World Water Day 2014
Water and Energy

An evaluation of the declining groundwater levels of the coastal aquifers of Guyana

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Introduction

- Freshwater accounts for 2.5% global water reserve
  - ~ 70% in ice capsand snow cover
  - < 1% in lakes and rivers
  - ~ 29% in groundwater sources

- Global freshwater demand has tripled since1950

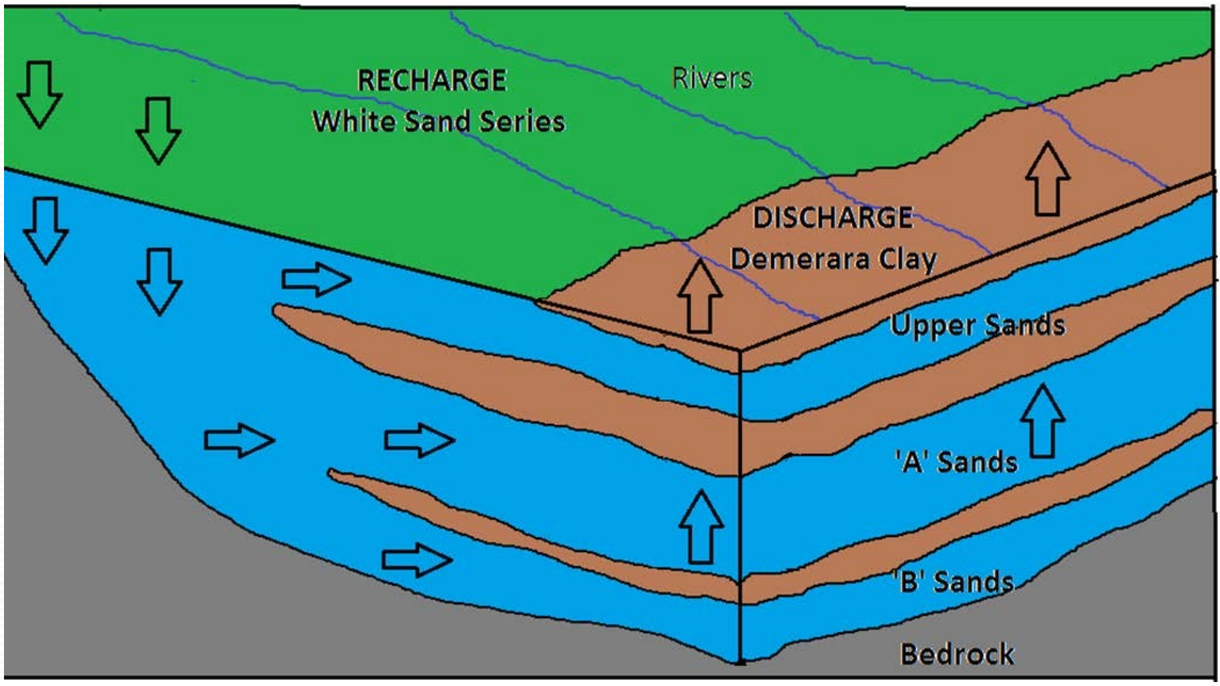
- Global groundwater use– food and agriculture

Introduction

- 23% of world's population lives within 1000 kmof the coast within an area less than 100 m above sea level
- Global population increases, locally this has not been the case
- Agriculture is also increasing and thus demand
- Reported 20 m decline in groundwater levels along coast

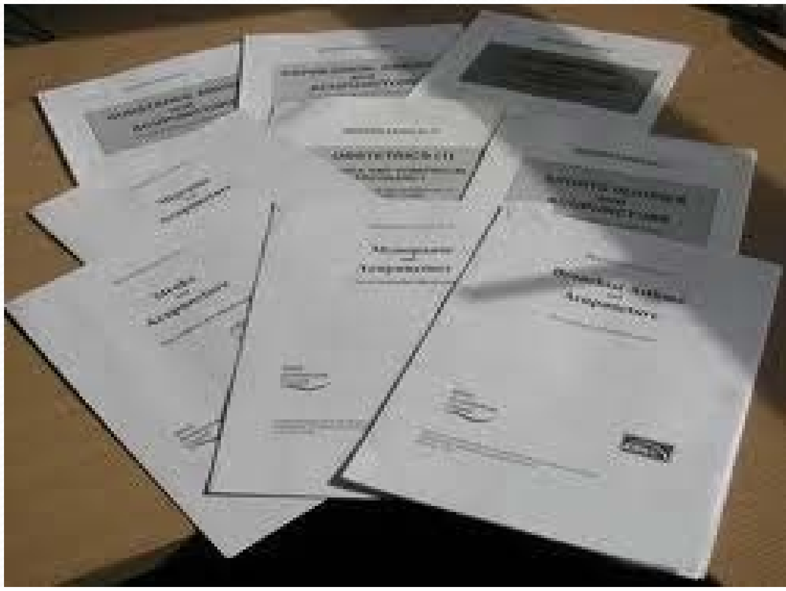
INTRODUCTION

- The coastal aquifer
  - Demerara Clay + Coropina Clay formation
  - Upper Sands
  - Intermediate Clay
  - 'A' Sands
  - Alternating Clay
  - 'B' Sands



INTRODUCTION

- Various studies completed
  - Worts, 1963
  - Bassier & Potter, 1972
  - Geer, 1980
  - Arad, 1983
  - Sir William Halcrow & Partners, 1993
  - Harley, 1996
  - Mercado, 1997
  - US Army Corps of Engineers, 1998
  - Osawa, 2010



Introduction

- Climate Change
  - Evidence of climate change recognized
  - But few studies one to address the impacts of Climate Change on groundwater sources
    - Large storage + long residence time
    - Difficult to assess impacts
    - Reacts more slowly to climatic fluctuations
  - Effects equally variable as parameters

INTRODUCTION

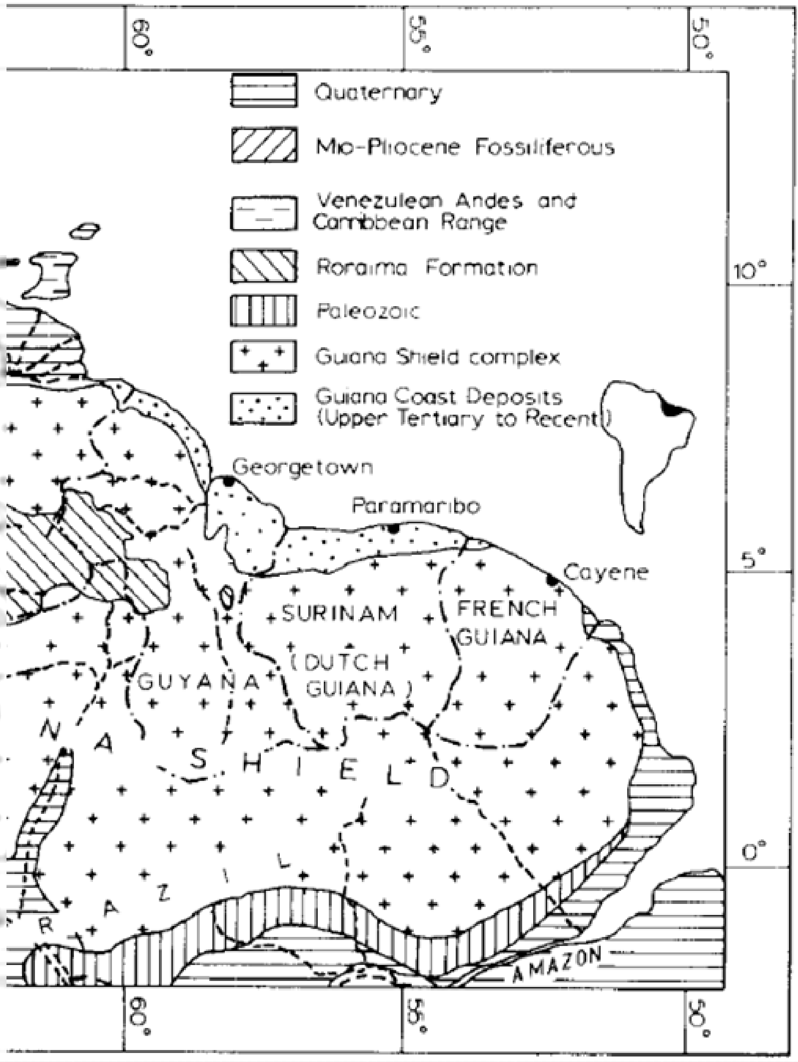
- Recharge
  - Difficult to estimate given varying parameters and geological conditions, local hydrology, land use
  - Timing of recharge critical
  - 15% reduction of precipitation with nochange in temperature would result in a reduction of recharge between 40 – 50%
- Abstraction
  - Increases in abstraction inevitably results in a decline in groundwatervalue
  - Decrease in groundwater levels consistent with population increase during the second half of the twentiethcentury

OBJECTIVES

- To generate a conceptual model of the coastal aquifer
- To evaluate the relationship between rainfall and groundwater levels
- To estimate recharge rate per year for the coastal aquifers
- To evaluate abstraction rates and the impact on groundwater levels

