Nexus interventions for small tropical islands: case study Bonaire

Water

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Water is a scarce natural resource on most small tropical islands, including Bonaire. Factors as 'when', 'where' and 'what kind of water' (in terms of quality) all steer water availability, and often results in a mismatch between water supply and water demand. The loss of water due to evaporation and run off is generally large, with the latter causing severe impacts on coastal ecosystems (e.g. mangroves, seagrass beds, coral reefs) through enhanced coastal eutrophication and sedimentation.

To meet the island demand, drinking water is generally produced from seawater via reverse osmosis, an energy-demanding process, that drives the price of water. Recycling of drinking water is therefore profitable, and as a result treated waste water is a valuable source of water on Bonaire. Current destinations for treated waste water are irrigation of gardens and crops, power plant cooling and the allocation into a wetland/pond. Application of the Nexus approach shows that necessities and prioritization of treated waste water provides opportunities for additional destinations of treated waste water, including agriculture, aquaculture and hydroculture. However, these alternative destinations involve certain quantity and quality requirements related to the treated 'grey' water. The varying requirements need to be discussed in a larger stakeholder settings, so that win-win situations can be identified and planned for. Additional nexus interventions include reducing the degradation and loss of freshwater resources through technical and ecological (Building with Nature) measures, rainwater harvesting (which limits run off related impact on coastal ecosystems), water reuse/recycling, increasing the use of renewable energy for desalinisation, low-cost wastewater treatment facilities such as artificial wetlands, increasing awareness on water conservation, and integrated water and land management.

	Current state	Desired state	Challenge	Nexus intervention
Rainfall & Groundwater	Limited supply, but integrated water management plan is lacking Low ability of soil to retain rainfall Water run off to coastal zone. Causes flooding of urban areas, and enhances erosion with severe impact on coastal habitats Ongoing salinization of groundwater due to sea level rise Groundwater is brackish, limiting its use Climate change effect on rainfall patterns and water	Retention of rain water to groundwater Improved quality of groundwater No/less water run off to coastal zone Surface retention and direct use of rainwater Shared fact finding	Rainfall is mostly restricted to the wet season Unknown groundwater balance and quality in time and space Unknown where to apply interventions to retain water and lower impact of run off on coastal habitats	Create awareness among stakeholders for the necessity to develop an integrated water management plan Set-up a programme to monitor groundwater level and quality to allow knowledge-based interventions Identify catchment areas and catchment specific characteristics (i.e. run off, vegetation cover, land use) to select key catchment areas for interventions to increase water retention/reduce run off
Drinking Water	High price due to use of imported fossil fuels for production Increased demand due to population growth/increasing living standards Unsustainable use (e.g. irrigation of gardens) Loss of drinking water during transportation to end user due to leaking pipelines	Affordable water Reduced demand Sustainable use Reduced loss	Decrease price of production Difficult to change consumption patterns	Use renewable energy to lower price Use educational programmes to raise awareness on necessity and benefits of water conservation Improve water transportation infrastructure
Grey Water	Used in irrigation (50%), other 50% in pond Treatment up to high standards resulting in nutrient-poor treated waste Infrastructure for transportation lacking	100% used for irrigation or other smart destinations Quality in line with destination	Infrastructure is missing to allocate grey water to places of use Stakeholder discussion on quality requirements	Evaluate most effective destination of grey water via multi stakeholder meetings based on quantity, quality and treatment steps needed

Box 1. Summary factsheet Nexus-Water

INTRODUCTION: CURRENT STATE, TRENDS & DRIVERS OF CHANGE

Water is critical to the survival of all living organisms. Yet, most small tropical island states, including Bonaire, are experiencing increasing shortage of fresh water as a result of multiple anthropogenic pressures (e.g. population growth, urbanization, rising living standards) and climate change impacts on their already vulnerable fresh water resources. Water scarcity has far-reaching impacts on sustainable development and could even jeopardize the continued human habitation of some islands.
Due to the lack of lakes and rivers on most small tropical islands, fresh water is typically derived from precipitation and/or groundwater storage. Fresh water is however not equal to potable water. The latter requires specific treatment steps before it becomes suitable for drinking. In the case of Bonaire, the following forms of water sources can be identified:

