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International Water Resources Association
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Kingdom of Morocco
Ministry of Equipment and Water

Mapping sea water intrusion in a basaltic formation using geophysical techniques

Presenter Name: Dr. Parvesh Balloo

Institution: University of Mauritius

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Supervisor: Assoc. Prof. Dr M. Nowbuth & Assoc. Prof Dr V.Proag

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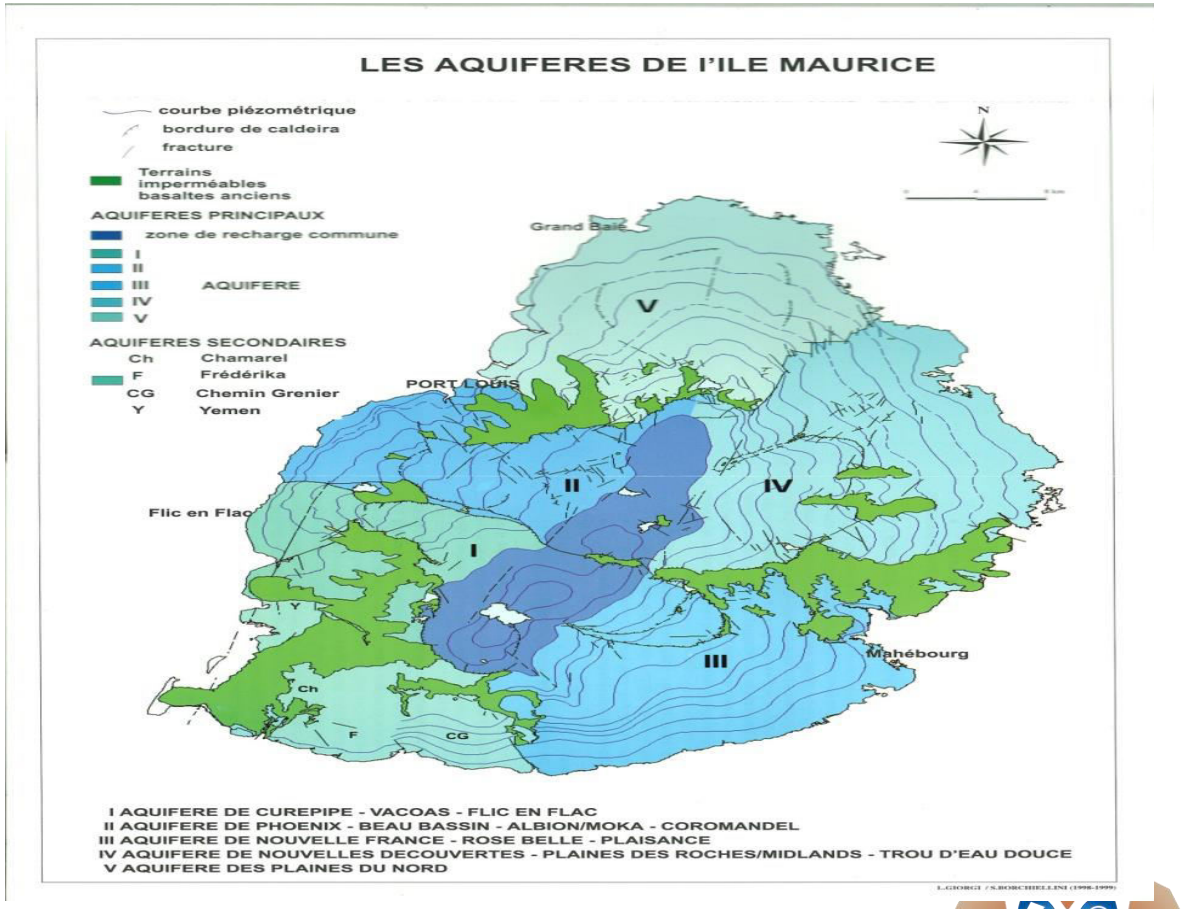
Agenda

- Introduction – Aim of the Project
- Methodology
- Results & Discussion – Main Findings
- Conclusion
- Impactful Output of the Project
- References

