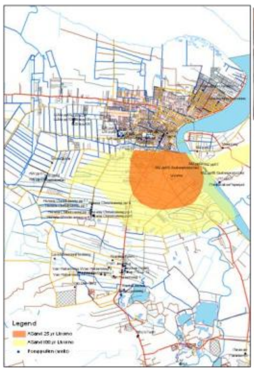
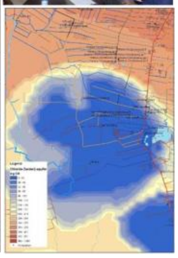
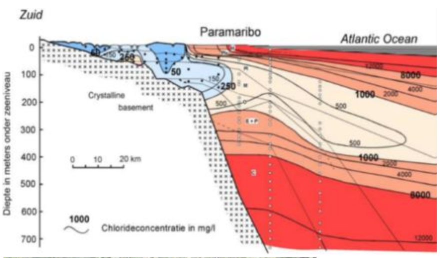
The United Nations Environment Programme (UNEP) on behalf of the Climate Technology Centre and Network (CTCN)

Report on Water Balances and Aquifers in Suriname



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)

RFP Number: 3100006085
Biruk KIBRET

08 MAY 2025

In association with

Project title:	Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge. Aquifer Recharge Against Droughts in Suriname (ARADIS)
Project number:	IS-471
Document:	Report on water balances and aquifers in Suriname
Client:	CTCN/ Ministry of Spatial Planning and Environment (MROM)

Version	**Status**	**Author (s)**	**Validated by**	**Approved by**	**Date**
1.0	Final	Groen J.	Wong Loi Sing R.	Patandin R.	May 08, 2025

Table of Contents

1 Background

In Suriname drinking water supply in the populated coastal districts depend mostly on groundwater abstractions. Well fields are found throughout the coastal districts and are operated by the Surinaamsche Waterleidingmaatschappij (SWM). Largest abstractions take place in and near Paramaribo city, the capital of Suriname, and Nickerie the second largest town. In addition, some agricultural enterprises, bottling companies and holiday resorts also abstract groundwater.

Demand for groundwater is ever increasing because of population growth and economic developments. Groundwater is also becoming an alternative to surface water for inland communities as the water quality of some rivers and creeks is deteriorating because of upstream mining activities. There is also a downstream threat to surface water quality. The fresh/brackish interface will move further inland due to the expected sea level rise during this century. Climate change is already felt as droughts have become more frequent and prolonged during the last decades. Consequently, the agricultural sector is now showing interest in groundwater as a source for supplementary irrigation.

Because of all these developments it is widely felt that groundwater is under stress or will be in the near future. This feeling is exacerbated by observations of increasing salinities, albeit very gradually, of wells near Paramaribo (Genivar, 2011). In 2015 the HACAS project was launched to assess the aquifers and groundwater in the coastal plain of Suriname and investigate the scope for further groundwater development (RTI, 2016). This study provided a somewhat more positive outlook on the groundwater resources around Paramaribo and resulted in plans to secure the drinking water supply up to 2040.

To cope with climate change and water demands in the more distant future and, the Ministry of Spatial Planning and Environment of Suriname (MinROM) recently launched the present study into the feasibility of managed aquifer recharge (MAR) as a strategy for sustainable groundwater development. The study is financed by the UN Environment Program (UNEP) though its implementing agency, the Climate Technology Centre and Network (CTCN). The official project name is "Enhance the resilience of Suriname´s water supply system by modelling drought risks and developing a roadmap of prioritized alternatives for aquifer recharge". The name was later abbreviated to Aquifer Recharge Against Droughts in Suriname with the acronym ARADIS.

The project took off in september 2024. During the inception phase a stakeholder mapping and a gender study was carried out leading to the formation of a Stakeholder Working Group (SWG). Also data acquisition started and methodologies for the subsequent phases were further elaborated. All findings were summarized in the inception report, which was presented, discussed with and approved by the SWG and MinROM in December 2024.

In phase 2, the present analytical phase, three activities will be carried out: 1) assessment of drought risks and water demand; 2) assessment of aquifers and water balances, described in the present report; and 3) assessment of the feasibility of various MAR techniques in the coastal plain of Suriname. Based on information from these assessments five sites will be identified where MAR techniques are technically feasible and offer appropriate solutions for stakeholders in need of water. At the end of phase 2 the five sites with the appropriate MAR systems will be presented to the SWG, who will select the final site, which will be designed as a pilot on phase 3.

2 Introduction

This assessment of aquifers is largely based on the HACAS hydrogeological assessment study of the Suriname coastal plain and the savanna zone. This study was carried out in 2016 by a consortium of RTI International, Acacia Water and ILACO NV (RTI, 2016). Under HACAS the major aquifers have been mapped and an outlook has been presented on future groundwater development for the drinking water supply. Valuable new insights in the extension of the aquifers and fresh groundwater were acquired by analyzing the geophysical logs of oil exploration wells of Staatsolie, the state oil company. The special study was carried out by MSc student Vanessa Sabajo of the University of Suriname (Sabajo, 2016) under supervision of prof Theo Wong and Dr Jacobus (Koos) Groen. All information from the oil exploration wells and other data and reports were captured in maps and sections showing the extent and depth of the formations and the presence of brackish groundwater (> 250 mg/l of chloride (Appendix 2 and 3).

The HACAS consortium choose to map complete formations, as the numerous aquiferous sand layers within the formations were difficult to discriminate as separate aquifers. Note that apart from the three exploited aquifers mentioned above, the deep Saramacca formation was added to the assessment as this formation proved to hold fresh groundwater in the western part of the Coastal plain.

The following Chapter 3 contains an overview of the aquifers, groundwater flow systems, salinity and water balances, groundwater development and MAR prospects. In Chapter 4, the hydrogeological maps and sections of the HACAS study are discussed in more detail with reference to Appendix 2 and 3 respectively. Most groundwater-related reports and articles used for the assessment are listed in Appendix 1.

3 Hydrogeology of the Coastal Plain of Suriname

3.1 Introduction

Suriname is situated in South America, between 1° north and 6° north, and is bordered by Guyana to the west, French Guiana to the east, Brazil to the south, and the Atlantic Ocean to the north. The Atlantic coast has a length of 350 km. The population of Suriname (540,000) is mainly concentrated in the coastal districts (500,000) and, in particular, the Paramaribo, Wanica, and Para districts around the capital of Paramaribo (385,000) (ABS, 2025; GENIVAR, 2011). The latter zone is often designated as Greater Paramaribo, the major supply area of the SWM. The coastal districts fall within the sedimentary coastal zone, where the major aquifers are found which are the object of this study (Figure 1). The major interior part of the country is underlain by crystalline basement rocks and is sparsely populated

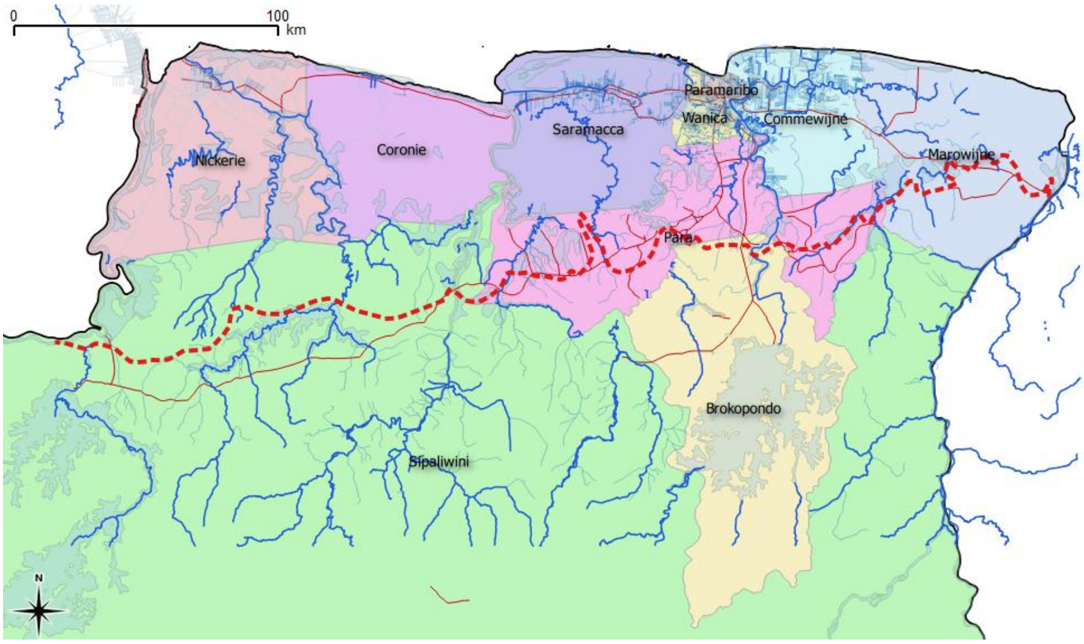


Figure 1. Map of coastal districts of Suriname. Red dotted line is the boundary between the sedimentary coastal plain and the savanna belt and the crystalline basement in the south.

3.2 Landscape

Much of Suriname is underlain by the crystalline rocks of the Guiana Shield forming a hilly landscape with tropical rainforest. In the north of the country, a belt of clastic sediments stretches along the Atlantic coast, having a width of 110 km in the west to 30 km in the east (Figure 2). Many earth scientists and biologists have investigated the sedimentary landscape in detail (Cohen and Van der Eyk, 1953; Van der Eyk, 1954, 1957; Zonneveld, 1955; Lindeman and Moolenaar, 1959; Brinkman and Pons, 1968; Veen, 1970; Teunissen, 1978). The sedimentary landscape can be divided into three geomorphological units: the savannah belt, the “old” or Pleistocene coastal plain, and the “young” or Holocene coastal plain.

The savannah belt in the south bordering the crystalline basement has a width ranging from 50 km in the west to 5 km in east. It forms an undulating landscape on Pliocene sands of the Zanderij formation (Figure 2). Elevations vary from +10 m (relative to mean sea level) in the north to +50 m in the south. Despite its name, only 30% of the savannah belt in the project area is covered by typical open savannahs with grasses, sedges, and low bushes (Teunissen, 1978). Most vegetation consists of xeromorphic dryland forest and savannah woodlands. Characteristic blackwater creeks, bordered by swamp and gallery forests, dissect the savannah belt. Apart from Zanderij airport, human impact is small in this sparsely populated area. Despite the tropical climate, savannah vegetation can persist because of the low moisture retention capacity and nutrient content of the coarse sandy soils and the regular burnings by the Amerindian population.

The actual coastal plain varies in width from 60 km to 30 km from west to east and is a flat marine plain primarily underlain mainly by clays with elongated east- to west-running beach barrier deposits (ritsen) as the main morphological features. The Pleistocene part of the coastal plain or the old coastal plain is a 15 to 20 km wide zone with elevations between +3 and +11 m. The plain is an assembly of plates (schollen) with a substratum of clays and fine sands, dissected by numerous swamps and creeks filled with Holocene clay and peat. The plain was probably formed during the Sangamonian (Eemian) and earlier transgressions and later dissected during the Wisconsinan (Weichsel) regression (Veen, 1970). The Pleistocene beach barrier deposits have in some places coalesced into more wide complexes, like the area around Lelydorp. Swamp grasses and swamp forests cover the inaccessible and marshy parts, mainly in the south, while dryland forest is found on the better-drained parts. In the Wanica and Para districts the original dryland forests have disappeared near settlements due to activities like agriculture, forestry and cattle breeding. In some areas old plantations have been abandoned and have become overgrown by secondary vegetation. In the area between the Rijsdijk road and Paranam in the Para district, the landscape has been strongly affected by the large and deep bauxite mines and the bauxite refinery at Paranam. The abandoned mines now form large lakes.

The Holocene or young coastal plain, elevated at +1 to +3 m, has a width of 40 km in the west decreasing to 10 km in the east. Locally it penetrates southward along the valleys of the major rivers in the coastal plain. The Holocene coastal plain has lost most of its original character because of agricultural activities, settlements, and the expanding city of Paramaribo. The vegetation was formerly marked by dryland forests on the beach barriers and better drained parts of the clayey plain, and by swamp forests on the low-lying parts. Grasses and shrubs dominate the recently formed land (after 1000 AD). In the youngest and most northern part, a 10 to 20 km–wide strip along the coast, soils still contain brackish water.