1) rainfall: stored in reservoirs and used for irrigation of crops and gardens
2) groundwater: used for irrigation of crops and consumption by cattle
3) drinking water: obtained from seawater via reverse osmosis and used for human consumption
4) grey water (from sewage treatment): used for irrigation of crops and gardens

Rainfall & groundwater

The partitioning of rainfall over surface runoff, infiltration and evaporation is determined by the amount of rainfall, wind conditions, temperature and the type of soil. The less rain, the more will evaporate before it is able to infiltrate in the soil and reach the aquifers. Soil, like the local "diabase" (weathered top layer of the volcanic formation) makes infiltration difficult, resulting in large run off via roois (seasonal streams). In the diabase terrain many dams and reservoirs (tankis) are constructed to retain rainwater. These reservoirs hold water during a few months after the rainy season. A large part of the stored water will evaporate, and depending on the local soil conditions, a part of the water will infiltrate into the soil or into the many cracks of the karstified limestones (Borst & De Haas, 2005), where it adds to the groundwater reservoir. On Bonaire, groundwater is generally brackish (electrical conductivity 2,000 to 4,000 µS/cm) and, apart from Fontein (a spring), there are no constant streams and springs (Borst and de Haas 2005). Across the island, large spatial differences in salinity levels of ground water exist. In figure 1 the geohydrological situation is schematized for the situation over Kralendijk and Fontein. Differences in soil composition results in different run off and infiltration patterns. The volcanic material acts as an impermeable base for the water flowing through the more permeable limestones. At the place where the volcanic material crops out again, such as at Fontein- at the east side- the water may come to the surface and forms a spring (Borst & De Haas, 2005). Water flowing sub-terraneously though limestone landscapes is accessed at many locations via manmade karst wells and natural karst caverns.

