Acronyme	**GIIWS**		
Titre du projet en français	**Approche intégrée de quantification des ressources en eau et de leur impact sur les écosystèmes des îles Galápagos**		
Titre du projet en anglais	A trans-disciplinary approach to quantify water resources and their impact on natural ecosystems in the Galápagos Islands		
Comité d'Evaluation référence (CE)[1]			
Projet multidisciplinaire	☐ OUI x NON Si oui, indiquer l'intitulé du second CE		
Coopération internationale (si applicable)	Le projet propose une coopération internationale ☐ avec les Etats-Unis (accord ANR/NSF) ☐ autres pays		
Aide totale demandée	463400 €	**Durée du projet**	36 mois

SOMMAIRE

[1] Indiquer la référence du CE choisi pour l'évaluation du projet (cf. tableaux page 3 et 4 du texte de l'appel à projets)

1. CONTEXTE ET POSITIONNEMENT DU PROJET / CONTEXT AND POSITIONNING OF THE PROPOSAL

The Galápagos Islands (Figure 1) are renowned worldwide for their endemic species and near-pristine ecosystems, compared to other oceanic archipelagos. Notwithstanding, after having been declared the first World Heritage Site by UNESCO in 1978, thirty years later they have now been placed on UNESCO's list of Heritage Sites in Danger (June 2007). Urgent action is needed to help the Islands face the consequences of increasing human pressure and development that threatens their ecological integrity (Figure 2). Amongst other critical issues such as the arrival and spread of introduced species, the archipelago is suffering from a lack of, and mismanagement, of natural resources, including the critical situation of water, in its widest sense, and contamination. The conservation of nature, as well as the maintenance of public health requires respect, responsibility, and a sustainable water management policy that is still missing in Galápagos partly because of poor knowledge of the regional hydrology. The object of scientific research in water sciences is not necessarily to promote further development, but can pave the way for sustainable and responsible interactions between local populations and their rich but vulnerable environment, even considering that economic considerations have dominated the use of resources. To this end the comprehensive understanding and quantification of the water cycle is an essential step forward and will be a long-term commitment to the conservation of the islands for there is no question that the presence and absence of fresh water has dictated the evolutionary pathways of many species, and the survival of man. This will become ever more important in the future with the risks from Global Warming and the ever increasing pressure of human demands driven by tourism based on nature (30,000 permanent inhabitants and 170,000 visitors, 2009). With time, external factors such as the onset of rapid changes in climatic conditions due to global warming will further exacerbate the water resource issues of the islands. Climate change may increase the frequency and intensity of El Nino Southern Oscillation events which bring torrential rains or drought and have devastating consequences on the ecosystems and human settlements in terms of infrastructure and livelihoods.

For the Galápagos Islands, the first initiative undertaken to understand the hydrology and hydrogeology of the volcanic Islands was made by d'Ozouville (d'Ozouville, 2009). It was supported by prior research into the geology of the islands (McBirney and Williams, 1969, Bow, 1979, Geist 1985). From a biological perspective, very little work has been done on the relationship between surface or groundwater availability for ecosystem studies. However some work has been done on the relationship between climatic parameters and the evolution of birds (Grant & Grant, 1996) or vegetation (Hammann, 1979). Paleoclimatic studies were undertaken in the Galápagos from the late 1960s onwards using core samples from crater lakes including the unique freshwater lake of the archipelago located on the easternmost island of San Cristobal (Colinvaux, 1968).

Today, all research projects must undergo a strict revision process by the Charles Darwin Foundation and the Galápagos National Park. This high interest in this project by Galápagos authorities is confirmed by the continuous support these two institutions have given the project in the last six years. The international project "Galápagos Islands Integrated Water Studies" (GIIWS) was initiated in 2003 by the University of Paris VI. It aims to improve the understanding of the water cycle over the Archipelago and to provide pertinent guidelines for both the conservation of the ecosystems and the management of the resources. This project has built its strength on forming not only an inter-disciplinary research team (collaborative and integrated research), but also expanding this team to include public and private high end European expertise, such as the European Space Agency in remote sensing, Department of Hydro-geophysics, Aarhus University for SkyTEM device (Heli-borne Time Domain Electro-Magnetism), Department of Geological Sciences, Michigan University in the field of Noble gas and Department of Ecology, Technische Universität Berlin in the field of Galápagos Ecology. Locally our project is included in the Annual Operative Plans of the local research institution (Charles Darwin Foundation - CDF) and the Galápagos National Park (PNG). The second phase of the project has begun in 2008 that will last until 2013. We are the first scientific team working on Galápagos Island hydrology and to this end we are identified as the principal scientific partner of the Foundation Charles Darwin in this field. This premise is to support the second phase of the GIIWS project and our application for a grant ANR-blanche.

Figure 1: Location map of Galápagos Archipelago. Inset shows the position of the Galápagos archipelago in the Eastern Pacific and of Ecuador in the South America.

Investing in research in Galápagos Island and helping to find a balance between economic development, the local impact and the conservation of the ecosystems is clearly a very important step in the conservation of this unique place for future generations. For this reason, the Galápagos Islands are highly emblematic and a showcase for conservation research. Working amongst other international scientists in collaboration with the Galápagos National Park and the Charles Darwin Foundation, our project will indirectly position France on the forefront of research aiming to achieve these conservation objectives for a better world, along with a high scientific profile.

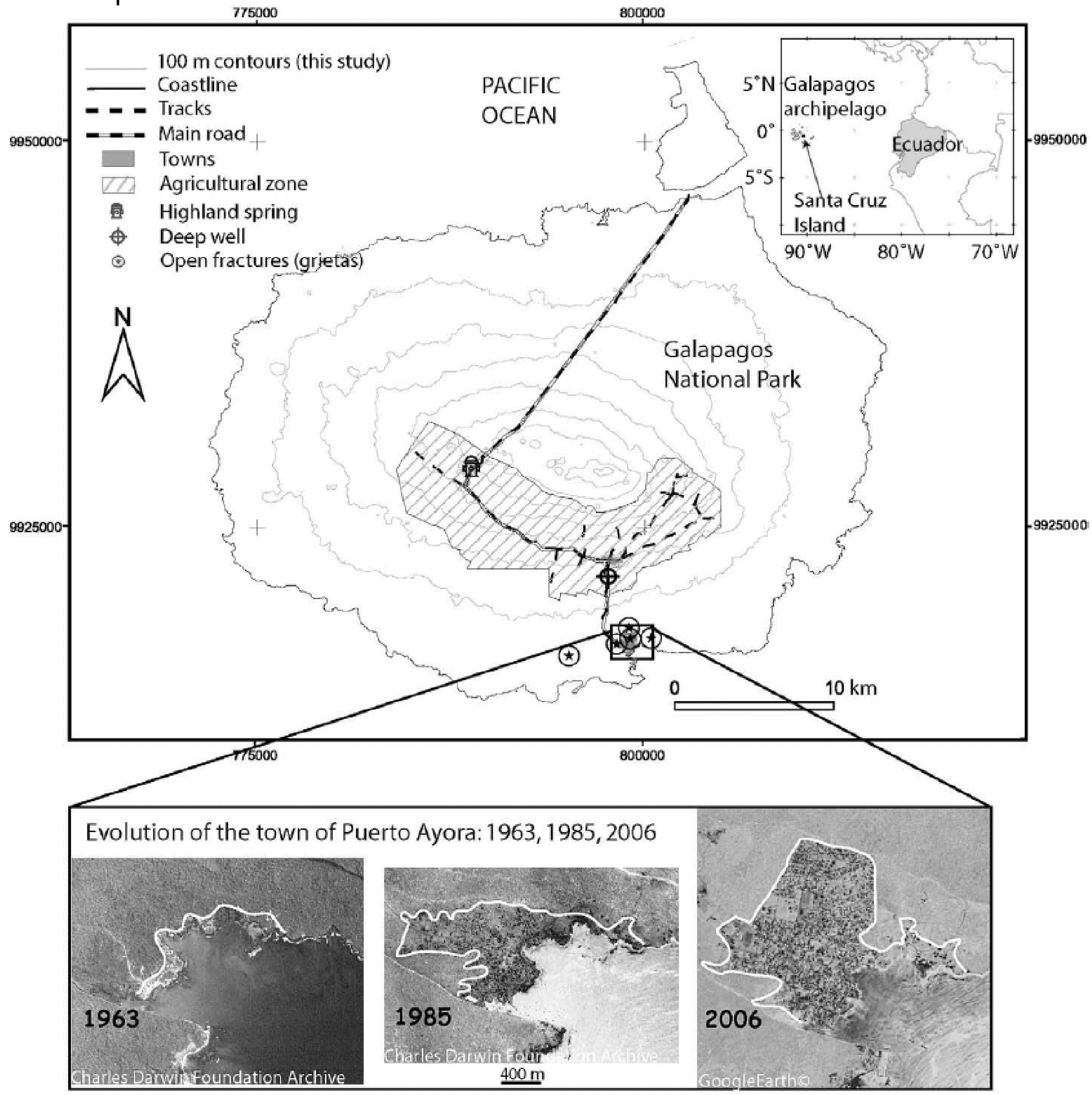

Figure 2: Location map of Santa Cruz Island, Galápagos. Inset shows the position of the Galápagos archipelago in the Eastern Pacific and of Santa Cruz Island within the archipelago. The whole island consists of Galápagos National Park land except the urban areas and agricultural zone. Permanent water resources are indicated. The lower inset shows the rapid development of the main town of Puerto Ayora (1963, 1985, 2006). The white outline marks the outer limits of the town. Road, tracks, agricultural zone, urban areas and coastline obtained from Charles Darwin Foundation-Galápagos National Park Service (FCD-SPNG), GIS, (d'Ozouville et al., 2008).

Beyond the challenging scientific component of this project, presented in section 2.1, our scientific approach takes into account the high stakes from a societal and environmental perspective. Through our results, we will guarantee that sustainable water management is incorporated into the urban planning in order to reduce contamination to the environment and improve basic sanitary conditions of the human population. Furthermore, restoration ecology is becoming a flagship of conservation projects, and our research will provide the necessary input to link natural sciences such as hydrology and soil physics with ecology.

2. DESCRIPTION SCIENTIFIQUE ET TECHNIQUE / SCIENTIFIC AND TECHNICAL DESCRIPTION

2.1. ÉTAT DE L'ART / BACKGROUND, STATE OF THE ART

Hydrogeology of intra-plate volcanic islands remains to some extent misunderstood: How does groundwater occur in the core of the edifice? How much groundwater transit through aquifers? How do basaltic formations evolve to form either impermeable bodies or pervious aquifers? This is principally due to the intrinsic complexity of these massifs in the succession of building and dismantling stages, and the lack of data capable of characterizing accurately the diversity of hydrodynamic functioning. Nevertheless, over the last three decades, these islands have known rapid growth and development so that investigations have been performed to fit the needs in freshwater, mainly by withdrawing from the coastal basal aquifer. The hydrogeology of several tropical and equatorial islands has been studied, and conceptual groundwater flow models have been proposed, some of which have been confirmed by numerical groundwater modelling. The Galápagos Islands are unique and unlike many of other well-known volcanic islands as they were discovered in 1535 and only permanently inhabited from the end of the 19th century (1869/1893). In that regard, cultural and scientific knowledge about the hydrology of the islands is far less than that of the Hawaiian Islands for example. Yet the knowledge acquired on these and other volcanic islands such as the Canary Islands or La Réunion Islands give a very interesting scientific background to this project.

National research teams in France have contributed to the hydrogeological understanding of volcanic islands, having led research on various islands from the Caribbean to the Indian Ocean and the Pacific Ocean. The islands of Guadeloupe (Fiquet et al., 2006) and Martinique (Lachassagne, 2006) have been studied by the BRGM but are formed by island-arc volcanism, which does not given rise to the same construction process of the volcanic edifice. More extensive research has been carried out by various teams on La Réunion islands (Join 1991, Violette 1993, Folio 2003). The study of La Réunion Islands over the last 20 years has given rise to different applied research projects, conceptual and mathematical models, and provides a better understanding of the hydrogeology of either an inactive (Piton des Neiges) or active (Piton de la Fournaise) hot-spot volcanoes. The islands of French Polynesia in the Pacific Ocean were studied by Pouchan et al, 1988 and later more research was carried out on Tahiti-Nui by Hildenbrand et al., 2005.

The first conceptual model on the hydrogeology of volcanic islands was carried out by Peterson (1972) and Mac Donald et al. (1983) on the Hawaiian Islands. Their initial groundwater flow model (Figure 3) is still used as a reference today, as more recent studies and an extensive data set have confirmed this model (Hunt, 1996 ; Gingerich and Voss, 2005), all the while proposing variant schemes to respect local specificities observed on some islands (Kauai and North-East sector of Maui, Gingerich and Oki, 2000). These alternate models have more in common with the second groundwater conceptual model proposed by Custodio et al. (1983, 1988) for the Canary Islands (Figure 4). Most of these studies were carried out based on vertical borewells or horizontal drainage galleries (Canary), piezometric observations, outflow measurements and geochemistry. Different new methodologies were gradually applied to the study of these volcanic islands giving rise to variants of the existing models. These methods include remote sensing (Peireira et al., 2007, d'Ozouville et al., 2008a), geophysical exploration (Descloitres et al., 1997; d'Ozouville et al., 2008b), isotopic geochemistry (Scholl et al, 1998), and thermal modelling (Violette et al., 1997). Research has also extended to islands previously poorly studied such as the Azores (Cruz and Silva, 2001) and Easter Island (Herrera et al., 2008).

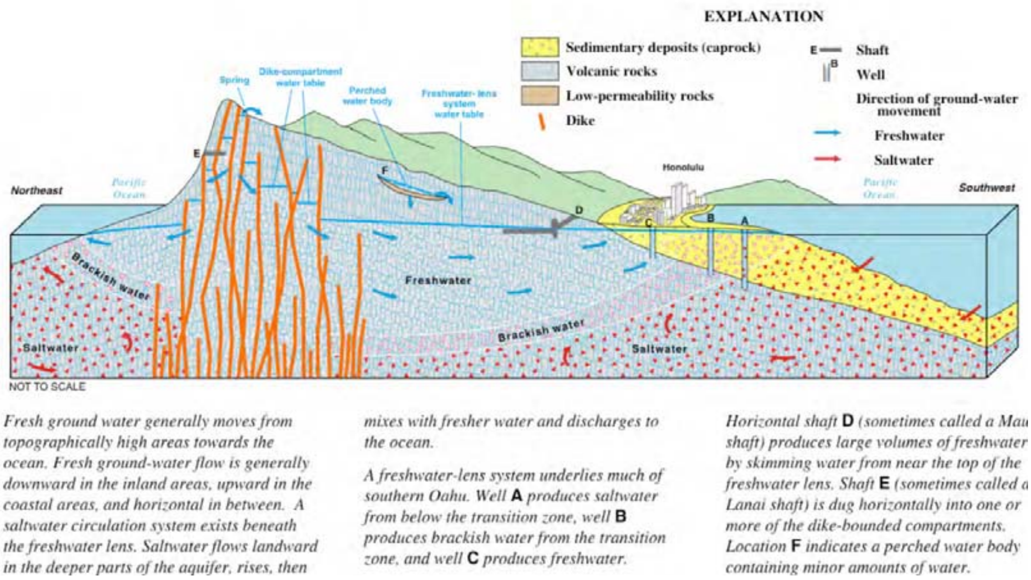

Figure 3: « Hawaiian » type conceptual groundwater model proposed by: Peterson (1972), Mac Donald et al., (1983) and modified by: Gingerich et Oki,(2000). The basal aquifer in equilibrium with salt water laterally infiltrated, possess a weak hydraulic gradient on the coastal fringe, and inland this basal aquifer is limited and relayed by the presence of dykes. On the massif core, the density of dyke increases and the water saturated basalt are compartmented and give birth to highland springs. Locally due to lithological discontinuities during the stage of volcanic building up, i.e.: scoria or cinder layers, line of springs can occur, outlet of perched aquifers, if these layers are cut off by the topography. Thus from the coast line to inland, the water saturated layer is encountered deeper and deeper, and highland the water resource is puzzled and unpredictable found.