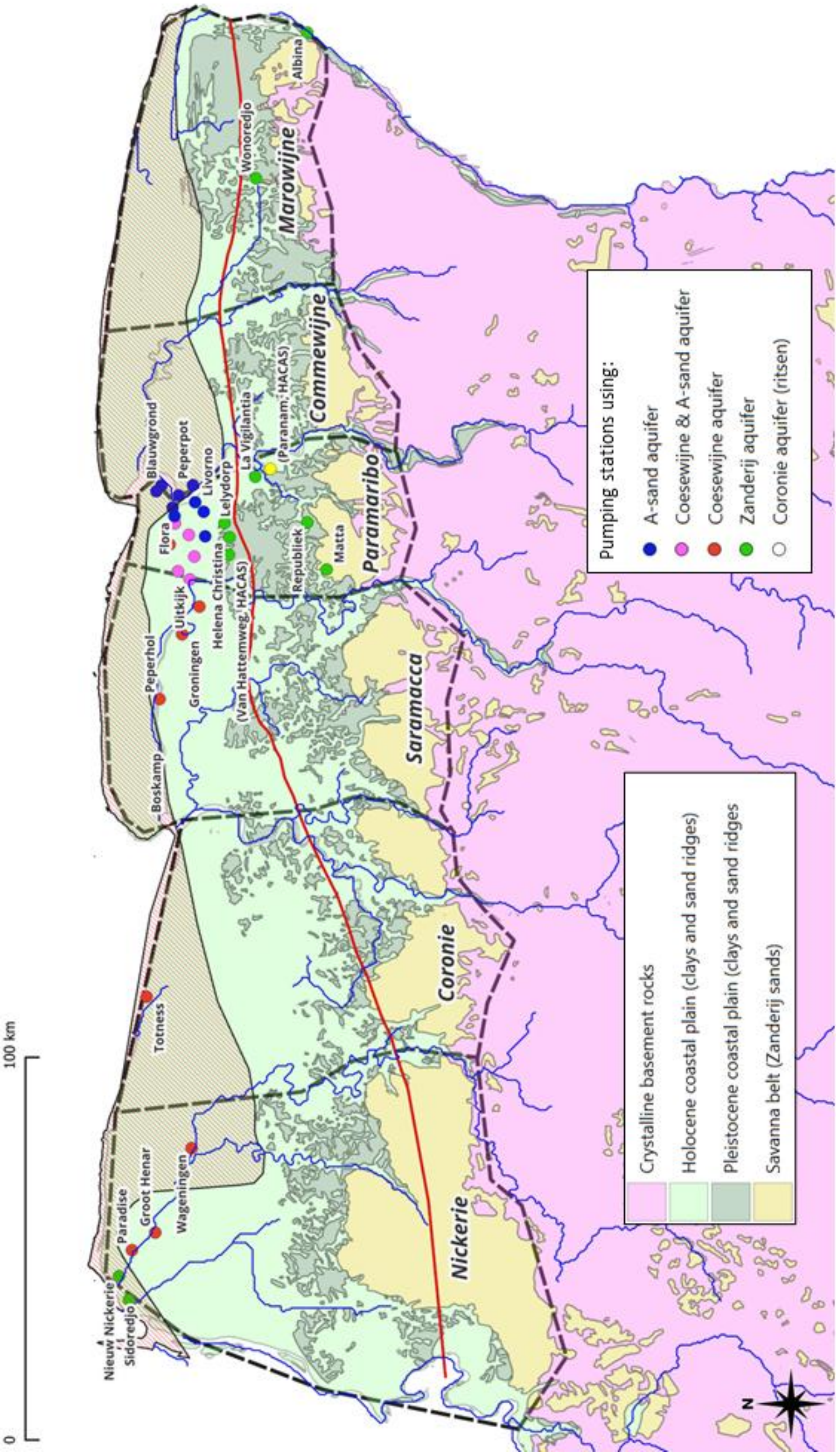


Figure 2. Geological map of the coastal plain and savanna belt with pumping stations. The dashed polygons are the water balance areas. As an example the red dashed zone in the north is the zone where the Coesewijne aquifers holds brackish groundwater. The red line is the southern limit of the Coesewijne formation (see Chapter 3 and Appendix 2 for the extent, depths and fresh groundwater occurrence of all formations (aquifers).

3.3 Geology

3.3.1 The Guiana Shield

The Proterozoic crystalline basement of Suriname is part of the Guiana shield and consists mainly of granitoid rocks with numerous elongated dolerite intrusions (De Vletter et al., 1998). In the northeastern part of Suriname, a region of metamorphic rocks occur consisting of metamorphosed volcanic-sedimentary rocks (Marowijne Group) and gneisses and amphibolites (Coeroeni Group). Metamorphic rocks (metabasalts and greenstones) underlie the northern part of the catchments of the Saramacca and Suriname rivers and are also encountered in boreholes in the coastal sedimentary zone. The top is strongly weathered, which could be detected in vertical electrical soundings (Velstra, 1996): the weathered layer appeared to have a very low resistivity of around 10 Ωm, which was also observed in similar volcanic-sedimentary deposits in West Africa (IWACO, 1987). Depth of the basement varies from a few meters to several tens of meters below surface in the savannah zone. In the coastal plain, the basement plunges to depths of about 750 m below sea level at Paramaribo and more than 1,500 m at Nickerie.

3.3.2 The Sedimentary Coastal Zone

The clastic Mesozoic and Cenozoic sediments in the coastal zone form the southern part of the Guiana Basin, which extends roughly from the Waini River in Guyana to Cayenne in French Guiana. The following descriptions of the sedimentary history and of the stratigraphy of the coastal plain are derived mainly from Wong (1984, 1989), Krook (1979), Hanou (1981), Veen (1970) and Brinkman and Pons (1968). Stratigraphic nomenclature is from Wong (1989, Figure 3)

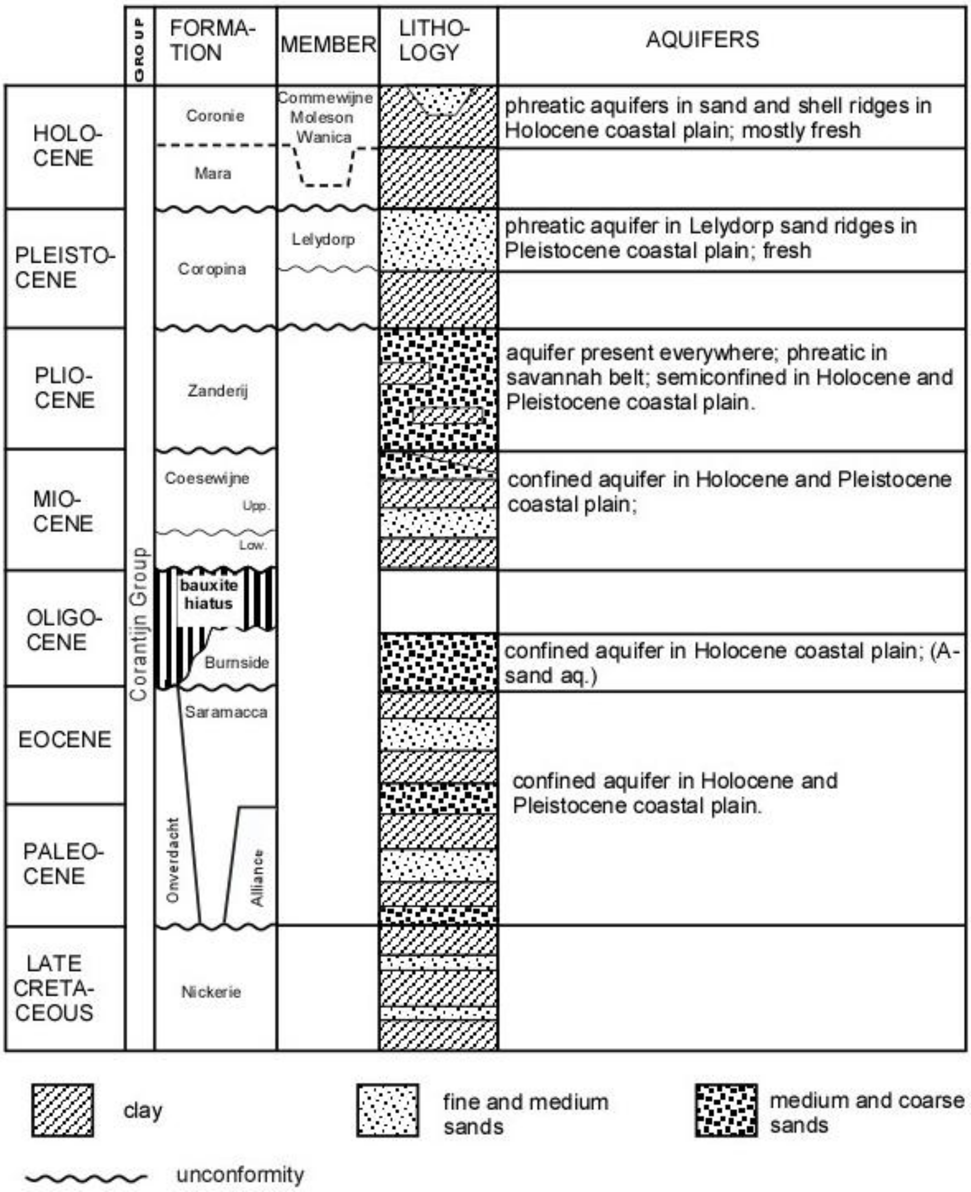


Figure 3. Stratigraphic table (after Wong, 1989)

The depositional center is located at the mouth of the Corantijn River, where the formations attain their maximum thickness. Sedimentation in the Guiana Basin started in late Jurassic to early Cretaceous times, when the African and South American shields began to drift away (Wong, 1976). The coastal plain is underlain with various formations increasing in thickness and depth towards the north and onlapping older sediments or the basement rocks (Figure 4). The Suriname coast is located on the hinge between the subsiding Guiana Basin and the rising Guiana Shield (Krook, 1994). Subsidence was accompanied by faulting and resulted in several horst and graben structures. Structurally, the study area around Paramaribo is located on the lower blocks on the eastern flank of the Bakhuis horst. The faults remained active until the early Tertiary (Wong, 1984, Hanou, 1981). The material for the subsiding basin was derived from the continuously rising crystalline basement directly south of the basin. After the early Miocene, the Amazon River became a more important source of supply (Krook, 1979). Earlier, when the Andes Mountains were not yet formed, drainage on the South American continent was directed towards the west (Krook, 1979).

North-south hydrogeological section at Paramaribo. Different stratigraphic units are indicated as well as chloride concentrations of groundwater (from Groen, 2002)

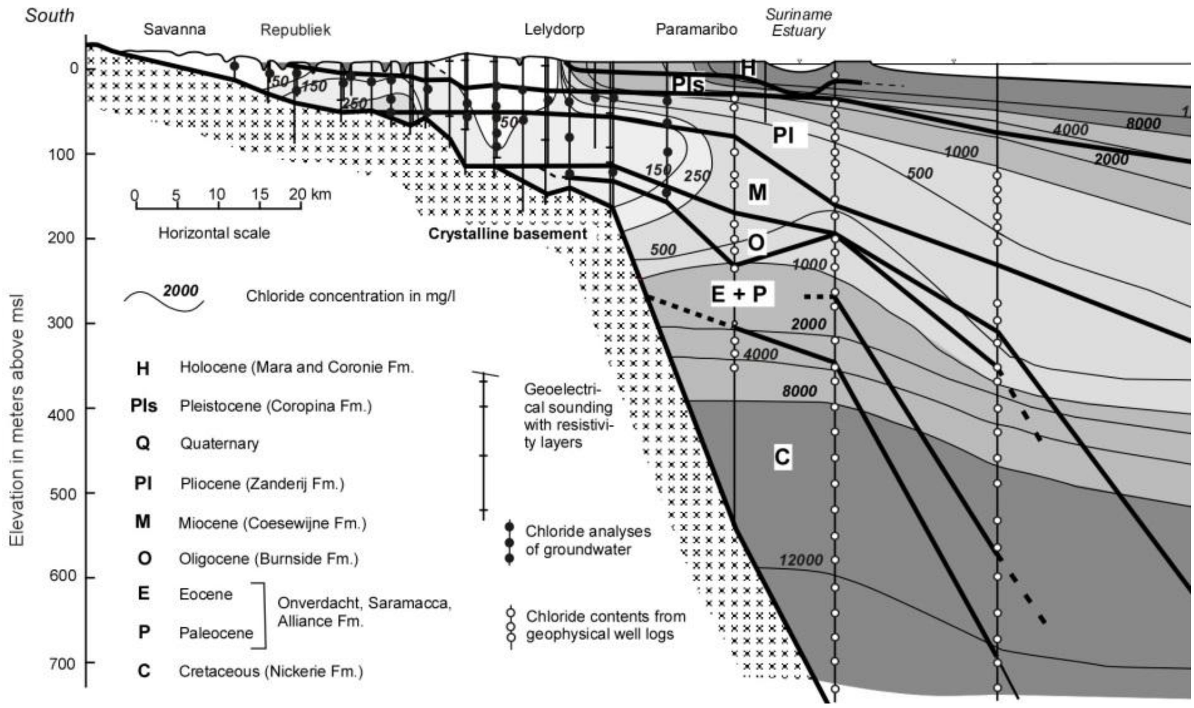


Figure 4. North-south hydrogeological section at Paramaribo. Different stratigraphic units are indicated as well as chloride concentrations of groundwater (from Groen, 2002)

3.3.3 Cretaceous: Nickerie Formation

The late Cretaceous sediments in the coastal zone consist of terrestrial unconsolidated and consolidated fine sands and kaolinitic claystones, classified as the Nickerie Formation. The Cretaceous sediments contain a high percentage of feldspar, which implies that the weathered top has been eroded (Krook, 1979). Apparently during the Cenozoic the impermeable Cretaceous material impeded flushing by aggressive meteoric groundwater, which leached most of non-quartz minerals from the overlying Tertiary sediments. Near Paramaribo the Nickerie Formation is found at a depths of 300 m below sea level (NSP). At Nieuw-Nickerie the top is encountered at 670 m. The top of the Cretaceous dips to a depth of about 3,000 m at the shelf slope, 150 km offshore. The top of the Cretaceous is recognized by a conspicuous density shift in geophysical well logs and seismic surveys for oil exploration.

3.3.4 Paleogene: Burnside, Saramacca, Onverdacht and Alliance Formations

During the Paleocene and Eocene mainly shallow marine sediments were deposited during several transgressive phases. Three formations are distinguished with different facies (Wong, 1986, 1989): the continental Onverdacht Formation is characterized by coarse kaolinitic sands and kaolinitic clays deposited in alluvial fans and braided rivers in the Paleocene and floodplains and coastal swamps in the more humid tropical Eocene. The 10 to 40 m–thick formation is locally found as “buried hills” capped with bauxite and laterite in a 10 km–wide small zone around Onverdacht and further eastward. The top of the formation is found close to the surface around Onverdacht to depths of 30 m below the surface near Lelydorp or more between the buried hills. Bauxite is the result of intensive weathering and leaching during the long Oligocene regression. The original sands were probably arkoses according to Krook (1979). Almost all bauxite in the study area has been excavated in open mines.