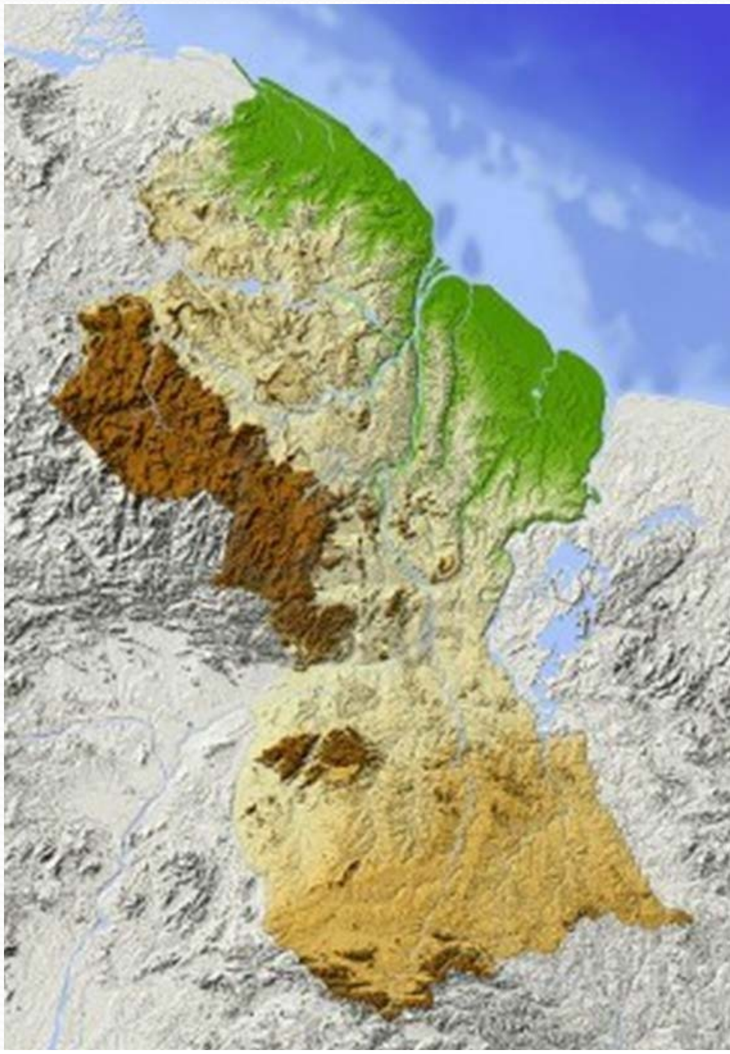
GEOLOGICAL SETTING

- Bordered by Surname, Brazil, and Venezuela
- Geologically part of Guiana Shield
- Terrigenous fluvially transported sediment including sand deposits
- Sandy coast of Guyana a result of debouching of Guiana Shield rivers
- Clays from Pleistocene to Holocene period



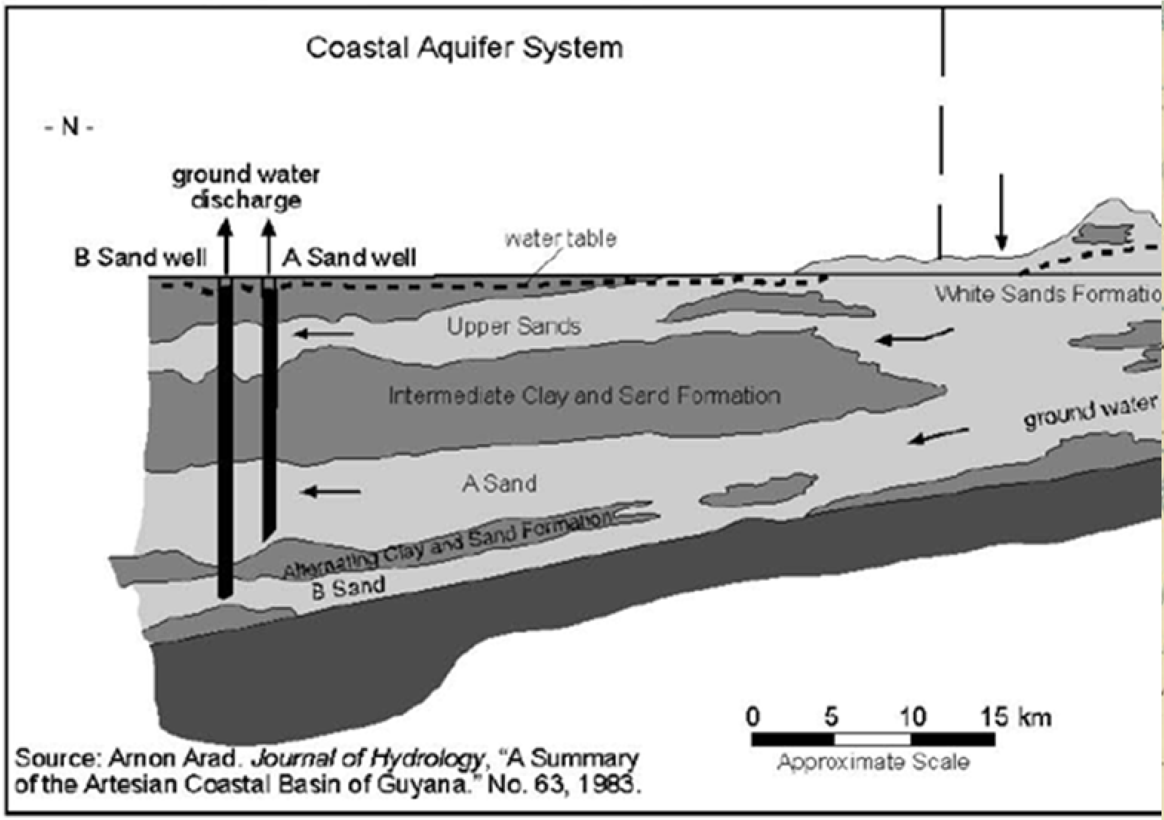
Geological Setting

- Physiographic features
  - Continental Shelf
  - Coastal plain
  - Highlands
  - Major rivers
    - Essequibo River
    - Demerara River
    - Berbice River
    - Corentyne River
    - Pomeroon River



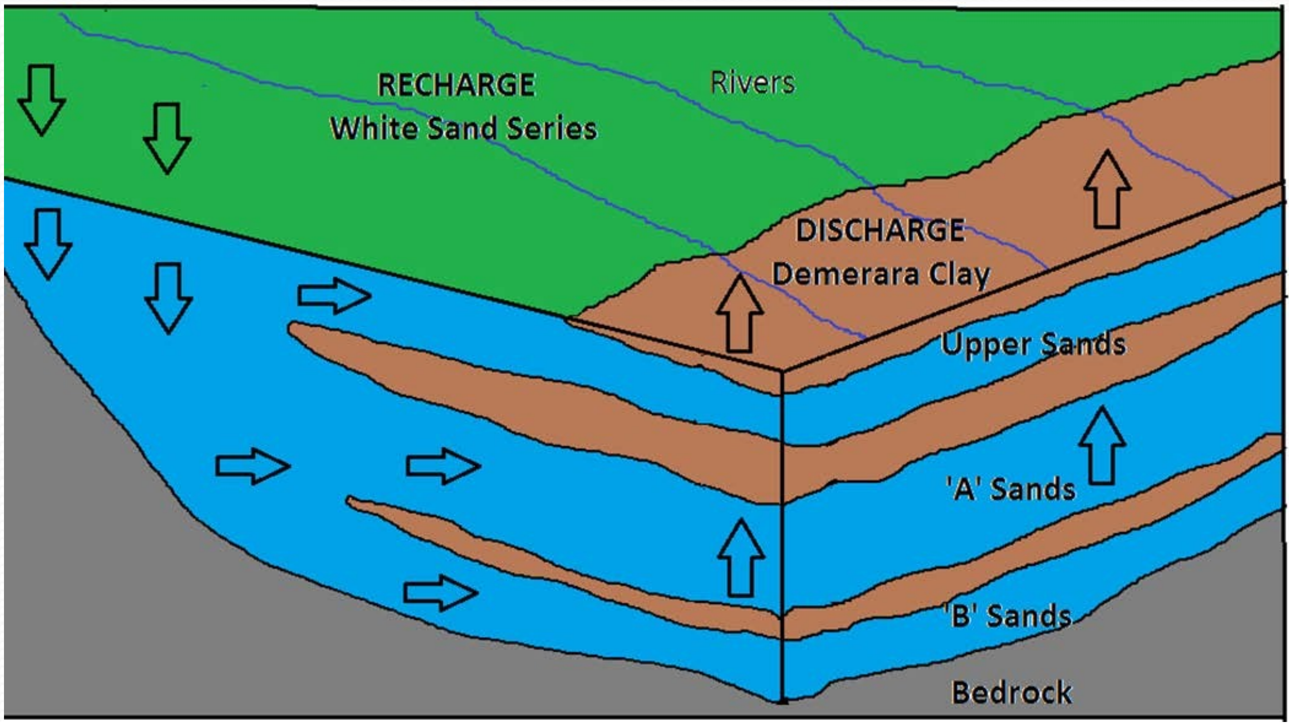
GEOLOGICAL SETTING

- Aquifer layers



Hydrology and Hydrogeology

- Tropical climate with two wet and dry seasons
- Annual precipitation exceeding 2000 mm year-1
- Average daily temperature between 25 and 27°C
- Recharge area 13,000 km²
- Rainfall within recharge area >2,500 mm year-1



