The United Nations Environment Programme (UNEP) on behalf of the Climate Technology Centre and Network (CTCN)

Final Report

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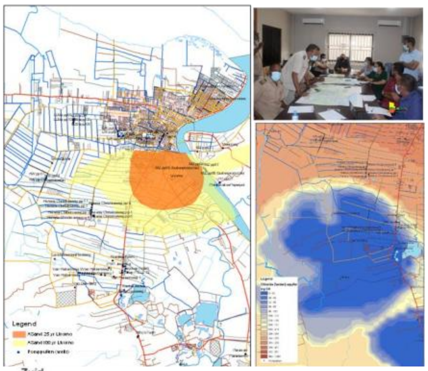

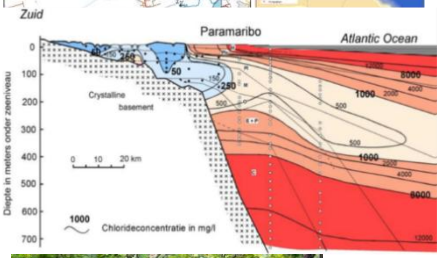

Consultancy services for

Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge

Acronym: ***ARADIS***

Climate Technology Centre and Network (CTCN)

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ILACO

In association with

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1 Project Outline

1.1 Introduction

The fore lying report is an account of the ARADIS research project, which was carried out in Suriname in the period from September 2024 to January 2026. The project investigated the possibilities of managed aquifer recharge as a strategy to combat drought in Suriname. ARADIS stands for *Aquifer Recharge against droughts in Suriname*. The full original name was *"Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge" (CTCN, 2023)*. The project was funded by the United Nations Environmental Program (UNEP) and supervised by the Climate Technology Centre and Network (CTCN), the working arm of the United Nations Framework Convention on Climate Change (UNFCCC). In Suriname, the project was first managed by the Ministry of Spatial Planning and Environment (ROM) and since September 2025 by the Ministry of Oil, Gas and Environment (OGM), hereafter named the client.

The project has been awarded to a consortium consisting of the engineering firm ILACO from Suriname, as leading partner, and the firms Acacia Water and RHDHV from the Netherlands. Apart from the client, the project deliverables have been reviewed at critical moments by a Stakeholder Working Group (SWG), which was formed during the inception phase.

The reports are attached as annexes to this document. See the list below for an overview of the reports included as annexes:
1. Gender Analysis
2. Stakeholder mapping
3. Inception report
4. Drought risks & water demand
5. Aquifers & water balances
6. MAR techniques & feasibility
7. Selection of potential MAR pilots
8. Design of the Hanover MAR system
9. Cost Analysis & Benchmarking Funds Hanover MAR System
10. Minutes of Meetings SWG Workshops

Other mandatory deliverables i.e. progress reports:
1. Monitoring & Evaluation (M&E) Plan and Impact Statement Form
2. AFCIA Results tracker Suriname
3. Technical Assistance Closure Report

1.2 Rationale

Suriname has a humid tropical climate. Annual precipitation ranges from 1700 along the northwestern coast tot 2700 in the center of the country. Seasons are defined by variations in rainfall, namely:
- The short rainy season (early December to late January);
- The short dry season (early February to mid-April);
- The long rainy season (mid-April to mid-August); and
- The long dry season (mid-August to early December).

There are also interannual variations related to the El Niño-Southern Oscillation (ENSO) cycle. During so called El Nino years the long dry season can increase both in intensity and duration. An El Niño episode occurs every 2-7 years and has large impacts on the hydrological conditions and consequently water supply, agriculture, ecosystems and other water dependent functions. Recently Suriname experienced an El Niño drought starting in 2023 and lasting far into 2024. Climate change scenarios indicate that yearly rainfall will decrease in future, though intensity of rainfall events during the rainy seasons will increase causing more frequent flooding in urban areas (UNEP, 2023). El Niño droughts are expected to increase in severity and duration causing decreasing runoff of rivers and creeks, lowering of water levels and salinization of both groundwater and surface water. Because of these expected climatic and hydrological changes, but also because of population and economic growth, the project aimed to explore the potential of managed aquifer recharge, or underground water storage, to enhance the availability of groundwater for various water users in Suriname.

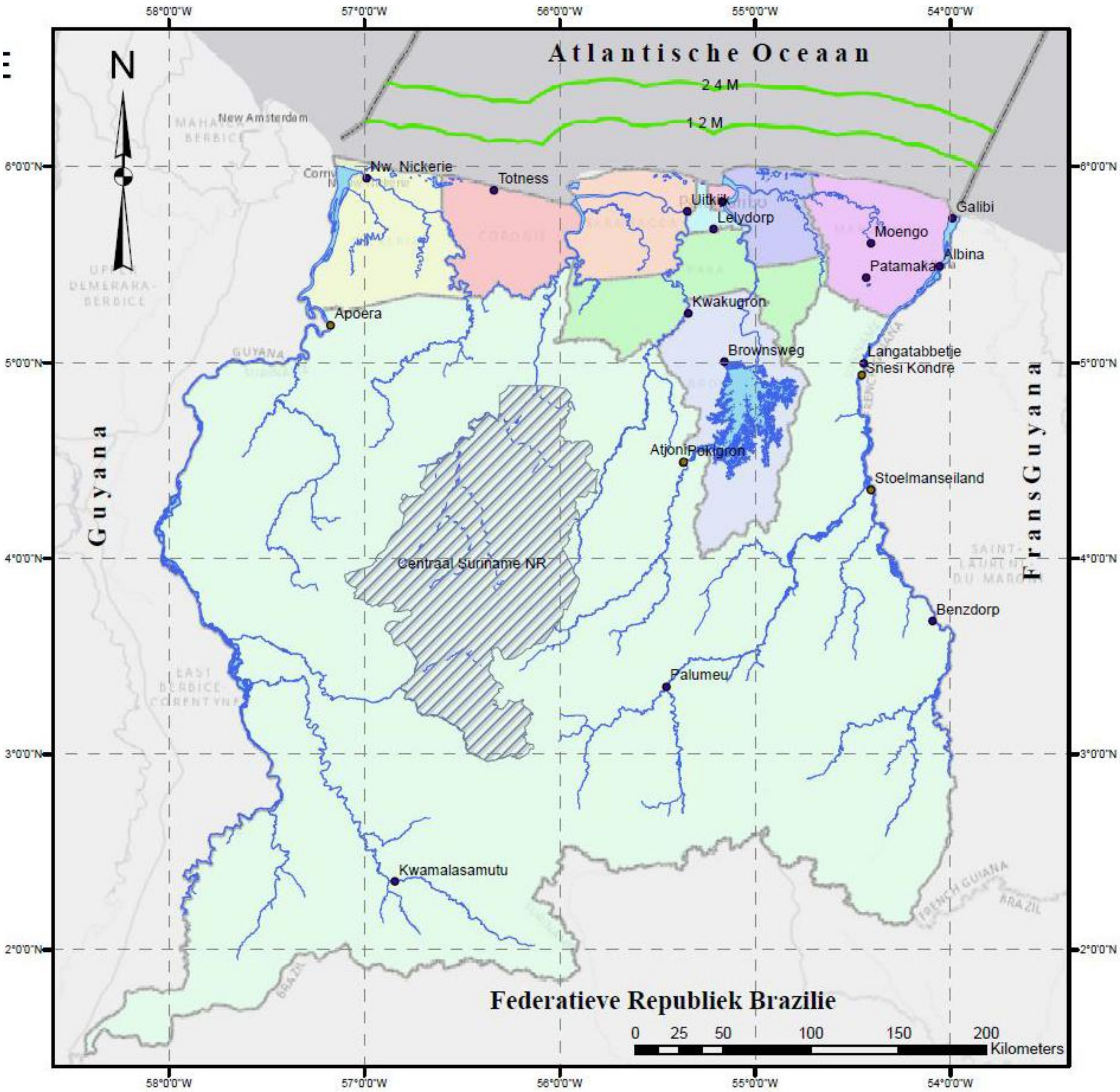

Figure 1. Republic of Suriname and districts. Six northern districts (Nickerie, Coronie, Saramacca, Paramaribo, Commewijne & Marowijne) encompass the coastal zone of Suriname, the target area of ARADIS project (Republiek Suriname, 2021)

Republiek Suriname, 2021. Meerjaren Ontwikkelingsplan 2022-2026 van de Republiek Suriname. Omdenken, Verbinden, Doen.

Problems are expected regarding the future water supply of various sectors. As far as drinking and industrial water supply is concerned groundwater is by far the most important source. This resource is already overexploited in some areas (RTI et al, 2016; TAUW, 2011; Genivar & ILACO, 2011; Groen, 2022). One of the strategies to cope with these developments is managed aquifer recharge (MAR) or underground water storage. Though applied in many countries in various forms, MAR is still a new and unexplored strategy in Suriname.

1.3 Planning

The project is carried out in three phases. Below an overview is given of the phases and main activities:

Phase 1: Inception
analysis of stakeholders,
analysis of gender roles,
inventory of data,
draft inception report
establishment and consultation SWG
preparation of inception report

Phase 2: Analysis
Drougths, climate, water demand
Aquifers, water balances
MAR technology
Preselection of 5 potential MAR pilot sites
Consultation of SWG and selection of pilot site

Phase 3: design and finalisation
Consultation of local stakeholders
3D aquifer mapping (geophysics)
Wells and well field
Water quality and water treatment study
Draft design of MAR system
Consultation and design approval of SWG
Benchmarking financial sources for follow up
Final workshop on broad perspective on groundwater and MAR with SWG and other stakeholders

2 Phase 1

2.1 Gender and social analysis

Regarding gender and social aspects of water supply, a distinction must be made between the coastal strip, consisting of the coastal plain and the savanna, and the interior of Suriname. In most residential areas in the coastal plain there is piped water supply with house connections. Supplier is the Surinamese Water Supply Company (Surinaamsche Waterleidingmaatschappij = SWM). The inland villages located along the larger rivers and creeks still largely depend on direct use of surface water. In a number of villages, water is supplied by the Water Supply Service of the Ministry of Natural Resources.

It is clear that gender roles differ significantly in these two areas. Women in the coastal districts bear primary responsibility for household water management, including cooking, cleaning, hygiene, and watering vegetable gardens, but they are not responsible for the water supply and maintenance of the water distribution system. Nevertheless, they are the first to feel the responsibility to find alternatives in case supply is interrupted. The same holds for female entrepreneurs operating small home-based businesses, such as catering and pastry making: in adequate water supply due to droughts leads to financial strain as they are forced to buy expensive water supplies.

In the interior, the role of women in water supply is much more important. Women are responsible for water collection for cooking, cleaning, and hygiene, often requiring them to carry water over long distances in case rivers and creeks are running dry. The also rely on precipitation to irrigate crops, making them vulnerable to drought-related food insecurity.

2.2 Stakeholder mapping

A comprehensive stakeholder analysis was conducted to secure support, ownership, and resources for the project. Three main categories of stakeholders were identified: those affecting water supply, those impacted by lack of water supply, and policymakers/data collection/knowledge institutes.

