/sq Km

3.4 Biophysical characteristics

3.4.1 Weather and climate change

Rainfall was estimated by the author through interpolation of data from local meteorological stations. According to calculations, it varies from 1,878 mm to 1,988 mm per year for both watersheds. This is similar to what is reported by Global Consultores (2008) that establishes a mean annual rainfall of 1,964 mm. The south-eastern areas of Paraguay, where the subject watersheds are located, have the lowest temperature in the Country and also the highest precipitation. According to meteorological stations, mean annual temperature is of 21°C, the hottest month is January (28°C) and the coldest July (16°C). According to Global Consultores (2008) the relative moisture of the air oscillates between 70 to 90% and potential evaporation-transpiration is of 1,047 mm.

Limia (2000) and Vazquez (2000) reported for the Paraguayan Environmental Secretariat a description of climate change scenarios for the Country. These scenarios were built considering tendencies in the emission of greenhouse gases to the atmosphere together with models of global circulation, and supported by the use of MAGICC (model for the assessment of greenhouse gas induced climate change) and SCENGEN (scenario generator) software.

Vazquez (2000) constructed three possible scenarios to predict climate change that could occur in Paraguay derived from greenhouse gases. The study subdivided the Country into 4 main regions. This division was made derived from methodological needs for the SCENGEN working at a spatial resolution of 5 times 5 degrees latitude – longitude. Each area or region in within is considered to have a homogeneous climate. Mboi Cae and Quiteria Rivers are both located inside Region III by Vazquez: latitude South 25° to 30° and longitude West 55° to 60°. Results of climate simulations applied to this area show main climate characteristics (temperature and precipitation) changes in three scenarios of greenhouse gases emission combined with three different global circulation models. Table 5 shows interpreted data from annual variation of temperature and precipitation for Region III referred to different time horizons, using the following scenarios as reference:

- Scenario IS92c with model UKTR.
- Scenario IS92a with model HadCM2.
- Scenario IS92e with model CCCEQ.

Table 5. Annual variation of temperature and precipitation for the years 2010, 2030, 2050 and 2100. Paraguay climate change Region III under three different greenhouse gases emission scenarios IS92c, IS92a and IS92e.

Time Horizon	Scenario 1		Scenario 2		Scenario 3	
	Temperature (˚C)	Rainfall (%)	Temperature (˚C)	Rainfall (%)	Temperature (˚C)	Rainfall (%)
2010	0.4	- 0.1	0.5	3.0	0.9	-1.6
2030	0.7	- 0.1	0.9	5.8	1.8	- 3.4
2050	1.0	- 0.2	1.4	8.9	3.0	- 5.5
2100	1.3	- 0.2	2.5	16.2	6.2	- 11.5

Uncertainty in climate change predictions allows currently only a draft of future conditions in a determined area, and data is still depending on greenhouse emissions in the future and methodologies vary greatly in results and even tendencies, however their availability for this area made it possible to analyze possible predictions of change in aquifer vulnerability of the aquifer, mainly affecting net recharge.

3.4.2 Physiography, topography and slope

According to descriptions by Gonzalez (2005), topography of the area is undulated and moderately steep towards the Parana River. Landscape is of soft valleys and crests (Figure 8).

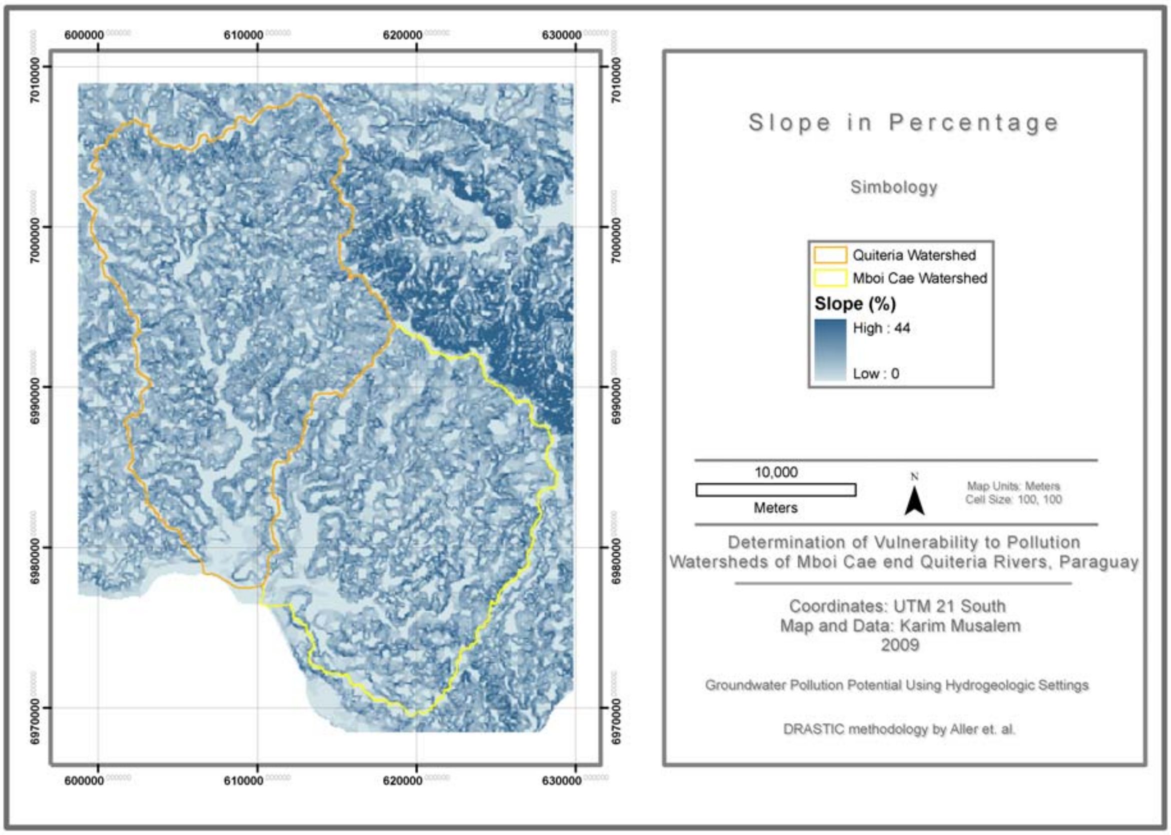


Figure 8. Slope in percentage in the Mboi Cae and Quiteria Watersheds in Itapua, Paraguay, calculated with digital elevation model by the author.

3.4.3 Geology and hydrogeology

According to the geological map of Paraguay (1986) both watersheds are found in basaltic areas from the *Alto Parana* Formation (Higher Parana). Even though sandstone formations are common in areas close to the Watersheds they are not present within (Figure 9).

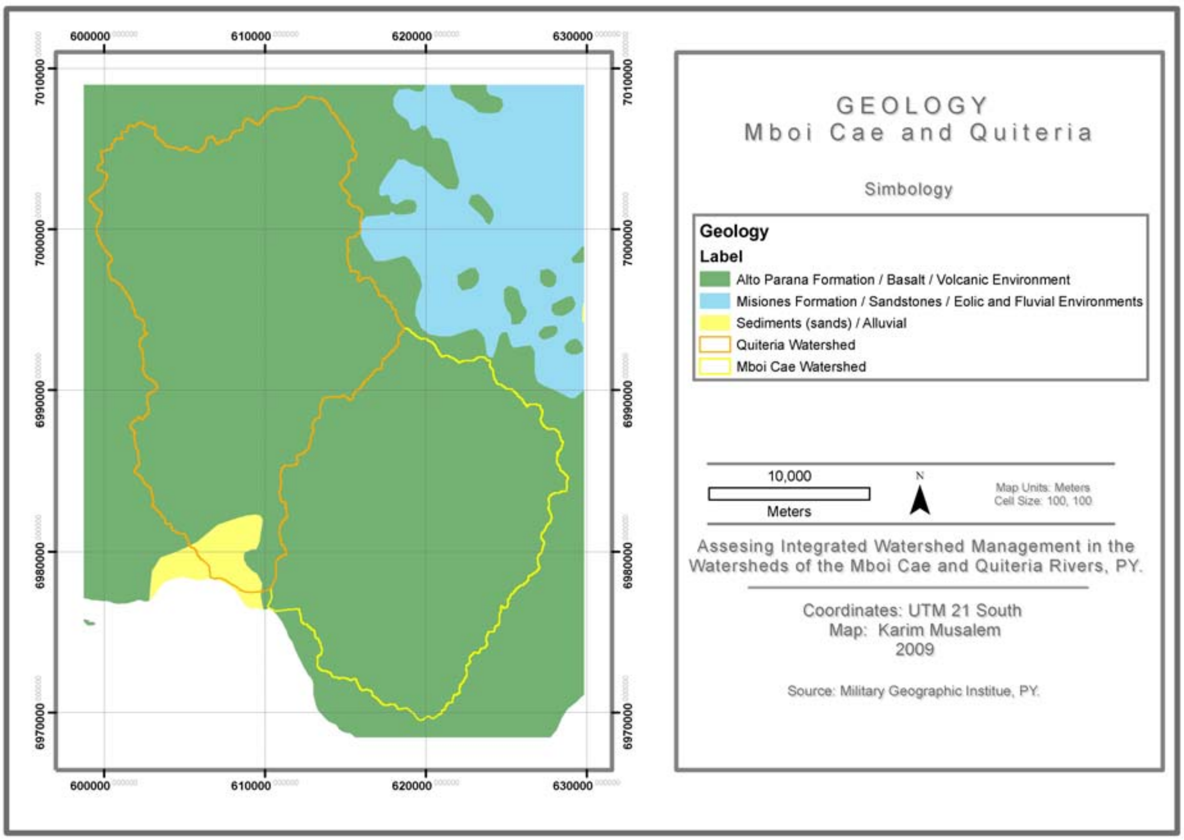


Figure 9. Distribution of geological formations in the Mboi Cae and Quiteria Watersheds, Itapua, Paraguay.

According to descriptions by Gonzalez (2005), the main drainage has a main collection river, the Parana River, and a tributary system of small rivers and intermittent rivers that drain the whole area as well as a presence of some low floodable fields. The evolution of a basaltic geomorphologic plateau resulted in stepped surfaces that influence considerably the shape of the drainage basins and the longitudinal profiles of water courses in the area and in the general morphometry of the region. According to Gonzalez (2005), successive basaltic spills during the Cretacic covered totally or partially sand rocks from Triassic-Jurassic periods. These geological events resulted in structural and lithological characteristics affecting the behavior of runoff and ground water of this region. Because of their lithological and structural nature, groundwater of the region is grouped in an area of rocks and basaltic soils: generally, crystalline basaltic rocks have a low hydraulic conductivity and are bad groundwater storages; however, horizontal discontinuities and vertical fractures allow recharge of water to lower sandstones beneath the basalt. Water is usually found as close as 10 or 12 m deep and are also usually extracted by home made wells with small pumps or buckets.

Hydro-geochemical characterization in the area classifies water as bicarbonate calcic-magnesic and calcic-sodic. Underground water is classified of excellent quality for human consumption with a pH of 6.2 to 7.0, and temperatures of 22 to 25 °C. This contrasts with superficial water which has a poor water quality due to urban wastewaters, outstanding the importance of this underground reservoir to supply water for potable and agricultural purposes. Gonzalez (2005) defines hydrology as dominated by the presence of the Parana River as a common collector. All superficial water is drained to this river through smaller rivers or streams.

3.4.4 Soil

A soil taxonomy study carried out by Global Consultores (2008) is reported as part of the works carried out by this consultancy group at the watershed level. 30 sampling sites and 8 soil profiles were analyzed to obtain the most detailed soil taxonomy map yet found in literature specifically for the Mboi Cae and Quiteria Watersheds. The report by Global Consultores was only available partially, due to an ongoing revision process and the lack of institutional will to provide access to it despite efforts to obtain it through formal channels, however the July 2008 draft was available and is presented here for informational purposes.

Table 6. Taxonomical units found in Mboi Cae and Quiteria Watersheds according to Global Consultores (2008)

Taxonomical units	Texture	Area Sq Km	% of the Watersheds
Co-association Rhodic Kandiudox	Fine clay	367.8	57.5
Co-association Rhodic Paleudult	Fine clay	08.7	01.4
Co-association Typic Kanhaplaquult.	Fine loam	94.8	14.8
Association Plinthudult/Lithic Udorthent	Fine clay	07.4	01.2
Association Typic Kanhapludult / Lithic Udorthent	Fine clay	05.9	00.9
Asociación Lithic Kandiudox / Lithic Udorthent	Fine clay	129.4	20.2
Urban areas	Urban	26.0	04.0
Total		640	100.0

The following description of the 3 most representative taxonomical units were taken from the same document and presented here in a summarized way.

Co association Rhodic Kandiudox, fine clay phase.

Covering over 55 % of the Mboi Cae and Quiteria Watersheds it occupies high lands and hills. Soils more than 150 cm deep with no superficial or internal drainage problems, free of rocks. Organic matter presence is high (probably derived from no-till farming – sic.). Low bases saturation 62% - 95%, variations were found in the analyzed profiles probably derived from crop management and lime addition. Strong acidity and very low Phosphorus content.

Co association Typic Kanhaplaquult, fine loam phase.

Covering approximately 15 % of the watersheds it dominates old valleys and recent alluvial deposits derived geologically from sediments of permanent erosion processes. These soils are usually wider in the mouth of the rivers, meeting with the Paraná River and become narrower in the upper areas eventually disappearing. Soils are shallow with the water table usually appearing at 50 cm

Association Lithic Kandiudox / Lithic Udorthent.

Present in lower hills with deepness reducing as they approach rivers or valleys. This taxonomical unit covers and approximate 20 % of the watersheds and usually not protected with the implementation of no-till farming. These taxonomic unit presents low fertility and high acidity due to a low quantity of exchange bases and low bases saturation. Exchangeable Al+++ is slightly toxic for the root system.

Usable Phosporus is low (as in the rest of the taxonomic units found in the watersheds).

According to a description to Gonzalez (2005), soils derived from basaltic rocks are classified as Oxisols (Kandiudalfic Eutrodox) and Ultisols (Rhodic Paleudult) with a clay texture along the subsoil profile and a dark red colour. “They are deep soils, well drained and with a good structure that gives them excellent physical properties. In the conditions of a natural forest, they contain high quantities of organic matter in the upper layers. In lower floodable areas, soils are classified as Typic Paleaquult (**Typic Kanhaplaquult According to Global Consultores)**, of fine loam. These soils have strong hidromorphism characteristics, which indicate closeness to the aquifer layer. These soils do not have a good aptitude for common agriculture crops of the area (soybean, corn, manioc, wheat, beans). The most representative soils of the Mboi Cae Watershed are Oxisols, with presence of entisols and ultisols close to the areas of the river. Quiteria Watershed has presence of ultisols and oxisols, with also entisols near the river (Figure 10). Soil taxonomy is based on the taxonomic system USDA Soil Survey Staff (2006).

An analysis by Global Consultores was made regarding soil and soil characteristics, and aptitude for agriculture and was reported to EBY in 2008. However the spatial distribution of the soils in the watersheds was taken from Paraguayan national soil map.

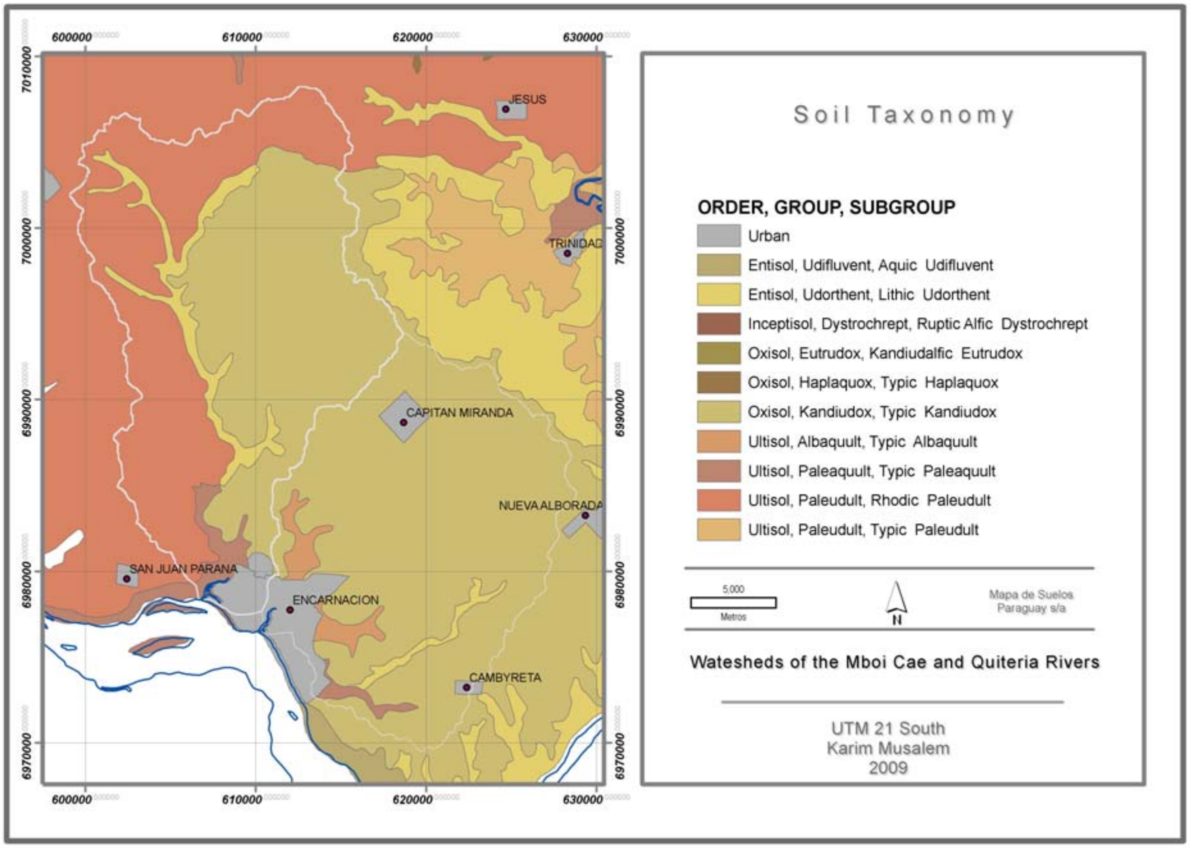


Figure 10. Soil Taxonomy in the Watershed of the Mboi Cae and Quiteria Rivers and nearby areas. Itapua, Paraguay.

Until now, no precise information or measurement was found at the moment regarding erosion; however, visual evidence of erosion occurs in rural roads and cultivation areas (Figure 11).

Figure 11. Photographs showing erosion in rural roads and cultivation areas. South 27°14,1 and West 55°46,9 / South 27°04 and West 55°53. (Mboi Cae) Itapua, Paraguay.

3.4.5 Land use

According to Gonzalez (2005), native vegetation has suffered strong alterations. There are few natural remnants left. Most of the current predominant vegetation is introduced, especially crops of cultivated grass plants. Native vegetation is associated with that of the Alto Parana Atlantic Forest and is found in soils originated from basalts or sand rocks when there are deep soils with good fertility.

Mechanized agriculture predominates in the basaltic area. Soybean is the most extended together with rotation crops of wheat, corn or sunflower. Main use of soil is intensive agriculture of soybean and sunflower, as well as grasslands. Original forest vegetation has been limited only to small patches and irregular fringes around the streams (An estimation of around 20% of the surface of the watersheds). Figure 12 shows forest vegetation cover in the area of the Watersheds, according to map reported by Guyra, Paraguay.

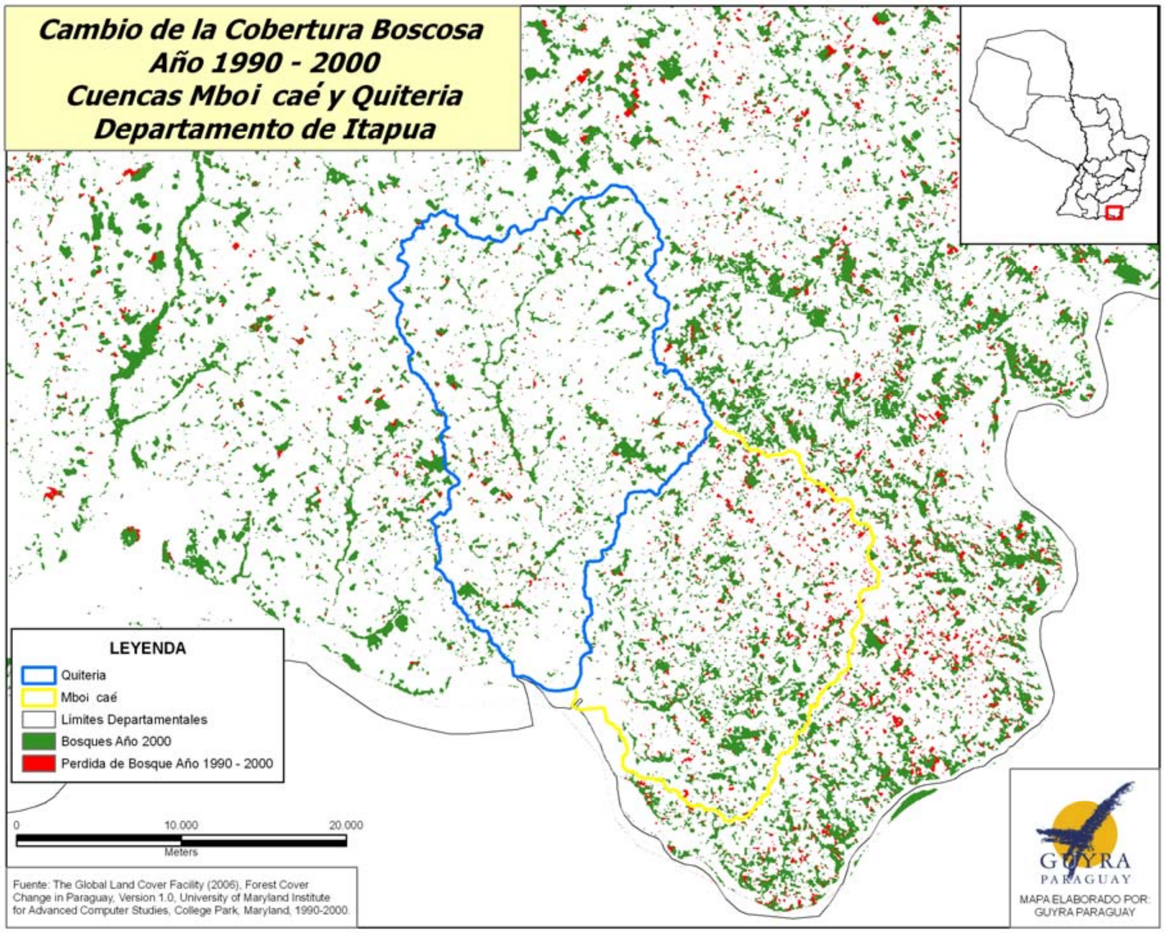


Figure 12. Forest coverage change 1990 – 2000, Watersheds of Mboi Cae and Quiteria Rivers. Itapua, Paraguay. Map source: Guyra Paraguay (Spanish).

3.4.6 Biodiversity

The Watersheds are inserted inside the area of distribution of the Alto Parana Atlantic Forest (APAF), it constitutes a singular ecosystem conforming one of the major humid subtropical forests in South America, and however, it is highly threatened and remains less than 7% of the original area. Paraguay administrates the major portion of this remaining forest, mostly localized in the border with Brazil and Argentina. APAF holds a wide variety of important species considering biological diversity, including 13,000 species of vascular plants, 100,000 invertebrates, 46 amphibians, 100 reptiles, and more that 250 species of fish, and 167 mammals; many of these species considered endemic as reported by Global Consultores (2008). The advancement of the agricultural frontier has displaced the forest, there are no protected areas inside the Watersheds.

3.5 Socioeconomic characteristics

3.5.1 Demography

Table 7 shows population of the Districts (Municipalities) that form part of the watersheds. This data corresponds to the total in the Districts and not necessarily population inside the study area. Even though 50% of Encarnacion Municipality forms part of the Quiteria Watershed, the major urban area, the City of Encarnacion, is found in the Mboi Cae Watershed. According to estimation by Global Consultores (2008) population actually living within the watersheds limits is approximately of 96.000 habitants.

Table 7. Population in the Municipalities within the Watersheds. Source: Dirección General de Estadística Encuestas y Censos (2002).

District	Total population	Living in urban areas	Living in rural areas
Encarnacion	97,000	68,960	28,040
Cambyreta	27,910	740	27,170
Cap. Miranda	8,810	2,100	6,710
Nueva Alborada	6,420	270	6,150
Fram	6,980	3,430	3,550
Jesus	5,790	2,350	3,440
La Paz	3,010	350	2,660
San Juan del P.	6,940	1,200	5,740

Population living in the study area come from different ethnic backgrounds and identities, such as Indigenous, European descendants (Spanish, German, Italian, Swiss, French), Polish, Ukrainian, Russian, Japanese, Chinese, Korean, Arabs and Lebanese (Global Consultores, 2008).

3.5.2 Education

During field work, education and research centres were observed and visited in the area, such as: Universidad Catolica Nuestra Señora de la Asuncion (UCA: Catholic University of Asuncion), National Itapua University (UNI), Agriculture Mechanization Centre (CEMA), Regional Agronomical Research Centre (CRIA), and also various agriculture technical schools. Some of these institutions are not exactly within the delimitation of the watersheds; however, they are closely connected to population and have influence in the subject watersheds.

3.5.3 Roads and transportation

The high and middle areas of the Mboi Cae and Quiteria Watersheds are almost totally covered with agriculture dirt roads. There is also a paved road (La Paz or

Graneros del Sur) that crosses most of the upper part of the watersheds. Dirt and paved roads seem not to consider any aspects regarding soil conservation (Figure 13).

Figure 14 shows roads and streets in the watersheds. Rural and urban areas are usually covered with dirt roads or stone roads. Some streets in the City of Encarnacion are paved as well as the main routes 1 and 2, that link Encarnacion with the capital of Paraguay, Asuncion, and Ciudad del Este, another urban location, bordering with Brazil.

Figure 13. Lateral view in a rural dirt road in the Watershed of the Quiteria River, Itapua, Paraguay.

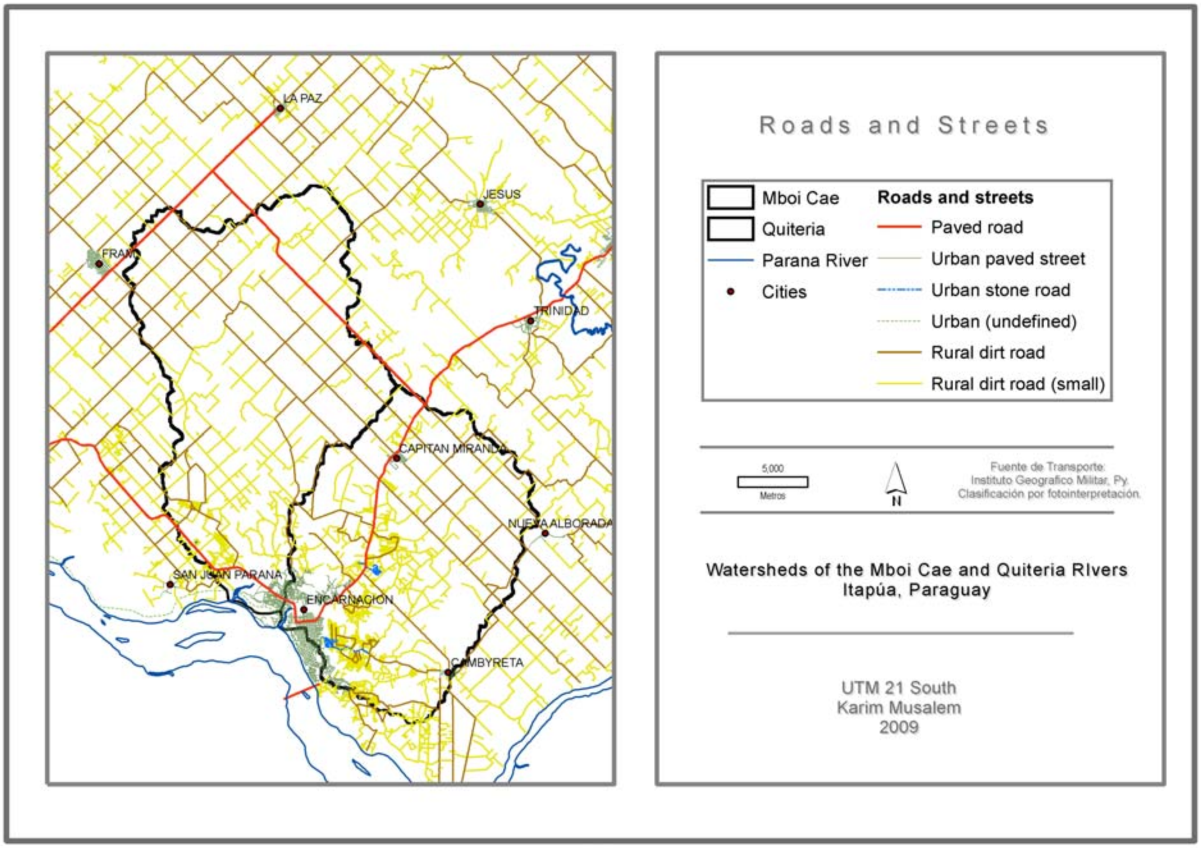


Figure 14. Main routes, roads, streets and localities in the Watersheds of the Mboi Cae and Quiteria Rivers. Itapua, Paraguay.

3.5.4 Water use

Information from YBE water quality analysis run in previous years and analyzed by Paez (2003) determined that water in Mboi Cae and Quiteria Rivers is not suitable for any kind of use. Both rivers showed an increase in the past few years of ammoniac nitrogen and faecal coliforms, all above limits permitted for any kind of use according to limits established by official health institution in Paraguay. Both rivers, although presenting an acceptable level of dissolved oxygen, maintain high quantities of organic matter and faecal coliforms. Although units are available, they are not presented here individually or temporarily, but parameters are shown according to their possibility of being used for different purposes (Table 8).

Table 8. Water quality parameters in Mboi Cae and Quiteria Rivers and their suitability to be used for different purposes according to Paez (2003); measurements for 1999-2000.

Mboi Cae River

Parameter	Class 1 Potable	Class 2 Recreational	Class 3 Aquatic life	Class 4 Industrial Use
Dissolved Oxygen	Yes	Yes	Yes	Yes
pH	Yes	Yes	Yes	Yes
BDOs	No	No	No	No
Ammoniac N	No	No	No	No
Total coliforms	No	No	No	No
Faecal coliforms	No	No	No	No

Quiteria River

Parameter	Class 1 Potable	Class 2 Recreational	Class 3 Aquatic life	Class 4 Industrial Use
Dissolved Oxygen	Yes	Yes	Yes	Yes
pH	Yes	Yes	Yes	Yes
BDOs	No	No	No	No
Ammoniac N	No	No	No	No
Total coliforms	No	No	No	No
Faecal coliforms	No	No	Yes	Yes

Paez (2003) concludes that both rivers have reduced their overall water quality in the period 1995 to 2000. This reduction in water quality has been suggested by Paez as a direct influence of the growth of the city of Encarnacion without the inclusion of proper water sanitation facilities to respond to such growth.

3.5.5 Update and tendencies in water quality

A tendency stationery Kendall test is reported by *Facultad de Ciencias Exactas y Naturales of the Universidad Nacional de Asuncion* for the YBE (2008), using data from years 1998-2003-2007. A tendency analysis is reported for Quiteria River, for testing point EA-7 located close to the river mouth, with Route 1 bridge crossing. Table 9 shows the results of the test where: S(TEND) is the direction of the tendency and the level of significance given by calculated Z value (value and sign), in relation to the theoretical value of 1,28, this significance is represented by the number of asterisks in the last column. If Z calculated is lower than the theoretical assumed value (1,28) tendency is not significant (NS).

Table 9. Tendency of water quality parameters in station EA7 (Watershed of the Quiteria River) and statistical representativeness. Source: YBE (2008).

Station	Variable	S (TEND)	TAU Kendall	Z CALC.	SIGNIFICANCE
EA-7 Quiteria In situ	Dis. Oxygen	-3	-0,02	-0,13	NS
	pH	32	0,24	2,01	**
	Conductivity	41	0,30	2,59	***
	Turbidity	-4	-0,08	-0,38	NS
EA-7 Quiteria Laboratory	Mat. orgánica	8	0,17	0,88	NS
	N-Amoniacal	-6	-0,13	-0,63	NS
	N-Nitrato	-17	-0,35	-2,00	**
	Phosphorus total	8	0,17	0,88	NS
	Coliforms. Tot.	-37	-0,82	-4,69	***
	Colif. faecal	-20	-0,43	-2,43	***

3.5.6 Main employment and income sources

According to Gonzalez (2005), Paraguay has a primary production economy, mostly agriculture and forestry, with a low industrialization of products. The Department of Itapua is one of the main producers of the Country, and with the highest level of transformation of primary produce. It is one of the richest Departments of Paraguay. Population in this Department is dedicated to primary production and services accompanying this production. Itapua is divided into 29

Districts, the highest number of Districts per Department in the Country; this usually leads to a better political and administrative organization.

Table 10 shows the main crops in the study area. Some other crops are cultivated in a lower scale, such as *Stevia* (sweetener), rice, peas, sunflower, sorghum, orange, tangerine, and others (Figure 15 and Figure 16). Also small scale animal production can be found, such as porcine, ovine, goats and birds.

Table 10. Main cultivated crops in the Watersheds of the Mboi Cae and Quiteria Rivers according to cultivated area and estimated production, Source: *Global Consultores (2008)*.

Crop	Cultivated (ha)	Estimated Production (Tons)
Soybean	13.449	18.275
Wheat	8.204	12.476
Cotton	2.836	3.668
Mate herb	2.380	2.608
Corn	2.346	4.260
Cassava	2.216	No data
Fodders	1.828	No data
Tung	1.779	7.104

Figure 15. Agriculture in the upper Quiteria River Watershed, intensive sunflower cultivation. Nov 2007. South 27°04, West 55°53, Itapua, Paraguay.