Hydrology and Hydrogeology

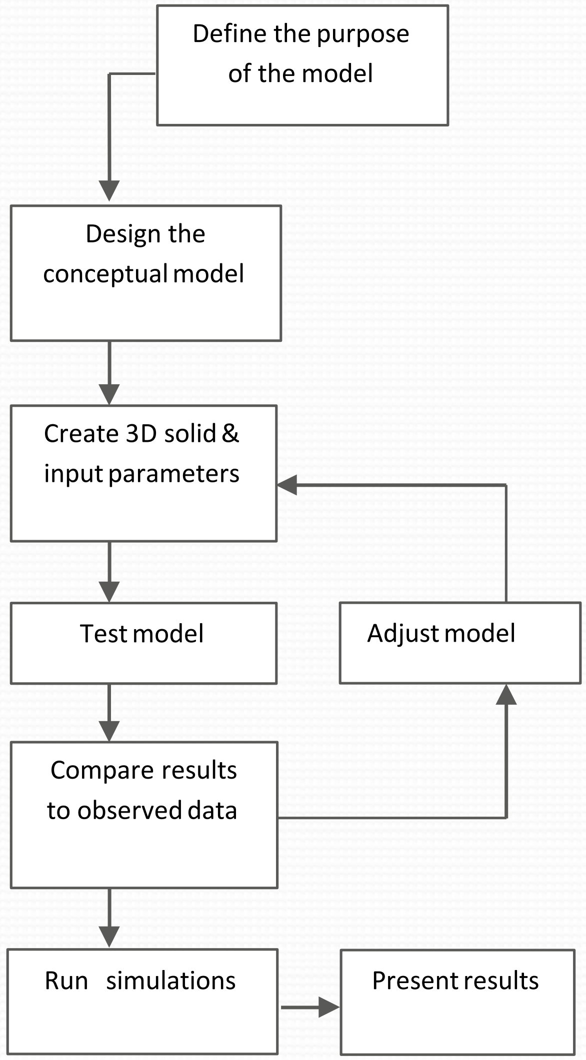
- Connectivity to Atlantic Ocean and major rivers within the aquifer basin
- > 200 wells within the 'A' Sands aquifer
- Head in 'A' Sands higher than in Upper Sands
- Lowest aquifer highest quality
- Transmissivity – 2,250 $m^2 d^{-1}$
- Conductivity – 75 $m d^{-1}$

METHODOLOGY

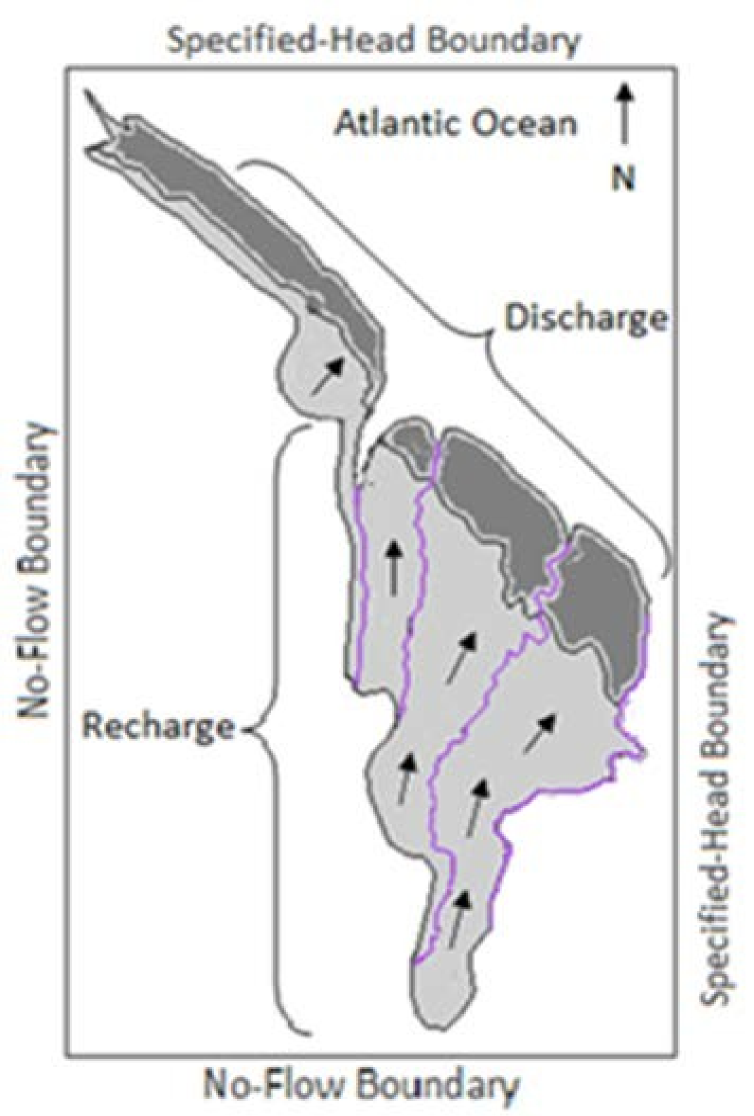
- 40 year period underreview (1970 – 2010)
- Groundwater Modelling Software (GMS) MODFLOW
- European Centre for Medium-Range Weather Forecasting (ECMWF) Re-Analysis-40 and Interim
- Abstraction and groundwater level data obtained from Guyana Water Incorporated (GWI)
- Geographical Information System (GIS) - ArcGIS 10
- Quality control of data

METHODOLOGY

- Conceptual model
  - Simply but not too simple
  - To assess the impacts of climate change and abstraction
  - Based on literature on the stratigraphic and geographic features
  - Comprises
    - Aquifer basin – coast + recharge area
    - Four rivers
  - Boundary conditions