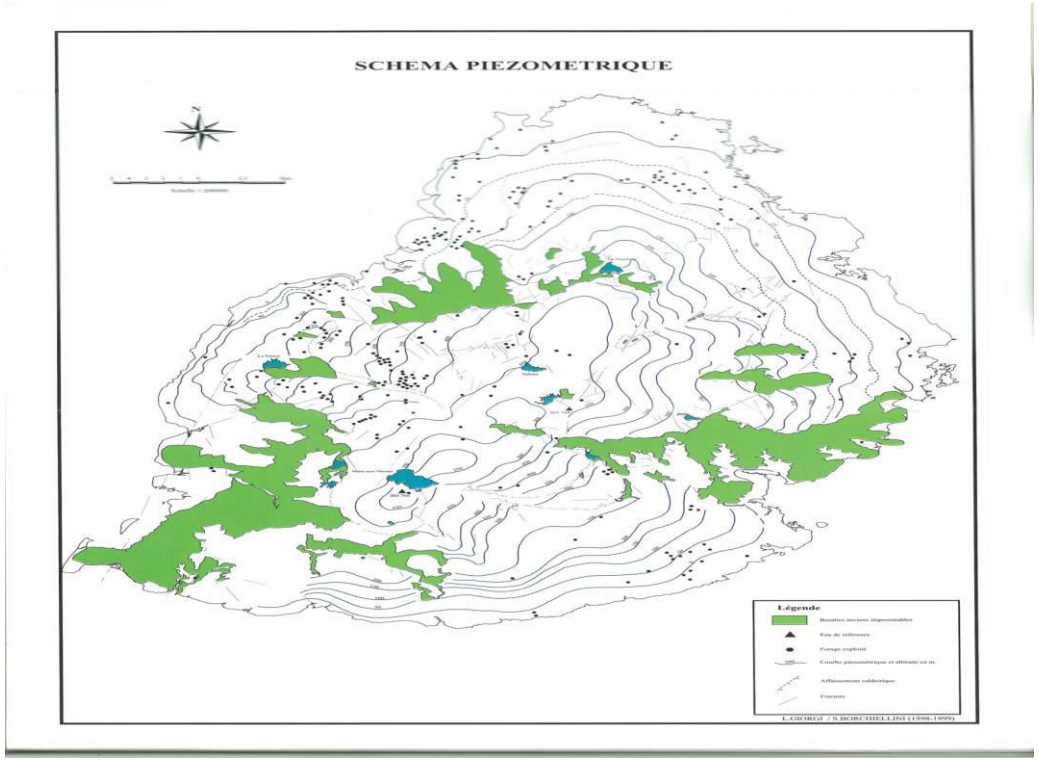
Introduction

- Analyse the dynamic movement of seawater/fresh water interfaces using geophysical electrical resistivity techniques and its impacts on heterogeneous formation of the island.
- Define a safe setback distance from the highwater mark for safe exploitation of brackish water
- Generate maps showing the extent of seawater intrusion