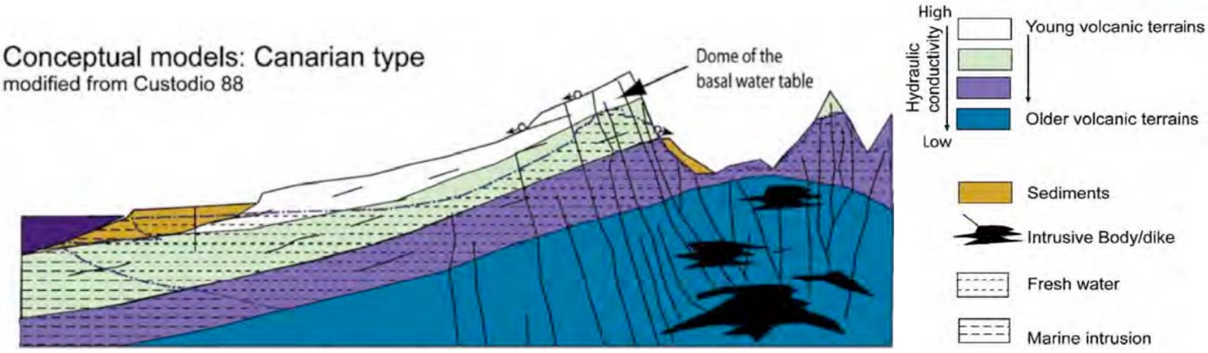

Figure 4: « Canary Island » type groundwater flow conceptual model by: Custodio et al. (1988), modified by Join et al., (2005). Their work is based on temporal evolution observations of groundwater discharges of horizontal drainage galleries and of groundwater mineralisation. These horizontal drainage galleries are the traditional way to provide fresh drinkable water to the population and to distribute it by gravity. This conceptual model describes a regionalised basal aquifer which its hydraulic gradient is weak at proximity of the coastline and it increases rapidly in the centre of the massif. The water level surface morphology is the result of the decrease of the hydraulic conductivity with depth and inland which limit the thickness of the aquifer accordingly to the substratum slope, depending on the recharge conditions submitted to orographic rainfall gradient and the outlet condition prescribed by the marine level at the periphery of the regional basal aquifer. Thus with this scheme, the basal aquifer is in equilibrium with salt water laterally infiltrated, exploitation of this groundwater resource has to be done with caution, but inland fresh groundwater resource exists and abounds where ever the well or gallery is drilled. From its depth/wide success of the water resource project will depend.

In this paragraph, we present the scientific context and stakes. The hydrogeology of the Galápagos has also remained largely unknown until the beginning of the GIIWS project, but the interest in studying these unique islands was far greater than that premise alone. In no other island is it possible to study the hydrology of a volcanic island with relation to a largely protected area from an ecological point of view as 97% of the territory is protected national park land and the islands still have 95% of their original biodiversity. Since its onset, this project has been aimed to contributing to the protection of the Galápagos ecosystems and providing elements to the sustainable development of the remaining 3% of territory. Given the above mentioned national and international context, the first part of the GIIWS project achieved a milestone in demonstrating how the different methodologies (geology, satellite imagery, geophysics, hydrology, hydrochemistry) could be used in a complementary fashion to build a complete and robust conceptual model (d'Ozouville, 2007). New and innovative techniques tested for the first time on insular volcanic terrain generated unpredictable results (Figure 5, d'Ozouville et al. 2008b). Today, in developing the next phase of this project, new scientific stakes are at hand locally and internationally. Our interest is now focused on combining the hydrological knowledge with the wealth of information on the unique ecosystems in order to provide keys to better understand and quantify hydrological processes within the conceptual model. And in return to generate information which will serve the purposes of the local authorities working on ecological restoration and invasive species management and the local authorities in charge of sustainable development of the local human communities.

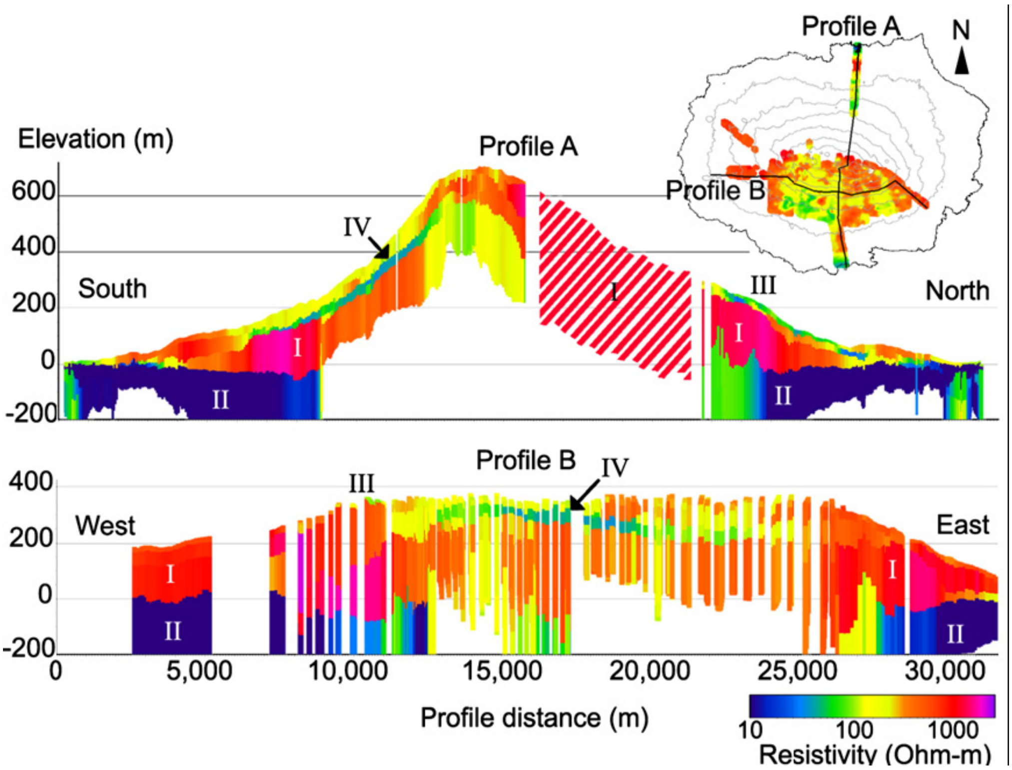

Figure 5: Two cross-sections reveal the internal structure of Santa Cruz Island and four units of hydrogeological interest. The positions of the south-north and west-east profiles across the island are shown on the inset over a background of near-surface average resistivity showing extent of mapped area. The profiles show the density of data generated and the penetration depth of between 200 and 300 m. The four units of hydrogeological interest are: (I) High-resistivity unsaturated basalts; (II) Seawater intrusion wedge underlying the brackish basal aquifer; (III) Near-surface, low-resistivity units consisting of colluvial deposits; (IV) Internal, low-resistivity unit of saturated basalts overlying an impermeable stratum of $50km^2$ of extent (d'Ozouville et al., 2008).

2.2. OBJECTIFS ET CARACTÈRE AMBITIEUX / NOVATEUR DU PROJET / RATIONALE HIGHLIGHTING THE ORIGINALITY AND NOVELTY OF THE PROPOSAL

This project aims to integrate research in water sciences with ecological knowledge of a vulnerable, volcanic insular environment: the Galápagos Islands.

The scientific and technical objectives of this project are:

1) To improve the understanding of hydrogeology in tropical volcanic islands of intra-plate origin.
2) To show the invaluable input of jointed investigations in hydrological and ecological sciences for the understanding of ecosystem functioning and restoration of ecosystems in fragile areas.
3) To address local challenges of conservation, protection of native and endemic ecosystem, and sustainable development, through collaborative interdisciplinary research in water sciences

This project is original/novel for Galápagos, as it is the first of its kind in the Galápagos Islands. For 50 years, the Charles Darwin Foundation and the Galápagos National Park have been supporting scientific endeavour into the fields of terrestrial and marine biology, but certain fields of earth/physical sciences such as the hydrology and even ecology of aquatic ecosystems have remained untouched. Our approach is ambitious, because starting a project where no prior information exists requires a strong vision to develop a research program, including multidisciplinary teams to overcome lack of data, difficulty of access to the field and to ensure that the results of the research will answer key questions in the scientific domains, in this case characterising hydrogeological models for volcanic islands, but also serve the local institutions in research and management in other fields.

Expected innovating scientific advances include: i) new understanding of groundwater flow in complex fractured volcanic formations where freshwater and salt water interact, ii) groundwater model based validation of 3-D geophysical exploration, iii) strong collaboration between biological sciences and natural sciences.

In order to achieve our objectives, certain scientific and technical challenges will have to be overcome. The following scientific challenges are foreseen and will be addressed:
1) Studying the boundary conditions, i.e.: infiltration/evaporation processes during “garúa season” (fog season) and “invierno season” and the quantification of the interception process by the vegetation;
2) Characterizing the physical and hydrodynamic parameters of the basal aquifer and the alterite cover; and
3) Defining the hydrodynamic role played by the dykes and the fractures network, in view to be able to build a numerical modelling of the water cycle along a flow path and to quantify the water fluxes released to the ocean along the hydrologic year.

The Galápagos Islands host unique worldwide renowned endemic ecosystems, it is the showcase of high level international scientific programmes, but is a remote province belonging to the state of Ecuador. This implies additional challenges that will be overcome by the strong ties existing between the project and the two key institutions which support research in Galápagos which are the Charles Darwin Foundation and the Galápagos National Park. We hold a 5-year experience in this field, and know that with support from these institutions, it is possible to carry out field investigations and complete administrative procedures including for the importation of materials to this unique natural laboratory.

The novel character of this project will be demonstrated by the final products developed at the issue of the proposed work. The existence of perched aquifer systems on the southern windward slopes of the inhabited islands will be confirmed by indirect validation of the results obtained with SkyTEM experiment. Understanding of the interaction between biological components and hydrology will bring new light to science in Galápagos.

Through this description, we hope to have demonstrated the interdisciplinary nature of the project and how the different scientific fields will complement and articulate around each other to generate the final success of the project. Finally we will be able to provide guidelines for sustainable water management in this pristine ecosystem to the local authorities in charge of natural resources management.

3. PROGRAMME SCIENTIFIQUE ET TECHNIQUE, ORGANISATION DU PROJET / SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT MANAGEMENT

3.1. PROGRAMME SCIENTIFIQUE ET STRUCTURATION DU PROJET / SCIENTIFIC PROGRAMME, SPECIFIC AIMS OF THE PROPOSAL

A good understanding of the hydrological context of Galápagos Islands is crucial for a sustainable water management and a precise assessment of the impact of different expected scenarios for this unique archipelago (invasive species spreading, land use changes, climate change). To serve those critical needs, our scientific programme will consist in (i) a quantification of recharge rates (ii) a analysis with an hydrogeological approach of the morphology, geometry and physical properties of volcanic formations, including the exploitation of all direct and indirect methods to characterize groundwater occurrence, and (iii) assess the consistency of the whole and potential consequences with numerical groundwater flow modelling.

Vegetation and soils, as controlling factors of groundwater recharge. One of the most determining factors in hydrogeology is the input from precipitation that will not be evaporated, nor transpirated, nor stored in the soil, but infiltrated to the underground. This input called “recharge” in hydrogeology, will by quantified with jointed investigations: all processes that may contribute to evaporation, transpiration, and storage of precipitated water must be taken into account. A particularity of several volcanic islands such as Hawaiian Archipelago, Canary Islands, Madeira and Réunion Island is the occurrence of a semi-permanent fog layer in the highlands which brings additional water and reduces transpiration during part of the year (Brauman et al., 2009 ; Ritter et al., 2008 ; Prada and Silva, 2001 ; Gabriel and Jauze, 2008). In these contexts, "throughfall" or “occult precipitation” below vegetation canopy can be higher than precipitated water above: fog liquid water conveyed by winds is intercepted by leaves and branches. Vegetation canopy has therefore an active role, both as a water consumer (evaporation and transpiration) and water "catcher" (fog interception).

Galápagos Islands have climatic similarities with their counterparts but present original features. “*Garúa*” cold and misty seasons from June to August alternate with the hot “*invierno*” seasons. El Niño inter-annual events induce high precipitation rates, and occur irregularly, approximately two to seven years. Along the year, trade winds from the southeast carry humid air that is up-welled along the windward steep slope, leading to a marked orographic effect and precipitation rate rising with altitude on the windward side of the island (Figure 6): 500 mm/yr on the coast to 1800 mm/yr at 600m (Snell and Rea, 1999). On the leeward side, the shadow effect is blatant and precipitation decreases dramatically. These discrepancies in precipitation and temperature result in vegetation staging and a blatant difference between each side of the islands. Imposed over these local processes, seasonal and inter-annual variations characterize Galápagos climate.
A preliminary study performed by Heinke Jäger showed the importance of fog interception in Galápagos, and suggests a high potential impact of land use changes and invasive species spreading over Santa Cruz hydrology. Nevertheless, an

accurate quantification of recharge rates is still missing in Galápagos. Recharge quantification remain the main purpose of this project, with particular attention paid to the vegetation canopy that will be investigated in collaboration with the Darwin Station, in Galápagos, which has gathered a 50 year experience in this domain.

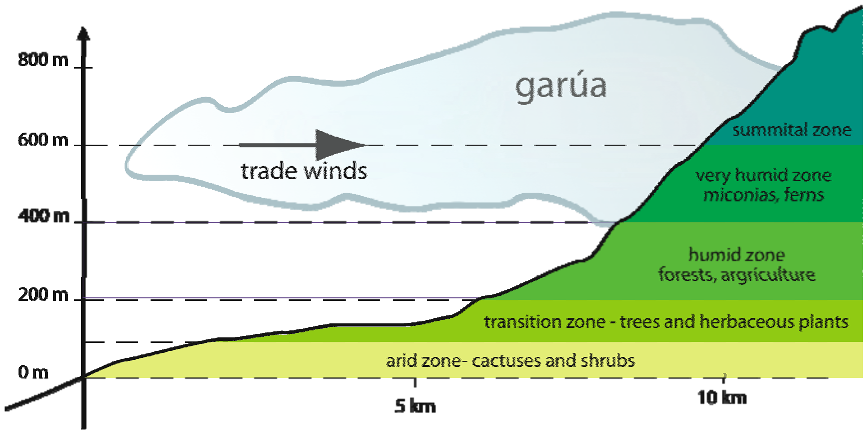

Figure 6: climatic and vegetation stages on the windward side of Santa Cruz. The orographic gradient of precipitation is high and become even more marked during the “garúa” season, characterized by the presence of a fog layer over ~400m a.s.l.

For a given recharge, rocks physical properties define groundwater occurrence. Once precipitated water has gone through this living skin that is soil and vegetation cover, it flows down in the unsaturated volcanic formations, possibly supply perched aquifers while impervious layers occur, and finally reaches the basal aquifer, in equilibrium with sea water. Our scientific programme will include a multi-scale characterization of rocks physical properties. We will adapt our methodology for each feature, from the scale of the lava flow where micro-fracturation may connect closed vesicles, to the scale of the island where dikes may act as extended impervious walls and compartment aquifers.

Geophysical soundings characterize aquifers geometry since saturation of porous rocks by water has for consequence a drop in rock electrical resistivity, which can be mapped by various sounding techniques (electrical and electromagnetic). In May 2006, extensive helicopter-borne transient electromagnetic soundings (SkyTEM) have been performed on Santa Cruz and San Cristóbal islands in the frame of the first phase of GIIWS project (d'Ozouville et al., 2008, d’Ozouville et al, in prep). It has provided valuable information and proposed a new hydrogeological conceptual model for these islands. Nonetheless, it remains an indirect method that requires calibration with drill holes that are to date scarce on Santa Cruz Island.

The top of the groundwater body, the "water table" can be directly measured in drill holes and outcropping of the water table in fault scarps locally named "grietas". These direct methods are essential because of their accuracy, but of a low spatial representativeness and drill holes present high costs and common technical challenges in volcanic contexts. For these reasons, few drill holes have been executed in Galápagos, and most of them intercept the brackish basal aquifer in coastal areas. With increasing pressure from the population, negotiations are running between local authorities of Galápagos and state government for the execution of new drill holes. The GIIWS team is the reference scientific partner of these Ecuadorian programs, it will ensure an optimum implantation of exploratory drill holes and, provide a framework for a sustainable management of the resource.