Figure 16. Grasslands in the upper Quiteria River Watershed. Some riparian forests visible. Nov 2007, South 27°25, West 55°53. Itapua, Paraguay.

3.5.7 Government and legal framework

When this research began, in 2007, a different legal panorama existed than the one currently taking place. In a few years, changes happened regarding water resources management in Paraguay. A water law did not exist before, and legislation was dispersed in different normative bodies that intended to give answer to sector-based realities. However, in mid 2007, Law Nº 3239/07 was promulgated "About Water Resources in Paraguay", which is currently in the beginning of its implementation and appropriation by society even though it still lacks regulation.

Amongst the principles of this Law, watersheds are considered as the basic unit for management of water resources. Also, it is established that superficial and subterranean waters are property of the State, and that water access to satisfy basic human needs is a human right. It is also mentioned that water resources are a finite and vulnerable resource with value at the social, environmental and economic levels. Amongst the basic objectives of the National Water Resources Policy, is to require integrated preservation, with a systemic view of watersheds, recharge areas of aquifers and wetlands.

The Paraguayan Environment Secretariat (SEAM) is the authority of application of this Law, until an institutional framework is defined that will take charge of the application of this Law and all its dispositions. On the other hand, SEAM, since before the promulgation of this Law has been promoting management and sustainable use of water resources, taking watersheds as planning units through the instrumentation of Resolutions.

Resolution Nº 2042/06 by which the terms of reference of the Watershed Management and Environmental Ordering plan are approved, mentions in its objectives the strengthening of the capacity of management of local and regional organisms, including governmental, NGOs, and communitarian organizations to establish the necessary mechanisms that allow effective coordination of State and private activities, interacting and harmonizing ordinances of Department and Municipal governments associated internally by a watershed, at the trans-boundary level if necessary, for the identification and solution of the needs of the population affected by the watershed.

Resolution Nº 170/06 by which the regulation for Watershed Council (Water Council) is approved, establishes that integrated water resource management in Paraguay should be instrumented through Water Councils defined by watersheds.

Within this context, in mid 2008, the Water Council of the Watersheds of the Mboi Cae and Quiteria Rivers was conformed, within a covenant between the SEAM and Yacyreta Binational Entity through which the Management Plan was elaborated for the watersheds. The objective of such covenant is to apply an Integrated Watershed Management policy relative to use, protection, and conservation of watersheds in the area of influence of the Yacyreta Dam.

4 Research questions

How much is known about the Mboi Cae and Quiteria Watersheds? What information is available and which is still missing to reach proper characterization? Where is the available information?

Which are the main socio-environmental conflicts of the watersheds? Which are possible solutions from the watershed council perspective? How are the identified conflicts linked with the present research?

Which is the integrated watershed management level reached in the watersheds of the Mboi Cae and Quiteria Rivers so far, according to the IWM standard?

What is the current vulnerability of pollution to the aquifer in the watersheds of the Mboi Cae and Quiteria Rivers? What will the differences be when using different models? How will the change in water level change vulnerability? Can any changes in vulnerability be predicted in the context of global climate change?

5 Objectives

1. To contribute with an assessment on the state of knowledge and available information of the area of the Watersheds of the Mboi Cae and Quiteria Rivers.

2. To identify the most important socio-environmental conflicts in the Watersheds and possible solutions from the Watershed Council perspective.

3. To determine integrated watershed management level in the watersheds of the Mboi Cae and Quiteria Rivers using the IWM standard in search to understand priorities for the future in this matter, advances, and as an experience of application of the standard.

4. To determine current and predicted vulnerability to pollution of groundwater in the Watersheds of the Mboi Cae and Quiteria Rivers through GIS-based models.

6 Methodology

The methodology consisted of the following basic stages; 1) An assessment of the state of knowledge of the watersheds, specifically to determine available information, where it is located and how specific it is; 2) A socio-environmental conflict analysis together with the Watershed Council where identification of conflicts and their possible solutions are provided from the perspective of the Watershed Council; 3) determining Integrated watershed management using a multi-criteria standard designed previously for this objective by Musalem, Jiménez, Faustino and Astorga (2006), conducting to a base line of the situation in the area, regarding IWM. And 4) the use of this previous collected data and maps to determine current and predicted groundwater vulnerability to pollution in the watersheds through the use of the DRASTIC model developed by Aller, *et al.* (1987) and the GOD model according to Foster, *et al.* (2002), allowing a comparison of both models usage and results. Figure 17 shows the schematic process of the methodological stages and their context within the research as a whole. Each methodological process is described fully in the following chapters. A next level of the methodological process includes integrating different aspects of the research in an integrated approach using triangulation whenever possible.

- State of knowledge analysis: A GIS was built processing basic information into new maps specifically for the Watersheds; also all available data of the Watersheds found was revised and placed in a comprehensive and summarized table.
- Socio-environmental conflicts were studied through a workshop with the Watershed Council, offering possible solutions and strategies from the perspective of this local organism and its capacities.
- Generating new information through the determination of IWM level: using an IWM standard. Understanding the level of IWM in the watersheds at the moment, emphasizing weak points.
- Generating new information through the application of the DRASTIC and GOD models. Determining aquifer vulnerability to pollution and prioritizing more vulnerable areas. Comparing results of the groundwater vulnerability models, their use, simplicity, and parameters.
- Integrating different parts of this research whenever triangulation is possible, also to stand out the similarities in information, possible links, and discrepancies, in order to enrich the IWM standard.

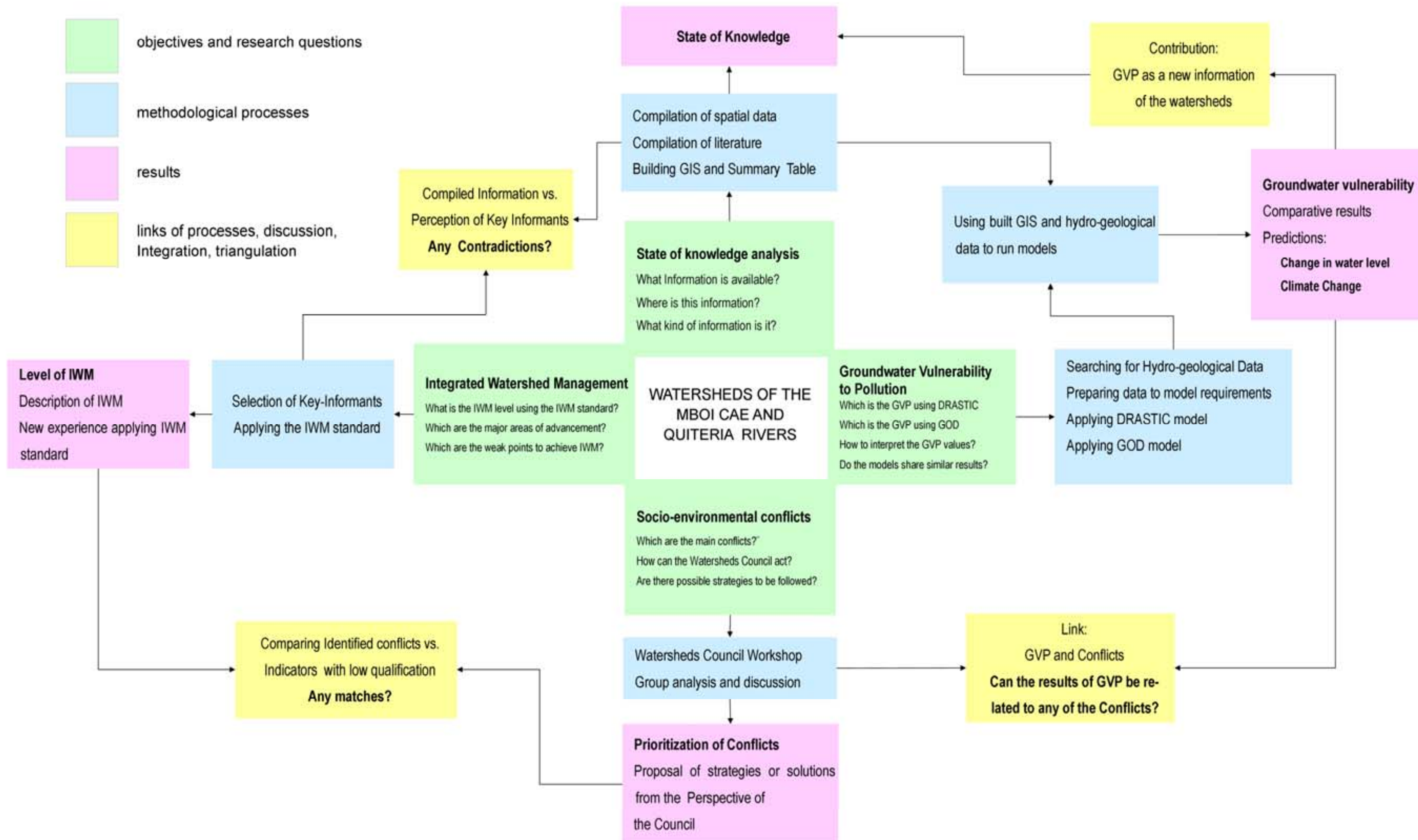


Figure 17. Schematic representation of the methodological process and results in the watersheds of the Mboi Cae and Quiteria Rivers in Paraguay.

6.1 State of knowledge

A first step was the construction of a Geographic Information System. To achieve this, a thorough collection of all spatial information available in various sources about these watersheds was done, using elements of characterization as determined by Jimenez (2004) as a framework reference. ArcGis Software, versions 9.1 to 9.3, was used to build this specific GIS. Projection of different available maps, shapefiles, satellites images, and aerial photographs was also done using Arc View 3.3 and extensions Projection Utility Wizard, setting work on a plain coordinate system UTM 21 S. GIS tools and extensions together with skills to apply and use these tools by the Author were combined and supported by consultation with other GIS software users and experts.

The construction of a GIS of the two Watersheds joined and projected spatial information available for the area, and was used for generating new information and maps, providing detailed information on the area and its characteristics. For example, using Spatial Analyst and 3D Analyst extensions in Arc View 3.3 allowed determination of topography and slope, derived from available information such as contour lines. Also, using Hydro or Basin1 extensions allowed determination of a precise delimitation of the watersheds obtainable from a Digital Elevation Model (DEM). Elements of a characterization for a watershed according to Jimenez (2004) were used as a guideline for this process which also included revising the main sources of information for the Watersheds in a thorough literature review and search for information of the study area.

According to Jimenez (2004), ideal components and variables of a watershed characterization can be subdivided into three main issues: a) Localization, morphometry and hydrology; b) Biophysical characterization; and c) Socioeconomic characterization. A characterization is a first step taken towards understanding the most important characteristics of the watershed and should be directed to have detailed information of the area. Given the information available, and following Jimenez's elements, a table was constructed to be able to visualize at a glance the availability of information of the watersheds, where it is localized, and the level of detail of the information. By analysing this table, a determination of main aspects about information of the watersheds can be achieved, resulting in: weak points, necessary research, well studied areas, etc. Results are presented in Section 7.1.

6.2 Conflicts and solutions

To identify conflicts a workshop was held in June 20th 2009 at Capitan Miranda Municipality (Figure 18). This workshop consisted of an open invitation to all members of the Watersheds Council and managed to gather 20 members for a period of time of approximately over 4 hours. The location was provided by the Municipality and Local Police. The president of the Watershed Council made necessary arrangements and invitation to all members of the Council (Addendum 2).

Figure 18. A discussion moment during the socio-environmental conflict analysis workshop held in Capitan Miranda with the Watershed Council. June 2009. Paraguay.

The workshop consisted on an initial session of explanation about the current research, an introduction to the area, the Watersheds and the approach of the research. After a brief explanation and presentation the following question was made to the participants: **“Which do you consider are the main socio-environmental conflicts in the watersheds?”**

Using participatory social research methodology by Geilfus (1987) called “rain of ideas” or “brainstorming”. Each of the participants working individually wrote in cards their separate answers. Each participant could write as many answers as he or she thought were necessary in separate cards. At that time, during the presentation or initial words, no specific conflicts had been mentioned, allowing each person to start the exercise without any predisposition.

After a time of 10 to 15 minutes of individual writing, each of the cards was read to the audience forming a frequency table. Every time a new conflict was mentioned a new registry was opened, every time a conflict was repeated (mentioned) an “x” was marked next to the existing registry. When similar conflicts were expressed in different ways, an open discussion was held to decide whether it should be registered as a new conflict or as the same as one mentioned before. All the time cards were read and collected the workshop participants also commented on the best ways to improve the writing grammar and grouped some conflicts together depending if they were related to their opinion.

Continuing with the exercise, the set of identified conflicts were read, summarized and counted leading to have a list of conflicts that were mentioned by the most participants and those mentioned fewer times. After this, a further consultation was made to prioritize the conflicts, arranging them according to their relative importance. The Watersheds Council agreed unanimously upon the prioritized conflicts as those that had been repeated more.

Once conflicts were identified, a set of 4 prioritized conflicts were selected to work in subgroups (Figure 19). Each person decided according to their interests, knowledge or experience to which of the four sub groups he or she should join to work in. Four different workgroups were conformed, discussing for over 30 minutes the possible solutions or strategies that the Watershed Council could follow to help solve this conflicts. These subgroups or focus groups intended, as described by Patton (1990), bringing together people of similar backgrounds and experiences to participate on specially targeted or focused issues.

Final conclusions of each workgroup were read to the rest of the participants, leading to a final discussion of each topic (conflict and solutions). Conclusions were elaborated and annotated as part of the results of the workshop. Results are reported in the corresponding Section 7.2.

Figure 19. Subgroup working on possible strategies to help solve the identified socio-environmental conflicts in the Watersheds of the Mboi Cae and Quiteria Rivers. Capitan Miranda, Paraguay.

6.3 Determination of IWM level: using an IWM standard

As basic information was being gathered, a base line was constructed using an integrated watershed management standard available from previous work carried out by Musalem*, et al.* (2006). The IWM standard was designed through the construction of Criteria and Indicators specific for integrated watershed management in rural areas; setting a certification scheme for IWM. Each of the indicators is derived into different levels or grades that can be judged and qualified by experts or key informants as defined by Geilfus (1987) and considering social research techniques as described as Kirby*, et al.* (2000), Providing with a rapid view (however in-depth) of the current status of integrated watershed management. Information is not collected directly for the purpose of this standard, but through key informants, however, triangulation is possible and constantly done to reconfirm information.

The IWM standard consists of 6 principles, 12 criteria, and 18 indicators, as well as parameters for each indicator, and a detailed description for their use and interpretation (Table 11). This IWM standard was used to determine the level of integrated watershed management in each of the selected micro watersheds. The IWM standard defines parameters for each of the indicators presented. The full methodology is explained in the document “Methodological proposal of an IWM certification standard” by Musalem (2005) and was used for this research. However, main steps for the application of the IWM standard are as follows:

- Gathering information from the watershed, characterization and current state of knowledge.
- Selection of key informants to work in several workshops where parameters and level of relevance of decision elements are thoroughly discussed and evaluated.
- Data analysis. Consisting of summarizing different opinions on different indicators as well as results from the workshops and semi-structured interviews.

- Interpretation of results. An output of a global qualification, as well as detailed information on each of the indicators.

Table 11. List of decision elements, criteria and indicators part of the standard used in assessing IWM for the watersheds of the Mboi Cae and Quiteria Rivers in Paraguay. Source: *Musalem*, et al. *(2006)*.

Decision Element	Concept of the element
Principle 1	**The watershed as a system**
Criterion 1.1	Integrated functioning and vision of the watershed
Indicator 1.1.1	Stakeholders and Institutions level of interconnection
Indicator 1.1.2	Level of convergence
Criterion1.2	High, medium and low parts of the watershed considered in the management.
Indicator 1.2.1	Level of protection of conservation areas of the micro watershed
Principle 2	**The social-environmental and co-development angle**
Criterion 2.1	Capitalization and Investment
Indicator 2.1.1	Level of capitalization and funding mechanisms: administration and implementation
Criterion 2.2	Inter-institutionalism. Close relationship among public and private sectors
Indicator 2.2.1	Level of inter institutionalism in the micro watershed
Criterion 2.3	Households (and their organizations) as the main objective of watershed development
Indicator 2.3.1	Level of consideration of IWM in infrastructure programs
Indicator 2.3.2	Level of environmental education
Indicator 2.3.3	Level of consideration of IWM in health centers
Indicator 2.3.4	Level of consideration of IWM in transportation routes
Principle 3	**Use of watersheds for planning and evaluation of impacts**
Criterion 3.1	Use of watersheds as the planning unit for territorial development
Indicator 3.1.1	Intervention activities planned with a IWM angle
Principle 4	**Water as the integration resource**
Criterion 4.1	Water quality as a proper watershed management result
Indicator 4.1.1	Evidence of sediments or pollutants in water streams
Indicator 4.1.2	Presence of debris or waste in water streams
Criterion 4.2	Water quantity as a result of a good watershed management
Indicator 4.2.1	Adequate water quantity during every season
Principle 5	**Reduction of vulnerability and risk by natural disasters**
Criterion 5.1	IWM directed to vulnerability reduction
Indicator 5.1.1	Buffer zones next to rivers
Indicator 5.1.2	Level of inclusion of risk assesmentin watershed development plans
Indicator 5.1.3	Recognition of relation between natural resources management and natural disasters
Principle 6	**Production and organization units as intervention units**
Criterion 6.1	Intervention actions according to the kind of practices adopted in production units
Indicator 6.1.1	Use of environmental friendly technologies in productive zones within the watershed
Indicator 6.1.2	Level of adoption of conservationist production and eco-enterprises

6.3.1 Selection of key informants

A set of 11 key informants were selected for this objective (Addendum 3). The key informants were selected to comply mostly with the following conditions:

- Knowledge of the area and local conditions. Persons who lived and worked in the area who have closeness to local problems, culture, social background, political conditions.
- Familiar with integrated watershed management concepts, natural resources management in the area, from government or non governmental institutions, related to natural resources policies. Scientists or University staff interested or studying in the area with natural resources management, ecology, etc.
- Decision-makers. Persons who have influence at the local level to make decisions and often represent an institution or group and/or with a position in government, municipality, NGO's, hydro-electrical power plant managing entity, watershed council, private companies, etc.

Methodology for this part of the research can be described as according to Kirby, *et al.* (2000) as being a " Non-random purposive sampling: people interviewed are selected on the basis that they are likely to be relevant to the subject being studied. (…) The sample reflects judgements made by the researcher (according to selection of key informants) that may be open to question. However, it does allow including significant individuals within the research". Particularly for this part of the study “purposive sampling” was also combined with a “snowball” sampling, which consists in starting with a small group of few key informants and asking them to recommend more persons to interview. According to Kirby*, et al.* (2000), this is a method usually associated with participant observation, “The links between individuals that such approaches reveal can unveil important insights, as well as providing the researcher with a sample”.

6.3.2 Workshops – Interviews

A personal arrangement was made with each of the key informants to discuss and evaluate together with the help of the researcher the IWM standard for each of the watersheds. Each workshop consisted of evaluating and assigning values to the proposed indicators through a qualification methodology.

Each indicator was first read to a complete understanding of the key-informant. Two separate questions were discussed. Firstly, an answer to the question or variants of the questions: How important or relevant do you consider this indicator to be? How pertinent do you think this indicator is to evaluate integrated watershed management? Answers were classified into: very low, low, intermediate, high, and very high relevance.

After obtaining the relevance of the indicator a second question was formulated to evaluate the indicator according to the current reality of the Watersheds. Each indicator consists of several examples to help the key-informant to make a decision. (i.e. a very high integration of institutions working at the local level *vs.* a very low integration of institutions working at the local level). This depends only on the capacity of the key-informant to answer this particular question, together with his or her experience in the area. This process was repeated for each of the 18 indicators being evaluated.

After the interview-workshop was finished, not only from analyzing and evaluating each indicator but after a further discussion to reassure the opinion of the key informants, a third step was carried on separately to translate opinions to corresponding values in a previously established qualification table.

Relevance of each indicator, so on referred to as (r) was classified as follows:

Relevance of each indicator	Assigned Value
Very high	5
High	4
Intermediate	3
Low	2
Very low	1

On the other hand, the evaluation of the conditions of the watershed and its corresponding value was translated to a scale from zero to three (0, 1, 2, 3) where zero corresponds to a low qualification and 3 to the highest possible qualification. (i.e. the existence of a watershed council with well determined capacities, members and financing would correspond to a high level of IWM (qualified as 3), on the other hand, the opposite of this condition would correspond to a low level of IWM, thus qualified as 0. Intermediate values were used in occasions where some conditions were fulfilled but not all of them). This value was assigned the letter “e”.

After data was translated into values (r) and (e), analysis was made resulting in diverse tables and graphics showing average of qualifications and overall qualifications of the watersheds regarding their level of integrated watershed management. Arranging values in percentage also permitted reassigning global qualifications into descriptors of the situation of the Watersheds.

Evaluation of the Watersheds per key informant (EK) was done through a formula corresponding to a weighted arithmetic mean, where (e) is considered the data to be averaged and (r) a weight for each qualification.

$$EK = \frac{\sum_{i}^{n} r \times e}{E}$$

Where:

(r) Relevance value given to each indicator by each key informant.

(e) Evaluation of each indicator by each key informant.

(E) Sum of (e).

(EK) Evaluation of the Watersheds by key informant.

Global Qualification of the watershed , is the average of EK,

$$GQ = \frac{\sum_{i}^{n} EK}{n}$$

GQ value was transformed into a percentage comparing it to the highest possible obtainable qualification, and then compared to the following discriminatory table:

GQ in percentage	Level of reached IWM	Description
0-25	Very Low	The watershed shows none or very few actions taken with the IWM angle.
25-50	Low	The watershed shows few actions with the IWM angle.
50-75	Regular	The watershed shows some actions with the IWM angle, however it is still necessary to improve some aspects.
75 - 100	Superior	The watershed has many effective actions and conditions related to IWM.

Even if a Global Qualification is obtained for the studied watersheds, it is together with the average qualifications of each indicator that this methodology results in relevant information. It is possible to visualize according to key informants where the highest values were obtained, and which need more attention. In order to understand these values, they can be related to the initial Principles considered for IWM. More criterions and indicators can also be added adapting to the concepts desired to be evaluated. For the purpose of this research the IWM concepts which have been worked by the Author in CATIE were taken into account. Results collected in this process for the Watersheds of the Mboi Cae and Quiteria Rivers are shown in the results Section 7.3.

6.4 DRASTIC: determining aquifer vulnerability to pollution

Aller*, et al.* (1987) developed a standardized system for evaluating intrinsic groundwater pollution potential using hydrogeology settings; this methodology called DRASTIC (represented in Figure 20) has been since then used in multiple studies, research and case studies: Lobo-Ferreira and Oliveira (1997), Agüero*, et al.* (2002), Chowdhury*, et al.* (2003), Napolitano and Fabbri (1996), Shahid (2000), Laino, Jiménez, Velázquez, Paez and Casanoves (2006), and many others. The acronym DRASTIC corresponds to the initials of seven base maps as follows: D: Depth to water / R: Net Recharge / A: aquifer media / S: Soil media / T: Topography / I: Impact of the vadose zone / C: Hydraulic Conductivity.

Each of the parameters was mapped and classified either into ranges or into significant media types which have an impact on pollution potential. Each factor or parameter was assigned a subjective rating between 1 and 10. Weight multipliers are then used for each factor to balance and enhance its importance. The final vertical vulnerability, the DRASTIC index (Di) was computed as the weighted sum overlay of the seven layers:

$$D_i = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$$

Where D, R, A, S, T, I, and C are the seven parameters, (r) is the rating value and (w) is the weight associated to each parameter.

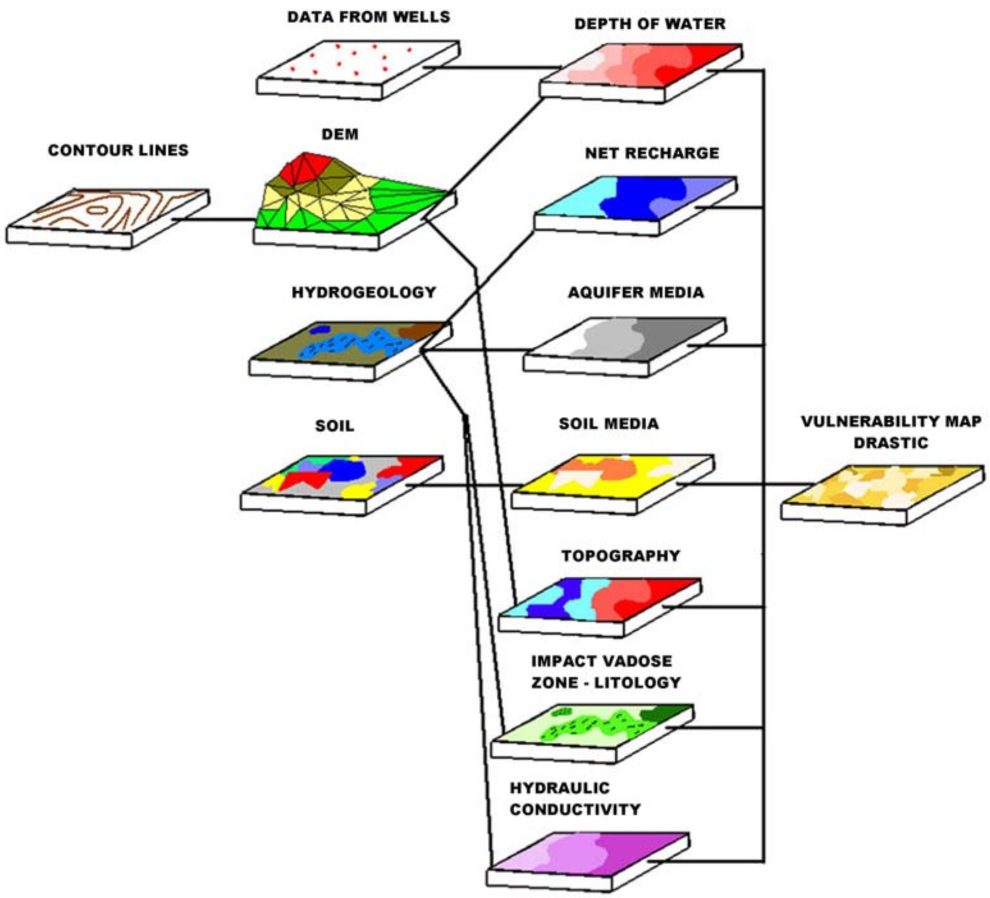


Figure 20. Schematic description of DRASTIC methodology used to determine aquifer vulnerability to pollution in the watersheds of the Mboi Cae and Quiteria Rivers. Source: Agüero*, et al.* (2002).

Information necessary to apply the DRASTIC model was obtained with a thorough collection process, a GIS construction and also digitalization of maps and experts consultation. Particular procedure for each of the parameters is shown in the following sections, as well as information on how data was collected for each particular data layer and processed is summarized in Table 12.

Table 12. Summary of the sources of information and process followed to obtain DRASTIC ratings for the Mboi Cae and Quiteria Watersheds in Paraguay.

DRASTIC Parameter	Sources	Process	Data to DRASTIC
Depth to water	Profiles of wells reported by SENASA showing static and dynamic levels + Other Guaraní aquifer hydrogeology studies.	Static levels were interpolated to the whole area of the watersheds	Depth in meters
Net Recharge	Geology maps + Hydrogeology studies that estimated net recharge for Basalts, and Sandstone in the Guarani Aquifer.	Net recharge was estimated mostly by geology in function of precipitation. For other areas, an estimated value from literature review was used directly	Millimetres per year
Aquifer Media	Geology Maps + Guaraní aquifer hydrogeology studies.	The rock which serves as aquifer, pores or fractures is directly related to the vulnerability to pollution	Lithology
Soil Media	Soil Maps +Literature review of previous work in soil taxonomy	Soil taxonomy subgroups were linked to texture using various studies in the area.	Texture
Topography	Contour lines of Paraguay	Contour lines were processed into a Digital Elevation Model. Using GIS slope was calculated	Slope (%)
Impact of Vadose Zone Media	Profiles of wells provided by SENASA + Geology maps of Paraguay	Direct reading of profiles and confirmation with geology maps.	Lithology
Hydraulic Conductivity	Direct data from works reporting typical values.	Literature review	Meters/day

Following Sections 6.4.1 to 6.4.9 describe the methodological steps followed to obtain DRASTIC ratings specifically for the area of the Watersheds of Mboi Cae and Quiteria Rivers.

6.4.1 Depth to water (D)

To determine depth to water, the use of static levels reported for various wells in the area was collected. A request was made to local water sanitation authority SENASA, which supplied with a database with information from wells located in the larger Itapua Department. Through the use of ArcGIS software, a buffer area of 15 km around (and within) the watersheds was used to select wells. Wells that did not have proper information registry were eliminated and a new set of 41 wells (Addendum 1) was used to determine aquifer depth, with data available from 1996 to 2005. The resulting IDW interpolation (Inverse Distance Weighting) after the depth was determined in meters was then translated to the DRASTIC rating (Figure 21). DRASTIC ratings and their equivalence to depth in meters are shown in Table 13.

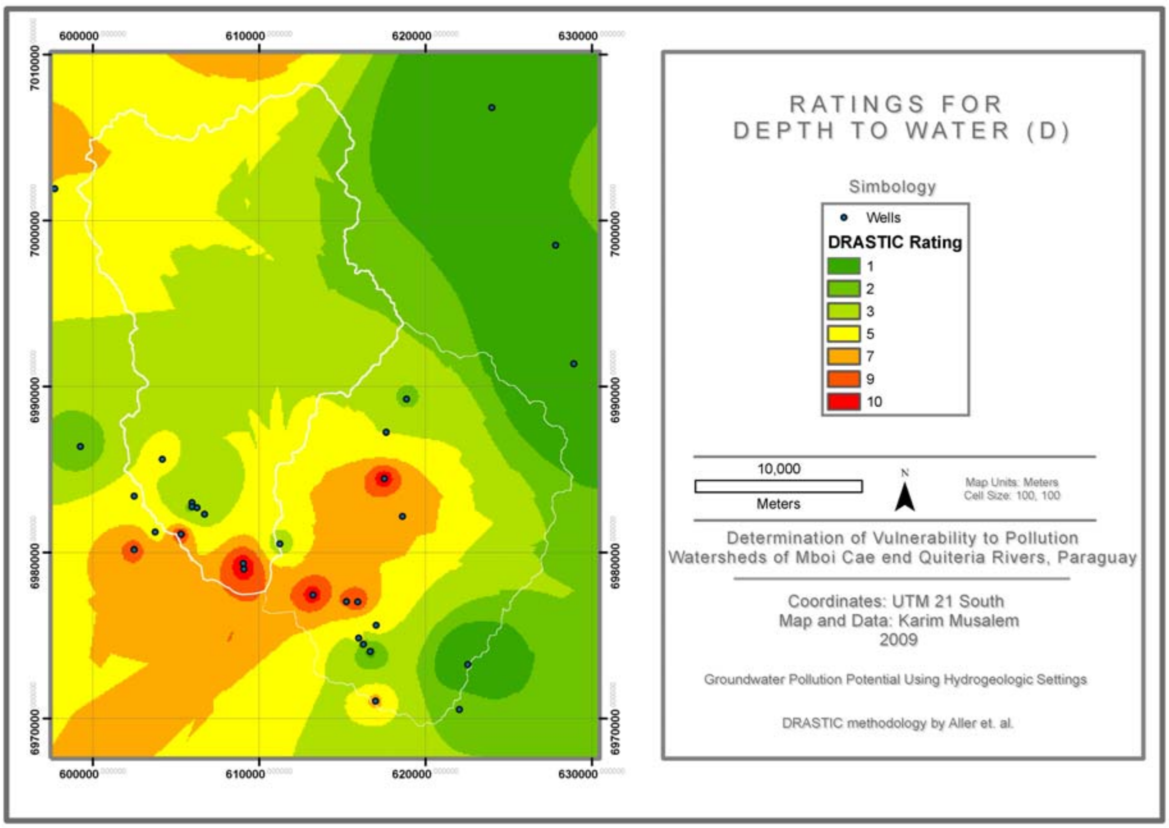


Figure 21. DRASTIC ratings for depth to water (D) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

Table 13. DRASTIC ratings for depth to water related to static levels according to methodology as described by Aller, *et al.* (1987).

Depth (m)	DRASTIC Rating
0 – 1.5	10
1.5 – 4.6	9
4.6 – 9.1	7
9.1 – 15.2	5
15.2 – 22.9	3
22.9 – 30.5	2
Higher than 30.5	1

6.4.2 Net recharge (R)

To obtain information about net recharge in the area, studies by the Guarani Aquifer project were revised, specifically those concerning geology and hydrogeology. This revision shows that there are two identified geological formations for this area: the Alto Parana Formation presenting a Basaltic lithology from a volcanic environment, and the Misiones Formation presenting sandstones from an Aeolian and fluvial environment, also a third geological area is identified constituted of mostly sediments (sands) from alluvial origin corresponding to the lower parts of the watersheds. A map of the distribution of these Formations in the eastern side of Paraguay is shown in a map by the Guarani Aquifer Project (Figure 22) and reported by Fariña (2009).

Natural recharge of the aquifer occurs through direct infiltration of rainfall. From a hydrogeological point of view, areas with sandstone constitute a direct recharge area of the aquifer, while those with basaltic presence are considered of indirect recharge through fissures. Basaltic rocks present numerous vertical and horizontal fissures and a rather permeable soil on top of them, resulting in rapid recharge areas of the aquifer localized beneath them. Basalts form communication and contact zones with the deeper water from the flouring sandstones.