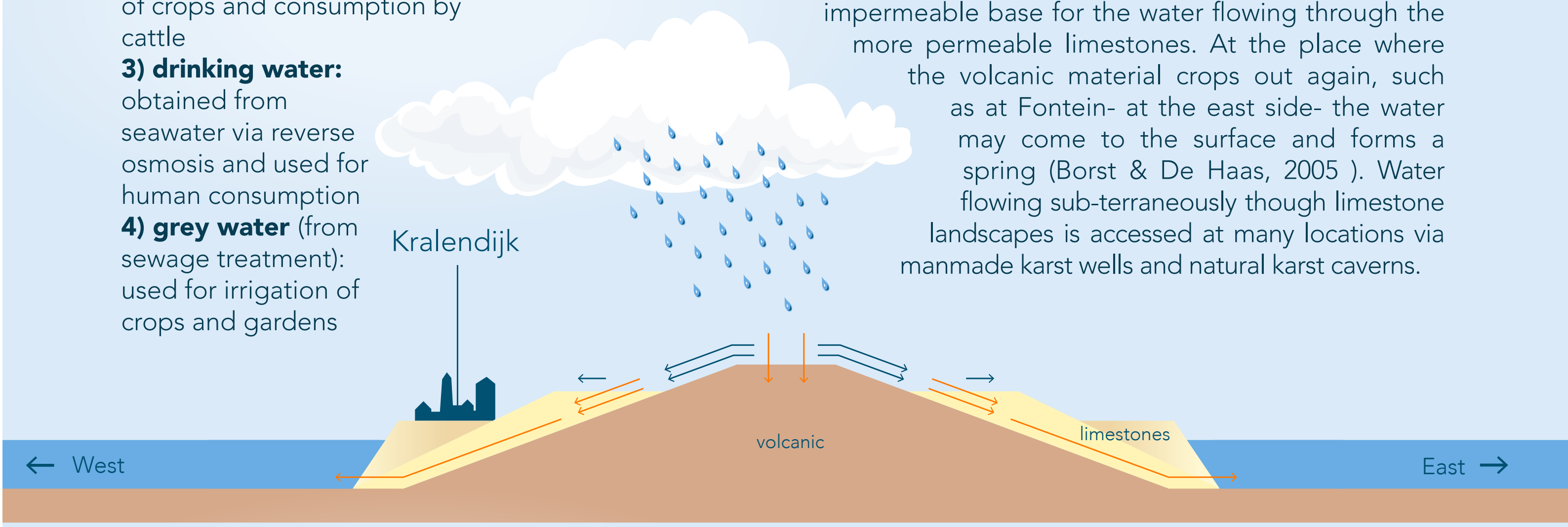
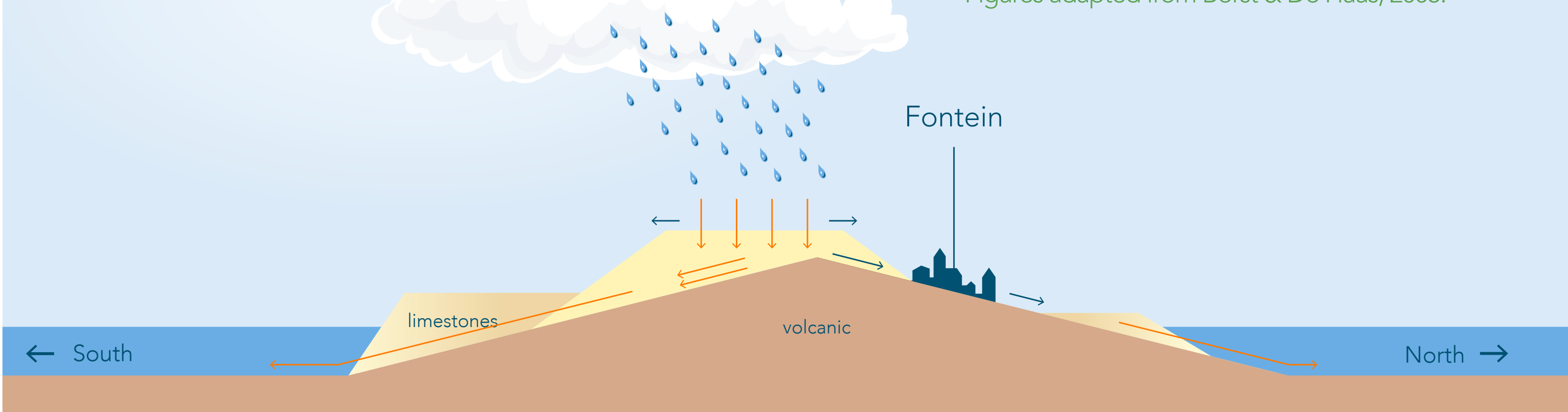


Figure 1. Above: Geohydrological situation in a schematic cross-section over Kralendijk.

Below: Geohydrological situation in a schematic cross-section over Fontein. Red arrows indicate infiltration, blue arrows indicate surface runoff.
Figures adapted from Borst & De Haas, 2005.



Rainwater is collected and only sometimes harvested in reservoirs during the rainy season which lasts from October to December. The water in these reservoirs becomes brackish, as a result of high evaporation rates. Local people use this water for irrigation of relatively salt tolerant crops like maize, for consumption by goats (Borst & De Haas, 2005) and occasionally for construction activities (pers. comm. Jan Jaap van Almenkerk). Salinity levels of the water provided by wells (Figure 4).