Introduction

- Piezometric level and Location of boreholes

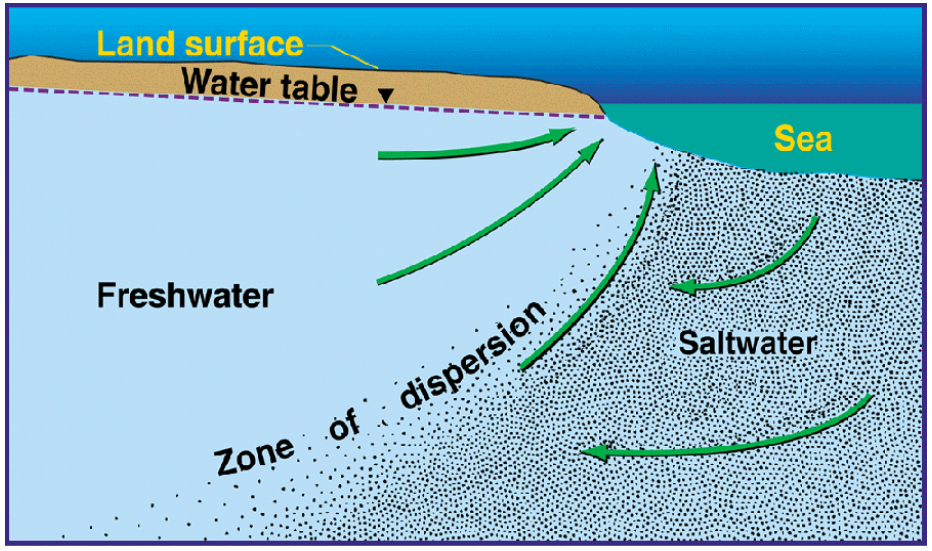


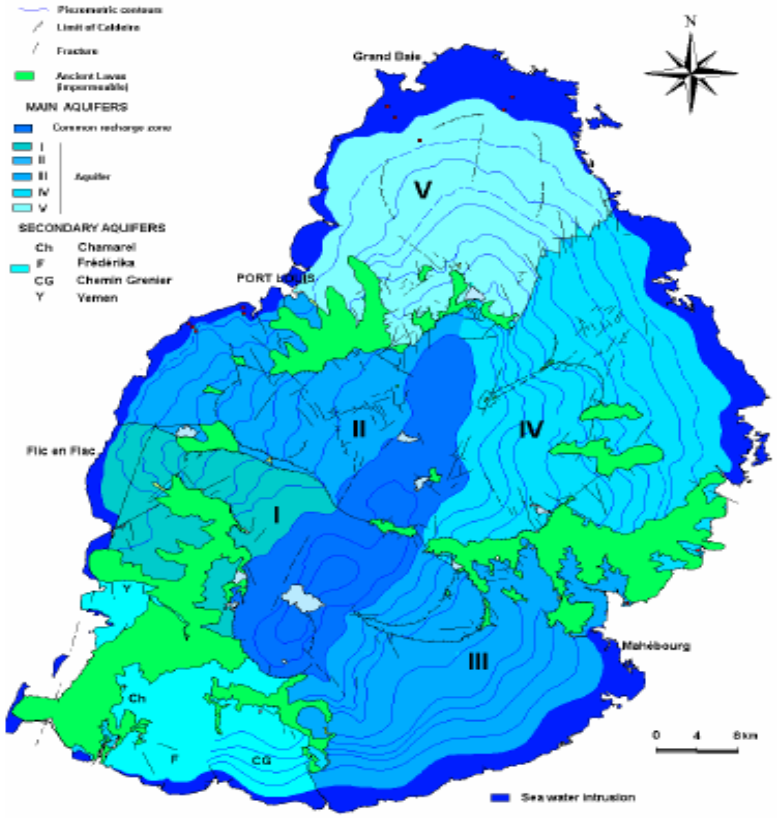
RESEARCH QUESTION

- **To what extent is pumping of groundwater along the coastal zones increasing the rate of seawater ingress in basaltic aquifers which are in dynamic contact with the sea?**

Introduction

- Seawater Intrusion
- The intrusion occurs due to the induced flow of seawater into freshwater aquifers.

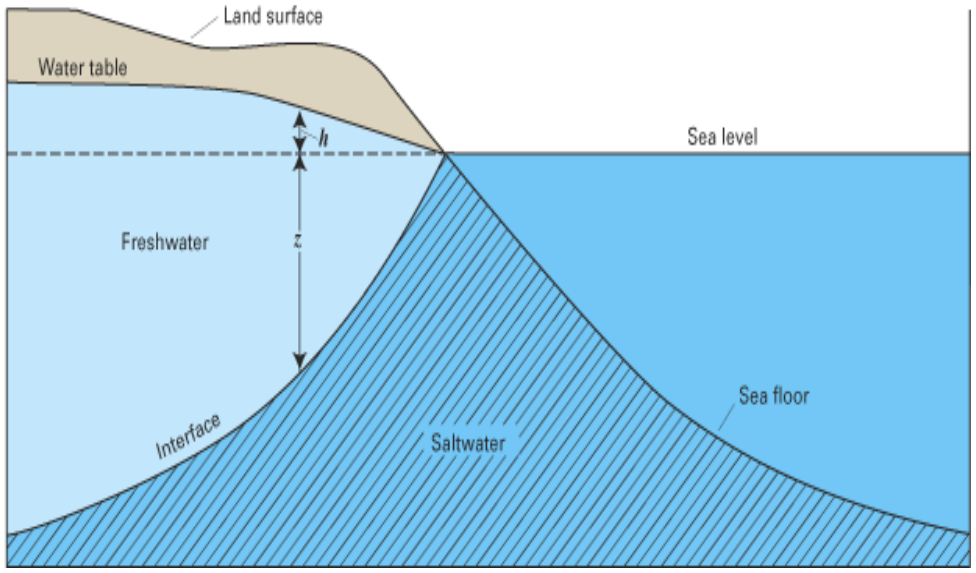




Ground-water flow patterns and the zone of dispersion in an idealized, homogeneous coastal aquifer