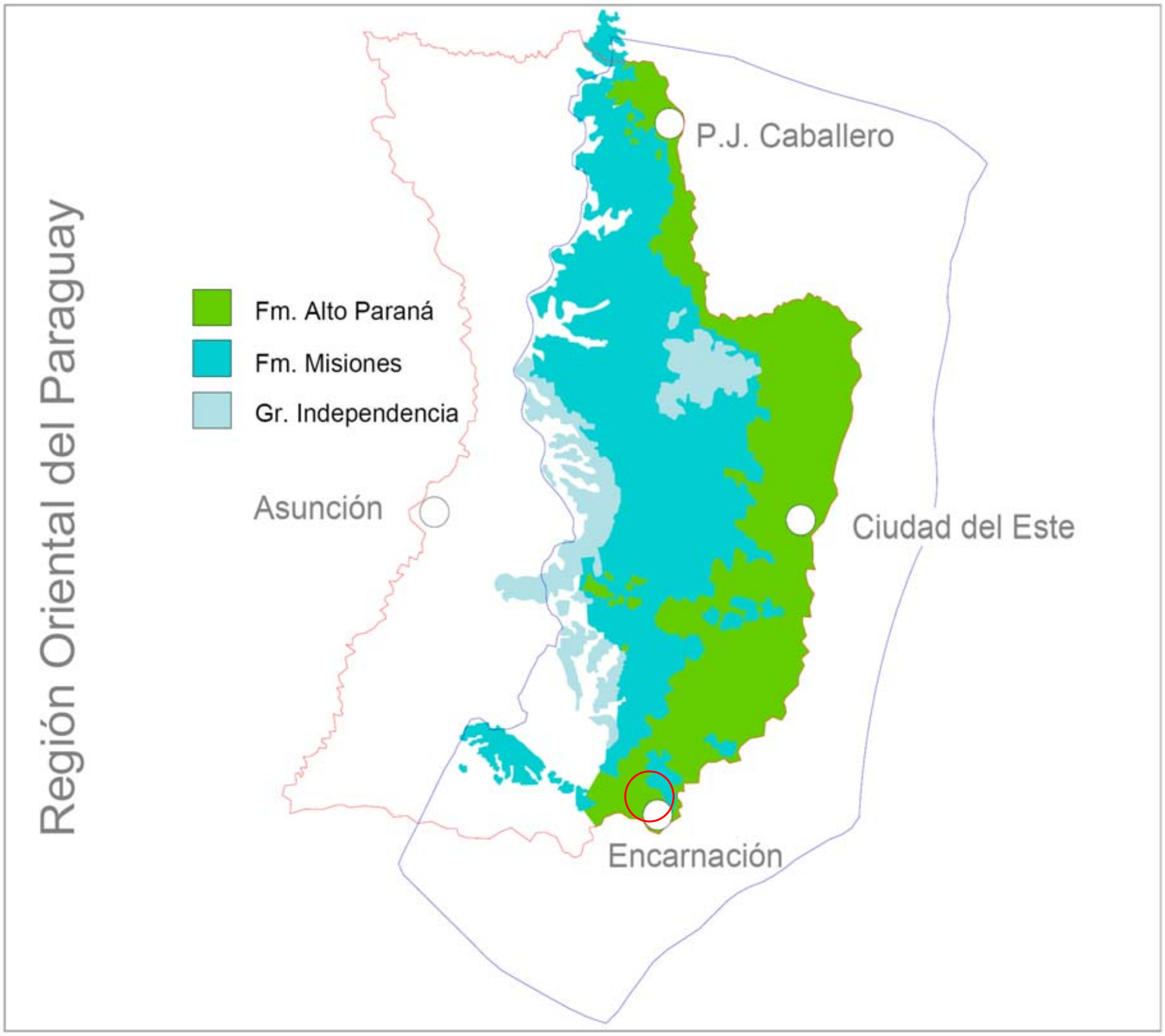


Figure 22. Distribution of geological formations according to Fariña (2009) in eastern Paraguay. Red circle marks approximate location of the Watersheds of the Mboi Cae and Quiteria Rivers. Larger blue line indicates approximate extension of the Guarani Aquifer. (Spanish).

To estimate recharge of the aquifer, considerations by Santa Cruz and Silva (2002) in Laino (2005) from the Pilot program Concordia – Salto were taken into account. This study was presented in a research made by the Guarani Aquifer System

Project regarding stratigraphy and hydrogeology and estimated a 3% net recharge of annual precipitation in Uruguay. Considering that this is a similar hidrogeological area (Alto Parana formation and the Guarani Aquifer System) the same value of 3% was used for areas with basaltic geology within the watersheds. For areas with sandstone from the Misiones Formation and for sediments, studies by de Guarani Aquifer System Project reported by Külls (2003) established a recharge of 136 to 150 mm/year and by Schmidt (2009) a net recharge for the Alto Parana Formation of 77 mm/year.

The distribution of geological formations, sandstones, basalts and sands was obtained from geology maps available at the Military Geographic Institute in Paraguay (1986). It is noticeable that most of the watersheds are located in basaltic geology areas, with just a small sand-alluvial area close to the mouth of the rivers (Figure 23).

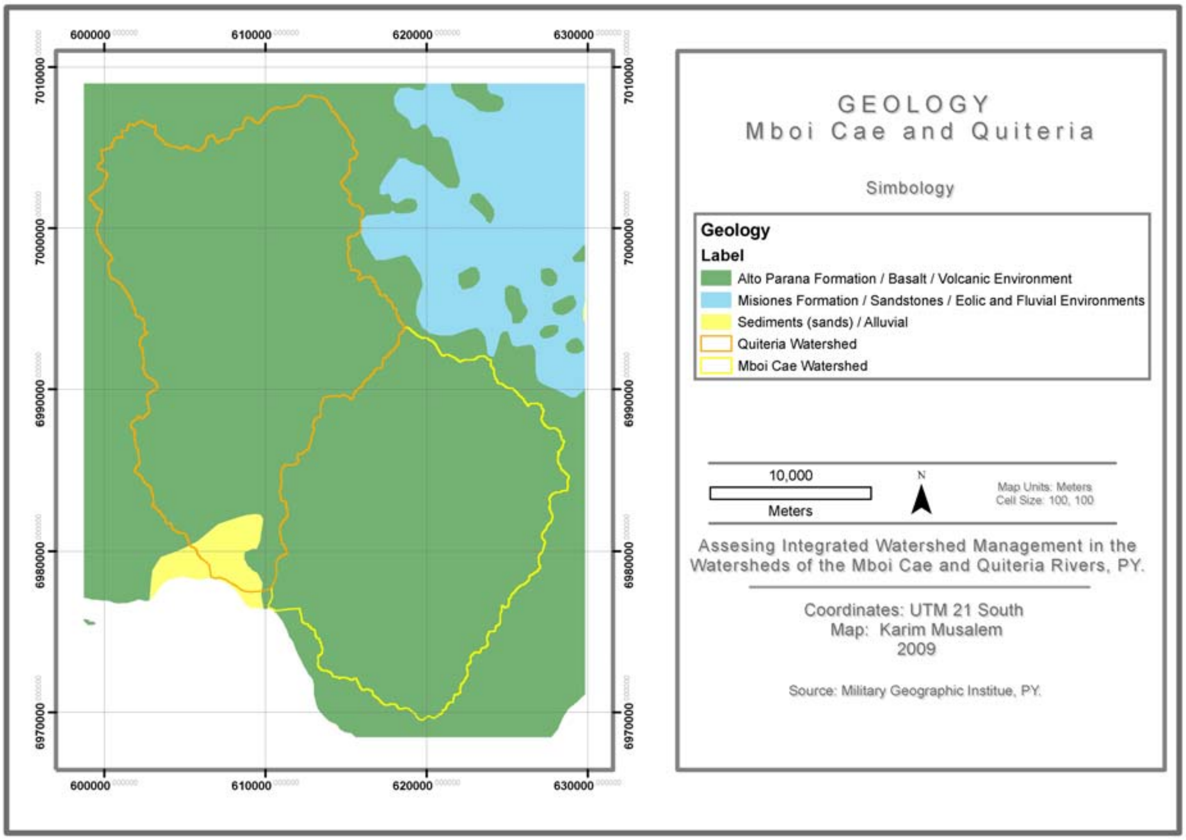


Figure 23. Geology in the watersheds of the Mboi Cae and Quiteria Rivers in Paraguay used to estimate net recharge.

Since net recharge is also in function of mean annual rainfall (in the case of the Alto Parana Formation), rainfall data collected for the characterization of the Watersheds was used. (See section about weather: 3.4.1). As for sand areas, despite having a 136 to 150 mm/year range for net recharge as reported by Külls (2003), any value within this range falls into one single DRASTIC rating, making it unnecessary to divide it in different values. The following map shows the final DRASTIC ratings for Net Recharge (Figure 24). Table 14 shows values of net recharge related to the DRASTIC ratings.

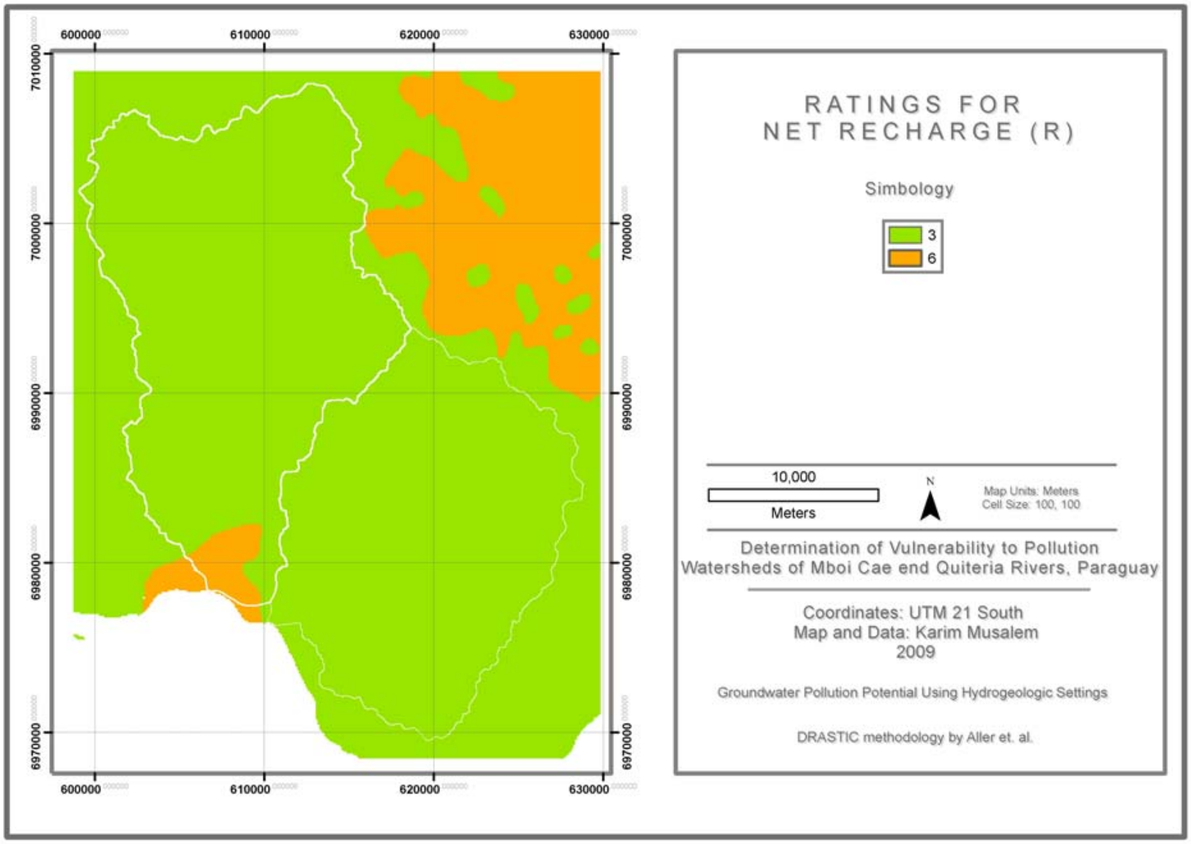


Figure 24. DRASTIC ratings for net recharge (R) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

Table 14. DRASTIC ratings for net recharge according to methodology as described by Aller, et al. (1987).

Net Recharge (R)	
Recharge (mm/year)	DRASTIC Rating
0 – 50	1
50 – 103	3
103 – 178	6
178 – 254	8
> 254	9

6.4.3 Aquifer media (A)

According to Aller, et al. (1987) "Aquifer media refers to the consolidated or unconsolidated rock which serves as an aquifer. An aquifer is defined as subsurface rock unit which will yield sufficient quantities of water for use. Water is contained in fractures or pores." Information about geology was taken from geological maps of Paraguay (1986) and translated to DRASTIC Ratings (Table 15 and Figure 25).

Table 15. DRASTIC ratings for aquifer media according to methodology by Aller, et al. (1987). Values marked (*) were present in current study area.

Aquifer Media	Rating A	Typical Rating
Massive Shale	1 – 3	2
Metamorphic/Igneous	2 – 5	3
Weathered Metamorphic/ Igneous	3 – 5	4
Glacial Till	4 – 6	5
Bedded Sandstone, Limestone* and Shale Sequences	5 – 9	6
Massive Sandstone	4 – 9	6
Massive Limestone	4 – 9	6
Sand* and Gravel	4 – 9	8
Basalt*	2 – 10	9
Karst Limestone	9 – 10	10

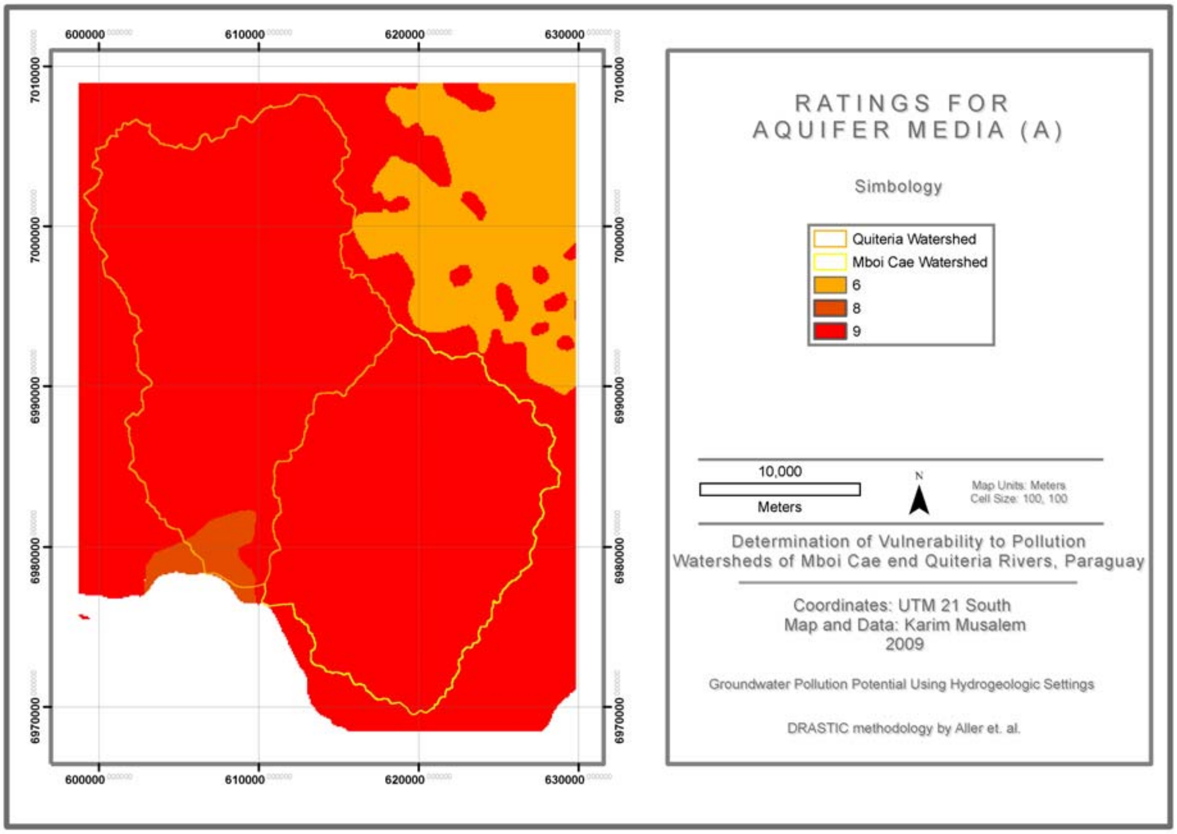


Figure 25. DRASTIC ratings for aquifer media (A) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

6.4.4 Soil media (S)

According to DRASTIC methodology by Aller, *et al.* (1987), “Soil media refers to the uppermost area of the vadose zone, characterized by significant biological activity, considered the upper weathered zone of the earth which averages 2 meters or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the vadose zone (…)” mostly depending on the texture of the soil.

To obtain data for soil media (Figure 26), many sources were combined. The distribution of soil taxonomy was obtained from digitalized soil maps of Paraguay (Military Geographic Institute). Secondly, each subgroup was related to its texture according to three different studies carried out in the area: A report consisting of soil studies based on field observation, morphology and physical and chemical analysis of soil horizons done by Global Consultores (2008); a Masters thesis research conducted by Laino (2005) where DRASTIC model was used; an unedited geological study by Gonzalez Erico (in Laino 2005) in the area; also the Soil Taxonomy Keys by USDA Soil Survey Staff (2006) were consulted. The report by Global Consultores is ongoing revision, and was available only partially for this study. Subgroups texture was also obtained from this report and translated to DRASTIC ratings. Table 16 shows soil taxonomy subgroups found in the area, estimated texture and DRASTIC ratings.

Table 16. Soil subgroups, estimated texture, and DRASTIC ratings used to determine soil media (S), in the Watersheds of Mboi Cae and Quiteria Rivers, Paraguay.

Soil Taxonomy Subgroup	Estimated texture	DRASTIC Rating
Aquic Udifluvent	no data*	0
Lithic Udorthent(basaltic)	clay, fine clay	3
Rhodic Paleudult	clay	3
Miscellaneous land	no data*	0
Typic Kandiudox	clay	3
Typic Paleaquult	loam, fine loam	6
Typic Paleudult	loam, sandy loam	3
Cities **	no data	10
Typic Albaquult	sandy loam	6

* Subgroup soil found outside watersheds (data not sought)
** Different value for cities was also considered: Section 6.4.5 for details

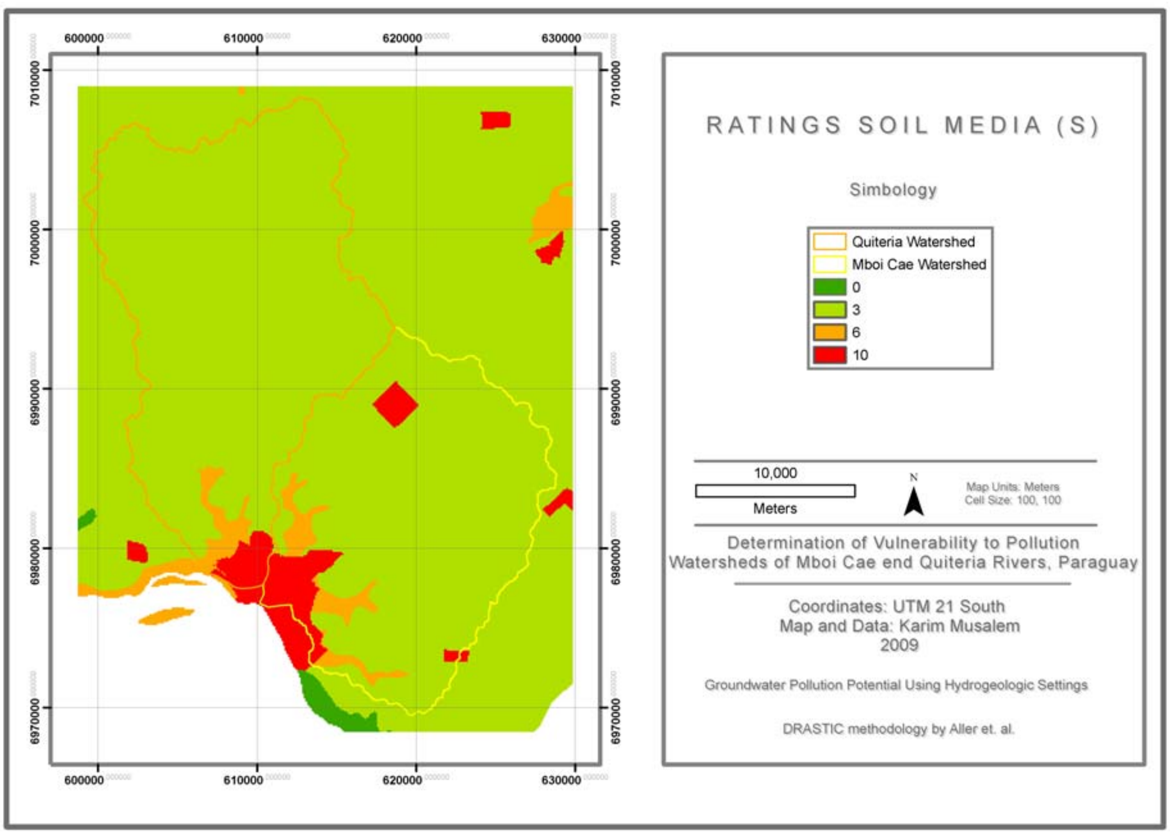


Figure 26. DRASTIC ratings for soil media (S) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

6.4.5 Alternative soil media (S alternative)

It was noticed that there was no data concerning soil taxonomy in urban areas in soil maps available for this study. Different approaches were found by different authors when this situation occurred. One of the following three options and justifications were found to assign DRASTIC index for soil media in cities or urban areas where no soil taxonomy was found.

- Urban areas are considered as a direct pollution source, especially when discharged water is not treated and is disposed of in wells or directly to river streams.
- Cities are considered as a low pollution source, because they limit infiltration (lack of permeability of streets and roads), thus having a reducing effect of contaminants entering the aquifer.
- Urban areas or cities should not be taken into account for the DRASTIC index because they are not part of the “intrinsic properties” of vulnerability of pollution to the aquifer.

In the previous section, however, a high value associated with a higher vulnerability to pollution was given to urban areas with no soil taxonomy specific data (mainly based on the grounds of a poor collection and water disposal system in the watersheds). Most of urban disposal water goes directly into shallow wells and also most of the streets, even in the larger City of Encarnacion are not completely paved, but are also stone roads allowing infiltrations. However, considering the purposes of the DRASTIC index, which desires not to evaluate on specific threats, but instead intends to determine the intrinsic hydro-geological settings and their vulnerability to pollution, a second “alternative” Soil Media map was constructed in which urban areas were given the values of surrounding areas, hence “absorbing” values from the characteristics found in their nearest neighbours. The results of using “alternative” Soil Media map and the resulting DRASTIC-nc map after these changes were done and presented in the Results Section.

6.4.6 Topography (T)

According to DRASTIC methodology by Aller*, et al.* (1987), topography refers to “the slope and slope variability of the land surface. Topography helps control the likelihood that a pollutant will run off or remain on the surface in one area long enough to infiltrate. Slopes which provide a greater opportunity for contaminants to infiltrate will be associated with higher ground-water pollution potential. Topography influences soil development and therefore has an effect on contaminant attenuation (…). Typically, steeper slopes signify higher groundwater velocity”.

Using contour lines available for Paraguay from the Geographic Military Institute, a standard procedure was followed to obtain slope: Contour lines were available at 10 meters for this area and transformed into a TIN (triangulated irregular network). A TIN is a digital data structure used in a geographic information system (GIS) for the representation of a surface. A TIN is a vector based representation of the physical land surface made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of non-overlapping triangles. Figure 27 shows the created TIN in a 3D perspective for the area of this study.

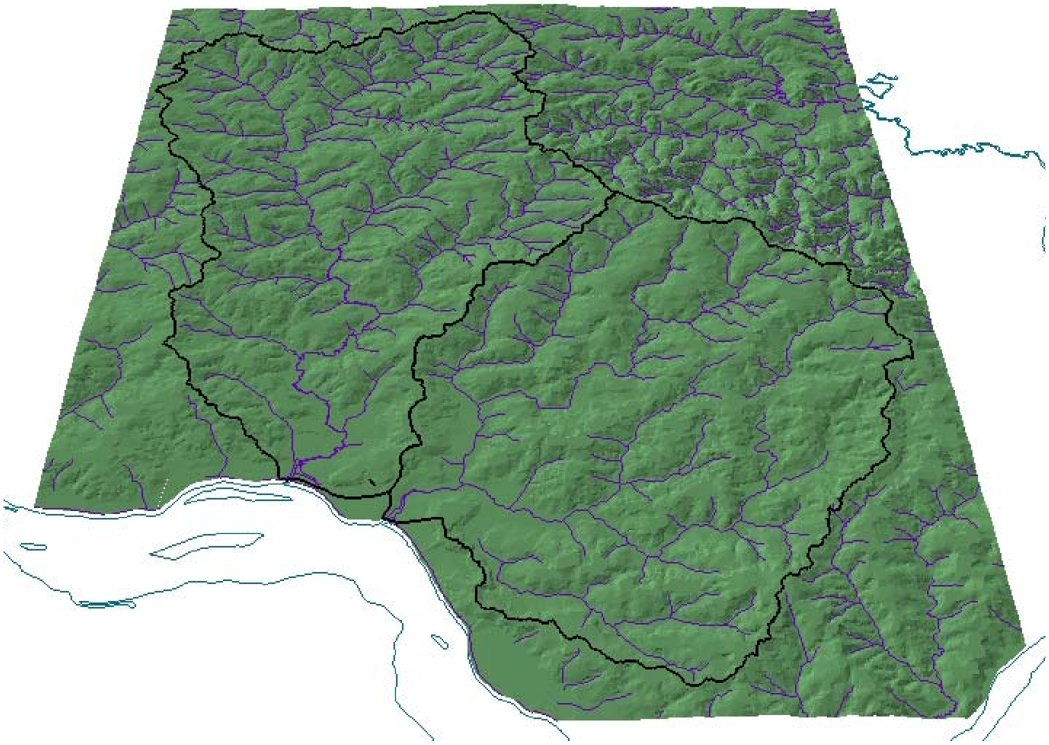


Figure 27. Triangulated Irregular Network (TIN) used to determine slope and topography (T) in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay. 3D perspective representation of the Watersheds. (Z value conversion factor: 3)

The TIN was then transformed into a raster, which allowed assigning height values to each of the pixels. (Pixel size selected was 100, 100 m). With the use of Arc GIS 9 tools, slope was calculated using the "slope function" which calculates the maximum rate of change between each cell and its neighbours. The resulting slope in percent is shown in Figure 28. Slope was reclassified according to DRASTIC ratings for Topography (T) in Table 17. The resulting map is shown in Figure 29.

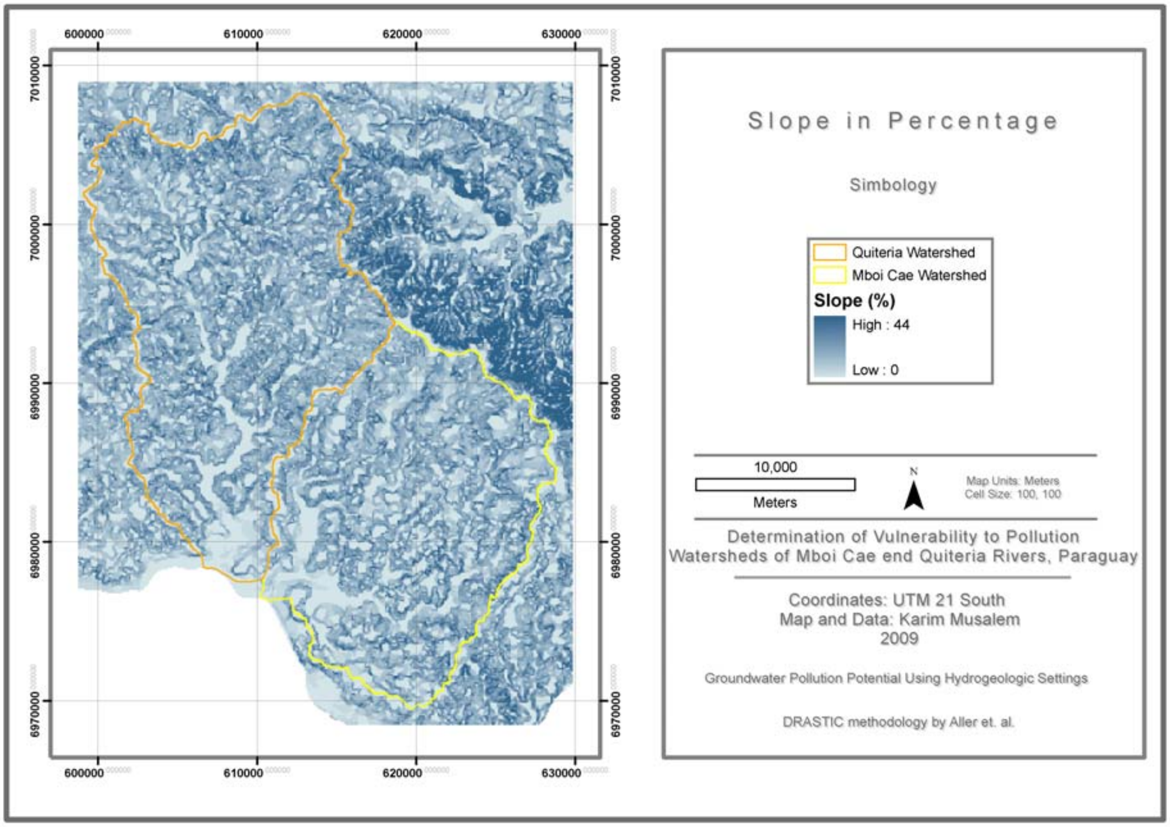


Figure 28. Slope in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay used to estimate topography in the DRASTIC model.

Table 17. Ratings for topography according to the DRASTIC methodology used in the determination of aquifer vulnerability in the watersheds of the Mboi Cae and Quiteria Rivers.

Topography (percent slope)	DRASTIC rating
0 - 2	10
2 - 6	9
6 - 12	6
12 - 18	3
Higher than18	1

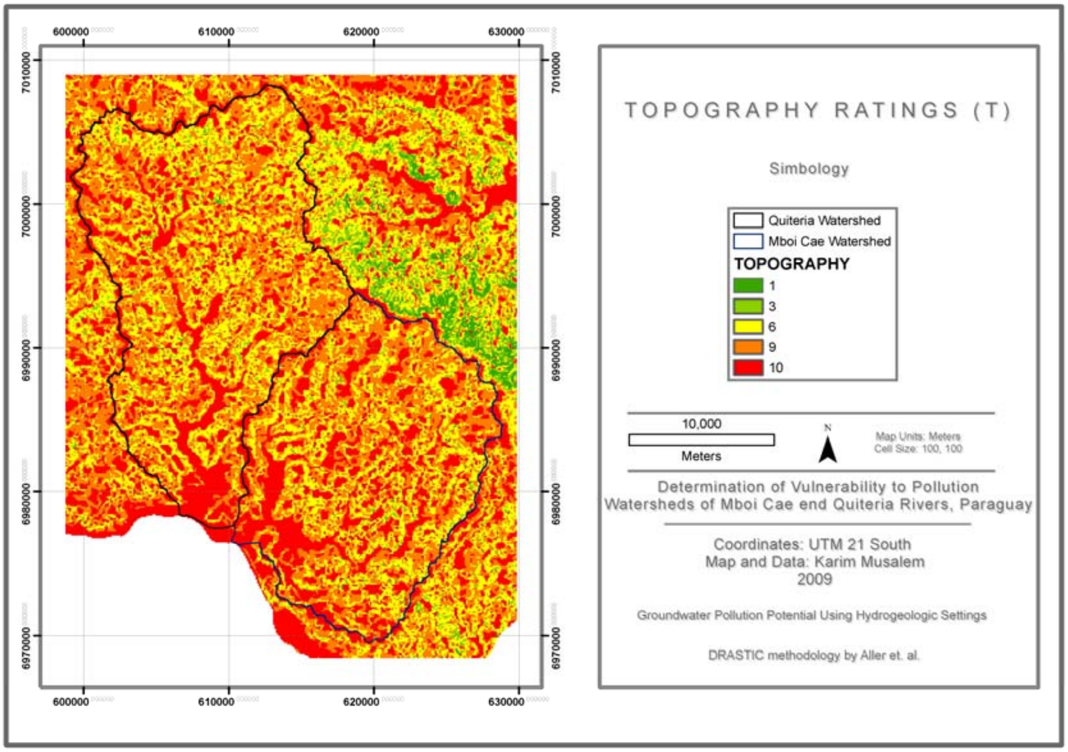


Figure 29. DRASTIC ratings for topography (T) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

6.4.7 Impact of the vadose zone media (I)

According to Aller, *et al.* (1987), “the vadose zone is defined as that above the water table which is unsaturated or discontinuously saturated. The type of vadose zone media determines the attenuation characteristics of the material below the typical soil horizon and above the water table. Biodegradation, neutralization, mechanical infiltration, volatilization and dispersion are all processes which may occur within the vadose zone. The amount of biodegradation and volatilization decreases with depth. The media also controls the path, length and routing, thus affecting the time available for attenuation and the quantity of material encountered.”

To determine the type of vadose zone present in the Watersheds, available information on wells was supplied by local water sanitation service (SENASA) A group of 23 well profiles was used, located inside the watersheds (Figure 30). Congruently with the basaltic geology of the area, all wells showed the same basaltic layers in the vadose zone, with some variations of the basaltic properties. However, for consideration in the DRASTIC ratings, resulting values were all rated with the same value. An example of the reading on one of the used well profiles (IT-P0055) is shown.

