Sustainable Groundwater Development in Trinidad and Tobago: Issues and Challenges

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ABSTRACT
This hydrogeological study was undertaken to provide a basis to understand the groundwater flow systems and their sustainable yield to plan and manage its development as a reliable source of water supply in Trinidad. The sustainability analysis revealed that most of the major aquifers are being overexploited resulting in steady decline in groundwater levels. In the coastal aquifers this decline has caused seawater intrusion. Most of the aquifers in Trinidad were also found to be vulnerable due to the absence of thick overlying aquitards. The potential for the invasion of deep bedrock brines were also identified in areas of intense groundwater abstraction. Based on this investigation, it was recommended to abstain from additional development of groundwater resources. A monitoring program that integrates both the physical and biological system at watershed scales were proposed to define sustainability of the aquifers. As an interim measure, suggestions were made to explore the feasibility of artificial recharge and brackish water development in specific areas.

RÉSUMÉ
Cette étude de hydrogeological a été entreprise de fournir une base pour comprendre les systèmes de flux d'eau souterraine et leur rendement viable pour planifier et gérer son développement comme une source fiable de provision d'eau dans Ile de la Trinité. L'analyse de durabilité a révélé que la plupart des aquifères majeurs sont overexploited ont pour résultat le déclin constant dans les niveaux d'eau souterraine. Dans les aquifères côtiers que ce déclin a causé de l'intrusion d'eau de mer. La plupart des aquifères dans Ile de la Trinité ont été aussi trouvés pour être vulnérables en raison de l'absence de recouvrir aquitards épais. Le potentiel pour l'invasion de saumures de fondement profondes a été aussi identifié dans les secteurs d'abstraction d'eau souterraine intense. Fondé sur cette investigation, il a été recommandé pour s'abstenir du développement supplémentaire de ressources d'eau souterraine. Un programme moniteur qui intègre le système physique et biologique aux échelles de tournant a été proposé de définir la durabilité des aquifères. Comme une mesure provisoire, les suggestions ont été faites explorer la possibilité d'artificiel recharge de le et le développement d'eau saumâtre dans les secteurs spécifiques.

1 INTRODUCTION

The Government of the Republic of Trinidad and Tobago has launched a major initiative to transform the nation into developed country status by the year 2020. Fundamental to the government's 20/20 vision is a major investment in infrastructure and the environment for the provision of a reliable water supply and waste water treatment facilities. GENIVAR was retained by the Water and Sewage Authority of Trinidad and Tobago (WASA) to prepare a Water and Sewer Servicing Master Plan (MP) for the Nation in 2006. This groundwater study was undertaken as part of the MP, to assess groundwater as a source of sustainable water supply. The island of Trinidad is approximately 70 km long and 40 km wide and is considered the southern most island of the Caribbean chain. The island comprises of folded and faulted sediments and low-grade metamorphic rocks, the complexity of which is reflected in the regional aquifer/aquitard systems. In general, locally two broad concepts are used in describing the aquifer systems: traditional aquifers and megawatersheds. This study was undertaken to provide guidance for the sustainable development of groundwater resources in Trinidad and discusses the issues and challenges in moving forward.

1.1 Physical Setting

1.1.1 Location

The twin island Republic of Trinidad and Tobago is the southernmost Caribbean nation, located off the northeast coast of Venezuela. Trinidad is located between 10° 00′ and 10° 50′ North Latitude and 60° 55′ and 61° 56′ West Longitude. (Figure 1). It has a total area of 4828 km^2 with approximate dimensions of 50 km east-west and 80 km north-south. The island is bounded on the north by the Caribbean Sea; on the west by the Gulf of Paria; on the east by the Atlantic Ocean and on the south by the Columbus Channel.

1.1.2 Climate

The climate in Trinidad is tropical, with two major seasons. Generally the dry season is during the months of January to May and wet season is during the months of June to December. The average annual temperature is 26°C with diurnal variations of less than 7°C (DHV Consultants BV 1999). The average annual rainfall in Trinidad is approximately 2000 millimetres, with over 78% of the precipitation occurring during the wet season (Water Resources Agency 2001, Bisson and Lehr 2004).