The Onverdacht Formation passes northward into the marine Saramacca Formation, though the transition is not clear due to faulting (UNDP/WHO, 1973). The formation is found everywhere in the northern part of the coastal plain. The formation consists of alternating quartz sands and kaolinitic clays forming series of depositional cycles, beginning with shallow-marine deposits, grading into beach and deltaic deposits, and finally ending with fluvial (pointbar and channel) deposits. The formation contains thick and continuous sand units, which enabled deep groundwater circulation. Oil in the Tambaredjo oil field is recovered from one of the lower sand units (T-sands), which is confined by an impermeable clay layer. The source rocks of the oil are the offshore lower Cretaceous marine shales (Wong, 1998).

The top of the formation is found at a depth of about −100 m (below sea level) just north of Lelydorp and slopes to −350 m at Nieuwe Nickerie.

Further north, the Saramacca Formation changes into the Alliance Formation, which consists of silty marls, clays, calcareous sands, and lignites, deposited in a shallow-marine environment and in coastal lagoons. The Alliance Formation is only found in the Commewijne district, north of the Commewijne River. The Saramacca Formation contains thick sand layers, especially in the upper part. Sand content varies from 50% to 80%.

During the Oligocene (10 million years BP), the sea withdrew while climate changed from humid tropical to semi-arid. Weathering during this long period led to bauxite formation on Paleogene sediments and crystalline basement rocks. Erosion products were deposited as braided-river and alluvial-fan deposits forming the Burnside Formation. In the Holocene coastal plain, the formation is found in the northern part of the young or Holocene coastal plain. Near Paramaribo, it is restricted in a northeast–southwest oriented tectonic basin along the coast. The top of the Burnside Formation is found at −150 m near Paramaribo to −300 m at Nieuwe Nickerie. The formation consists primarily of sands (80 to 100%). The thickness varies from 5 m to 80 m. These sands are also known as the A Sands, a name still in use by the SWM.

Low feldspar contents and the absence of calcite and aragonite in the Paleogene sediments are signs of prolonged leaching by groundwater flow (Krook, 1979). Krook also believes that the mostly kaolinitic Tertiary clays (of marine origin) originally had a higher content of smectites and illites and that they were later transformed as a result of weathering and leaching. Magnetite and hematite appear to be the dominant iron(hydr)oxide minerals.

3.3.5 Neogene: Coesewijne and Zanderij Formations

During the early Miocene transgression, clays, sandy clays and sands with glauconite and lignite layers were deposited as beach sands and swamp clays with mangrove vegetation (Coesewijne Formation). Compared to the older formations, the deposits of this formation contain much more clay (40% to 80%), originating from the proto-Amazon catchment. On the continental shelf, the facies of the Coesewijne Formation change into a shallow-marine carbonate platform. After a regression lasting 2 to 3 million years, sedimentation resumed during the mid-early Miocene. More sands (beach and fluvial deposits) were then deposited, which characterizes the upper part of the Coesewijne Formation. The top is found at a depth of −60 to −110 at Wanica and Paramaribo to −200 to −230 at Nickerie.

After a long regression of about 5 million years during the late Miocene, the Pliocene started with a transgression reaching as far as Republiek (Krook, 1979). The transgressive deposits have been removed largely during the subsequent Pliocene regression. Mainly coarse, white, and brown, kaolinitic sands with interbedded kaolinite clays, were then deposited in braided streams and on alluvial fans under semi-arid conditions (Krook, 1979, Van Voorthuysen, 1969). These deposits, comprising the Zanderij Formation, crop out in the savannah belt. Intensive weathering and leaching gave the savannah sands their characteristic bright white appearance. In the coastal plain, the Zanderij Formation dips below Quaternary sediments. At the coastline, the formation is found at a depth of −40 to −50 m.

Just as with the Paleogene sediments, the Neogene sediments contain hardly any weatherable minerals like calcite and the more unstable silicates (Krook, 1979). Unpublished mineralogical analyses by Krook (related to Krook, 1979) show that limonite (amorphous iron hydroxide) is the most abundant iron(hydr)oxide in the Pliocene and Miocene formations. He also found authigenic siderite in the top of the Pliocene formation. Pyrite appeared to be present in all Tertiary formations. The mostly kaolinitic clays in the marine Coesewijne Formation may have been transformed from clays with a higher smectite and illite content through weathering, as Krook (1979) suggested for the Paleogene clays.

3.3.6 *Pleistocene: Coropina Formation*

In the Pleistocene or old coastal plain, marine deposits are found related to one or more Pleistocene transgressions. The deposits classified as the Coropina Formation consist mainly of clays (mudflats) interspersed with sand barriers. At the base of the formation, fluvial sands are found in some places, marking a continental sedimentary environment during the early Pleistocene.

Two members are distinguished (Brinkman and Pons, 1968; Veen, 1970). The Para Member dates from the early Eemian or Yarmouthian (Holsteinian) interglacial and consists mainly of marine clays. The top of the Para Member is characterized by strong mottling (paleosol). The Lelydorp Member, which contains more sandy deposits than the Para Member, was probably formed during the late Eemian interglacial. The Lelydorp Member is found in the northern part of the Pleistocene or old coastal plain. Characteristics are the elevated complexes (up to 11+ NSP) of sand barriers between Lelydorp and Santigron in Wanica and south of the road between Uitkijk and Boskamp in Saramacca. These Lelydorp sands form a more or less continuous shallow aquifer. According to Van der Eyk (1957), Eemian sea level reached a maximum of 8 m above present sea level. Brinkman and Pons (1968) distinguish two phases for the Lelydorp Member: the Onoribo phase characterized by deposition of clays rich in organic material and pyrite during a rising sea level, and the Santigron phase, during which clays with less pyrite and sand barriers were deposited after sea level had reached a stable level.

Weathering during the Wisconsinan affected the Pleistocene sediments consisting mainly of clays. Carbonates have largely disappeared (< 0.3%). Also organic matter content is generally low (< 0.4%), though Veen (1970) and Levelt and Quakernaat (1968) occasionally found high organic carbon contents in the lower part (up to 12%). Oxidation can be recognized by the intense yellow and red mottling of iron oxides formed after breakdown of siderite and pyrite. XRF analyses of a few Koewarasan samples showed that sulfur has almost entirely disappeared. According to Veen (1970) and Levelt and Quakernaat (1968), weathering also transformed the clay minerals. Data from Levelt and Quakernaat (1968) show that kaolinite contents have increased at the expense of illite contents in comparison with the composition of Holocene clays. The content of smectite is comparable to that of the Holocene clays (0–20%). Finally it is worth noting that the Pleistocene clays in the south contain acid and very dilute pore water and have a low base saturation (Levelt and Quakernaat, 1968; Veen, 1970).

3.3.7 Holocene: Mara and Coronie Formations

During the early Holocene (12 ka to 6 ka BP), sea level rose from a depth of 100 m to its present level (Roeleveld and Van Loon, 1979; Fairbanks, 1989). In the course of the sea level rise, the large sediment load of the Amazon River could no longer be discharged in the deep sea far offshore. The sediment was taken northward with the Guiana Current and deposited along the coast. The Holocene sediments obliterated most of the Pleistocene erosion topography. Because the Holocene transgression did not reach the level of the previous Sangamonian transgression, the Pleistocene coastal plain in the south was spared, though the gullies were filled with the peaty clays of the Mara Formation and can still be recognized as swamps. After sea level rise slowed down between 7 and 6 ka BP, coastal aggradation began and extensive tidal-flat clays alternating with beach barriers with sands and shells were deposited in the Holocene coastal plain (Coronie Formation). Brinkman and Pons (1968) discerned three distinctive phases in the coastal aggradation: the Wanica phase from 6 to 3 ka BP, the Moleson phase from 2.5 to 1.3 ka BP, and the Commewijne phase from 1 ka BP to present. The main part of the young Holocene coastal plain dates from the Wanica and Moleson phase. Along the coast, north of the Saramacca and Commewijne rivers, recent deposits of the Commewijne phase are found. In this littoral zone sedimentation and coastal aggradation continues (Augustinus, 1978; Augustinus et al., 1989). A series of mud banks, where suspended load from the Guiana current precipitates, is continuously moving westward; while between the mud banks, energy-rich environments create elongated beach barriers. Oceanographic surveys show that these mud deposits are present on the sea floor to a distance of 30 km offshore and have a maximum thickness of 20 m (Nota, 1958, 1969). Further north, sandy deposits are found on the sea floor. Just as in the coastal plain, the Holocene deposits have obliterated the Pleistocene topography apart from Pleistocene paleochannels of the major rivers like the Marowijne (Nota, 1971). Other submarine morphological features are old coastlines and coral reefs, which indicate interruptions of the Holocene transgression. A coastline at a depth of 21 to 25 m was found dating from 8 to 9 ka BP (Nota, 1958; Van der Hammen, 1963). A coral reef at 80 to 90 m depth has an age of 12 to 17 ka BP (Nota, 1958, 1971).

3.4 Aquifers and formations

The coastal Tertiary formations in Suriname increase in thickness from tens to hundreds of meters from south to north. They consist of complexes of alternating but often discontinuous sand and clay strata with thicknesses varying from a few meters to tens of meters (Wong 1989, Hanou, 1981). The analysis of the Staatsolie well logs in this study confirmed this (Appendix 3). In such a hydrogeological setting it is difficult to denote specific sand strata or groups of strata as distinct regional aquifers. Iinterspersed clay layers form hydraulic resistances but have not prevented deep cross-formational flow. This is witnessed by the salinity pattern of Figure 4 and specifically the large body of low salinity groundwater, which appears to be present in the entire coastal plain (this study). This meteoric groundwater, formed during glacial periods, is not confined to a specific aquifer but pervades most of the Tertiary formations (Post, 1996; Groen, 2002).

Also from a practical point of view, aquifers are difficult to define. Groundwater wells have screens with typical lengths of 2 to 20 m but generally do not penetrate the entire formation. This is not necessary given the required capacities. Also screens of limited length are deliberately placed in specific strata to avoid attracting brackish groundwater from overlying or underlying strata. This implies that the effective or contributing aquifer thickness for a well is smaller than the potential thickness of the aquifer. Likewise the aquifer properties determined by pumping tests are only valid for the effective part of the aquifer around the tested wells. This makes it difficult to correlate strata and hydraulic parameters based on wells far from one another.

It was therefore decided to map the extent and the tops and bottoms of the formations (Hydrogeological maps of Appendix 2). The formations are based on the stratigraphy and nomenclature of Wong (1989). Note that the commonly used name of A-sand aquifer is the equivalent of the Burnside formation. Although outside the scope of the terms of reference of this study, we included the Saramacca Formation in this study, in addition to the Zanderij, Coesewijne, and Burnside (A-Sand) Formations. The analysis of the well logs of Staatsolie (RTI, 2016) demonstrated the good aquifer properties of this formation and its fresh groundwater reserves.

In general the Tertiary formations have good hydraulic properties in most parts of the coastal plain. They sustain wells with capacities from 10 (in and near the savannah zone) to 100 m3/hr. The main limitation for groundwater development is its salinity (Section 2.4.3).

3.5 Groundwater Flow Systems

3.5.1 Pleistocene and Holocene sand and shell ridges

The Coropina and Coronie formations deposited during the Eemian and Holocene transgressions consist mainly of clayey deposits. As described above also beach barriers were formed which can be recognized as elongated and often isolated 100 to 1000 m wide east-west running sand ridges in the coastal plain. The sand ridges have been mapped in detail and can be found in the soil maps and vegetation maps of the coastal plain (Paragraph 3.7). Groundwater recharge in these sandy is probably just as high as in the savannah sands (350 to 500 mm/yr). The high recharge rate explains why the sand ridges, even the recent ones, have been entirely flushed within a few hundred to thousands of years, since they have been formed. The thickness of these fresh groundwater bodies in these ridges varies from several meters to 10 m. Groundwater recovered by dug wells from the sand ridges used to be the main source of drinking water in the period before 1933 (establishment of the SWM). The ridges have been mapped in detail for the 1:100.000 soil and vegetation maps of the coastal plain (Vuure and Alderlieste, 1977, Teunissen, 1978). Thickness of the fresh groundwater in the ridges can be easily assessed with geoelectrical soundings, as have been carried out for studies in Commewijne (IWACO, 1981) and more recently in Coronie (Manurat, 2023). Though most dug wells in the Paramaribo and the other settlements have been abandoned, they receive more attention lately as a potential source for farmers who suffer from the prolonged droughts, which have become more frequent (Groenewoud, 2023; Manurat, 2023). This concern was also expressed during the first SWG meeting in December 2024.

Given the small width of the ridges and thickness of the aquifer groundwater recharge and groundwater recovery potential is restricted. Groundwater can best be recovered via a collector drain ending in a sump. Groen (2024) designed a system for a 200 m wide sand ridge in Coronie consisting of a 100 m long drain from which 7 m3/day could be recovered.

3.5.2 Tertiary Formations

Groundwater in the Tertiary formations in the coastal plain is basically stagnant. This can be derived from heads measured before 1958 around Paramaribo, which do not display a groundwater gradient in the aquifers (Figure 5). This was corroborated by paleogroundwater modelling, which demonstrated how after the Holocene transgression groundwater flow became immobilized (Groen et al, 2000b; Post, 1996). The age of groundwater predating the Holocene transgression was confirmed by radiocarbon resulting in ages varying from 3000 to 35000 years BP (Groen, 2002; Verleur, 1991; UNDP/WHO, 1973). This all leads to the conclusion that he major part of the fresh to low salinity groundwater bodies in the coastal plain of Suriname has been emplaced during Pleistocene and early Holocene times when deep groundwater circulation prevailed, driven by low sea levels and incised valleys of the major rivers in Suriname (Post, 1996; Groen, 2002; Figure 7). This situation with stagnant and fossil groundwater prevails in most of the coastal plain. Only in Paramaribo and Wanica regional groundwater flow has been triggered by the numerous pumping stations established after 1960 (Figure 7).

