



Water Supply and Demand Management in the Galápagos

A case study of Santa Cruz Island

María Fernanda Reyes Pérez



UNESCO-IHE
Institute for Water Education



Santa Cruz Island, a tourism hub in the Galapagos, is facing significant challenges with too many tourists and residents, but insufficient water resources. There are no permanent freshwater resources on Santa Cruz, and the municipal system provides only an intermittent supply of untreated brackish water.

This study quantified water demand and supply for different categories of users and different types of water resources. Over 380 surveys of households, hotels, restaurants and laundries were performed, and 18 water meters were installed in the city town of Puerto Ayora to confirm the water demand. In addition, this data was used to estimate future water demand, and five intervention strategies were developed to address future water scarcity considering different population growth scenarios. A multi-criteria decision analysis followed to evaluate the intervention strategies based on environmental, technical, social and economic factors. Finally, the existing water supply network was modelled to assess the ability of the network to meet future water demand and a method was developed to estimate water losses in roof tanks.

Results indicated water demand reaching between 163–w428 litres per capita per day, which is high for a water scarce island with an intermittent supply, suggesting the presence of non-registered tourist accommodations or excessive wastage of water at household levels. Sustainable options such as rainwater harvesting, grey water recycling, and water demand reduction, among others, seem to be sufficient only for low population growth scenarios. The most feasible option to completely meet the growing water demand in the case of rapid population growth is the installation of a seawater desalination plant. However, a desalination plant in this eco-sensitive area could have negative environmental impacts. Therefore, water consumption needs to be addressed, fixed water tariffs should be abolished and governmental targets for tourism should be reconsidered in order to preserve this fragile and unique ecosystem. This scientific study provided insights to improve water resources management and further contributes to the creation of effective policies to preserve these resources. Additionally, the outcomes can be applied to other tropical islands in similar situations.

 **CRC Press**
Taylor & Francis Group
A BALKEMA BOOK

This book is printed on paper
from sustainably managed
forests and controlled sources

ISBN 978-0-8153-7247-9



9 780815 372479

an informa business



Water Supply and Demand Management in the Galápagos | **María Fernanda Reyes Pérez**



WATER SUPPLY AND DEMAND MANAGEMENT IN THE GALÁPAGOS: A CASE STUDY OF SANTA CRUZ ISLAND

DISSERTATION

Submitted in fulfilment of the requirements of
the Board for Doctorates of Delft University of Technology
and
of the Academic Board of the UNESCO-IHE
Institute for Water Education
for
the Degree of DOCTOR
to be defended in public on
Thursday September 28, 2017, at 15:00 hours
In Delft, the Netherlands

by

Maria Fernanda REYES PEREZ

Master of Science in Environmental and Energy Management,
Twente University, Enschede- The Netherlands

born in Quito, Ecuador

This dissertation has been approved by the
promotor: Prof. Dr. M. D. Kennedy
copromotor: Dr. N. Trifunovic

Composition of the Doctoral Committee:

Chairman	Rector Magnificus, Delft University of Technology
Vice-Chairman	Rector UNESCO-IHE
Prof. Dr. M. Kennedy	UNESCO-IHE / Delft University of Technology, promoter
Dr. N. Trifunovic	UNESCO-IHE / Supervisor
Independent members:	
Prof. Dr. C. Mena	Universidad San Francisco de Quito/Galápagos Science Center
Dr. P. Gikas	Technical University of Crete
Prof. Dr. D. Butler	University of Exeter
Prof. Dr. L. Rietveld	Delft University of Technology
Prof. Dr. M. McClain	Delft University of Technology / UNESCO-IHE, reserve member

This research was conducted under the auspices of the Graduate School for Socio-Economic and Natural Sciences of the Environment (SENSE)

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informal business
© 2017, M. F. Reyes Perez

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publishers.

Although all care is taken to ensure the integrity and quality of this publication and information herein, no responsibility is assumed by the publishers or the author for any damage to property or persons as a result of the operation or use of this publication and or the information contained herein.

Published by:
CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN 978-0-8153-7247-9 (Taylor & Francis Group)

“Emancipate yourselves from mental slavery, none but ourselves can free our minds.”

- Bob Marley

A mi familia con todo mi amor,

Voor mijn Klein met lief.

Acknowledgements

This thesis is the result of five years of hard work in Santa Cruz Island, located in the wonderful Archipelago of Galápagos, and Delft. Every single person I encountered along this journey, has somehow contributed to this piece of work. Therefore, I would like to name each one of them and thank them (I hope not to forget anyone).