Numerical modelling of groundwater flow as a prospective tool to investigate groundwater occurrence. The dynamic of groundwater flow can be investigated with numerical flow models based on mass conservation and the constitutive equation of flow, the Darcy law. Because we miss accurate data on rocks hydraulic properties and calibration data from drill holes, we won't be able to obtain accurate predictive simulations. Nevertheless, we will obtain from our investigations quantitative data on recharge rates and an extensive characterization of volcanic formations. A modelling approach will let us test our hypotheses on groundwater occurrence. Flow modelling as a tool for testing hypothesis in volcanic contexts has been used by a number of authors: Souza and Voss (1987), Custodio et al. (1988), Violette et al. (1997), Oki et al. (1998), Gingerich and Voss (2005) and Join et al. (2005). Furthermore, the occurrence of perched aquifers has been investigated with numerical methods by Wu and al. (1998), Hinds et al. (1999), and Niswonger and Fogg (2008) and sensitivity analysis has been performed by Zhang et al. (2006) in volcanic context. Sensitivity analysis is a crucial criterion to assess the confidence we can have in a numerical model. It allows a better management of uncertainties, orientate possible further data acquisition.

Though it is not our primary objective because of the expected limited accuracy, a groundwater numerical model could provide a tool to qualify potential impacts of climate and land use change over Galápagos hydrogeology, and consequent risks for biodiversity and populations.

Investigations will be concentrated on Santa Cruz Island. Santa Cruz, the most inhabited island of Galápagos lacks freshwater resources, which is a challenge for public health and misses a wastewater treatment plant, which is a danger for native ecosystems both marine and terrestrial. We therefore propose to concentrate our field investigations on Santa Cruz Island, which deserves most of attention and where our researches could provide valuable information to face local challenges.

Santa Cruz presents the best road network and the international airport of Baltra and hosts the main infrastructures of our partner, the international Darwin research station (CDF). For this reason, Santa Cruz is also the most monitored island of the Archipelago, and long term data series, crucial for water sciences are available. Precipitation and main climatic variables have been recorded since 1965. Projects of mapping have been conducted in the eighties by local authorities (INGALA) and French cooperation (ORSTOM, current IRD) so that morphological and vegetation maps covering the whole island are available. A number of various investigations have been performed in ecology (Jäger et al., 2009), but are fewer in hydrology, at the exception of Noémi d'Ozouville's thesis and water quality monitoring by the Japanese cooperation.

Concentrated field activities do not mean reduced range of application. In spite of concentrated field activities on Santa Cruz Island, our results will remain relevant for other islands with similar geological and climatic contexts: other islands of Galápagos Archipelago (San Cristóbal, Floreana, Isabela), and as well Hawaiian Archipelago, Réunion Island and Canary Archipelago for instance.

Three taks, and three specific objectives, as a framework for an innovating and challenging set of investigations. Investigations will be organized in three tasks, with respective specific objectives that will serve the final objective: the definition of a quantified hydrogeological conceptual model.

Task 1	Hydro-ecological investigations, climatic and soil monitoring
Specific objectives	Characterize the active role of vegetation and soils; quantify recharge rates; assess the impact of land use changes.
Task 2	Multi-scale hydrogeological characterization of volcanic rocks
Specific objectives	From the sample to the regional scale, define the controlling features of volcanic rocks porosity and hydraulic conductivity
Task 3	Groundwater dynamics with numerical modelling
Specific objectives	Validate the conceptual model; assess the impact of potential scenarios (land use change, climate change, invasive species spreading).

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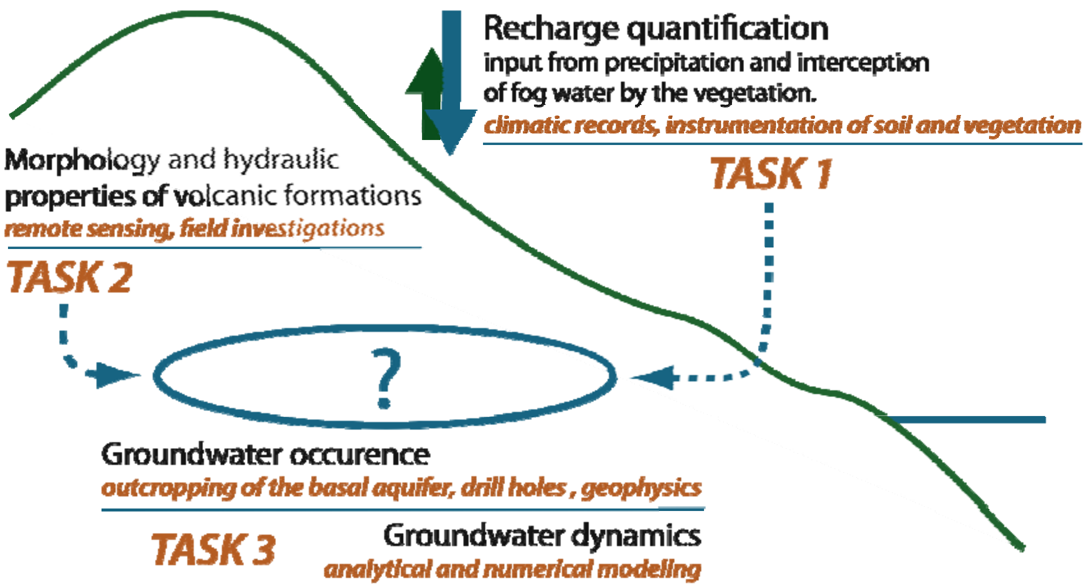


3.2. COORDINATION DU PROJET / PROJECT MANAGEMENT

In this section, we will describe the organisational aspects of the project and the modalities of coordination, and individual tasks.

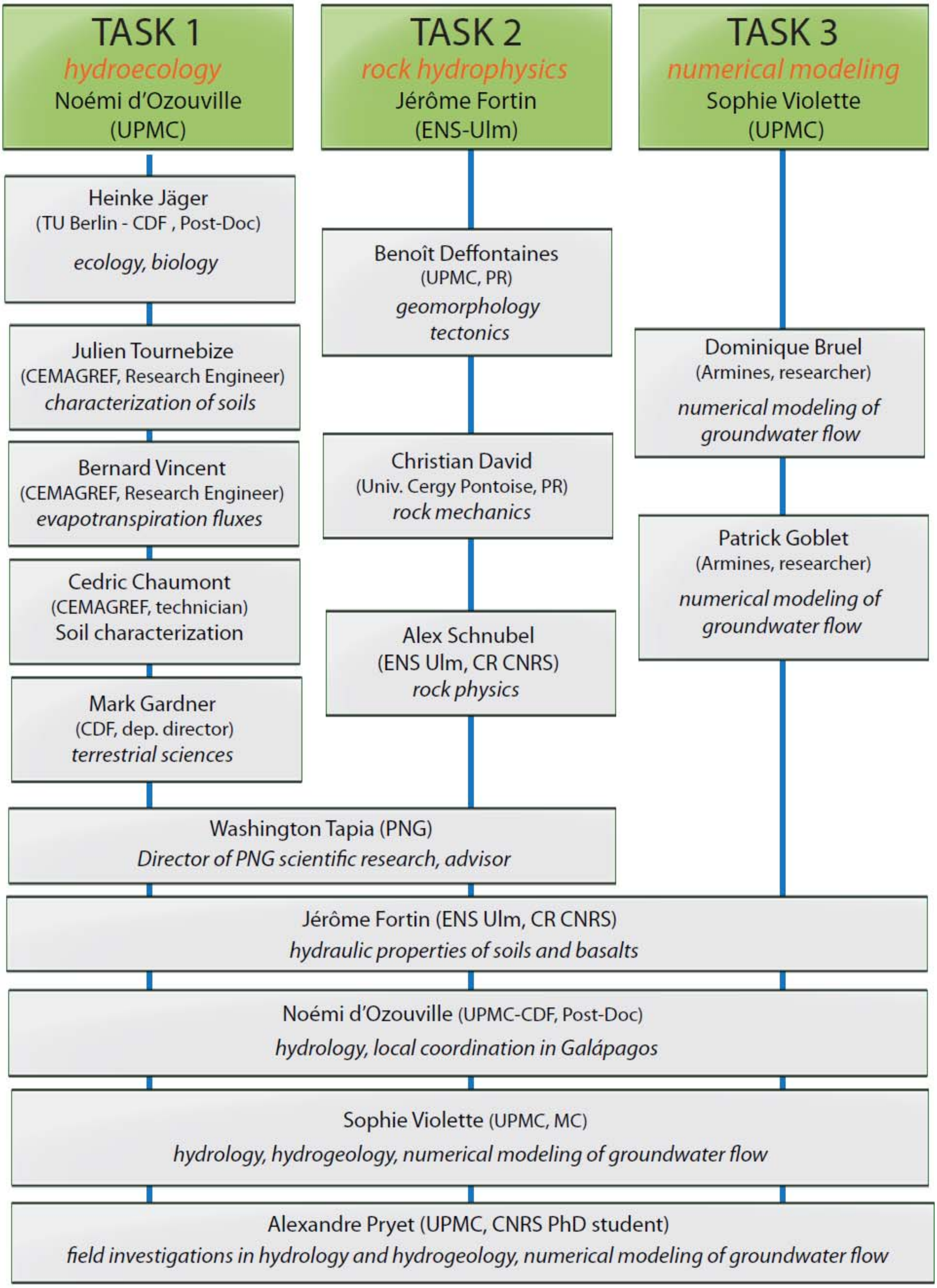
Project coordination
Sophie Violette will oversee the global coordination of this project as she has been coordinating the Galápagos Islands Integrated Water Studies program now for over seven years with great success. The Université Pierre et Marie Curie, Paris, France, disposes of all the necessary infrastructure in terms of information technology, laboratories and materials to maintain appropriate levels of communication with all of the partners in the project. The project coordinator is also a mobile person who will participate in field work in the Galápagos Islands and coordination meetings in places other than Paris when required. Bi-yearly coordination meetings are organized in Paris with the European members of the scientific group of the project to discuss the advances of the research and the results.

Coordination in Galápagos
A vital component of our coordination approach is to have a dedicated coordinator of all the field activities and all the local institutions in Galápagos. This role has been carried out by Noémi d'Ozouville since the end of her PhD. Her fluent knowledge of Spanish, English and French makes her a great communicator amongst scientists and technical professionals alike. This role is very important to ensure that all the research permits are available on time and all the field logistics are carried out seamlessly. Without this local input, many days are often lost at the onset of fieldwork for organisational reasons. Through this funding opportunity, we hope to be able to give Noémi d'Ozouville a formal Post-doctoral position at Université Pierre et Marie Curie, based at the Charles Darwin Foundation in order to facilitate her role as local coordinator. Bi-yearly coordination meetings are organized in Puerto Ayora with the local collaborating institutions.

Task coordination
Each task defined in section 3.1. has a scientific coordinator. Each scientific coordinator is responsible for maintaining active communication within the specific task and resolving any issues that arise within that task. The scientific coordinators will also maintain active communication amongst each other and inform each other of the advances or difficulties that each task may be encountering as it goes along.

Field trips
Field trip planning will start a minimum of three months before the expected data. Initial coordination of the field work will be carried out within the specific task and then in coordination with Noémi d'Ozouville.

The below, the flowchart presents the organisational aspects in graphic form.


TASK 1
hydroecology
Noémi d'Ozouville
(UPMC)
TASK 2
rock hydrophysics
Jérôme Fortin
(ENS-Ulm)
TASK 3
numerical modeling
Sophie Violette
(UPMC)
Heinke Jäger
(TU Berlin - CDF , Post-Doc)
ecology, biology
Julien Tournebize
(CEMAGREF, Research Engineer)
characterization of soils
Bernard Vincent
(CEMAGREF, Research Engineer)
evapotranspiration fluxes
Cedric Chaumont
(CEMAGREF, technician)
Soil characterization
Mark Gardner
(CDF, dep. director)
terrestrial sciences
Benoît Deffontaines
(UPMC, PR)
geomorphology
tectonics
Christian David
(Univ. Cergy Pontoise, PR)
rock mechanics
Alex Schnubel
(ENS Ulm, CR CNRS)
rock physics
Dominique Bruel
(Armines, researcher)
numerical modeling of
groundwater flow
Patrick Goblet
(Armines, researcher)
numerical modeling of
groundwater flow
Washington Tapia (PNG)
Director of PNG scientific research, advisor
Jérôme Fortin (ENS Ulm, CR CNRS)
hydraulic properties of soils and basalts
Noémi d'Ozouville (UPMC-CDF, Post-Doc)
hydrology, local coordination in Galápagos
Sophie Violette (UPMC, MC)
hydrology, hydrogeology, numerical modeling of groundwater flow
Alexandre Pryet (UPMC, CNRS PhD student)
field investigations in hydrology and hydrogeology, numerical modeling of groundwater flow

3.3. DESCRIPTION DES TRAVAUX PAR TÂCHE / DETAILED DESCRIPTION OF THE WORK ORGANISED BY TASKS

3.3.1 TÂCHE 1 / TASK 1: HYDROECOLOGY, ESTIMATION OF GROUNDWATER RECHARGE AND FOG INTERCEPTION BY THE VEGETATION IN DIFFERENT CONTEXTS (NATIVE SPECIES IN THE VERY HUMID AND HUMID ZONES, AGRICULTURAL ZONES) IN THE HIGHLANDS

Coordinator: Noémi d'Ozouville
Participants: Alexandre Pryet, Heinke Jäger, Julien Tournebize, Bernard Vincent, Cédric Chaumont, Jérôme Fortin, Washington Tapia, Mark Gardener, Sophie Violette

To quantify accurately recharge rates to the groundwater system, meteoric precipitation cannot be the unique consideration. Several processes on land surface and vegetation cover (evapotranspiration, interception of fog water) and in the soil profile (storage and fluxes) need to be taken into account. To this effect, climatic context, vegetation covers and soil hydraulic properties will be investigated considering Galápagos particular nature.

The scientific program of task 1 is to investigate climatic discrepancies and the active role of Galápagos soils and various vegetation canopies (endemic, native and recently imported species) on the regional hydrology of Santa Cruz. To achieve this, we will process data from GIIWS databases and climatic records from our partner the Darwin Station. An extensive data acquisition is planned with non-permanent weather and soil instrumentation, and characterization of the vegetation.

1.1. Determination of net rainfall with a semi-permanent fog layer in the highlands

We will measure **precipitation** over the canopy with rain gauges, **fog intensity** with cylindrical fog net, **throughfall or occult precipitation** (the amount of precipitated water below the vegetation) with collectors and rain gauges. **Wind speed**, **air temperature** and **humidity** are as well important variables, particularly for evapotranspiration estimates.

We will benefit from the experiences of recent advances in this domain described by MacJannet et al. (2005), Brauman et al. (2009), Prada et al. (2009) and Ziegler et al. (2009). Precipitation can be measured with classic rain gauges, preferably equipped with tipping bucket for data logging. Fog net will be cylindrical to avoid bias from the wind direction. Fog net water will be collected and monitored with a tipping bucket rain gauge placed below, or a pressure probe in a collecting tank. Throughfall below vegetation is expected to be higher than meteoric precipitation as interception rate of fog droplets by the vegetation can be markedly higher than evaporated water on the leaves. In order to avoid weak relevance, a wide network of collectors has to be installed under the vegetation cover. A particularly difficult task is the estimation of stem flow, which can be assessed with spiral collars fitted around trunks. This is one of the reasons why instrumentation of the soil horizon is also important, since it integrates most of this phenomenon.

1.2. Quantification of percolating water flux beneath root zone

Physical properties of soils will be investigated. Three classical techniques will be carried out: granulometry, in situ experiments with Guelph Permeameter and laboratory experiments for soil water retention curves, saturated hydraulic conductivity determination. All those techniques will provide parameters to characterize the hydrodynamic behaviour of the different soils.