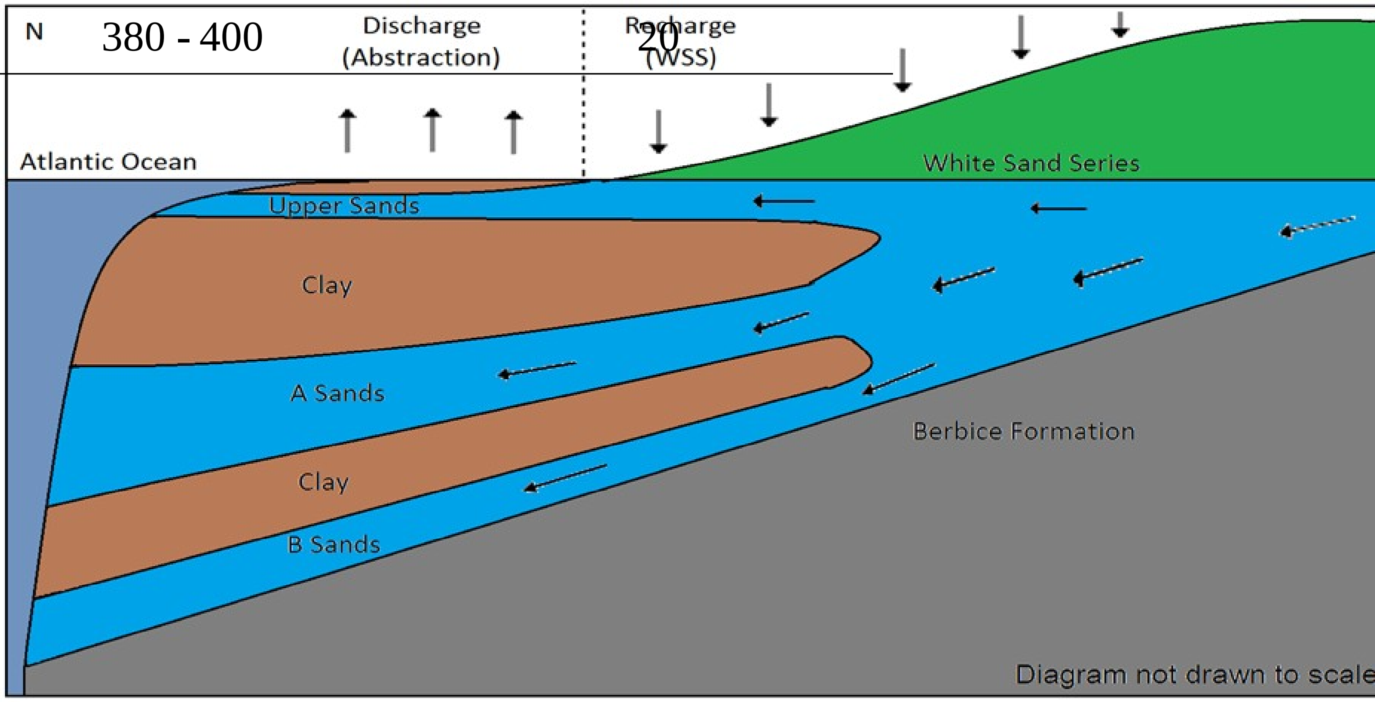


METHODOLOGY



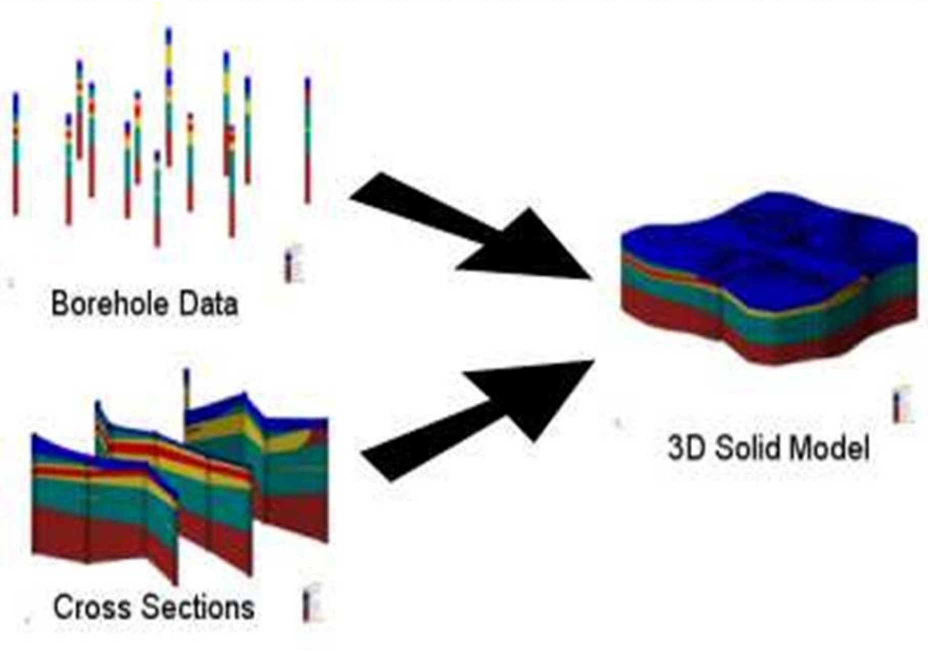
METHODOLOGY

Formation	Avg. depth below ground surface (m)	Average thickness (m)
Demerara Clays	0 - 50	50
Upper Sands	50 - 80	30
Intermediate clays	80 - 200	120
‘A Sands’	200 - 240	40
Lower Alternating clays	240 - 380	140
‘B Sands’	380 - 400	20



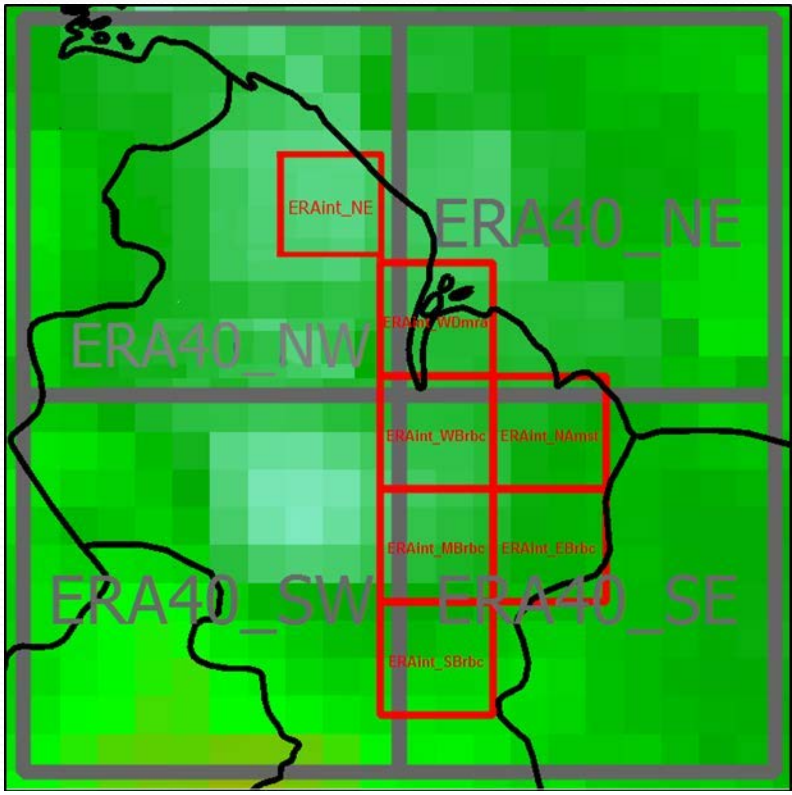
METHODOLOGY

- Numerical model
  - GMS MODFLOW Three-Dimensional Finite Difference Model
    - SIP (strongly implicit procedure)
    - SSOR (slice successive over-relaxation)
  - Borehole data created using literature
  - Cross-sections manually created
  - 3D solid created using Inverse Distance Weighting (IDW)
  - 3D Finite difference grid comprised 6 layers, 40 rows, an 80 columns