First of all, I would like to start by thanking my sponsor SENESCYT (Secretaría de Educación, Ciencia Tecnología e Innovación), who contributed financially so I could carry out my PhD. Then, many special thanks to my promoter and Professor Maria Kennedy, who has always been very kind, supportive and understanding, who always helped me to improve every chapter in every possible way. I thank you very much for your criticism because it made me see things that, after some time, I could not recognize anymore. I thank you deeply for all the feedback and ideas, as well as for the financial support towards the end of the study. Thank you Maria!

My sincere gratitude to my mentor and friend, Nemanja Trifunovic, who is not only an expert in the field of water supply and distribution, but is also a very wise, patient and enthusiastic human being, always carrying a smile on his face and having positive comments about any circumstance (really admirable!). Thanks Nemanja for your help, your words of support, your understanding in the moments of crisis and above all for your patience and contribution to this research. I hope we can enjoy in the future a fresh grilled tuna on the beautiful island of Santa Cruz. Also, thanks for your help on my writing, I know it was very hectic all the repetitions, as well as the elaborated and run-on sentences☺.

Also, to Saroj Sharma, my second mentor who had always a positive comment and word of motivation in the joint meetings. Thanks also for all the positive comments and fast revision of manuscripts, they really helped me to organize my ideas. Also, to Chantal and Bianca, who were always so efficient in any administration matter I needed. To Jolanda Boots, the best PhD admission officer there can be. To my MSc. student Diah Prameshwari for the contribution on Chapter 6 and many special thanks to my other MSc. student Aleksandar Petricic, for all your contribution on Chapter 7, your hard work was admirable and helped me a lot, especially on the second or third analysis! Thanks a lot!

This study would not have been possible without the contribution of all the people in Santa Cruz Island. To Delio Sarango, the chief of the Department of Potable Water of Santa Cruz, so

many thanks for all the information provided, for giving so much of your time to this research, for always being reachable through whatsapp and answering questions along five years of work, as well as lending me the 18 water meters, equipment, transportation and so many other things. Also, Delia and Sandra, who were always willing to contribute with data and helped me find the families to install the water meters. Thanks to the personnel who helped on the installation and un-installation of the meters: Don Efren Valle, Vinicio Gaona, Jose María Masaquiza, Don Juan Pacheco and Lorena Intriago. Also, thanks to Daniel Proano for being part of the project and providing ideas for the interviews. To Eva Anagono, Lorena, Joanna and Mariano for helping me carry out the surveys, which was a lot of hard work. In the Dirección del Parque Nacional Galápagos, thanks to Wacho Tapia with all the administration process for my research stay, as well as all the advices. Thanks also to Galo Quezada, who also facilitated my stay in the islands. Thanks to Noemi d'Ozouville for the contacts provided. Also many thanks to Carlos Mena, Steve Walsh and all the staff of the Galapagos Science Center, which were always willing to help and contribute. To Tito Guerra from SENAGUA for the data provided. To the USFQ, my local university and the people in the Environmental Engineering Department: Rene Parra, Rodny Penafiel and Valeria Ochoa. Lastly in Galapagos, thanks to the friends there who helped me as well: Mayrita (la major masajista del mundo), Kari, Osamu, Sebas, Vale... you made me have a wonderful time there!

To all my friends in Ecuador, who were always there to support me and encourage me to continue and do not give up. Goshguis Vivi y Benji, my best friends since elementary school, who are always there, no matter how long it is that we don't speak, it feels like not a day has passed by. Many special thanks to Vivi Lopez for your creation for the cover of this book and all the time spent! After so many discussions, we finally got a beautiful version. To Dani Barriga (polla), Cris Viteri (alias Fago), Andres Becdach (Giito), Pablo Morales (Peladito) y Esteban Ruiz (Ivy), my closest friends in life, who I miss every day and miss our university "crazy" years. Also, Ilamita Caro Cordovez and Cris Gomezjurado, even though we met few years ago, I know that I can always count on you girls.

To the gang in Delft: Vero, Pato, Jessi, Luisita, Erika, Alida, Juliette, Mauri, Yared, Aki, Mark, Pablo, Neiler and Miguel (veci). So many memories with all of you, who made it this journey, somehow easier. Also to the amigoss/running/partying group, my family here: Mohaned (Mohi): thank you for your patience with my Dutch grammar☺. I will never forget the 'onafhankelijkheid' word, which I had to repeat close to 50 times so could pronounce it properly! Berend, so many thanks for the talks, words of comfort, and all the fun. I love your

dance steps and I hope you can replicate them when we travel all together to Ecuador and Colombia. Also to Can, who became member of the group later, but still very special to all of us. Thank you for always being available for some shoes advice (haha). Thanks amigos for all the parties, 'despacito' dancing, all our dinners and tequilas, we always had such a great time!! I am really going to miss you all! Very special thanks to Juanca and Motassem, who helped me with hydraulics, calculations and the EPANET model. You both were my little angels who helped in my moments of despair (hahaha). To my Ecuadorian friends Gaby and Saira, who always made me feel at home!