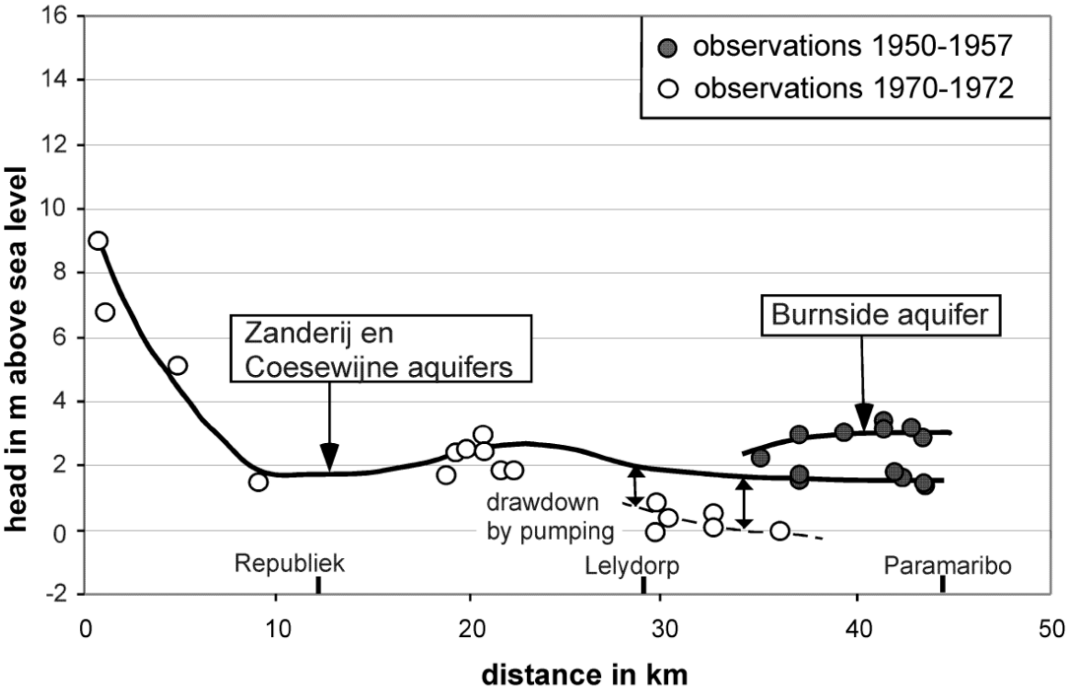


Figure 5. North-South section in coastal plain near Paramaribo with groundwater heads in Zanderij and A-sand aquifers during prepumping period. Flat gradients indicate stagnant conditions in coastal plain. Large gradient In the savanna belt south of Republiek indicates groundwater flow in the Zanderij aquifer, but flow is discharged in creeks and marshes north of the savanna belt (from Groen, 2002).

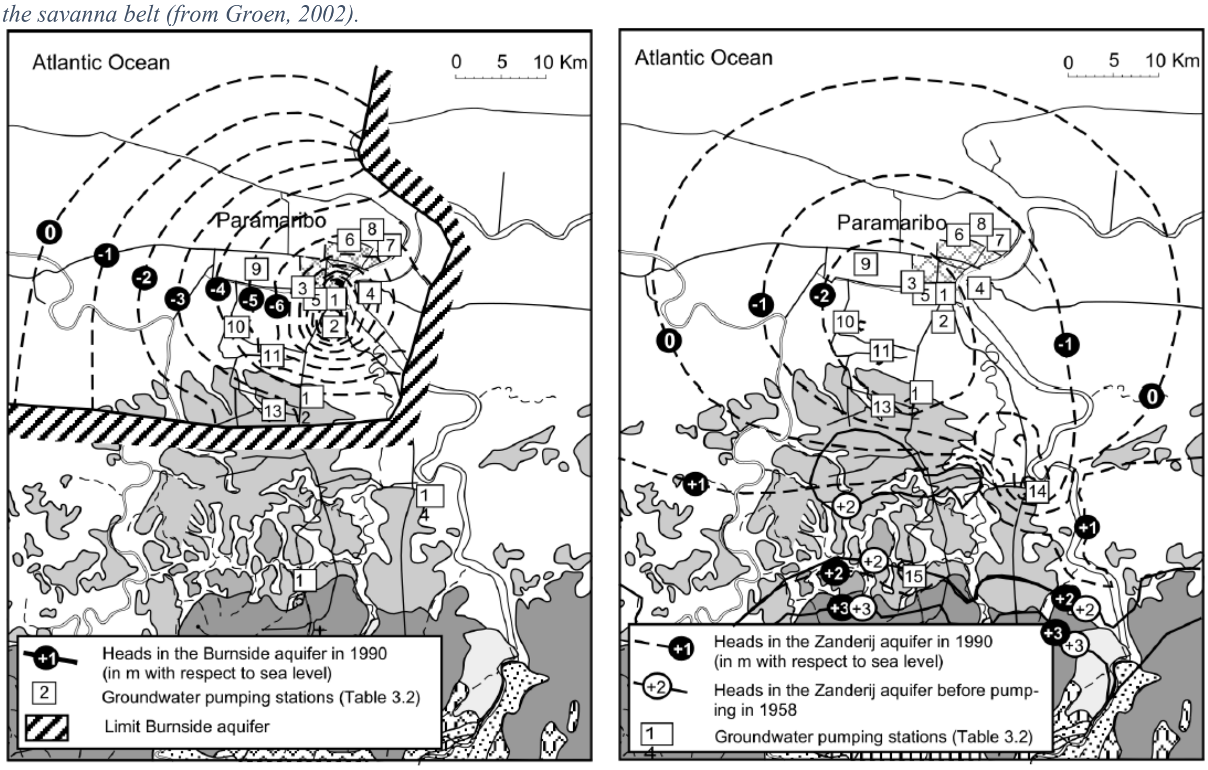


Figure 6. Contours of groundwater heads in Burnside or A-sand aquifer (left) and Zanderij aquifer (right) in 1990 (from Groen, 2002)

Figure 6 shows the decline of groundwater heads around Paramaribo in the Burnside or A-Sand aquifer (> 20 m in 1990) and the Zanderij aquifer heads (> 2 m in 1990). Subsidence in Paramaribo and Wanica as a result of the groundwater exploitation is limited to several tens of centimeters (Tauw, 2011a; Wittenberg, 2016). The very high hydraulic resistance of the Pleistocene and Holocene clays in the coastal plain prevent natural or induced groundwater recharge to the Tertiary aquifers. On the basis of pumping tests (Fredric R. Harris, 1993; Mente, 1990b; IWACO, 1983) Groen (2002) reported values of at least 100,000 days. Induced recharge will be very limited and will not compensate the abstractions from the deep Coesewijne and A-sand aquifers, as recharged water would also need to cross the Tertiary clays.

The only zone where natural recharge is taking place is the savanna belt, shown in Figure 2, where the Zanderij formation and aquifer is cropping out (Groen, 2002; Frederic. R. Harris, 1991e). However, groundwater in the Zanderij aquifer does not flow far into the coastal plain and recharge the Tertiary aquifers (Figure 5 and 7). All groundwater infiltrated in the savanna belt is locally drained by the blackwater creeks and the bordering swamps of the coastal plain. Recharge depends on rainfall and local conditions of soil and vegetation. Based on catchment studies and chloride mas balance studies Groen (2002) reported values of 350 to 500 mm/yr for the savanna belt.

The hydrogeological setting of deep isolated paleogroundwater bodies is found throughout the Suriname coastal plain extending into the Guiana coast, where Arad (1983) found similar conditions.

3.6 Groundwater Salinity

The salinity pattern in the coastal sediments has been the object of several studies (UNDP/WHO, 1973; Groen et al, 2000a; Groen, 2002; Frederic. R. Harris, 1991e). Figure 4 shows the typical pattern along a section at Paramaribo (Groen, 2002). Along coasts a relatively sharp interface between fresh meteoric and saline marine groundwater is commonly expected, but this is missing in Figure 4. Groundwater increases only very gradually in the seaward direction. The fossil groundwater with low chloride content (< 1,000 mg/l) forms a prolonged tongue, extending 90 km into offshore shelf deposits. In fact, chlorinities of the groundwater in the Tertiary water-bearing strata seldom surpass 1000 mg/L. High salinities in the Saramacca and Nickerie formations at Paramaribo (below 180 m) originate from connate groundwater or marine transgressions during the Tertiary or early Quaternary (Groen et al, 2000, Figure 7). High salinities in the upper part, from 30 to 100 m depth, result from the recent Holocene transgression (12,000 to 2,000 yr BP, Figure 7). From that time, up to the present day, salt has been migrating downward, either by slow diffusion, where thick impermeable clays of the Coropina, Mara, and Coronie formations are present, or density-driven flow below creeks incised into the sandy strata below (Groen et al, 2000; Groen 2002). Figure 7 shows how below the elevated Pleistocene sand ridges near Lelydorp groundwater was not influenced by the transgressing sea and lowest salinities.

The pattern in Figure 4 showing the low salinity paleogroundwater tongue is typical for the coastal plain of Suriname. Nevertheless, the pattern may vary along the coast. An important marker is the 250 mg/l chloride contour, which is the salinity standard for drinking water in Suriname. As an example the brackish zone (> 250 mg/ l chloride) in the Coesewijne formation is shown in Figure 2. It shows the 250 mg/l chloride contour line meandering through the coastal plain. Note that the this contour line is different for the various formations (see Appendix 2).

It is important to make it clear once again that groundwater beyond the critical 250 mg/l chloride contour is not very salty. In the entire coastal plain groundwater and in all aquifers salinity (chlorinity) remains below 1000 or 1500 mg/l. This implies that groundwater salinities in coastal wells will not sharply rise, once they start to abstract groundwater from beyond the contour line.

With respect to evaluating other options - in case fresh groundwater will get depleted - desalination of this moderately brackish groundwater is not costly and could even be cheaper than long distance transport or treatment of surface water

Various studies investigated the trend in salinity of the production wells and well fields in and around Paramaribo (RTI, 2016, Tauw, 2011; Berger, 2002). In most wellfields the salinity remains stable until 2040. Only some well fields close to the 250 mg/l contour line display a slightly increasing trend of the overall salinity. The salinization trend is very gradual because of the large diffusive salinity gradient in the transition zone between fresh and saline groundwater. (Figure 4). The HACAS study (RTI, 2016) concluded that the present well fields and some new proposed wellfields could secure the fresh water supply to the Greater Paramaribo region until 2040 at least.

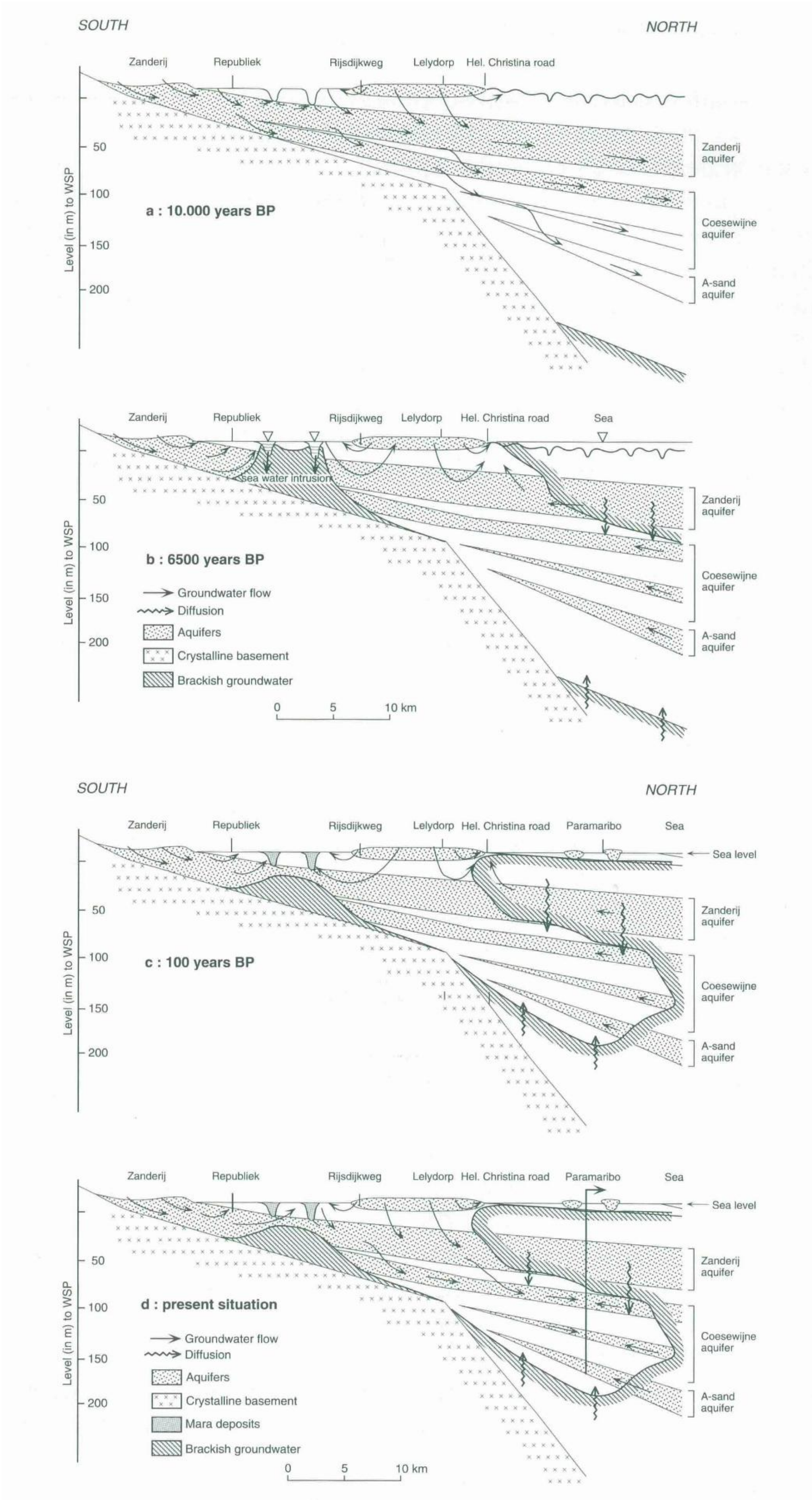


Figure 7. Groundwater flow systems in the coastal plain of Suriname (from Groen, 2002)

3.7 Climate Change

In the framework of the HACAS project, effects of climate change also have been studied (RTI, 2016, Technical Memo 3).