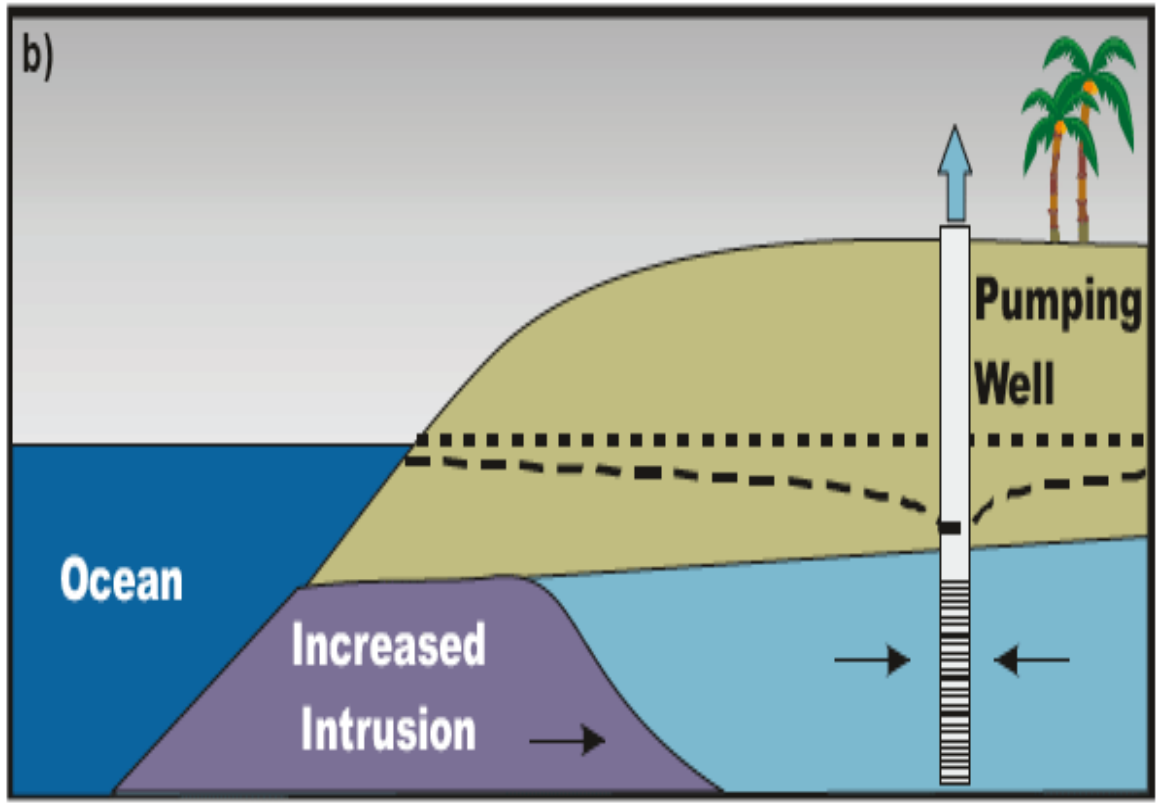
Introduction

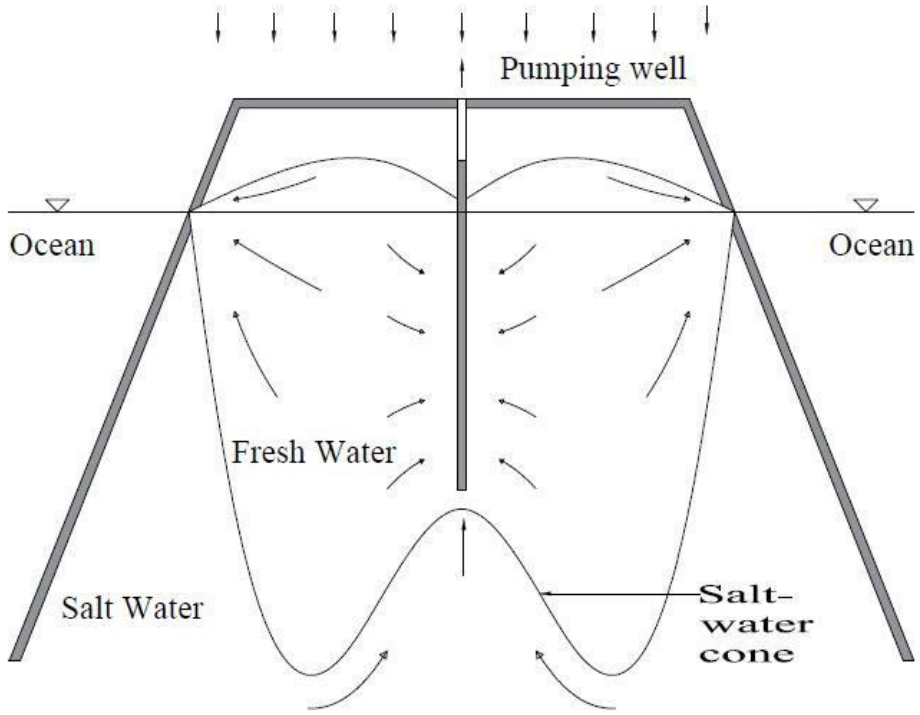
- Seawater Intrusion
- Ghyben-Herzberg relation between Fresh and Saline Waters
- Hydrostatic equilibrium existing between the two fluids of different densities (Z = 40 hf)