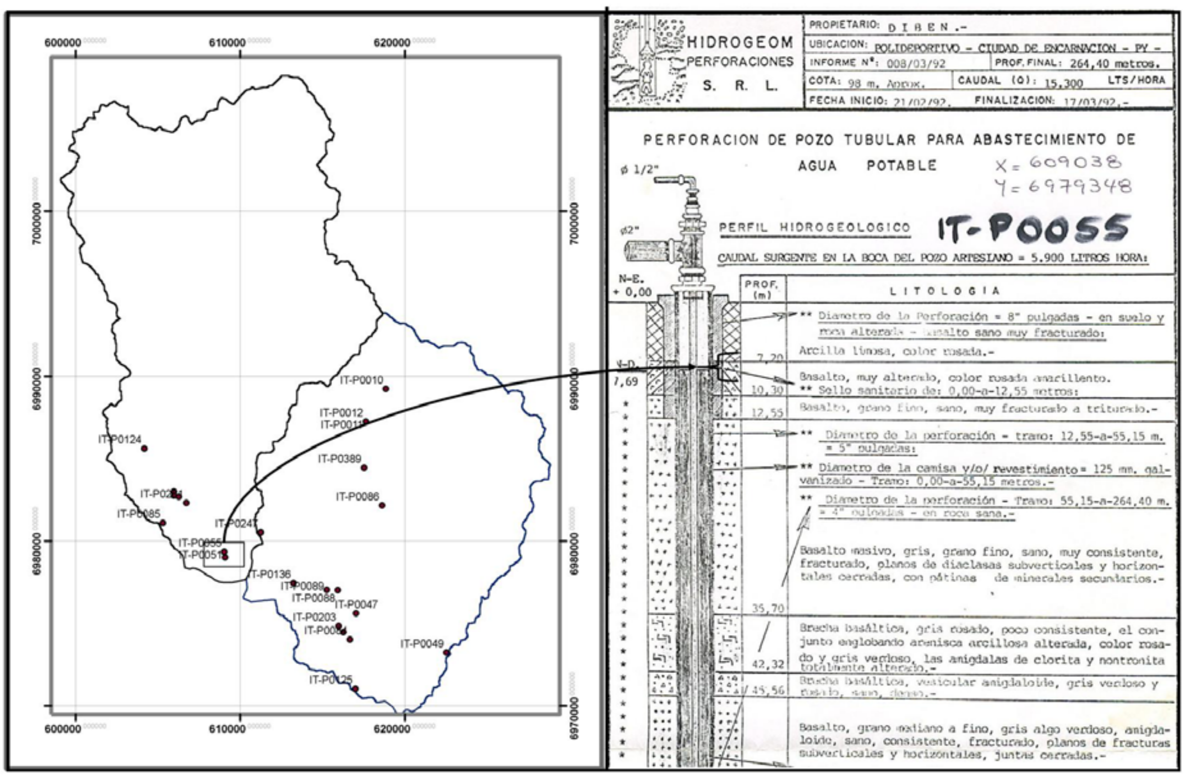


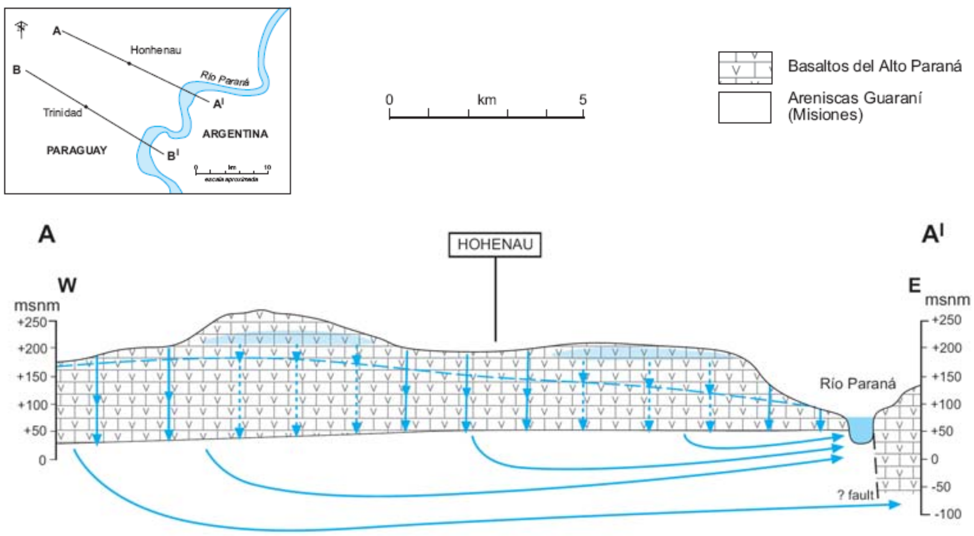
Figure 30. Diagram showing an example reading of the vadose zone type and the location of wells used to determine impact of the vadose zone media (I) in the watersheds.

On a further look to geology of the area (Figure 23) a small fraction of the watersheds, close to the mouth of the rivers, is characterized by having sands from alluvial sediments, since no profiled wells are located within this area, the vadose zone was determined as the value offered for this type of geology. The DRASTIC ratings selected for impact of the vadose zone present in the area of the watersheds are presented in (Table 18). Sandstone areas were assigned a typical DRASTIC rating, however they are not present inside the Watersheds, but only in bordering areas or outside the Watersheds and considered only for visualization purposes.

Table 18. Ratings for Impact of the vadose zone media according to the DRASTIC methodology used in the determination of aquifer vulnerability in the watershed of the Mboi Cae and Quiteria Rivers.

Vadose Zone	Typical Rating
Basalt	9
Sand	8
Sandstone	6

A hydrological crossing from the Itapua - Paraguay Pilot Project in the Guarani Aquifer by Foster*, et al.* (2002) shows a similar area north of the watersheds which presents a common geology of basalts from the Alto Parana Formation. The following diagram was obtained from this document to illustrate recharge of the Guarani Aquifer in the area. The strong fractures present in basalts in this area led to assign a high value to impact of the vadose zone for the watersheds. As a result of geology combined with available profiles for wells Figure 31 shows the assigned DRASTIC ratings for impact of the vadose zone media.



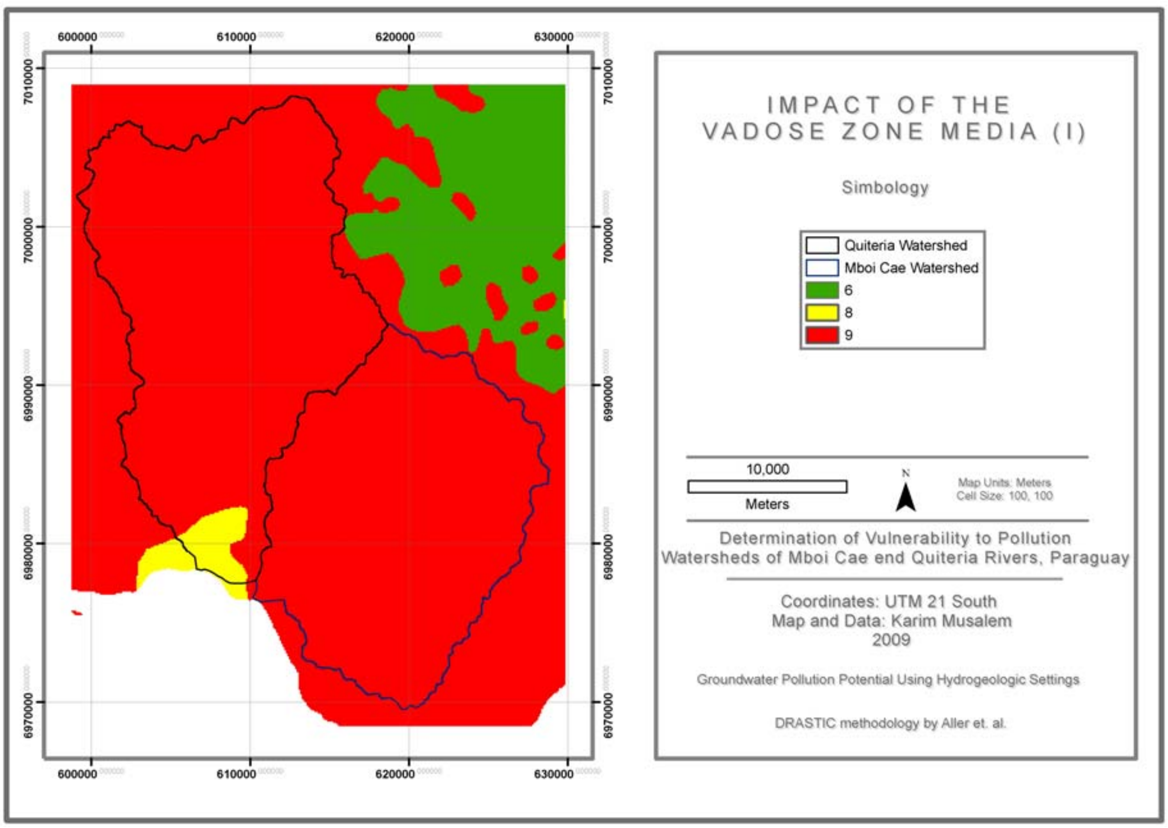


Figure 31. Hydrological crossing from the Itapua - Paraguay Pilot Project in the Guarani Aquifer by Foster*, et al.* (2002) and DRASTIC ratings for impact of the vadose zone media (I) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

6.4.8 Hydraulic conductivity of the aquifer (C)

As defined by Aller*, et al.* (1987) "Hydraulic conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient. The rate at which groundwater flows also controls the rate at which a contaminant moves away from the point at which it enters the aquifer. Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of inter-granular porosity, fracturing and bedding planes. Hydraulic conductivity is divided into ranges where high hydraulic conductivities are associated with higher pollution potential."

In the case of the Watersheds of the Mboi Cae and Quiteria Rivers, the fractured basalt has been reported by Fariña (2009) to have a very high hydraulic conductivity, ranging from 43m/d to even higher levels, supported by work carried out by (Godoy 1991 and De Salvo 1991). The given explanation for such a high level of hydraulic conductivity is the presence of horizontal and vertical fractures and their interconnection in the Alto Parana Geological Formation. Since this was the only available information regarding hydraulic conductivity, a constant raster was created with this value (Figure 32) using the DRASTIC ratings for hydraulic conductivity (Table 19).

Table 19. Ratings for hydraulic conductivity (C) according to the DRASTIC methodology, used in the determination of aquifer vulnerability in the watershed of the Mboi Cae and Quiteria Rivers.

Hydraulic conductivity		DRASTIC Rating (C)
(m/day)	(cm/s)	
0.04 – 4.08	$4.6x10^{-5} – 4.7x10^{-3}$	1
4.08 – 12.22	$4.7x10^{-3} – 1.4x10^{-2}$	2
12.22 – 28.55	$1.4x10^{-2} – 3.4x10^{-2}$	3
28.52 – 40.75	$3.4x10^{-2} – 4.7x10^{-2}$	6
40.75 – 81.49	$4.7x10^{-2} – 9.5x10^{-2}$	8
> 81.49	$> 9.5x10^{-2}$	10

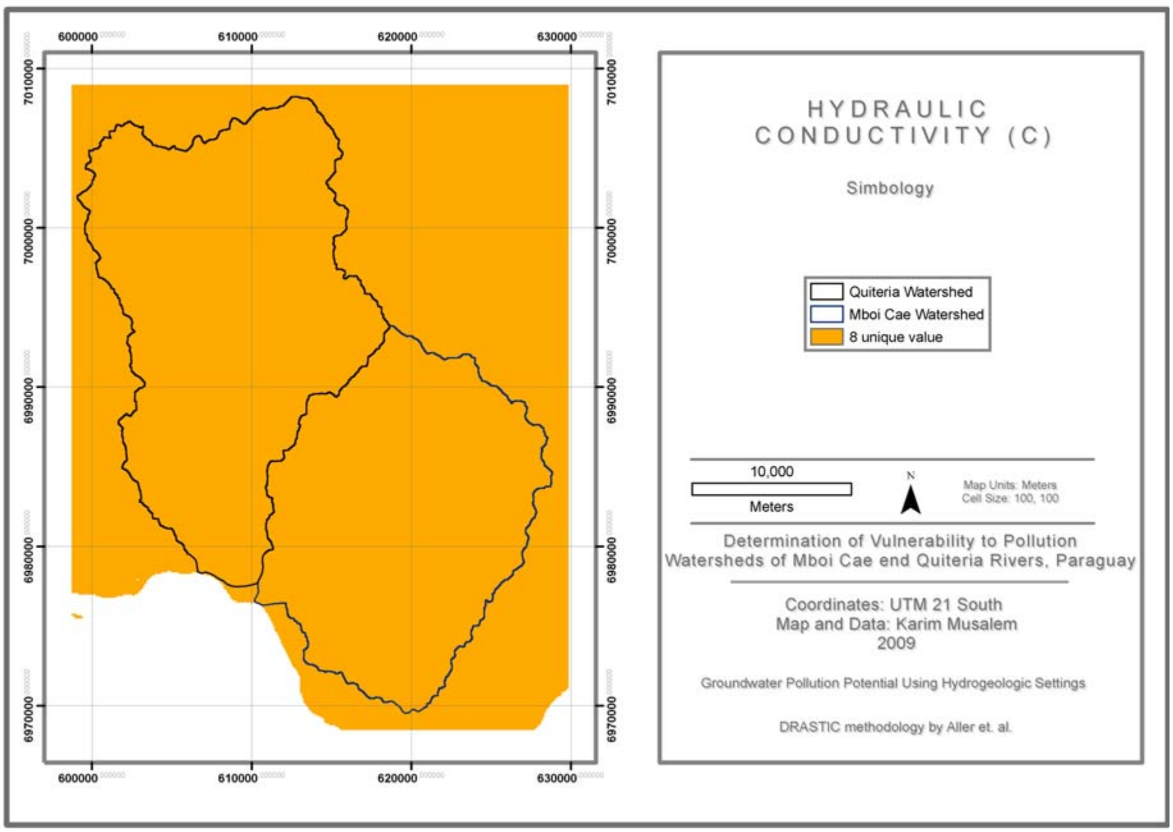


Figure 32. DRASTIC ratings for hydraulic conductivity (C) used in the determination of aquifer vulnerability to pollution in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

6.4.9 Creating DRASTIC vulnerability map

Following the DRASTIC methodology, the proposed model was built inside ArcGIS software, using the "model builder tool". Ratings for each parameter were determined as described previously in this chapter. **Pesticide DRASTIC weights were assigned for each of the parameters**. This is recommended by the methodology whenever the main concern is that of pollution from agricultural activities. Table 20 shows both pesticide and non-pesticide weights according to DRASTIC methodology. However non pesticide weights were NOT used in this study.

Table 20. Parameters and corresponding weights used to determine aquifer vulnerability to pollution according to Aller, et al. (1987). DRASTIC methodology pesticide weights were used for this research.

Parameter	Weight	
	Pesticide	Non pesticide
D = Depth to water	**5**	5
R = Recharge	**4**	4
A = Aquifer media	**3**	3
S = Soil media	**5**	2
T = Topography	**3**	1
I = Impact of the vadose zone media	**4**	5
C = Conductivity of the aquifer	**2**	3

The final DRASTIC map is shown in the results section, together with further interpretation of the final values obtained for the Mboi Cae and Quiteria Watersheds. Changing values corresponding to parameters Depth to water and Net recharge made possible the prediction of possible changes in aquifer vulnerability to pollution in the Watersheds in the context of the change of water level of the reservoir and global climate change.

6.5 GOD: determining aquifer vulnerability to pollution

Foster, *et al.* (2002) published a guide for groundwater quality protection, which includes in detail (Figure 33) a previously developed methodology for aquifer vulnerability to pollution aliased GOD, considering three parameters:

- Groundwater confinement (G) in the aquifer under consideration.
- Overlaying strata (O) (vadose zone) in terms of lithological character and degree of consolidation that determine their contaminant attenuation capacity.
- Depth to groundwater table (D) or to groundwater strike (in confined aquifers).

According to GOD methodology the resulting aquifer vulnerability to pollution index is considered as the product of these three parameters: $APV = G \times O \times D$.

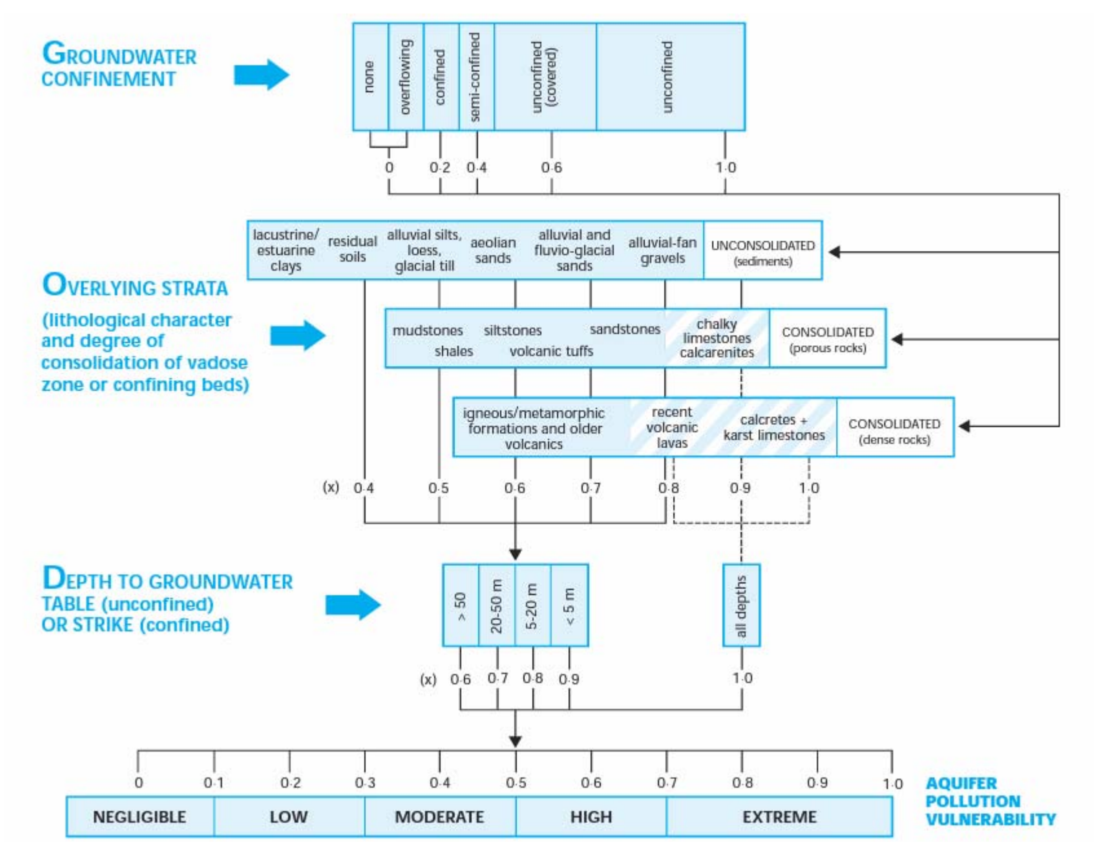


Figure 33. GOD scheme used to determine aquifer vulnerability to pollution by Foster, *et al.* (2002).

The proposed GOD methodology was applied to the Watersheds of the Mboi Cae and Quiteria Rivers, as follows:

6.5.1 Groundwater confinement (G) a look at the aquifer

Data for groundwater confinement was directly taken from studies made for the Guarani Aquifer System Project and reported by Schmidt (2009). The area of the Watersheds is considered to be part of the “basalt aquifer” or Alto Parana Formation which main characteristic is to be an unconfined aquifer, such contrasts with sandstone aquifers (typically called Guarani) and Cuaternary Aquifers which are considered confined. To understand the three hidrogeological units and how they interact in the Guarani Aquifer System, as well as to define how the characteristic for this particular value was considered in this study Figure 34 was taken into account, also from Schmidt (2009).

It is necessary to define at this moment that GOD model was used to determine the vulnerability of the aquifer contained in the basaltic Alto Parana Formation also called the “basalt aquifer”. This decision was made considering the desired comparability with the DRASTIC model. Guarani Aquifer System consists of different aquifers interconnected or interrelated between them. The basalt aquifer typically receives direct recharge from precipitation, but also contributes through dripping to the inferior located Guaraní aquifer (Misiones Formation) and the Permian aquifer (Guaraní-Independencia). Value for this particular parameter “G” was considered to be = 1 for all the area of the Watersheds.

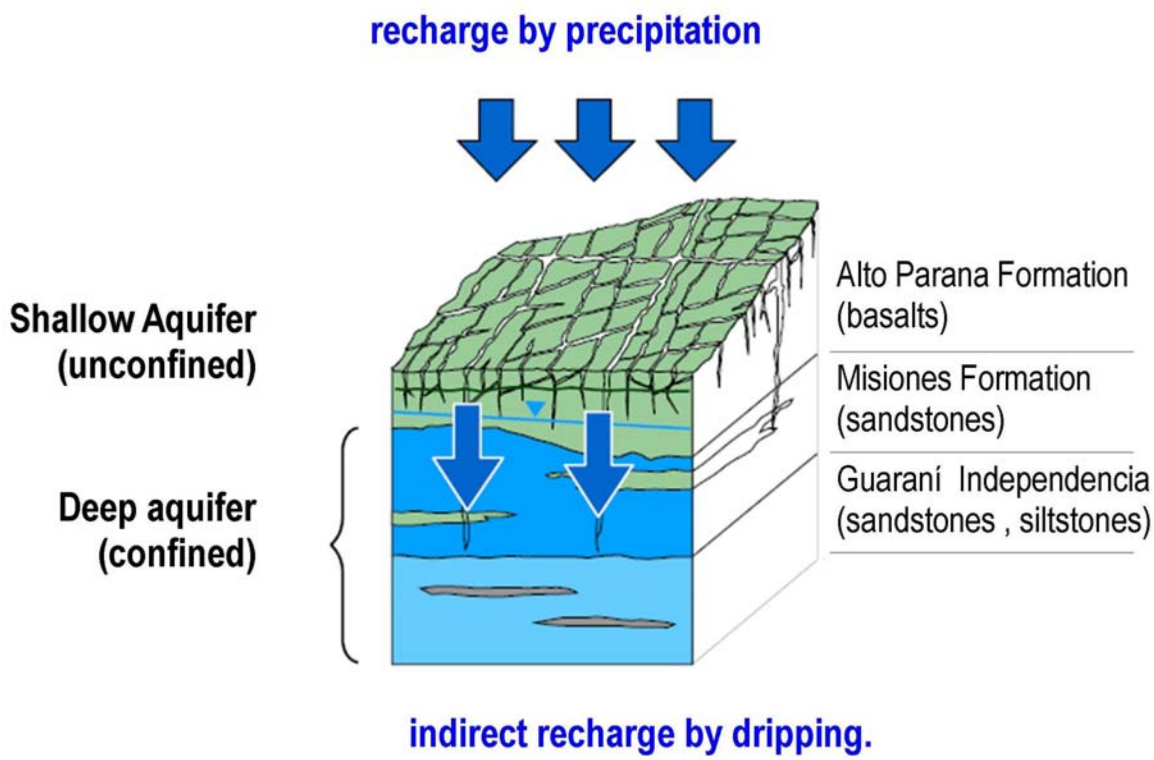


Figure 34. Conceptual Model of the Guarani Aquifer System with basaltic covering. Used to determine groundwater confinement of the aquifer (basalt aquifer). Illustration by Schmidt (2009).

6.5.2 Overlaying strata (O) (vadose zone)

General characteristics of the vadose zone for this area are the same as for the DRASTIC model (See impact of the vadose zone in DRASTIC methodology, Section 6.4.7). The area of the Watersheds has basically a predominant basaltic strata and a smaller area covered with alluvial sands, close to the mouth of the rivers to the Parana River. The distribution of this vadose zone is similar to the used by the DRASTIC model and was similarly used for the application of GOD, thus, values for overlaying strata “O” are: 0.6 in basaltic strata and for 0.7 in alluvial sands.

6.5.3 Depth to groundwater table (D) or to groundwater strike (in confined aquifers)

Depth to groundwater (Figure 35) was obtained using the same information available from SENASA wells available for the area. See section for variable D (depth to water, section 6.4.1.) in DRASTIC model. Each parameter of the GOD model, including depth to groundwater, was reclassified according to the GOD values in Figure 33.

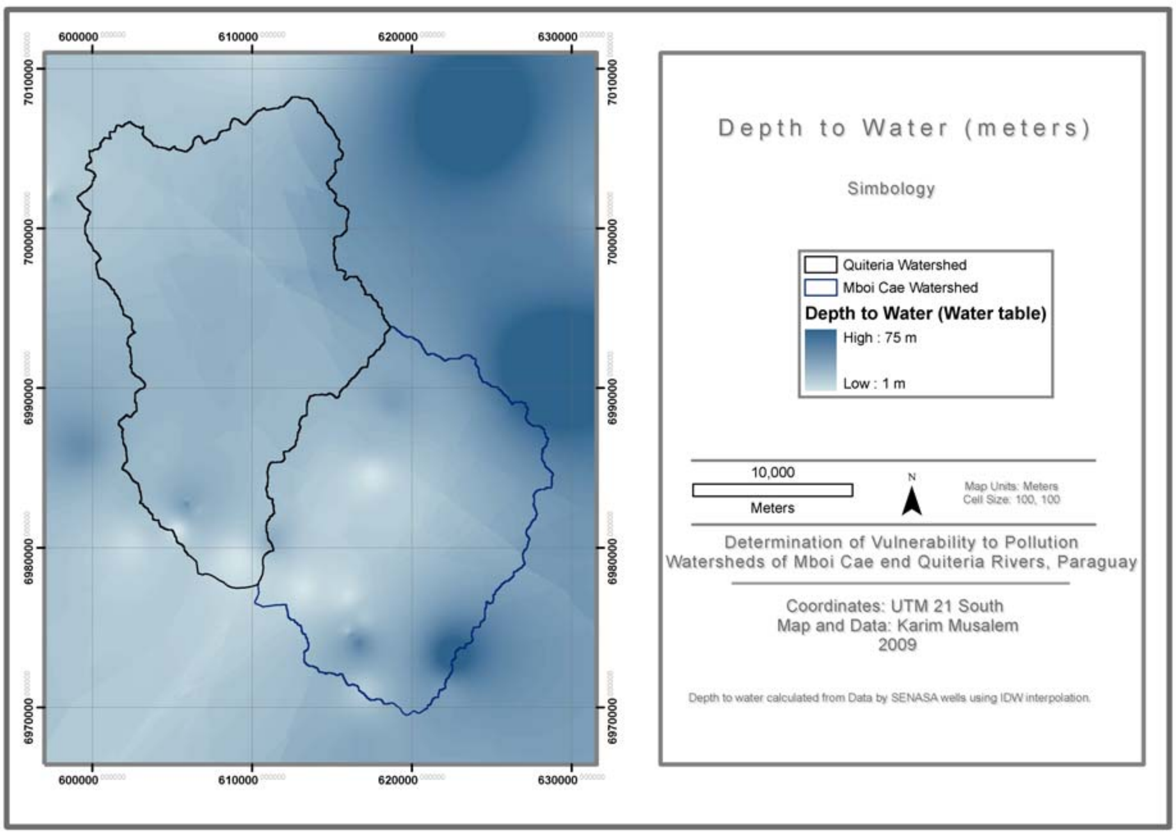


Figure 35. Depth to groundwater (D) (to the basalt aquifer) used in the determination of aquifer vulnerability to pollution using GOD model in the Watersheds of the Mboi Cae and Quiteria Rivers, Paraguay.

7 Results

7.1 State of knowledge and available information

This first exploratory part of the research condenses into one single table the available information for the Mboi Cae and Quiteria Watersheds. It is here called a “state of knowledge” table, because it helps identify easily which areas, according to Jimenez’s ideal characterization elements, were found, which were not, and most importantly where the information was found, and the level of the information going from regional, to municipal, or watershed levels. If information was not found specifically for the watersheds or could not be inferred from other information it was left blank, including undocumented information. Conceptually, these two watersheds have been studied, worked and visualized as a unit, even though they are two separate watersheds, locally they have one single Watershed Council, working both watersheds as a whole. Even though it was an intention of this study to separate them at first, it was difficult to find partitioned information. Also the local perception is of them being a single unit; it was difficult not only in the elaboration of this state of knowledge table and review process, but also in workshops and in the applications of the IWM management standard. Considering this common unit, whenever information is found independently, it is reported as such. If no specification is done, it is assumed that it is considering both watersheds together. State of knowledge (Table 21) consists of columns and rows representing the following information:

- DIVISIONS: A subdivision of the elements of characterization to order information.
- TYPE: Kind of information according to how it is presented. MAP: maps; MEAS: Measurement (numeric data); GRAPH: Data displayed in a graph; VISUAL OBS: visual evidence, photographs, etc; DATA: value or characteristic in a textual context.
- X marks placed in corresponding source where the information is available:
- AUTHOR: Any possible information generated by the Author specifically at the watershed level for this study.
- GLOBAL-EBY: A set of 2 documents generated by a private consultancy Global Consultores and Yacyreta Binational in 2008 specific for the watersheds.
- CENSO: Any information coming from National Census by Dirección General de Estadística Encuestas y Censos (2002).
- SENASA: Any information coming from Paraguayan Water Sanitation Service.
- EBY-SIGNIF: A YBE published document consisting of regional history and territorial identity by Levinton (2007).
- OBS: Observation on the precise location of the information. Letters are Acronyms for the Source.
- LEVEL: WAT: watershed, MUNICIP: municipal, COUN: Country, REG: Regional.