To my girls, Angie and Nata (my paranyymph): without you girls, my life in Delft would have been boring, but you really spiced it up. All the parties, the dinners and your friendship was simply something that made me want to stay. I will never forget our trip to Terschelling and all the anecdotes! I will miss you girls so much, all our talks, coffees, carrot cakes, dinners, trips, kapsalons and all the after-parties at Kobis Grill, please don't forget our anthem: Mi No Lob. You girls are simply the best and I can't thank you enough for your friendship and for becoming my sisters here. Thanks also for all the personal training and routines at the gym, every day was fun with bodypump, spinning, Angie's weight programs, running and 10 K's competitions.

To the love of my life, Peter, who is the motor of my life: without you I don't think I would have been able to finish. Thanks for all your unconditional support, for all your love, for all your care and your HELP. Thanks for always listening to me and always finding the right words to comfort me. Thanks for the Dutch lessons and correcting my schrijfpodrachten and many special thanks for the translation of the summaries, which, I know were very hectic!! You are the most amazing man I have ever met and I am so happy you have become part of my life; you are my TWO. I love you with all my heart! This is just the beginning of an amazing trip together. Ik hou van jou mijn kleintje!

Also thanks to my Dutch family for their support and care: Tineke, Ap, Marjan, Daan, Isabelle and Jasmijn. Thank you for always making me feel I was at home, and being so caring!

Last, but not least, to all my family. To my mother Charo, who is the most remarkable woman on the planet, smart and beautiful, you have always been my role model. To my brother, Goyo, who always gave me free therapy sessions in my moments of despair and my other paranyymph. Thank you for checking my thesis ☺. To my father, who, despite his personal journey, he made me feel he was always proud of me. To Angie, Juani, Samirula, Mami Ro and all the aunts, uncles and cousins who welcomed me every time I went to Ecuador with a party, a cafecito, or

a delicious cangrejada. Also, thanks to God who gave me this opportunity and put the right people at the right time. I can't be more thankful for this amazing 5 year journey!!

Gracias a Dios y a la vida por todo lo que me han brindado, solo puedo decir que me siento bendecida!

Summary

The Galápagos Islands, a province of the Republic of Ecuador, is a volcanic archipelago of significant ecological importance. For centuries, water resources on the islands have been perceived as scarce and consequently, water issues have been recognized as an important and urgent matter. As in many other tourist islands, water resources have been severely threatened by the expansion of the tourist industry. In addition, data regarding water supply and demand are scarce since the vast research carried out on these islands focuses mainly to the conservation of endemic species, putting aside the impact of human activities on water resources.

Santa Cruz Island, the hub of tourism of the Galápagos Archipelago, is experiencing significant challenges regarding water quantity and quality. There are no permanent freshwater resources in this island. The municipal system supplies only (untreated) brackish ground water (800-1200 mg/l of Chloride) intermittently. Water scarcity is felt mostly in the town of Puerto Ayora, which is the centre of tourism, where the average supply is three hours per day. In Puerto Ayora, there are no water meters and the water tariff structure is fixed. The municipal supply system has not been able to cope with the current growth in tourism and local population (7% annual growth of tourism and 3.3% annual growth of local population). Non-revenue water ranging from 35% (this thesis) to 70% (previous studies) on the island, poor maintenance and old piping systems adds also to the provision of an erratic service within this island.

The research presented in this thesis focuses on water supply and water demand management on Santa Cruz Island. Firstly, water supply was analysed in order to identify the issues contributing to the current situation regarding the intermittency of water supply. Results showed three sources of supply: (1) brackish ground/crevice water distributed by the municipal supply, (2) bottled-desalinated groundwater produced by small private companies and (3) brackish ground/crevice water privately extracted and sold by water trucks. From this study, the estimated quantity supplied per capita (including all three sources) is ± 370 lpcpd, which is high compared to the capital city Quito (210 lpcpd).

Thereafter, water demand was estimated considering the different demand categories such as domestic households, hotels, restaurants and laundries. Water demand was assessed through approximately 400 surveys (including domestic households, hotels, restaurants and laundries), which were distributed all around the town of Puerto Ayora. The quantification of water demand was performed for each of the three sources previously identified. Results showed that

the average per capita demand from the municipal supply was estimated as ± 163 lpcpd, which can be considered high for an island with no freshwater resources and intermittent supply for approximately 3 hours per day. Later, in order to verify the specific domestic demand, 18 water meters were installed around the town of Puerto Ayora. In addition, the readings from approximately 300 water meters previously installed on three pilot zones established by the municipality were analysed and compared with the results of the 18 water meters add as part of this study. Both showed very high domestic water consumption, the average obtained from the 18 water meters showed an average demand of $164 \text{ lpcpd} \pm 94 \text{ lpcpd}$ of standard deviation. The average domestic demand for the pilot zones were estimated at $182 \text{ lpcpd} \pm 31$, $195 \text{ lpcpd} \pm 80$ and $428 \text{ lpcpd} \pm 70$, for pilot zone 1, pilot zone 2 and pilot zone 3, respectively. In many of the pilot zones outliers were identified with average consumption as high as $4,500 \text{ lpcpd}$, suggesting excessive wastage of water within households and/or informal tourist accommodations, or both.