This project is particularly innovating since it includes jointed investigations of weather, vegetation and soils. **Soil suction monitoring** is one of the best ways to estimate the direction and possibly intensity of water fluxes in an unsaturated soil. To this effect, we will set up several tensiometers at different depth in the soil profile and measure tensions. Precipitation events and infiltration of water in the soils will be appropriately monitored with automatic recording devices connected to pressure transducers. **Soil volumic water content** can be estimated with various types of probes but the most relevant systems are based on soil permittivity measurements, which are directly related to the water content. Two systems are proposed: Time-Domain-Reflectometry and Frequence-Domain-Reflectometry. Measurements of soil volumic water content will be performed at the same depth as tensiometers so as to characterize in-situ the characteristic curves of the soils. Soil temperature monitoring is also a way to track water fluxes with the heat transport equations. Probes are easy of installation and relatively cheap.

A particular care will be paid for the management of uncertainties of measurements and heterogeneities in the soil since they may dramatically influence the data. To this effect, we intend to perform calibration with weighing methods, and to check the spatial relevance of our measurements with replicate probes and a portable TDR Soil.

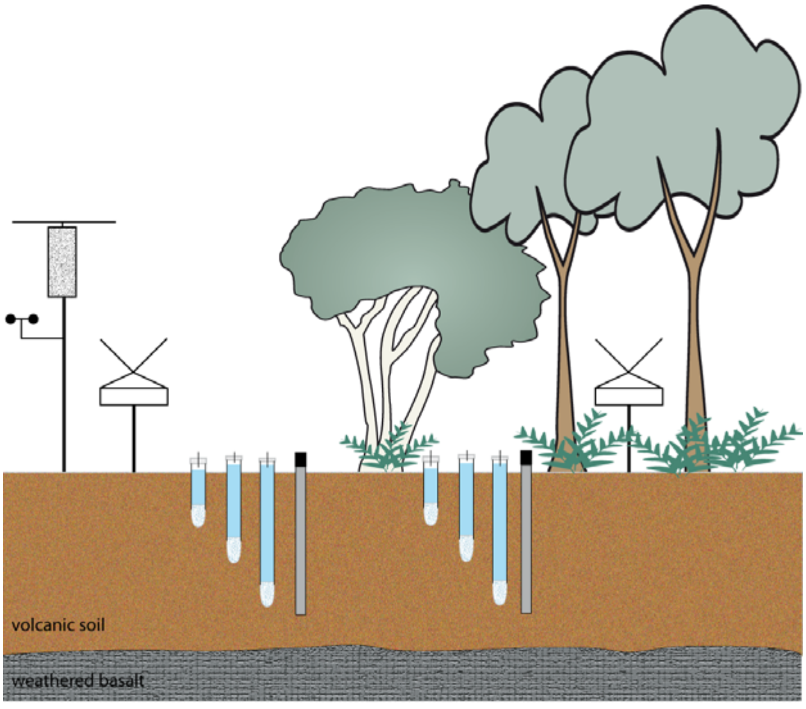


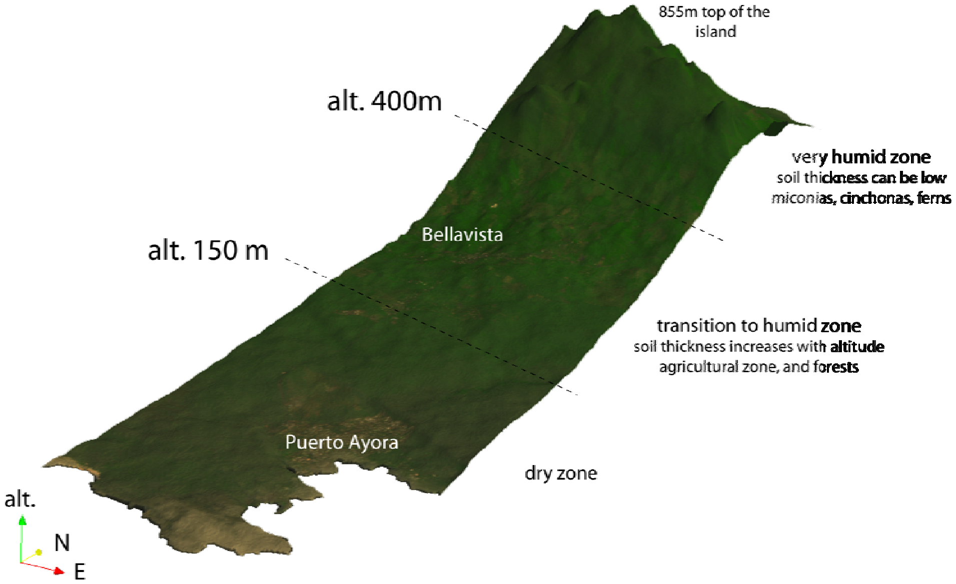
Figure 7: Hydroecological station equipment: weather and soil monitoring station including (from left to right) open air: wind sensor, cylindrical fog collector, rain gauge, set of tensiometers and humidity

probes in the soil. Below vegetation : set of tensiometers and humidify probes, throughfall collector.

These probes, summarized in Figure 7, can be connected to an automatic data logger, which can record data with short time steps. GIIWS project has operated such automatic stations and will join its effort with CEMAGREF staff., frequent maintenance with a local operator is a must and will be carry out.

Our partner from the Charles Darwin Station will execute characterization of plants which will include the Leaf Area Index (LAI) determination and possibly sap fluxes in the stems.

As mentioned above, investigations will be concentrated on the windward southwest mountainside of Santa Cruz Island, and more accurately where roads suitable ease access by motor vehicles. For each climatic stage and vegetation type (Figure 8), an appropriate station will be set up. We will therefore be able to quantify the respective behaviour of different vegetation cover; and later assess possible effects of different scenarios (invasive species spreading, extension/reduction of the agricultural zone).



Climatic stage	vegetation cover	instrumentation
transition/humid zone	forests	weather, soil, plants
transition/humid zone	farming : grasslands	weather, soil, plants
transition/humid zone	farming : café trees, Psidium	weather, soil, plants
humid/very humid zone	Scalesia forest	weather, soil, plants
very humid zone	Miconias, Cinchona, ferns	weather, plants
humid windy summit zone	pampa	weather, soil, plants

Figure 8: Distribution and types of stations in vegetations stages

1.3. Modelling approach to characterize recharge

After a period of data acquisition, 1D inverse modelling approach will let us obtain characteristic curves of soils that will be compared with curves obtained empirically from soil samples. A 2D and possibly 3D direct modelling approach of soil water will then be exploited to simulate infiltration of water fluxes and recharge from precipitation. This approach let us assess the sensitivity of recharge with respect to climatic variables, possibly altered by natural climatic variability (e.g.: Niño/Ninã) and global climate change. The HYDRUS software (versions: 1D, 2D, and 3D) could be implemented with all data from column determination to plot and to mountainside.

3.3.2 TÂCHE 2 / TASK 2: MEASUREMENTS OF THE PHYSICAL AND HYDRODYNAMICAL PROPERTIES OF THE VOLCANIC EDIFICE AT VARIOUS SCALES

Coordinator: Jérôme Fortin
Participants: Christian David, Benoît Deffontaines, Alexandre Pryet, Alex Schubnel, Noémi d'Ozouville, Sophie Violette

Understanding the hydrodynamic evolution of groundwater flow in basaltic formations requires precise knowledge of the flow properties of the host rocks at different scales. The main rock units are basaltic lava series intervened by intrusive rocks (mostly dikes and sills) and lava tunnels. How to relate the permeability to the geological structures? Is the permeability of the basal aquifer controlled by stratification boundaries (lava flow, paleo-soil...); or by faults and fractures along intrusive bodies? By means of a pluridisciplinary approach in rocks mechanics, geomorphology and remote sensing, different scales will be investigated: from the scale of the sample (cm) to the scale of the island (several kilometers).

2.1. At the local and outcrop scales: petrophysical data acquisition

Responsible: Jérôme Fortin

The interpretation of the resistivity distribution obtained by the Skytem experiments (Figure 5) requires a better knowledge of the electrical conductivity of rocks (unsaturated or saturated basalts) as well as its hydraulic conductivity. In this task, we plan to investigate at the scale of sample the physic properties of the Galápagos basalts, as well as the physics properties of paleo-soils, which may impede downward infiltration to the basal aquifer and sustain perched aquifers.

As a consequence, a part of this project is to collect samples at the surface, which could be representative of host rocks of the basal aquifer. At the scale of the lava flow, it has been shown, in Iceland or in the Azores, that the texture of the rock evolves with its height: at the top of the lava flow the basalt is relatively fine grained with groups of larger vesicles, whereas at its bottom the lava flow is coarser grained with a dominant inter-crystalline porosity (Franzson et al. 2001). The method to obtain rock samples involves surface sampling at a scale of a lava flow at different locations. In addition to the sampling of basalts, samples from paleo-soil (Figure 9) will be cored.

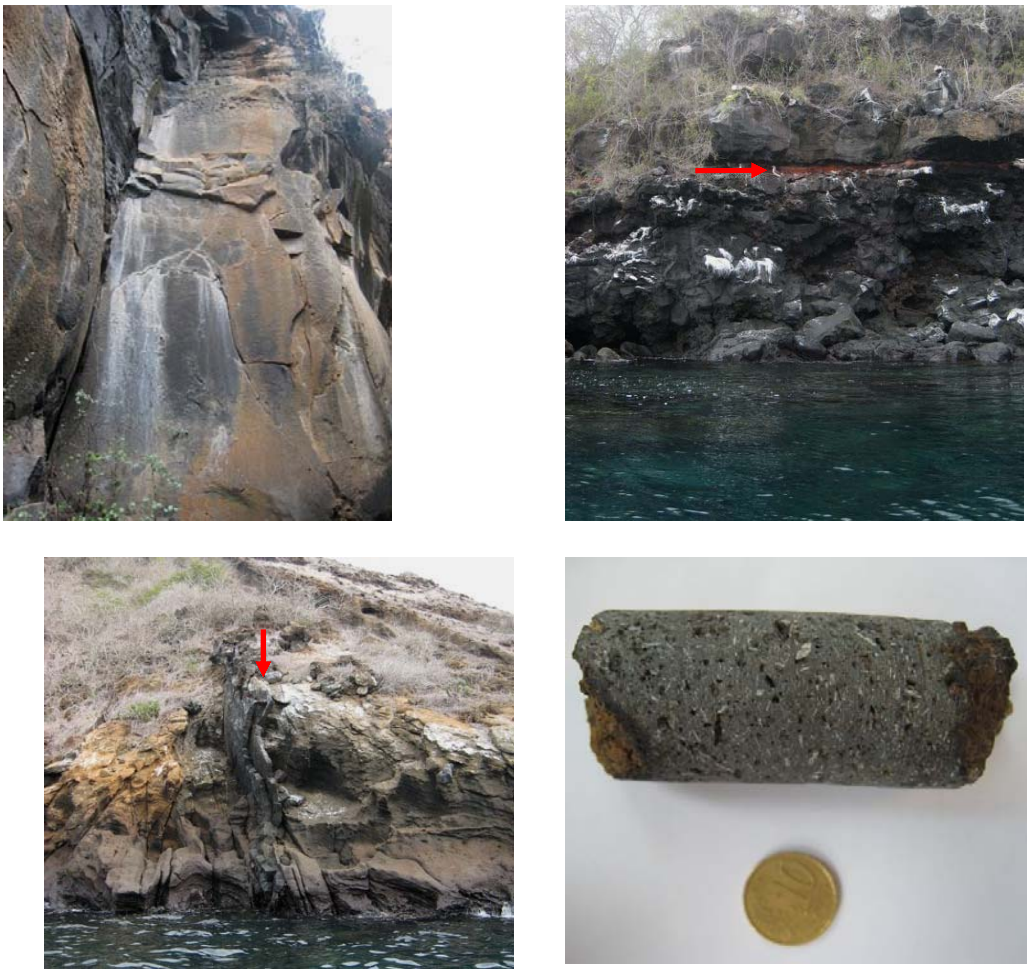


Figure 9 : (from top left to bottom right) (a)Fault scarp revealing thick massive lava flows on Santa Cruz ,(b) paleo-soil overlain by younger lava flows on Floreana Island (red arrow) and (c) Dyke on Floreana Island (red arrow) and (d) sample from Santa Cruz Island reveals connected vesicles.

On theses samples, petrographically analyses through thin sections and laboratory measurements will be carried out. The electrical conductivities of the different samples will be investigated at the *Laboratoire de Géosciences et Environnement de* Cergy. The electrical conductivities will be measured in different conditions: in dry or in saturated conditions and the samples will be saturated with fresh- or sea water. The electrical conductivity will be studied at a fixed frequency of 1 kHz, and the effect of the frequency in the range of 0.1-100 kHz will be explored. Pore size distribution will be determined with mercury injection (experimental set-up available in Cergy).
Other measurements including porosity, elastic wave velocities, and hydraulic conductivity, at ambient pressure and room temperature, will be done at the *Laboratoire de Géologie of the Ecole Normale Supérieure*. The permeability-electrical conductivity relationship will be investigated as these properties depend in a very sensitive fashion on the microstructure of rocks (Gueguen and Palciauskas, 1994).

In addition to the ambient measurements, permeability as well as the elastic wave velocities evolutions with pressure will be investigated. These data will be very useful for the flow models at the regional scale (Task 3). This will be done with the 2 triaxial cells available at the *Ecole Normale Supérieure* (Fortin et al., 2005). The samples will be exposed to confining pressure in the range of 0-30 MPa (equivalent to about 0-1000 m). Karato (1983) found that the permeability of basalt, collected during DSDP in the young oceanic crust near the Galápagos Spreading Center, tended to fall as confining pressure increased to 5 MPa, but were little influenced by subsequent increases. However, recent studies on basalt from Etna, Iceland, and the Azores (Benson et al., 1999, Johnson, 1980, Fortin et al. in preparation) tends to show that the permeability tend to decrease exponentially with pressure.

The different data (porosity, permeability, elastic wave velocities, and resistivity) obtained on Galápagos samples will be also compared to the data collected during DSDP in the young oceanic crust near the Galápagos Spreading Center (Karato, 1983) and to the data from Azores samples (*collaboration ENS – University of Lisbon* under *FREEROCK Project*) and to the data from Icelandic samples (*collaboration ENS-Université du Maine – University of Reijkavick under GEOFLUX project*)

2.2. At the regional scale, geomorphology together with GIS and remote sensing techniques.

Responsible: Benoît Deffontaines

At a larger scale, volcanic formations investigated in 3.3.2.1 are affected by discontinuities that are dikes and sills, lava tunnels, faults and paleo-soils. Both the geometry, distribution, mechanism of propagation and physical properties of these features will be investigated to define their respective impact over groundwater flow. Dikes are sub-vertical magmatic intrusions that can use pre-existing fracture systems and develop within the edifice in accordance with local stresses from tectonic, magmatic and gravitational origins (Chadwick and Dietrich, 1995; Gudmundsoon, 2002). In volcanic edifices, networks of dikes form the plumbing system of eruptive fissures and cones, they are influenced by the tectonic stress history. So as to identify those possible flow barriers and preferential flow discontinuities, cones and faults will be mapped in the frame of this project by means of GIS and remote sensing techniques, together with field investigations. As well, stress field history will be investigated since they influenced the formation of these features. Figure 10 shows an example of cone and fracture mapping on San Cristobal Island (in proggress). We propose to complete these mapping on Santa Cruz Island, which will serve flow models at the regional scale (Task 3).

To complete this task, we have at UMR.7619-*Sisyphe* Laboratory in Paris 6 the required 2D and 3D GIS softwares, additional SPOT and ASTER imageries may be acquired.

Figure 10: Example of cone (brown) and fracture (yellow) mapping on San Cristobal Island completed with SRTM90 and SPOT images, presented over Landsat image (GIIWS project, unpublished).

3.3.3 TÂCHE 3 / TASK 3: GROUNDWATER DYNAMICS WITH FLOW AND TRANSPORT MODELS AT THE REGIONAL SCALE, INTERACTION WITH THE OCEAN

Coordinator: Sophie Violette

Participants: Alexandre Pryet, Dominique Bruel, Patrick Goblet, Jérôme Fortin, Noémi d'Ozouville

Groundwater modelling in Galápagos Island is to date a challenging task: few data on recharge and hydraulic properties, few drill holes to calibrate the model, unknown geometry of the system. The method has nonetheless been regularly used in similar contexts such as in Canary Islands (Custodio et al., 1988), Hawaiian Archipelago (Oki et al., 1998; Gingerich and Voss, 2005) and La Réunion Island (Violette et al., 1997; Join et al. (2005).