Table 21. Summary table of the state of knowledge and available information of the Watersheds of the Mboi Cae and Quiteria Rivers, according to elements suggested for a Characterization by *Jimenez (2004).*

DIVISION	DIVISION	DIVISION	TYPE	AUTHOR	GLOBAL-EBY	CENSO	SENASA	EBY SIGNIF	OBS	LEVEL
GENERAL ASPECTS	LOCATION		MAP	X	X				G-E: PAG.78 DIAGNOSIS	WAT
GENERAL ASPECTS	MORPHOMETRY	AREA	MAP/ MEAS	X					A: CALCULATIONS USING SIG	WAT
GENERAL ASPECTS	MORPHOMETRY	SHAPE		X					A: USING SIG (DEM), DATA FROM IGM AND GOOGLE EARTH	WAT
GENERAL ASPECTS	MORPHOMETRY	BASE MAP OF THE WATERSHED	MAP	X					A: USING SIG	WAT
GENERAL ASPECTS	MORPHOMETRY	HYPSOMETRIC CURVES (ELEVATIONS)	MAP/ MEAS	X	X				A: USING SIG, GPS, DATA FROM IGM AND GOOGLE EARTH. G-E: PAG.76/137 DIAGNOSIS	WAT
GENERAL ASPECTS	HYDROLOGY	LONGITUDE AND INCLINATION OF THE MAIN RIVER	MEAS/G RAPH		X				G-E: PAG.68/138-139 DIAGNOSIS	WAT
GENERAL ASPECTS	HYDROLOGY	ORDER AND LONGITUDE OF THE DRAINAGE BASIN (DRAINAGE LONGITUDE/SQ KM OF AREA)	MEAS		X				G-E: PAG.69 DIAGNOSIS	WAT
GENERAL ASPECTS	HYDROLOGY	FLOW	MEAS		X				G-E: PAG.71 DIAGNOSIS	WAT
GENERAL ASPECTS	HYDROLOGY	DRAINAGE BASIN MAP	MAP		X				G-E: PAG.74 DIAGNOSIS	WAT
GENERAL ASPECTS	HYDROLOGY	WATERSHED SUBDIVISIONS	MAP/ MEAS		X				G-E: PAG.73/69 DIAGNOSIS	WAT
BIOPHYSICAL	WEATHER	MONTHLY RAINFALL	GRAPH		X				G-E: PAG.79 DIAGNOSIS	REG
BIOPHYSICAL	WEATHER	RAINFALL DISTRIBUTION IN TIME AND AREA	DATA/ MEAS		X				G-E: PAG.79 DIAGNOSIS	REG
BIOPHYSICAL	WEATHER	RAINFALL MAP	MAP		X				G-E: PAG.81 DIAGNOSIS	COUN
BIOPHYSICAL	WEATHER	MONTHLY TEMPERATURE DISTRIBUTION	GRAPH/ MAP		X				G-E: PAG.81-83 DIAGNOSIS	REG/COUN
BIOPHYSICAL	WEATHER	RELATIVE MOISTURE	DATA/G RAPH		X				G-E: PAG.83-84 DIAGNOSIS	REG
BIOPHYSICAL	WEATHER	SUNLIGHT								
BIOPHYSICAL	WEATHER	EVAPOTRANSPIRATION	DATA/G RAPH/M		X				G-E: PAG.84-86 DIAGNOSIS	REG

DIVISION	DIVISION	DIVISION	TYPE	AUTHOR	GLOBAL-EBY	CENSO	SENASA	EBY SIGNIF	OBS	LEVEL
			EAS							
BIOPHYSICAL	WEATHER	WINDS								
BIOPHYSICAL	PHYSIOGRAPHY	GEOGRAPHIC FORMATIONS	DATA	X					NATIONAL MAPS IGM	
BIOPHYSICAL	PHYSIOGRAPHY	LANDSCAPE DESCRIPTION	DATA		X				G-E: PAG.37 DIAGNOSIS, PAG.39 PLAN.	WAT
BIOPHYSICAL	PHYSIOGRAPHY	PHYSIOGRAPHIC MAP	MAP	X					A: USING SIG (DEM).	WAT
BIOPHYSICAL	TOPOGRAPHY AND SLOPE	KINDS OF TOPOGRAPHY	MAP	X					A: USING SIG	WAT
BIOPHYSICAL	TOPOGRAPHY AND SLOPE	SLOPE RANGE AND AREA	MAP /MEAS/ GRAPH	X	X				A: USING SIG. G-E: PAG.134-139 DIAGNOSIS	WAT
BIOPHYSICAL	GEOLOGY	MAIN GEOLOGICAL UNITS	MAP	X	X				A: USING SIG. G-E: PAG.125-126 DIAGNOSIS	WAT
BIOPHYSICAL	GEOLOGY	GEOLOGICAL UNITS MAP	MAP	X					A: USING SIG	WAT
BIOPHYSICAL	HYDRO-GEOLOGY	HYDRO-GEOLOGICAL INFORMATION	MAP /DATA	X	X				G-E: PAG.168 DIAGNOSIS	REG
BIOPHYSICAL	HYDRO-GEOLOGY	HYDROLOGICAL RECHARGE MAP		X	X				G-E: PAG.168 DIAGNOSIS	REG
BIOPHYSICAL	SOIL	DESCRIPTION AND COVERING	DATA/ MAP	X	X				A: USING SIG. G-E: PAG.98-115 DIAGNOSIS	WAT
BIOPHYSICAL	SOIL	EROSION	DATA/ VISUAL OBS.	X	X				A: PHOTOGRAPHIC OBSERVATION. G-E: PAG.121 EROSION RISK, DIAGNOSIS	WAT
BIOPHYSICAL	LAND USE		DATA/ MAP	X	X				A: BASE ON GONZALEZ. G-E: PAG.115-125/225 DIAGNOSIS	WAT
BIOPHYSICAL	MAIN NATURAL THREATS									
BIOPHYSICAL	ECOLOGICAL ZONES		DATA		X				G-E: PAG. DIAGNOSIS	
BIOPHYSICAL	BIODIVERSITY	ANIMAL AND VEGETABLES SPECIES	DATA		X				G-E: PAG.292-326 DIAGNOSIS	REG
BIOPHYSICAL	BIODIVERSITY	EXTINCT AND THREATENED SPECIES	DATA		X				G-E: PAG.294-295 DIAGNOSIS	REG
BIOPHYSICAL	BIODIVERSITY	ENDEMIC SPECIES	DATA		X				G-E: PAG.292-326 DIAGNOSIS	REG
BIOPHYSICAL	BIODIVERSITY	PROTECTED AREAS								

DIVISION	DIVISION	DIVISION	TYPE	AUTHOR	GLOBAL-EBY	CENSO	SENASA	EBY SIGNIF	OBS	LEVEL
BIOPHYSICAL	STRATEGIC RESOURCES OF THE WATERSHED									
SOCIOECONOMIC	DEMOGRAPHY	POPULATION	DATA	X	X	X			A: BASE ON CENSO, 2002. G-E: PAG.224/276/278 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	DEMOGRAPHY	COMPOSITION	DATA	X	X	X			A: BASE ON CENSO, 2002. G-E: PAG.278 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	DEMOGRAPHY	NUMBER OF FAMILIES	DATA		X	X			G-E: PAG.276 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	DEMOGRAPHY	GROWTH POPULATION RATE	DATA			X				MUNICIP
SOCIOECONOMIC	DEMOGRAPHY	MIGRATION	DATA		X	X			G-E: PAG.8 EXEC SUMMARY.	MUNICIP
SOCIOECONOMIC	DEMOGRAPHY	HISTORICAL DATA	DATA			X				MUNICIP
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	AVAILABLE HEALTH SERVICES								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	POPULATION COVERED								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	ACCESS								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	FREQUENCY OF USE								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	PREVENTION PROGRAMS								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	MOST COMMON DISEASES AND DEATH CAUSES								
SOCIOECONOMIC	HEALTH AND SOCIAL SECURITY	SANITATION IN RURAL HOMES								
SOCIOECONOMIC	EDUCATION	ALPHABETIZATION	DATA		X	X			G-E: PAG.278 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	EDUCATION	SCHOOLS	DATA	X	X	X			G-E: PAG.278 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	EDUCATION	OTHER EDUCATIVE CENTERS	DATA	X					A: OBSERVATIONS	REG
SOCIOECONOMIC	HOUSING									
SOCIOECONOMIC	ROADS AND TRANSPORTATION		MAP/ DATA	X					A: USING SIG	
SOCIOECONOMIC	WATER USE	HUMAN CONSUMPTION		X					A: QUALITY WATER	
SOCIOECONOMIC	WATER USE	SERVICE AND ADMINISTRATION								
SOCIOECONOMIC	WATER USE	WATER FOR ELECTRICITY GENERATION	DATA	X						REG
SOCIOECONOMIC	WATER USE	AGRICULTURE	DATA		X				G-E: PAG.46-47 PLAN	

DIVISION	DIVISION	DIVISION	TYPE	AUTHOR	GLOBAL-EBY	CENSO	SENASA	EBY SIGNIF	OBS	LEVEL
SOCIOECONOMIC	WATER USE	RECREATION OR ECOTOURISM								
SOCIOECONOMIC	INSTITUTIONAL SERVICES	ELECTRIC ENERGY	DATA		X				G-E: PAG.280-282 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	INSTITUTIONAL SERVICES	DISPOSAL OF USED WATER	DATA		X				G-E: PAG.280-282 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	INSTITUTIONAL SERVICES	GARBAGE COLLECTION	DATA		X				G-E: PAG.280-282 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	INSTITUTIONAL SERVICES	STREET CLEANING								
SOCIOECONOMIC	INSTITUTIONAL SERVICES	WATER TREATMENTS								
SOCIOECONOMIC	INSTITUTIONAL SERVICES	TECHNICAL ASSISTANCE								
SOCIOECONOMIC	CULTURAL, RELIGIOUS, RECREATIONAL AND POLITICAL ASPECTS IN THE AREA		DATA		X			X	G-E: PAG.284 DIAGNOSIS. EBY SIG: CULTURAL ASPECTS	REG
SOCIOECONOMIC	INDUSTRIAL ACTIVITIES		DATA		X				G-E: PAG.237 DIAGNOSIS	REG
SOCIOECONOMIC	MAIN EMPLOYMENT AND INCOME SOURCES		DATA		X				G-E: 212-234/279 DIAGNOSIS	MUNICIP
SOCIOECONOMIC	TENANCY OF THE LAND		DATA		X	X			G-E: PAG.9 RESUMEN EJEC.	MUNICIP
SOCIOECONOMIC	LOCAL ORGANIZATION		DATA		X				G-E: PAG.52 PLAN	MUNICIP
SOCIOECONOMIC	INSTITUTIONALISM		DATA		X				G-E: PAG.35/52 PLAN	MUNICIP
SOCIOECONOMIC	RURAL DEVELOPMENT PROJECTS AND PROGRAMS		DATA		X				G-E: PAG.16-30 RESUMEN EJEC., PLAN.	
SOCIOECONOMIC	GOVERNMENT AND LEGAL FRAMEWORK		DATA	X	X				G-E: PAG.238-275 DIAGNOSIS, PAG.4-6/10 RESUMEN EJEC., PAG.22-33 PLAN.	MUNICIP/COUN

.

7.2 Conflicts and solutions

After consultation with the Watershed Council in a workshop, and using participatory research techniques described in the methodology, the following Table 22 and Table 23 enlist socio-environmental conflicts as identified by the participating Watershed Council members and condensed into similar categories.

Table 22. Identified conflicts, and number of times repeated by different participants. Elements were joined to form groups with repeated ideas.

Original Ideas (mentions)	Identified conflict or problem after combining ideas into groups	Freq.
Deforestation and no protection of rivers and water sources (6) wells (1) Maintenance of wetlands(2) Conflict between forested areas and human settlements (2) Deforestation close to populated areas (firewood) (2) Loss of Biodiversity (2)	Deforestation and loss of riparian forests and protective vegetation in rivers and water sources (deep wells included) caused by closeness to populated places (firewood) expansion of agriculture or livestock. Negative effects include loss of biodiversity and water quality.	15
Soil Contamination (5) Insufficient use of clean production techniques (3) Over exploitation of Soil(2) Degradation and erosion(2)	Chemical pollution of soil derived from misuse of fertilizers and pesticides in agriculture. Reduced use of clean production techniques and overexploitation of soil and soil degradation (erosion).	12
Health and Environmental education (7) Insufficient wastewater treatment (2)	Health problems derived from lack of environmental education, water contamination and lack of wastewater treatment.	9

Table 23. Identified conflicts, and number of times repeated by different participants. Elements were joined to form groups with repeated ideas. (Cont.)

Original Ideas (mentions)	Identified conflict or problem after combining ideas into groups	Freq.
Solid wastes treatment (5) Air Pollution (1) Open air waste disposal (1) Hospital waste treatment (2)	Inadequate or insufficient solid wastes treatment and disposal deriving in air and water pollution. Inadequate treatment of hospital wastes.	9
Land use conflicts derived from a lack of urban planning (3)	Land use conflicts derived from a lack of urban planning.	3
Conflicts related to Yacyreta Dam (displacement, flooding)(2)	Conflicts related to Yacyreta Dam (displacement, flooding).	2
Conflicts derived from rights and use of water (2)	Conflicts derived from rights and use of water.	2

By determination of the Watershed Council during the workshop, the first four conflicts, with the highest number of mentions, were selected to be worked in subgroups to offer possible strategies to help solve these problems from the perspective of the Council. Table 24 and Table 25 show each of the selected socio-environmental conflicts and the conclusions reached by the subgroups and discussed by the whole workshop participants in terms of solutions from the perspective of the Watershed Council.

Table 24. Possible solutions and strategies proposed from the perspective of the Watershed Council to the identified social-environmental conflicts of the area.

Identified conflict or problem	Possible solutions and strategies proposed from the Watershed Council.
Deforestation and loss of riparian forests and protective vegetation in rivers and water sources (deep wells included) caused by closeness to populated places (firewood) expansion of agriculture or livestock. Negative effects include loss of biodiversity and water quality.	Considering that the Paraguayan laws obligate landowners to leave a minimum 100 m of riparian forests protecting rivers and at least a 25 % or rural land to conservation, a possible strategy is to coordinate with national and local authorities to identify areas and landowners that do not comply with national laws. To promote reforestation and the importance of keeping coverage in compliance with current laws, as well as capacitating local authorities and the community through different workshops, technical visits and talks to the farms. To promote, given the presence of municipal authorities in the Watershed Council, the creation of local tree nurseries to reduce costs in reforestation and to be used in reforestation programs supported by the municipalities.
Chemical pollution of soil derived of misuse of fertilizers and pesticides in agriculture. Reduced use of clean production techniques and overexploitation of soil and soil degradation (erosion).	To ask formally from the Watershed Council to the involved institutions (Environment Secretariat and Agriculture and Livestock Ministry and local Institutions) to give information on the regulatory norms for the application of chemicals in agriculture, as well as the environment protection specifications. Also, to promote education on rational use of chemicals. To promote together with municipalities and the community the creation of collection points for emptied bottles of agrochemicals. From the Watershed Council to continue promotion of rational use of soil through different proven techniques in the area, such as rotating crops and no-till farming. To collaborate with local research institutions to prove benefits in the use of this techniques.

Table 25. Possible solutions and strategies proposed from the perspective of the Watershed Council to the identified social-environmental conflicts of the area. (Cont.)

Identified conflict or problem	Possible solutions and strategies proposed from the Watershed Council.
Health problems derived from lack of environmental education, water contamination and lack of wastewater treatment and other pollution.	To initiate the elaboration of formal and informal environmental education programs with each of the Municipalities of the watersheds, depending on the different problems of each. To promote mass media use to communicate basic health related issues, to support the elaboration of educational material for schools. Integrating different institutions involved in a coordinated work using the Watershed Council as a meeting point.
Inadequate or insufficient solid wastes treatment and disposal deriving in air and water pollution. Inadequate treatment of hospital wastes.	To plan incidence in the following stages of the conflict: generation, transportation, and final deposition of solid wastes. Generation: promoting education on disposal of wastes by local users, urban. Transportation: to promote the capacity of municipalities to collect, with proper vehicles, and with a continuous schedule. Final deposition: to agree at the local level, promoting dialogue between municipalities and institutions on the construction of a necessary waste disposal area to be constructed with common efforts and with state of the art technology for waste treatment.

7.3 IWM assessment

A first perspective of the results was obtained by graphing individual qualifications obtained for each indicator. Figure 36 shows qualifications for each indicator obtained after application of the IWM assessment methodology. The following were obtained from analysis of data from key informants through the help of workshops-interviews.

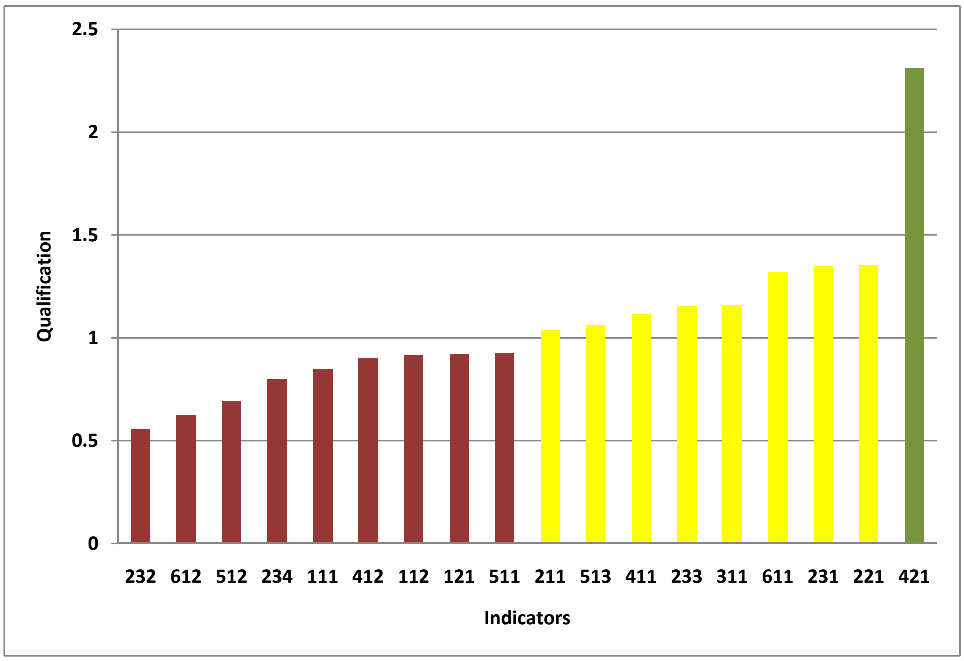


Figure 36. Decision elements and their average qualification for the Watersheds of the Mboi Cae and Quiteria Rivers. Weighted mean obtained for each indicator using relevance assigned by each key informant.

Using the same descriptors as those used for data collection, and according to methodology, these results are interpreted in three groups and are presented in the following tables:

- Indicator with inferior qualification (0 to 1) Very low to low (Table 26)
- Indicators with intermediate qualification (1 to 2) from low to high (Table 27)
- Indicators with a superior qualification (from 2 to 3) High to very high. (Table 28)

Table 26. Inferiorly qualified indicators. Aspects that indicate a low performance locally towards achieving IWM.

Indicator	Description
2.3.2	There is a very low level of environmental education (lowest qualified in the group)
6.1.2	A very low adoption of conservationist production techniques and ecoenterprises
5.1.2	A very low level of inclusion of risk assessment in watershed developing plans
2.3.4	A very low level of consideration of IWM in transportation routes
1.1.1	Low level of connection between stakeholders and institutions
4.1.2	Presence of debris and waste in water streams
1.1.2	Low level of convergence
1.2.1	Low level of protection of conservation areas
5.1.1	Reduced buffer zones next ro rivers (highest qualified)

Table 27. Intermediately qualified indicators. Aspects that indicate intermediate performance locally towards achieving IWM.

Indicator	Description
2.1.1	Some capitalization and funding mechanisms (lowest qualified in the group)
5.1.3	Some recognition of the relation between natural resources management and natural disasters
4.1.1	Some evidence of sediments and pollutants in water streams
2.3.3	Some level of consideration of IWM in health centers
3.1.1	Intervention activities sometimes consider an IWM angle
6.1.1	There are some environmental friendly techniques used in production areas, but they are not the most common
2.3.1	Intermediate level of consideration of IWM in infrastructure programs
2.2.1	Some first steps have been taken to achieve interinstitutionality in the watersheds.

Table 28. Highly qualified indicators. Aspects that indicate a good performance locally towards achieving IWM.

Indicator	Description
4.2.1	Adequate water quantity during every season

After qualifications were reviewed separately by indicator, a key-informant overall qualification of the Watersheds was calculated. Global qualification was calculated to be of 35%, after averaging individual qualifications by each of the key-informants (Figure 37). This value represents, according to methodology, still very few actions that indicate achieving a high level of IWM in both Watersheds.

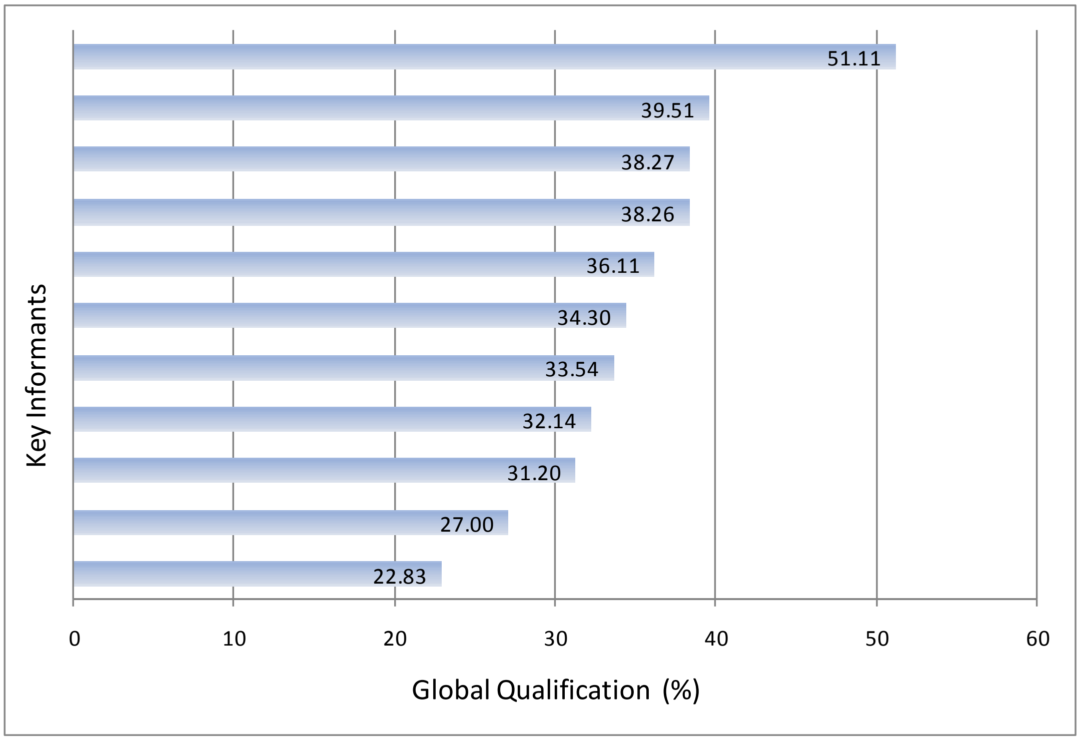


Figure 37. Overall evaluation of the level of IWM per key informant (EK) presented in percentage in the watersheds of the Mboi Cae and Quiteria Rivers. Mean is calculated 35% of IWM achievement (GQ).

Another analysis was carried out relating qualifications of individual indicators with their principles. As stated before, each indicator was derived from one of the six principles that are considered within the definition of Integrated Watershed Management. By looking at qualification for each Principle, the following graph (Figure 38) resulted.

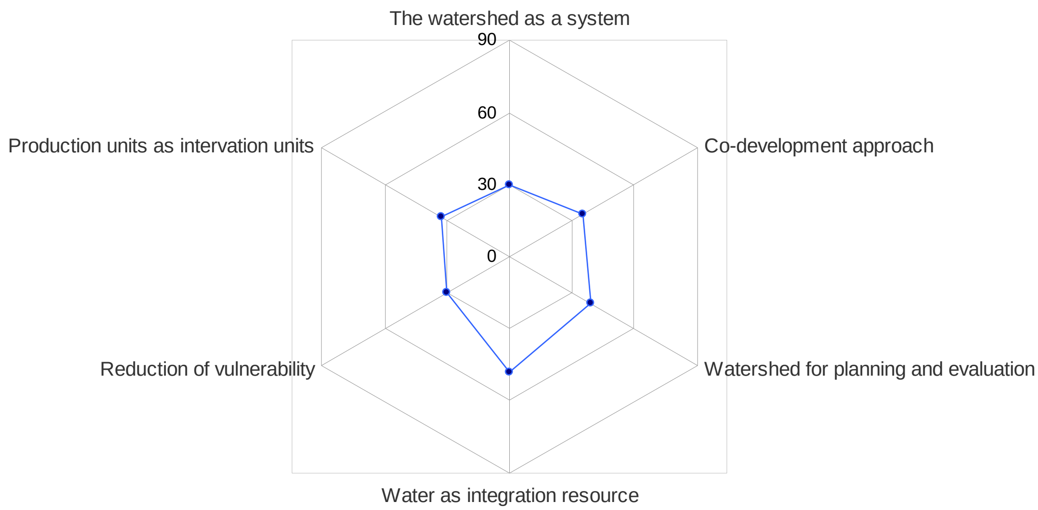


Figure 38. Graph showing qualification of each of the IWM Principles. Values are given in percentage of achievement, being 100 the highest possible qualification given by the standard.

7.4 Aquifer vulnerability to pollution using DRASTIC.

The following map (Figure 39) was obtained after all DRASTIC layers were processed into DRASTIC ratings and weights were assigned according to the established methodology. This map shows in an unclassified display all values found in the watersheds. To understand these results, a further reclassification was made using several recommended interpretations by different authors.

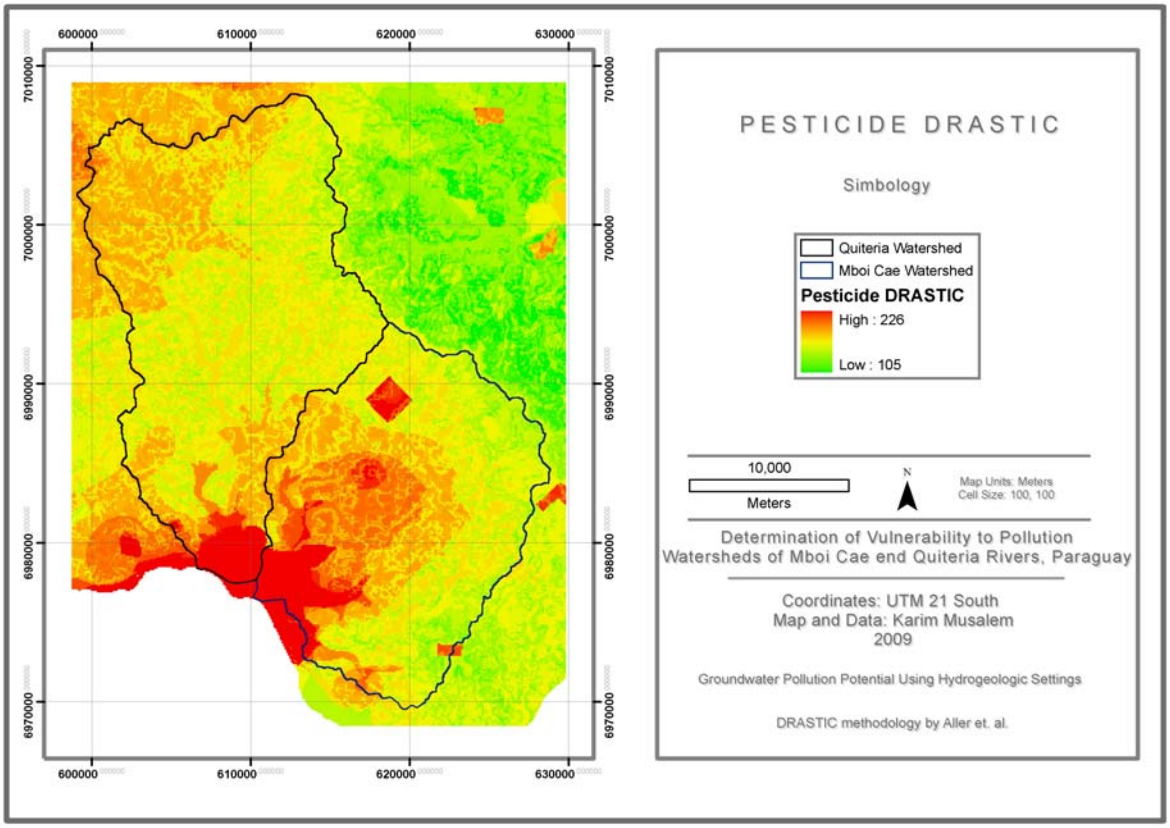


Figure 39. Aquifer vulnerability to pollution according to DRASTIC index in the Watersheds of the Mboi Cae and Quiteria rivers in Paraguay.

DRASTIC methodology does not offer an absolute classification or ranking of the index for its interpretation. It does however suggest classification according to values found in an area, creating and dividing ranks depending on minimum and maximum values found in the area of study. However, case study presented with the DRASTIC methodology (which considered most of the United States) divides values from less than 79 to higher than 200 (with 6 categories in between every 19 units), assigning a colour scheme known as " US national colour code for DRASTIC index ranges" (Table 29). Following this interpretation, Figure 40 shows DRASTIC vulnerability interpreted according to the US national colour code.

Table 29. DRASTIC index classification from Aller, et al. (1987) and interpretative values according to US national colour code.

DRASTIC index rate	Colour	R, G, B	Potential Vulnerability	Hectares	Percentage
Lower 79	Violet	238, 130, 238	Minimum		
80 – 99	Indigo	75, 0, 130	Very low		
100 – 119	Blue	0, 0, 255	Low	4	< 0.06
120-139	Dark green	0, 128, 0	Medium Low	13872	22
140 – 159	Light green	0, 255, 0	Medium High	36055	56
160 – 179	Yellow	255, 255, 0	High	10166	16
180 – 199	Orange	255, 127, 0	Very High	1938	3
Higher 200	Red	255, 0, 0	Maximum	1880	3

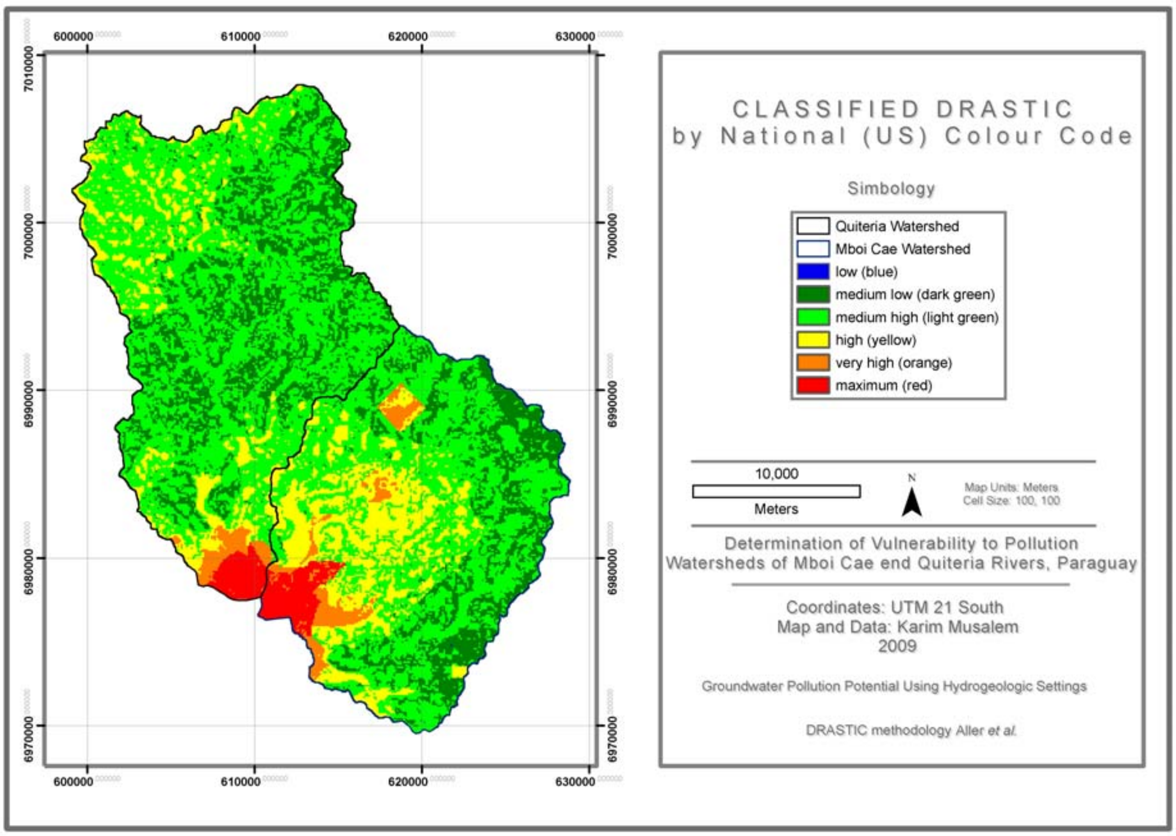


Figure 40. Aquifer vulnerability to pollution according to DRASTIC index reclassified by National (US) colour code in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay.

On the other hand, a relative classification is possible; this allows viewing in perspective the areas of the watershed which are more or less vulnerable, relatively within the study area. The classification is made into three equal interval categories, dividing all values present into three categories (rounded to the closest integer). A green, yellow and red colour scheme was selected and shown in Figure 41.

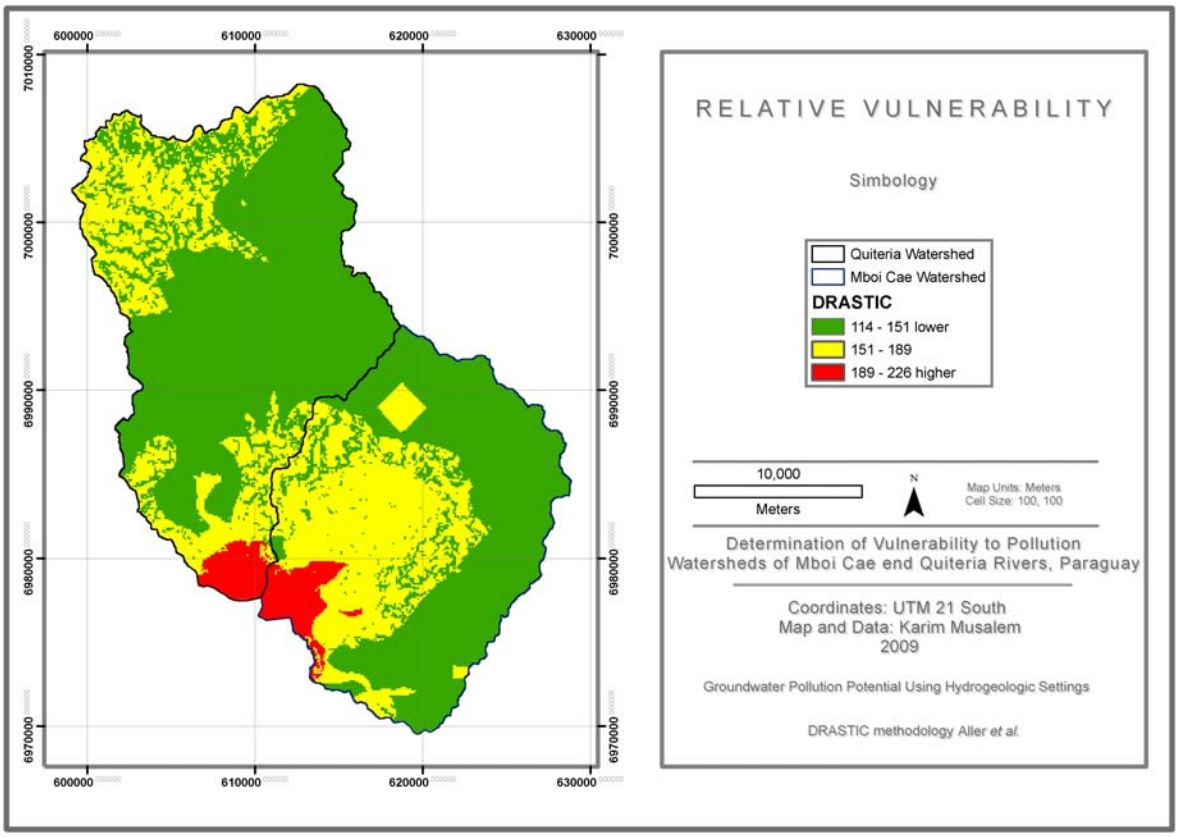


Figure 41. Relative aquifer vulnerability to pollution according to DRASTIC index in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay.

7.5 Using alternative soil media in DRASTIC

As described before in the DRASTIC methodology (Section 6.4.5), soil media was subject of differences in opinion when regarding urban areas, and how it should be interpreted. The following maps show when urban areas were taken as direct pollution sources and also when urban areas were given the surrounding soil values (values changed only for inside the Watersheds: Figure 42).