A prognosis of urban water supply and demand was carried out for the next 30 years, for four different annual growth scenarios. These scenarios were: (1) slow growth- 1% for the local population and tourism, (2) moderate growth- 3% for local population and 4% for tourism, (3) fast growth- 5% for local population and 7% for tourism (current situation) and (4) very fast growth- 7% for local population and 9% for tourism. Results showed that without any intervention (business as usual) water demand coverage will barely reach 50% for the slow growth scenario and 10% for the very fast growth scenario. Consequently, five intervention strategies were developed and evaluated as options to solve current and future water scarcity. The strategies included sustainable options such as reducing per capita water demand, installing water meters, reducing leakage, rainwater harvesting and grey water recycling as well as the installation of a seawater desalination plant on the island. These strategies were assessed using several Key Performance Indicators (KPI's), in terms of water demand coverage with supply, costs and energy use over the next 30 years. Results showed that the intervention strategy involving the installation of a seawater desalination plant is the only strategy that can completely meet the demand in a future 'rapid population growth' scenario, while simultaneously improving water quality (reducing salinity at the tap). However, this is the most expensive and energy intensive solution for the island. The intervention strategy that includes all options, except desalination, will suffice, but only for the 'slow population growth' scenario, which is very unlikely to happen.

Afterwards, a Multi-Criteria Decision Analysis was performed, with the aim of evaluating the five intervention strategies assuming a 'moderate population growth' scenario. The strategies were categorized and evaluated under four criteria: environmental, technical, economic and social, and considering four groups of stakeholders: local decision-makers (governmental authorities), local experts (researchers, academia and environmentalists), domestic end-users and hotels. The proposed strategies were finally ranked based on the different stakeholder's perspectives, providing the preferred strategy considering the selected criteria. Results differed for each stakeholder group: for local decision makers the intervention strategy including the installation of a desalination plant ranked first, while for local experts, domestic end-users and hotels, that strategy was ranked last and they preferred more environmentally friendly options. In addition, a sensitivity analysis was carried out, which showed that the most sensitive criteria are the environmental, technical and social ones, and small changes in the values of their weights may significantly change the ranking of the intervention strategies.

In addition, the water supply network of Santa Cruz was evaluated with EPANET software, aiming to assess the current and future performance under the different growth scenarios, using Demand Driven Analysis (DDA) and Pressure-Driven Analysis (PDA) approaches. Each approach suggested that the current network suffices for 24 hour supply, in terms of quantity of water and pressure available within the network. Likewise, the household storage facilities were evaluated, developing a methodology (using the Emitter Coefficient feature of the software) with the aim of estimating water loss (overflow) from roof tanks for several scenarios of water consumption, leakage and storage tank capacity. Results showed that water losses from roof tanks varied from 5 to 32% of the total water supplied in the town of Puerto Ayora.

The water demand estimated, as well as water losses within households is surprisingly high for an island where there are no permanent freshwater resources and intermittent supply for three hours per day. Most likely, this is a direct consequence of a fixed water tariff structure, which does not provide any incentive to people to save water. Therefore, any future growth in tourism should be limited. If the very fast tourist growth scenario is defined as a governmental target (9% annually), inevitably, a seawater desalination plant will need to be installed. This will solve water quantity and quality issues, and is independent of the amount of rainfall on the island, but many negative environmental impacts may be generated, especially regarding brine disposal, chemical discharge, energy consumption and fuel importation. For the fast and moderate growth scenarios, the proposed sustainable strategies (including leakage reduction, water meter installation, per capita demand reduction, rainwater harvesting and grey water recycling) would

be partially sufficient, suggesting that at least for some activities a smaller seawater desalination plant may need to be installed as well. For the slow growth scenario, the proposed intervention strategy comprising sustainable strategies would be sufficient, suggesting that governmental tourism targets should be re-considered. If current growth trends continue, the overexploitation of brackish water from the basal aquifer may increase the salinity of the supplied water, driving the need for a desalination plant. Therefore, the amount of water that is currently consumed on the island needs to be addressed, fixed water tariffs should be abolished and the governmental targets for tourists visiting the island should be re-considered in order to preserve this fragile and unique ecosystem.