Introduction

- Seawater Intrusion
- Fresh water lens around the coast





Introduction

- Seawater Intrusion
- Increasing rate
  - Sea Level rise
  - Increase pumping
  - Constant threat to our coastal aquifers
- Monitoring
  - CWA
  - Ministry of Environment (EIA)
- Geophysical techniques coupled with groundwater modeling has now become an important tool to study sea water intrusion.

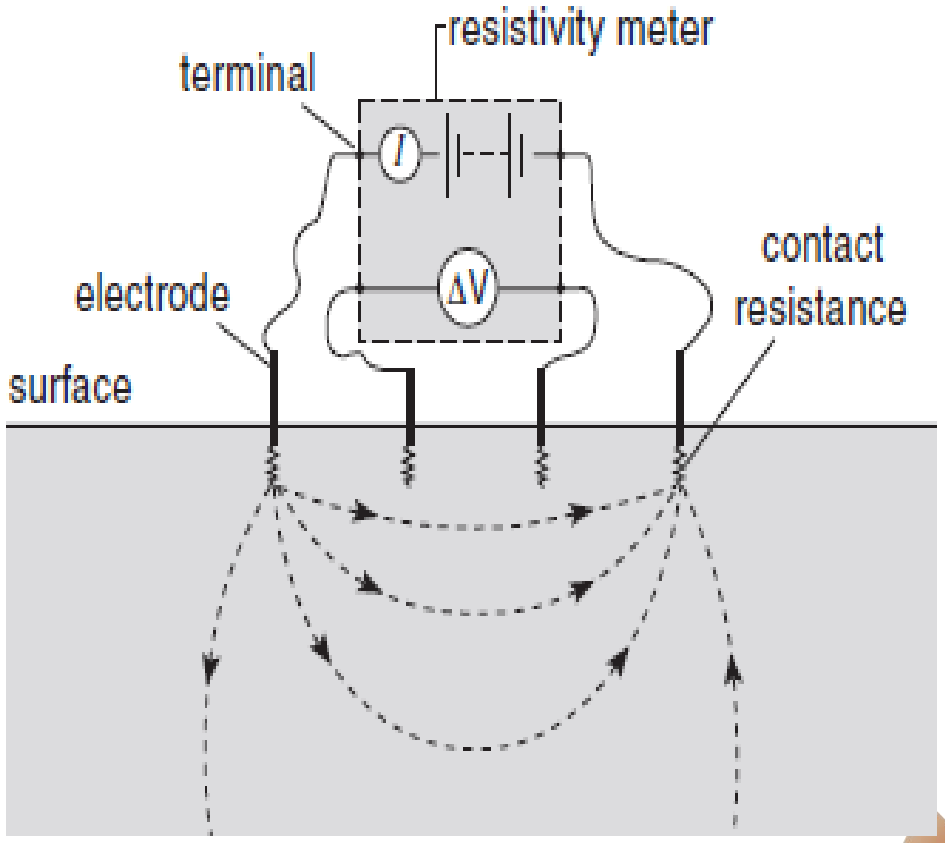
- Involve taking measurements at or close to the Earth's surface that are influenced by the internal distribution of physical properties.
- Show how the physical properties of the Earth's interior vary laterally and vertically.

Introduction

- Geophysical methods
  - Using earth's natural field
  - Using an artificial energy into the ground
  - Operative physical property: Electrical conductivity (earth resistance)
  - Electrical Resistivity Technique
    - Direct Current Resistivity: Vertical Electrical Sounding

Methodology

- A four electrodes geophysical electrical resistivity meter was used to map the thickness of the different subsurface layers at various sites around the coastal zone of the island.