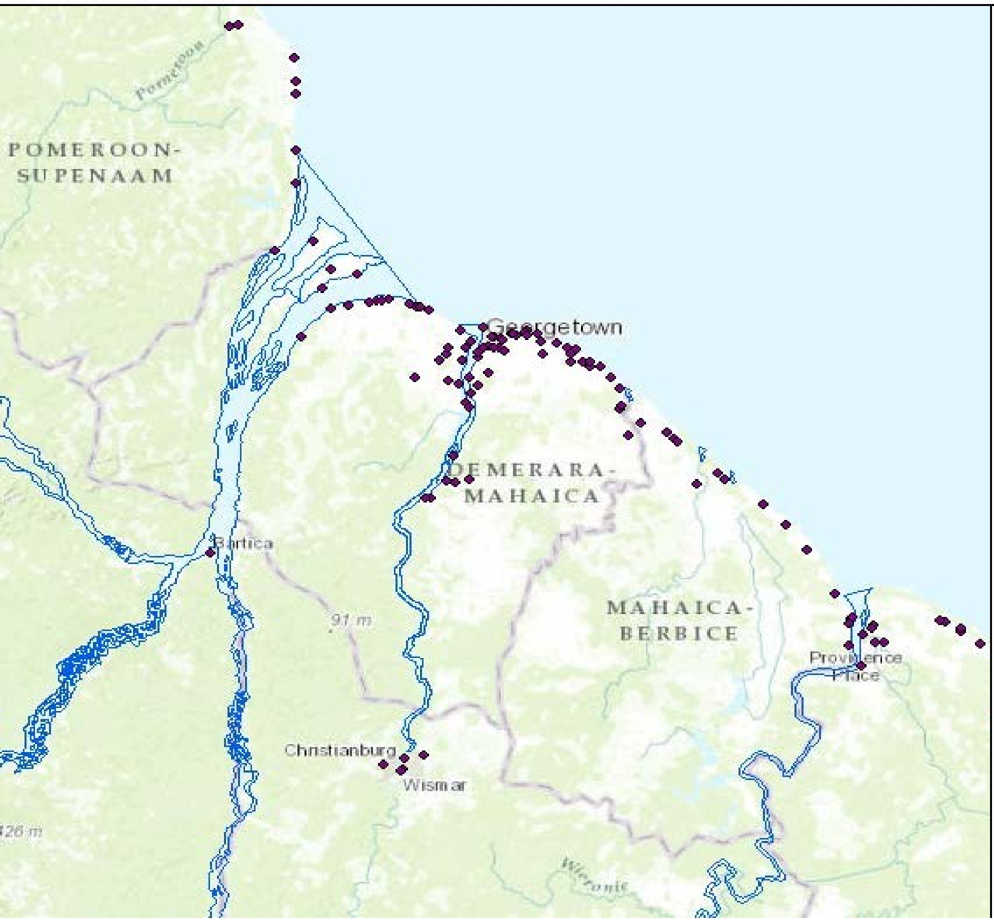
METHODOLOGY

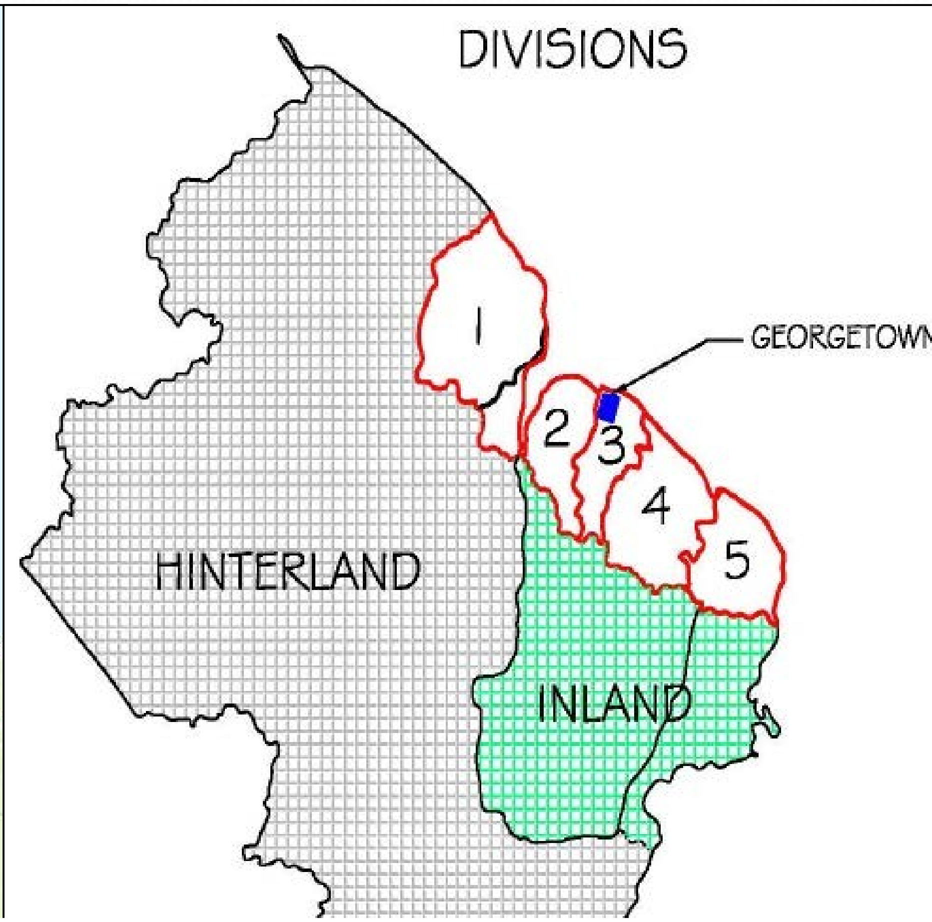
- Rainfall
  - ECMWF Re-Analysis (ERA) 40 and Interim
  - ERA-40 (Sept. 1957 to Aug. 2002)
    - Version cycle 23R4 (CY23R4)
    - 60 vertical levels
    - Horizontal resolution T159 (~125km)
    - 3D variational data assimilation
  - ERA-Interim (Jan. 1979 to Apr. 2012)
    - Version cycle 31r1 (CY31r1)
    - Horizontal resolution T213 (~80km)
    - 4D variational data assimilation
  - Monthly, seasonal, and annual analysis



METHODOLOGY

- Water level





METHODOLOGY

- Recharge
  - Previous estimate threeevaporations rates
    - Halcrow – 65 year periodestimate
    - ERA-40 evaporationrates
    - Thornthwaiteequation
  - Evaporations rates then used to calculate potentialrecharge

$$PET = 1.6L_d \left(\frac{10T}{I}\right)^{a}$$

Equation 1: Thornthwaite equation for potential evaporation

Where;

L_d = daylight time

T = monthly mean air temperature

$$a = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5})I^2 + 0.01791I + 0.49239$$

$$I = \sum_{j=1}^{12} \left(\frac{T_j}{5}\right)^{1.514}$$

METHODOLOGY

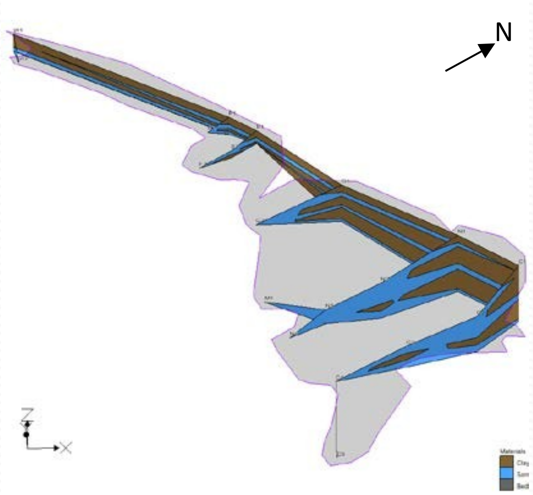
- Abstraction
  - Data generated from various sources
    - Raw data from GWI
    - Previous studies
  - Conversions required given age of data
  - Data available did not complete 40 year period
  - Historic and current rates inputted into the model

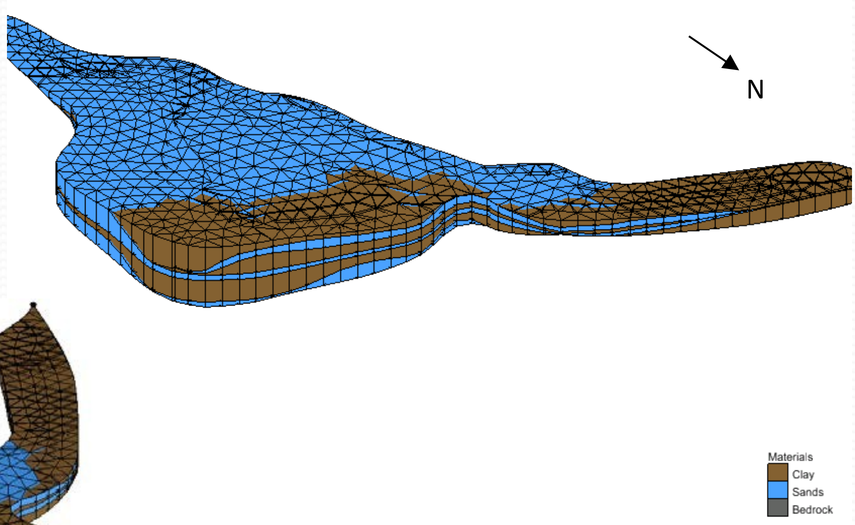
LIMITATIONS

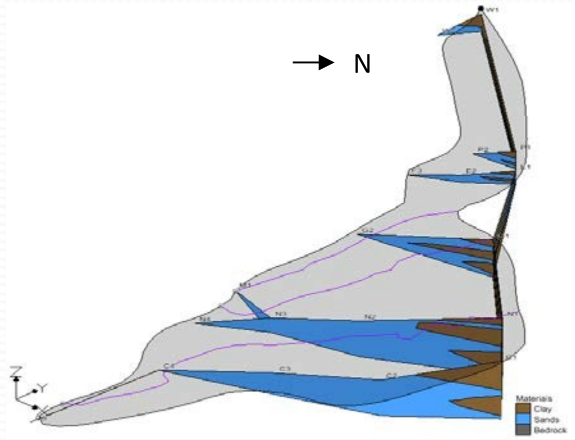
- Poor data availability and data quality
- No defined methodology for water level readings, particularly an established datum
- Lack of boreholes lithologies
- Lacks of additional info, such as net radiance and other variables, to permit use of Penmonth equation for evaporation rates

