Water resource management: the Pelican Bay watershed

Noémi d'Ozouville

PhD in Hydrogeology, collaborator CDF

A watershed is a hydrological term that refers to an area where the water that falls as precipitation flows into a single common point or eventually into a single river, lake, or sea. It is also defined as a physiographic unit consisting of a system of rivers defined by topography. All that lives in the watershed, humans, plants, and animals, are inter-connected with the flow of water.

There are 32 principal watersheds in Santa Cruz, with surface areas ranging from 5 km^2 to 50 km^2 (Figure 1). The majority of the watersheds flow from the summit to the sea. However, there are no permanent rivers, only sporadic streams that flow during the rainy season or during heavy mists or *garúa*.

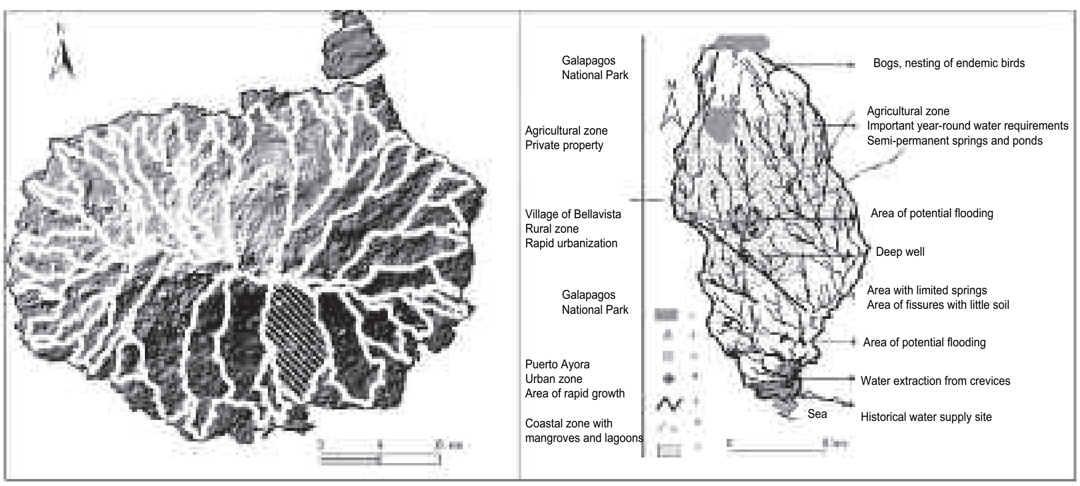

Figure 1. Figure 1. Relief map of Santa Cruz (d"Ozouville *et al.*, 2008b) showing the watersheds with an area greater than 5 km^2 (left); detail of the Pelican Bay watershed (right): 1) hills; 2) old water collection at Cerro Gallita; 3) crevices exploited for water; 4) deep wells; 5) fissures; 6) drainage network; and 7) agricultural zone.

Characteristics of the Pelican Bay watershed

The Pelican Bay watershed covers 43 km^2, extending from the top of Cerro Crocker, the highest point of the island, through the towns of Bellavista and Puerto Ayora, and ending in the sea at Pelican Bay (Figure 1). It is of particular importance because it includes: (i) protected areas of the Galapagos National Park; (ii) agricultural zones; (iii) rural areas; (iv) urban areas, and (v) the three locations for water extraction by the municipality for supplying the population. During El Niño events, several sections of this watershed flood due to surface water flow. Historically, colonists would obtain brackish water for their needs at Pelican Bay; during El Niño years fresh water springs were observed flowing into the bay. The two meteorological stations in Galapagos with the longest historical records, the Charles Darwin Research Station (CDRS) at 2m above sea level and Bellavista at 194 m above sea level, are both found within this watershed.

Climatic conditions 2007-2008

Analysis of historical meteorological data of the CDF show that the hydrological year in Galapagos runs from June to May. Effective rainfall (that which contributes to recharging the hydrological system) begins with the garúa or cool season (June to December) and is minimal in April and May (d'Ozouville, 2007). The year 2007-08 was characterized by colder than average temperatures during the garúa season and higher than average precipitation during the hot or rainy season. The rainfall of 2007-08 was similar to that of the 1991-92 El Niño. However, oceanic conditions indicating an El Niño event were not recorded in the Pacific. It was, in fact, considered a La Niña.