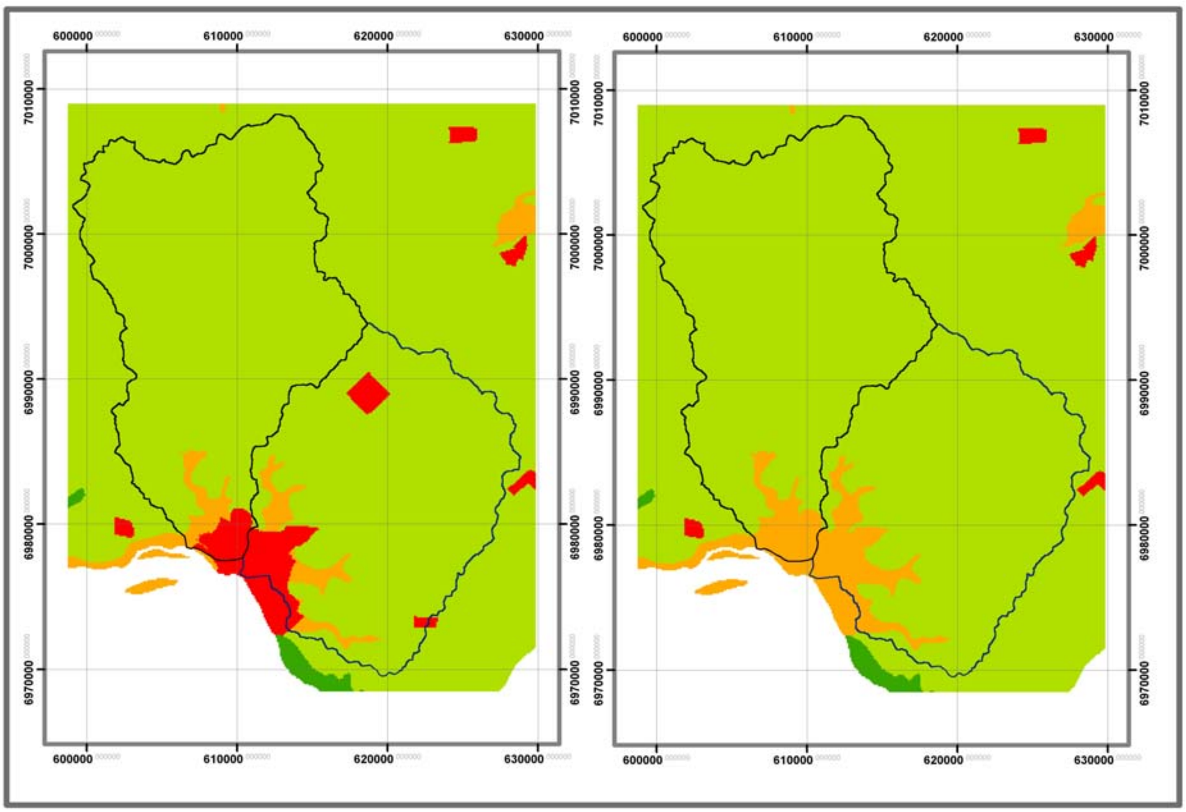


Figure 42. Using different values for soil media (S) in the DRASTIC methodology. Left: Urban areas as direct pollution sources (red) vs. Right: urban areas using values of neighbouring areas.

This also leads to a different final DRASTIC index map (Figure 43). It is noticed how this particular interpretation changes high values significantly. Reducing the area with very high values, however the general tendency in the Watersheds remains. In a way this shows the importance of interpretation of the DRASTIC methodology and can show the importance that urban areas represent as point pollution source in the GVP assessment, and eventually in management decisions for the aquifer. DRASTIC-NO-CITIES (DRASTIC-nc) will be used as a common abbreviation in this study when cities or urban areas are not considered as direct pollution source but assume values of neighbouring areas.

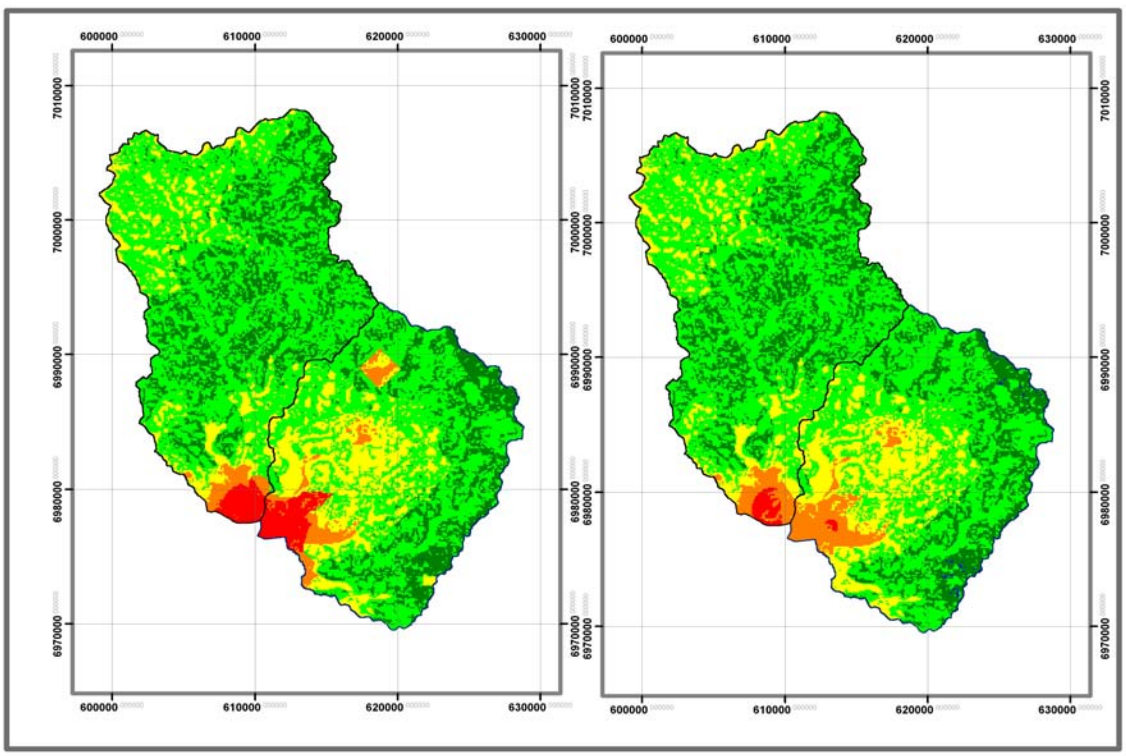


Figure 43. Comparison of resulting DRASTIC vulnerability (according to US national colour code) using different values for soil in urban areas. Right shows GVP when assuming soil taxonomy as similar to neighbouring areas, Left shows GVP if urban areas are estimated as direct pollution sources.

7.6 Aquifer vulnerability to pollution using GOD

Results of the GOD model show a 96 % of the area of the Watersheds with values of 0.3 – 0.5 (moderate vulnerability to pollution). However, a 4 % (Values 0.51 -0.6) resulted as high vulnerability. Figure 44 Shows that these higher values are present in lower areas of the Watersheds, where depth to groundwater is reduced and alluvial sands tend to be present.

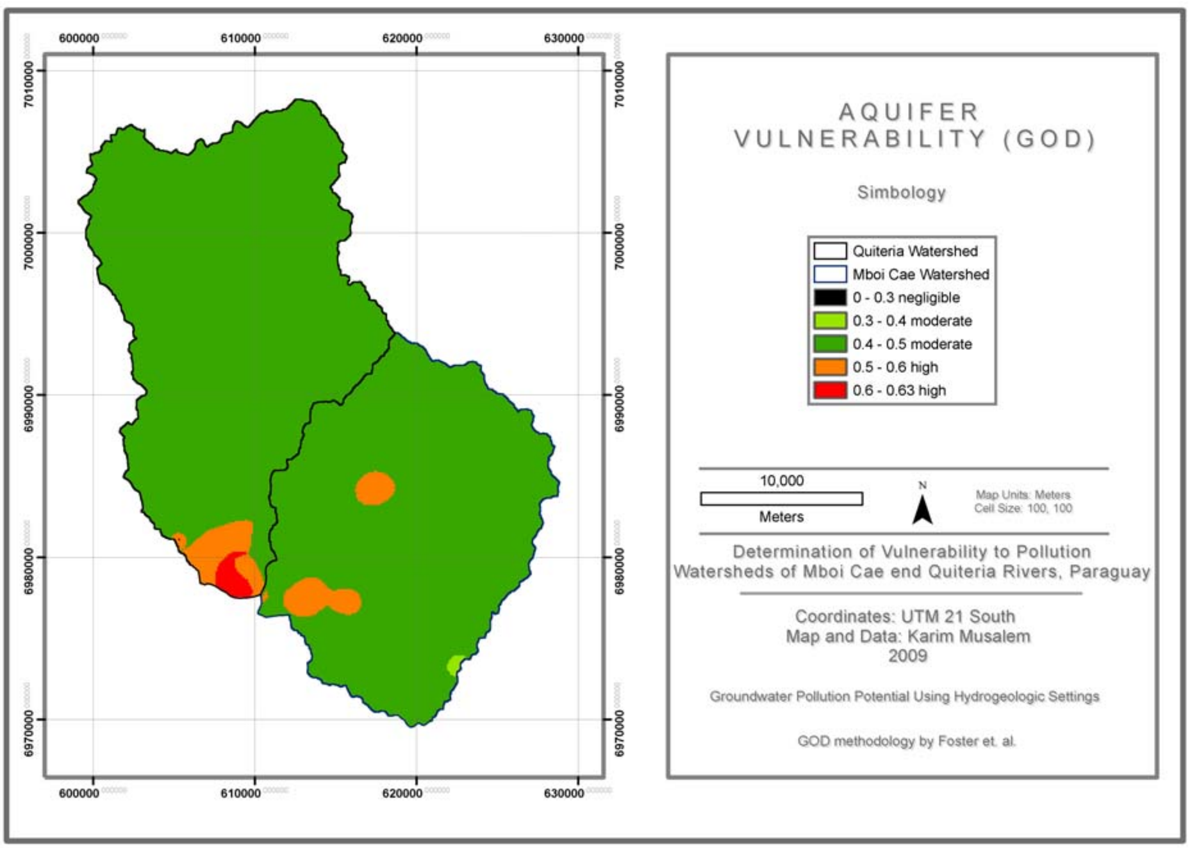


Figure 44. Distribution of aquifer vulnerability to pollution according to GOD index in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay.

7.7 Comparing DRASTIC and GOD

The DRASTIC and the GOD models compared to each other have different descriptors. Assuming what each author suggests from results interpretation and their methodologies, Table 30 and Figure 45 describe a possible comparative table of descriptors and the corresponding areas as result from this study.

Table 30. Comparative table of the GOD and DRASTIC models, assuming similar descriptors. Areas calculated according to reference indexes by each author. Values corresponding to the total area of the Watersheds of the Mboi Cae and Quiteria Rivers.

DRASTIC	Area ha	% of watersheds	GOD	Area ha	% of watersheds
Low	4	0.0	Negligible - Low	1	0.0
Medium low	13872	21.7	Moderate (lower values)	92	0.1
Medium high	36055	56.4	Moderate (higher values)	60986	95.4
High	10166	15.9	High (lower values)	2436	3.8
Very high	1938	3.0	High (higher values)	400	0.6
Maximum	1880	2.9	Extreme	0	0.0

The distribution shown in both models are similar in their general tendency (Figure 46), having a higher vulnerability area towards the mouth of the rivers, precisely where the city of Encarnacion is located and where the area of the flooding will take place when the filling of the dam occurs.

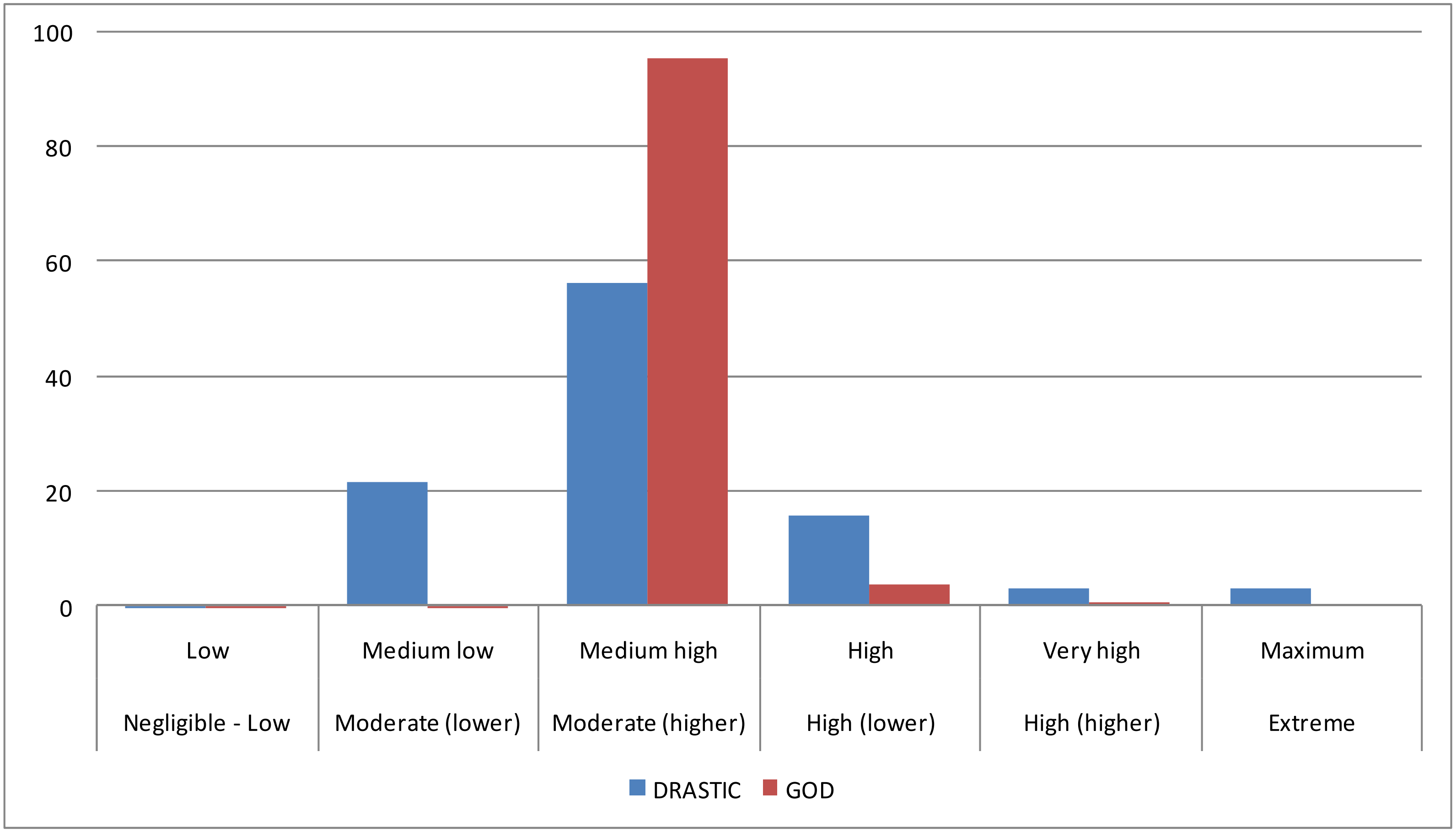


Figure 45. Comparative graph of the GOD and DRASTIC models, assuming similar descriptors. Areas calculated according to reference indexes by each author. Percentages corresponding to the total area of the Watersheds of the Mboi Cae and Quiteria Rivers.

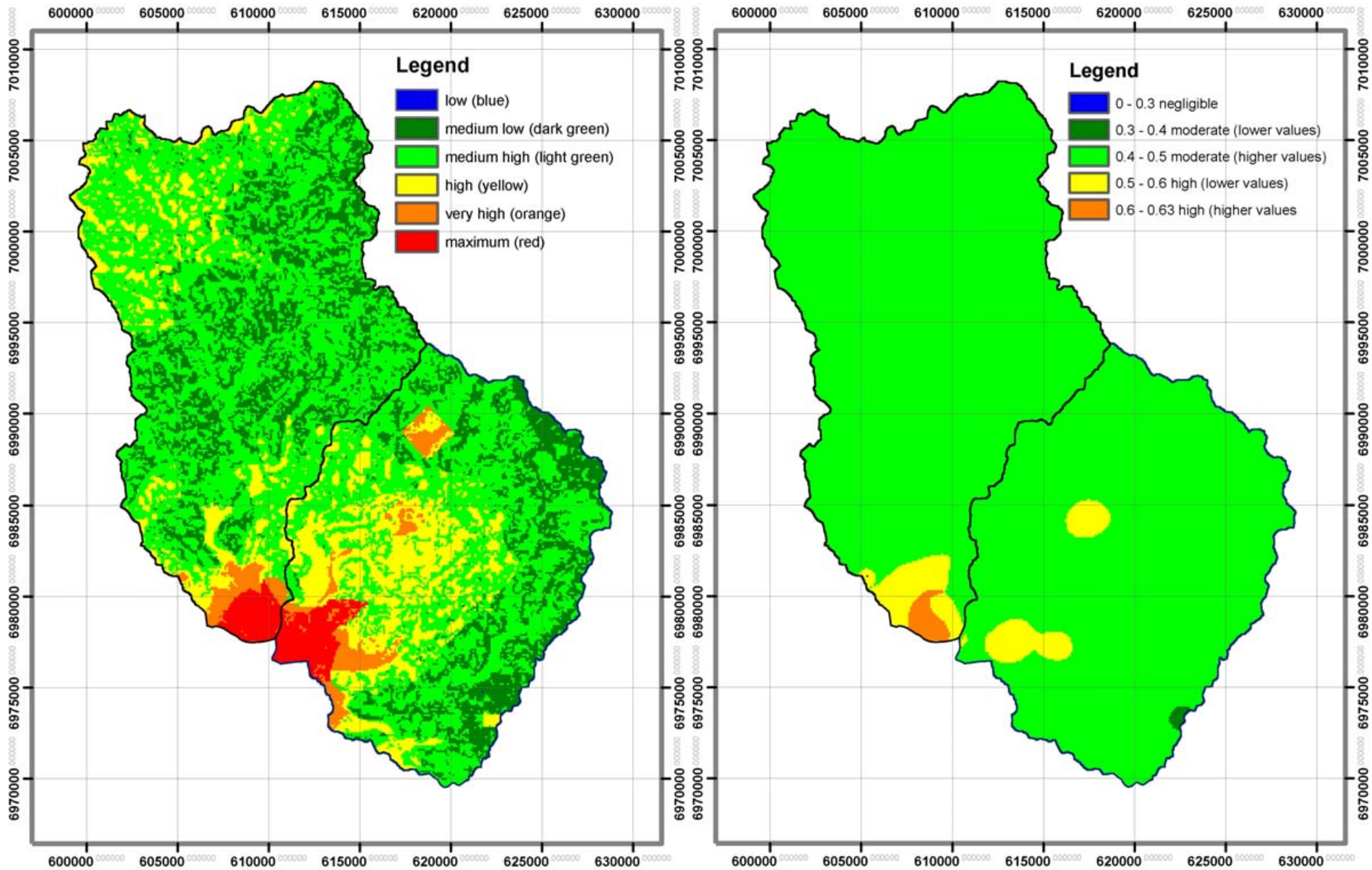


Figure 46. Aquifer vulnerability to pollution maps, using Pesticide DRASTIC (cities considered direct pollution with high vulnerability values) and GOD models, classified with US national colour code in the Watersheds of the Mboi Cae and Quiteria Rivers in Paraguay

7.8 Predictions in aquifer vulnerability to pollution

Information of hydrogeological studies carried out by Lotti-Associatti (1999) for YBE and also a counter-revision made by hydrogeologist Miguel Auge (n/a) to this study, regarding the possible effects of water table elevation to the aquifer show that still little is known on how groundwater will behave once the water level of the Dam has changed from the current 78 to 83 m. In one side of the predictions Lotti assures that due to the strong basaltic hydrogeology of the area, only a small “marginal fringe” of approximately 12,5 meters will be affected generating changes in the water table of the aquifer; in the other hand, a second observation by Auge opposes this prediction by stating that there is not enough hydrogeological data available in the area to determine how change in the water level of the reservoir will affect the aquifer, concluding the need for a stronger sampling using boreholes and the use of tridimensional models instead of the two dimensional models used by Lotti. So far no such complementary studies have been found in literature or Yacyreta.

Considering this information, a scenario was constructed to help visualize and compare possible changes in aquifer vulnerability to pollution, considering a worst case scenario, where the change in the water table is equivalent to the elevation of the dam reservoir. Although very unlikely to actually occur, considering information from Lotti, it serves the purpose of showing the extreme event of affecting the water level (depth to water parameter) in the whole area of the Watersheds.

The resulting comparative maps (Figure 47) show the original “DRASTIC ratings”, “DRASTIC-no cities” (See details on alternative soil media Section 7.5) and the “DRASTIC worst case Scenario 1” where Depth to water (D) was changed by 5 meters (minus 5) using Map Algebra tool in Arc Gis 9.3 and then translated to DRASTIC ratings. All other parameters of the DRASTIC index remain the same. A graph comparing the same Scenario 1, with DRASTIC-nc and DRASTIC can be seen in Figure 48.

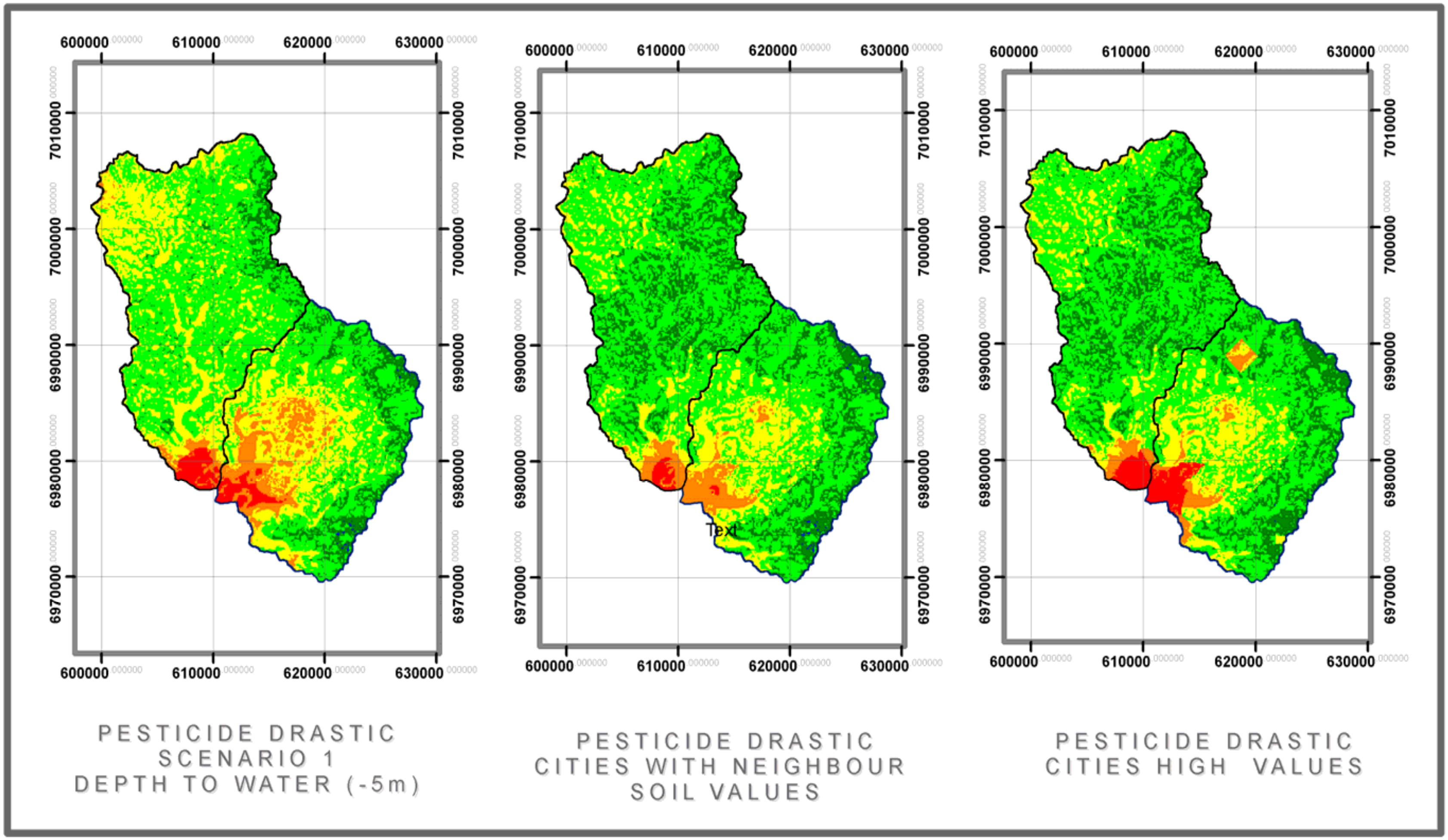
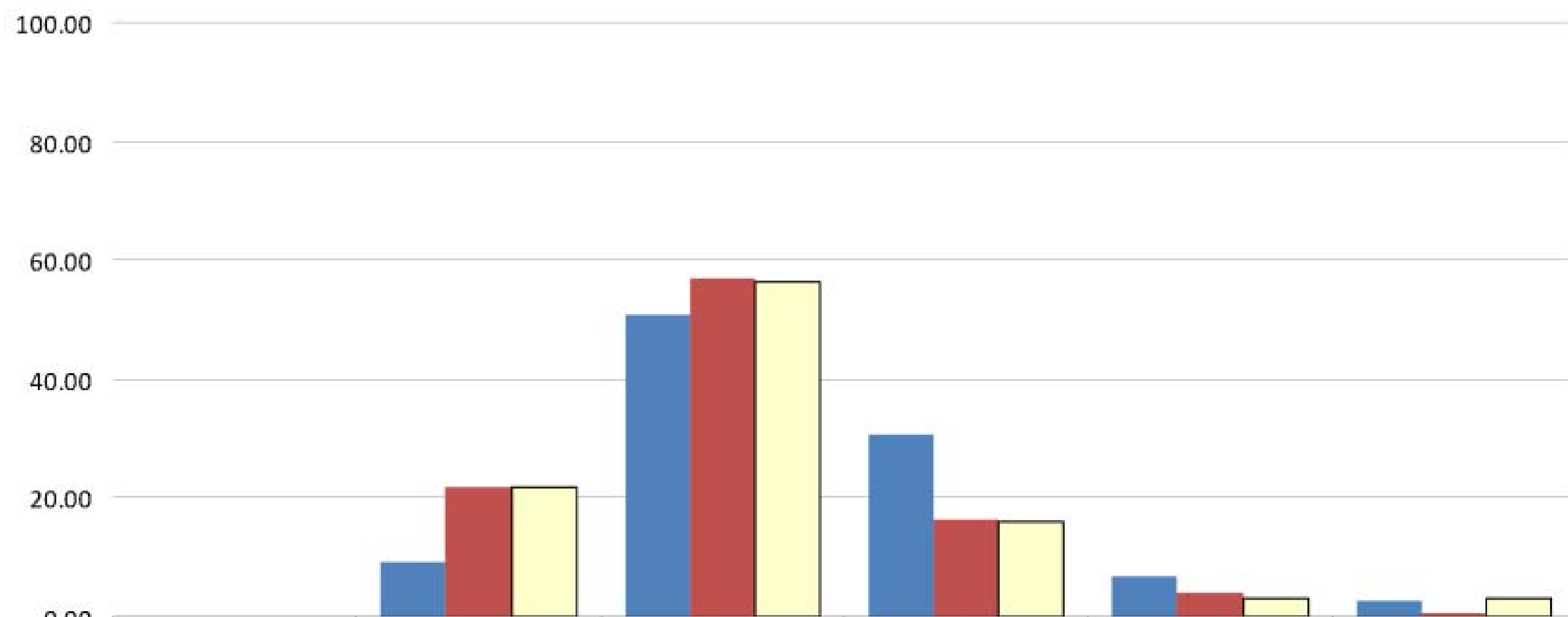


Figure 47. Comparative maps of DRASTIC ratings using left: Pesticide DRASTIC with predictive worst case scenario (rising of 5 meter change in phreatic level; center: Pesticide DRASTIC (cities not considered as direct pollution sources); right: Pesticide DRASTIC (cities considered highest vulnerability values). Classified by US colour code, Watersheds of the Mboi Cae and Quiteria Rivers.



	Low	Medium low	Medium high	High	Very high	Maximum
Scenario 1	0.07	9.04	50.90	30.59	6.81	2.59
DRASTIC (nc)	0.10	21.81	57.02	16.29	4.12	0.66
DRASTIC	0.0	21.7	56.4	15.9	3.0	2.9

Figure 48. Comparative graph of DRASTIC ratings using: pesticide DRASTIC with predictive worst case scenario (rising of 5 meter change in water table; pesticide DRASTIC-nc (cities not considered as direct pollution sources); and pesticide DRASTIC (cities considered highest vulnerability values). Percent of area in the Watersheds of the Mboi Cae and Quiteria Rivers.

7.9 Predictions in the context of global climate change

During the planning stage of this research, information of changes in climate through the use of different greenhouse gas emissions scenarios was found in literature (See Section 3.4.1 about climate in the area). It was suggested for this study that available information using different scenarios could be used to predict possible changes in aquifer vulnerability, specifically affecting net recharge (Parameter R in DRASTIC model). Figure 49 shows the predicted changes in precipitation and temperature in the area of the Watersheds.

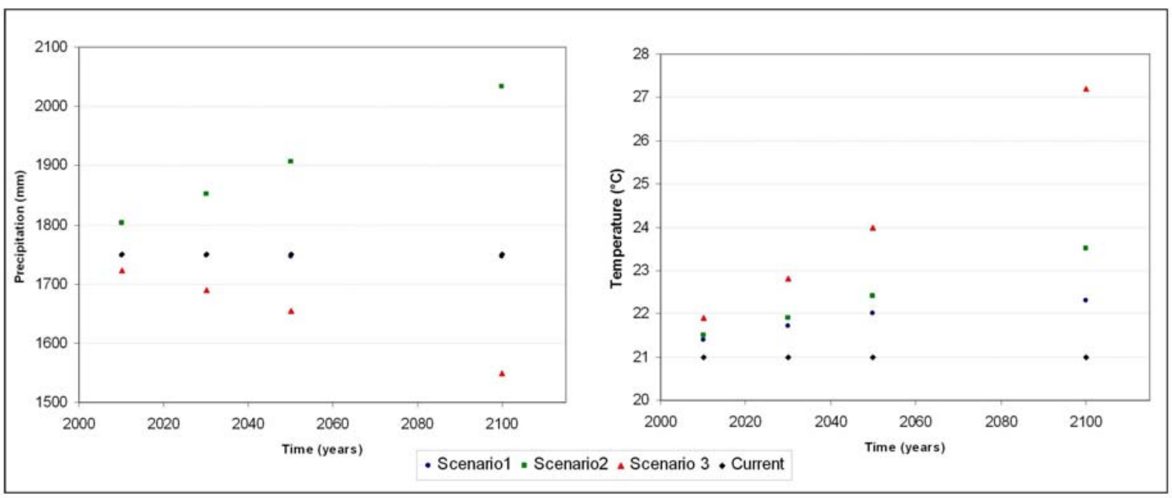


Figure 49. Prediction of changes in mean annual precipitation and mean annual temperature caused by global climate change according to three different greenhouse gases emission scenarios in the area of the Mboi Cae and Quiteria Rivers, Encarnacion, Paraguay, as reported by Limia (2000)and Gonzalez (2005).

The most extreme predictions about changes in precipitation occur considering a time frame of 100 years (since 2000) corresponding to the highest peaks (+16.2 % and -11.5 %). These changes in precipitation were used to change values in net recharge. Net recharge values for the DRASTIC model were initially taken from literature review, estimating a net recharge equivalent to a 3% of precipitation for the basaltic area of the watersheds (See Section 6.4.2 about net recharge). However changing the precipitation values, with the two extreme values found in literature in a 100 year span, did not seem to affect the final DRASTIC outcome. Even though values did change in the resulting maps, the classes that determine vulnerability were not significantly modified by this change in precipitation.

8 Discussion

8.1 Studying a dynamic process

At the beginning of the present work *in situ* and at its first planning stages, a lack of information was detected for the Watersheds. Some information available was outdated, did not cover the complete area of the Watersheds and strictly considered hydraulic data, focused merely on the construction of the dam and the effect of the dam. Also data on chemical water quality analysis was regularly updated. However, parallel to the realization of this research, a process of interest, compilation, and participatory research began to arise at the same time and, in a matter of two to three years, changed the availability of information from being scarce and disperse into much more concentrated and complete. Works in Mboi Cae and Quiteria have not only compiled information but also new information has been produced through soil analysis, social research, new updates on water quality and have led to the installation of the Watershed Council, with members of the

Municipalities, professors from local Universities, technicians from YBE, and persons representing various organizations and institutions from private sectors or from government agencies, and independent researchers as the Author.

Many of this multiple efforts have changed the situation of knowledge and information available for the Quiteria and Mboi Cae Rivers and their watersheds in the last years. Still many of this information is not available for open public, but only at the local level for some members of the Watersheds and the involved government agencies revising documents. Obtaining this information has been difficult and a challenge of this research, despite the fact there is a signed agreement of cooperation between the EBY and this research. However, anticipating its liberation, the present study documents in the state of knowledge section this information, whether it is in revision stage or published officially. These parallel works were mainly conducted by the Yacyreta Binational Entity, the Environment Secretariat through a private consulting group. Without a doubt, it provided a lot of the information available about the Watersheds while compiling data from other sources. The final reports are under revision at the moment.

The results obtained in this research were found to be concurrent to what is described by Bonnell (2004) in a revision of The Hydrology, Environment, Life, and Policy (HELP initiative) component of the Internacional Hydrological Programme (IHP) which aims to facilitate dialogue between hydrologists, social and economic scientists, water resources managers, water lawyers, policy experts, and river-basin stakeholder communities in setting a research agenda driven by local policy issues. Bonnell (2004) describes the need of a first assessment stage of knowledge in a watershed, outstanding the main components of this assessment stage as:

- "Simulation of future change scenarios (e.g. land use, demography or socio-economics)in the water cycle and supply/demand for different future catchment states, as well as checking model predictions based on known changes in the catchment environmental–social status.
- Definition of 'gaps' in scientific knowledge (e.g. process hydrology understanding) that require development of a technical implementation strategy by hydrologists in collaboration with basin stakeholders and managers. Such steps are taken to support already-defined land–water management and policy issues".

This research addresses these two components recommended in the HELP approach by assessing the existing information in the watersheds at the general level, the social and the environmental and the future change scenarios regarding aquifer vulnerability to pollution. As an output, similar to what is sought by the HELP programme; this study also helped identifying knowledge gaps that require responses from the research community.

8.2 Integrating workshops with IWM standard

From the socio-environmental workshop held with the Watershed Council, four aspects were prioritized that have a coincidence of appearance when also applying the IWM standard, the same four aspects can be related to at least one very low or inferiorly qualified indicator.