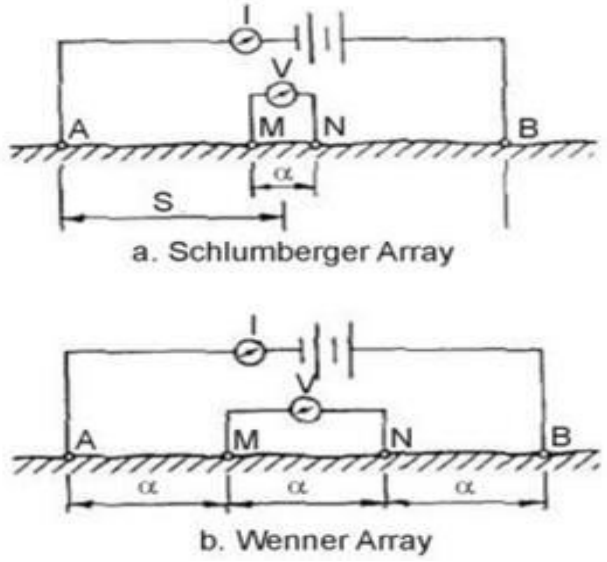
Methodology – Selection of Sites

- **Easy access**
- **Available space on site to carry out VES tests**
- **Sites are linked to coastal aquifers**
- **Existing lithology provides supportive information on the hydrogeology of the sites**
- **Sites sit on intermediate and recent basaltic formation which are permeable**
- **Form part of master plan for both Government and Private sectors for future developments**
- **Four corners of the island**

Methodology – The Study Areas

Methodology

- **The Schlumberger and the Wenner methods were used to gather information about the depth and the extent of the different formations and of the seawater wedge.**



Type of Array	Apparent Resistivity
A M N B a a a Wenner	$\rho_a = 2\pi a \frac{\Delta V}{I}$
A M N B Sclumberger	$\rho_a = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \frac{\Delta V}{I}$

Adapted from: Charry 2012

Methodology

- **The Interpretation Theory – Inverse Slope Method**
- **Ramanuja (2012) described this method to solve the field equation directly to obtain the resistivities and thicknesses of the subsurface layers from the field data.**

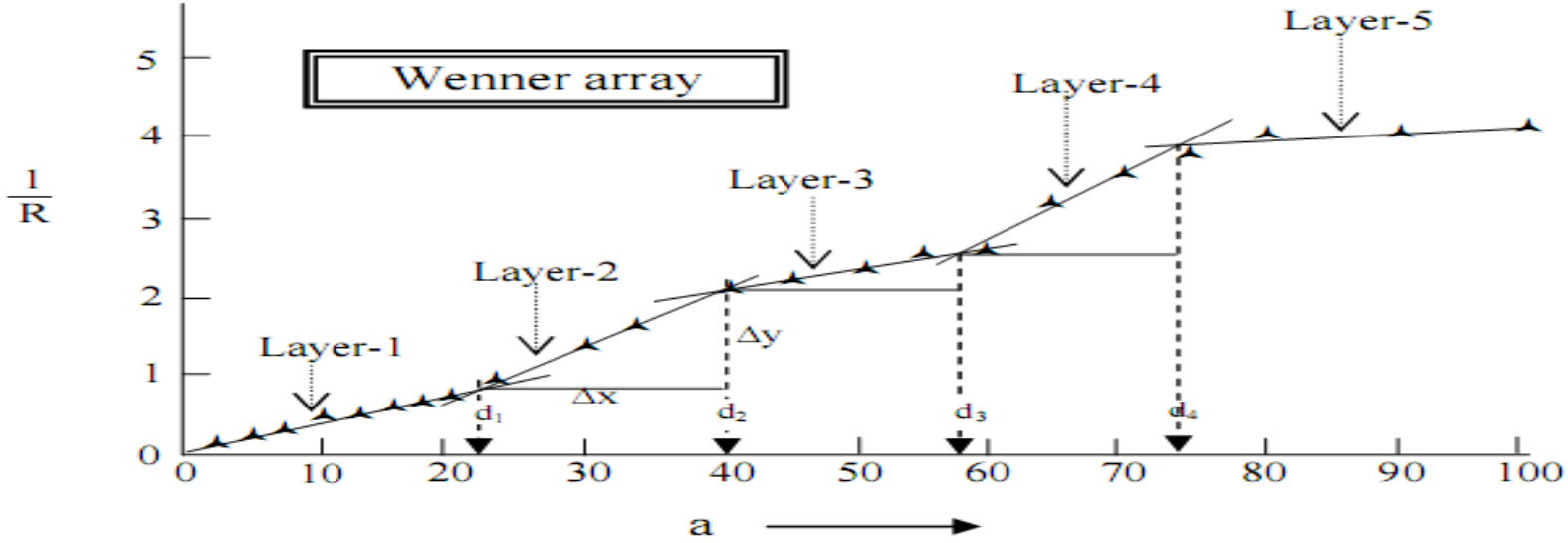


Figure: Plotting 1/R Vs. a (a = electrode separation)

Methodology

- **Physico Chemical Characteristics**
- The Physico chemical data including conductivity and total dissolved solids were used to validate the sea water intrusion inland.