Stakeholders affecting the lack of water supply include mining companies, industrial sectors like breweries, and entities responsible for pollution, such as the Ornamibo waste disposal site and farmers using agrochemicals.

Stakeholders impacted by water shortage include local communities, agricultural producers, health institutions, and businesses like food and beverage industries.

Policy-making stakeholders include government ministries (e.g., Ministry of Natural Resources (Ministerie van Natuurlijke Hulpbronnen = NH), Ministry of Public Works and Spatial Planning Ministerie van Openbare Werken en Ruimtelijke Ordening = OWRO), the Water Platform (an existing informal group of stakeholders in water) and various international organizations.

Data collectors relevant to the project include water supply companies, the General Bureau of Statistics (ABS), the SWM, the ministries of OWRO, NH and OGM), the Anton de Kom University of Suriname, the State Oil Company (Staatsolie NV), the Geological Service of Suriname (Geologische Mijnbouwkundige Dienst = GMD)

Stakeholders were mapped based on their influence, interest, and impact to develop effective engagement strategies, categorizing them into three groups: affecting supply, impacted by lack of supply, and policymakers/data/knowledge institutes. Water Supply Companies were assessed as having High Influence, High Interest, and High Impact across both categories where they were listed.

Table 1. Stakeholders in water in Suriname

Stakeholder			
A. Stakeholders affecting the Lack of Water Supply	**Influence**	**Interest**	**Impact**
1. Water Supply Companies	High	High	High
2. Industrial Sectors	High	Low	High
3. Government Agencies	High	Medium	High
4. Urban Developers	High	Low	High
5. Agricultural Practices	High	Low	High
B. Stakeholders impacted by the Lack of Water Supply:			
1. Water Supply Companies	High	High	High
2. Local Communities	Low	Medium	High
3. Agricultural Producers	Medium	High	High
4. Health Institutions	Medium	High	High
5. Businesses/Organizations	Medium	High	High
C. Policymakers, Data-collection/Research, Knowledge Institutes			
1. Government Officials	High	Medium	High
2. Environmental NGOs	High	High	High
3. International Organizations	High	High	High

The Stakeholders Working Group (SWG) was established, prioritizing stakeholders with medium-high scores in influence and impact, to ensure inclusivity and balanced decision-making, including the gender perspective.

Table 2. Stakeholder Working Group in ARADIS Project

	Stakeholder Working Group		
Gender	**Name**	**Institute**	**Role**
F	Gonda Asadang	Min. NH	Dir. Water
M	Alwin Linger	Water Forum	
M	Dewdath Bhaggoe	Min. OWRO	Dep. Dir. Research and Innovation
F	Gladys Sno	Water Forum	
F	Ashwinie Hemai	SWM	Dep. Dir. Strategy and Policy
F	Eline Graanoogst	NVB	
M	Max Huisden	AdeK	AdeK - RC Environmental Sciences
M	Vinood Kisoensingh	RUBECOM N.V. (RUDISA)	Plant Manager / Mechanical Engineer

2.3 1st SWG meeting

The 1st SWG Workshop was held on December 5 2024, with attendance from official SWG members and supporting experts. Due to the broad scope of the project, a 'Pool of Experts and Resource Persons' (PoER) participated in the SWG meeting to provide technical support from different departments and fields of expertise. The PoER is considered an important addition to the official SWG and was integral to the success of the first workshop.

During the workshop the draft inception report was discussed. Main points were establishment of the coastal plain as the project area and some changes in the order of activities. Main changes were the selection of 5 potential MAR areas/techniques only after the three different studies under phase 2 had been carried out (droughts, aquifers and MAR technology) and the shift of the 3D aquifer mapping from Phase 2 to Phase 3. The logic of the last change was based on the fact that only one site was to be investigated according to the TOR, which only became known after the decisive SWG meeting at the end of Phase 2.

Following the first Stakeholders Working Group (SWG) Workshop, the Ministry of Agriculture, Livestock and Fisheries (Min. LVV) and the State Oil Company (Staatsolie NV) were added to the list of invited stakeholders due to their relevance to the project scope.

3 Analysis

3.1 Droughts, climate change and impacts

Based on precipitation series from various stations over the past 40 years, the frequency of major droughts in Suriname was investigated. The SPI-12 index (Standardized Precipitation Index) was used for this purpose. This index indicates how much cumulative precipitation in a month deviates from the average. Cumulative precipitation of a month is precipitation in that month plus that of the 11 preceding months. A negative SPI-12 value for a particular month means that precipitation in the preceding period was lower than normal. Positive values indicate the opposite. The reason for using this cumulative precipitation is that drought only becomes noticeable in the soil over a longer period. Figure 2 shows the normalized SPI-12 of mean precipitation in Suriname for the months from 1986 to 2025.

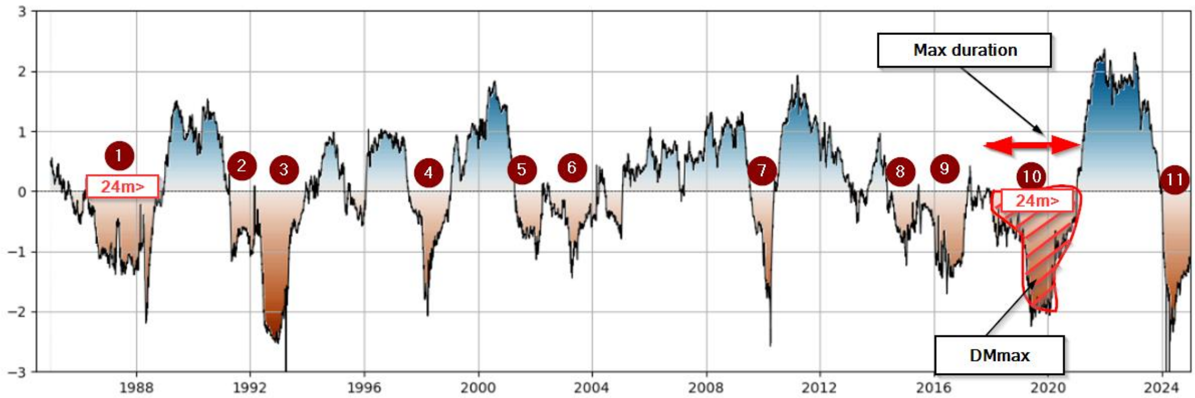

Figure 2. SPI-12 values for the mean precipitation series in Suriname. The integers represent the number of drought events (SPI < -1) (Annex 4)

A drought is defined as a period in which the SPI-12 values are below -1 (-1 is one standard deviation below average). During the last 40 years, there have been 11 major droughts. Most drought years appear to be related to El Niño events (once every 4 years). Drougths vary in duration and intensity. Severe droughts occurred din 1993, 2019 and 2024 (once every 15 to 20 years). The DHI index (Drougth Hazard Index) was used to study the geographic variation of drought hazard. The DHI index for a specific location is based on a long series of SPI values derived from the CHIRPS rainfall database (https://www.chc.ucsb.edu/data/chirps). The DHI index combines frequency of droughts at a location, as well as the duration and intensity of the droughts (Annex 4). The DHI values are divided into three classes and are shown in Figure 3. It appears that areas like the Para and Brokopondo districts and the Tapanahony River basin are more drought-prone than others. Other areas classified as high with drought hazard are sparsely populated. Note that the three classes are qualitatively defined. Actual climatic differences may not be that significant.

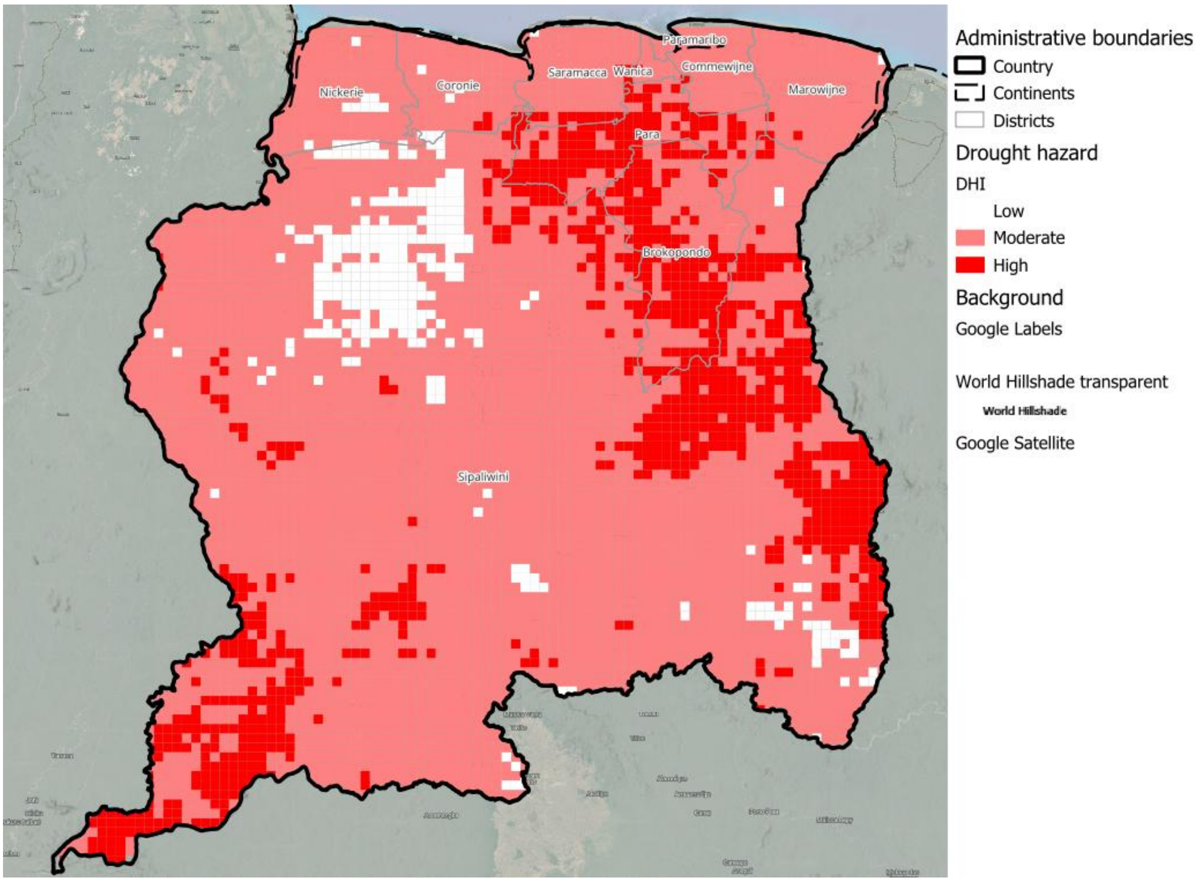

Figure 3. Drougth Hazard Indices in Suriname (Annex 4)

Analysis of records of meteorological stations in Suriname, some dating 100 years back, show no statistical significant trend in rainfall, except for the Totness station, where rainfall seems to decrease over time. Average annual temperature have increased by 0.75 °C and sealevel has risen about 20 cm since 1900. Though the pattern of drought and heavy rains may not have changed much, the experienced impacts may have increased (larger urban area, higher dependency on agricultural production and transport or simply better communication).