Suriname has a wet tropical climate with an average annual temperature of 27.1°C and a total rainfall of 2,200 mm at Paramaribo. Seasonal temperature variation is small: the maximum difference of monthly averages is 2°C. Daily temperature fluctuates between an average daily maximum of 31°C and an average daily minimum of 23°C. Seasons are marked by the rainfall pattern shown in Figure 8

Suriname has a long rainy season from April to mid-August followed by a long dry season until December. Less predictable both in timing and amount of rain are the short rainy season in December and January and the short dry season in February and March. Pan evaporation at Paramaribo varies from 100 mm/month during the long rainy season to 170 mm in the long dry season.

A far as hydrology is concerned, the most important effects resulting from global climate are the rise in sea level and the changes in rainfall and evaporation. Mean sea level at Suriname is expected to rise 0.40 m by 2040 and 0.85 m by 2100 (Nurmohamed, 2016 unpublished). The rise in sea level will lead to an upstream shift of the fresh/brackish boundary in the major rivers. The relation has been investigated by Amatali (2011, in Min. ATM, 2013) and Amatali & Naipal (1999). For instance, during low flow in the dry season, the 300 mg/l chloride boundary in the Suriname River is now found at Paranam, but will move upstream to Jodensavanna by 2100. These changes need to be taken into account in evaluating river water intakes and bank infiltration groundwater wells.

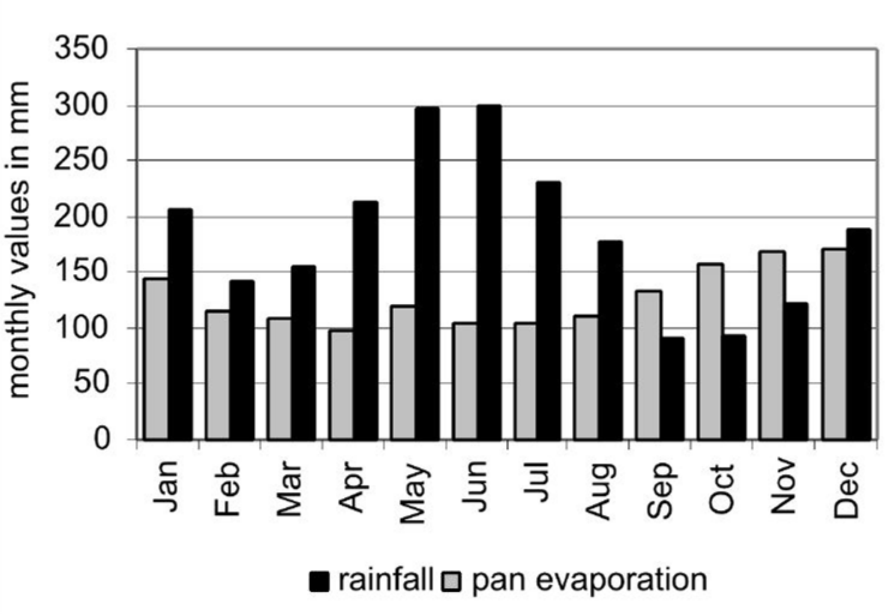


Figure 8. Rainfall and pan evaporation at J.A Pengel International airport (from Groen, 2002)

Rise in river water levels will also affect large parts of the coastal plain, where they are hydraulically connected by creeks and canals to the rivers. Groundwater levels will rise and salinization may take place.

Extreme events like high intensity rains will occur more frequently (Min. ATM, 2013). As a result temporary flooding will take place more frequently. In combination with the higher levels of surface waters, this may provoke waterlogging where drainage is insufficient. The rise in water levels and insufficient drainage may affect SWM infrastructure and operations. Risk and calamity policies are warranted.

Groundwater recharge will decrease in the future in the coastal plain. Based on various publications estimates are given in Technical Memo 2 (Volume III) for future recharge (Groen, 2002; Nurmohamed et al., 2008; Min. ATM, 2013). Groundwater recharge is expected to be 28% and 86% lower in 2040 and 2100, respectively for the savannah area. However, most recharge does not reach the productive aquifers but is quickly drained from the clayey soils in the coastal plain. Only the Zanderij aquifer in the savannah zone and the sand ridges in the coastal plain receive recharge, which is about 350 to 500 mm/yr at present.

Groundwater pumping stations at Republiek, Wonoredjo, and Albina are located near the savannah zone and could notice influence from the reduced recharge in the adjoining savannah. Lower groundwater recharge will lead to a decline of water levels in the savannah zone. However, this may be compensated by rising surface water levels in the coastal plain because of sea level rise. Production at these stations is relatively low and does not surpass the natural recharge in the surrounding area. Also in this area, no large-scale groundwater production is foreseen. All in all, climate change effects for these stations will be limited. No adaptive measures are foreseen.

The fresh groundwater in the Zanderij, Coesewijne, A Sand, and Saramacca aquifers is stagnant fossil water, formed by deep groundwater circulation during the Pleistocene and early Holocene. Climate change will not affect the groundwater salinity pattern and the production capacity of these aquifers. Present and projected SWM pumping stations are not at risk.

4 Groundwater balances and groundwater potential

4.1 Methodology and data

4.1.1 Renewable groundwater

For defining the water balances a distinction is made between the southern savanna belt with active groundwater flow systems and the northern coastal plain with fossil groundwater. In the former zone sustainability of groundwater abstractions can be evaluated by comparing these with the amount of renewable groundwater (or groundwater recharge).

Recharge to the Zanderij aquifer in the savanna belt has been set at 425 mm/yr, the average of the reported values in Groen (2002). It is assumed that only 20 % of the natural recharge in the Savannah zone (renewable resources) can be safely withdrawn without causing severe environmental and social impacts (sustainable development). This amount minus the present abstractions in the Savannah zone sets the scope for further groundwater development. The 20 % rule of thumb (scarcity threshold) is applied in several studies (WWAP/UN-Water. 2018), though it is an arbitrary value. Relatively large groundwater abstractions may still lead to unwanted local impacts, even if on a regional basis all abstractions remain below the threshold. Environmental impact assessments are always necessary.

4.1.2 Non-renewable or fossil groundwater

Fossil groundwater is non-renewable. In principle groundwater abstraction from the aquifers in the coastal plain is a form of mining and therefore sometimes considered unsustainable. However, if large reserves could meet the water demands for hundreds of years, should they not be developed first instead of other more expensive or complex alternatives?

To illustrate: this question arose in 1991 during the feasibility study for the expansion of the Paramaribo water supply by 2000 m3/hr. Two alternatives emerged: 1) groundwater abstraction by means of hundreds of small wells in a difficult to access swamp area along the Tawaykoera creek north of the savanna belt or 2) abstraction by means of 20 large wells along the Van Hattemweg in Lelydorp, much closer to Paramaribo. The first alternative were considered sustainable because the wells were fed by groundwater flow from the savanna belt. The wells along the Van Hattemweg the second alternative were located in an isolated pocket of fossil fresh groundwater, which had just been discovered. Model calculations showed that the van Hattemweg wells would turn brackish after 200 years. After consultation with the donor (IDB), the last alternative was finally chosen because of the lower costs and the simpler operation and maintenance.

Therefore in this study the recoverable volumes of water in the aquifers were determined and compared to the present groundwater productions. The groundwater volumes were calculated based on the surfaces and average thicknesses of the formations as shown in the formation maps of Appendix 2 (RTI, 2016); estimated sand (or aquifer) percentage of sand in the formations is 40 % (Hanou, 1981) and estimated porosity is 30 % (Sabajo, 2016). Furthermore it was assumed a maximum of 40% of the fresh groundwater reserve is recoverable.

4.1.3 Groundwater abstractions

Table 1 contains a list of groundwater abstractions (well fields) in the coastal plain. The locations are shown on the map of figure 9. The colors on the maps indicate the aquifers being exploited.

Table 1. Groundwater abstractions in the coastal plain and savanna belt of Suriname

Production stations SWM and rest		Production from aquifers (m3/hr)			
		Zanderij (sav.)	Zanderij (coast.)	Coesewijne	A-zand
Nickerie	Nieuw-Nickerie		215		
	Sidoredjo		222		
	Henar			114	
	Paradise			154	
	Wageningen			92	
	rest		100		
	Total fresh		100	360	
	Total brackish		437		
Coronie	Totness			167	
	rest			50	
	total			217	
Saramacca	Boskamp				
	Peperhol			122	
	Groningen			124	
	Kampong Baroe			138	
	Uitkijk			81	65
	rest			100	
	Total			565	65
Paramaribo-City	Tourtonne				132
	Blauwgrond				235
	WK-Plein				607
	Flora				132
	Leysweg			140	270
	Livorno				562
	rest			50	200
	Total fresh			50	762
	Total brackish			140	1376
Paramaribo-Wanica	Leiding 9a			583	
	Koewarasan			300	130
	Helena Christina				528
	Lelydorp		338		
	van Hattemweg		976		
				100	
	Total		1314	983	658
Paramaribo-Para	Republiek	300			
	La Vigilantia		272		
	Mata	8			
	rest	50	100		
	Total	358	272		
Commewijne	Meerzorg				255
	Peperpot				75
	Total				330
Marowijne	Wonoredjo	43			
	Albina	100			
	Total	143			

red means: some wells have chloride contents above 250 mg/l

Most of the abstractions refer to the SWM production stations. There are not many other groundwater users, mainly bottling companies, agricultural enterprises and tourist centers. Locations and productions are also not systematically registered. In the Table 1 abstractions for this "rest" category have been estimated, but this requires further study.

As shown on the map most of the pumping stations are located in the coastal plain. Most of the abstracted groundwater (93 %) is water from fossil aquifers with non-renewable groundwater.

Note that in the Paramaribo water balance area some abstractions have been indicated between brackets, which denote future potential productions proposed by HACAS (RTI, 2016). See the more detailed map of Figure 9.

4.1.4 Water balancing

For practical reasons the coastal plain and the savanna belt have been divided into 6 water balance areas (Figure 2). The water balance areas are bounded to the west and east by the major rivers in the coastal plain, to the north by the sea and to the south by the outcrop of the crystalline basement. They coincide more or less with the coastal districts of Suriname and have been named thereafter. Table 2 and 3 contain the outcome of the water balances. Water balances have been drawn up for each water balance area (columns) and each aquifer (rows). Table 2 reflects the water balance of the savanna belt where renewable groundwater is present in the Zanderij aquifer

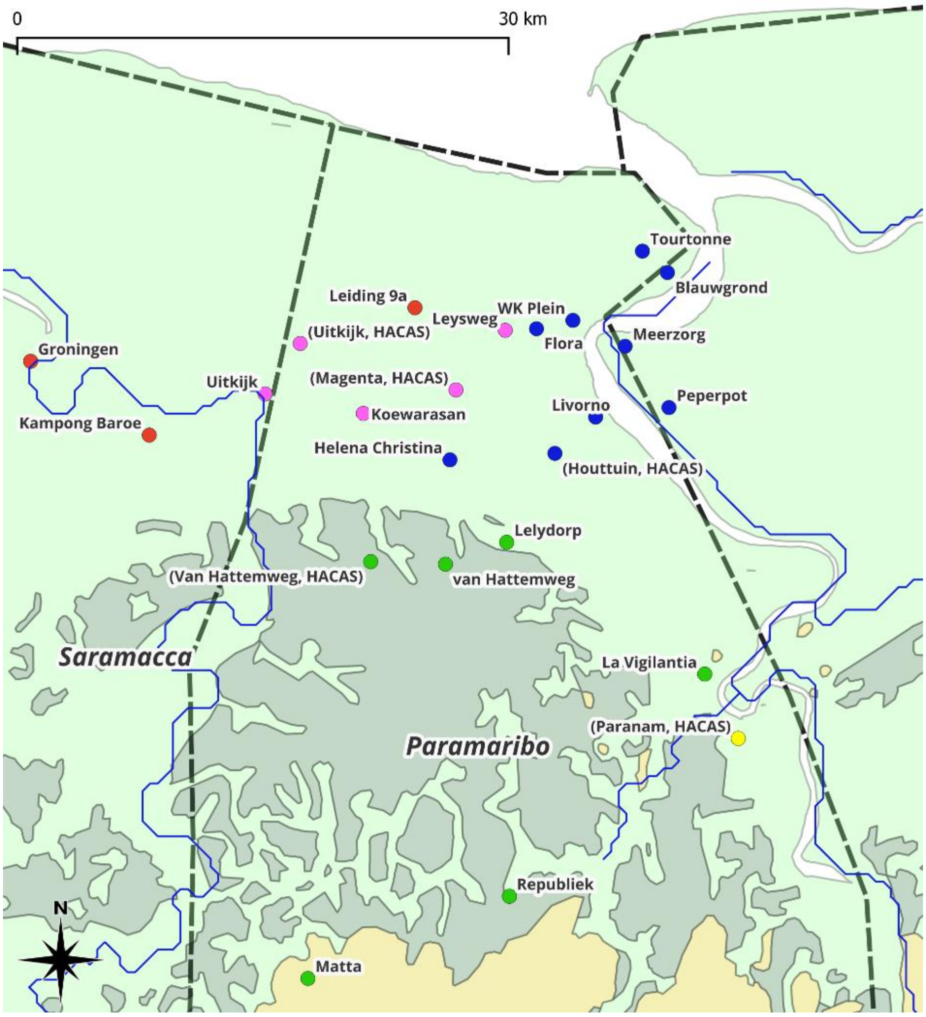


Figure 9. Pumping stations of Surinaamsche Waterleidingmaatschappi in the Paramaribo water balance area. Productions are listed in Table 1. Note that the pumping stations in brackets, (e.g. Magenta, HACAS), represent potential pumping stations proposed by the HACAS study (RTI, 2016).