In addition to temporal variation (dry and wet seasons), rainfall is spatially variable. Most of the rainfall is concentrated in the northeast portion of Trinidad, where up to 3048 millimetres of rainfall occurs (Agard 2004). The evaporation rate is very high, accounting for up to 60% of the total rainfall received in some areas (Water Resources Agency 2001).

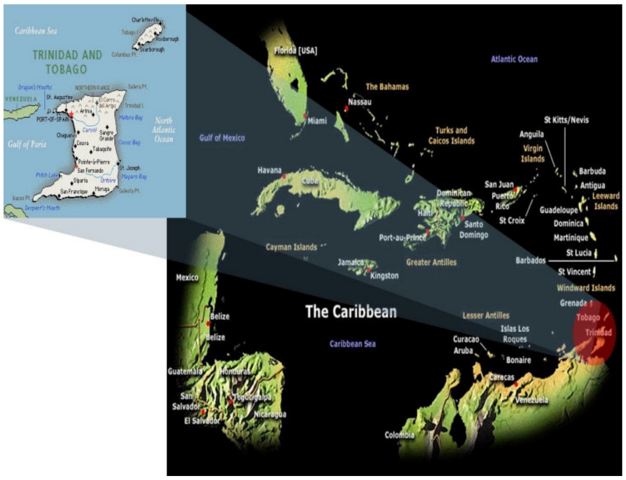

Figure 1. Location of Trinidad and Tobago.

1.1.3 Physiography

There are 5 main physiographic features in Trinidad: the Northern Range, the Northern Basin, the Central Range, the Southern Basin and the Southern Range.

The Northern Range is the main mountain range in the north, stretching east-west across the entire width of Trinidad with a maximum elevation of about 940 meters above mean sea level. This range has a width of 16 km and is characterized by rugged topography with very steep slopes. It is the headwaters for 2 major rivers: the Caroni river and the Oropouche River that both flow down the southern slope. The Caroni River drains the western part of the Northern Range and the Oropouche River the eastern part. The main tributaries of the Caroni River are San Juan River, St. Joseph River, Tacarigua River, Arouca River, Oropuna River, Guanapo River, El Mamo River and Aripo River.

The Northern Basin is located between the Northern Range and Central Range. It consists of undulating alluvial materials with a maximum elevation of 60 meters above mean sea level. The Northern Basin comprises of the flood plains and alluvial fans of the North Oropouche and Caroni rivers. The Oropouche Swamp on the east and Caroni swamp on the west are two important wetlands in the Basin.

The Central Range of Trinidad consists of rounded hills and ridges that trend across the island from the south-west to north-east. The feature is 56 km in length and varies in width from 8 to 15 kilometres. The northern slope in the central range is steeper than the southern slope. It has a maximum height of 307 meter above mean sea level at Tamana Hill. The Central Range is drained by the Oropouche River to the east, by the Caroni River to the west, by the Guaracara and Navet Rivers to the southwest and by the Poole River to the southeast (DHV Consultant BV 1999).

The Southern Basin is located between the Central Range and the Southern Range, and consists of undulating alluvial materials with an elevation of less than 40 meters above mean sea level. The Southern Basin comprises of the flood plains of the Nariva, Ortorie and South Oropouche river systems. The Nariva Swamp, which is the largest swamp of the island, is located in the eastern part of the Southern Basin.

The Southern Range is characterized by discontinuous low hills that trend across the island from the south-west to the north-east, with highest elevation at 303 meters above mean sea level in the Trinity Hills. The Southern Range is drained by the South Oropouche River to the west, by the Ortoire River to the east, and by Moruga River to the south.