Achievements of Tasks 1 and 2 will provide recharge rates, information on rock hydraulic properties, position of regional impervious discontinuities (dykes, red baked paleo-soils) and drains (faults, lava tunnels and fractured dikes). Prospective groundwater flow simulation will assess the coherence between controlling factors (boundary conditions and rock hydraulic properties) and groundwater occurrence inferred by geophysics and drill holes, and other configuration proposed in the literature (Figures 3 to 4).

Groundwater flow simulation will first be performed on 2D-cross section with the METIS code from Paris School of Mines (Goblet, 1981). It solves groundwater flow in unsaturated and saturated media, with the resolution of Richards and Diffusivity equations respectively by finite elements method. The objective will be to assess the occurrence of a perched aquifer on the windward mountainside of the massif accordingly to the geometry as inferred by the geophysics model (Figure 5) and with a methodology similar to Wu and al. (1998), Hinds et al. (1999), Niswonger and Fogg

(2008) and Zhang et al. (2006). To this end the recharge rates estimated on Task 1 will be prescribed and the hydraulic conductivity contrast in between the thin impervious layer and the pervious one will be searched out. This first modelling will help to quantify how the groundwater flow leaks through the impervious layer and/or overflows at the lateral extremity of the perched layer downward to supply the basal aquifer.

The second groundwater flow simulation, performed on 2D-cross section with the same code will include both perched and basal aquifers. For the latter, the boundary condition to the ocean will be taken into account. This modelling will allow us to quantify the groundwater flow released to the ocean and to estimate the extent of the mixing zone in between fresh and saline water.

The third groundwater flow simulation will be done in 3D at regional scale to represent the windward mountain side of the massif, including the two kinds of aquifer, i.e.: perched and basal one. To this end we will deduce the geometry, the barrier and drain features, from the geomorphological analysis (Task 2) and the geophysical model. The hydrodynamic parameters distribution will be inferred from the measurements acquired in the Task 2 and the literature (e.g.: Custodio, 2004; Gingerich and Voss, 2005). To this end we will probably need to test different concepts to represent the wide heterogeneity of the hydrodynamic properties. We will start with a simple model of REV (such as Metis code can do) to a more complex one such as the discrete fracture network with matrix contribution (see description of Altman et al., 1996; Figure: 11) such as the one developed by Baujard and Bruel (2004) and Bruel et al. (2007). Recharge rates distribution at the regional scale will be extrapolate from the local measurements (Task 1). Groundwater flow modelling will be validated with the groundwater level records of the basal aquifer acquired in the “grieta” and boreholes. This modelling could then be constrained by isotopic and noble gas tracers that will be provided by our collaborator from Michigan University.

At each step of these modelling, sensitivity analysis will be performed to assess and quantify the accuracy of our results. This step is essential as our final target is to provide scientific evidences to the local authorities which will serve to define guidelines for water resource management.

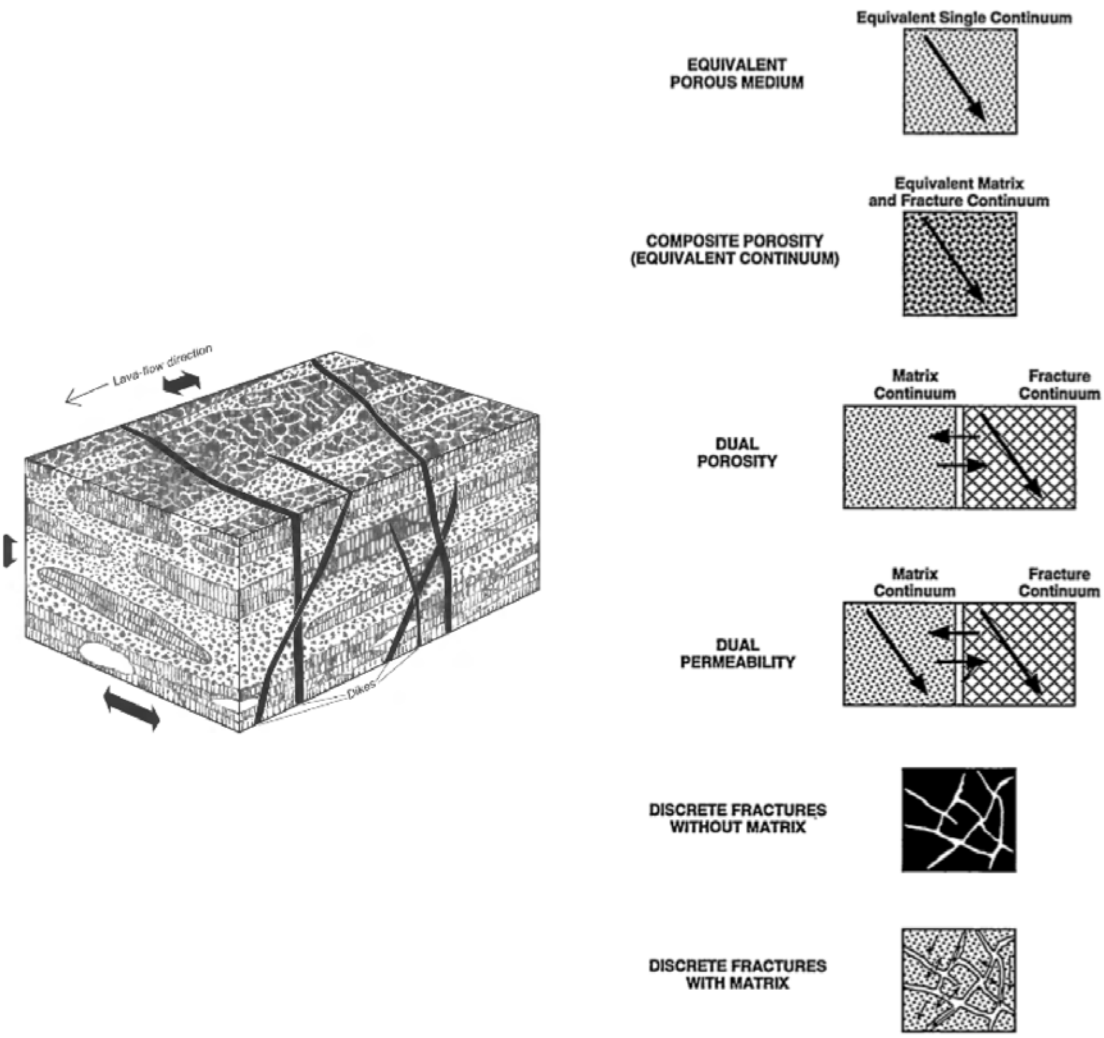


Figure 11: Left: 3D-block showing the heterogeneity observed in volcanic media from Hunt (1996); Right: Different medium models applicable to volcanic formations proposed by Altman et al. (1996)

3.4. CALENDRIER DES TÂCHES, LIVRABLES ET JALONS / PLANNING OF TASKS, DELIVERABLES AND MILESTONES

This interdisciplinary research program will be completed within a clear framework and a defined schedule: each participant, specialist of a research field, will have to provide results that will be exploited by the whole team. Interaction, data sharing and synchronization have therefore a critical importance. Task 3, which will consists in groundwater modelling will be completed with the set of results from tasks 1 and 2, and has therefore to start after the completion of these tasks, though preliminary investigations are possible.

In Galápagos Islands, climatic conditions are characterized by an alternation between the cool and misty “*garúa*” season (January-June), and the hot and rainy “*invierno*” season (July-December)(Figure 12). We expect strength and intensity of the “*garúa*” season to be the critical controlling factor of groundwater recharge, so that our investigations will concentrate on this season, with particular focus on interception of fog water by the vegetation. As a consequence, our schedule will be organized consistently with these seasonal alternations.

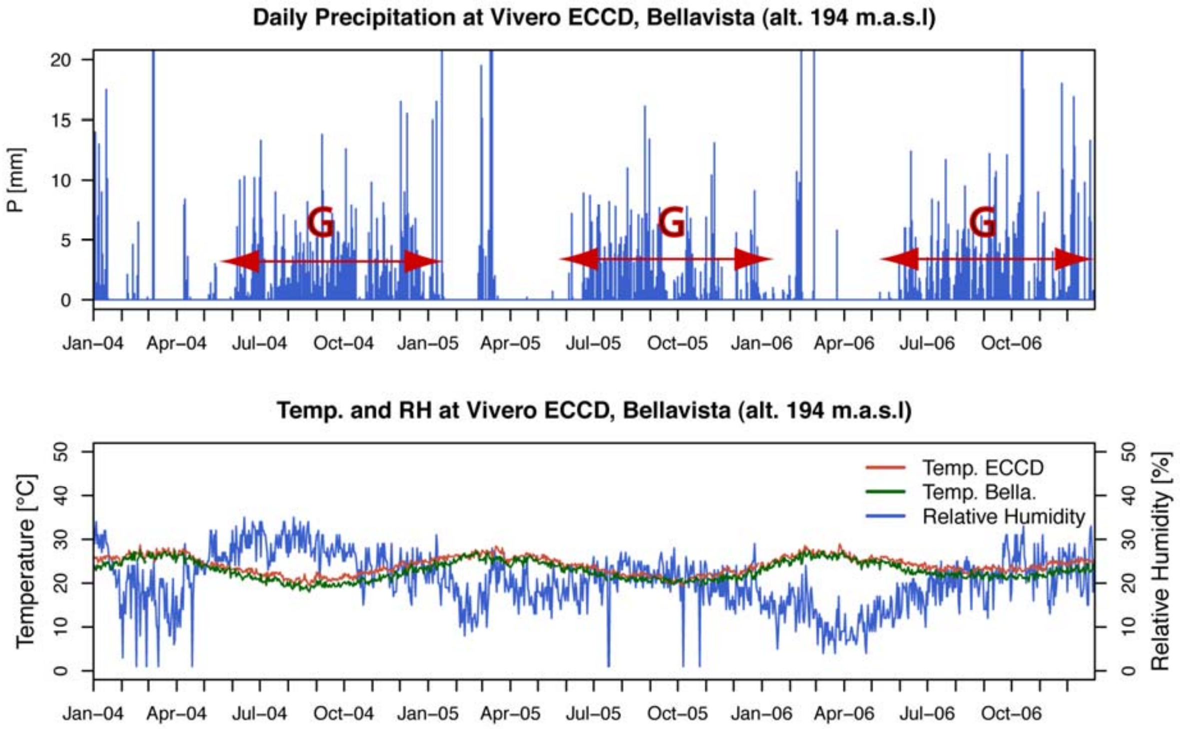


Figure 12: we will adapt our schedule to the natural alternation between the cool and misty "*garúa*" season (Jan-June), and the hot and rainy "*invierno*" season (Jul-Dec)

Imposed over these annual variations, the inter-annual Niño/Niña anomalies of sea water temperature, hot and cold respectively, may influence dramatically the climatic context. Current status determined by the NOAA is « El Niño advisory », that may « begin to decrease in early 2010 » but « persist through April-May-June 2010 ».

Instrumentation on Santa Cruz is supposed to be set up in July 2010 and run up to end 2011, so as to monitor at the minimum two seasonal alternations. In case of major climatic event or instrument failure that could alter the relevance of our result, instrumentation may be kept longer on the field (up to end 2012).

The results of each task will provide data to obtain the « products » presented in table 1, with their expected date of delivery, that may be delayed in case of prolonged instrumentation.

		2010			2011				2012				2013	
task 1: hydro-ecology	where ?	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2
Resp. Noémi d'Ozouville														
climate, veg. and soil monitoring	Galápagos													
soil sampling	Galápagos													
soil samples characterization	France													
vegetation characterization	Galápagos													
task 2: rock hydrophysics														
Resp. Jérôme Fortin														
rock sampling	Galápagos													
field investigations	Galápagos													
rock samples characterization	France													
GIS and remote sensing	France													
task 3: numerical modelling														
Resp. Sophie Violette														
2D modelling with METIS code	France													
modelling with DFN and dbl. K/PHI	France													
3D modelling	France													
Consortium meeting	-	1			2			3			4			5

Table 1: Schedule of the project

	product description	date of delivery
task 1	**hydro-ecology**	
T1.1	quantification of fog interception by the vegetation during the "garúa" misty season on Santa Cruz	December 2011 possibility to extend to June-13
T1.2	Characterization of soils physical properties and distribution on the windward side of Santa Cruz	December 2011 possibility to extend to June-13
T1.3	Quantification of contemporary recharge rates to the groundwater system from an extensive climatic and soil instrumentation on Santa Cruz	December 2011 possibility to extend to June-13
T1.4	Assessment of potential effects of climate change, land use changes and invasive species spreading over Galápagos hydrology	December 2011 possibility to extend to June-13
task 2	**rock hydrophysics**	
T2.1	Characterization of Galápagos basalts hydrophysical properties from sampling and field investigation	December 2011
T2.2	Assessment of the hydrogeological impact of major discontinuities (faults, dykes,…) over regional groundwater flow from remote sensing and field investigations	December 2011
task 3	**numerical modelling**	
T3.1	2D Numerical modelling approach to define a quantified hydrogeological conceptual model for Santa Cruz Island	December 2011
T3.2	An assessment of the controlling factors of perched groundwater in basaltic formations, application on Santa Cruz geological context from 2D complex medium modelling	March-2013
T3.3	Possible impact of climate change, land use change, and invasive species spreading over Galápagos Hydrogeology with a 3D regional numerical modeling for Santa Cruz Island	June-2013
task 4	**Coordination project**	
T4.1	meeting, logistics, writing report and articles, dissemination of results towards the local authorities	Each 6 months

Table 2: Products, person in charge and expected date of delivery

The task 4 will entirely dedicated to coordination. The principal coordinator of the GIIWS proposal, Sophie Violette, will spend two months each year to this task. The local coordinator in Galapagos Islands, Noémi d'Ozouville, will spend also two months each year to this task. Each Task coordinators will spend one month to coordinate its own task. The coordination will consist in: meeting, logistics, writing report and articles, dissemination of results towards the local authorities.

4. STRATEGIE DE VALORISATION DES RESULTATS ET MODE DE PROTECTION ET D'EXPLOITATION DES RESULTATS / DATA MANAGEMENT, DATA SHARING, INTELLECTUAL PROPERTY AND RESULTS EXPLOITATION

Consortium Communication

In order to facilitate the communication between collaborators of our team, located mainly in Paris, Fontainebleau, Anthony, Cergy-Pontoise, but also in Ecuador, we will organize meetings every 6 months in Paris with webcam conference facility for Ecuadorian collaborators. Because of the current activity in the Galápagos, it is essential to maintain open discussions between the members of our team and with researchers participating in the relevant projects on ecohydrology in Galápagos Islands.

We therefore have set up a website (www.Galápagos-hydroloy.com) where information related to field conditions, climate, hydrology, hydrogeology, geology, biology, published data access and new results will be annotated and made freely available. Unpublished data will be made available to members of the consortium only, with restricted access to part of the website.

Data Distribution and Workshop Organization

In order to collaborate actively with the different partners, the hydro-climatological and biological data will be available on a this website to compare results and share data.

In addition, we also plan to organize a workshop in Puerto Ayora (Santa Cruz) in 2012 consisting of a meeting of our group with the other groups involved in Galápagos Islands projects and actors in water management. For this purpose a request of special funding will be made in 2011.

Publications of Results

The results of this project will be published in peer-review international journals and presented at international conferences (AGU and EGU).

5. ORGANISATION DU PARTENARIAT / CONSORTIUM ORGANISATION AND DESCRIPTION

5.1. DESCRIPTION, ADÉQUATION ET COMPLÉMENTARITÉ DES PARTENAIRES / RELEVANCE AND COMPLEMENTARITY OF THE PARTNERS WITHIN THE CONSORTIUM

The principal strength of the team involved in this study is the bringing together of qualified researchers for the achievement of a multidisciplinary project using new and advanced methodologies. The main thematic of the proposal deals with the understanding of the water cycle over the Galápagos Archipelago in the perspective to provide pertinent guidelines for both the conservation of the ecosystems and the management of the resources. We propose to combine the hydrological knowledge with the wealth of information on the unique ecosystems in order to provide keys to better understand and quantify hydrological processes within conceptual model. And in return to generate information which will serve the purposes of the local authorities working on ecological restoration and invasive species management and the local authorities in charge of sustainable development of the local human communities.