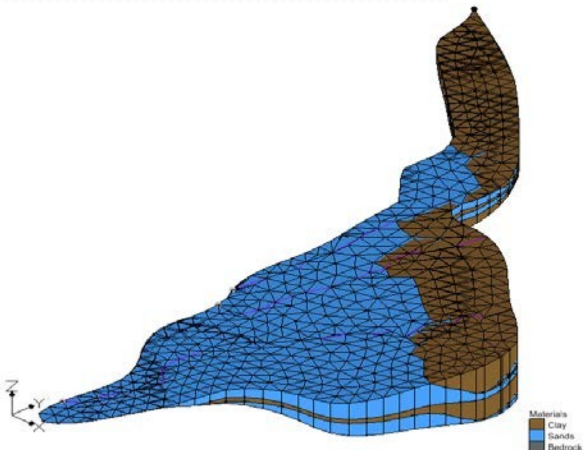
Results

- Conceptual model



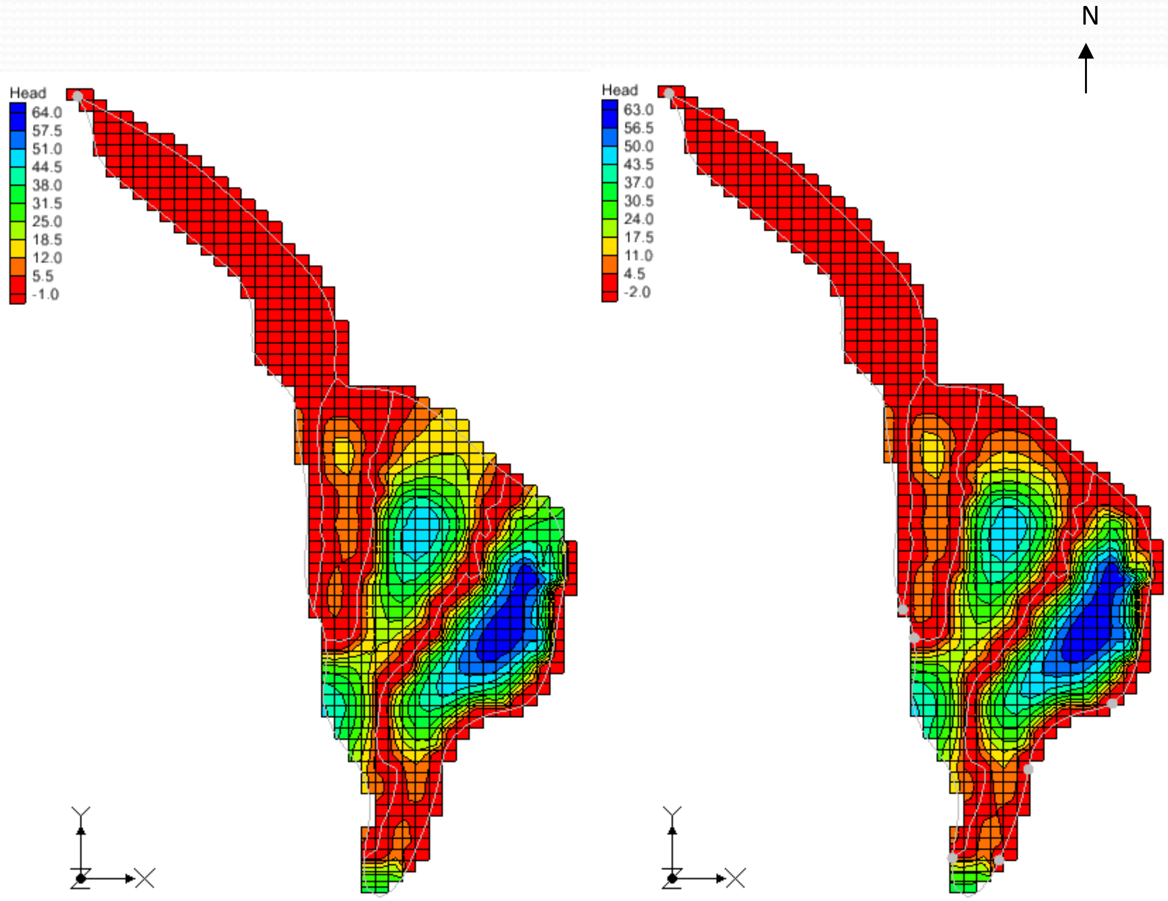






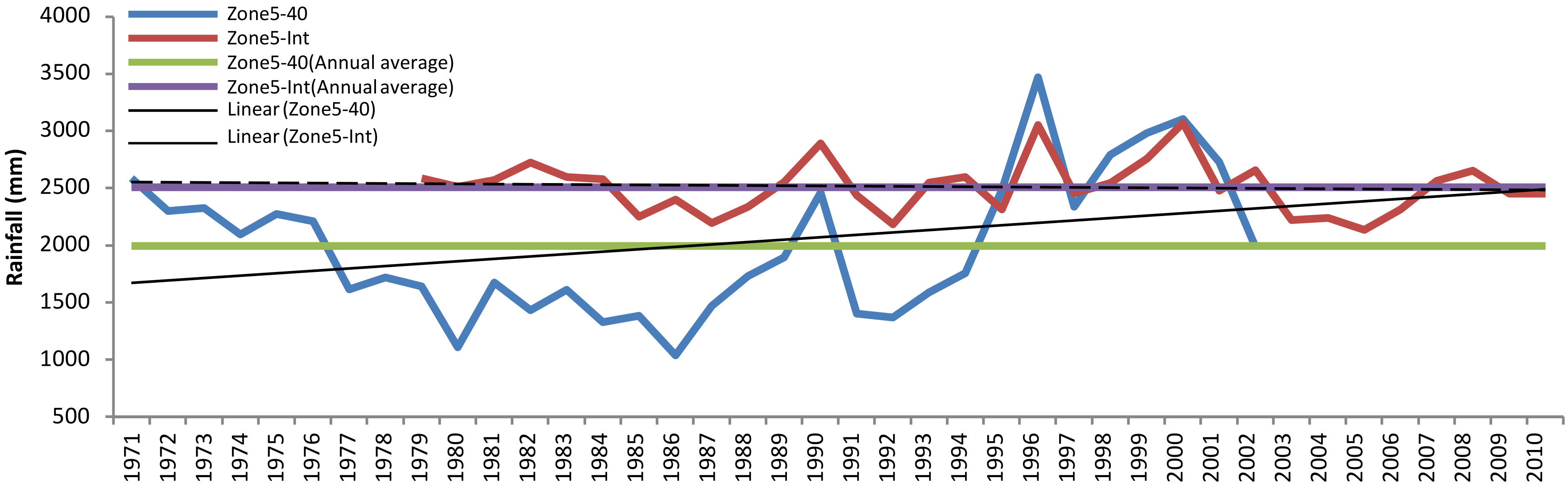
Results

- Conceptual model
  - Rivers
    - No convergence without connectivity
  - Ocean
    - Left – without
    - Right – with
  - Sensitivity analysis completed



Results

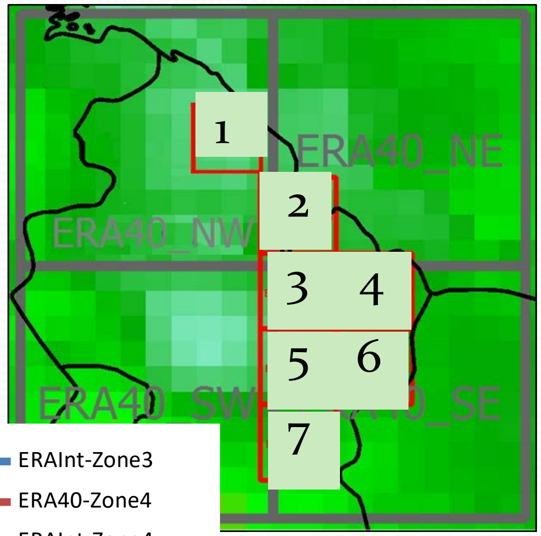
- Climate
  - Rainfall
    - ERA-40 higher average along the coastal zones
    - ERA-Interim suggests little to no change

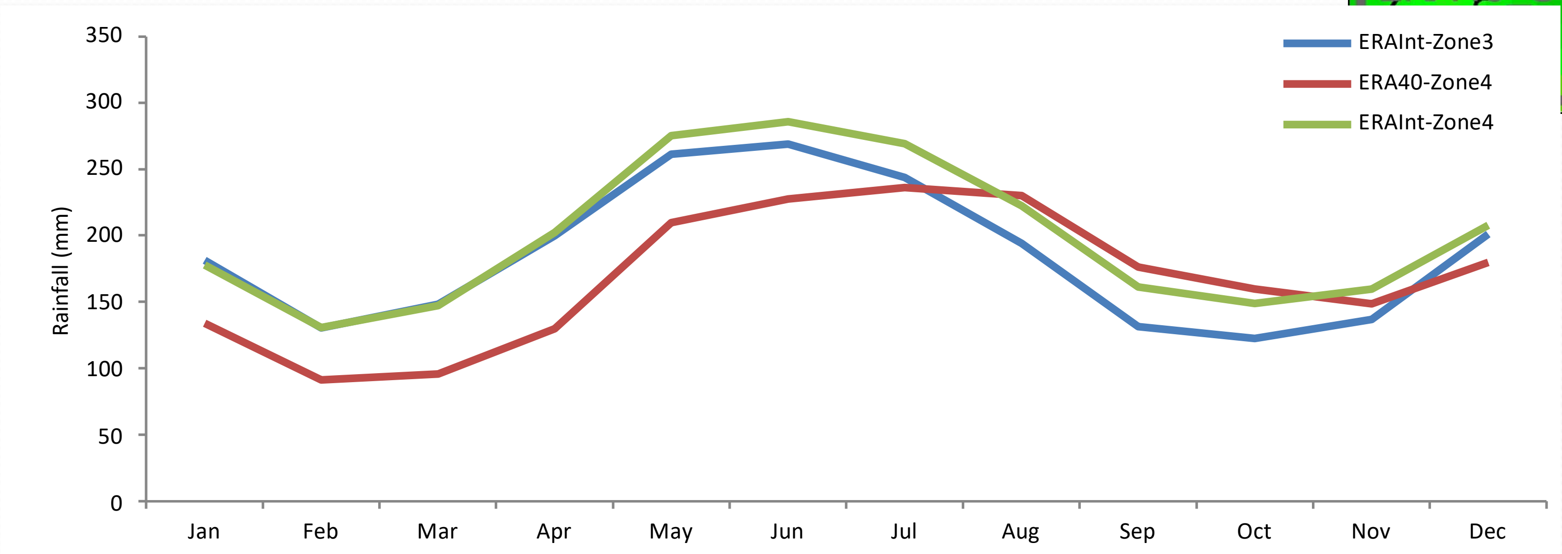


Total annual rainfall for Zone 5 comparing trends between the ERA-40 and ERA-Interim datasets for 1971-2010

Results

- Climate
  - Rainfall
    - Compatibility of two data sets varied among zones and seasons
    - Similar patterns but inconsistent averages