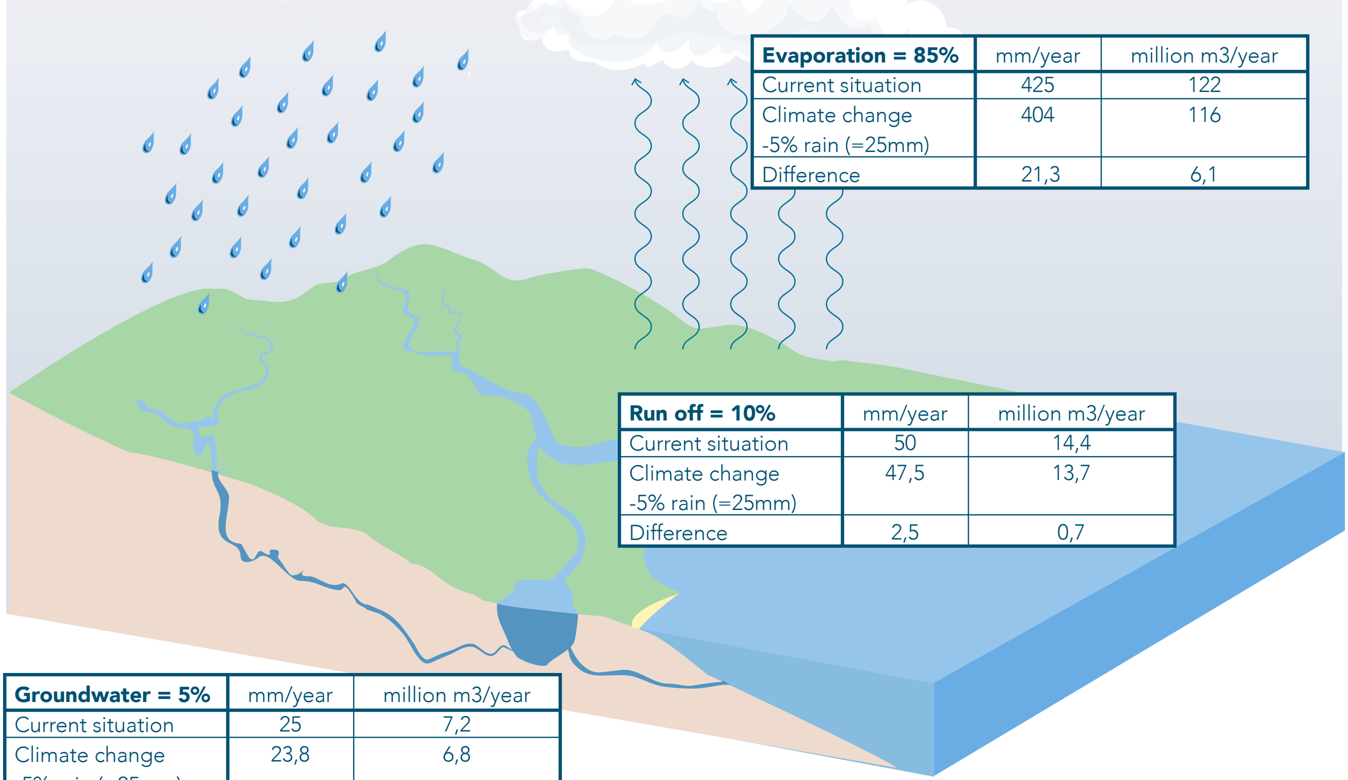
The recharge of ground water levels by rainwater infiltration will likely decrease due to climate change. ICCP predicts (intermediate low-emissions scenario), that the Caribbean Region by the end of this century will face a decrease in rainfall of 5 to 6% (ICCP, 2013). The current annual rainfall of ~500 mm (litre/m2) would then be ~475 mm. When extrapolated to the total surface of Bonaire (288 km2) this decrease of rainfall equals a decrease of an annual 7.200.000 m3 of rainwater. Based on previously documented evaporation rates for Bonaire and the expected percentage of rain water lost due to run off (Borst & De Haas, 2005), only 5% of this rainwater will recharge into the groundwater system (Figure 2). This results in a decreased water availability to the groundwater system of **360.000 m3 per year.** This will further decrease water availability for crop irrigation and animal husbandry, increasing the pressure on already limited water supplies. Moreover, a decrease of fresh water input to the ground water reservoir will increase the risk of salinization of groundwater. Deeper saline groundwater will be able to move upward to replace the space previously occupied by freshwater, salt water intrusion lead to even higher salinity levels of groundwater in the wells. Salinization of groundwater resources will also be exacerbated by predicted sea-level rise and the storage capacity of groundwater aquifers will be further reduced.