For this project the latest climate models have been analysed and confirm trends reported in earlier publications (Rep. of Gov. of Suriname, 2023; ABS, 2023, IDB, 2021). Annual and monthly rainfall will decrease by 16 to 21 %, but intensities of individual rainfall events will increase.

Most noticeable is the decline of average monthly rainfall in the short rainy and short dry season in the period from December to April (Figure 4). We may expect that the long dry season will more frequently last until April, the onset of the long rainy season. Such a drought event took place in 2024.

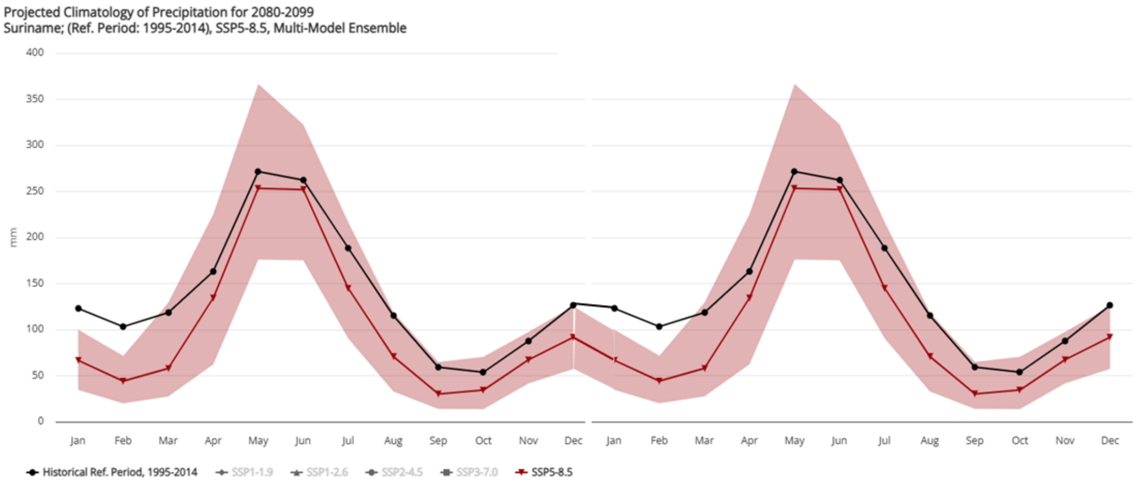

Figure 4. Average present (1995-2014) and future (2080-2099) precipitation in Suriname according to climate modeling (SSP5-8.5 scenario) (Annex 4).

Table 3. Hydrological and environmental effects of droughts

Compart ment	**Hydrolog. Effects**	**Derived Effects**	**Environmental effect (Sector)**
Surface water	Declining water levels Drying up of rivers, creeks and swamps		Long distance to water intake (Drinking water interior) Navigability of rivers (Transport interior, Tourism) Damage to ecosystemen (Nature conservation, Tourism) Decline of water level and inflow to Lake Brokopondo (Energty supply)
	Stagnation and reduced through flow of lakes and swamps	Concentration of solutes Eutrophication	Chem. contamination (Public Health) Water borne diseases (Public Health) Damage to ecosystems (Nature conservation, Tourism)
	Decrease of baseflows in major rivers	Seawater intrusion in major rivers	Limitations for water intake for irrigation, drinking water supply and other users

Soil	Dehydration		Crop damage (Agriculture) Damage to ecosystemen (Nature conservation, Tourism)
Groundw ater	Reduced recharge Decline of groundwater levels		Drying up of shallow wells Possibly decrease in capacity deep wellsputten (Drinking water supply & other groundwater users) Decrease of storage

3.2 Hydrological, environmental and societal effects of droughts

Table 3 summarizes the impacts of droughts on the hydrological systems in Suriname and the consequential environmental and societal effects.

3.2.1 Surface water

Irrigated rice cultivation in Nickerie depends on water supplies from the Nanni Swamp and the Nickerie River. Water shortage and crop damage can occur if the swamps dry up or if the Nickerie River turns brackish due to seawater intrusion.

Other users affected by the reduced water supply and the drying up of creeks and swamps are eco-resorts along the creeks in the savanna belt, particularly south of Paramaribo, and fishermen in the creeks.

The Suriname Drinking Water Company (SWM) extracts surface water from the Cottica and Suriname Rivers at Moengo and La Liberte, respectively. At La Liberte, where salinity levels in the Suriname River are already relatively high, membrane filtration is applied. These SWM pumping stations may be at risk if salinity levels rise above permissible levels during droughts and seawater intrusion.

Communities living along the major inland rivers rely heavily on rivers, creeks, and springs for drinking water supply, washing and cleaning. They will be severely affected if these water sources dry up and they need to fetch water from more distant sources. Navigability of the rivers, the major means of transport in the interior, is also hampered when water levels and discharges will decline during severe droughts.

Stagnation or reduced throughflow can affect water quality of creeks and swamps and consequently public health. Concentrations of pollutants may increase beyond acceptable limits. Stagnant water can become breeding grounds for numerous diseases.

Finally, the effects on ecosystems must also be mentioned. Drying out swamps and decreasing river flows can cause irreversible changes in biodiversity and the tourist sector.

Droughts also affect the Brokopondo Lake and the hydropower plant. Low inflows and low reservoir levels could jeopardize the electricity supply for the surrounding area and Paramaribo.

3.2.2 Soil

soil dehydration Rainfed agriculture in the coastal zone, mainly vegetable and fruit growers, will be effected during prolonged droughts by. Apart from the rice cultivation in Nickerie, irrigated agriculture is not common, though some farmers are using surface water from the creeks and swamps for supplementary irrigation during droughts. If these dry up (hydrological effect 2), damage will be inevitable. The same applies to farmers who use dug wells in sand ridges, such as in Coronie. These too can dry up (hydrological effect 3).

3.2.3 Groundwater

During droughts groundwater recharge diminishes and groundwater levels fall, which effects water production from wells. The Drinking Water Supply Company (SWM) is the major groundwater user in Suriname. Most SWM's production wells in the coastal zone are generally deep and not very sensitive to temporary lower groundwater levels. A temporary drop in water level in a wells increases hydraulic lift and may reduce pump discharge somewhat. Larger problems arise if dynamic water levels in overexploited wells reach the intake of the submersible pumps and pumps start to suck in air.

Shallow wells drilled in the savanna zone and sand ridges are more susceptible to droughts and falling groundwater levels than deep wells. A shallow well may completely fall dry if groundwater level drops by more than 1 meter. Shallow wells were once important for drinking water supply. They are still used for agriculture (Coronie).

Bottling companies, livestock and poultry farms, and some industries also abstract groundwater using drilled wells. The same comments as above apply to these.

We noticed some stakeholders attribute the increasing salinities in some SWM wells to droughts and climate change and excessive exploitation. However, the wells in Paramaribo pump groundwater from aquifers with fossil groundwater, unrelated to climate change (Paragraph 3.4)

3.3 Water demand

The water master plan (Genivar & ILACO, 2011) estimated water demand for all districts in Suriname (Figure 5). Demands in coastal districts were based on estimates of domestic water use (ranging from 150 l/p/day to 200 l/p/day) and industrial, commercial and institutional demand. Water demands are highest in the Paramaribo and Wanica districts. Projected demands are expected to stabilize at 275,000 m^3/day in 2040 or 300,000 m^3/day, if NRW losses cannot be decreased.

The HACAS project (RTI et al, 2016) estimated lower water demands (Figure 5). Present production by SWM for domestic and institutional users is still lower than the projected water demands (Figure 5). For 2040 a deficit of 65,000 m^3/day is anticipated given the HACAS (2016) demand assumptions. SWM manages various pumping stations in Paramaribo, some of which produce brackish water. If these pumping stations will be closed, the target for 2040 increases to 112,000 m^3/day. HACAS (2016) proposed realization of a number of pumping stations south of Paramaribo to compensate for this deficit in 2040 (Paragraph 3.5)

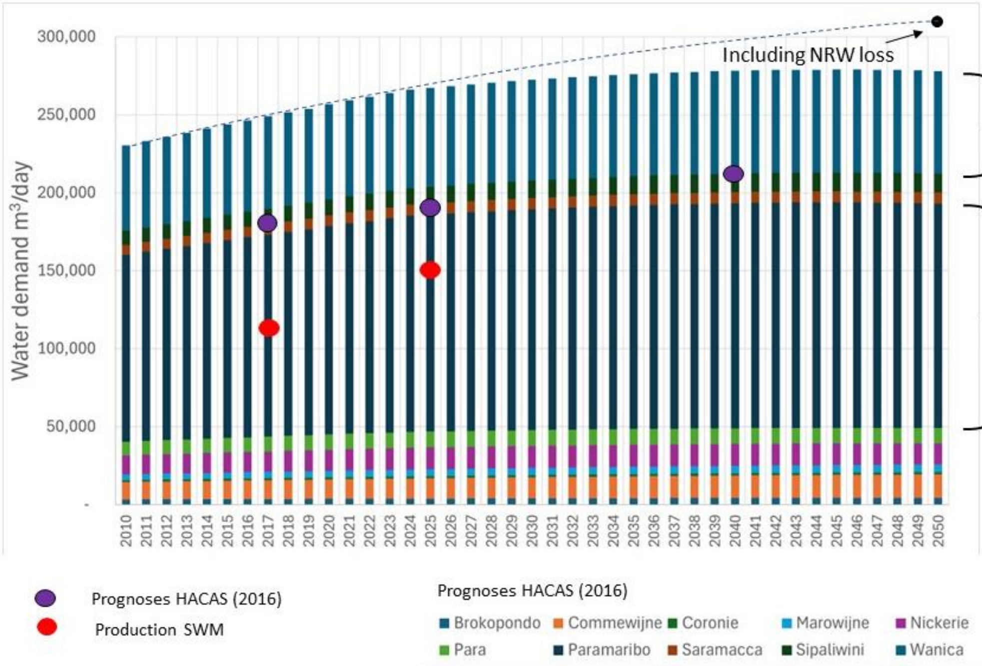

Figure 5. Water demand and water production (after Genivar & ILACO, 2011 and RTI et al, 2016)

3.4 Aquifers

The description of the coastal aquifers was mainly based on the HACAS groundwater assessment study (RTI, 2016), the PhD study of Groen (2002), the study of the stratigraphy of the coastal plain by Wong (1989) and the groundwater study of UNDP/WHO (1972). Crystalline basement rocks underly the major part of the country, which in the north dips below the sedimentary wedge of coastal zone. The coastal aquifers consist of sand layers within the Tertiary and Quaternary formations (Figure 6). Most aquifers are confined by overlying clay layers. Only the Tertiary Zanderij aquifer is exposed in the savanna zone. For a more detailed description of the aquifers we refer to Annex 5.