Methodology - Comparative Study

- **Determination of the most appropriate geophysical method**

Table 1.0:Summary and Comparison of Results for Flic en Flac

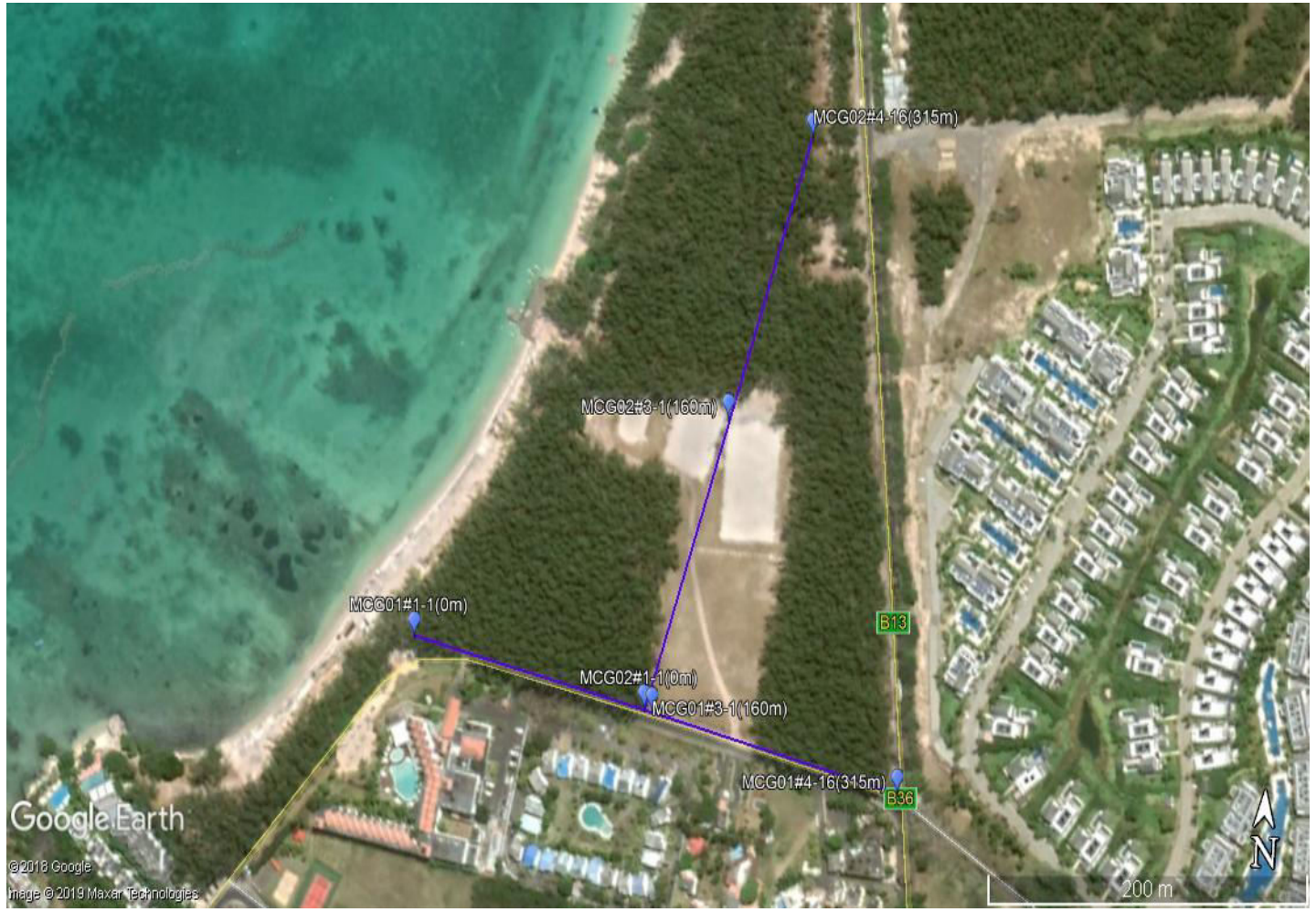
Description	Wenner Method	Schlumberger Method
No. of layers identified	4	2
On site test	Time consuming	Fast
Interface Depth (m)	3.5 , 6 , 34	3
Resistivity (ΩM)	2.75 , 23.81 , 38.89 , 342.47	53.57 , 225
Water quality	Brackish to fresh	Fresh to very fresh