Drinking water

At present, the supply of drinking water for the approximate 20,000 inhabitants of Bonaire is produced from desalinated seawater via reversed osmosis and additional treatment steps, as managed by WEB Bonaire. This desalinisation treatment demands much energy, resulting in a relatively high price for water. The price of water is subsidised by the Dutch government in order to keep water affordable for the population.

In 2016, WEB produced 1,600 m^3 of drinking water, and partner GE Water & Process Technology added 4,000 m^3. For 2016, this brings the total production capacity on Bonaire at 5,600 m^3/day. The actual production is much lower, being only 4,800 m^3 of water production per day in 2018. Based on the history of construction activities and current construction requests, WEB predicts that daily water production and consumption will increase to 6,400 m^3 in 2024 and 8800 m^3 in 2030. Upscaling of the production is in line with this increase in demand.

Figure 2. Water balance of Bonaire related to climate change



Rainfall	mm/year	million m3/year
Current situation	500	144
Climate change -5% rain (=25mm)	475	136,8
Difference	25	7,2

Evaporation = 85%	mm/year	million m3/year
Current situation	425	122
Climate change -5% rain (=25mm)	404	116
Difference	21,3	6,1

Run off = 10%	mm/year	million m3/year
Current situation	50	14,4
Climate change -5% rain (=25mm)	47,5	13,7
Difference	2,5	0,7

Groundwater = 5%	mm/year	million m3/year
Current situation	25	7,2
Climate change -5% rain (=25mm)	23,8	6,8
Difference	1,3	0,36

Grey water

The first water treatment plant of Bonaire has been operational 2014, providing ~216,000 m^3 of treated waste water (grey water) per year. Increasing production is expected in the future due to population growth-related and increased in water use. Treated waste water is in potential a sustainable source of irrigation water. After taking some precautionary measures with regard to pollution, treated waste water can be used in agriculture. As treated waste water is relatively inexpensive compared to drinking water, it can be used to improve and scale-up water-demanding agricultural activities on the arid lands of Bonaire (see "Food from the land factsheet"), while simultaneously reducing the pressure on available fresh water resources.

Allocation of treated waste water

The initial plan was to allocate 75% of the treated waste water for irrigation of hotel gardens. However, due to technical problems with regard to the development of the necessary to transport the treated water from the treatment plant to the hotel gardens, the hotels have not been able to receive any treated waste water yet. As a result, hotels now use drinking water for irrigation of their gardens. Some hotels recycle their own untreated waste water for garden irrigation purposes. As all hotels have been built along the coast on porous limestone karst lands, this untreated grey water leaches rapidly into the adjacent coral reef habitat with many adverse effects for the nearshore coral communities.

Treated waste water is presently successfully being used for agricultural purposes (livestock fodder production and horticulture). Also in this case, logistic constraints to distribution are a major steering factor in the allocation of treated water. As a consequence, only 50% of the treated water is currently being used for irrigation of crops. A few fields (total 20 hectares) near the treatment plant, are irrigated directly with part of the available treated water (depending on the period up to 800 m^3/day), for fodder production for livestock, while a few trucks also transport water to nearby farmers. The remaining water is discharged into ditches near the water treatment plant, where it is slowly lost due to evaporation.

In 2021, the expected amount of usable effluent will have increased to 1400 m^3/day, due to increased consumption and thus increased waste water supply. Of this about 120 m^3 will be directed for vegetable crops, and 1280 m^3 for irrigation of 35 hectares for fodder production. However, getting the water to other areas where it can be used (such as the East Coast where a total of 25 hectares could be irrigated), but the necessary infrastructure is lacking (pipelines) and there is no solution yet in sight.