Five formations with aquifers can be discerned:
1. Isolated Quaternary sand and shell ridges at the surface (not shown in Figure 6)
2. Piocene Zanderij aquifer
3. Miocene Coesewijne aquifer
4. Oligocene A-sand or Burnside aquifer
5. Paleocene and Eocene Saramacca aquifer

The Saramacca aquifer was not indicated as a target aquifer in the TOR of the project. However, the HACAS study (RTI et al, 2016) discovered large fresh groundwater reserves in this aquifer west of Paramaribo. The aquifer was therefore included in this study.

The isolated sand and shell ridges are discontinuous aquifers, also not mentioned in the TOR. Before the establishment of the SWM and its pumping station, shallow dug wells in these sand bodies played an important role for the drinking water supply. The SWM and other groundwater users use wells sunk into Zanderij, Coesewijne, and A-sand aquifers. Depths vary from 50 to 250 m.

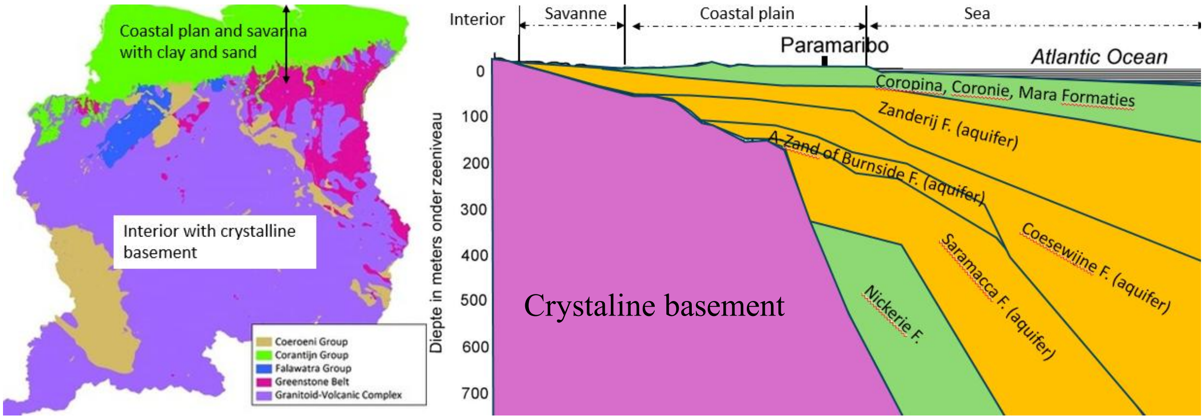

Figure 6. Geology of Suriname.

The aquifers (2 to 5, see above) in in the coastal plain of Suriname contain mainly fossil fresh groundwater. Fresh groundwater filled the aquifers during the last ice age (90,000 to 10,000 years BP). Conditions were much different from today: sea level was 50 to 100 m below present level; the coastal plain consisted of a hilly savanna type landscape with entrenched river and creeks; the coastline was found some 90 km offshore from the present shoreline. When sea level rose to its present level during the Holocene, groundwater flow in the aquifer halted and recharge ceased.

Only in the savanna zone, where the Zanderij aquifer is exposed, groundwater recharge takes place. However, most of this recharge is locally discharged into the savanna creeks and the bordering swamps of the coastal plain. Recharged groundwater does not reach the deeper and further northward located aquifers.

Salinities in the aquifers, expressed as chloride concentration, gradually increase towards the north (Figure 7). Even far offshore salinities are still relatively low (Groen, 2002). High salinities are found in the marine clays in the young coastal plain (northern part) and the deep Cretaceous sediments.

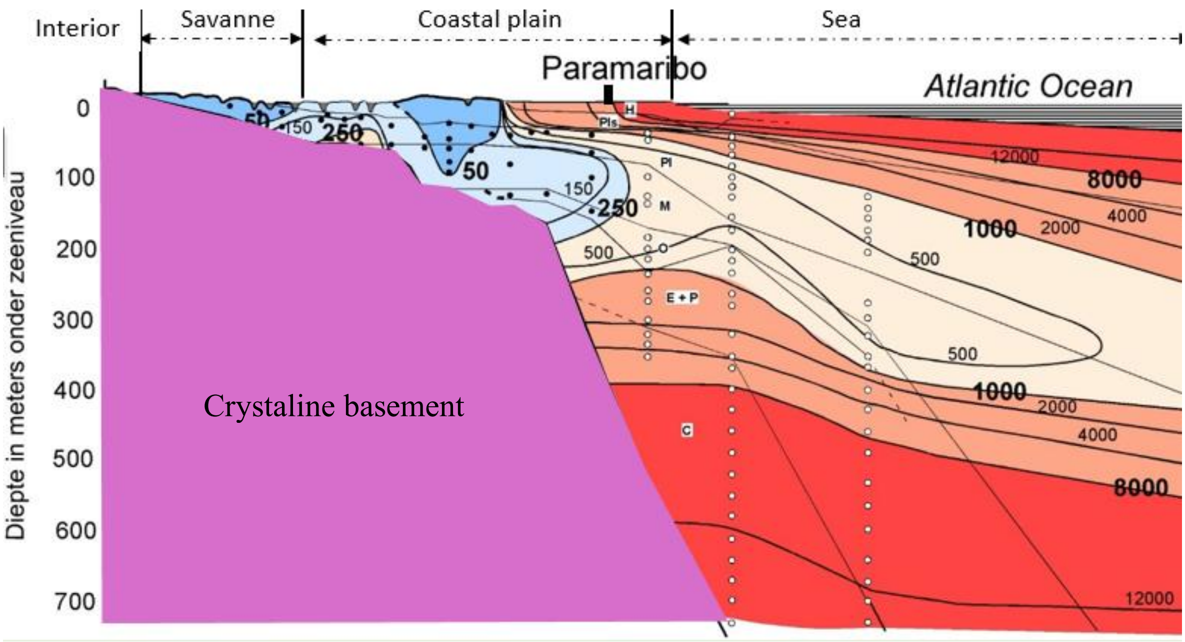

Figure 7. Chloride concentrations in aquifers in the coastal plain (from Groen, 2002)

Figure 7 shows that Paramaribo is located above the 250 mg/l chloride contour, the WHO guideline for potable groundwater. This explains why wells in the North of Paramaribo supply groundwater with higher salinities. By mixing water from the northern and southern pumping stations, water supply still meets the standard.

During the HACAS study (RTI et al, 2016) the aquifers were mapped in more detail based on all available information from hydrogeological reports, water well and oil well data (Figure 8).

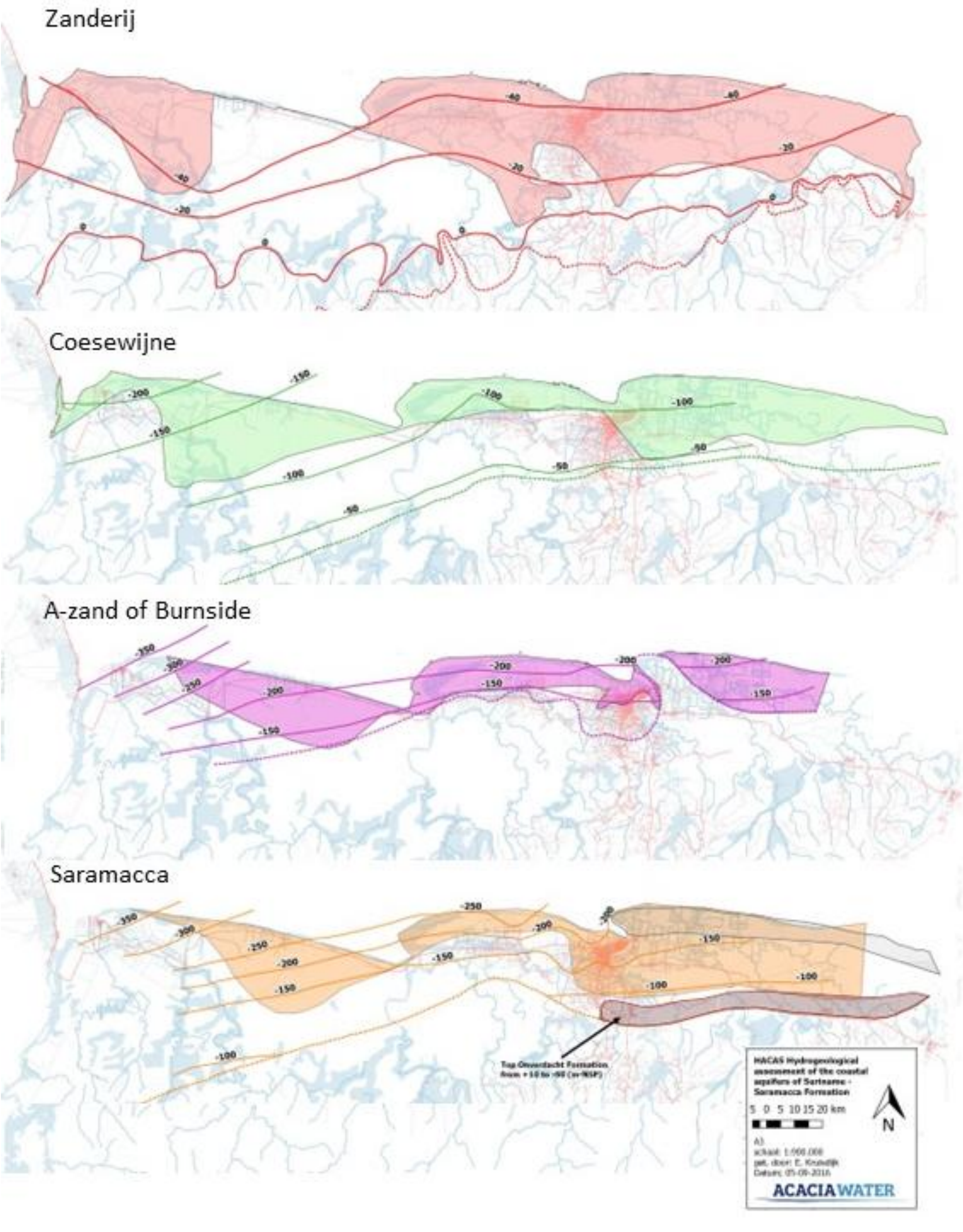

Figure 8. Maps of major aquifer in the coastal plain showing the southern limit (dashed line), depth of the top of the aquifers (contour lines) and the presence of brackish groundwater (coloured shades) (from RTI et al, 2016).

The HACAS maps indicate the southern extent of the aquifers and the depth to the top of the aquifers. Also zones are indicated where the aquifer contains only brackish groundwater (> 250 mg/l chloride). In general, the depths and thicknesses of the aquifers increase westward. Likewise fresh groundwater reserves are also larger in the western part of the coastal plain (RTI et al, 2016)

3.5 Water Balances

For this study, several water balance areas were identified, which more or less correspond to the coastal districts (see Figure 10). For each district and aquifer the availability of fresh groundwater and the sustainable groundwater extraction were determined. See Annex 5 for a more detailed description.