The higher than average rainfall during the hot or rainy season of 2007-08 was related to the presence of warm surface water that extended from the coast of Ecuador to Galapagos. These warm waters caused excessive precipitation and flooding in continental Ecuador. An understanding of the climate and its high annual variability is fundamental to watershed management because water demands by humans are based on their needs and not the natural limits of the resource, while water demands of the agricultural sector actually increase during years of low rainfall.

Current use of water resources

Water is extracted from the basal aquifer (d'Ozouville *et al.*, 2008a) that lies under the Pelican Bay watershed at three sites:

1) **The Deep Well.** Located at km 6.5 on the road to Baltra, extraction from the deep well began in 2002 and supplies Bellavista and the surrounding areas with water. The water is taken from the basal aquifer at a depth of 158 m. The salt content is less than 1 g/l and there is no evidence of contamination by fecal coliform (information supplied by Galapagos National Park Service (GNPS) and the Japanese International Cooperation Agency (JICA)). The deep well has a high risk of contamination due to its location close to the highway, the suburbs that are growing around it, and the potential for salt intrusion.

2) **The Mission Crevice.** Located at the center of Puerto Ayora behind the Colegio San Francisco, this water source has been exploited since the 1980s and provides water to various sections of Puerto Ayora. It has salt levels higher than 2 g/l and a high level of contamination by fecal coliform (information supplied by the municipality of Santa Cruz and INGALA *et al.*, 1989). This crevice has a high risk of contamination due to the high population density surrounding it.

3) **Pampas Coloradas Crevice.** Located on the road to Baltra in front of the gas station of PetroComercial and the Pampas Coloradas soccer stadium, this crevice has been exploited since the 1980s and provides water to sections of Puerto Ayora. It is also known as the INGALA Crevice. Its salt content is approximately 1.5 g/l and there is contamination by fecal coliform (information supplied by the municipality of Santa Cruz and INGALA *et al.*, 1989). This water source has a high risk of contamination due to its proximity to PetroComercial and the Electric Plant.

Monitoring data of these water sources are scarce. There are no historical records of the variations in the water table, the volumes of water extracted, or water consumption. In October 2003, a system was established to measure the water table (d'Ozouville, 2007). In November 2007, a system to measure both water extraction and use of these three sources was initiated. This article presents the first data on the status of the extraction and use of water resources from the basal aquifer of the Pelican Bay watershed.

Extraction of water from the deep well and water use in Bellavista

The deep well is exploited through pumping. Each day the pumping hours, the flow rate, and the volume of water pumped are recorded.

The cost of water production (extraction, treatment, distribution, etc.) for the municipality is approximately US\$3/m^3 (Delio Sarango, GMSC, pers. com.). The cost of well water for the consumer, which is subsidized by the municipality, is US\$1.21/m^3 (1 m^3 = 1000 liters). The water extracted from the well supplies the houses in Bellavista and the surrounding area. Each house has a water meter. The municipal records of water payments permit a calculation of the volume of water used by customers of the deep well.

The average flow from the pump is 8.9 l/s. This value is greater than the tested limit of the pump (6 l/s) and the rate recommended to ensure that intrusion of sea water and contamination of the well do not occur (Proctor and Redfern Int. Ltd., 2003). However, the pump is never run for a full 24-hour period (generally from 0 to 18 hours). The volume of water extracted per day for the days when the pump is operating varies between 88 and 195 m^3 (Figure 2).

The monthly extraction rate from November 2007 to May 2008 ranged from 2734 m^3 to 6053 m^3, while the volume consumed ranged from 2222 m^3 to 4335 m^3 (Figure 2). In both cases, the lowest amount was recorded in March when precipitation was highest. These data suggest that some residents of the highlands collect rainwater and do not use well water while they can collect rainwater. Although precipitation remained high in April, the same tendency was not observed, because the precipitation came in two very heavy downpours, which did not permit storing sufficient water for the month.

Two key points arise from these data:

1) There is a loss of water between extraction and use. All of the water extracted from the deep well supplies Bellavista and the surrounding neighborhoods, so all of the water should pass through the water meters of the houses. Therefore, the amount extracted should equal the amount consumed. Between November 2007 and May 2008, between 500 m^3 and 2800 m^3 of water extracted from the well were not accounted for, which represents a monthly revenue loss between US\$605 and US\$3388 for the municipality of Santa Cruz.