1.1.4 Hydrology

The Water Resources Agency, a division of the Water and Sewage Authority is responsible for the nation's water resources management. In order to carry out its mandate, the Agency has divided Trinidad into nine hydrometric areas. These hydrometric areas are major hydrologic units, which correspond with surface water divides of watersheds (Figure 2). These hydrometric areas can be subdivided into fifty-four subwatersheds.

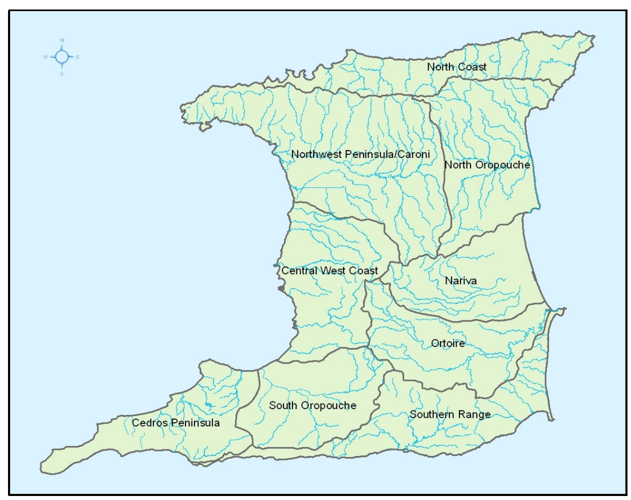

Figure 2. Drainage Map of Trinidad

1.2 Geology and Hydrogeology

1.2.1 Geology

The island of Trinidad lies within a 200 km wide tectonic plate boundary zone between the Caribbean Plate and the South American Plate. The geology of the island is dominated by rocks of sedimentary origin. The island consists of three ranges of mountains and hills, including the Northern, Central and Southern Ranges. Two deep sedimentary basins, including the Northern Basin and

Southern Basin, separate the mountainous areas (Figure 3).

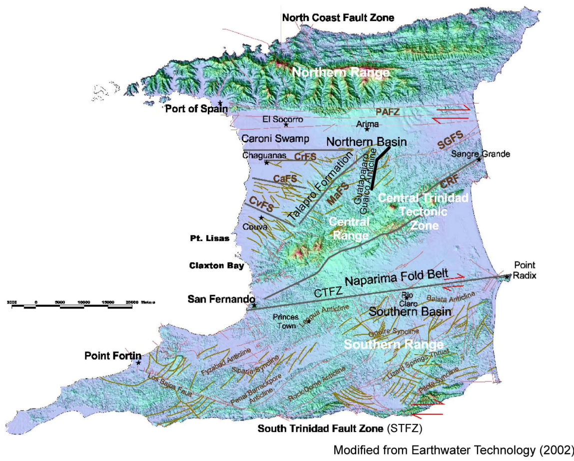

Figure 3. Physiography and Structural Geology of Trinidad

The mountains of the Northern Range consist mostly of metamorphic rocks, which provide the parent materials for the colluvial and alluvial deposits in the valleys. To the south, the mountainous area gives way to a series of converging alluvial fans and more flat lying alluvial and marine sedimentary deposits of the Northern Basin. The basin abuts the rounded hill ridges of the Central Range, which consist of sedimentary deposits ranging from limestone to sands and shales. The Southern Basin is a deep sedimentary basin that is a source of hydrocarbon deposits. The Southern Range consists of clay-rich, deep marine sediments in the anticline structures, while the synclinal structures are dominated by sandy deposits.

1.2.2 Hydrogeology

The hydrogeology of Trinidad has been investigated under two broad concepts: traditional aquifers and megawatersheds. The traditional aquifer system in Trinidad comprises of four major aquifer systems and seven minor aquifers. The major aquifer systems of Trinidad are: 1) Northwest Peninsula Gravels; 2) Northern Gravels; 3) Central Sands; and, 4) Southern Sands. The minor aquifers are: 1) Coastal Alluvials; 2) Valley Alluvials; 3) Limestone; 4) Caroni Surface Gravels; 5) Mayaro Sandstone; 6) Goudron Sandstone; and, 7) Gros Morne Sandstone (Figure 4).