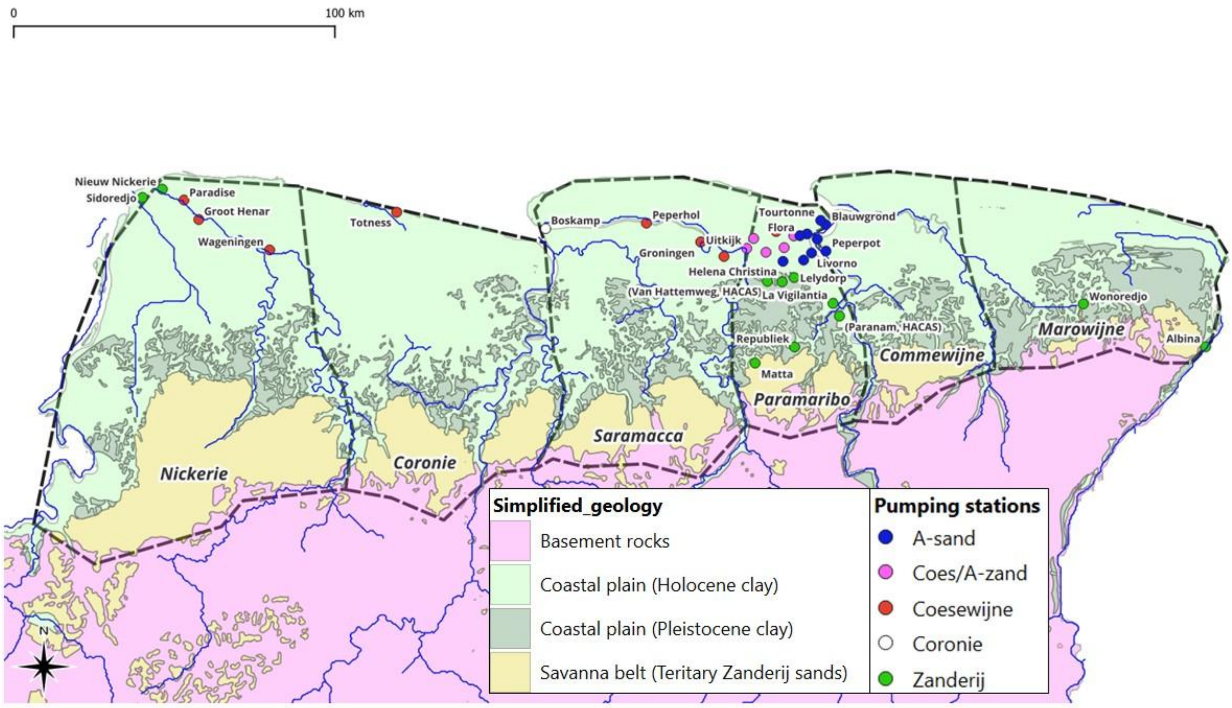

Figure 9. Water balance areas of the coasdtal plaian and the savanna (Annex 5)

In the savanna belt, it is assumed that sustainable water extraction from the Zanderij aquifer may not exceed 20% of the natural groundwater supply (Table 2). This 20% rule is often applied due to a lack of detailed information, such as in the UN World Water Development Reports as a threshold above which "water scarcity" occurs, with all sorts of adverse environmental effects (UN-Water, 2018). Groundwater recharge in the savanna belt has been estimated at 425 mm/year based on Groen (2002).

Extracting fossil groundwater in the coastal plain with little or no recharge will lead to increasingly large drawdowns of groundwater levels and eventually the replacement of freshwater by brackish and salt water (salinization). To study impacts, lifetime of abstraction and optimization of abstraction scenarios, groundwater modelling is necessary. The duration of groundwater abstraction could range from decades to centuries, depending on extraction rate relative to groundwater reserves in the aquifers. As a rule of thumb, we assume 40% of fresh groundwater in the coastal aquifers will be recoverable.

Based on these key figures (20% of recharge in the savanna zone and 40% recoverable reserves in the coastal plain) and groundwater abstractions (Paragraph, groundwater water balances have been set for the 6 water balance areas. These provide rough indications where shortages in groundwater abstraction exist or can be expected later this century (For a detailed analysis, refer to Annex 5).

The aquifers in the Commewijne area do not hold much fresh groundwater. The A-zand aquifer holds fresh ground water in the far west at Meerzorg and Peperpot, but these reserves will soon be depleted by salinization (TAUW, 20111; RTI et al, 2016). Most likely there is fresh groundwater in the Zanderij aquifer in the far south in and near the savanna. However transport to the villages along and north of the coastal road ("Verbindingsweg") is problematic because of the extensive swamps. For Commewijne the problems of water shortage seem to have be resolved after the realization of pumping station La Liberte in 2021, where drinking water is produced using surface water from the Suriname River

In the Paramaribo water balance area large groundwater abstractions are found for the drinking water supply of Greater Paramaribo. For the year 2024 a deficit between demand and supply of 65,000 m3/day is expected. This will increase to 112,000 m3/d if the brackish SWM wells will be closed. The HACAS project (RTI et al, 2016) made a plan for a number of new pumping stations south of Paramaribo (Wanica and Para). If these stations will be realized, water supply for Greater Paramaribo is secured in 2040 and probably also to the end of the century.

In the other water balance areas of Saramacca, Coronie en Nickerie, current extractions from the aquifers are very low compared to the large groundwater reserves. Groundwater abstraction could be continued for several ages and millennia.

3.6 MAR objectives and techniques

Managed Aquifer Recharge (MAR) is the purposeful replenishment of groundwater in aquifers for later use or environmental benefit (Dillon et al, 2009).

MAR can have several purposes:

<u>for water supply:</u>
1. Underground storage followed by reuse during periods of drought and water shortages (drinking water supply, industrial water supply, and irrigation)
2. Underground storage to improve water quality (removal of pathogenic organisms, breakdown and adsorption of harmful chemicals, blunting peak concentrations)

<u>for regional water management:</u>
3. Underground storage to prevent flooding (blunting peak discharges)
4. Underground storage to maintain or improve environmental conditions, such as base flows in rivers and groundwater levels, or to combat salinization and land subsidence. Only objectives 1 and 2 are relevant to this study.

There is a wide variety of MAR techniques as shown in Figure 10.

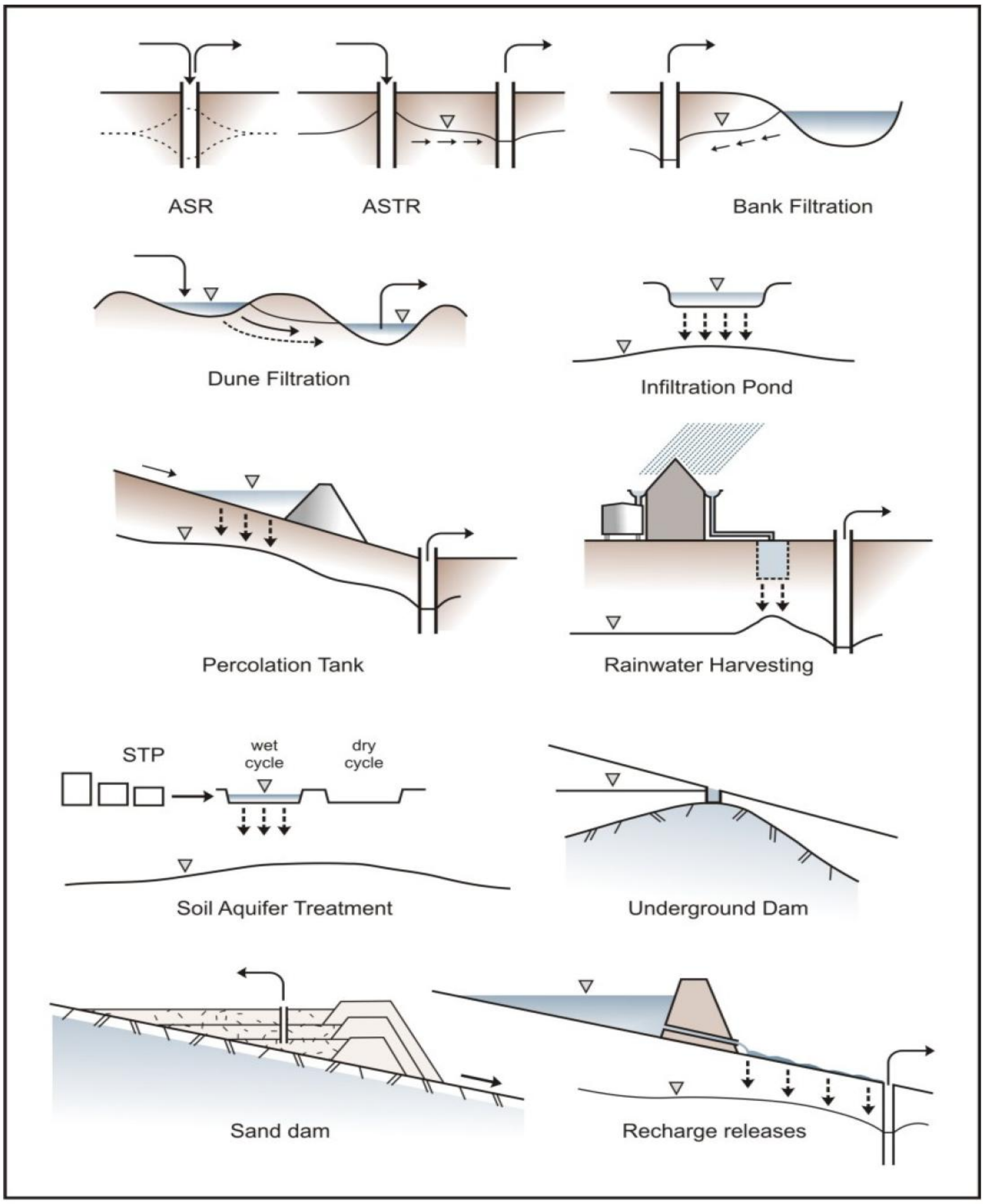

Figure 10. Managed aquifer recharge (MAR) techniques (Dillon et al, 2009)

3.7 MAR techniques

3.7.1 Injection wells (well, shaft, and borehole recharge)

Water can be infiltrated into deeper aquifers via wells. A distinction is made between a well, in which infiltration and extraction alternate (ASR wells) and systems with two or more wells, in which a well either only infiltrates or extracts (ASTR wells). The aquifers must be confined by impermeable or semi-permeable layers. Another objective could be the strategic placement of injection wells to prevent or slow down salt intrusion near pumping stations. Injection wells could be applied in the aquifers in the coastal plain. In fact, it is the only applicable MAR technique in the coastal plain, where thick Holocene and Pleistocene clay layers at the surface prevent recharge by other MAR techniques.