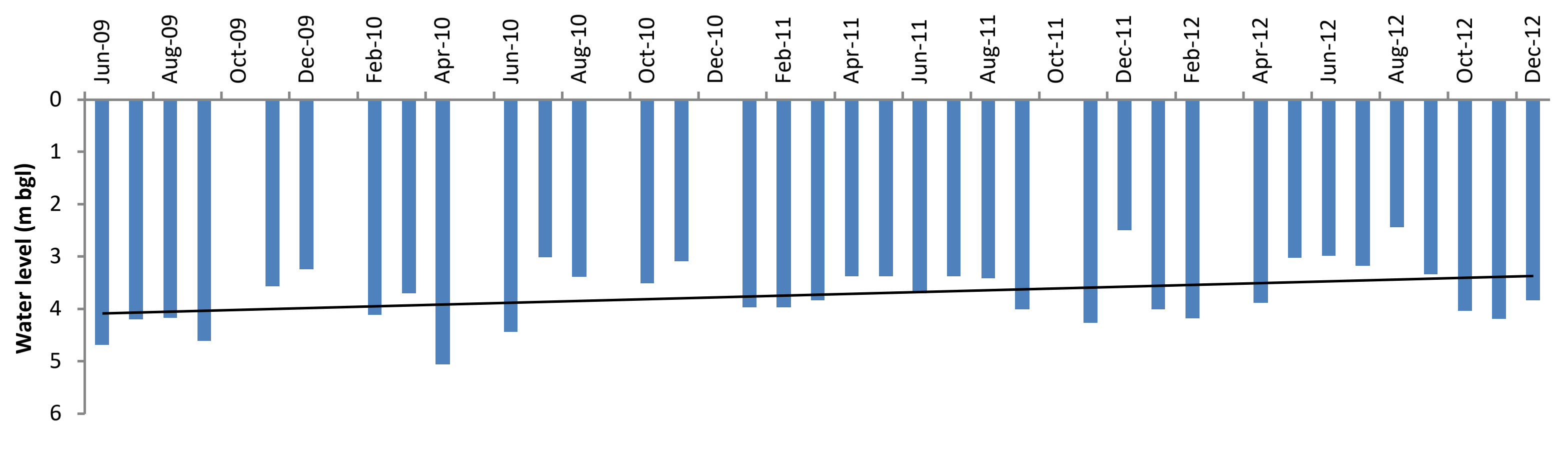


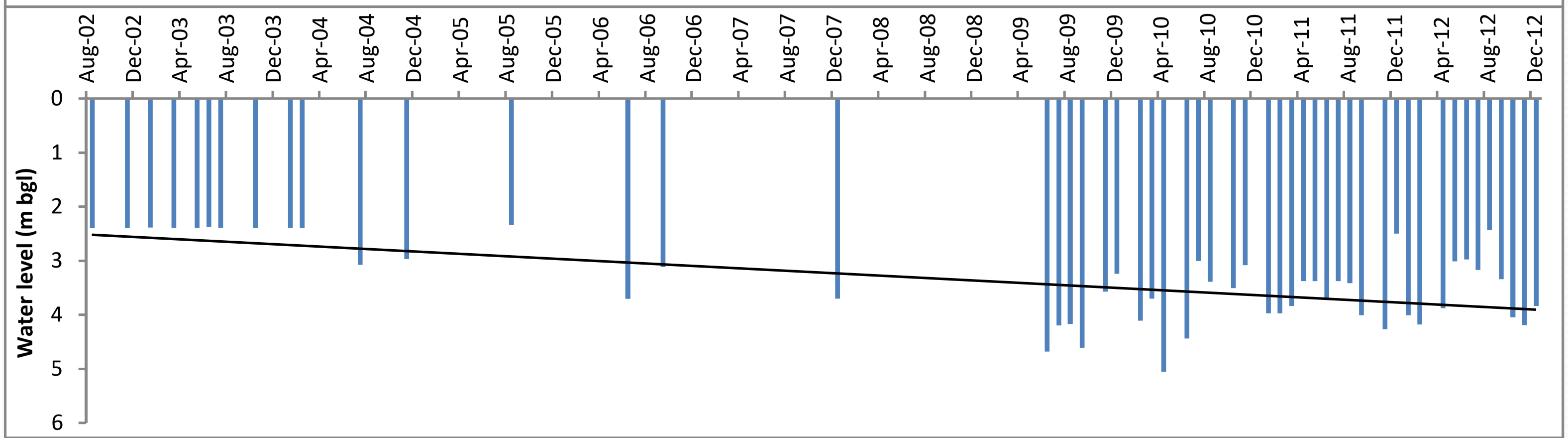


Average monthly rainfall for ERA-40 and ERA-Interim for Zones 3 and 4

RESULTS

- Climate
  - Groundwater level





Reported water level at Adventure, Division 5 for the period August 2002 to December 2012

Results

- Climate
  - Groundwater level

Divisions	Location	Groundwater level (m below surface)	
		Minimum	Maximum
1	Essequibo Coast Wakenam Island, Essequibo Leguan Island, Essequibo	7.24	16.16
2	East Bank Essequibo West Coast Demerara West Bank Demerara	7.65	27.89
3	East Bank Demerara Georgetown, Demerara East Coast Demerara	12.85	35
4	West Coast Berbice West Bank Berbice	1.91	8.91
5	East Bank Berbice Canje, Berbice Corentyne, Berbice	0.98	11.91

Minimum and maximum groundwater levels below surface level along the coast

RESULTS

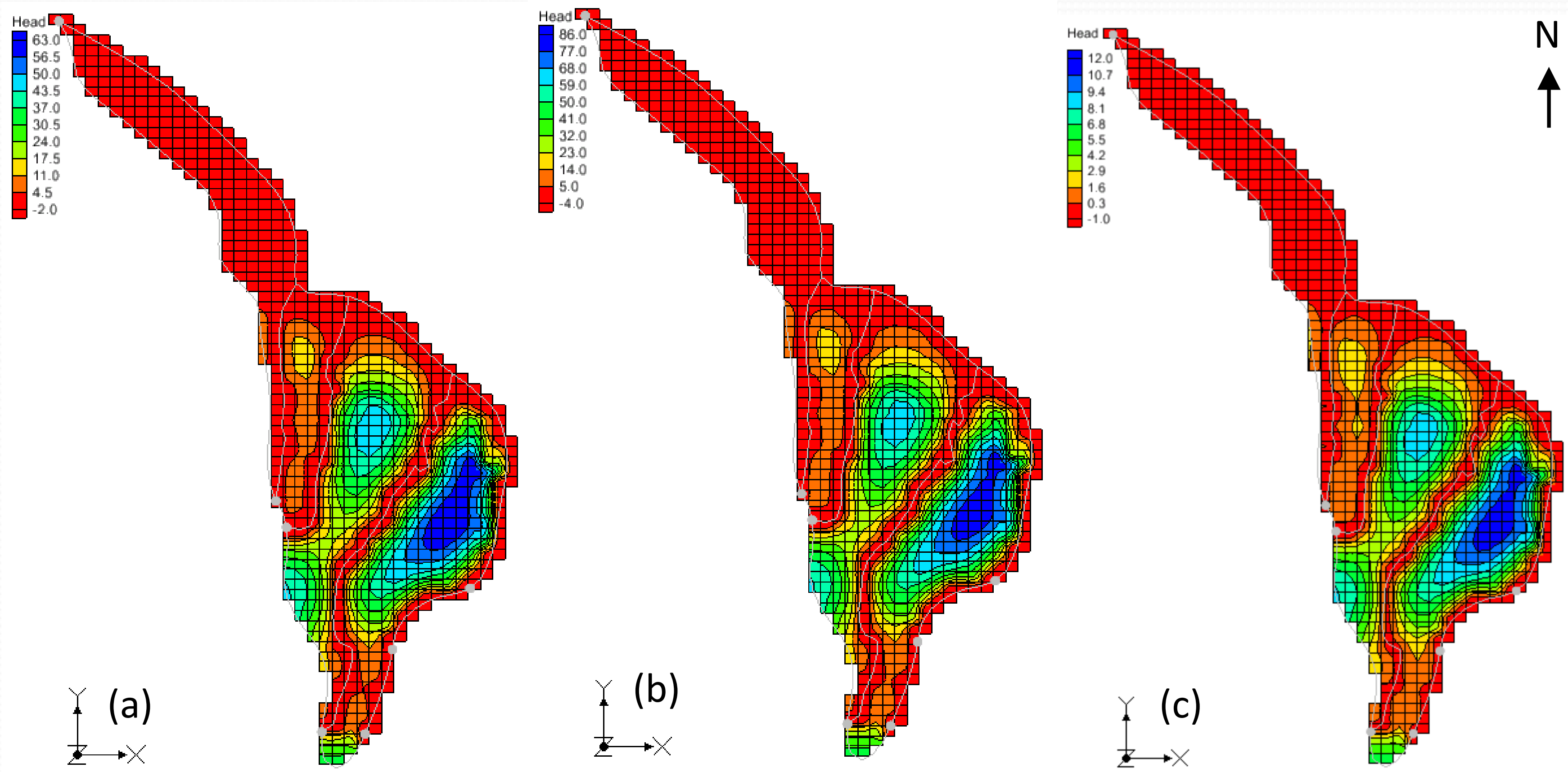
- Recharge
  - No recharge along coast
  - ERA-40 indicates highest potential recharge
  - Thornthwaite indicates lowest potential recharge

	Rainfall (mm year^{-1})	Evaporation (mm year^{-1})	Effective Rainfall (mm year^{-1})	Potential Recharge (mm year^{-1})	Recharge rate (m d^{-1})
Historic (Halcrow)	2323	1132	1240	992	0.0027
ERA-40	1707	78	1629	1303	0.0036
Thornthwaite	1707	1664	235	1188	0.0005