The term Megawatershed is used to refer to deep-seated sub-surface groundwater systems that may consist of gravel, fracture-hosted (fed) bedrock or sedimentary structures, which are integrated in terms of recharge, discharge, storage, circulation and containment. They may not coincide with surface topographic divides, and may receive recharge from areas of several surface watersheds. A recent investigation by Earthwater Technology (2002) identified 6 Megawatersheds and 25 aquifer systems throughout Trinidad that could be considered as potential groundwater resources, with an estimated production rates of approximately 65 million m^3/year. The expected development of groundwater resources has not yet occurred in this system.

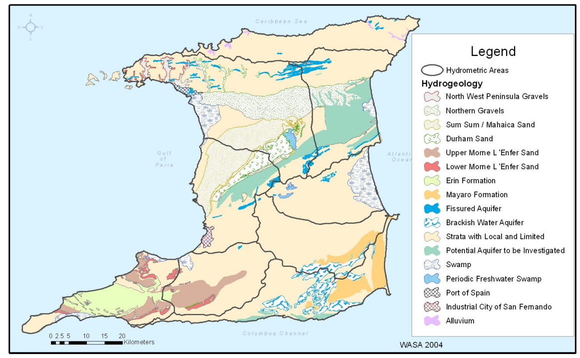

Figure 4. Hydrogeological Map of Trinidad

2 METHODS

A summary of tasks associated with completing this work included the following:

- Collection and review of water supply systems information, as it relates to groundwater wells and aquifer characteristics;
- Visit all groundwater supply installations;
- Appraise and evaluate aquifers currently being utilized in terms of recharge and discharge mechanisms, current and potential abstraction capacity, water quality, and contamination risks;

3 RESULTS AND DISCUSSION

3.1 Hydrogeology

The groundwater supply sources in Trinidad are grouped according to their location in major aquifer units. A comparison of the most recent production rates to the expected safe yield for each of the major aquifers provides an indication of the sustainability of each of these groundwater supply sources (Table 1). Safe yield as presented in the background reports was defined as the annual recharge of the aquifers. Recharge was estimated using a standard water balance, where recharge was equal to rainfall less surface runoff and evapotranspiration. A groundwater utilization map based on safe yield is presented in Figure 5. More detailed figures of groundwater production, including subaquifers, can be found in the Review of Groundwater Resources Part I: Trinidad (GENIVAR, 2007).

3.2 Geochemistry

Water quality information was available for 391 groundwater samples of different production and observation wells in Trinidad between 1970 and 2001. From this dataset, only 48 samples satisfied a charge balance of major anions and cations. These 48 samples were used to assess the geochemistry of the major and minor aquifers.

According to our assessment, groundwater in the Northwest Peninsula Gravels aquifer system is dominantly of calcium bicarbonate ($Ca\text{-}HCO_3$) type, with minor occurrences of calcium chloride (Ca-Cl) type water in several aquifers. The groundwater in the Northern Gravels aquifer system is dominantly of calcium bicarbonate type ($Ca\text{-}HCO_3$), with some sodium bicarbonate type ($Na\text{-}HCO_3$) water found in certain aquifers. The groundwater in the Central Sands is a combination of calcium bicarbonate ($Ca\text{-}HCO_3$) type, magnesium bicarbonate ($Mg\text{-}HCO_3$) type, and sodium bicarbonate type ($Na\text{-}HCO_3$). Samples from the Southern Sands aquifers exhibited groundwater of magnesium bicarbonate ($Mg\text{-}HCO_3$) type and sodium bicarbonate type ($Na\text{-}HCO_3$). The groundwater signature from minor aquifers ranges from calcium sulphate ($Ca\text{-}SO_4$) type in limestone to sodium bicarbonate ($Na\text{-}HCO_3$) type near the coast. These findings suggest the chemistry of water shows distinct characteristics at specific locations.