While loss from leakage is assumed to be common, it would tend to be constant over a long period of time. Leakage should not equal more than 500 m^3, the minimum volume recorded as "lost" in November and March. In the other months, the volume lost represents up to 40% of the volume extracted, taking into account a fixed loss due to leakage of 500 m^3. This loss must be accounted for by some other explanation, such as unauthorized water connections. The reduction in unauthorized connections in November and March can be explained by the abundant rainfall providing a sufficient natural supply of water.

2) Based on the water use data and the population census (1608 inhabitants; INEC, 2007), water consumption in Bellavista and the surrounding areas is between 45 and 87 l/person/day. This volume is very acceptable when compared with domestic water use worldwide[1].

1 The FAO (Food and Agriculture Organization) recommends a minimum value for domestic water use at 50 l/person/day, which includes 2 to 5 l for drinking, 20 l for sanitation, washing clothes, etc.; 15 l for bathing, and 10 l for cooking. In developing countries the value ranges from 60 to 150 l/person/day. In developed countries the range is between 300 and 800 l/person/day.

However, three points are important to consider: 1) inhabitants also collect rainwater; 2) data are lacking regarding the collection of rainwater; and 3) unauthorized connections are not taken into account.

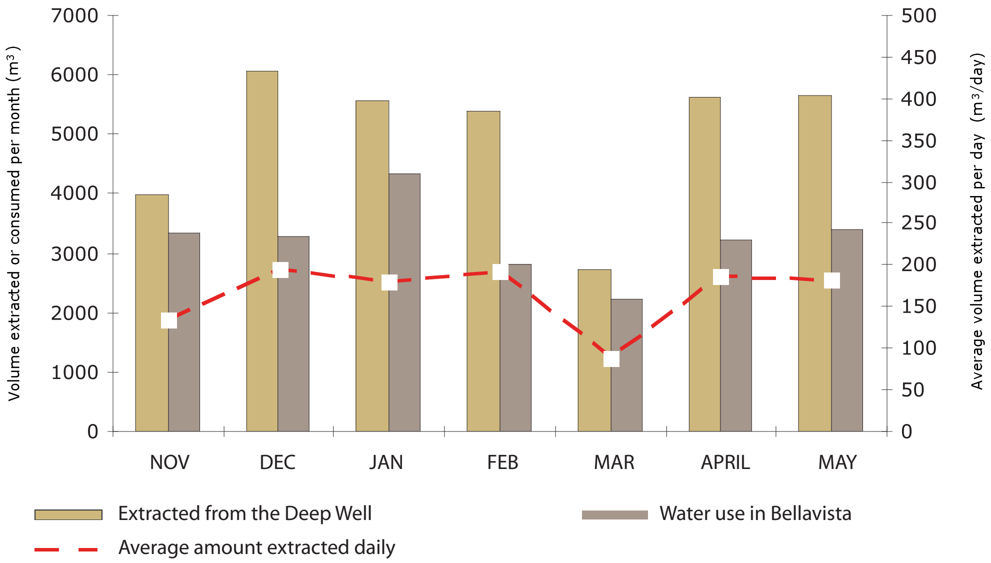

Figure 2. Monthly volumes of water extracted from the Deep Well and used in Bellavista from November 2007 to May 2008 and the average amount extracted per day. Source: Municipality of Santa Cruz.

The volumes of water extracted from the crevices in Puerto Ayora were calculated based on the flow rate and operation times for each pump (Table 1). There are no daily records for the pumps, so the data represent an average based on typical hours of operation.

Table 1. Estimated water flow rates from the crevices located in Puerto Ayora. Source: Municipality of Santa Cruz.