The potential for sustainable development, being 20 % rule of recharge as described above, is indicated for each water balance area and also the present groundwater abstraction in these areas.

Table 3 contains the water balances of the coastal plain with non-renewable groundwater in the Zanderij, Coesewijne, A-sand (Burnside) and Saramacca aquifers. In this areas sustainable development has been defined as the maximum yearly abstraction that can be maintained for 30 years given the recoverable amount of groundwater, as described above. This approach for defining the suitable development is rather arbitrary and results, in some of the western water balance areas, in very high potential abstraction rates. Though they may not be very realistic, they give an impression of the potential of the aquifers.

Table 2. Waterbalances of the Zanderij aquifer in the savanna belt

			Water balance areas					
		Name	Marowijne	Commewijne	Paramaribo	Saramacca	Coronie	Nickerie
Withdrawal	**Prwsent groundwater withdrawal**	10^6 m^3/yr	1.1	2.6	47.5	5.1	1.7	7.2
	Expected withdrawal 2040 (115 % from HACAS, 2016	10^6 m^3/yr	1.3	3.0	54.6	5.8	2.0	8.3
Zanderij aquifer (savanne)	Surface Zanderij outcrop area	km^2	282	397	529	824	1046	2485
	Annual groundwater recharge (425 mm/yr)	10^6 m^3/yr	120	169	225	350	444	1056
	Annual discharge in creeks and swamps	10^6 m^3/yr	119	169	222	350	444	1056
	Sust. development: 20 % of annual recharge	10^6 m^3/yr	24	34	45	70	89	211
	Annual withdrawals	10^6 m^3/yr	1.1	0.0	2.9	0.0	0.0	0.0
Scope for development		10^6 m^3/yr	22.9	33.7	42.1	70.0	88.9	211.2

Table 3. Waterbalances of the aquifers in the coastal plain

			Water balance areas					
		Name	Marowijne	Commewijne	Paramaribo	Saramacca	Coronie	Nickerie
Withdrawal	**Present groundwater withdrawal**	10^6 m^3/yr	0.0	0.0	0.0	4.7	0.0	0.8
	Expected withdrawal 2040 (120% from HACAS, 2016	10^6 m^3/yr	0.0	0.0	0.0	5.4	0.0	0.9
Zanderij aquifer	Surface fresh aquifer	km^2	766	652	761	1800	3888	3693
	Average thickness fresh aquifer	m	15	15	25	30	40	75
	Fresh recoverable groundwater storage	10^6 m^3	552	469	913	2592	7465	13295
	Sust. development: max. abstraction in 30 yr	10^6 m^3/yr	18	16	30	86	249	443
	Annual withdrawals fresh	10^6 m^3/yr	0	0	12.7	0	0	0.8
	Annual withdrawals brackish	10^6 m^3/yr						3.5
Coesewijne aquifer	Surface fresh aquifer	km^2	927	263	587	1654	2564	4634
	Average thickness fresh aquifer	m	50	50	40	50	40	60
	Fresh recoverable groundwater storage	10^6 m^3	2225	631	1127	3970	4923	13346
	Sust. development: max. abstraction in 30 yr	10^6 m^3/yr	74	21	38	132	164	445
	Annual withdrawals fresh	10^6 m^3/yr	0	0	8.3	4.5	1.7	2.9
	Annual withdrawals brackish	10^6 m^3/yr			1.1			
A-zand aquifer	Surface fresh aquifer	km^2	0	49	360	318	1387	2398
	Average thickness fresh aquifer	m	0	15	15	20	25	25
	Fresh recoverable groundwater storage	10^6 m^3	0	35	259	305	1664	2878
	Sust. development: max. abstraction in 30 yr	10^6 m^3/yr	0	1.2	8.6	10.2	55	96
	Annual withdrawals fresh	10^6 m^3/yr	0	2.6	11.4	0.5	0.0	0.0
	Annual withdrawals brackish	10^6 m^3/yr			11.0			
Saeamacca aquifer	Surface fresh aquifer	km^2	25	130	159	1560	2838	4622
	Average thickness fresh aquifer	m	10	15	30	125	125	175
	Fresh recoverable groundwater storage	10^6 m^3	12	94	229	9360	17028	38825
	Sust. development: max. abstraction in 30 yr	10^6 m^3/yr	0	3.1	7.6	312	568	1294
	Annual withdrawals	10^6 m^3/yr	0	0	0	0	0	0
Scope	Total fresh recoverable groundwater storage	10^6 m^3	2788	1230	2528	16227	31080	68343
	total sust. development max abstr, 30 yr	105 m^3/yr	93	41	84	541	1036	2278
	lifetime fresh withdrawal (present rate)		n.v.t	464	78	3208	17836	18502
	lifetime fresh withdrawal (2040 rate)		n.v.t.	403	68	2789	15510	16089

4.2 Water balances in the savanna belt

4.2.1 Zanderij aquifer

Groundwater recovery from the Zanderij aquifer in the savanna belt, or the zone bordering the savanna, is much higher than the amount of groundwater which is presently abstracted (Table 2). In In the Sustainable recovery varies from 24 to 211 million m3/yr in the water balance areas, while abstractions vary from 0 to 2.9 million m3/yr (abstractions only in the eastern balance areas). The largest groundwater recovery is in the Paramaribo balance areas (Republiek wellfield). Even in this area sustainable development of 45 million m3/yr (Par. 4.1.1) is still 15 times the actual recovery of 2.9 million m3/yr. In reality the scope for groundwater development in the savanna zone may even be higher, if wells are located along the perennial creeks and function as bank infiltration wells (MAR). This is the case of the Republiek wellfield, the oldest well field established in 1933 (Groen, 1998). The water engineers at that time deliberately positioned the wells along the Coropina creek to secure recharge.

4.3 Water balances in the coastal plain

4.3.1 Zanderij aquifer

In the coastal plain the Zanderij aquifer contains only fossil groundwater. Induced recharge because of the large groundwater abstractions around Paramaribo is not taken into account (worst case) as discussed in Par. 3.5.2. The amount of recoverable fossil groundwater from the Zanderij aquifer, as defined in Par. 4.1.2., varies from 469 to 13925 million m3 in the water balance areas (Table 3).

Fossil groundwater from the Zanderij aquifer is recovered in the Nickerie and Paramaribo waterbalance areas for the epynomous cities in these areas: These are the Nieuw-Nickerie en Sidoredjo stations for Nieuw-Nickerie town and the van Hattemweg and Leydorp stations for Paramaribo city.

The Hattemweg en Leydorp pumping stations in the Paramaribo water balance area abstract the largest volume of 12.7 million m3/yr, while the recoverable amount of fossil groundwater is 913 million m3. This implies that the two stations would last for about 70 years. This is a balk park estimate but in the same order of magnitude as the predicted lifetime of the van Hattemweg well field of 100 to 200 years (Frederic. R. Harris, 1991e). `Note that this this study did not take into account the Lelydorp well field.

The Nieuw-Nickerie and Sidoredjo pumping stations near Paramaribo abstract 4.3 million m3/yr. Note that a large part of this production, 3,5 million m3/yr, is already brackish. The fresh reserves of fossil Zanderij groundwater in the Nickerie water balance area amount to 13295 million m3. This suggest a large scope for development of Zanderij aquifer. However, further exploration should be oriented south of Nieuw-Nickerie town.

4.3.2 Coesewijne aquifer

Recoverable groundwater from the Coesewijne aquifer varies from 631 to 13346 million m3 in the water balance areas. Highest groundwater abstraction of 9.4 million m3/yr takes place in the Paramaribo water balance area (Koewarasan, Leiding 9a, Leysweg pumping stations. 1.1 million m3/yr of this abstraction is brackish.

As the recoverable amount is 1127 million m3 in the Paramaribo water balance area, present fresh groundwater production from this aquifer could be continued for about 135 years.

In the water balance areas further west (Saramacca, Coronie and Nickerie) the recoverable amounts of groundwater from the Coeswijne aquifer are very high compared to the abstractions. No bottlenecks in meeting supply and demand are foreseen in these areas for the coming centuries. In the eastern water balance areas of Marowijne and Commewijne, the Coesewijne aquifer is not being exploited, as it holds mainly brackish groundwater.

4.3.3 A-zand aquifer

The recoverable amounts of fresh groundwater from the A-zand aquifer increase from east to west. In the Marowijne water balance there are no reserves. In Commewijne estimated reserves are 35 million m3 and are only found in the outer western part near Meerzorg. Groundwater abstraction at Meerzorg and Peperpot stations is 2.6 million/yr and would in principle last for another 13 years, However wells in this areas show a gradually rising salinity trend. So the lifetime of these pumping station may be somewhat shorter.

The recoverable amount of groundwater in the Paramaribo water balance area is 259 million m3. In this area 22.4 million m3/yr is being abstracted from the A-zand aquifer, of which 11.0 is brackish (The northern pumping stations Tourtonne, Meerzorg, WK Plein, Leysweg and Flora produce groundwater with salinities just above the WHO guideline of 250 mg/l). This implies fresh groundwater abstraction from the A-zand in this area would last for another 23 years.

In the western water balance areas of Saramacca, Coronie and Nickerie, the A-sand aquifer is not exploited apart from the Uitkijk pumping station (0.5 million m3/yr)

4.3.4 Saramacca aquifer

The Saramacca aquifer is the lowermost Tertiary aquifer in the Suriname coastal plain. In the Saramaca, Coronie and Nickerie water balance areas it holds vast quantities of fresh groundwater varying from 9360 to 38825 m3. Near Nickerie fresh groundwater is even encountered at depths of 600 m (RTI, 2016). The Saramacca aquifer is not exploited in any of the water balance areas. According to the HACAS study groundwater in the Saramacca aquifer between and south of Uitkijk and Groningen may be of strategic importance for the Paramaribo water supply in the period after 2040 (RTI, 2016).

4.3.5 Development potential of combined aquifers in the coastal plain

At the bottom of Table 3, the scope is given (grey) for groundwater development for all aquifers combined in each water balance area. This gives the 1) recoverable amount of groundwater, 2) maximum abstraction for 30 years, 3) time the present abstraction from the coastal aquifers can be maintained and 4) time the expected abstraction in 2040 can be maintained. (The 2040 abstraction is a better approximation for the average abstraction in this century). Based on this, it can be concluded that the water supply for Greater Paramaribo can be continued for the next 70 to 80 years. Most important aquifers for further development are the Coesewijne and Zanderij aquifers, as storage in the the A-zand aquifer is limited.

4.4 Conclusions regarding the potential for groundwater development

It should be noted that this water balance study has an indicative value for the planning of future water extraction. Exploration with geophysical techniques (TDEM) and test drilling is still required followed by simulations with groundwater models. With these investigations well fields can be designed in more detail.

Special attention should be given to the water supply of Greater Paramaribo. In that respect, it is advised to review the HACAS study and its recommendations (RTI, 2016). Fresh groundwater supply could be secured in any case to 2040 with a production of 91 million m3/yr according to this study. New pumping station were proposed at Houttuin (A-zand and Coesewijne), Magenta (Coesewijne), Uitkijk (A-zand and Coesewijne), van Hattemweg (Zanderij) en Paranam (Zanderij). For the period after 2040 HACAS advises to explore the aquifers in the Saramacca area, roughly between Uitkijk and Groningen and south of the Saramacca River. It is advised to update and review the HACAS study and its recommendation with respect to the present insights in climate change and socio-economic developments.

In this study and the HACAS study (RTI, 2016) the potential for fresh groundwater development has been assessed. It must be noted that in the brackish zones of the coastal plain (Appendix 2), groundwater salinities or rather chlorinities in the aquifers rarely exceed 1500 mg/l. This is still quite low compared to seawater 20000 mg/l). Therefore, If all fresh groundwater would have been exhausted - which is not likely to occur this century - desalination of this brackish groundwater could be the next option. Desalination of brackish groundwater may even be less costly and complex than development of surface water, which will also be effected by upstream saline intrusion because of the expected sea level rise this century

4.5 Potential for MAR

Given water demands, drought risks and groundwater availability MAR systems are of interest in the Paramaribo and Saramacca water balance areas only.

The five principle so MAR are summarized below in the diagrams of Figure 10. The diagrams make clear that in the coastal plain with thick clay layers at the surface the only feasible MAR technique, would recharge the deep aquifers by means of ASR or ASTR injection wells. These type of wells could serves to sustain the recovery from the abstraction wells and prevent salinization. ASR and ASTR systems require pretreatment of source water, continuous monitoring and regular regeneration of the injection wells, whose capacity tend to decrease due to inevitable clogging of well screens. ASR and ASTR is costly and requires special operation and maintenance expertise, which SWM may not have at this moment. As demonstrated above, fresh groundwater resources are not exhausted and replacing and displacing wells could mitigate salinization and declining water levels to a large extent. In this light MAR by deep injection wells in the coastal plain is not recommended.

MAR in the sand and shell ridges may be more interesting, but not for public drinking water supply. Water recovery from the ridges may be of interest as supplementary irrigation for farmers, who experience problems of prolonged and frequent droughts during the last decades. Water can be recovered through collector drains (Groen, 2024). These systems are recharged by induced recharge from the neighbouring swamps and can therefore be categorized as bank infiltration systems.

MAR by bank infiltration is also the preferred system in the savanna area and the bordering coastal plain. Wells can be placed along rivers and creeks incised in the Zanderij aquifer. The oldest wellfield in Suriname along the Coropina Creek at Republiek is an example of such a system. Large scale MAR is feasible in this area along creeks and rivers, which have a reliable discharge and water quality and where the Zanderij aquifer has a sufficient thickness and is hydraulically connected to surface waters. One of the new well fields recommend by HACAS at Paranam near the Suriname river can be considered as a MAR system (Figure 9).