Table 1. Groundwater Production in Trinidad.

Aquifer	# Wells	Safe Yield (m^3/d)[1]	Avg. Rate (m^3/d)[1]	% Safe Yield
NW Peninsula Gravels	59	74,000	79,919	108
Northern Gravels	79	101,410	85,686	84
Central Sands	37	25,540	33,491	131
Southern Sands	105	60,860	35,473	58
Coastal Alluvials	3	45,340	1,381	3
Valley Alluvials	9	13,930	4,470	32
Limestone	12	10,680	22,263	208
Southeast Sandstones[2]	11	42,800	4,295	10
Totals	315	374,560	266,978	71

[1]The number of production wells described in this table includes private wells

[2]These are not formally grouped as a major aquifer. They include the Mayaro Sandstone, Gros Morne Sandstone and Gourdon Sandstone.

The results of the present study, as well as information provided by the Water Resources Agency (2001), indicates that the natural groundwater quality in Trinidad is generally fresh and falls within the limits set for potable water by the World Health Organization (WHO), except for the iron in most areas. However, most of the aquifers are very vulnerable due to the absence of thick overlying aquitard layers. Potential sources of pollutants to the aquifers are: leaching from hazardous waste dumps; underground fuel storage tanks; untreated sewage; industrial activities; pit latrines and septic tanks; and, agricultural activities. Saline water intrusion from oceans as well as intrusion of brines from deeper bedrock formations can also be considered an issue in areas of intense groundwater abstraction and petroleum exploration and development.

3.3 Well Condition Assessment

Well condition assessments were performed on all 172 production wells, as well a number of observation and abandoned wells, in Trinidad. A Water and Sewage Authority operator escorted the field team and answered questions relating to the wells. Major issues identified during the well condition assessment were mostly related to the proximity of the wells to surface water bodies and access to the wellheads.

Many of the production wells are located adjacent to surface water bodies, or in their floodplains. This is a concern as these wells may be considered to be groundwater under the direct influence of surface water (GUDI), and therefore may require additional treatment to ensure safe drinking water quality. In addition, compromised surface seals around the wells, such as cracked or absent concrete pads, damaged well caps, or holes in casings, increase the potential for entry of contaminants into the aquifer. This potential is increased further in locations where site security was found to be a concern, especially in areas where fencing and gates were either not present or significantly damaged, allowing access of unauthorized persons.

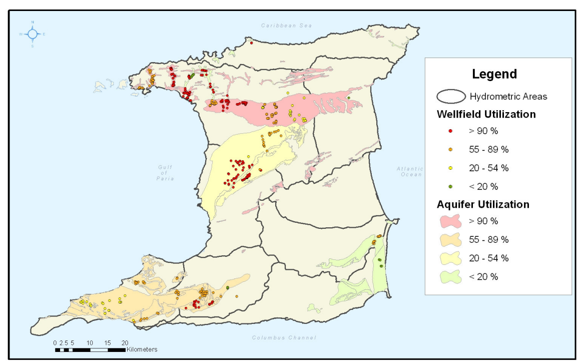

Figure 5. Groundwater Utilization Map for Trinidad

3.3.1 Potential Water Quality Threats Assessment

During the site visits to evaluate the existing condition of the wells, potential threats to water quality were assessed through observation of land uses and site conditions around the wellhead. A preliminary evaluation of potential contaminant sources can be inferred as follows:

- Residential areas - potential for vandalism;
- Rural residential areas - potential for contamination by septic systems;
- Commercial and Industrial areas - potential for commercial and industrial pollution (i.e. solvents, hydrocarbons);
- Agricultural areas - potential for contamination by pesticides, herbicides, fertilizers;
- Livestock areas - potential for contamination by animal feces;

- Oil producing areas - potential for contamination by hydrocarbons and deep brines;
- Other areas, including power stations, transformers, gas stations - potential for contamination by hydrocarbons and fuel tanks;
- Other wells on site - provide preferential conduits for contamination; and
- Surface water - Wells in close proximity to surface water are generally considered to be under the influence of surface water until proven otherwise (termed “GUDI” in Ontario). This is a major issue as under GUDI conditions, groundwater is treated as equivalent to surface water to safeguard the potable water supply.