Most MAR techniques, especially injection wells, require fresh pre-treated high-quality injection water. Nevertheless clogging is unavoidable due to the sedimentation of suspended solids, iron oxidation and bacterial growth. Pre-treatment of injection water from rivers and creeks is expensive. In addition it has to be transported from distant intakes, as seawater reaches far inland during droughts and low discharges.

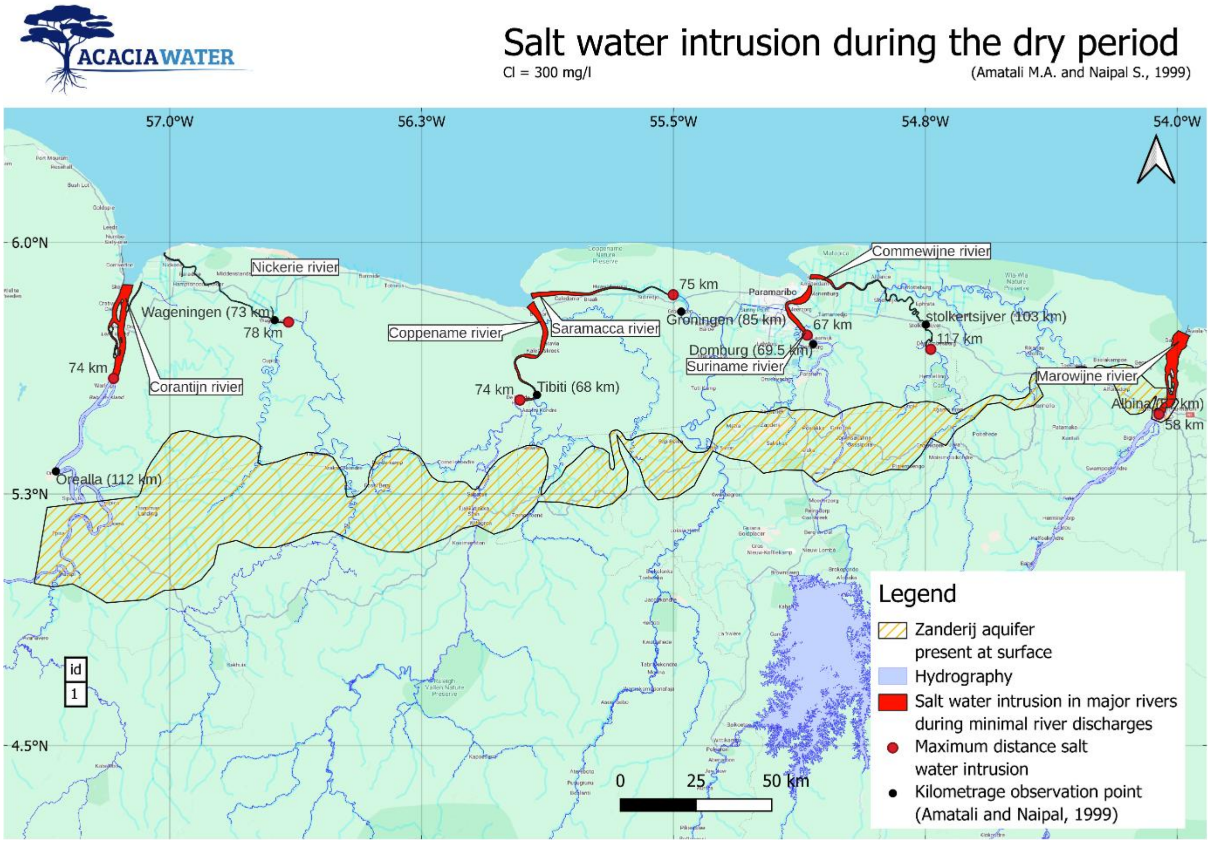

Figure 11. Upstream seawater intrusion in major rivers of Suriname. Intrusion is marked by the 300 mg/l chloride concentration (from Amatali and Naipaul, 1999)

Figure 15, based on the study by Amatali and Naipaul (1999), shows the upstream brackish water intrusion in the major rivers of Suriname rivers. Intrusion is marked by the 300 mg/l chloride concentration.

Sea level is expected to rise by 1 m by the end of this century. This will cause brackish water to reach further upstream. Model studies in similar rivers elsewhere indicate that brackish water can reach some 10 to 15 km further inland due to sea level rise (Haddout & Maslouhi, 2018; Prandle, 2004)

3.7.2 Bank Infiltration along surface waters

Bank infiltration is a MAR technique in which wells pump groundwater from aquifers that are in hydraulic contact with surface water (permanent rivers, creeks, and lakes). Pumping from wells close to the watercourse will lower groundwater levels below the water level in the rivers. Consequently, water will infiltrate from the river and will flow to the bank infiltration wells. This is a form of MAR because the infiltration is artificially induced and leads to additional aquifer recharge.

Bank infiltration is applicable along surface water which is in direct hydraulic contact with the underlying aquifer, generally the Zanderij aquifer. This is the case, for example, at Republiek, the oldest SWM pumping station, where wells extract water from the nearby Coropina Creek (Cola creek). A key issue is protecting the quality of the creek or river against pollution upstream. Occasional contaminant peak in surface are attenuated by groundwater flow towards the wells. Another condition for this technique is locating the bank infiltration wells out of reach from the seawater intrusion. Therefore bank infiltration along rivers and creeks is restricted to the southern part of the coastal plain and the savanna.

The former bauxite mines (Lelydorp II and III) near Lelydorp could provide an opportunity for bank infiltration. In these deep abandoned mines the clay and sand layers above the bauxite deposits have been excavated. The mines, now filled with water, intersect the Zanderij aquifer. This idea was already launched in 1994, when the mines were still in operation (Groen, unpublished). Again, in this case protection of the lake against pollution is crucial.

The bank infiltration principle could also applied in the sand and shell ridges. Groundwater in the thin and narrow ridges can be recovered via shallow drains. Groundwater will be replenished by the surrounding swamps. This way the drains function as bank infiltration systems. Capacities of these systems are quite low, but could serve as a source of water for farming.

3.7.3 Spreading techniques

Spreading methods refer to MAR techniques that direct surface water and rainwater to locations favoring infiltration, such as artificial ponds and canals. Once infiltrated the groundwater flows to nearby drains and wells for recovery. These kind of large scale MAR systems are have been implemented in the dunes of the Netherlands for the water supply of Amsterdam and The Hague. Such storage requires a permeable subsoil and a sufficiently deep natural groundwater table to enable storage and high infiltration rates. In principle, infiltration ponds could be created in the savanna zone or sand ridges of Suriname. However, groundwater levels in these areas are not very deep (max. 2 m). Therefore, the additional storage and infiltration rates are limited. Another disadvantage is that this form of MAR requires acquisition of large land surfaces.

3.7.4 Runoff harvesting

Runoff harvesting refers to methods for capturing rainwater flowing from paved surfaces and rooftops. The water can be stored and gradually infiltrated in wells or ponds. Soil runoff water can also just be retarded to allow infiltration. Most of these methods are meant to prevent flooding or to replenish soil moisture in semi arid regions (agriculture).
Most of these methods are beyond the scope of this study, which deals with drought and water supply.

3.7.5 Dams

Watercourses can also be dammed to achieve infiltration and underground storage. Where an aquifer lies on the surface, water can infiltrate from a reservoir behind the dam (recharge dams. Dams would only be suitable in the creeks in the savanna zone of Suriname. However, the low landscape relief limits the height of dams. In addition, shallow groundwater levels, would not lead to much additional recharge. Also for this technique, land needs to be acquired for the reservoirs.

3.8 Potential MAR sites in Suriname

The principle of elimination for the selecting the 5 potential MAR pilots was based on the limitations arising from the underlying studies on droughts, climate, aquifers, water balances and MAR techniques (see preceding paragraphs).

3.8.1 Considerations by water system

Effects of droughts on surface water (falling water levels and base flows, deteriorating water quality, reduced flow, and salt intrusion) are difficult to mitigate with the MAR techniques, as envisioned in this project. The effects of droughts and climate change on surface water require an integrated approach in managing the catchment upstream from where these problems occur. Many small-scale interventions in the entire catchment are more effective, such as reforestation, adapted land cultivation techniques, small check dams et cetera. Also better spatial planning, land and water protection in catchments would be more appropriate (Table 3)

In contrast to surface water drought and climate change effects on soil and groundwater compartment can be locally mitigated and are therefore the primary objective of this study (Table 3).

3.8.2 Considerations by Sector

A large number of companies and institutions have an interest in groundwater as they abstract groundwater for their operations. For drinking water supply purposes, SWM and the Water Supply Service (DWV) of the Min. of Natural Resources (NH) are the largest users. Other smaller users include bottling companies, industries, livestock and poultry farms, ecoresorts, and possibly farmers (supplementary irrigation).

MAR is an option for SWM when groundwater extraction in the coastal plain south of Paramaribo will reach its limits at this century (Paragraph 3.5). For other smaller users, MAR is not an option. They do not contribute much to the expected water shortages and likely cannot afford complex MAR systems. Only for companies near creeks and rivers in the southern part of the coastal plain, bank infiltration may be a possibility.

Irrigated rice cultivation depends on surface water supplies from the Nanni Swamp and the Nickerie River. As described in the paragraph above, a MAR system can do little to mitigate drought (Paragraph 3.8.1)

3.8.3 Considerations by geography

Geographically, we see that the drinking water supply problems occur primarily in the Paramaribo, Wanica and Para districts (Greater Paramaribo). In other areas, large fresh groundwater reserves are available in one or more aquifers, which can be developed by regular groundwater pumping stations and will last for centuries to come. In the Commewijne district fresh groundwater resources are very limited, but since 2021 drinking water from surface water is supplied to this district (La Liberte).

Sufficient groundwater can still be extracted in the Paramaribo area through conventional wells and pumping stations for several decades and likely until the end of this century, provided new pumping stations south of Paramaribo are realized (RTI et al, 2016). One of the pumping statins could be a MAR system near Paranam (Paragraph 3.8.5).

3.8.4 Considerations by MAR technique

In the coastal plain with clay layers are at the surface, well injection is the only feasible MAR technique. However, this is not an attractive technology for Suriname due to the expensive pre-treatment and transport of the injection water, as well as the intensive management and maintenance of the wells.

Spreading techniques and dams in the savanna creeks are also not efficient, as they result in little infiltration and storage due to the high groundwater levels.

Rainwater harvesting with underground storage could be an option for industrial or agricultural businesses with large roof surfaces, providing a cheap alternative to process water. This technique is not further investigated due to limited capacity.

The most suitable and simple MAR technology is bank infiltration where surface water is in hydraulic contact with the Zanderij aquifer. This technique can be realized in the savanna zone and the southern part of the coastal plain. Special cases are the lakes of the old Lelydorp II and III mines (see above). Water recovery with drains in sand ridges is also an option, but is not included in the decision making process, because of the small capacities.

3.9 5 potential MAR pilot projects

After considering all the factors, the consultants have proposed the following potential MAR pilot projects:

1. Bankside infiltration along the Para Creek near Hanover
2. Bankside infiltration along the Suriname River near Overbridge/La Simplicite
3. Bankside infiltration along the Suriname River near Paranam
4. Bankside infiltration along the Saramacca River near Pikin Saron
5. Bankside infiltration around the Lelydorp III mine

The locations of the potential projects are shown in the Figures 12.