Comparison of estimated recharge rates

RESULTS

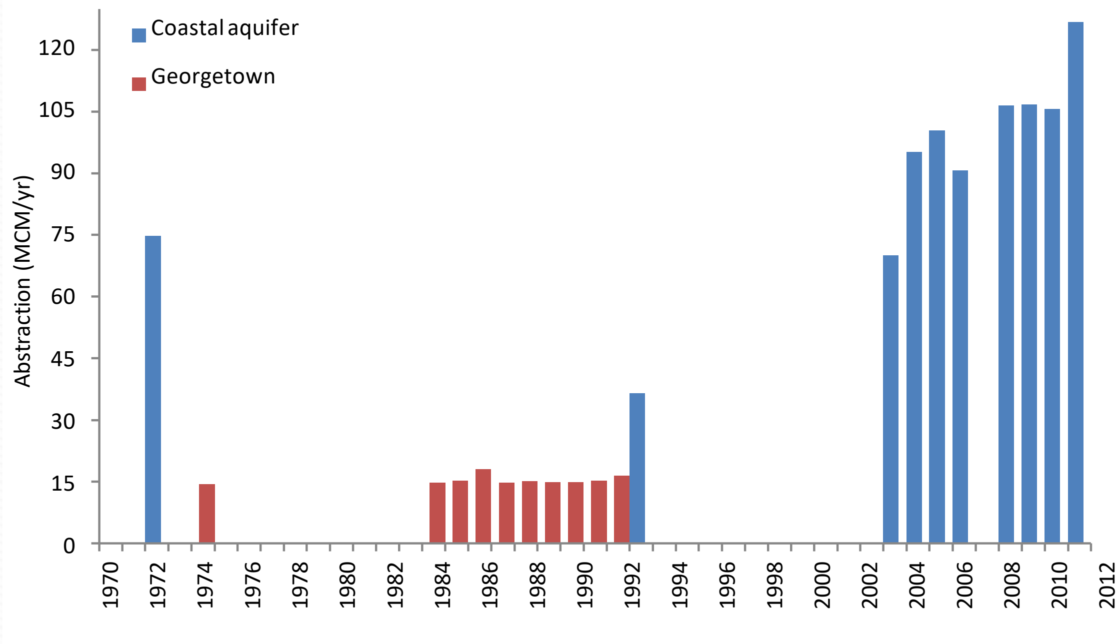
- Recharge



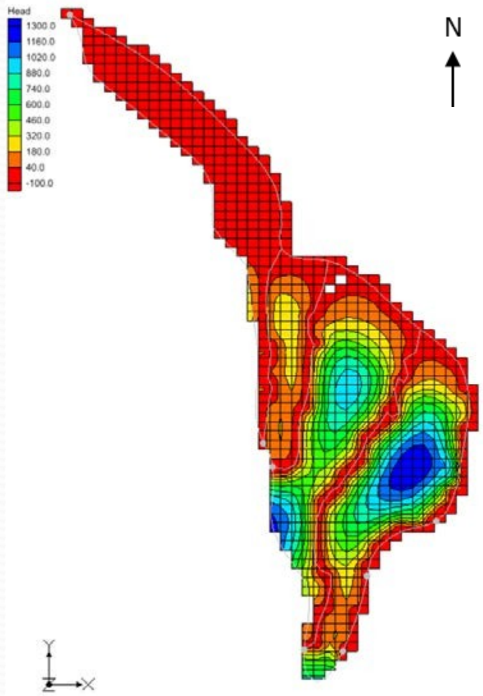
Model output with the estimated recharge rates; R= 0.0027 m d^{-1} (a) R=0.0036 m d^{-1} (b) R=0.0005 m d^{-1} (c)

Results

- Abstraction rates
  - Decrease in abstraction for first 20 years
  - Abstraction increased over 18 year period
    - 36.5 MCM year^{-1} to 106.6 MCM year^{-1}
- Bassier & Potter (1992) project rates to reach 111.21 MCM year^{-1} by 2000, was exceeded in 2012



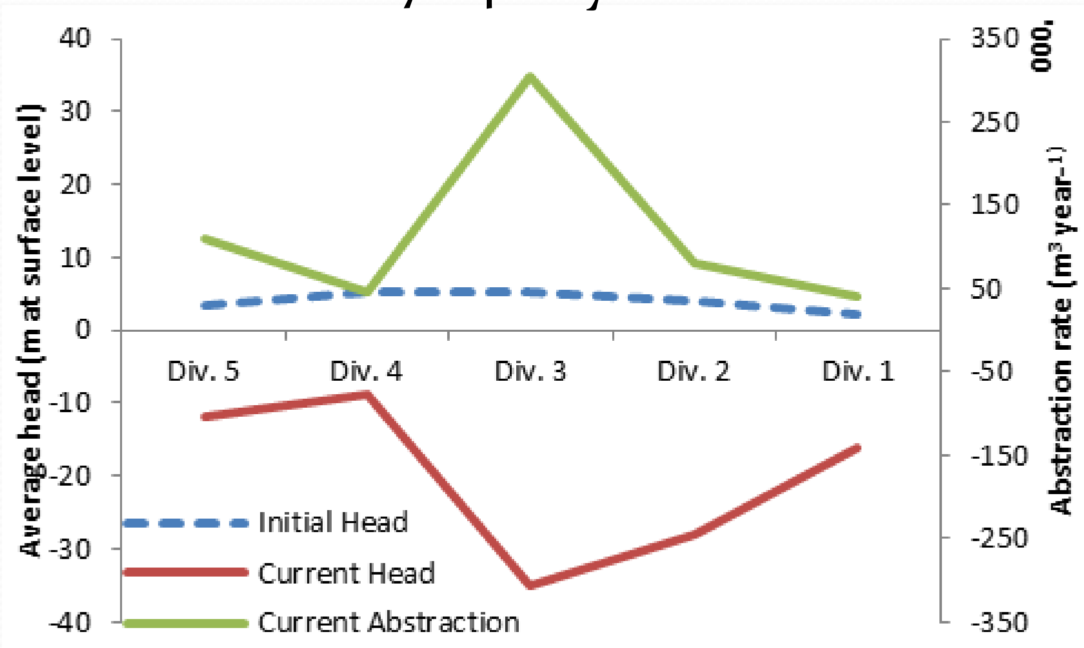
Available abstraction rates for the period 1970 – 2012 for the whole coastal basin and for Georgetown



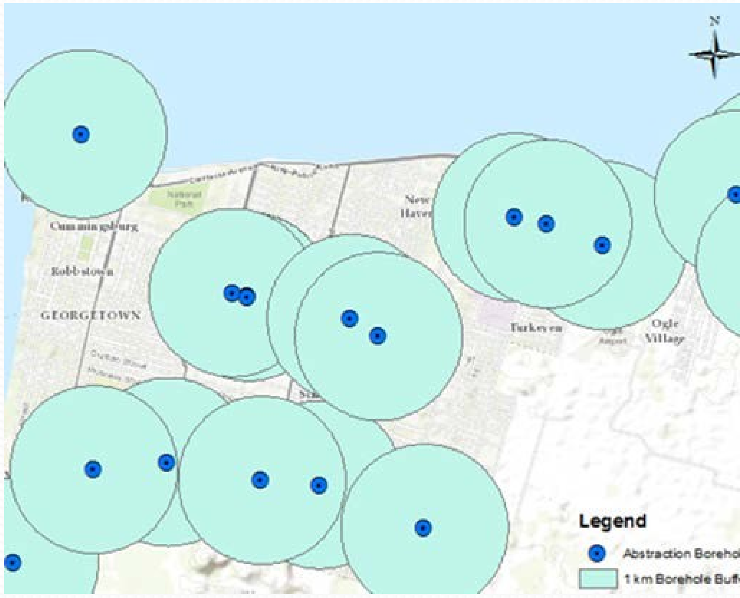
Groundwater levels with current abstraction rates

Results

- Abstraction rates
  - Per capita consumption
    - 2004 – 103.99 $m^3 year^{-1}$
    - 2010 – 157.91 $m^3 year^{-1}$
    - 2012 – 187.84 $m^3 year^{-1}$



Comparison of initial and current groundwater levels against current abstraction rates



Abstraction boreholes within Georgetown with 1 km buffer

DISCUSSION

- Conceptual Model
  - Model accepted with IDW interpolation of aquifer thickness
  - Connectivity to rivers and ocean accepted
  - Connected to ocean via 'A' and 'B' Sands aquifers
  - Upper Sands salinity related to historic time rather than saline intrusion

Discussion

- Climate
  - Data within region poorbut model accounted well for variability
  - ERA-Interim improvement on ERA-40 as such this data was accepted for the rechargearea
  - Greater correlation for dry season than wet
  - Relationship with groundwater level could not be established
  - Distribution of wells and data gathering procedures play a pivotal role in groundwater levelsrecorded

Discussion

- Recharge
  - Estimates vital for the management of this resource
  - Halcrow's estimate most realistic
  - ERA-40 low evaporation attributed to humidity bias which has been improved in Interim
  - Thornthwaite simplest method, lack of data did not permit use of more complex and reliable equations such as Penmonth equation

Discussion

- Abstraction
  - As abstraction increasesgroundwater levels expected to decrease
  - Given vast recharge and storage capacity outweighs current abstraction rates
  - Obvious decline from historic readings
  - Convergence of cones of depression

Conclusion

- Groundwater models prove valuable
- Poor data quality and availability plague the sector
- Response time necessary for management of resource
  - Requires more reliable and current data
- Recharge estimates are critical
- Abstraction rates increase but vast resources combats this
- Convergence of cones of depression may be responsible for reported decline

RECOMMENDATION

- Conceptual model
  - Lithologies of wells identified
  - Comparison of Guyana and Suriname aquifers
- Climate
  - Analysis of compatibility of ERA-40 and ERA-Interim
- Recharge
  - Potential and actual evaporation rates necessary
- Abstraction
  - Non-digital data needs to be digitized
  - Standard procedure for data collection necessary

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