	Flow rate (Q) (l/s)	Hours of Operation	No. Hours	Average daily volume (m^3/day)
Mission Crevice				
Pump #1	22	7h00 - 18h00	11	871.2
Pump #2	12	7h00 - 16h00	9	388.8
Pampas Coloradas (INGALA) Crevice				
Pump #1	15	6h30 - 18h00	11.5	621
Pump #2	15	6h30 - 18h00	11.5	621
Pump #3	30	6h30 - 18h00	11.5	1242
Pump #4	18	6h30 - 16h30	10	648
Pump #5	18	6h30 - 16h30	10	648
Total (m^3/day)				5040

The average daily volume of water extracted from the Mission and Pampas Coloradas crevices is 5040 m^3/day. This water is complemented by six water systems used by businesses or institutions. These systems are not registered at the municipality and could be significant: S. Amy; Tesalia; Finch Bay; M. Gallardo; M. Schrier; Charles Darwin Research Station, and other private users, for example the water supply for houses on Punta Estrada.

There are no data on water use in Puerto Ayora. The houses do not have meters and the users pay a fixed monthly rate based on their category of use (Table 2). This represents a monthly revenue of US$14 000 for the municipality to cover a portion of the costs of production and maintenance of the network and equipment.

Table 2. Water rates and revenues by category in Puerto Ayora. Source: Municipality of Santa Cruz.

Municipal categories for water rates	Monthly water rate (US$)	No. Registered	Monthly municipal revenue (US$)
Domestic	5.00	1298	6490
Official	6.00	24	144
Commercial	11.00	563	6193
Swimming pool	28.00	2	56
Industrial Residential	28.00	7	196
Industrial Hotel	45.00	13	585
Industrial Laundromat	45.00	6	270
Industrial Water Production	45.00	2	90
TOTAL		1915	14024

In November 2007, 13 water meters were installed in both homes and businesses in Puerto Ayora to obtain quantitative data on the average water use for the various categories of consumers. Data were obtained through the middle of December 2007. At that time the meters were discontinued because the consumers complained that the meters caused a drop in their water pressure. Between 10 November and 10 December, while the meters were functioning, the average monthly water use of houses was 87 m^3, with a range of 10-170 m^3 (Figure 3). The water use was much higher than the monthly average in Bellavista (13.5 m^3). Water use in the other categories was also highly variable.

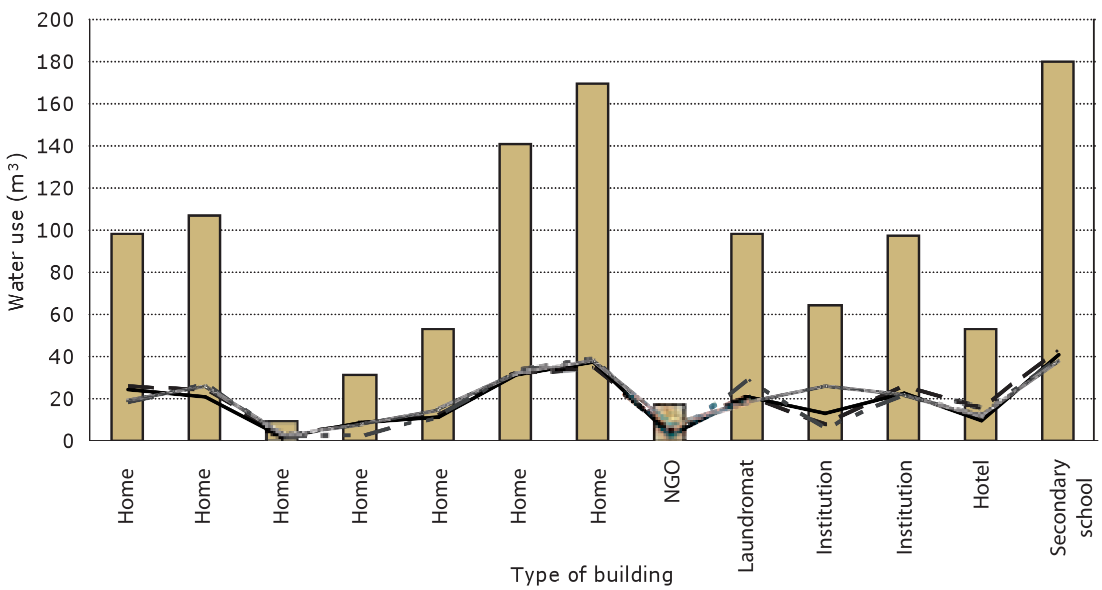

Figure 3. Water use in Puerto Ayora recorded by water meters in November/December 2007. Source: Municipality of Santa Cruz.