- Deforestation and loss of riparian forests and protective vegetation in rivers and water sources (deep wells included) caused by closeness to populated places (firewood) expansion of agriculture or livestock. Negative effects include loss of biodiversity and water quality. Related to indicators 5.1.1 reduced buffer zones next to rivers with indicator 1.2.1, a low level of protection of conservation areas.
- Chemical pollution of soil derived of misuse of fertilizers and pesticides in agriculture. Reduced use of clean production techniques and overexploitation of soil and soil degradation (erosion) with indicator 6.1.2 a very low adoption of conservationist production techniques and eco-enterprises.
- Health problems derived from lack of environmental education, water contamination and lack of wastewater treatment and other pollution, with indicator 2.3.2, there is a low level of environmental education.
- Inadequate or insufficient solid wastes treatment and disposal deriving in air and water pollution. Inadequate treatment of hospital wastes with indicator 4.1.2, presence of debris and waste in water streams.

This can be interpreted as that there is a certain relation between the ideas expressed by the Watershed Council and those that were expressed individually by key informants (months before the workshop). Similarly in the opposite exercise, relating the worst qualified indicators to the conflicts and issues prioritized in the workshop shows a similar pattern. Some of these ideas are discussed later in this section. However it can be pointed out that the conformation of a watershed council in Mboi cae and Quitera can be seen as helpful when dealing with identifying conflicts and their solutions, in this sense, Ghanbarpour, Hipel and Abbaspour (2005) conclude after work in Iran that “The existence of conflict between stakeholders in watershed management alternatives originated not only from different stakeholders' interests, but also from a lack of institutional coordination. Coordination of governmental plans with community preferences and experts' judgements can be carried out at the initial stage of the planning process, which could be accomplished through the establishment of a watershed council.” In a similar way the Watershed Council with representatives of various institutions at various levels benefited from this interactive situation and managed to identify common problems, needs and strategies for solutions.

8.3 The competence of the Watershed Council

The process of determining socio-environmental conflicts led to the prioritization of 4 main conflicts by the Watershed Council and possible strategies to help solve, mitigate or reduce this conflicts, exclusively from the perspective and possibilities of the Watershed Council. Resolution 170 / 06 which specifies the creation and regulation of watershed councils in Paraguay establishes the following as of competence of the Watershed Council:

- To promote debate of topics related to water resources and to coordinate activities of the governmental institutions involved.
- To arbitrate in a first administrative instance, conflicts regarding or related to water resources.

The particular conformation of this Council, with representatives of government institutions, municipalities and other organizations acts as a contact point to integrate different interests and more importantly to generate ideas and ways to convince authorities to take action on aspects regarding water and natural resources management, or to guide such authorities through recommendations emitted from agreements constructed from the Watershed Council. As described by Samra and Eswaran (2000), “watershed-level institutions” are necessary in incorporating the needs of the watershed community needs and aspirations, where the conventional “straitjacket” approach has to give way to participatory and interactive institutional framework. Studies carried out by Lubell (2004) after analyzing farmer participation in Florida (US) explain that the "view from the grassroots has important implications for several aspects of collaborative management." Lubell's central argument is that collaborative management requires cooperation from grassroots. This study decided on most of its objectives on the interest collected in the initial stages of the research through consultations with the Environment Office of the YBE.

Some of the proposed activities or strategies as a result from the workshop are direct actions and activities to be executed by the Council, which currently receives no funding, however, it is hoped that this situation could change in time through the search of possible financing. This concern is common, as put by Tortajada (2001) "Nearly all of the river basin organizations in Latin America need significant evolution before they can become effective units for management and planning. Further decentralization in terms of authority, decision-making and financial and human resources and the enhancement of institutional capacities are prerequisites if these institutions are to become viable units for efficient water resources management in the future."

During the workshop no reference was made to concrete possibilities of arbitration from the Council in any specific conflict. Most (if not all) the proposed strategies and solutions are directed to create environmental conscience in social and productive activities or in developing programs to mitigate most of the negative impacts through education and information. As put by Molle (2009) "The river basin has become a contested scale at which many interests are deployed. A good illustration of this point is provided by the strategies of the Ministries of Environment that have been established in many countries with the mandate to regulate the use of natural resources but without the administrative and political power needed to oppose traditional powerful line agencies (typically Irrigation Departments, Ministries of Agriculture, etc.)". This perhaps is an exact representation with what is happening with the Watershed Council of the Mboi Cae and Quiteria, as it has still no direct actions, it stands only as an arena where other institutions may interact.

Deforestation and loss of riparian forests and protective vegetation in rivers and water sources (deep wells included) caused by closeness to populated places (firewood) expansion of agriculture or livestock is a recognized conflict which was considered by de Watershed Council. As discussed during the workshop, one of the main possibilities to reduce this problem and its negative effects is to force application of current laws in Paraguay by helping the Environment Secretariat to detect owners who do not comply with the regulation, however, it is noticeable that since most of the deforestation has already taken place it will not only be necessary to stop deforestation, but also it will be necessary to recover forests and riparian ecosystems considering species which adapt to the current conditions, on the other side of the problem, is land that has ownership conflicts, that is affected by third parties or that have irregular settlements, any of which could make it difficult to identify a responsible person or could be a consequence of a greater conflict.

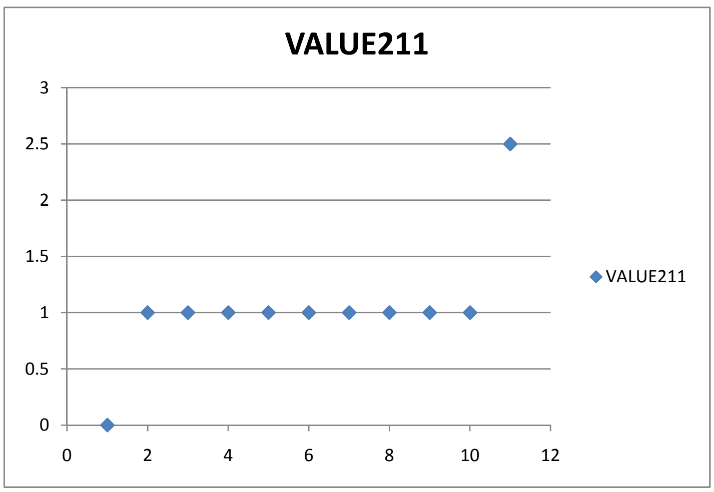
Chemical pollution of soil derived of misuse of fertilizers and pesticides in agriculture, reduced use of clean production techniques and overexploitation of soil and soil degradation (erosion) was also a prioritized conflict which combines the most important economic activity in the area which is the intensive cultivation of soybean and sunflower with the presence of the Guarani Aquifer System. It was discussed in the workshop that no evidence of pollution has been found when chemical products were applied with the correct doses and in well diagnosed problems. It was also commented on the lately availability of newer eco-friendly products that were available on the market. Also, regarding erosion, it was discussed how no-till farming and contour lines when adopted contributed to reduce erosion importantly. However these two productive activities are not used by all farmers in the Watersheds. Key-informants during the application of the IWM standard confirmed that there is a very low adoption of conservationist production techniques and that some environmental-friendly techniques were used in productions areas, but they were the least common.

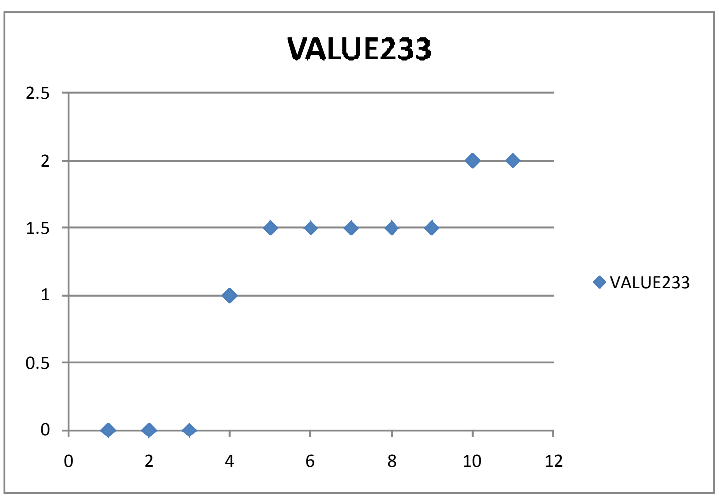
From this particular information, the Watershed Council proposes to continue promoting rational use of soil, specifically in collaboration with research institutions to prove benefits of the use of these techniques in the long term. Also, as a separate comment from a member of the Council, the importance of counting with tangible indicators, examples and analysis that can really determine soil pollution in the local productive areas and the risk of pollution to the aquifer was said to be of utmost importance and necessity. As part of this study, two groundwater vulnerability models were applied in the area; this particular socio-environmental conflict is deeply related to this part of the study and is reported separately.

8.4 Key informants and different opinions

The IWM assessment methodology allows recognizing in a very short time some of the principal characteristics of a watershed and the level of integrated management. Since it depends mostly on information given by key-informants, it is also subject of being biased, depending on each of the experiences, interests, or access to information or misinformation. Working with key-informants provides information which can be then compared to other data, such as literature review, studies, or other evidence which by triangulation helps to reduce erroneous or tendentious information. This triangulation is not always possible (i.e. when other information is not available, when time to compare is limited) however; an easy way to firstly analyze data given by key informants is to observe the consistency of the answers given and their similarity with the rest of the key-informants. Kirby*, et al.* (2000) defines triangulation as “the use of more than one method to try to encounter the weaknesses of one particular method by combining it with another that is strong in that area. (…) the logic of doing so is to try to obtain the highest levels of both validity and reliability.”

Patton (1990) explains about confirming and disconfirming cases: “In the early part of qualitative fieldwork the evaluator is exploring—gathering data and beginning to allow patterns to emerge. Over time the exploratory process gives way to confirmatory fieldwork. This involves testing ideas, confirming the importance and meaning of possible patterns, and checking out the viability of emergent findings with new data and additional cases.” In a simple exercise the following graphs show two indicators and the corresponding values (without considering weight used for other calculations). The first corresponds to an indicator where most of the key informants agree, and the second to an indicator where key informants disagree. These are extreme cases found in this study:





In the first example For indicator 2.1.1, nine out of eleven key-informants agreed that the condition that best described it better was number 1, which states that “there is a low level of capitalization and cooperating financial institutions, they exist, however, they are irregular, external, and have shown not to be self sustainable”. Average values were taken into account to finally obtain results and interpret information in general, it is important to acknowledge that a weighted averaged is considered to help minimize each key informant’s bias. At the moment of the workshop-interview, each key informant defines the weight he or she will give to a certain indicator depending on the importance it reflects in his opinion and experience.

On the other hand, for indicator 2.3.3, only five key informants agreed on a specific descriptor for this indicator; three more agreed in a second opinion and the rest considered other opinions. This particular indicator provides a qualification for “level of consideration of IWM in health centres” In this case, three key informants considered that health centres are not involved in environmental campaigns and/or that there is no relation and they work independently, while most of the key informants give an intermediate to medium high value to this relation. stating that there is such a relation; however it is still not sufficient. Since this can be a difficult indicator to prove directly or to triangulate (considering that if it exists, it is probably not documented), it comes to a higher importance what key informants related to this particular aspects and areas can say about this topic. In a future applications of the IWM standard will perhaps not only consider the importance of the indicator for a weighted average, but a weight for “experience on a subject” could be considered also for each indicator given the experience and knowledge of the key informant on particular areas. As a side comment, for indicator 2.3.3, it was precisely people working in health and environmental subjects that gave similar values to the indicator. A further challenge in improving the standard could be to find a way to express these differences and coincidences.

Results for IWM assessment can be interpreted by indicator or by global qualification. Each indicator’s final qualification can say important things about how management is happening in the watershed and specify problem areas and issues. If combined with some other information like the one obtained from the socio-environmental conflict analysis or any other information available from literature review. It is important to notice that a global qualification is simply the result of adding individual values obtained by the indicators and it can be deceiving if not accompanied with more information to explain it.

8.5 A different evaluation range

When the first application of the IWM standard was done in Honduras by Musalem*, et al.* (2006), Indicators were evaluated according to a series of descriptors. Each key-informant would choose the best descriptor that would apply to the reality in the watershed. Afterwards, this information was transformed into discrete values ranging from 1 to 4. This led to the wrong perception that when an indicator was qualified with a very low value, it would reflect as not the lowest possible option, causing some confusion in graphs and interpretation. For the current study, the range was changed from 0 to 3, including zero as a possibility for very low qualified indicators. Nevertheless, all ranges of interpretation of the values for this study were adapted to this difference in range.

When this standard was applied in Honduras by Musalem, Jiménez, Faustino and Astorga (2006), a Global Qualification was determined as of 58 % of the total possible qualification. As a second experience, this shows how the example of the Sesesmiles River Watershed experience had advances probably derived from actions of the FOCUENCAS II Program “Innovation, learning and communication for the adaptation and co-management in watersheds” that began in October 2004, although latest publications by Kammerbauer, Leon, Castellon, Gomez, Gonzalez, Faustino and Prins (2009) show even much better results in the latest years (standard was applied in Sesesmiles in 2005).

8.6 DRASTIC and GOD

From this comparative exercise, it is noticed how DRASTIC results show a wider distribution of values, probably derived from the higher number of parameters (7) compared to the GOD model (3), also that the heterogeneity of values used for the DRASTIC model was much higher, than those used for the GOD model, Similar remarks were made by Agüero*, et al.* (2002) while discussing their experience in applying the same models in the Central Valley of Costa Rica. Agüero*, et al.* (2002)

compared the GOD and DRASTIC models in Costa Rica. Considering both models, differences about the methods were made regarding use, data collection and simplicity of the models. Agüero and Pujol found similar vulnerability values with both models, and showed capable of determining intrinsic vulnerability in a similar manner.

The DRASTIC model has been used worldwide to determine aquifer intrinsic vulnerability; however, a constant discussion is the relation of the DRASTIC index with the real pollution found in the aquifer. Leone, Ripa, Uricchio, Deak and Vargay (2009) after studying the vulnerability and risk evaluation of agricultural nitrogen pollution for Hungary's main aquifer using DRASTIC and GLEAMS models conclude that since "DRASTIC is a parameter/qualitative method, the correlation is low, but significant. In fact, what is really significant in the DRASTIC performance evaluation is the general correspondence of trends, which means a correspondence between higher nitrate content and higher DRASTIC scores." This is not necessarily true for all areas where this and other pollutants have been sought.

According to Rupert (1999), "The DRASTIC method has been used to develop groundwater vulnerability maps in many parts of the United States; however, the effectiveness of the method has met with mixed success - Koterba and others (1993), U.S. Environmental Protection Agency (1993), Barbash and Resek (1996), Rupert (1997)- DRASTIC maps usually are not calibrated to measure contaminant concentrations." Rupert also suggests improvements to the DRASTIC

Groundwater vulnerability mapping by calibrating the rating scheme to measured nitrite plus nitrate as nitrogen. However, DRASTIC still can be considered a first approach to GVP, specifically when information is limited or when the vulnerability concept does not include only a particular pollutant threat or risk but as described by Lobo-Ferreira*, et al.* (1997) “vulnerability is the one that refers to the intrinsic characteristics of the aquifer, which are relatively static and beyond human control”. The same authors concluded after work in Portugal that although specific vulnerability mapping is scientifically sounder, it must be realized that there will generally be insufficient data available to perform specific vulnerability mapping.

The only area where a similar study was found to place in similar conditions in Paraguay is the Capiibary River Watershed in Itapua as reported by Laino (2005), also neighbouring watershed and draining to the Parana River. The results in such area however are not comparable considering the presence of not only basaltic geology but also sandstones which are theoretically a direct recharge area of the Guarani Aquifer in the Guarani Aquifer System and containing different hidrogeological characteristics. Laino discusses how each of the variables can be obtained through different procedures, with different levels of precision, certainty and confidence.

This particular research objective can be seen as corresponding with recommendations by United Nations Educational Scientific and Cultural Organization (UNESCO) (2006) which states that “Groundwater resources can, in many instances, supplement surface water, particularly as a source of drinking water. However, in many cases, these aquifers are being tapped at an unsustainable rate or affected by pollution. More attention should be paid to sustainable management of non-renewable groundwater." This study generates a knowledge tool about the watersheds that will provide with information and justification on possible management activities and decision making. As put by Gogu*, et al.* (2000) "the concept of groundwater vulnerability is a useful tool for environmental planning and decision-making (…) and that applying different methods to the same zone and using the same data showed that the relatively simple methods could provide similar results to the complex ones."

Since DRASTIC and GOD are a first step to assessing groundwater vulnerability to pollution and considering that literature review suggests reconfirming data with pollution values of specific pollutants and risks, a validation of the model at the local level is suggested for future research. This implies a much greater analysis of groundwater quality and monitoring in the area.

8.7 What makes the difference in DRASTIC?

The DRASTIC outcome maps, show patterns that are not at all easily related visually to the income data: in other words, it is difficult to understand at a first instance, which of the 7 parameters are influencing more in the final relative differences in the outcome and the relative distribution of the vulnerability classes within the Watersheds. In an attempt to understand this, a correlation matrix was constructed with the use of the Band Statistics tool within ArcGis 9.3 Software. The correlation presented here indicates the strength and direction of a linear relationship between two variables (Table 31). DRASTIC-nc map was used for this correlation.

Table 31. Correlation matrix of the seven DRASTIC-nc layers and the final outcome map (DRASTIC-nc, see Section 7.5 for details). Correlation matrix run with all data n = 63915. All values significative, red values mark high correlations.

	D	R	A	S	T	I	C	DRASTIC
D	1.00	0.24	-0.24	0.40	0.11	-0.24	0.00	0.84
R		1.00	-1.00	0.37	0.09	-1.00	0.00	0.36
A			1.00	-0.36	-0.09	1.00	0.00	-0.36
S				1.00	0.16	-0.36	0.00	0.65
T					1.00	-0.09	0.00	0.54
I						1.00	0.00	-0.36
C							1.00	0.00
DRASTIC								1.00

For the particular values used in this research to apply the DRASTIC model, the correlation matrix shows a stronger correlation between the final DRASTIC outcome with Depth to Water, Soil Media, and Topography (0.84, 0.65, and 0.54). In an opposite side, the final outcome is less correlated to hidraulic conductivity, impact of the vadose zone, aquifer media and net recharge. Parameters with higher correlation values are more heterogeneous in the watersheds and thus create more differences in the final map, low correlation values show, in the other hand, very homogeneous data for the whole Watersheds and affect less in the final map and relative differences in the outcome map. An absolute correlation is found with parameters R and A, R and I and A and I, this parameters were inferred from geology in the area (Impact of the vadose zone was also confirmed data from wells) and thus were expected to be strongly correlated. A value of 0 correlation found in hydraulic conductivity is explained by a constant value used for the whole area of the Watersheds, the correlation coefficient remains undefined.

This particular correlation helps understand which values are having more significance in the final DRASTIC outcome map. Since some data is relatively homogeneous in the watersheds, they become of poor interest to separate the most and least vulnerable areas within the watersheds, while other more heterogeneous data help separate maximum and lower vulnerability areas in the watersheds. The reason each dataset was similar within the watersheds or that it had fewer values (2 or 3) or more heterogeneous values depends mostly on scale, availability of data and/or the information used to estimate the value for each parameter

8.8 Model precision and data availability.

Section 2.5 about the Guarani Aquifer which also includes a literature review about groundwater vulnerability models, more specifically on DRASTIC, mention how the precision of the models vary according to different interpretations and data input. Some authors find information on groundwater vulnerability as a useful tool, others have worked on specific pollutants or seeking the relationship between estimated *vulnerability* and real pollution or measured pollution. A high vulnerability value (for example) does not imply that the pollution has occurred or that it will definitely occur, It does suggest, however, that pesticide (or other pollutants) leaching and contaminating groundwater is more or less likely to occur considering the hidro-geological characteristics of the study area.

A second concern when using a model, besides its effectiveness, or the use that will be given to the outcome has to do with scale. Models DRASTIC and GOD have been used, tried and developed at many scales, in cities, regions, countries, watersheds, parks, etc. Scale is also related to the quality of the data and the information available. In the case of the Mboi Cae and Quiteria Watersheds, while some information was found to be heterogeneous (depth to water) other was homogeneous (hydraulic conductivity was a same value for all the study area) this was caused by different levels of detail in the information that was available for each parameter. Also some conditions *per se* are more heterogeneous that others. For example it is expected that geological conditions to be more similar in a small area like the one covered by our subject watersheds, not so in a larger area.

With these considerations in mind, it becomes necessary to express that at our best capacity, time, and resources, the data used for the models was the best available within local knowledge, publications and resources. Data for the models was obtained mainly from work by other researchers; some information had to be *estimated* when exact information was not found. The data presented with each of the parameters shows where and how this information was calculated and or assumed. However, as more detailed information is available in the future, better data quality could be used to arrive to better estimations than the one presented here.

8.9 Why so many vulnerability maps?

The results of this work show different vulnerability maps that were obtained as an outcome of the application of the DRASTIC and GOD models. DRASTIC has been used as a method for determining groundwater vulnerability to pollution in several conditions, however, the interpretation of the DRASTIC map has been subject of various research and discussion, ranging from its application, data collection, to its visualization, interpretation and effects on policy making. For example, Bojórquez-Tapia, Cruz-Bello, Luna-González, Juárez and Ortiz-Pérez (2009) have pointed out the importance of leading DRASTIC to a better policy making through the generalization of the DRASTIC outcome based upon psychophysics' principles (a theory that describes the people's response to a stimulus) to generate alternative groundwater vulnerability categorization schemes (V-DRASTIC). Other researchers like Gogu*, et al.* (2000) have used DRASTIC to provide with information that can lead to policy-making and decision for the need of protection of the aquifer in certain areas. The following list is a summary of the presented DRASTIC maps in this document. All DRASTIC maps in this research used pesticide ratings.

- DRASTIC relative vulnerability map. Shows the most vulnerable and least vulnerable areas within the Watersheds.
- DRASTIC classified by National US Colour code. Shows the vulnerable areas in a recognizable colour scheme easily comparable with other DRASTIC maps in literature.
- DRASTIC-nc classified by National US colour code and using alternative soil (nc - no cities). Shows vulnerability when cities are not considered as a direct pollution source and not taken into account in the outcome map.
- DRASTIC all values, not classified. Shows all the range of values with the maximum possibility of contrast.
- DRASTIC predictive map. Shows the DRASTIC vulnerability maps if certain values are changed in scenario building considering the change in water level.
- GOD map. A comparative map of aquifer vulnerability using the GOD model.

8.10 Differences in perception and reality

A particular item that did not show consistency and that may lead to correction of the standard and its application in future occasions is water quality. While the application of the standard in Mboi Cae and Quiteria resulted in an “intermediate level of pollution” in water streams (Indicator 4.1.1 some evidence of sediments and pollutants in water streams). Information found in literature review like the one by Paez (2003) reports a much higher level of pollution in water, reporting it as unsuitable for any use.

To understand these differences, the following are some proposed ideas that could eventually explain the lack of consistency in this particular subject:

- Water quality analysis are based in samples taken in the lower parts of the watersheds, close or near urban areas (a map of this affirmation can be seen in Paez 2003 and could not be copied as reference for this document). This may contrast with the particular view of key informants as well as the Watershed Council that might be considering middle and higher parts of the Mboi Cae and Quiteria Rivers.

- When asked about water quality, key-informants could be relating the question to available water for human consumption, which is usually extracted from wells of the Basalt Aquifer from the Guarani Aquifer System.
- The Mboi Cae and Quiteria Rivers eventually derive their waters to the Parana River which has a much bigger flow, volume, and diluting capacity of pollutants. This might reduce the "perception of importance" of these rivers in the overall pollution in the Yacyreta Lake.

8.11 Similarities in perception and reality

Concurring information appeared in two of the main results of this study:

- In the workshop with the Watershed Council: Deforestation and loss of riparian forests and protective vegetation in rivers and water sources
- In the application of the standard: Indicators 5.1.1. Reduced buffer zones next to rivers and 1.2.1 Low level of protection of conservation areas.

As an example of triangulation of this information using other data than the one collected in the previously mentioned methodologies, a GIS procedure was followed to review the particular situation using similar methodology as the one applied by Dose (2009) in the Capiibary river in Paraguay. Having obtained information about vegetation in the Watersheds from Guyra Paraguay (vegetation map), a buffer area was delimited around the rivers and tributaries of the Mboi Cae and Quiteria. The buffer area was constructed using Paraguay Laws which define a minimum 100 m width protection fringe.

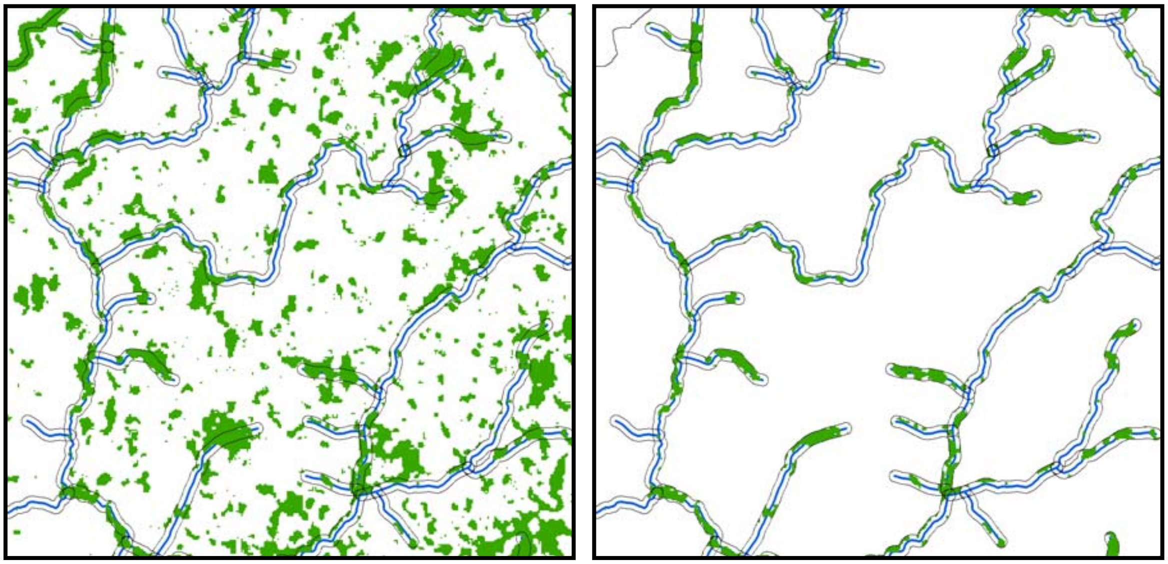


Figure 50. Delimitation of the minimum protective fringe for rivers (according to current local laws) of 100 m (on each side) of a section of the Mboi Cae River, used to measure forest cover and compliance with current laws.

After this procedure was completed, measurements were done to determine how much of the rivers actually had the minimum required protective fringe. Results reported in this study for Mboi Cae is of only a 26 % of protective fringe and Quiteria: 24 %. While this is just approximation using available information about vegetation and rivers compiled during the state of knowledge analysis, it certainly shows that perceptions by the Watershed Council and key-informants, in this case, are close to what can be determined by GIS procedures. This result is lower than any found by Dose (2009) where values ranged from 30 % to 56 % in Capiibary River Watershed (neighbouring watershed) while determining the percentage of forest cover compliance with National laws, and is probably derived from the differences in population density.

8.12 A national conflict not considered as one locally

It is unavoidable to notice that the impact and importance of the socio-environmental conflict originated from the finalization of the filling of the Yacyreta dam, at the local level, and from the results of this workshop, was considered one of the least prioritized conflicts in the area. It is of interest to see how the many concerns of the rising of the Yacyreta Dam are of less interest compared to others such as soil pollution, deforestation of riparian areas, water pollution and health related problems to any of these. Referring to literature from Africa Peace Forum*, et al.* (2004) “Conflict-sensitive approaches to development, humanitarian assistance and peace building”, specifies that “Conflict analysis can be carried out at various levels (eg. local, regional, national, etc) and seeks to establish the linkages between these levels. Identifying the appropriate focus for the conflict analysis is crucial: the issues and dynamics at the national level may be different from those at the grassroots.”

The question arises on why this particular problem is not considered as important and only possible conjectures can be presented here as comments made by key-informants:

- Tiredness: Yacyreta Dam has been influencing the area for more than 30 years: Local population perceives it now not as a conflict but as a project that should be finished as soon as possible and that all preparation on infrastructure has taken too long. Most of the project is finished and local population would like necessary infrastructure to be accelerated.
- Lack of trust: Displaced and or affected social movements are not trusted locally or nationally as genuine. Some are said to be manipulated by political parties or to be used by free-riders to obtain benefits from the social conflict.

- The Argentinian example. Just across the border, the evidence of the highly advanced project in the Argentinian side in Posadas, regarding the construction of streets and the arrangements in the bordering city is a notorious contrast with the Paraguayan City of Encarnacion which is still in a construction phase and dealing with irregular settlements.
- More good things than bad. The project offers more opportunities of an organized local development than without the project. Both rurally and in the cities.
- The problem only affects the city in the lower floodable parts of the Watersheds and those who are living there.

The impact of the Yacyreta dam at the local level, mainly the problems derived from displacement have been subject of studies such as the one carried out by Ferradas (1997) . Ferradas' main conclusion after examining the practice of anthropologists and other social scientists in the relocation process is that in the specific case of Yacyreta, "although programs and plans of social action claim to pursue structural transformations, they generally do not achieve those goals, and only operate at a symbolic level which represents the professional, class, and regional ideologies of the development practitioners". The new approach taken by the Yacyreta Binational Entity (roughly at the beginning of this research in 2007), by facilitating the IWM process in coordination with local and national institutions and with the participation of stakeholders could perhaps offer a new local perception on water and environmental issues and its link with the Yacyreta Dam. The Watershed Committee as a centre of change in vision where the necessary communication channels to address all water and environmental related problems is open can become a strong instrument to improve the local sustainable management of water resources.

9 Conclusions

How much is known about the watersheds? What information is available and which is still missing to reach proper characterization of the watersheds of the Mboi Cae and Quiteria Rivers? Where is the available information?

Summarising all available information in the state of knowledge and available information table shows that many elements have been covered by this study and by parallel studies and work in the Watersheds approaching a characterization. Even though this information could not be compared to previous availability, it is noticeable that most of the information has been generated in the past two years, with the exception of demographics and information provided or obtained by the National Census by Dirección General de Estadística Encuestas y Censos (2002). The state of knowledge stage was also useful and determinant in the capacity of applying the DRASTIC and GOD models for aquifer vulnerability to pollution, providing with all the information necessary. In the other hand it is noticed that much of the information is still provided at the municipal level and that some of the presented data (Global Consultores) was calculated according to the presence of the Municipalities in the Watersheds, which cannot be considered a highly precise measurement.

Which are the main socio-environmental conflicts of the Watersheds and their possible solutions from the Watershed Council perspective? How are the identified conflicts linked with the present research?

The main socio-environmental conflicts were identified as being basically those related to deforestation, lack of conservation of riparian conservation areas; also, pollution of soil and water and soil degradation by malpractices in agriculture; health related problems to pollution of water and soil and environmental degradation and finally problems derived from solid wastes and their insufficient treatment and deposition. At the same time, the Watershed Council was capable of analysing these prioritized problems and proposed a set of strategies according to its legal competence. It is intended that this research will help the Watershed Council in the future to justify actions in the Watersheds.

The identified conflicts were found to be concurrent with results from other different parts of the research, basic triangulation of information from the conflict analysis, the IWM conflict, and the first state of knowledge and available information phase was done, identifying consistencies and discrepancies in the results and discussing them in their details.

Which is IWM level reached in the Watersheds of the Mboi Cae and Quiteria Rivers so far, according to the IWM standard?

The IWM standard shows that even though there has been work in the last couple of yeas regarding IWM, it has approximately covered a 35 % of the total possible qualification. Taking into account that processes of management show results in the long term, it is probably the beginning of this process and the current level of advancement that is being represented in the obtained Global Qualification. The differences in information and the general situation of the Watersheds have been reported through the research and probably help explain this level of advancement.

The IWM standard or certification scheme should continue its adaptation process, collecting as much information as possible of its use, errors, problems, applications, and advantages. In some particular indicators, such as water quality (which in this study indicated differences in opinions contrasting with chemical analysis) a thorough reconsideration should be made on how to present the information to key-informants or how the question should be formulated. A possible solution could be to separate the Indicator about water quality into different indicators (high, middle and low parts of the watershed) another for water bodies (lakes, lagoons, coastal areas) and thirdly about potable water, supplying water systems and water for human consumption. This separation could allow the key-informant to consider water quality not as an overall characteristic and also allowing making comparisons with available specific water analysis.

Not only was a Global Qualification obtained from this particular application of the IWM standard, also a set of individually qualified indicators helped determine areas that need critical advancement, or on the other hand, areas that have reached a good (or better) level of advancement. The IWM captured a moment of the conditions of the Watersheds, and perhaps in some months or years these conditions can change. Updates can be made regularly, thus, converting the IWM standard in a dynamic tool to help the Watershed Council and institutions review advancements over time.

What is the current vulnerability of pollution to the aquifer in the watersheds of the Mboi Cae and Quiteria Rivers? What will the differences be when using different models?

Aquifer vulnerability to pollution was found to be intermediate-high similarly using both DRASTIC and GOD models. Higher vulnerability values were found towards the lower parts of the study area with both models showing similar descriptors and values in the respective scales. Most of the differences in values between vulnerable and non vulnerable areas were given by geology and depth to water contrasts in the watersheds. A medium to high vulnerability to pollution level shows that concerns about pollution of the aquifer in the midterm are real and should be considered to instrument possible programs dedicated to the minimization of contaminants in agriculture, but also, since the highest vulnerability areas are located in the lower parts of the watersheds, where urban areas are settled, it is important to identify pollution sources in urban areas as an important (and possibly major) threat to the Basalt Aquifer firstly (where most water is extracted for human consumption in the area) and secondly into the Guarani Aquifer System.

What is the predicted change in groundwater vulnerability to pollution after the water level changes?