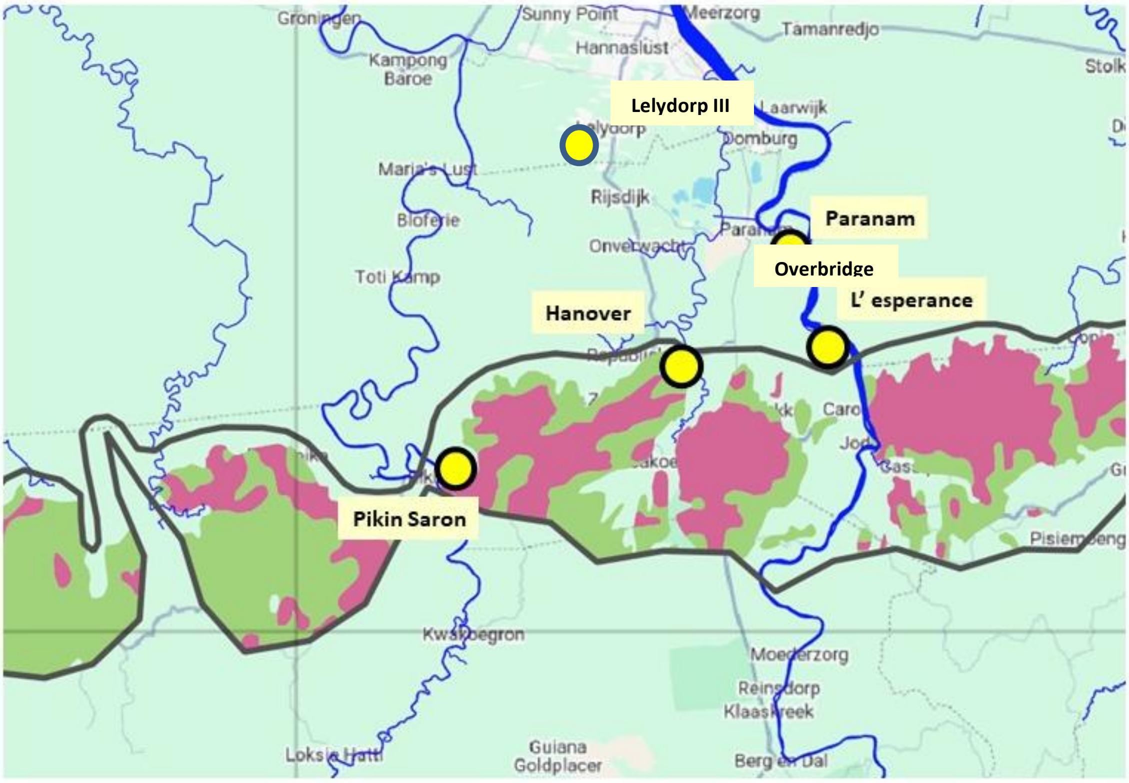

Figure 12. 5 potential MAR sites.

3.10 2nd SWG meeting

During the second SWG meeting on 15 April 2025, all results of phase 2 were presented and discussed with the SWG. Finally, the SWG opted for the MAR pilot at Hanover. The main reason was the better guarantees of good water quality of the Para River and the water demand of local community.

4 Phase 3: Detailed design of MAR pilot

4.1 Geophysical survey

Phase 3 started with consultation of the local community of Hanover (plantagebestuur) and a site survey. Subsequently a geophysical survey with ERT soundings was conducted. These soundings provide 2D images of the electrical resistivity of the subsurface. The goal was to locate the Zanderij aquifer where it is hydraulically connected to the Para River (Annex 8).

The first five soundings were carried out near the village of Hanover (Figure 13). However, at this location the sand layer was not well-developed and also not hydraulically connected to Para Creek, which appeared to be running through valley fill of Mara clay. The bottom of the creek also consisted of clay. The final two measurements further upstream were more successful. At site 6 and 7, a 10 to 15 m thick sand layer was found near the river, starting from the ground level. The creek bed also consisted of sand. Ultimately, the location of measurement 6 was selected for further design of the wells and the well field. For a more detailed report on the geophysical measurements we refer to Annex 8.

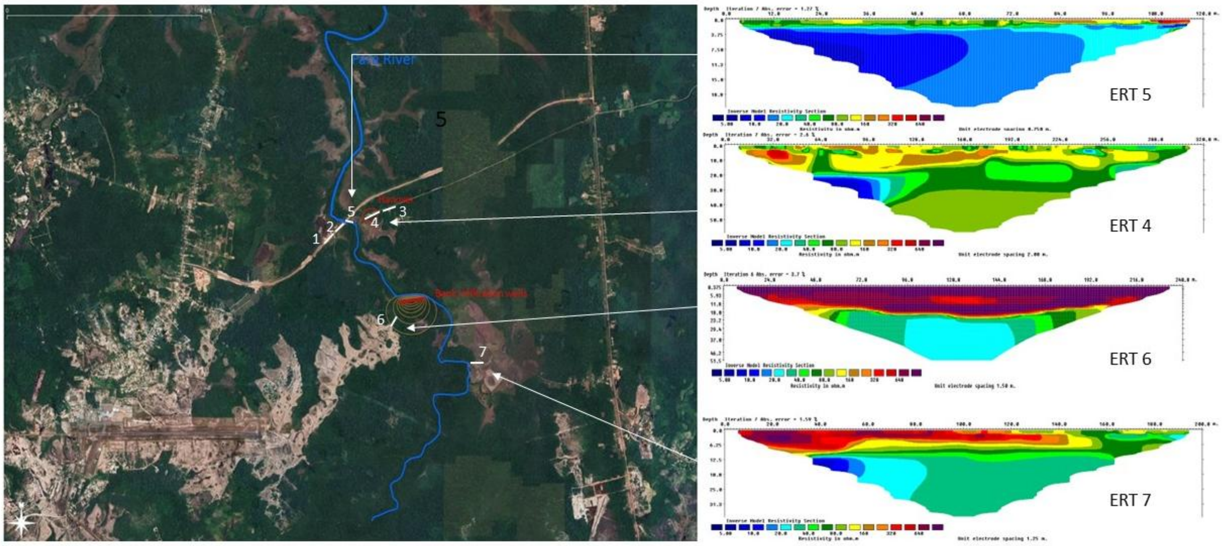

Figure 13. Geophysical ERT soundings around Hanover

4.2 Design

The design of the well and well field is shown in the figure 14. The well field consists of a row of 20 wells parallel to the river at a distance of 100 m The wells are spaced 25 apart and have an average discharge of 15 m³/hour. Groundwater level drawdowns are limited to 2.5 meters near the wells. The protection zones consist of the water supply around the wells based on a minimum 30-day travel time of groundwater and protection zones I and II based on a 25-year travel time (Figure 15). Annex 8 contains a more detailed description of the design.

Based on water analyses of the groundwater (including existing analyses from the surrounding area) and the Para Creek, a conceptual water treatment system was proposed. Treatment conforms to the present treatment process at the SWM station of Republiek, where groundwater is extracted under similar conditions. The groundwater is quite diluted, but is iron-rich and has a low pH. The treatment is aimed at removing iron and increasing the pH through aeration, followed by filtration through a sand and shell filters.

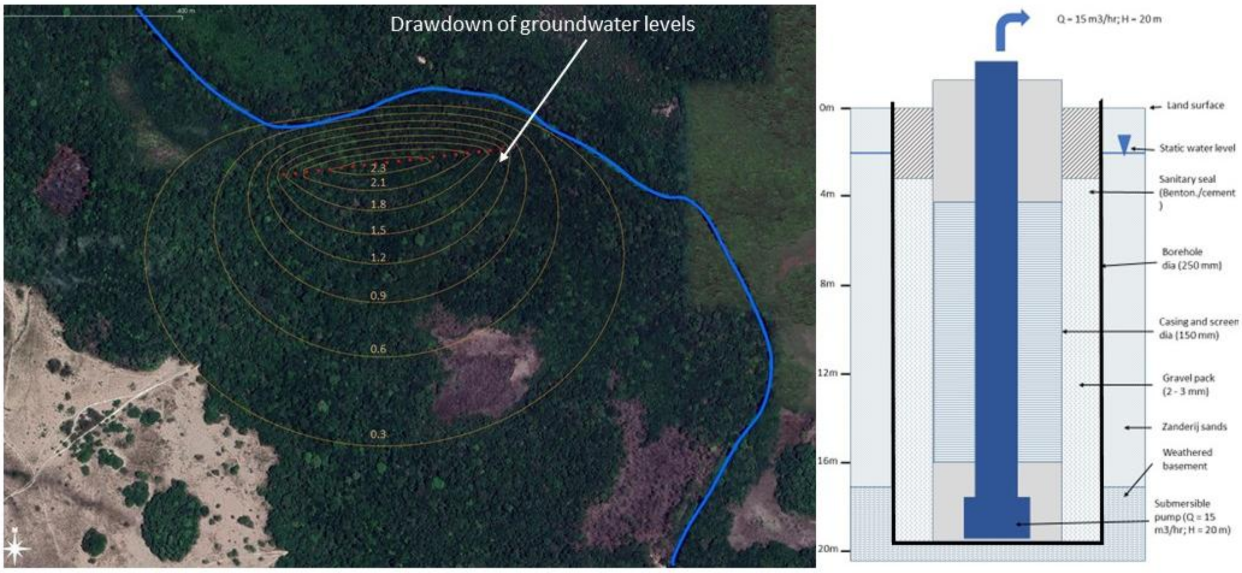

Figure 14. Design of wells and well field south of Hanover

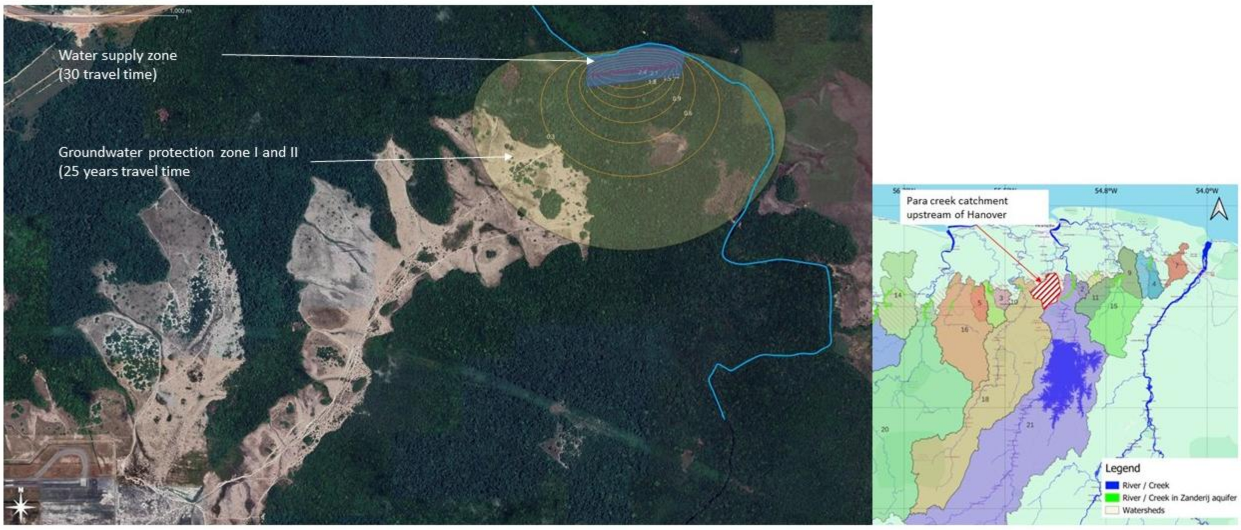

Figure 15. Protection zones for Hanover bank infiltration wells

4.3 Benchmarking finance sources

Overall, the project shows strong alignment with major international climate and development financiers. Multilateral climate funds such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF) are well suited due to their focus on climate mitigation, renewable energy access and institutional strengthening, although they involve complex and time-consuming approval processes. The NAMA Facility offers high strategic value for transformational mitigation actions but is highly competitive and requires advanced readiness.