Water use per person per day in Puerto Ayora was calculated using two methods:

1) Assuming an average of 3.5 persons per house in Puerto Ayora (INEC, 2007), the data from the water meters results in a water use ranging from 92 to 1567 l/person/day, with an average of 802 l/person/day. The high variability demonstrates the importance of

obtaining more data to identify existing problems.

2) Using the volume of water extracted from the basal aquifer and census data for the population (9163 inhabitants in Puerto Ayora; INEC, 2007), water use is 550 l/person/day. This value is lower than the average resulting from the meters, but confirms that there is an unmeasured water use in Puerto Ayora that must be explained and corrected.

Various points must be taken into account in relation to these data:

1) INEC census data may underestimate the actual population size.

2) There is a significant floating population in this town due to tourism, which is not accounted for in water usage.

3) The rate of leakage is important.

4) There is a high level of water loss when pumps are left on after the tanks are filled.

5) Changes in lifestyle (bathtubs, swimming pools) are resulting in increased use.

6) There has been a significant increase in construction in recent years.

To provide one example, the average daily volume of water that is carried by tanker truck to supply tourist boats, farms in the highlands, and others is estimated at 167 m^3. If this is subtracted from the total, the water use per person per day in Puerto Ayora decreases to 530 l/person/day.

These data indicate that the extraction of water from the basal aquifer is excessive based on the calculated requirements and that it is indispensable to acquire additional information in order to answer the following questions:

1) What is the volume of water extracted for commercial, institutional, and private use that is independent of the municipal water delivery system?

2) What is the distribution of the water carried by tanker trucks by sector?

3) What is the distribution of water among the different sectors (industrial, commercial, agricultural, tourism, and domestic)?

4) What is the actual population in the Puerto Ayora/Bellavista area, considering illegal residents, floating population, etc. ?

Conclusions and recommendations

The hydrological balance can be calculated for each watershed. In the case of the Pelican Bay watershed, the rate of recharge by infiltration of effective precipitation to the subterranean system is estimated at 8 million m^3/year, while the current data indicate an extraction rate of 1.9 million m^3/year. Although the extraction rate is lower than the recharging rate, the hydrodynamic and geochemical characteristics of this watershed indicate that the basal aquifer has a low volume of fresh water and that it is in a fragile equilibrium with the sea. In addition, the amount of precipitation entering the system on an annual basis is highly variable due to the climatic variability of Galapagos, whereas the demand for water continues to increase. Climatic data are critical to understanding the dynamics of the water resource and its availability over time.

The 2007-08 hydrological year demonstrated the unpredictable nature of the Galapagos climate. It is critical that a larger monitoring network be established to understand the complexities of the hydrological system and to better prepare for any effects of climate change. In addition, this study identified two serious problems associated with the Pelican Bay watershed and the use of subterranean water: (i) high volumes of water have not been

Photograph: Verónica Toral

accounted for, as observed at the Deep Well, and (ii) the average use in Puerto Ayora appears to be much greater than the amount recommended on an international scale. Currently, the initiation of a comprehensive metering system for water use in Santa Cruz is of great importance for decision-makers, as this is the only way to identify trends in water use and to have access to the information needed to make decisions regarding water resource management.

To improve the use of the limited water resource, the following measures are recommended:

1) Provide training for institutions in the recording, analysis, and proactive use of water data. For example, the municipality should work to identify the source of discrepancies between the rates of extraction and use in Bellavista.

2) Expand the metering system to obtain quantitative data of the volume of water used by each sector: tourism, agriculture, industry (construction, laundromats, etc.), and commercial.

3) Implement payment by volume of water used in Puerto Ayora as currently occurs in Bellavista to provide incentive for better water use practices, lower the average use per person, and increase the revenue received by the municipality for maintenance of the water system and to improve services.

4) Implement regulations, such as floats in tanks, control of water use in swimming pools, limits on watering and irrigation, and incentives for collecting rainwater.

5) Continue to collect data on the extraction of water from the basal aquifer and require that all private water users maintain a monthly record of volume used.

6) Create a working group to implement a strategy for the integrated management of the watersheds.

7) Continue scientific research to determine the exact rate of aquifer recharge and the effects of climatic variability.