The team is composed of qualified and internationally renowned scientists with strong complementary backgrounds:

Ecology: M. Gardener, H. Jäger, W. Tapia
Rock physics, experimental and theoretical approach: C. David, J. Fortin, A. Schubnel
Geomorphology and structural geology: B. Deffontaines
Soil Characterization: C. Chaumont, A. Pryet, J. Tournebize
Evaporation: B. Vincent
Hydrology: C. Chaumont, N. d'Ozouville, A. Pryet, J. Tournebize
Hydrogeology: D. Bruel, P. Goblet, N. d'Ozouville, A. Pryet, S. Violette
Numerical Modelling: D. Bruel, P. Goblet
A federation built around these different competences and experience reinforces the multidisciplinary approach and is crucial for strong data analysis and robust joint interpretations.

The GIIWS proposal is supported by a national partnership in between 4 institutions: UPMC (S. Violette), Armines (D. Bruel), CEMAGREF (J. Tournebize) and ENS (J. Fortin) and a long living Ecuadorian collaboration with the research institution (Charles Darwin Foundation - CDF) and works in close collaboration with the Galápagos National Park (PNG), the regional planning institution (INGALA) and the municipalities.
Dominique Bruel is Senior Researcher, Paris School of Mines-ARMINES, member of the Research Unit "HSR" Center for Géosciences. Field of interest: fractured rock hydrology, transport of heat and contaminants in porous/fractured media, modelling of Thermo-Hydro-Mechanical interactions in hard rocks. Relevant experience for the project comes from early participation in HDR research, in national programs (Geothermie Profonde Généralisée, Mayet de Montagne site, France; MAC2) and in the successive steps of the European EGS program at Soultz sous Forêts.

Julien Tournebize is research engineer with a specialization in soil transfer. He graduated from the National School of Water and Environment Engineering of Strasbourg in 1997. He defended his PhD in 2001 which topic was "Impact of grass cover in Alsacian vineyard on nitrate transfer". He jointed the "Transfer in Agro-Systems" team in 2001. He spent 2 years in Japan as visiting researcher (2003-2004) to work on transfer in paddy field systems. His research focuses mainly on the preservation of water quality at small rural catchment.

Jérôme Fortin is a young research associate (CNRS) recently recruited at the Laboratoire de Géologie (ENS-Ulm). He is a specialist in rock physics, experimental and theorical approach. He had worked on the characterization of soil physical and hydrodynamic properties of alterite cover in Galápagos Island. He also develops competences on the role of fluids in the mechanical behaviour of the crust: seismicity induced by fluid circulation in the Icelandic and the Azores hydrothermal systems through experimental studies.

5.2. QUALIFICATION DU COORDINATEUR DU PROJET / QUALIFICATION OF THE PROJECT COORDINATOR

Sophie Violette is Assistant Professor in Hydrogeology and joins the UPMC in 1995 "Laboratoire de Géologie Appliquée" nowadays UMR.7619-Sisyphe. She developed her expertise on hydrogeology and volcanic island context during her PhD (1990-1993), her temporal Assistant Professor position (1994-1995) and the first phase of the GIIWS project (2003-2007). During her Ph-D she studied the hydrogeology of the Piton de la Fournaise volcano using hydrological and thermal modelling (Violette et al., 1997). Then she studied the mechanical role of rainfall to trigger eruptions using a mechanical stress model (Violette et al., 2001). Galápagos Islands Integrated Water Study project (GIIWS) was a wonderful opportunity to test her expertise on hydrogeology of volcanic Islands in a different climatologic and geological context. It was also a great opportunity to used innovative indirect methodology, such as teledetection (d'Ozouville et al., 2008a) or SkyTEM device (d'Ozouville et al., 2008b; Auken et al., 2009) to reveal the internal structure of a volcano in terms of hydrogeological potential. Her scientific activity includes a large proportion of modelling of groundwater flow constrained by geological, geochemical, isotopic or thermal data. She has a strong experience in collaborative research and coordination of research projects with national (PNRH-Paris Basin Modelling, Eclipse- Paris Basin Modelling-Paleoclimate) and international collaborators (Kaluvelly basin-India; GIISW phase I). Finally, her multidisciplinary background and her field experience, which includes Ecuador, but also: La Réunion, Bulgaria, Madagascar and India make her an ideal candidate for managing the present project.

5.3. Qualification, role et implication des participants / contribution and qualification of each project particpant

Partenaire 1 *UPMC* *UMR.7619-Sisyphe*	Nom	Prénom	Emploi actuel	Discipline	Personne .mois	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur/ responsable	*VIOLETTE*	*Sophie*	*Assistant Professor*	Hydrogeology	18	*Coordinator of the project and of the Task 3* *Hydrogeology and modelling*
membre	d'Ozouville	Noémi	Post-doc	Ecohydrology	36	Local coordinator of the project and Coordination of the Task 1 Ecology and hydrology Scientific dissemination toward local authorities in charge of natural resources management
membre	Pryet	Alexandre	PhD	Hydrology Hydrogeology	24	Field work, data analyses and modelling
Collaborateur UMR-ISTEP	Deffontaines	Benoît	Pr	Geomorphology Structural geology	6	Responsible of task 2.2 Field work, data analyses and GIS
Collaborateur UT-Berlin & CDF	Jäger	Henke	Post-doc	Ecology Biology	12	Field work and data analyses
Collaborateur CDF	Gardener	Mark	Senior Researcher	Ecology Biology	3	Local authorities in charge of natural resource conservation and restoration
Collaborateur GNP	Tapia	Washingto n		Ecology Biology	3	Local authorities in charge of natural resource conservation and restoration

Partenaire 2 *Armines*	Nom	Prénom	Emploi actuel	Discipline	Personne .mois	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur/ responsable	*Bruel*	*Dominique*	*Senior Researcher*	Hydrogeology Numerical modelling	8	*Coordinator Partner 2* *Hydrogeology and modelling*
membre	Goblet	Patrick	*Senior Researcher*	Hydrogeology Numerical modelling	4	*Hydrogeology and modelling*

Partenaire 3 *CEMAGREF*	Nom	Prénom	Emploi actuel	Discipline	Personne .mois	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur/ responsable	*Tournebize*	*Julien*	*Researcher Engineer*	Soil characterization	4	*Coordinator Partner 3* *Field experiment and infiltration modelling*
membre	Vincent	Bernard	*Researcher Engineer*	Evaporation	3	*Field experiment and evaporation quantification*
membre	Chaumont	Cédric	*Assistant Engineer*	Soil characterization	3	*Field experiment and laboratory measurements*

Partenaire 4 *ENS - Laboratoire de Géologie*	Nom	Prénom	Emploi actuel	Discipline	Personne .mois	Rôle/Responsabilité dans le projet 4 lignes max
Coordinateur/ responsable	*Fortin*	*Jérôme*	*Researcher*	Physic and rock mechanic	12	*Coordinator Partner 4* *Field experiment, laboratory measurements and modelling*
membre	Schubnel	Alex	*Researcher*	Rock Physics	4	*Laboratory measurements*
Collaborateur Université Cergy-Pontoise	David	Christian	*Professor*	Rock Physics	4	*Laboratory measurements*

6. JUSTIFICATION SCIENTIFIQUE DES MOYENS DEMANDES / SCIENTIFIC JUSTIFICATION OF REQUESTED BUDGET

6.1. PARTENAIRE 1 / PARTNER 1: UPMC

- *Équipement / Equipment*

Equipment is required to set up the experimental sites of the Task 1, Hydroecological station equipment: weather and soil monitoring station including (from left to right) open air: wind sensor, cylindrical fog collector, rain gauge, set of tensiometers and humidity probes in the soil. Below vegetation: set of tensiometers and humidify probes, throughfall collector. These probes will be connected to an automatic data logger, which can record data with short time steps. For each climatic stage and vegetation type an appropriate station will be set up. To this end 6 stations will be set up. The detailed required equipment of these Hydroecological stations is provided in the following tables.

Humid Zone 4 sites

	COMPONENT DESCRIPTION	SUPPLIER	SUPPLIER REF.	UNIT PRICE (€)	QUANTITY	TAX	AMOUNT (€)
soil	set of tensiometers (30, 60, 90, 115 cm long)	SDEC	SMS20XX	24.50	6	19.60%	175.81
	tension sensor for tensiometers	SDEC	SKT850T	167.32	4	19.60%	800.46
	Vertical profile of 6 temperature probes	SOLS-MESURES	UMS/TH3-V	521.30	1	19.60%	623.47
	Vertical profile of 6 VSWC thetaprobes	SOLS-MESURES	PR2/6	1436.20	1	19.60%	1717.70
weather	tipping bucket rain gauge over/beside vegetation	CAMPBELL	ARG100	385.00	1	19.60%	460.46
	through fall collectors below vegetation	GIIWS		50.00	1	0.00%	50.00
	tipping bucket rain gauge below vegetation	CAMPBELL	ARG100	385.00	1	19.60%	460.46
	cylindrical fog net with its collector (and diver probe)	GIIWS	-	100.00	1	0.00%	100.00
	air humidity /temperature sensor	CAMPBELL	CS215+MET20	352.00	1	19.60%	420.99
data logging	data logger	CAMPBELL	CR1000	1350.00	1	19.60%	1614.60
others	energy supply : 12V batteries	ELECTRONAUTIC		40.00	2	0.00%	80.00
	water proof enclosure / mast	CAMPBELL	ENC 12/14	228.00	1	19.60%	272.69
			QUANTITY OF STATIONS:	1		TOTAL (€):	6776.64

Very Humid Zone (2 sites)

	COMPONENT DESCRIPTION	SUPPLIER	SUPPLIER REF.	UNIT PRICE (€)	QUANTITY	TAX	AMOUNT (€)
weather	automatic rain gauge above vegetation	SDEC	ARG100	385.00	1	19.60%	460.46
	automatic rain gauge below vegetation	SDEC	ARG100	385.00	1	19.60%	460.46
	cylindrical fog net with its collector (and diver probe)	GIIWS		100.00	1	0.00%	100.00
	air humidity /temperature sensor	CAMPBELL	CS215+MET20	352.00	1	19.60%	420.99
	rover (funnel + collector)	GIIWS		80.00	4	0.00%	320.00
data logging	data logger	CAMPBELL	CR200	408.00	1	19.60%	487.97
			QUANTITY OF STATIONS:	1		TOTAL (€):	2249.88

Additional portable equipment

	COMPONENT DESCRIPTION	SUPPLIER	SUPPLIER REF.	UNIT PRICE (€)	QUANTITY	TAX	AMOUNT (€)
all applications	accurate weighing machine	VWR		298.00	1	19.60%	356
weather	45mm diameter spiral auger	SOLS-MESURES	DLT/ML2-AG1-SL	237.20	1	19.60%	283
	VSWC Probe Hydrosense TDR manual portable system	CAMPBELL	CD620+CS620	702.00	1	19.60%	840
						TOTAL (€):	1480

Equipment is also required for the purpose of task 2, to get water level measurement of the basal aquifer on the boreholes and “grietas”. CDT diver probes which ensure pressure, temperature and electrical conductivity records will be choose. The number is 10 and their cost 1000 € each.

For the two tasks a specific laptop able to go the field will be necessary, its cost is evaluated to 1500 €.

For the task 3, a labtop with good computing facilities and suitable softwares will be necessary, its cost is evaluated to 2500 €.

For the local coordinator a laptop is also required, its cost is evaluated to 1500 €.

Equipment	**48600 €**
Hydro-climatic experiment stations	33100
CDT Divers	10000
Labtops	5500

- *Personnel / Staff*

One PhD student, Alexandre Pryet will participate in this project and will be in charge of a main part of the estimation of groundwater recharge and fog interception by the vegetation in different contexts and will perform the first 2D simulation to assess the occurrence of perched aquifer. The PhD fellowship is funded by the CNRS (BDI grant).

A Post-doc Position will be supported by the ANR-Blanche GIIWS application.
The high environmental and social stakes which surround the current state of development of the Galápagos Islands implies that research projects undertaken in the Islands carry a certain responsibility in their execution and that medium to long term commitment should be encouraged. Also the scientific content of projects needs to fill current gaps of knowledge and complement existing research. Given this background, Noémi d'Ozouville, instigator of the Galápagos Islands Integrated Water Studies project following a six months stay in the islands as a volunteer, is now living in the Galápagos Islands following a successful PhD setting the bases for Galápagos Hydrology. She continues to work for the Galápagos Islands Integrated Water Studies program as local coordinator and her recent informal collaborations with fellow marine biologists and botanists has led her to expand her scientific field of expertise to hydro-ecology. Within the context of a post-doctoral fellowship at the Université Pierre et Marie Curie, she will be based at the Charles Darwin Research

Station where she will build up a collaborative long-term hydro-ecology program within the restoration ecology flagship projects. Her knowledge of the field, her strong ties with the local institutions, and her scientific and analytical capacities give her an unprecedented position to carry out this task. She will coordinate the deployment of instruments in the field with the collaborating scientists and local institutions and will ensure a smooth transition of the collected data to the appropriate databases and scientists. Her main theme of research will be the characterization of the "garúa" season as a key element to understanding the hydrology of the islands, the highland ecosystems and more recently identified as a critical system in view of potential impacts of climate change.
Her attachment with the Université Pierre et Marie Curie will give her the scientific support and entourage to achieve the set objectives, whilst the Charles Darwin Research Station is the optimal place for a scientist to work while in the field and guarantees daily contact with the biological sciences community. Her status at the Charles Darwin Research Station will also facilitate the coordination component with other local institutions.

One Post-doc, Heinke Jäger will participate in this project and will be in charge of the ecological aspect of the project. Her post-doc fellowship is funded by the TU-Berlin.

Salary	**162000 €**
Post-Doc Position 36 months * 4500 €	162000

- *Ministry.Prestation de service externe / Subcontracting*

In view to ensure collaborative work with the CDF and the PNG, logistic fees have to be paid by the GIIWS team to these institutions. To realize the maintenance of the hydro-ecological stations and the pressure probes a technician will be recruited. This will be subcontracted to the CDF.

Subcontracting	**40000 €**
CDF and GNP logistic fees	10000
CDF Maintenance of hydroclimatologic experiment 36 months	30000

- *Missions / Missions*

Task 1 and 2 required mission such as field work at least 15 days each, estimated cost 5000 € (ticket far, visa, local taxi for displacement to the field, accommodation, material and samples shipping). Eight missions are planned. Dissemination of results to the scientific community will required at least 3 missions, 2000 € each.

Missions	**46000 €**
Field work experiment, 8 missions	40000
Scientific dissemination, 3 missions	6000

- *Dépenses justifiées sur une procédure de facturation interne / Internal expenses*

- *Autres dépenses de fonctionnement / Other expenses*

Field work on task 1 and 2 and computing facilities task 3 required consumable, publishing expense also has to be considered.

Other expenses	**22500 €**
Consumable for field work	10000
Consumable for computing facilities	7500
Publishing expense	5000

6.2. PARTENAIRE 2 / PARTNER 2: CEMAGREF

- *Équipement / Equipment*
- *Personnel / Staff*
- *Ministry.Prestation de service externe / Subcontracting*
- *Missions / Missions*

Implication of CEMAGREF team on Task 1 required mission such as field work at least 15 days each, estimated cost 5000 € (ticket far, visa, local taxi for displacement to the field, accommodation, material and samples shipping). Three missions are planned. Dissemination of results to the scientific community will required at least 2 missions, 2000 € each.

Missions	**19000 €**
Field work experiment, 3 missions	15000
Scientific dissemination, 2 missions	4000

- *Dépenses justifiées sur une procédure de facturation interne / Internal expenses*
- *Autres dépenses de fonctionnement / Other expenses*

Field work and computing facilities on task required consumable, publishing expense also has to be considered.