Given the complexity of the hydrogeological conditions in the area of the Watersheds, as well as insufficient data to determine precise effect of the change in water level to the aquifer (despite efforts by Lotti and desacreditation by Auge of Lotti's research) a scenario-approach was taken to show possible effects of the change of water level in groundwater vulnerability: the worst case scenario, defined as an increase of 5 meters to the water table (meaning a reduction in DRASTIC parameter D "Depth to water") was used to visualize, compare and quantify proportionally to current vulnerability. Results show that areas with very high vulnerability will increment in over 14 %, moving the higher vulnerabilities not only to the lower parts of the Watersheds, but to the middle areas including areas where soybean is produced intensively. This increase in vulnerability suggests the need of considering protection of the aquifer especially regarding the use of agrochemicals and intensive soy production. Even though efforts have been made at the local level to reduce the impact of soybean and sunflower production, the increase in vulnerability to pollution of the aquifer should be directed to stronger actions to prevent it. Local increase in vulnerability and the intensive soybean production could affect the shallow aquifers where water is extracted for local population and further to the Guarani Aquifer System through dripping to the deep sandstone aquifer.

As a recommendation of this research, after acknowledging the possible limitations of the use of models and also the advantages to determine intrinsic vulnerability to aquifer that these provide in a simplified manner, a possible framework of strategies for considerations to protect aquifer vulnerability can be extracted from work by de Loe and Kreutzwiser (2005). Some of the strategies proposed by the previously mentioned authors are technical, financial, social, economical and political. While this work brings a clear suggestion to groundwater protection mainly focused in the lower half of the Mboi Cae and Quiteria watersheds, the definition of strategies of protection of the aquifer should be a wider and recommended work to be carried out in the area. It is necessary that Yacyreta Binational Entity considers the increase of vulnerability as a possible effect of the dam and should seek to reanalyze it once the water level after the filling of the dam is concluded and to take necessary precautions and protection of the aquifer in the context of the minimization of the impacts of the dam and the improvement (or maintenance) of water quality.

10 Cited literature

Africa Peace Forum, Center for Conflict Resolution, Consortium of Humanitarian Agencies, Forum on Early Warning and Early Response, International Alert, and Saferworld 2004. Conflict-sensitive approaches to development, humanitarian assistance and peace building: Chapter 2 Conflict analysis. 40 p.

Agüero, J. and Pujol, R. 2002. *Análisis de vulnerabilidad a la contaminación de una sección de los acuíferos del Valle Central de Costa Rica* (Vulnerability analysis to pollution in the Valle Central aquifers in Costa Rica). Tesis Ing., Ingeniería Civil. University of Costa Rica. San Jose. 195 p.

Aller, L., Bennett, T., Lehr, J., Petty, R., and Hacket, G. 1987. DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings. 600/2-87/035. Dublin, Ohio. 455 p.

Bergkamp, G., Orlando, B., and Burton, I. 2003. Change. Adaptation of water management to climate change. UICN. Gland, Switzerland and Cambridge, UK. 53 p.

Blomquist, W. and Schlager, E. 2005. Political pitfalls of integrated watershed management. Society & Natural Resources 18:2, 101-117. DOI: 10.1080/08941920590894435.

Bojórquez-Tapia, L.A., Cruz-Bello, G.M., Luna-González, L., Juárez, L., and Ortiz-Pérez, M.A. 2009. V-DRASTIC: Using visualization to engage policymakers in groundwater vulnerability assessment. Journal of Hydrology. 373(1-2): pp. 242.

Bonnell, M. 2004. How do we move from ideas to action? The role of the HELP programme. International Journal of Water Resources Development. 20: pp. 3,283 — 296.

Cabral, A. 2005. *Uso sustentable del Sistema Acuífero Guarani* (Sustainable use of the Guarani Aquifer System). Informe del Proyecto. SAG-PY. Asuncion, Paraguay. 11 p.

Ceballos, R.P. and Avila, J.P. 2004. *Vulnerabilidad del agua subterránea a la contaminación en el Estado de Yucatán* (Groundwater vulnerability to pollution in Yucatan State). Ingeniería Revista Académica. 8(1): pp. 33-42.

Chowdhury, S., Iqbal, M., and Szabo, J. 2003. Comprehensive approach of groundwater resource evaluation: a case study in the Chippewa Creek watershed in Ohio. Ohio Journal of Science. 103(5): pp. 134-142.

Clay, J. 2004. World agriculture and the environment: a commodity to commodity guide to impacts and practice. Washington. Island Press - World Wildlife Fund. 194 p.

Cucchi, F., Forti, P., and Zini, L. 2004. The vulnerability of complex karst hydrostructures: Problems and perspectives. Geofisica Internacional. 43(4): pp. 8.

de Loe, R.C. and Kreutzwiser, R.D. 2005. Closing the groundwater protection implementation gap. Geoforum. 36(2): pp. 241-256.

Dirección General de Estadística Encuestas y Censos 2002. *Censo Nacional* (Paraguay Census). Asunción. Secretaria Tecnica de Planificacion. 117 p.

Dose, E. 2009. Caracterización, evaluación y diagnóstico de los recursos naturales como base para proponer un Plan de Manejo de los recursos hídricos en la Cuenca del Aº Capiibary. Thesis Ing. Agr., Facultad de Ciencias Agropecuarias. Universidad Católica "Nuestra Señora de la Asunción". Hohenau, Paraguay. 196 p.

Fariña, S. 2009. Environmental Protection and Sustainable Development of the Guaraní Aquifer System VOL 2. SAG- PY Geology and Hydrogeology. Asuncion. 31 p.

Fariña, S., Vassolo, S., Cabral, N., Vera, S., and Jara, S. 2004. *Caracterización hidrogeológica e hidrogeoquímica del Sistema Acuífero Guaraní* (Hidrogeological and hidrochemical characterization of the Guarani Aquifer System). *In* XIII Congresso Brasileiro de Águas Subterráneas (ABAS). (2004, Cuiaba). pp.

Ferradas, C.A. 1997. From vegetable gardens to flower gardens: The symbolic construction of social mobility in a development project. Human Organization. 56(4): pp. 450-461.

Food and Agriculture Organization of the United Nations, European Observatory of Mountain Forests, International Centre for Integrated Mountain Development, and Red Latinoamericana de Cooperación Técnica en Manejo de Cuencas Hidrográficas 2006. The new generation of watershed management programmes and projects: a resource book for practitioners and local decision-makers based on the findings and recommendations of a FAO review, ed. Food & Agriculture Org. Vol. 150. 128 p.

Foster, S., Hirata, R., Gomez, D., D'Elia, M., and Paris, M. 2002. Groundwater Quality Protection:a guide for water utilities, municipal authorities, and environment agencies, ed. Groundwater Management Advisory Team (GW MATE). Washington DC. 104 p.

Foster, S., Kemper, K., Garduño, H., Hirata, R., and Nanni, M. 2006. The Guarani Aquifer Initiative for Transboundary Groundwater Management. 2nd ed. World Bank. 20 p.

Geilfus, F. 1987. *80 Herramientas para el desarrollo participativo* (80 Tools for participative development), ed. Prochalate–IICA. San Salvador, El Salvador. 208 p.

Gerasidi, A., Apostolaki, S., Manoli, E., Assimacopoulos, D., and Vlachos, E. 2009. Towards the formulation of a new strategy of water resource management for urban areas achieved through participatory processes. Urban Water Journal. 6(3): pp. 209-219.

Ghanbarpour, R., Hipel, K.W., and Abbaspour, K.C. 2005. Prioritizing long-term watershed management strategies using group decision analysis. International Journal of Water Resources Development. 21: pp. 2,297 — 309.

Global Consultores 2008. *Gestión Integrada de las Cuencas: Vision Diagnóstica de los escenarios* (Integrated management of the Mboi Cae and Quiteria watersheds: Diagnosis of the watersheds scenarios). Entidad Binacional Yacyreta (EBY). Encarnación. 332 p.

Gogu, R. and Dassargues, A. 2000. Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. Environmental Geology 39:6, 549-559. DOI: 10.1007/s002540050466.

Gonzalez, E. 2005. *Proyecto Piloto Itapúa - Paraguay: Proyecto de Proteccion Ambiental y Desarrollo Sostenible del Sistema Acuifero Guarani.* (Pilot Project Itapúa - Paraguay: Environmental protection and sustainable development of the Guarani Aquifer System Project) Unedited, Unpublished. Environmental Secretariat of Paraguay (SEAM). 58 p.

Hardy, S.D. and Koontz, T.M. 2009. Rules for Collaboration: Institutional Analysis of Group Membership and Levels of Action in Watershed Partnerships. Policy Studies Journal. 37(3): pp. 393-414.

Heathcoate, I. 1997. Integrated Watershed Management. New York. John Wiley & Sons. 402 p.

Jimenez, F. 2004. *La cuenca hidrográfica como unidad de planificación, manejo y gestión de los recursos naturales* (Watershed as a unit for planification, and management of natural resources) Notes from Integrated Watershed Management Course. CATIE: Turrialba. 60 p.

Kammerbauer, H., Leon, J., Castellon, N., Gomez, S., Gonzalez, J.M., Faustino, J., and Prins, K. 2009. Plataformas de concertación: una apuesta por la gobernabilidad local en cuencas hidrográficas, experiencias y lecciones aprendidas por el programa Focuencas II en Honduras y Nicaragua, ed. CATIE. Tegucigalpa, Honduras. 71 p.

Kirby, M., Kidd, W., Koubel, F., Barter, J., Hope, T., Kirton, A., Madry, N., Manning, P., and Triggs, K. 2000. Sociology in Perspective. AQA (Assessment and Qualifications Alliance). UK. Heinemann. 831 p.

Külls, C. 2003. Groundwater recharge of the Guarani Aquifer. Previous investigations, estimation methods and recommendations. 19 p.

Laino, R. 2005. *Manejo del recurso hídrico en la cuenca del Arroyo Capiibary: implicaciones para la gestión ambiental del Acuífero Guaraní* (Management of water resources in the watershed of the Capiibary river: implications for the environmental development of the Guarani Aquifer). Tesis Mag. Sc., Tropical Agricultural Research and Higher Education Center (CATIE). Turrialba, Costa Rica. 104 p.

Laino, R., Jiménez, F., Velázquez, S., Paez, G., and Casanoves, F. 2006. *Manejo del recurso hidrico y vulnerabilidad a la contaminacion del acuifero Guarani en la cuenca del Arroyo Capiibary, Paraguay* (Management water resources and pollution vulnerability of the Guarani aquifer in the watershed of the Capiibary river). Recursos Naturales y Ambiente. (48): pp. 65-74.

Leone, A., Ripa, M.N., Uricchio, V., Deak, J., and Vargay, Z. 2009. Vulnerability and risk evaluation of agricultural nitrogen pollution for Hungary's main aquifer using DRASTIC and GLEAMS models. Journal Of Environmental Management. 90(10): pp. 2969-2978.

Levinton, N. 2007. Yacyretá, una nueva significación: la relación entre espacio y sociedad como consecuencia de la implementación de un megaproyecto. Buenos Aires. Entidad Binacional Yacyreta. 288 p.

Limia, M. 2000. *Construcción de escenarios de cambio climatico para Paraguay* (Construction of climate change scenarios for Paraguay). Programa Nacional de Cambio Climático. Dirección de Ordenamiento Ambiental - Subsecretaria de Recursos Naturales y Ambiente - Ministerio de Agricultura y Ganadería. Asunción. 13 p.

Lobo-Ferreira, J. and Oliveira, M. 1997. Drastic groundwater vulnerability mapping of Portugal. *In* Groundwater: an endangered resource: 27th Congress of the International Association for Hydraulic Research. (1997, San Francisco, USA). 132-137 pp.

Lotti-Associatti 1999. *Estudio hidrogeológico, topográfico y geotécnico del area de Posadas, Garupa y Encarnación* (Hydrogeological, topographical and geotechnical study of Posadas, Garupa and Encarnación):Executive Summary. Y.B. Entity. Rome. 26 p.

Lubell, M. 2004. Collaborative Watershed Management: A View from the Grassroots. Policy Studies Journal. 32(3): pp. 341-361.

Meichtry, N., Llano, V., and Martens, S. 2006. *Estructura de la comunidad fitoplanctónica del embalse Yacyreta y su relación con variables limnológicas*. (Structure of fitoplankton communities in the Yacyreta reservor and their relationship with limnological variables). Electronic Document. *In* Cuarto Congreso Argentino de Presas y Aprovechamientos Hidroeléctricos: Comite Argentino de Presas. (2006, Posadas, Argentina). 15 pp.

Molle, F. 2009. River-basin planning and management: The social life of a concept. Geoforum. 40(3): pp. 484-494.

Musalem, K. 2005. *Propuesta Metodologica para la certificación del manejo integrado de cuencas en América Tropical* (Methodological proposal for integrated watershed management certification in tropical America). Tesis Mag. Sc., Centro Agronómico Tropical de Investigaciones y Enseñanza. Turrialba. 96 p.

Musalem, K., Jiménez, F., Faustino, J., and Astorga, Y. 2006. *Certificación del manejo integrado de cuencas en América Tropical. Parte 1: Estándar propuesto.* (Certification of integrated watershed management in tropical America Part 1: proposed standard). Recursos Naturales y Ambiente. 48: pp. 22-28.

________ 2006. Certificación del manejo integrado de cuencas en América Tropical. Parte 2: Estudio de caso en la microcuenca Sesesmiles en Copán Honduras. (Certification of integrated watershed management in tropical America Part 2: study case in Sesesmiles, Copán, Honduras). Recursos Naturales y Ambiente. 48: pp. 22-28.

Napolitano, P. and Fabbri, A. 1996. Single-parameter sensitivity analysis for aquifer vulnerability assessment using DRASTIC and SINTACS. *In* HydroGIS 96: Application of Geographic Information Systems in Hydrology and Water Resouces Management: Proceedings of the Vienna Conference. (1996). 559-566 pp.

Obando, F. 2005. Situación del recurso hídrico subterráneo de la subcuenca del río Aguas Calientes, Nicaragua. Undeground water resources situation of the Aguas Calientes River Watershed, Nicaragua. Tropical Agricultural Research and Higher Education Center (CATIE). Turrialba, Costa Rica. 111 p.

Oporto, O. and Vassolo, S. 2003. *Aguas Subterráneas - El Acuífero Guaraní* (Groundwater - Guarani Aquifer). SAG-PY Boletin No 1. Asuncion. Dirección General de Protección y Conservación de los Recursos Hídricos - Secretaria del Ambiente (SEAM). 13 p.

Paez, C. 2003. *Calidad de aguas en arroyos urbanos de Encarnación* (Water quality in urban rivers of Encarnacion). Y.B. Entity. Ayolas, Paraguay. 64 p.

Patton, M. 1990. Designing qualitative studies in Qualitative evaluation and research methods, Sage. California. pp. 169-186.

Ramakrishna 1997. Estrategias de extensión para el manejo integrado de cuencas hidrográficas: conceptos y experiencias, ed. Proyecto IICA/GTZ. San José, Costa Rica. 319 p.

Revenga, C., Murray, S., Abramovitz, J., and Hammond, A. 1998. Watersheds of the World: ecological value and vulnerability. World Resources Institute: Washington, DC

Rupert, M. 1999. Improvements to the DRASTIC Ground-Water Vulnerability Mapping Method. USGS Fact Sheet FS–066–99, ed. N.W.-q.A.P. NAWQA. Boise, Idaho. U.S. Geological Survey. 6 p.

Sadoff, C.W. and Muller, M. 2009. Better water resources management – Greater resilience today, more effective adaptation tomorrow. Perspectives on water and climate change adaptation, ed. Global Water Partnership. Co-operative Programme on Water and Climate. 13 p.

Samra, J. and Eswaran, H. 2000. Challenges in ecosystem management in a watershed context in Asia in Integrated Watershed Management in the Global Ecosystem Toronto, Canada. pp. 19-32.

Schmidt, G. 2009. *Uso sostenible del Sistema Acuífero Guaraní en la Región Oriental del Paraguay* (Sustainable use of the Guaraní Aquifer System in Eastern Region of Paraguay). Vol. 1 Generalities and Summary. Hannover and Asuncion. BGR and Paraguayan Environment Secretariat (SEAM) SAG-PY. 21 p.

Shahid, S. 2000. A study of groundwater pollution vulnerability using DRASTIC/GIS, West Bengal, India. Journal of Environmental Hydrology. (8): pp. 9.

Soil Survey Staff 2006. Keys to Soil Taxonomy, 10th ed. USDA-Natural Resources Conservation Service. Washington, DC. 325 p.

Sullivan, C. and Meigh, J. 2007. Integration of the biophysical and social sciences using indicator approach: addressing water problems at different scales in Integrated assesment of water resources and global change: a North-South Analysis, Springer. Dordrecht, The Netherlands. pp. 111-128.

Tilt, B., Braun, Y., and He, D.M. 2009. Social impacts of large dam projects: A comparison of international case studies and implications for best practice. Journal Of Environmental Management. 90: pp. S249-S257.

Tortajada, C. 2001. Institutions for Integrated River Basin Management in Latin America. Water Resources Development. 7(3): pp. 289–301.

Trevisan, M., Padovani, L., and Capri, E. Assessment of potential risk groundwater pollution from agricultural non-point sources. Ist. di Chimica Agraria ed Ambientale - Sez. Chimica Vegetale n/a [accesed August 2009]; Available from: http://www4.unicatt.it/icaa/docs/Trevisan.pdf.

United Nations Educational Scientific and Cultural Organization (UNESCO) 2006. Water: a shared responsability. The United Nations World Water Development Report 2. Paris, France. 601 p.

Vazquez, M. 2000. *Construcción de escenarios de cambio climatico* (Climate change scenario construction). Asunción. 36 p.

Vignola, R. 2005. Fortalecimiento de instrumentos decisionales para la provisión de agua para consumo humano en El Salvador. Mag. Sc., Tropical Agricultural Research and Higher Education Center (CATIE). Turrialba, Costa Rica. 174 p.

Watler, W. 2008. Análisis de vulnerabilidad a la contaminación del recurso hídrico en al subcuenca del Río Siquirres, Costa Rica. Tropical Agricultural Research and Higher Education Center (CATIE). Turrialba, Costa Rica. 212 p.

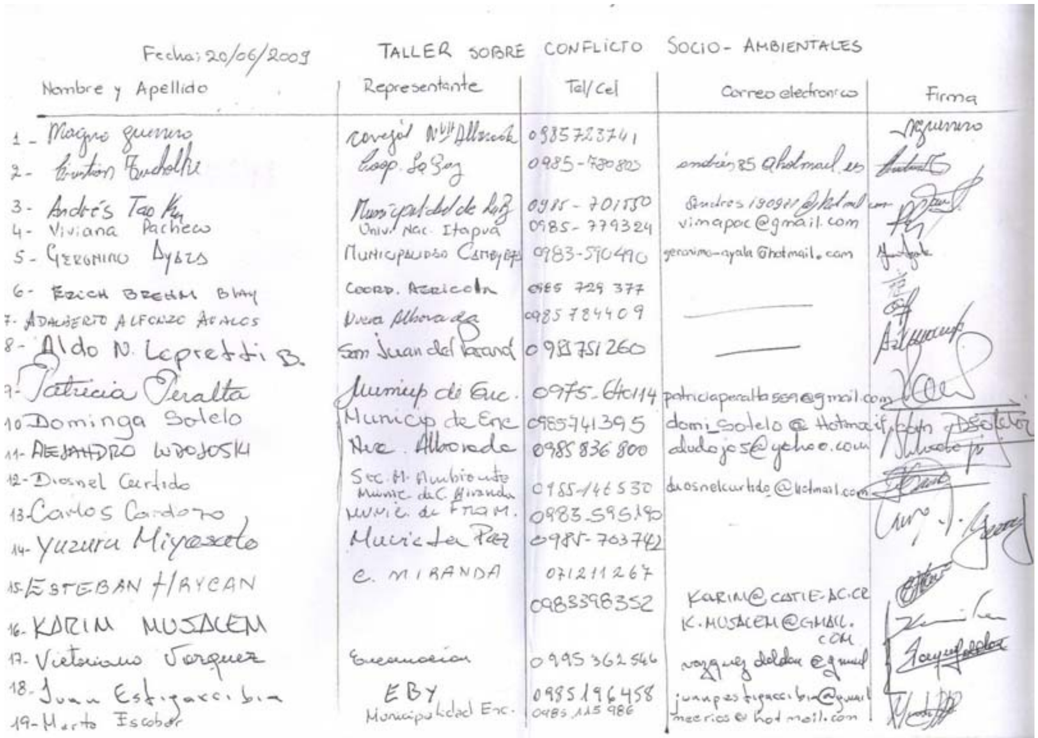
YBE 2008. Informe Final. Programa de calidad de agua. Arroyos Urbanos y peri-urbanos de Encarnación. Asunción. 14 p.

11 Addenda

Addendum 1. Wells used for the determination of "depth to water" (D) through the interpolation of static level for the DRASTIC model to determine aquifer vulnerability to pollution in the Watersheds of Mboi Cae and Quiteria, Itapúa, Paraguay.

ID	LOCALITY	DEEP (m)	DATE	FLOW	STATIC LEVEL (m)
IT-P0010	*CAPITAN MIRANDA*	*116*	*n/d*	*24.00*	*24.50*
IT-P0011	*CAPITAN MIRANDA*	*115*	*n/d*	*12.00*	*0.00*
IT-P0012	*CAPITAN MIRANDA*	*122*	*01/07/1996*	*40.00*	*30.60*
IT-P0022	*FRAM*	*62*	*01/08/1980*	*30.00*	*0.00*
IT-P0031	*JESUS*	*139*	*01/04/1984*	*5.00*	*65.00*
IT-P0034	*TRINIDAD*	*78*	*01/04/1986*	*12*	*35.00*
IT-P0041	*SAN JUAN DEL PARANA*	*184*	*01/07/1992*	*4.60*	*3.70*
IT-P0042	*SAN JUAN DEL PARANA*	*100*	*01/11/1996*	*35.00*	*3.00*
IT-P0047	*B°SAN JUAN*	*137*	*01/06/1993*	*35.00*	*10.00*
IT-P0048	*B°SAN JUAN*	*146*	*01/06/1995*	*30*	*27.00*
IT-P0049	*CAMBYRETA*	*206*	*01/06/1993*	*30.00*	*55.00*
IT-P0051	*NUEVA ESPERANZA*	*228*	*01/08/1996*	*20*	*0.00*
IT-P0052	*ITA PASO*	*282*	*01/04/1997*	*10.00*	*19.05*
IT-P0055	*POLIDEDORTIVO (DIBEN)*	*264*	*01/03/1992*	*15.30*	*0.00*
IT-P0058	*POTRERO SANTA MARIA (VILLA)*	*99*	*01/07/1995*	*60.00*	*15.00*
IT-P0067	*CAMPICHUELO*	*217*	*01/12/1997*	*40.00*	*21.10*
IT-P0068	*SAN JOSE OBRERO*	*80*	*01/05/1998*	*20.00*	*10.50*
IT-P0078	*PUERTO SAMUHU*	*117*	*01/03/1998*	*4.50*	*23.50*
IT-P0079	*SAN BLAS INDEPENDENCIA*	*170*	*01/03/1998*	*25.00*	*23.50*
IT-P0084	*SAN MIGUEL KURUZU*	*140*	*01/11/1997*	*30.00*	*34.50*
IT-P0085	*AZOTEA*	*306*	*01/03/1998*	*29.00*	*0.00*
IT-P0086	*B° GUAZU-ARROYO PORA*	*158*	*01/11/1997*	*40.00*	*7.70*
IT-P0088	*CHAIPE*	*117*	*01/07/1997*	*70.00*	*1.00*
IT-P0089	*CHAIPE*	*129*	*01/07/1997*	*41.00*	*4.20*
IT-P0090	*LA PAZ*	*116*	*01/08/1997*	*40.00*	*0.00*
IT-P0091	*LA PAZ*	*163*	*01/09/1997*	*16.00*	*5.05*
IT-P0124	*SANTO DOMINGO*	*152*	*01/12/2000*	*25.00*	*14.00*
IT-P0125	*PRADERA ALTA*	*121*	*01/02/2001*	*38.00*	*8.00*
IT-P0136	*COPETROL SANTA MARIA*	*0*	*01/01/1996*		*0.00*
IT-P0141	*PASO GUEMBE*	*118*	*01/02/2003*	*3*	*75.50*
IT-P0198	*VIRGEN DE ITACUA*	*91*	*01/02/2001*	*15.00*	*21.00*
IT-P0203	*B°SAN JUAN*	*135*	*01/08/1996*	*50.00*	*10.40*
IT-P0247	*SAN ANTONIO YPECURU*	*232*	*01/12/2002*	*10.10*	*18.50*
IT-P0278	*ITA PASO*	*286*	*01/03/2001*	*8*	*30.00*
IT-P0279	*ITA PASO*	*306*	*01/03/2002*	*8.00*	*20.00*
IT-P0281	*8 DE DICIEMBRE (ITA PASO)*	*200*	*01/01/2003*	*10.13*	*15.00*
IT-P0336	*SAN BLAS CERRO CORA*	*103*	*01/03/2001*	*20.00*	*29.00*
IT-P0362	*FRAM*	*285*	*01/05/2005*	*40.00*	*15.00*
IT-P0372	*SAN LUIS DEL PARANA*	*162*	*01/10/2004*	*7.97*	*30.00*
IT-P0388	*SAN NICOLAS Bº GUARANI*	*222*	*01/10/2003*	*8.44*	*14.85*
IT-P0389	*YTORORO*	*190*	*01/02/2003*	*9.70*	*0.00*

Addendum 2. List of assistance of members of the Watershed Council participating in the socio-environmental conflicts workshop. Held June 20th 2009 in Capitan Miranda, Itapua, Paraguay.



Fecha: 20/06/2009 TALLER SOBRE CONFLICTO SOCIO- AMBIENTALES

Nombre y Apellido	Representante	Tel/Cel	Correo electronico	Firma
1 - Magno Guerrero	Concejal Nva Alborada	0985723741		
2 - [illegible]	Coop. La Paz	0985-780805	andres85@hotmail.es	
3 - Andrés Tao Ku	Municipalidad de La Paz	0985-701550	Andres190981@hotmail.com	
4 - Viviana Pacheco	Univ. Nac. Itapua	0985-779324	vimapac@gmail.com	
5 - Geronimo Ayala	Municipalidad Cambyretá	0983-590490	geronimo-ayala@hotmail.com	
6 - Erich Brehm Blay	Coord. Agricola	0985 729 377		
7 - Adalberto Alfonzo Avalos	Nueva Alborada	0985 784409	——	
8 - Aldo N. Lopretti B.	San Juan del Paraná	0985751260	——	
9 - Patricia Peralta	Municip de Enc.	0975-640114	patriciaperalta559@gmail.com	
10 Dominga Sotelo	Municip de Enc	0985741395	domi_sotelo@hotmail.com	
11 - Alejandro Wdojoski	Nva. Alborada	0985 836 800	aludojo5@yahoo.com	
12 - Diosnel Curtido	Sec. M. Ambiente Munic. de C. Miranda	0985-146530	diosnelcurtido@hotmail.com	
13 - Carlos Cardozo	Munic. de FRAM.	0983-595190		
14 - Yuzuru Miyasato	Municip La Paz	0985-703742		
15 - Esteban Haycan	C. MIRANDA	071211267		
16 - KARIM MUSALEM		0983398352	KARIM@CATIE.AC.CR K.MUSALEM@GMAIL.COM	
17 - Victoriano Vazquez	Encarnacion	0995 362 546	vazquez doldan @gmail	
18 - Juan Estigarribia	EBY	0985196458	juanpestigarribia@gmail	
19 - Marta Escobar	Municipalidad Enc.	0985 115 986	meerios@hotmail.com	

Addendum 3. Key Informants participating in the application of the multi-criteria standard to determine level of IWM in Mboi Cae and Quiteria Watersheds.

Title	POSITION OR PLACE OF WORK	NOMBRE	APELLIDO
ENG, MSC	ENVIRONMENT OFFICE EBY POSADAS	CARLOS	BASALDUA
PROF.	ENVIRONMENT OFFICE CAPITAN MIRANDA	DIOSNEL	CURTIDO
ENG, MSC	ENVIRONMENT OFFICE EBY ENCARNACION	JUAN	ESTIGARRIB IA
CHEM.	FORMER SOCIAL COORDINATOR SOCIAL EBY	LUIS	HAURON
BACH	ENVIRONMENTAL SCIENCES SPECIALIST	VICTORI A	LOPEZ PEREIRA
BIO CHEM. MSC	ENVIRONMENT SECRETARIAT ITAPUA	VIVIANA	PACHECO
BACH. MATH	ENCARNACION MUNICIPALITY	PATRICIA	PERALTA
BACH	ENVIRONMENT PROGRAM COORDINATOR EBY	MAURICI O	PERAYRE
ENG, MSC	PROFESSOR AT CATHOLIC UNIVERSITY FORMER PRESIDENT WATERSHED COUNCIL CAPITAN MIRANDA	ANTONIO	SCHAPOVAL OFF
AGRO ENG	ENTREPRENEUR LA PAZ MUNICIPALITY	ANDRES	TAOKA
ENG	ENVIRONMENT PROGRAM DIRECTOR ENCARNACION. CURRENT PRESIDENT OF WATERSHED COUNCIL	VICTORI ANO	VAZQUEZ

Addendum 4. Values and weight given by key informants in the process of applying the IWM standard in the Watersheds of the Quiteria and Mboi Cae Rivers. W: weight / V: Value given by key informant / W ave: Weighted average / %: Percentage

	A	B	C	D	E	F	G	H	I	J	K	Sums	W ave	%
W111	5	5	5	5	4	4	5	5	4	5	5	52		
V111	0	1	1	0	1	1	1	1	1.5	1	1	9.5		
111	0	5	5	0	4	4	5	5	6	5	5	44	0.85	28.21
W112	5	5	5	5	5	4	5	4	5	5	5	53		
V112	0	1	1.5	0	1	2	1	2	1	0	1	10.5		
112	0	5	7.5	0	5	8	5	8	5	0	5	48.5	0.92	30.50
W121	5	4	5	5	5	5	5	4	5	4	5	52		
V121	1	1	2	1	1	1	1	1	0	0	1	10		
121	5	4	10	5	5	5	5	4	0	0	5	48	0.92	30.77
W211	5	4	4	4	4	4	5	5	5	5	5	50		
V211	1	1	2.5	1	1	0	1	1	1	1	1	11.5		
211	5	4	10	4	4	0	5	5	5	5	5	52	1.04	34.67
W221	5	4	4	4	5	4	5	5	5	5	5	51		
V221	1	1	2	1	1	2	2	1	1	1	2	15		
221	5	4	8	4	5	8	10	5	5	5	10	69	1.35	45.10
W231	5	4	4	4	4	4	5	5	4	5	5	49		
V231	3	1	3	0	3	1	1	1	1	0	1	15		
231	15	4	12	0	12	4	5	5	4	0	5	66	1.35	44.90
W232	5	5	5	5	5	5	5	4	5	5	5	54		
V232	0	1	1.5	0	0	1.5	1	0	0	0	1	6		
232	0	5	7.5	0	0	7.5	5	0	0	0	5	30	0.56	18.52
W233	5	4	4	4	4	4	5	4	4	5	5	48		
V233	0	1.5	1.5	1	1.5	1.5	2	0	0	1.5	2	12.5		
233	0	6	6	4	6	6	10	0	0	7.5	10	55.5	1.16	38.54
W234	5	4	3	4	3	4	5	5	4	3	5	45		
V234	3	1.5	0	0	0	0	1	1	0	0	1	7.5		
234	15	6	0	0	0	0	5	5	0	0	5	36	0.80	26.67
W311	5	4	4	4	4	5	5	5	4	5	5	50		
V311	1	1	3	1	2	1	1	1	0	1	1	13		
311	5	4	12	4	8	5	5	5	0	5	5	58	1.16	38.67
W411	5	4	5	4	5	5	5	5	5	5	5	53		
V411	3	0	2	1	0	1	1	1	0	2	1	12		
411	15	0	10	4	0	5	5	5	0	10	5	59	1.11	37.11
W412	5	4	4	4	5	4	5	5	5	5	5	51		
V412	0	1	1	1	0	1	1	1	1	2	1	10		
412	0	4	4	4	0	4	5	5	5	10	5	46	0.90	30.07
W421	5	2	4	4	4	4	3	3	3	5	3	40		
V421	0	2	3	3	3	3	2	3	3	1.5	3	26.5		

	A	B	C	D	E	F	G	H	I	J	K	Sums	W ave	%
421	0	4	12	12	12	12	6	9	9	7.5	9	92.5	2.31	77.08
W511	5	4	4	5	5	5	5	5	5	5	5	53		
V511	2	1	0	1	0	1	1	1	1	1	1	10		
511	10	4	0	5	0	5	5	5	5	5	5	49	0.92	30.82
W512	5	2	3	5	4	1	4	5	1	2	4	36		
V512	1	1	1	1	0	0	1	0	0	1	1	7		
512	5	2	3	5	0	0	4	0	0	2	4	25	0.69	23.15
W513	5	2	4	5	4	1	2	5	1	2	2	33		
V513	1	1	1	1	1	0	2	1	0	1	2	11		
513	5	2	4	5	4	0	4	5	0	2	4	35	1.06	35.35
W611	5	4	4	4	4	4	4	5	4	5	4	47		
V611	1	1	1	1	2	2	1	1	1.5	2	1	14.5		
611	5	4	4	4	8	8	4	5	6	10	4	62	1.32	43.97
W612	5	4	4	4	4	4	3	5	4	5	3	45		
V612	1.5	1	0	1	0	0	0	1	0	1.5	0	6		
612	7.5	4	0	4	0	0	0	5	0	7.5	0	28	0.62	20.74
WV Sum	97.5	71	115	64	73	81.5	93	81	50	81.5	96			
W Sum	90	69	75	79	78	71	81	84	73	81	81			
W ave	1.08	1.03	1.53	0.81	0.94	1.15	1.15	0.96	0.68	1.01	1.19			
%	36.11	34.30	51.11	27.00	31.20	38.26	38.27	32.14	22.83	33.54	39.51			

Printed March 2010