3.4 Groundwater Resource Evaluation

Previous hydrogeological studies carried out between 1999 and 2002 estimated safe yields of 101×10^6, 174×10^6 and 549×10^6 m^3/year, respectively, for all major aquifers in Trinidad. These values are significantly different from each other. The value of 549×10^6 m^3/year was estimated under the concept of megawatersheds. However, despite a high value of estimated available groundwater (549×10^6 m^3/year) reported by Earthwater Technology (2002) under this concept, the expected development of groundwater resources has not yet occurred in the megawatershed aquifers. It is believed that the estimate made by the Water Resources Agency (1999/2000) of the safe yield (174×10^6 m^3/year) can be considered a defendable concept for identifying additional groundwater sources in the short-term, since their quantification involved the safe yield and optimal yield, examination of long-term water levels, as well as historical information on water quality. However, no details on each of these subjects were available during the preparation of the Water and Wastewater Master Plan assignment.

Groundwater production data from 1995 through 2006 indicate that average daily groundwater abstraction rates from WASA wells from 1995 through 2000 remained in the range of 180 to 210 ML/day. This increased to over 220 ML/d in 2001, and has been in the range of 240 ML/d in 2005 and 2006. The greatest increases in recent years in groundwater production have occurred in the following wellfields: Carapo, Four Roads, Las Lomas, Moka, Paramin, Sangre Grande, and Tucker Valley. It is also evident that recent groundwater takings have declined in some of the wellfields, including Carlsen Field, Coora/Siparia, Freeport/Freeport-Todd, King George V Park, and Penal.

In addition to WASA owned and operated wells, there are numerous private wells in operation. Between 1999 and 2006, the average daily groundwater abstraction rates from these wells remained constant around 27 ML/d. Prior to 1999, average daily groundwater abstraction rates from private wells totalled less than 20 ML/d.

Production data for private and WASA wells indicate that the average daily groundwater abstraction rate in Trinidad totals approximately 267 ML/d.

3.5 Sustainable Development

Sustainable Development of Groundwater Resources has been identified as one of the subjects of prime importance in Trinidad. Sustainable development can be planned through a scientific understanding of the water balance in watersheds and eco-systems it supports, and the potential sources and release of natural and anthropogenic contamination.

A review of existing monitoring information obtained for Trinidad suggests lack of an integrated approach in data gathering and thus, the uncertainty in producing sound scientifically defendable sustainable use volumes for the country.

3.5.1 Monitoring

It has been determined that water balance studies in the past were based on limited monitoring information that integrated the different components of the eco-system, i.e. groundwater, surface water and the flora and fauna it supports. Sustainable water taking involves a sensitive balance between water supply and the preservation of the natural functions of the eco-systems it supports.

Water quality also plays a major role in defining sustainable yield. Water quality degradation can occur in aquifers both from natural and anthropogenic sources. The geology of Trinidad is complex due to the active crustal movements in the geologic past. These tectonic events have shaped the country into mountains and basins resulting in complex geology and aquifer systems. Overdraft of these aquifers may lead to contamination from potential intrusion of seawater and deep-seated brines. In addition, lack of land use planning can lead to potential introduction of man-made contaminants. In understanding sustainable development, these aspects need to be assessed and, if possible, quantified to develop sustainable water supply. Major issues identified in Trinidad within the last few decades are over exploitation of the aquifer in the north and centre with the intrusion of sea water in the northwest coast, subsurface presence of oil and gas in the south west posing major challenges in groundwater development, and the presence of brackish water in the southeast.