Development banks, including the Inter-American Development Bank (IDB) and the Caribbean Development Bank (CDB), demonstrate strong alignment with climate resilience, sustainable infrastructure and energy security, with generally more predictable and accessible procedures. The Adaptation Fund is relevant for resilience and adaptation components and is typically simpler to access than large climate funds, provided a strong adaptation rationale is demonstrated.

EU climate funds and bilateral or philanthropic sources can play an important complementary role, particularly as co-financing to improve project viability. Philanthropic and bilateral programs are often more flexible and faster to mobilize, making them attractive for innovative or distributed renewable energy components.

4.4 3rd and 4th SWG meeting

During he third SWG meeting on 13 November 2025 the draft design was presented for approval. On December 12 the final SWG workshop was held, where all results of the study and the final design were presented to a wider audience of stakeholders.

5 Conclusions

The following conclusions can be drawn from the ARADIS study:

The Suriname Water Supply Company (SWM) is the major groundwater user in Suriname. Other stakeholders are bottling companies, agricultural enterprises and tourist centers. These users as well as governmental bodies and knowledge centers were represented in the Stakeholder Working Group (SWG).

Gender roles are very different in the coastal plain and the interior. In the coastal plain, the primary project area, gender roles are not much different compared to the interior of Suriname, weher women bear the responsibility for the supply of domestic water. The Suriname Women Asssociation was represented in the SWG.

Climate changes are not very significant, where it concerns rainfall records over the last 100 years. Only the series of the Coronie meteorological station show a downward trend in precipitation. Droughts occur now once every four years; extreme long duration droughts once every 15 years. Temperature has risen by about 0.75 oC since 1900 and sealevel by 20 cm. Though, climate may not have changed much up till now, the social impacts of excessive rainfall and droughts have increased.

Climate is expected to change this century. Precipitation will decrease by 16 tot 21 %. However, intensities of rainfall events will increase. Decrease in rainfall will be most noticeable in the period from December to April (the short rainy season and the short dry season). This implies that the present long dry period from September to December will often last longer. The frequency of such droughts and extreme droughts will increase. Sea levels will rise by approximately 75 cm.

A shortage of 65,000 m^3/d is projected for the water supply for households, institutions, and businesses in 2040, based on assumed water demand. This applies particularly to the Greater Paramaribo supply area. If the SWM pumping station currently pumping brackish groundwater were to be closed, the shortage would increase to 112,000 m^3/day.

The aquifers in the coastal plain of Suriname west of Paramaribo (Saramacca, Coronie and Nickerie districts) hold large reserves of fresh groundwater.

In Commewijne groundwater in the aquifers is mostly brackish. There are no alternatives besides abstraction of brackish groundwater with low salinities (Cl contents 500 to 1000 mg/l) and intake of surface water, as is presently taking place at La Liberte.

The waterbalance studies show that in the Paramaribo region (Paramaribo, Wanica, Para) groundwater reserves can meet the water demand until the end of the century. The HACAS study in 2016 already took this shortage into account and proposed several new pumping stations in the Wanica and Para districts south of Paramaribo.

In Nieuw Nickerie water abstraction from the Zanderij aquifer is limited because of poor groundwater quality. Water demand can be met in future by new wells into the deeper Coesewijne aquifer.

Under the present conditions bank infiltration is the most efficient MAR technique in Suriname. Bank infiltration wells can be placed along creeks, rivers, lake and swamps, which are in direct hydraulic contact with the underlying aquifer, generally the Zanderij aquifer (or sand ridges in some cases).

Favorable sites for MAR bank infiltration systems are in the savanna zone and in the southern part of the coastal plain. 5 locations have been selected: Pikin Saron along the Saramaaca River, Hanover along the Para River, Overbridge/La simplicite and Paranam along the Suriname River and the Lelydorp III and II mine lakes.

Because of the good water quality of groundwater at Hanover and the Para Creek and the pristine nature of the Para Creek catchment upstream of Hanover, Hanover was selected for the pilot MAR project.

Based on geophysical soundings a location was selected about 2 km upstream of Hanover, where the Zanderij aquifer contains coarse sands with a thickness of 10 tot 15 m and the Para Creek is direct contact with the aquifer.

A design was made of a row of 20 wells along the left bank of the creek with a total production 300 m3/hr. Such a pumping station could supply drinking water to the local communities (Hanover) as well as the airport zone.

Protection zones have been delimited around the well field according to the upcoming new water laws of Suriname.

Protection of ground and surface water is crucial as well as land use planning. It is important legislation will be implemented as soon as possible.

Other possibilities for bank infiltration are:

1. On of the 5 options was bank infiltration at Paranam. This option was not explored in more detail, but it could still be an attractive option for a large SWM pumping station in future. If groundwater is fresh and the Suriname River is hydraulically connected to the Zanderij aquifer at Paranam, high capacity wells could be drilled. Formerly high capacity wells existed at the nearby SURALCO refinery. The capacity of such a bank infiltration system would almost be unlimited by extending the row of wells along the river. If this option will be investigated further, the quality of the Suriname River must be investigated and monitored. Als geophysical soundings are recommnded

2. Bank infiltration along the rivers in the interior of Suriname is an attractive intervention. Surface water supply to local communities is often at risk during droughts and floods. The high sedimentary terraces (> 10 m above the river) along the river offer favorable sites for wells (Gersie et al 2021). Even wells drilled in the crystalline bedrock, though of limited capacities (1 m3/hr) are feasible. Geophysical soundings are recommended.

3. A special form of bank infiltration are drains in the thin and isolated sand ridges in the coastal plain. Though groundwater reserves in the ridges are small, the drains will draw water from the bordering swamps into the ridges. Capacities are small, but these kind of cheap systems can be attractive as a means for supplementary irrigation. Drs Oclaya Verwey is carrying out a PhD study into the dynamics and potential use of sand ridges in the coastal plain

6 References

ABS. (2023). Klimaatverandering Statistieken en Indicatoren. Climate Change Statistics and IndicatorsAlgemeen Bureau voor de Statistiek (ABS)/ General Bureau of Statistics (GBS)

Amatali M. A. & Naipaul S., (1999). Country study climate change suriname. Water resources. Climate Change Division Profile. Technical report no. 4a, Dec. 1999

CTCN (2023). Project Concept Note - Technical Assistance Response Plan (AF-2021000199/2023000037). Enhance the resilience of Suriname´s Water Supply System by Modelling Drought Risks and Developing a Roadmap of Prioritized Alternatives for Aquifer Recharge.

Dillon P., Pavelic P., Page D., Beringen H. & Ward J. (2009). Managed Aquifer Recharge: An Introduction. 13. Waterlines Report Series, CSIRO. National Water Commission Australia.

Genivar & ILACO (2011). Suriname Water Supply Masterplan. Volume I and II. Genivar (Trinidad), ILACO (Suriname). Client Surinaamsche Waterleidingmaatschappij.

Gersie, K. S., Van Balen, R. T., & Kroonenberg, S. B. (2021). The Interplay between Tectonic Activity, Climate and Sea-Level Change in the Suriname River Valley, Tropical South America. Quaternary, 4(2), 11.

Gov. of Suriname (2021). Meerjaren ontwikkelingsplan 2022 – 2026 van de Republiek Suriname. Omdenken, Verbinden, Doen.

Government of the Republic of Suriname. (2023). Third National Communication of the Republic Suriname to the United Nations Framework Convention on Climate Change. UNEP, GEF Ministerie van Ruimtelijke planning en Milieu.

Grégoire, P. (2022). Stakeholder mapping: when, why, and how to map stakeholders. Borealis.

Groen J. (2002). The effects of transgressions and regressions on coastal and offshore groundwater. Ph.D. thesis, Vrije Universiteit, Amsterdam.

Haddout & Maslouhi, 2018; Haddout, S., & Maslouhi, A. (2018). One-Dimensional hydraulic analysis of the effect of sea level rise on salinity intrusion in the Sebou estuary, Morocco. Marine Geodesy, 41(3), 270-288.

IDB. (2021). State of the climate report: Suriname. Inter-American Development Bank

Prandle, 2004) Prandle, D. (2004). Saline intrusion in partially mixed estuaries. Estuarine, Coastal and Shelf Science, 59(3), 385-397.

RTI Int., Acacia Water & ILACO (2016). Hydrogeological Assessment of the Coastal Aquifers in Suriname (HACAS). Final Report—Volume 2. Hydrogeologial Assessment. Client Surinaamsche Waterleiding Maatschappij.

TAUW (2011). Crashprogramma Drinkater 2009. Surinaamsche Waterleiding Maatschappij.

UNDPNDP/WHO, 1972. Public water supplies and sewerage project, Volume III: Water Resources. (Hydrogeological and Hydrological Studies). United Nations Development Programme and World Health Organization, 128 pp.

UN-Water (2018). UN World Water Development Report. Nature-based solutions for water. United Nations.

Ward, J., & Dillon, P. (2009). Robust design of managed aquifer recharge policy in Australia. Water for a healthy Country Flagship Report to National Water Commission.

Wong, Th. E. (1989). Revision of the stratigraphy of the coastal plain of Suriname. Mededeling
Natuurwetenschappelijke Studiekring voor Suriname en de Nederlandse Antillen No 123, 64 pp.

7 Colophon

Client	:	The United Nations Environment Programme (UNEP) on behalf of the Climate Technology Centre and Network (CTCN)
Beneficiary	:	Government of the Republic of Suriname; Ministry of Spatial Planning and Environment
Project	:	Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge.
Subject	:	Final Report
File/ Code	:	IS-471
Acronym	:	ARADIS project
Author	:	Groen J.
Contributions/Validation	:	Wong Loi Sing R. & Lachman S.
Authorisation	:	R. Patandin
Date	:	19 December 2025