Other expenses	**8000 €**
Consumable for field work	5000
Consumable for computing facilities	1000
Publishing expense	2000

6.3. PARTENAIRE 3 / PARTNER 3: ENS

- *Équipement / Equipment*
- *Personnel / Staff*
- *Ministry.Prestation de service externe / Subcontracting*

For the purpose of task 2, the electrical conductivities will be measured in different conditions: in dry or in saturated conditions and the samples will be saturated with fresh- or sea water. The electrical conductivity will be studied at a fixed frequency of

1 kHz, and the effect of the frequency in the range of 0.1-100 kHz will be explored. Pore size distribution will be determined with mercury injection. These experiments will be subcontracted to University of Cergy-Pontoise.

Subcontracting	**2500 €**
Experimental work on electrical conductivity measurements	2500

- *Missions / Missions*

Implication of ENS team on Task 1 and mainly on 2 required mission such as field work at least 15 days each, estimated cost 5000 € (ticket far, visa, local taxi for displacement to the field, accommodation, material and samples shipping). Three missions are planned. Dissemination of results to the scientific community will required at least 2 missions, 2000 € each.

Missions	**19000 €**
Field work experiment, 3 missions	15000
Scientific dissemination, 2 missions	4000

- *Dépenses justifiées sur une procédure de facturation interne / Internal expenses*

- *Autres dépenses de fonctionnement / Other expenses*

Field work (Participation at the acquisition of a permeameter), experimental work (Thin sections preparation, Supplies/Consumables for permeability measurements and other physical properties) and computing facilities on task 1, 2 and 3 required consumable, publishing expense also has to be considered.

Other expenses	**21000 €**
Consumable for field work	8500
Consumable for experiment work	9500
Consumable for computing facilities	1000
Publishing expense	2000

6.4. PARTENAIRE 4 / PARTNER 4: ARMINES

- *Équipement / Equipment*

- *Personnel / Staff*

- *Ministry.Prestation de service externe / Subcontracting*

- *Missions / Missions*

For implication of ARMINE team on Task 3 two for dissemination of results to the scientific community will required at least 2 missions, 2000 € each.

Missions	**4000 €**
Scientific dissemination, 2 missions	4000

- *Dépenses justifiées sur une procédure de facturation interne / Internal expenses*

- *Autres dépenses de fonctionnement / Other expenses*

For the purpose of task 3 consumable and publishing expense have to be considered.

Other expenses	**3000 €**
Consumable for computing facilities	1000
Publishing expense	2000

7. ANNEXES

7.1. RÉFÉRENCES BIBLIOGRAPHIQUES / REFERENCES

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7.2. BIOGRAPHIES / CV, RESUME

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Profile Hydrology, Hydrogeology, Hydrogeological modelling

Formation
2003 - Habilitation to Direct Research: Paris 6 - Conceptualization and modelling of aquifer systems.

1993 - Doctor in Hydrogeology: *Thesis in Hydrology Sciences* Paris 6 - Groundwater modelling through Fournaise volcano: water balance and thermal exchange approaches

1990 - Graduate in Hydrogeology: *D.E.A."National of Hydrology"*, Laboratoire de Géologie Appliquée. Paris 6 & Centre d'Informatique Géologique, ENSMP

1998 **- Undergraduate in Geology:** *Maîtrise "Sciences of Earth"*, University of Caen

Research Thematic deals with the understanding of circulation over large time and space scales and is carried along two different lines: i) understanding fluid transfer in sedimentary basins; ii) hydrogeological study of vulnerable systems situated in volcanic island, crystalline or sedimentary-coastal environments and subjected to grave human- and/or climate-induced stress. The two lines of inquiry are closely related as both included a large proportion of modelling of groundwater flow constrained by geological, geochemical, isotopic or thermal data.

List of 5 Recent Publications

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Research visits: CNRS delegation (full time researcher) September 2003 to August 2005, with six months sabbatical at Stanford University USA, GES Department, Steve Gorelick team. Visitor Scientist (two months) at The John Hopkins University USA, Earth Science Department, Grant Garven team.

Other Professional Experience
Responsible of programs: 'PBM-Tracer – Phase III', 2008-2010, industrial partnership (GdF-Suez); 'GIIWS – Phase II', 2008-2012, with N. d'Ozouville as local coordinator
Advisor or Co-Advisor of: 1 Post-doc, 15 PhD students, 17 graduate students and 10 undergraduate students since 1993.
International Collaborations: CDRS-Equator, ESRIN/ESA-Italy, FSS-Bulgaria, Aarhus University-Denmark, INAMI-Equator, JHU-USA, Michigan University-USA, Minneapolis University-USA, NGRI-India, PETROBRAS-Brazil, SNPG-Equator, Stanford University-USA, USGS-USA
Teaching activities concern general and quantitative hydrogeology lectures, fieldworks and modelling seminar for undergraduate and graduate students.

Name: d'OZOUVILLE Noémi **Gender:** F **Age:** 31 **Position:** Consultant, Conservation International

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Equateur
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Profile
Applied research in hydrology and hydrogeology.

Formation/Positions:
2008-2009: Coordinator of the Galápagos Climate Change Vulnerability Assessment program.
2007-2009: Galápagos Coordinator of the Galápagos Islands: Integrated Water Studies (GIIWS) project
2002-2007: Ph.D in Hydrogeology, Univ. Paris VI (Supervisors: S. Violette and G. de Marsily)
« Etude du fonctionnement hydrologique dans les Iles Galápagos: Caractérisation d'un milieu volcanique insulaire et préalable à la gestion de la ressource. »
2006: Prix de la Chancellerie des Universités de Paris.
2001-2002: DEA (Master) Hydrogeology-hydrology, Paris VI.
1996-2000: M.Sci Environmental Geosciences, University College London

Research Thematic:

Hydrology and hydrogeology of fragile ecosystems, undergoing increasing anthropogenic pressure, are studied through an interdisciplinary approach, based on the complementarity of different scientific methods. Some of the key challenges of the work are: a) finding cost effective ways of carrying out field based investigations and b) testing novel methods which can generate results new to science. Currently developing a hydro-ecology program at the Charles Darwin Foundation to address climate change impacts on the Galápagos ecosystems, the need for ecosystem restoration, and the ongoing quest to conserve of the pristine biodiversity.

List of 5 Recent Publications:

N. d'Ozouville, G. Di Carlo, F. Ortiz, F. De Koning, S. Henderson, and E. Pidgeon, 2010. Galápagos in the face of climate change: considerations for biodiversity and associated human well-being. In: Galápagos Report 2009-2010. Ingala, FCD, PNG. Quito.

E. Auken, S. Violette, **N. d'Ozouville**, B. Deffonatines, K. Sorensen, A. Viezzoli, and G. de Marsily. 2009. An integrated study of the hydrogeology of volcanic islands using helicopter borne transient electromagnetic: Application in the Galápagos Archipelago. *Comptes Rendus Geosciences*, Hydrogeophysics. **341**, 899-907. doi: 10.1016/j.crte.2009.07.006

N. d'Ozouville, B. Deffonatines, J. Benveniste, U. Wegmuller, S. Violette and G. de Marsily. 2008. DEM generation using ASAR (ENVISAT) for addressing the lack of freshwater ecosystems management, Santa Cruz Island, Galápagos. *Remote Sensing of Environment*, Applications of Remote Sensing to Monitoring Freshwater and Estuarine Systems, **112,** 4131-4147. doi: 10.1016/j.rse.2008.02.017

N. d'Ozouville, E. Auken, K. Sorensen, S. Violette, G. de Marsily, B. Deffonatines and G. Merlen. 2008Extensive perched aquifer and structural implications revealed by 3D resistivity mapping in Galápagos volcano. *Earth and Planetary Sciences Letters*. **269,** 518−522. doi: 10.1016/j.epsl.2008.03.011

M. Adelinet, J. Fortin, N. **d'Ozouville**, and S. Violette. The relationship between hydrodynamic properties and weathering of soils derived from volcanic rocks - Galápagos Islands (Equator), 2007. *Environmental Geology, doi:10.1007/s00254-007-1138-3.*

Name: JÄGER Heinke **Gender:** F **Age:** 43 **Position:** scientific assistant and post doctoral researcher

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Department of Ecology
Chair of Ecosystem Sciences and Plant Ecology
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Germany
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Profile Plant Ecology, Invasion Biology, Island Ecosystems

Formation

2008 – PhD Dissertation in Ecology: "Invasion and control of the introduced red quinine tree (*Cinchona pubescens*) in Galápagos: long-term impacts on the native flora"

2000 – 2005 Senior Plant Ecologist at the Charles Darwin Foundation, Galápagos

Since 2003 Member of the IUCN Galápagos Plant Specialist Group (Species Survival Committee)

1999 – Graduate in Plant Ecology: Oldenburg University, Germany

1995 – Undergraduate in Biology: Konstanz University, Germany

1984 – 1991 Research Technician at the Institute of Crop Science and Plant Breeding, Kiel University, Germany.

Research Thematic i) understanding the ecology of island ecosystems, especially the interactions of plants with different biotic and abiotic variables, ii) conservation of threatened plant and animal species, iii) identifying fundamental principles of biological invasions. This especially includes the evaluation of climate variables on the establishment and spread of invasive plant species and of the impacts of invasive plant species on the resident flora. Another focus of the research is the anthropogenically induced spread of non-native species.

List of 5 Recent Publications

Jäger, H. & Kowarik, I. (accepted) Resilience of native plant community following manual control of invasive *Cinchona pubescens* in Galápagos. Restoration Ecology.

Jäger, H., Kowarik, I. & Tye, A. (2009) Destruction without extinction: Long-term impacts of an invasive tree species on Galápagos highland vegetation. Journal of Ecology 97: 1252-1263.

Kowarik, I., Jäger, H., Fischer, L. & von der Lippe, M. (2009) Positive and negative effects of biological invasions on oceanic islands using the example of the red quinine tree (*Cinchona pubescens*). Ber. d. Reinh.-Tüxen-Ges. 21, 162-173.

Jäger, H., Tye, A. & Kowarik, I. (2007) Tree invasion in naturally treeless environments: Impacts of quinine (*Cinchona pubescens*) trees on native vegetation in Galápagos. Biological Conservation 140: 297-307.

Tye, A. & Jäger. H. (2000) *Galvezia leucantha subsp*. *porphyrantha* (Scrophulariaceae), a New Shrub Snapdragon Endemic to Santiago Island, Galápagos, Ecuador. Novon 10(2): 164-168, Missouri Botanical Garden, USA.

Research visits: Charles Darwin Foundation (twice every year from 2005 – 2009), Brown University (3 months each in 2008 and 2009), University of Rhode Island (3 weeks in 2009).

Scientific Collaborations: Brown University, Délégation à la Recherche de la Polynésie française, Tahiti, Freie Universität Berlin, South Pacific Regional Environment Programme, Samoa, Technische Universität München, University of Delaware, University of Rhode Island, U.S. Geological Survey, Hawaii.

Teaching and Mentoring: advising of 1 PhD student, 2 graduate students and 6 undergraduate students, tutorial wild flower identification and field courses in vegetation sciences (2009), lectures and field courses about the Galápagos Flora at Universidad San Francisco de Quito, Ecuador (2009)

Name: PRYET Alexandre **Gender:** M **Age:** 24 **Position:** PhD Student, UPMC-CNRS

Contact

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75252 Paris Cedex 05

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Profile Hydrology, Hydrogeology, Hydrogeological modeling

Research Thematic: Quantitative hydrogeology in hard rock and volcanic environments. Field investigations in volcanic geomorphology and hydrology, soil characterization and monitoring.

Education

2008 – present**:** PhD Student at the UPMC-CNRS Sisyphe Lab "Characterization of hydrogeological potential of volcanic islands, applied on Galápagos Islands."

2007- 2008: Master Student at the Freie Universität Berlin, department of Hydrogeology

2005-2008: Student at the French National School of Geology (ENSG Nancy)

Internships / Student projects

2008: IGIP (Darmstadt, Germany – Benin, West Africa) – 5 months – Hydrogeology and remote sensing: "Remote sensing with ASTER imagery as a tool for drill hole implantation for village water supply in hard-rock contexts"

2007: French Geological Survey (Réunion Island, France) – 3 months – Hydrogeology and protection of the resource from industrial activity in coastal areas of volcanic island.

2007: LIAD (Nancy, France), Student project – C++ programming to implement a finite element transport model in porous medium to the Gocad geomodeler.

Name: BRUEL Dominique **Gender:** M **Age:** 47 **Position:** Senior Researcher

Contact

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email: dominique.bruel@mines-paristech.fr Phone: 01.64.69.47.54 Fax: 01.64.69.47.03

Profile Hydrology, Hydrogeology, Numerical modelling

Formation

1990 - Ph.D in Hydrology and Quantitative Hydrogeology - ENSMP

1985 - Engineering diploma – ENSH-Grenoble, option Water Resources and Planning

Research Thematic

- Conceptualization of physical processes acting in fluid transfers through hydrogeological systems in continuous or fractured media
- Development of numerical simulation tools, use of computer codes

Activities in the field of fractured media

Study of water resources in fractured media, characterization of the hydrogeological properties of semi confined aquifers

* Partner of the CNRS EC2CO, MACH1 programme, hydrogeology of carbonated cracked media - flow, managed by Poitiers University (2006)

* Participation in the France-India cooperation programme CEFIPRA, project IFCGR n°2013-1, 1999-2003, on hydrogeology in semi-arid climatic conditions. Characterization of transfers in the cracked weathered superficial zone and developing of the best strategies for the use of the resource at the scale of an overexploited watershed

Exploitation of heat deeply present in hard rocks (Enhanced Geothermal Systems)

* Use of stochastic methods for the geometrical description of discontinuous media. FRACAS Code, partnership ADEME, BRGM

* Treatment of thermo-hydro-mechanical couplings in the fractures of a rock mass and simulation of tracing tests. Help for the dimensioning of an experimental geothermal project such as Hot Fractured Rock. European Project of Soultz sous Forêts, 1994-1998 ; 1998-2000, 2001-2004, FP6-Strep 2004-2007.

List of 5 Recent Publications

Bruel, D. (2007) Using the migration of the induced seismicity as a constraint for fractured hot dry rock reservoir modelling. *Int. J. Rock. Mech. Mining Sci., doc: 10.1016 /j.ijrmms .20 07.07.001.*

Baujard,C. and Bruel, D. (2007) Recent results on the impact of fluid density on the pressure distribution and stimulated area in a fractured reservoir using a finite volume numerical code. *Geothermics,* 35, 607-621

Bruel, D., Faisal, K. and Engerrand, C. (2007). Upscaling of slug test hydraulic conductivity using a Discrete Fracture Network modelling in granitic aquifers. *Groundwater Dynamics in Hard Rock Aquifers*, *Sustainable Management and Optimal Monitoring Network Design*. S Ahmed, R. Jayakumar, A Salih (eds), Capital Publishing Company, New Delhi, pp.123-133

Jeong, W.C. Bruel D., and Cho, C.H.O. (2006) Numerical experiments of flow and transport in a variable-aperture fracture subject to effective normal stresses. *Journal of Hydraulic Research,* 44, n°2, pp. 259-268

Gonçalvès J., Violette S., Guillocheau F., Pagel M., Bruel D., Robin C., Marsily G. de, Ledoux E., (2004). Contribution of a 3D regional scale basin model to the study of the past (diagenetic) fluid flow evolution and the present hydrology of the Paris basin, France. *Basin Research*, vol. 16, issue 4, 569-586

Other Professional Experience

Supervising of: theses (C. Baujard, 2005 ; W.C. Jeong, 2000), post-doctorate young researchers (C. Engerrand, 2000 ; E. Preziosi, 1998 ; Ph. Renard, 1997), DEA and Master2.

Participation in theses juries

in Internal Geophysics (examinor)

Name: TOURNEBIZE Julien **Gender:** M **Age: 36** **Position:** Research Engineer

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Profile Hydrology, Soil Science, Unsaturated Soil Modelling

Formation

2001 - Doctor in Physic: *Thesis in Fluid Mechanic, University of Strasbourg. "Impact of grass cover in Alsacian Vineyard on nitrate transfer", supervisor Ph. Ackerer & C. Gregoire.*

1997 - Graduate in Soil Science, Hydrogeology, Hydrology: *D.E.A."Protection, Aménagement, Exploitation du Sol et du Sous-Sol (PAE3S)*, ENSG/ENGEES/ENMN, Nancy.