3.5.2 Integrated Assessment

Determining sustainable yield in aquifers is a challenge that needs to be addressed through integrated watershed understanding, which includes understanding the surface watersheds, the aquifer/aquitard systems and the water balance through an integrated study approach. In addition, this study has to be complimented by land use assessment and its potential influence to water treatment and supply. Once the sustainable yields are understood, additional demand should be met through alternative solutions such as Aquifer Storage Recovery (ASR), use of brackish water could be utilized.

4 CONCLUSIONS

The following conclusions can be made from this study:

- Sustainable development of groundwater resources in Trinidad needs to be planned on the basis of scientific studies, which integrate the physical and the natural ecosystem as well as take into consideration land use planning issues.

- In the northwest part of Trinidad, seawater intrusion has occurred in coastal aquifers and raises the importance of modelling studies in order to quantify the processes.
- The existing water quality data also suggests areas of chloride impact associated with the potential mobilization of saltwater in the oil and gas field areas of the southwest.
- During the dry season, ASR can be a viable option in meeting part of the demand for water supply.

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REFERENCES

Agard, J. (2004). Report of an assessment of the Northern Range of Trinidad, Trinidad and Tobago.

de Verteuil L., Stawicki A. W, Hoag R. B., Bisson R. A., Ingari J. C., Maharaj U. S. and Mulchansingh K. (2001). Sedimentary Megawatershed Delineation: The Role of Genetic Sequence Stratigraphy and Complex Fault System Analysis in Groundwater Resources Assessment in Trinidad. CWWA 10th annual Conference & Exhibition 1st – 5th October 2001, in Collaboration with Water Authority – Cayman.

Bisson, Robert A. and Lehr, Jay H. Modern(2004). Modern Groundwater Exploration Discovering New Water Resources in Consolidated Rocks Using Innovative Hydrogeologic Concepts, Exploration, Drilling, Aquifer Testing, and Management Methods, John Wiley & Sons, Inc

DHV Consultants BV, Delft Hydraulics and Lee Young & Partners (1999). Water Resources Management Strategy for Trinidad and Tobago, Final Report. The Government of Trinidad and Tobago, Ministry of Planning and Development.

Dillon Limited, Consulting Engineers (1970). Trinidad Water Resources Survey, Final Report, 1969. (with 1:50,000 groundwater map of Trinidad showing limits of 1:10,000 mapping of Aquifers) March 1970).

Earthwater Technology Trinidad & Tobago LLC. (2002). Hydrogeological reassessment of Trinidad, Volumes I, II, III and IV.

Fetter, C. W. 2001. Applied Hydrogeology, Prentice-Hall, Inc.

Lennox Petroleum - Earthwater Technology International (2002). Tobago Groundwater Water Assessment and Well Development Programme. Part A – Hydrogeological Assessment. The Water and Sewage Authority of Trinidad and Tobago.

Lloyd, J. W. and Heathcote, J. A (1985). Natural Inorganic Hydrochemistry in Relation to Groundwater, Clarendon Press, Oxford.

Maharaj, UTAM (2004). Unprecedented Groundwater Discoveries in a small Island Developing State (SIDS). In: Modern Groundwater Exploration Discovering New Water Resources in Consolidated Rocks Using Innovative Hydrogeologic Concepts, Exploration, Drilling, Aquifer Testing, and Management Methods, by Robert A. Bisson and Jay H. Lehr, John Wiley & Sons, Inc

Metcalf & Eddy International Inc. (1970). Water Study Trinidad and Tobago.

Water Resources Agency (1989). Hydrogeology map of Trinidad.

Water Resources Agency (1999/2000). Groundwater Master Plan 1999/2000

Water Resources Agency (2001). National Report on Integrating the Management of Watershed and Coastal Areas in Trinidad and Tobago. Water Resources Agency.

Water Resources Agency (2004a). Water Resources Assessment of La Brea / Point Fortin Region.

Water Resources Agency (2006). Presentation on recommended sources for water supply development in Trinidad & Tobago.

Water Resources Agency (WASA, 2004). Data

Water Resources Agency (WASA, 2007). Data