DESIRED FUTURE STATE

Rainwater and groundwater

Freshwater provisioning on Bonaire is still an unbalanced process, leading to crop damage or loss, and impacts on nature. Borst and De Haas already stated in 2005, that groundwater quality and quantity can be improved by retaining more rainwater (Borst and Haas, 2005) and this is still an aim today and for the future. In addition, an integrated water management plan should be implemented, which includes measures that prevent rainwater run-off to the coastal zone, and subsequent run-off related degradation of coastal habitats through sedimentation and eutrophication.

Drinking water

Affordable and accessible drinking water for everybody, that is produced, distributed and consumed in a sustainable way. Reverse-osmoses is an energy demanding process. In near future, a new seawater reverse-osmose (SWRO) installation will be installed, which will be a factor 1.6 more efficient in terms of energy use, because the water intake and pump system use less energy. The brine will be discharged at ~60 meters to reduce ecological impact on reef, instead of current situation where brine is discharged at surface. In nexus terms this new installation to produce water is a more sustainable solution: more efficient water production, with lower energy use, and in addition poses less impact on the environment (less CO^2 emission, less risks of oil spills, less brine in shallow coastal water). Lower energy use means lower costs, and cheaper product for the people who can spend the money on other things in their household (e.g food).

Grey water

All waste water from domestic use is recycled in a waste water treatment plant, so that treated waste water can be used for irrigation of food crops. Year-round availability of treated waste water will allow for year-round production of fodder for livestock and the irrigation of different types of salt resistant crops and the use of innovative techniques such as hydroponics, aquaponics and drip irrigation. Improved infrastructure related to the transport of treated waste water will allow irrigation of crops at multiple locations on Bonaire.

KNOWLEDGE NEEDS AND CHALLENGES

Rainfall and groundwater

Careful rainwater and groundwater management, including planning of land and water use, provide major environmental and socio-economic perspectives for sustainable development. The first step needed is an identification of the best potential water catchment and retention areas and most critical areas regarding impact (workshop outcomes, and Borst & De Haas, 2005, Roberts et al., 2017). Furthermore, the annual rainfall (144 million m^3/year) could in theory supply for the drinking water needs of the population. Question could be how to retain this water.

More detailed research, including the monitoring of groundwater levels and quality over a longer period would provide a better understanding of the groundwater system and run-off. Remote sensing techniques, together with run-off modelling (figure 3), presented in geographical information system (GIS) can assist both governmental organizations and future research projects, by identifying catchment areas for the most effective placement of dams. Since 2005, techniques for remote sensing have improved, and can be very useful for landscape management.