1997 **- Graduate in Engineering from National School of Water and Environment Engineering of Strasbourg.**

Research Thematic deals with the understanding of water and solute (nitrate and pesticide) transfer from plot to small rural catchment. Researches focus on soil transfer processes and surface and subsurface flow interactions. Approaches are based on monitoring at different scales (soil profile, outfall discharge, …), on tracer experiments for "in situ" or controlled conditions in laboratory, and on modelling.

List of 5 Recent Publications

Billy, C., Billen, G., Sebilo, M., Birgand, F., and **Tournebize, J.** (2010). Nitrogen isotopic composition of leached nitrate and soil organic matter as an indicator of denitrification in a sloping drained agricultural plot and adjacent uncultivated riparian buffer strips. Soil Biology and Biochemistry 42, 108-117.

Branger, F., **Tournebize, J.**, Carluer, N., Kao, C., Braud, I., and Vauclin, M. (2009). A simplified modelling approach for pesticide transport in a tile-drained field: The PESTDRAIN model. Agricultural Water Management 96, 415-428.

Passeport, E., **Tournebize, J.**, Jankowfsky, S., Prömse, B., Chaumont, C., Coquet, Y., and Lange, J. (underpress). Artificial Wetland and Forest Buffer Zone: Hydraulic and Tracer Characterization. Vadoze Zone Journal. Accepted.

Tournebize, J., Arlot, M. P., Billy, C., Birgand, F., Gillet, J. P., and Dutertre, A. (2008). Quantification et maîtrise des flux de nitrates : de la parcelle drainée au bassin versant. Ingénierie Eau Agriculture et Territoires. Special Issue, 5-25.

Tournebize, J., Watanabe, H., Takagi, K., and Nishimura, T. (2006). The development of a coupled model (PCPF-SWMS) to simulate water flow and pollutant transport in Japanese paddy fields. Paddy and Water Environment 4, 39-51.

Watanabe, H., Nguyen, M. H. T., Souphasay, K., Vu, S. H., Phong, T. K., **Tournebize, J.**, and Ishihara, S. (2007b). Effect of water management practice on pesticide behavior in paddy water. Agricultural Water Management 88, 132-140.

Research visits: Visitor Scientist at Tokyo University of Agriculture and Technology, Tokyo, Japan, from March 2003 to June 2004.

Other Professional Experience
Advisor or Co-Advisor of: 1 Post-doc, 3 PhD students, 10 graduate students and 10 undergraduate students since 1998.
Teaching activities concern agricultural landscaping, surface water quality and water management lectures for undergraduate, graduate students and continuing vocational training.

Name: CHAUMONT Cédric **Gender:** M **Age: 41** **Position:** Assistant Engineer

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Profile Hydrometry, Soil Science, Instrumentation & Metrology

Formation

1989 - Two-year technical degree: *Control of the water in agriculture, agricultural secondary school of Nîmes.*

1987 - School leaving certificate: *D' Series (Speciality agriculture)*, *agricultural secondary school of Angers.*

Research Thematic My work is the experiment in the field of the quantity and quality of water transfer. I develop monitoring systems of measurement at the scale of laboratory (physical model) or the scale of plot or small rural catchment area with per example: soil characterization, discharge and residence time of water.

List of 5 Recent Publications

Passeport, E., Tournebize, J., Jankowfsky, S., Prömse, B., Chaumont, C., Coquet, Y., and Lange, J. (underpress). Artificial Wetland and Forest Buffer Zone: Hydraulic and Tracer Characterization. Vadoze Zone Journal. Accepted.

Mechanisms of surface runoff genesis on a subsurface drained soil affected by surface crusting: a field investigation, (2005). Augeard B., Kao C., Chaumont C., Vauclin M. / Physics and Chemistry of the Earth, 30, 598-610. doi:10.1016/j.pce.2005.07.014

Evaluation of the sap flow determined with a heat balance method to measure the transpiration of a sugarcane canopy (2005). Chabot, R., Bouarfa, S., Zimmer, D., Chaumont, C., Moreau, S. Agricultural Water Management, Volume 75, Issue 1, Pages 10-24.

Four-electrode conductivity probes for estimation of spatial distribution of solute transport in variably saturated soils. Paris T.; Kao C.; Chaumont C.; Tournebize J. / Poster EGU Nice 2004

Experimental estimation of solute transport parameters in unsaturated soil : From the soil column to the tank. Paris, T.; Kao, C.; Chaumont, C.; Tournebize, J.; Gaudet, J.P.; Bariac, T.; Benedetti, M.Communication EGU Nice 2004

Other Professional Experience

International cooperation (Volunteer of the national service): 1990-91 with IRD **"Resistance of the millet to the water stress".**
Technical Advisor: 1 Post-doc, 12 PhD students, 12 graduate students since 1992.
Teaching activities concern agricultural landscaping and continuing vocational training.

Name: FORTIN Jérôme **Gender:** M **Age:** 32 **Position:** Research associate, CNRS (CR2)

Contacts:

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fortin@geologie.ens.fr 01.44.32.22.06
http://www.geologie.ens.fr/~fortin/

Profile: Rock physics, experimental and theoretical approach

Formation:

2005 : Ph.D in Geosciences, at the ENS (Supervisors: Y. Guéguen and Y. Leroy)
« Compaction homogène et compaction localisée des roches poreuses – Etude théorique et expérimentale »
2002 : Graduate in Hydrogeology DEA Hydrogeology-hydrology, Paris VI.
2002 : Engineer diploma in the rural engineering, water and forest (ENGREF)
2000 : Admitted to the national competitive exam for recruiting teachers ('Agrégation'),in civil engineering
1999 : Undergraduate in Civil Engineering, Ecole Normale Supérieure de Cachan

Research Thematic:

Mechanics of porous rocks: localization of the deformation; evolution of the permeability induced by compaction or localization. Investigation of elastic properties of porous/cracked saturated rocks, frequency effect. Development of effective media models and poroelastic models. Role of fluids in the mechanical behavior of the crust: seismicity induced by fluid circulation in the Icelandic and the Azores hydrothermal systems through experimental studies.

List of 5 Recent Publications:

M. Adelinet, J. Fortin, Y. Gueguen, A. Schubnel and L .Geoffroy. Frequency and fluid effects on elastic properties of basalt: Experimental investigations, in press in *Geophysical Research Letters*.
J. Fortin, S. Stanchits, G. Dresen and Y. Gueguen. Acoustic emissions monitoring during inelastic deformation of porous sandstone: comparison of three modes of deformation. *Pure and Applied Geophysics,* 2009, doi : 10.1007/s00024-009-0479-0.
M. Adelinet, J. Fortin, N. D'Ozouville, and S. Violette. The relationship between hydrodynamic properties and weathering of soils derived from volcanic rocks - Galápagos Islands (Equator), 2007. *Environmental Geology, doi:10.1007/s00254-007-1138-3.*
J. Fortin, A. Schubnel, and Y. Guéguen. Effect of pore collapse and grain crushing on ultrasonic velocities and Vp/Vs, 2007,. *Journal of Geophysical Research. 112, doi:10.129/2005JB004005*
J. Fortin, S. Stanchits, G. Dresen and Y. Guéguen. Acoustic emission and velocities associated with the formation of compaction bands, 2006. *Journal of Geophysical Research. Vol. 111. B10203, doi:10.1029/2005JB003854,*
11 publications in peer review journals since 2005.

Research visits : *2006, 2007, 2004 (16 months) :* GeoforschungsZentrum Postdam, Geomechanics and rheology department, Germany, in the team of G. Dresen. *2002 (3 months)* : Laboratory of rock physicks, Stony Brook, State of New York, in the team of T.F. Wong

Other Professional experience:

- 2005-2009 : Assistant professor at the Geosciences Department of the Ecole normale supérieure (Paris).
- Advisor or Co-Advisor of: 2 PhD students and 5 graduate students since 2006.
- Industrial partnership (CEA and Areva) 2007-2010

1. UPMC - Université Pierre et Marie Curie (Paris VI)
UMR.7619-Sisyphe - Equipe "hydrogéologie"
Intervenants GIIWS: N. d'Ozouville, A. Pryet, S. Violette
In collaboration with UMR.7693-ISTeP
And collaborators: B. Deffontaines
In collaboration with Charles Darwin Foundation and Galápagos National Park
And collaborators: M. Gardner (CDF), H. Jager (CDF & TU-Berlin), W. Tapia (PNG)

The research unit Sisyphe is supported by the French National Research Council (CNRS) and the Université Pierre et Marie Curie (UPMC). Besides having a strong expertise in quantitative hydrogeology, it has pioneered integrated water quality studies, owing especially to the 20-year long regional research project PIREN-Seine, which focuses on the links between the Seine River and the social systems within its watershed. Since the early 2000s, Sisyphe has also conducted several projects on the impacts of climate change on water resources, hydrological regimes, and water quality in this regional scale watershed. L'UMR 7619 Sisyphe includes offices, labs for biogeochemistry, hydrology and geophysics, and a basement for special experiments.
Major equipment: The hydrology laboratory uses classical hydrology and hydrogeology field equipment such as piezometers, tensiometers, temperature sensors, and researchers can perform ion exchange chromatography and time domain reflectometry. The geophysical laboratory has a vast number of instruments for close-surface measurements, the SYSCAL-PRO electrical resistivimetry system, a new mobile electrostatic method for investigating the stratigraphy of a site, a time domain electromagnetics system (Slingram mode), temperature measurement capabilities to 1000°C, The RM15 resistivimetry system, magnetic resonance imaging, and ground-penetrating radar.
L'UMR 7619 has significant computational facilities, including personal computers, and a computer cluster for numeric hydrologic and hydrogeologic modeling (including GR, surface model CLSM, and the Seneque water quality model).
Other: The UMR shares a mass spectrometer with other UPMC laboratories for stable water isotopic analysis and the isotopes of oxygen and carbon and light-gas stable isotopes (through DIIRMS). And the collaboration with the School of Mines of Paris offers access to an ion probe and to hydrogeological numerical codes (NEWSAM, MODCOU, SIM, METIS…).

UMR.7693-ISTeP
Intervenants GIIWS: B. Deffontaines

The Paris Institute of Earth Sciences (ISTeP) had been created on January the first, 2009 as a common French National Research council (CNRS) and the Paris VI – Pierre and Mary Curie University Research unit (UMR 7193). This Institute gathers more than 120 researchers Postdoc, PhD students and technicians issued from the Tectonic lab (former UMR 7072), Petrology and Mineralogy lab. (Former UMR 7160) and the former JE 2477 « Biomineralisations ». Its main research thematic deals with: lithosphere rheology, sedimentary basin evolution, biomineralisations as environment tracers and planetary dynamic deduced from the petro-geochemistry.

The ISTeP is composed of 6 research teams: Biomineralisations and sedimentary environments; Sedimentary basin Evolution; Lithosphere, deep processes; Magmas, minerals, and materials; Petrology, geochemistry, volcanology; Sismotectonics and fractured systems. Furthermore ISTeP is helped on the formation of researchers Ecole Doctorale 938: Geosciences and Natural Ressources (GRN.P6). ISTeP had got numerous national partners such as (ANDRA, BRGM, IFP, Ifremer, IRSN...), as well as international ones (IODP, ILP) or industrials (British Petroleum, ENI, GDF Suez, Shell, Total...).

2. ARMINES - EMP – Mines-Paristech, Centre Géoscience - Equipe "SHR"
Intervenants GIIWS: D. Bruel, P. Goblet

ARMINES is a non-profit making organisation funded in 1967 and created in accordance with the French Act of 1901. ARMINES' relationship with the engineering and management schools, notably the Ecoles des Mines network under the supervision of the Ministry of Industry (Paris, Douai, Alès, Saint-Etienne, Nantes and Albi-Carmaux), are governed by agreements. ARMINES also brings together the laboratories of the Ecole Polytechnique, the Ecole Nationale Supérieure des Techniques Avancées (ENSTA), the Ecole Navale and the Ecole des Ponts et Chaussées. ARMINES was the first partnership research structure created in France.
In line with the nature of partnership research, the operational unit is a joint research centre managed jointly by ARMINES and its partner engineering schools, whereby ARMINES provides its own personnel, investment and operating resources according to the volume of contractual activity. With over 50 joint research centres located in 12 sites throughout France, ARMINES's research teams work in many domains of the engineering sciences and in particular in materials sciences and engineering, energy and environment, earth of environmental sciences and Information technology, automation, applied mathematics and imaging.
ARMINES has been taking part in major European research programmes for over 15 years, with particular interest in geothermal and renewable energy activity, through JOU2-CT92, JOR3-CT95 or recently FP6-STREP EGS Pilot plan programs.
A special European affairs team was set up in 1993 to support researchers involved in such programmes. A specific tool was developed in-house so as to manage these consortia and went online in 2004: a web platform: www.armines-euromanagement.fr
ARMINES is also a member of EIRMA (European Industrial Research Management Association), EARTO (European Association of Research and Technology Organisations) and EARMA (European Association of Research Managers and Administrators). Since 2007 ARMINES is a full member of the FP7 National Contact Point dedicated to the administrative, financial and legal issues.

3. CEMAGREF - Equipe "Hydrosystems and Bioprocesses"
Intervenants GIIWS: C. Chaumont, J. Tournebize

The research unit Hydrosystems and Bioprocesses produces scientific knowledge applicable to the hydrographic systems in man mad catchment concerning more specifically:

- rainfall-runoff modelling at catchment scale,

- impacts of agricultural landscaping in small rural catchment on water fluxes and water quality,
- determination of river ecosystems and fish population interaction,
- bioprocesses in sewage treatment plant,
- management of landfill including biogeochemical and microbial functioning,

 Team "Transfer in Agro-HydroSystem":
The main research topic and expertness is focus on the functioning characterization of agricultural landscaping at small rural scale. The team develops some approaches (observatory and modelling) concerning water management. The team's skill leans on a mastery of in situ instrumentation, developping automatic monitoring devices dedicated to surface and soil water fluxes (quantity and quality). The team drives also several experimentations at laboratory scale.

4. ENS - Equipe “Laboratoire de Géologie of ENS”
Intervenants GIIWS: J. Fortin, A. Schubnel
Collaborator : C. David from the Laboratoire Géosciences et Environnement de Cergy

The Laboratoire de Géologie of ENS is both a place for research and a place of training in Earth Sciences through teaching and research. Although the size of the laboratory is modest, it covers a very wide spectrum of research topics: geophysics, seismology, geodesy, seismotectonics, geology, rock mechanics, mineralogy, geomaterials. This strongly favors exchanges between topics which is a strong feature of the laboratory. The scientific approaches is characterized by the will to strongly couple observations/measures, experiments and modeling in order to understand the mechanisms at work, to model them and possibly to predict long term evolutions. Scale changes, spatial as well as temporal, are characteristics of our approach. All these studies are based on earth/sea experiments and measurements, satellite observations and field studies in various key places of the Earth. Another characteristic of the laboratory is its rich experimental infrastructure: materials characterisation techniques, high pressure/ high temperatures equipments as well as experimental deformation equipment under controlled conditions. The collaboration with the Laboratoire Géosciences et Environnement de Cergy is motivated by the fact that the scientific approaches of this laboratory are closed to the approaches of the ENS, and also by the fact that the Laboratoire Géosciences et Environnement de Cergy is also characterized by a rich experimental infrastructure, which is complementary to the experimental infrastructure available at the ENS.

7.3. IMPLICATION DES PERSONNES DANS D'AUTRES CONTRATS / INVOLVEMENT OF PROJECT PARTICIPANTS TO OTHER GRANTS, CONTRACTS, ETC …

Part.	Nom de la personne participant au projet	Personne. mois	Intitulé de l'appel à projets Source de financement Montant attribué	Titre du projet	Nom du coordinateur	Date début & Date fin
N°	Sophie Violette	6	PND		Benoît deffontaines	2010-2012
N°	Benoît Deffontaines	48	PND		Benoît deffontaines	2010-2012