As mentioned above, water quality is an issue. There are alarming report of rivers and creeks being polluted by mining activities and housing developments. Particularly mercury pollution of the Suriname is a concern. So water quality and water protection are crucial issues in designing MAR systems.

5 Hydrogeological sections and maps

5.1 Hydrogeological Sections

An important source of information for this assessment were the geophysical well logs of the oil exploration logs of Staatsolie, Suriname's state oil company. The well logs have been interpreted based on the methodology applied earlier on some well logs in Suriname by Groen et al (2000) and Groen (2002). For a more detailed description of the method we refer to these publications. The method is based on the Archie equation for clean sand strata (Archie, 1942). In this equation formation resistivity is linearly related to water resistivity via the formation factor. The formation factor is determined on the basis of porosity and some empirical constants (Noorthoorn van der Kruijff, 1970; Groen et al. 2000a) After correcting to reference temperature the water resistivity is converted to chloride concentrations in water using an empirical relationship after Groen et al. (2000a) and Groen (2002). Clean sand strata in the well logs were discriminated using the gamma ray log (80 GAPI as criterion, personal communication Griffith Staatsolie). Formation resistivity was based on resistivity or induction well logs. Porosity was calculated from well density logs. Ambient temperature was taken from well logs or calculated from the depth using the average geothermal gradient (UNDP/WHO, 1973).

The sections (Appendices 3-1 to 3-8) contain well logs showing gamma ray, density, and resistivity logs and composite columns with interpreted clay (gray) and sand (yellow) based on the gamma ray log (left part of column) and chloride concentration in several classes (right part of column). The chloride concentration classes are 0 to 250 mg/L (dark blue), 250 to 500 mg/L (light blue), 500 to 1000 mg/L (yellow), 1000 to 2000 mg/L (orange), and more than 2000 mg/L (red). The calculated chloride concentrations have an uncertainty, which will be studied further (scientific publication of University of Suriname, Staatsolie and Acacia Water). Based on a few water samples taken from drinking water wells not far from the oil exploration wells (Totness, Wageningen, Paradise), it is concluded that the calculated chloride contents appear to be higher than actual analyses. This means that groundwater attributed to the 250–500 mg/L class (light blue) may have chloride contents lower than 250 mg/L. We therefore conclude that the light blue zones in the well logs may also represent fresh groundwater and are worth exploring.

The sections Commewijne 1 and Commewijne 2 running through the northern part of Commewijne District (Appendix 3-2 and 3-3) demonstrate that there is no fresh groundwater in this area, except for well COM01 near Pomona. Here fresh groundwater may be present in the Saramacca Formation between −210 and −230 m.

The wells in section Weg naar Zee, west of Paramaribo in Wanica District (Appendix 3-4), show that fresh groundwater is probably is present from −90 to −220 m in the Coesewijne and Burnside Formations (light blue). This corresponds with the situation in Paramaribo to the east.

The wells in the Uitkijk section (Appendix 3-5) display the presence of fresh groundwater starting from 150 to 180 m up to 300 m in the Coesewijne and Saramacca Formations (tops of the Burnside Formation have not been found here, but may exist).

The same situation is found in the southern five wells of the Tambaredjo section near Groningen and the Tambaredjo oil field (Appendix 3-6). Further north, groundwater salinity increases gradually in this section. The two northern wells in the Tambaredjo section contain brackish groundwater.

In the southern five wells of the Calculatta section (Appendix 3-7) fresh water occurs in some strata between −200 and −280 m in the Saramacca Formation and between 100 and 120 m in the Coesewijne Formation in wells CC17 and CC16. Salinities in this area are less favorable than that in the Uitkijk section and in the southern part of the Tambaredjo section at Groningen in the Tambaredjo oil field.

Along the Coronie section (Appendix 3-8) fresh groundwater seems to be restricted to the Zanderij and the top of the Coesewijne Formation to a depth of about −130 m. Only in the southern well COR03 fresh groundwater extends up to 200 m in the Coesewijne and Saramacca Formations. Groundwater salinities from the well log interpretation are indicated here as light blue, but analysis from pumping station Totness prove that groundwater has a chloride concentration lower than 250 mg/l.

In the wells of the Nickerie section (Appendix 3-9) fresh groundwater is present between −200 and −300 m in the Burnside and Saramacca Formations. In the southern wells NIC08 and NIC09 the Burnside Formation holds brackish groundwater.

The West-East section through the coastal plain (Appendix 3-10) shows a varying groundwater salinities. Most wells are part of the sections described above. Interesting are the wells NIC06 and NIC07 at Nieuw Nickerie in the far west. In these wells fresh groundwater is found in the Coesewijne and Burnside formations between −200 and −240 m. Also here calculated chloride concentrations seem to be higher than those found in analyzed samples from the nearby pumping stations at Paradise and Groot Henar. The deeper part of the well logs, not shown in the section, reveal that fresh groundwater extends up to 750 m, which is well into the Nickerie Formation. So we may conclude that the deeper part of the Saramacca Formation in the western part of Nickerie District holds large quantities of fresh groundwater. This was also reported by UNDP/WHO (1973). Well COM16 in Commewijne District at the other end of the West East Section of Appendix 3-10 shows that the Saramacca Formation may contain fresh groundwater between −200 to −230 m near Alliance.

5.2 Hydrogeological Maps

As explained in section 2.4.1, the term. Formations rather than Aquifers have been mapped for this study. The studied formations are the Zanderij, Coesewijne, Burnside (ASand), and Saramacca. According to the project RFP, the first three formations or aquifers were the objects of the study. The Saramacca Formation was added by the HACAS team after large fresh groundwater reserves were found in this aquifer during the study.

The southern extension and contour lines of the depth of the top (with respect to NSP) of each formation is shown on the maps. Also the depth of the top of the Cretaceous Nickerie Formation and the crystalline basement are indicated.

Regarding the groundwater salinity, brackish groundwater zones have been mapped with color shadings for each formation. In these zones all groundwater in the formation has chloride contents above 250 mg/L and is unsuitable for water supply. In the remaining blank zones the formation contains groundwater with chloride contents lower than 250 mg/L, at least in some sand strata. Mapping groundwater salinities in more detail (various depths, more contour lines) proved to be impossible due to low data density and uncertainties in values (wells logs).

The maps provide practical insight for planning groundwater development and management. If wells need to be drilled in new water demand areas, the maps show which formations are eligible based on salinity and which depth zones need to be explored (between top of the formation and top of the underlying formation). This is in line with earlier findings stating that fresh groundwater is not present in the populated part of this district, apart from Meerzorg (Burnside or A Sand Formation) and Morico (Coesewijne Formation) (IWACO, 1981; Mente, 1990a, Acacia Institute, 2007a, Tauw, 2011b, HACAS Technical Memo 1).

5.3 Saramacca Formation

The Cretaceous Nickerie Formation and the crystalline basement is an old erosion surface formed during the Upper Cretaceous. It can be regarded as an impermeable basis for the groundwater system in the Tertiary formations (UNDP/WHO, 1973; Groen, 2002). The depth of this basis is shown in Appendix 2-1. In the southern part of the savannah zone (southern limit of the Zanderij Formation in Appendix 2-5), basement rocks are found only a few meters below the surface, which is several tens of meters above NSP. Further north, basement slopes to a depth of −5 m (with respect to NSP) around Adolf Pengel airport and −150 m south of Paramaribo, where it dips below the Nickerie Formation. The top of the Nickerie Formation continues to slope downward to −350 m at the coast north of Paramaribo. The map in Appendix 2-1 shows the deepening and southward extending trend of the sedimentary basin towards Nieuw Nickerie town where the top of the Nickerie Formation is found at −670 m. This pattern is found in all Tertiary formations.

The thickness of the Eocene and Paleocene Saramacca Formation varies from about 125 m in the east at Commewijne and Paramaribo to 300 m in the west at Nieuw-Nickerie. The top of the formation slopes from −100 m at Lelydorp to −200 m at the coast north of Paramaribo and from −100 m in the southern part of Nickerie district to −370 m at Nieuw Nickerie (Appendix 2-2). The formation contains thick sand units forming regional aquifers. Sand contents varies between 50 and 70%. UNDP/WHO (1973) reports hydraulic conductivities varying from 5 to 40 m/day. Well known are the T-sands at the base of the formation, which host the oil of the Tambaredjo oil field, 35 km west of Paramaribo.

At Paramaribo, the formation contains brackish groundwater. West of Paramaribo in Wanica and Saramacca districts, 20 to 60 m thick layers of fresh groundwater are found in this formation (Appendix 2-2, Hydrogeological Sections in Appendices 3-3 to 3-5). Noorthoorn van der Kruijff (1970) reported that groundwater within the basal oil-bearing T-sands is brackish, but that fresh groundwater is found just above the overlying clay seal. In Nickerie District, where the formations reach their greatest thickness, layers of more 100 m of fresh groundwater are found. The entire formation down to 600 m may contain fresh groundwater here (Appendix 3-8). This was previously suggested by UNDP/WHO (1973).

5.4 Burnside (A Sand) Formation

Burnside Formation is often also referred to as the A Sand aquifer. The Burnside Formation is restricted to the northern part of the coastal plain (Appendix 2-3). The top of the formation is found at −130 to −180 m around Paramaribo and −325 m at Nieuw-Nickerie. The thickness varies from 20 to 50 m. The coarse sands of the Oligocene Burnside Formation form a well-defined and interconnected unit of coarse sands and have good aquifer properties. Sand content varies between 60 to 85%. Well with capacities of 70 m3/hr or more can be constructed. Groundwater in this formation is recovered by several pumping stations in Paramaribo for drinking water supply (WK-Plein, Livorno, Leysweg, Tourtonne, Blauwgrond, Flora, Meerzorg). In Paramaribo, the formation is being overexploited as can be observed in the rising salinities and large drawdowns of hydraulic heads. In Wanica there is still scope for additional development. Water from the Burnside Formation is also recovered at Uitkijk (Saramaca), Helena Chrsitina (Wanica), Meerzorg (Commewijne), and Wageningen (Nickerie)

Around Paramaribo, hydraulic conductivities and transmissivities vary from 30 to 80 m/day and 900 to 3,200 m2/day respectively (UNDP/WHO, 1973). The high transmissivity at the Leysweg well field is related to the relatively large thickness and gravely nature of the aquifer. The pumping test at Wageningen pumping station in Nickerie District carried out for this project indicated a transmissivity of 900 m2/day and a hydraulic conductivity of the sands of 45 m/day (HACAS Technical Memo 2). For areas without much information on aquifer properties, a hydraulic conductivity of 65 m/day should be ascribed to the Burnside sands.

Clays below and above the pumped parts of Burnside Formation probably have high hydraulic resistances. A sign of the high resistance is the fact that salinity of the pumped water from the Paramaribo pumping stations only slowly increased over the years. Salinization resulted from lateral advection rather than from cross-formational flow from the brackish Saramacca Formation above and the Coesewijne formation below (HACAS Technical Memo 4; Groen, 2002). Another indication is the high artesian heads measured in the prepumping period before 1960, which exceeded the heads in the overlying Coesewijne Formation. Hydraulic resistances are in the order of ten thousands of days. Expressed in vertical hydraulic conductivities, we assume that the Tertiary clays have values in the order of 0.001 m/day.

The formation contains fresh groundwater south of Paramaribo, where the formation is deposited in a large basin. Also in some parts along the coastal east-west road in Saramacca District the formation holds fresh groundwater. (Burnside is absent south of the east-west road.) In the Coronie District, the formation is of little importance for groundwater development as it is either absent or holding brackish groundwater. In Nickerie District, the Burnside Formation contains fresh groundwater like at Wageningen. Further west, the top of the formation deepens to −350 m.

5.5 Coesewijne Formation

The Coesewijne Formation consists of alternating clays and sand layers and is highly varying. Sand content varies from 25 to 75%. Sometimes, a distinction is made between upper and lower Coesewijne aquifers at Paramaribo with the upper Coesewijne having the best aquifer properties. The thickness varies from 50 m in the east to 100 m in the west pf the coastal plain. Around Paramaribo, the top is encountered at −60 m around Lelydorp, and slopes to −100 m north of Paramaribo. In Nieuw Nickerie the formation is found at −200 m.

The Coesewijne Formation holds brackish water in the Commewijne District and the northern part of the Marowijne District. South and west of Paramaribo, the formation is fresh and exploited by several pumping stations (Koewarasan, Leiding 9a, Helena Christina, Leysweg, Groningen, Kampong Baroe, Tijgerkreek, Coroniet [1 well], Paradise, and Groot Henar). There is little information regarding this formation in Coronie District. It seems that the aquifer contains fresh groundwater only in the upper parts.

The Coesewijne Formation is exploited by a large number of pumping stations in the coastal plain. The transmissivities of the aquifer vary between 150 and 500 m2/day with an exceptional high value at Leysweg (2,330 m2/day) and a very low value at Tijgerkreek (56 m2/day). An average hydraulic conductivity of 30 m/day can best be used for areas with little information (HACAS Technical Memo 2).

Hydraulic resistance of the clays and lignite layers in the lower part of the formation is high, as explained in Section 3.4, and probably amounts to ten thousands of days. Vertical hydraulic conductivities of the clays are in the order of 0.001 m/day. The resistance of the overlying clays separating the Zanderij sands from the Coesewijne sands is also expected to be high in the Holocene or young coastal plain. Towards the south, in the Pleistocene or old coastal plain, these sands form a single unit with the Zanderij sands. Consequently, hydraulic resistance will be much lower in that zone.

5.6 Zanderij Formation

The Zanderij Formation contains mainly sands and forms a good aquifer. Sand content generally ranges from 60 to 90%. The formation is present in the entire coastal plain and the savannah zone. The thickness varies from a few meters in the south of the savannah zone where it overlies the crystalline basement to about 50 m north of Paramaribo. At Nieuw-Nickerie the thickness is about 150 m. The formation crops out in the savannah zone, where elevations are +10 to +50 NSP. Along the coast, the top of the formation is encountered at around −50 m.