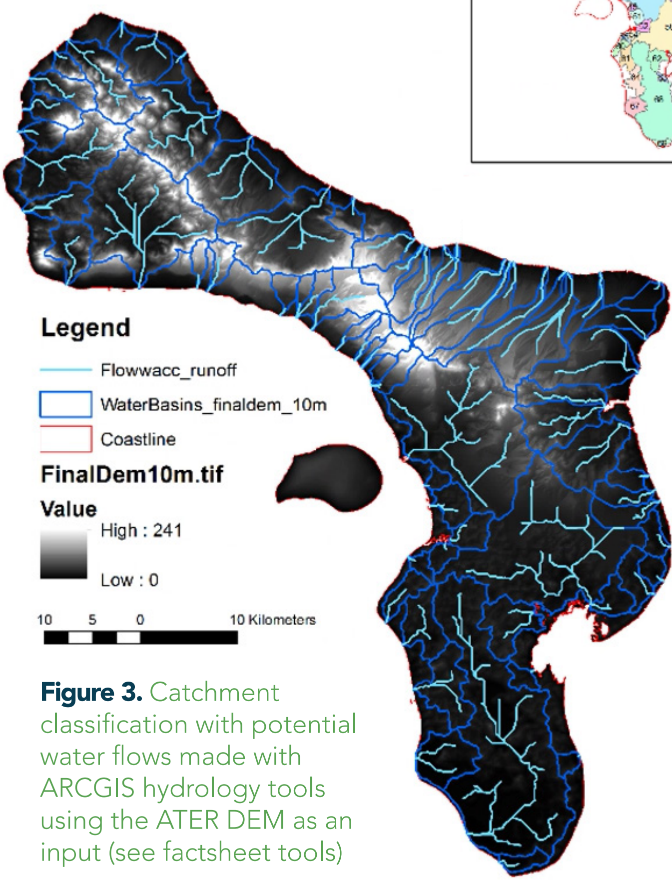


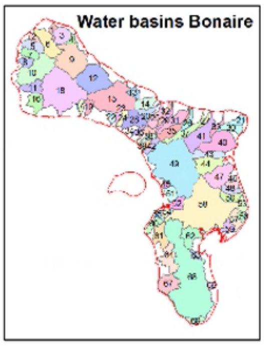
Figure 3. Catchment classification with potential water flows made with ARCGIS hydrology tools using the ATER DEM as an input (see factsheet tools)

Drinking water

Regarding security of drinking water on Bonaire, future challenges lay in lowering the costs related to the production of drinking water out of seawater, while additionally lowering human consumption through awareness raising campaigns on water use efficiency, pollution prevention and best agricultural practices.

Grey water

Quantity and quality issues for various end users asks for an assessment of needs and supply criteria. Currently, there is no infrastructure to transport treated waste water to end users like hotels near the coast and farms in rural areas. In light of the calcareous structure of the soil on Bonaire in combination with the high number of different land owners, construction of a pipeline infrastructure to transport treated waste water across Bonaire will be both expensive and difficult to implement. It will most likely require corporation of land owners. Optional above ground installation of pipelines could be an alternative.



During the process of waste water treatment, nutrients like nitrogen and phosphorus are removed from the water. This is good for water reused near the coast for hotel garden irrigation as it will reduce nutrient leaching into the coastal coral reefs. However, nutrient removal due to treatment is not an advantage when this is used for agricultural crop irrigation at inland farms as the nutrients can there be put to good use for crop production and will reduce the need for imported fertilizers.

Future grey water demand may also increase by allocation of grey water to ponds/wetlands systems to provide wildlife with a year-round accessible freshwater source, or for its use in aquaculture. Questions on water quality in relation to nature development or food production are foreseen. Effluent can contain a variety of contaminants that can accumulate in soils, crops or even the food chain and impact biological processes. Proper understanding of the water characteristics is needed to help allocating the water for suitable purposes.

Potential limitations of the treatment plant, and to meet quality requirements that depends on the increased volumes to process are not included in this study but should be looked into.

POSSIBLE NEXUS INTERVENTIONS

In this section interventions are presented to improve freshwater availability and use on Bonaire. Note that each suggested intervention assumes that water production and use should be compliant with human health criteria and environmental policy criteria.

Groundwater

Improved retention of rainwater can be achieved by restoring building and maintaining dams. Using modern remote-sensing technologies, catchment areas and their specific characteristics in terms of water run-off, vegetation cover, and soil moisture content, should be quantified, to provide policy makers with the knowledge on which measures are suitable for each specific catchment area. Water retention and prevention of run-off prevention can also be improved by increasing the vegetation cover. This could be achieved by revegetation programmes or by reducing the grazing pressure by free roaming livestock.