In the savannah zone and a small zone in the coastal plain bordering the savannah, the Zanderij Formation contains fresh groundwater and receives active recharge. Groundwater is recovered from this formation at Albina, Moengo/Wonoredjo, and Republiek. The formation is not very thick in this zone. Well capacities are small and vary between 5 to 15 m3/day. Further north, groundwater is basically stagnant in this formation, just as in the older formations.

In the old or Pleistocene coastal plain pockets of fresh groundwater are present in the Zanderij Formation below undissected and elevated areas, notably the Lelydorp sands. In these zones, the Zanderij Formation has not been affected by the Holocene transgression and even receives some recharge (Groen, 2002). Such a zone has been found at Lelydorp, where groundwater is exploited by the van Hattemweg well field (Frederic R. Harris, 1991e) and south of Paranam, where the SURALCO wells used to produce groundwater. Similar pockets of fresh groundwater may also be present under the Lelydorp sand ridges south of the road between Uitkijk and Boskamp in Saramacca District.

In the Holocene or young coastal plain of the Marowijne, Commewijne, and Saramacca districts the formation is brackish. However, in the Coronie District, fresh groundwater occurs in the Zanderij Formation along the coast, where the Totness pumping station draws water from this formation. It is expected that also in the rest of Coronie District fresh groundwater is present in this formation. In Nickerie District the Zanderij Formation is mainly brackish. A tongue of fresh groundwater protrudes from the south towards Nieuw Nickerie. The pumping station at Nieuw-Nickerie and Nickerie West or Sidoredjo presently pump brackish groundwater from the Zanderij formation with chloride concentrations well over 250 mg/L. For these stations alternative groundwater production sites need to be identified in the near future. Investigations demonstrated the presence of fresh groundwater in the Europolders south of the town of Nieuw-Nickerie (Mente 1989b; Van Doorn, 2002). Another possibility is groundwater from the Coesewijne aquifer at Paradise or Groot Henar.

Transmissivities of the Zanderij aquifer range from 700 to 200 m2/day, which underlines the good aquifer properties. An exception is the remarkably low transmissivity at Powakka of 430 m2/day, where 30 m of sands have been encountered in the wells. Hydraulic conductivities range from 25 to 150 m/day. A typical value of 45 m/day is suggested.

The overlying Quaternary clays of the Coropina, Coronie, and Mara Formations have very high hydraulic resistances. Long-duration pumping tests indicated values from 5 x 104 to more than 2 x 105 days. Given the thickness of the clays, the vertical hydraulic conductivity is about 10-4 m/day (Frederic. R. Harris, 1991e; Terracon Anguilla Ltd, 1994: Mente, 1990a).

5.7 Sand Ridges of the Coropina and Coronie Formations

The superficial Lelydorp sand ridges in the Pleistocene or old coastal plain (Coropina Formation) form a local aquifer with a thickness of 2 to 8 m and contain fresh groundwater. The same holds for the sand ridges of the Holocene or young coastal plain, where brackish groundwater is generally found at only a few meters depth. These sand ridges originally contained brackish groundwater, but have been flushed during the recent Holocene. Groundwater from these sand ridges was traditionally recovered from open dug wells, which are still used in remote places without a public water-supply system, like in Commewijne District. Generally the sand ridges form elongated bodies with widths up to 100 m, which do not permit large scale groundwater exploitation. In some areas bundles of ridges form wide complexes where groundwater can be recovered by long strings of shallow wells or drains in large quantities. The ridges south of Tamanredjo form one of these complexes where groundwater exploration has been carried out (HACAS Technical Memo 1). The sand ridges have been accurately mapped during soil surveys and can be found on the 1:100,000 soil maps of Suriname.Summary hydrogeological assessment (from RTI, 2016)

5.7.1 Data inventory

The hydrogeological assessment was based on an inventory of well data and reports by . Data were provided by Staatsolie and SWM for the study of. Most relevant reports were those of Biswana, 2016, Hanou (1981), Wong (1989) and Groen (2002). It comes as no surprise that the hydrogeologically best documented areas appeared to be the Greater Paramaribo (between the airport and Paramaribo) and the area north of the Saramacca river between Groningen and Calcutta. In these two areas the operations of these organizations are concentrated. In the rest of the coastal plain little additional information from water wells was found apart from the drilling campaigns in the fifties, sixties and seventies of the last century, mostly near the population centers (UNDP/WHO, 1973). Therefore oil exploration wells in the coastal plain were analyzed to complement the existing data and insights. The chloride concentrations, determined on the basis of geophysical logs of these oil wells, are not accurate but provide a continuous depth record of the groundwater salinity. This report is joined effort of the HACAS team, SWM, Staatsolie and the Anton de Kom University of Suriname

5.7.2 Aquifers and formations

Along the northern coast of Suriname a wedge of sediments have been deposited against the Guiana Precambrian basement since the opening of the Atlantic Ocean in the Early Cretaceous. Within this wedge the clastic Tertiary formations contain numerous unconsolidated sand strata with good aquifer properties. The pumping stations of the Suriname Waterleiding Maatschappij draw groundwater from The Oligocene Burnside (or A-sand) formation, the Miocene Coesewijne Formation and the Oligocene Zanderij Formation. Well depths vary from 15 m into the Zanderij formation at Albina to about 250 m into the Coesewijne and Burnside Formations at Nickerie.

Highest hydraulic conductivities and transmissivities are found in the terrestrial sands of the Zanderij and Burnside (or A-sand) formations. In general individual sand strata are discontinuous and separated by clay layers. It proved to be difficult to delineate a specific aquifer within a formations. In addition, the water supply wells have screen lengths varying between 2 and 20 m and only partially penetrate the formations. We therefore mapped the formations rather than the aquifers. The deep Eocene and Paleocene Saramacca Formation was added to this study after analysis of oil well logs learned that the formation holds fresh groundwater.

5.7.3 Groundwater salinity

The potential for groundwater production in the coastal plain depends mainly on the groundwater salinity. The salinity pattern is complex and is the result from consecutive regressions and transgressions. In general a zone of low salinity (< 1000 mg/l of chloride) and in most places fresh (< 250 mg/l of chloride) groundwater is present in the Tertiary succession, although is position varies from place to place. This is best illustrated by Figure 2-4. This figure shows that in the young or

Holocene coastal plain high salinities (> 1000 mg/l) occur in the upper part up to a depth of 50 to 75 m overlying the low salinity zone. These high salinities are the result of downward intrusion of salt water after and during the Holocene transgression. In the old coastal plain and Savannah zone in the south, which were not been affected by the transgression, fresh groundwater is already found at shallow depth. The low salinity zone may extend to a depth of 200 m at Paramaribo) or to 600 m at Nieuw Nickerie. Deeper down the groundwater salinities rise again to form a transition zone to deep marine and connate groundwater. Figure 2-4 and the hydrogeological sections in Appendix 3 show that within the low salinity zones horizontal salinity gradients vary from 10 to 20 mg/km.

The low salinity groundwater in the Tertiary formations is a stagnant body of fossil or paleo groundwater formed during the last glacial when sea level was more than 100 m below the present level (Groen, 2002) There is no modern recharge. Recharge and natural groundwater only takes place in the Savannah zone in the south, where the Pliocene Zanderij formation crops out, and in isolated sand ridges in the coastal plain. This shallow fresh groundwater is locally drained by creeks and artificial drainage systems (Groen, 2002).

5.7.4 Groundwater development and the use maps

All formations including the Saramacca formation contain productive sand layers. Hydraulic conductivities of sand strata vary from 30 to 65 m/day. Clay layers especially the Coropina clay at the surface have high hydraulic resistances. In general wells with capacities of 50 to 100 m3/hr can be constructed for most demand area in the coastal plain. Capacities can be maximized by exploiting more sand layers with long screens or multiple screen sections. The situation for the Zanderij aquifer in the savannah zone and the bordering old coastal plain is different Wells are less productive (< 15 m3/hr), because of the limited aquifer thickness and the small allowance for head drawdown in the wells. This situation applies to the Albina, Moengo/Wonoredjo and Republiek production stations. The maps of the formations in Appendix 2 show extension, depths of the tops of the formations and the zones where the formations only holds brackish groundwater (> 250 mg/l). These brackish zones are found in the northern parts of the coastal plain, though the southern limits of these zones vary strongly. The maps give an overview where fresh groundwater can be expected in each formation and how deep one has to drill to reach the formations.

5.7.5 Urban Nickerie

Salinities in the wells of some urban pumping stations have surpassed the 250 mg/l limit. However the rate of change of salinities is very small since pumping had started. Among these are the pumping stations of Nieuw Nickerie and Nickerie West (Sidoredjo) in Nickerie District, which presently recover brackish water from the Zanderij Formation. In future, we advise to abandon these well fields and develop a new one with a future capacity of 10000 m3/day near the existing pumping stations of Groot Henar and Paradise, east of Nieuw Nickerie, where fresh groundwater of excellent quality is pumped in small quantities from the Coesewijne Formation (< 3000 m3/day). Another possibility is a new well field in the Europolders, south of Nieuw Nickerie, where the Zanderij aquifer contains fresh groundwater. Given the expected production groundwater water will attracted from a more or less circular capture zone around the stations with a maximum radius of about 2 km. As chloride contents are below 100 mg/l and salinity gradients are in the order of 20 mg/km fresh groundwater production is assured until 2040. Exploratory drilling and detailed design using groundwater modelling is required for this new well field.

5.7.6 Urban or Greater Paramaribo

In Paramaribo the pumping stations WKPlein, Leysweg, Flora, Tourtonne and Blauwgrond abstract groundwater from the Burnside (or A-sand) Formation with salinities over 250 mg/l. Overall water quality remains within acceptable limits, as this water is mixed with fresh groundwater from nearby stations south and west of Paramaribo (Greater Paramaribo). Total production in Greater Paramaribo now is about 120000 m3/day. The expected increase in water demand in 2040 by another 120000 m3/day can be secured by 5 large well fields south of Paramaribo (Zanderij, Coesewijne en Burnside aquifers). These 5 well fields have been identified in this study and tested with the new GMS groundwater model. The low groundwater salinities of these new stations can be maintained up to 2040 lead to a further decrease in overall salinity, even though salinities of the existing stations will continue to increase further. Exploratory drilling and detailed design using groundwater modelling of these new well fields are required.

5.7.7 Rural stations in Nickerie, Coronie and Saramacca Districts

In the remaining rural pumping stations of Nickerie, Coronie and Saramacca Districts fresh groundwater is abstracted in small quantities (< 3000 m3/day) from the A-sand (Wageningen), Zanderij (Totness) and Coesewijne formations (Tijgerkreek, Kampong Baroe and Groningen). We do not expect that salinities of the pumped aquifers of these stations will rise above the acceptable limit of 250 mg/l before 2040, for the same reasons as mentioned above (low salinity gradients and small capture zones). We conclude that production at the existing stations can continue or can even be expanded without further studies.

5.7.8 Commewijne District

In Commewijne District fresh groundwater is not as abundant as in other districts, while many settlements with growing population still do not have piped water supply (Tamanredjo). On top of the present production of 5000 m3/day at Meerzorg an additional 12000 is required. The Burnside formation at Meerzorg at the western end of the district is already overexploited. Options for new fresh groundwater sources are the Coesewijne Formation north of the Commewijne River and at Morico near the far eastern border, about 30 km from Tamanredjo. Also groundwater could be abstracted from the shallow sand ridges south of Tamanredjo. Development of all these sources is relatively costly and technically complicated. The Morico option seems to be the best option. Apart from these fresh groundwater sources, also surface water and brackish groundwater are viable options, but probably more costly. For Morico additional geophysical surveys and exploratory drilling are recommended.

5.7.9 Marowijne District

In Marowijne district settlements and pumping stations are located in the old coastal plain close to the savannah zone. Groundwater is drawn in small quantities from the shallow and thin layer of Zanderij sands at Moengo/Wonoredjo and Albina/ Marijkedorp. Individual well capacities are not high, as explained above. Limited expansion of the stations is feasible, but geophysical surveys are required to define the variable depth and thickness of the Zanderij sands and the overlying Coropina clays. The covering clay layer plays an important role with respect to groundwater protection against contamination. Though groundwater is generally fresh close to the savannah, geophysics are also useful in order to avoid brackish groundwater pockets, which may have entered the Zanderij formation below creeks filled with Holocene Mara deposits.

5.7.10 Climate change

Climate change has limited impacts on the groundwater resources. Most exploited aquifers are deep, confined and contain fossil groundwater, which do not receive modern recharge. Only the phreatic groundwater in the savannah and local sand ridges is recharged by infiltrating rainwater. Recharge of this shallow groundwater, presently estimated at 350 to 500 mm/yr, will drastically decline because of reduction of rainfall, increase of overland flow during the more frequent rainstorms and increase of evapotranspiration. This will lead to declining groundwater levels and possibly attraction of brackish water. Effects may become noticeable after 2040, but only around the pumping stations at Republiek, Moengo/Wonoredjo and Albina.

Sea level rise leads to salt intrusion in the major rivers, which restricts the possibilities of river water intake of bank water infiltration by wells. Also groundwater levels will rise in the coastal plain in general. In combination with higher frequency of rainstorms this may lead to more frequent waterlogging. Additional measures may be needed to safeguard the infrastructure and functioning of the pumping stations in the coastal plain.

.

6 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	:	Report on Water Balances and Aquifers in Suriname
File/ Code	:	IS-471
Acronym	:	ARADIS project
Author	:	J. Groen
Contributions	:	R. Wong Loi Sing, M. Kasankarijo, V. Ramcharan
Authorisation	:	R. Patandin
Date	:	May 08, 2025

7 Appendices

1. Bibliography
2. Hydrogeological Maps
3. Hydrogeological Sections (from RTI, 2016)