Improved retention and effective distribution and use of rainwater will result in:

- Reduced loss of fertile top soil due to run-off of rainwater
- Reduced risk of economic damage caused by flooding of urban areas
- Decreased impact of sedimentation on coastal habitats (e.g. mangroves, seagrass beds, coral reefs)
- Increased agricultural production

Drinking water

The price of drinking water on Bonaire is highly dependent on the price and the amount of energy needed to produce and transport drinking water. Currently, ~60% of the energy supply on Bonaire comes from burning fossil fuels that need to be imported from elsewhere, and as a result are expensive. Moreover, over 70% of the drinking water on Bonaire is produced by an outdated water reverse-osmose plant, which is far less efficient in water and energy use compared to more recently developed seawater reverse-osmose plants which will be installed in near future. In addition, a large proportion of drinking water is lost during transportation to end users, possibly due to leaking pipelines. The island is blessed with much sun and wind which provide important perspectives for the further development of sustainable sun and wind energy production. In addition, the availability of deep cold waters nearshore, provide possibilities for Ocean Thermal Energy Conversion (OTEC).. By developing of a more efficient water production and distribution infrastructure, and the use of readily available alternative sustainable energy sources can likely provide additional ways to reduce the price of drinking water.

Grey water

Besides the issue of the distribution of treated waste water, water quality is also an important constraint. Within the treatment plant, various treatment steps are used to meet stringent water quality criteria and to it to be used in the hotel gardens at the west coast. When these criteria on nitrogen and phosphorus content are met, coral reefs will be safer from the risk of nutrients leaching into coastal waters. However, at present this "over"-treated water is not being used by hotels, but by farmers, which for their purposes could benefit from the use of less-treated water with higher nutrient concentrations. Farmers at present are using (imported) nitrogen and phosphorus to fertilize their crops. This addition of nutrients to the nitrogen and phosphorus cycle on Bonaire is an un-effective side-effect of the current over-treatment of waste water. It should be discussed among all stakeholders what quality requirements have to be met for different purposes, and to allocate the water accordingly. Maybe, it could be possible to withdraw waste water at an earlier stage in the treatment cycle for the farmers and at a later stage for hotel use.

GOVERNANCE

With proper water management, freshwater availability for various uses can be increased, water prices can be reduced and profitable and sustainable agricultural production can be made possible for Bonaire. The "Bestuursprogramma 2016-2019 Bonaire" and the beleidsvisie landbouw" both pave the way to a more sustainable manner of agriculture, within the ecological limits of the system. The defined action list is long and ambitious but also quite specific. Various defined plans can be financed via the recently declared bestuursakkoord (November 14, 2018), and the allocation of funds are already partly provided via the "regio envelop". Although the plans are clear (more sustainable agriculture, with use of treated water) no concrete actions have yet been defined regarding the underlying water management needs such as as spatial and infrastructure planning. Without a proper and structural vision and actions on future water management, the plans defined in the bestuursakkoord will be difficult to reach.

Water allocation between sectors

As explained above, the different types of water resulting from active water management, can be used for different competing purposes. Therefore, in addition to (a) water production, (b) water quality and the necessary infrastructure for (c) distribution, (d) water allocation between sectors and users will be a key governance matter to address in a water management plan. In particular the allocation of grey water between sectors and their different quality requirements should be discussed and agreed among parties involved (WEB, RCN. OLB, hotels, LVV, farmers,...) and decided in concordance with a strategic development vision for the island. At present water distribution problems constrain which parties have access to treated waste water. Because waste water availability is also not limiting (production exceeds current use), the matter of water allocation is not yet a major issue. However, as soon as the produced wastewater becomes available to a larger group of potential users from different sectors, the matter of equitable allocation will become important.

Figure 4. Groundwater station

FUTURE PRIORITIES & RESEARCH NEEDED

Draft a water management plan, including:

- Groundwater assessment in terms of quality and availability
- Identification of priorities for water retention in relation to coastal impact areas.
- Develop effective systems for long-term storage of freshwater for instance by means of the use of impermeable synthetic lining of catchment dams and basins.
- Design an effective system for freshwater harvest, distribution and use from catchment dams. At present, most water retained behind catchment dams is not actively used and ultimately lost to evaporation.
- Study magnitude and effects of climate change on water demand, supply and quality.

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Colophon

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