Methodology - Comparative Study

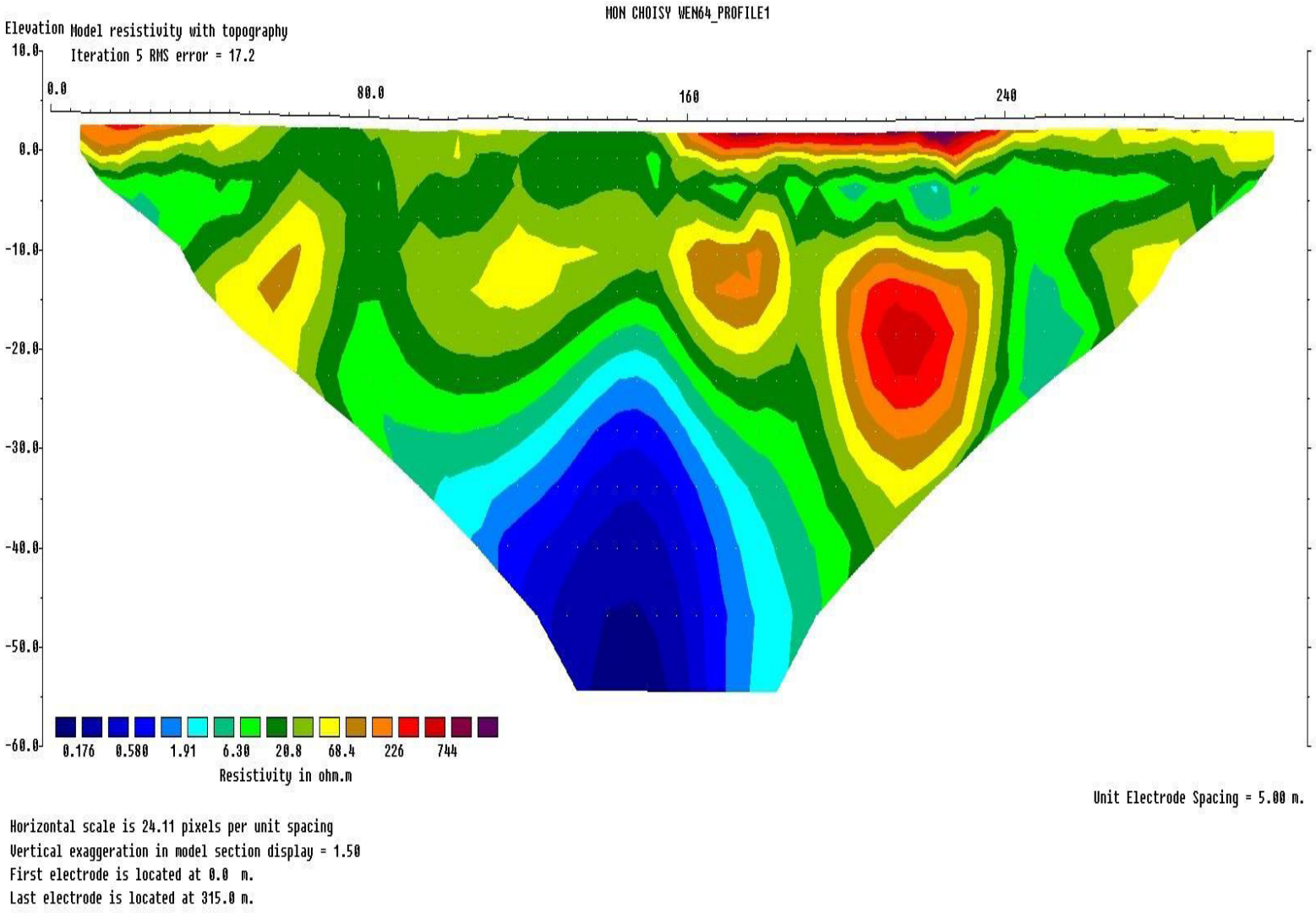
Table 2.0 : Summary and Comparison of Results for Cascavelle

Description	Wenner Method	Schlumberger Method
No of layers identified	2	1
On site test	Time consuming	Fast
Interface depth (M)	11.5	Nil
Resistivity (ΩM)	48.78 , 125	78.51
Water quality	Fresh	Fresh

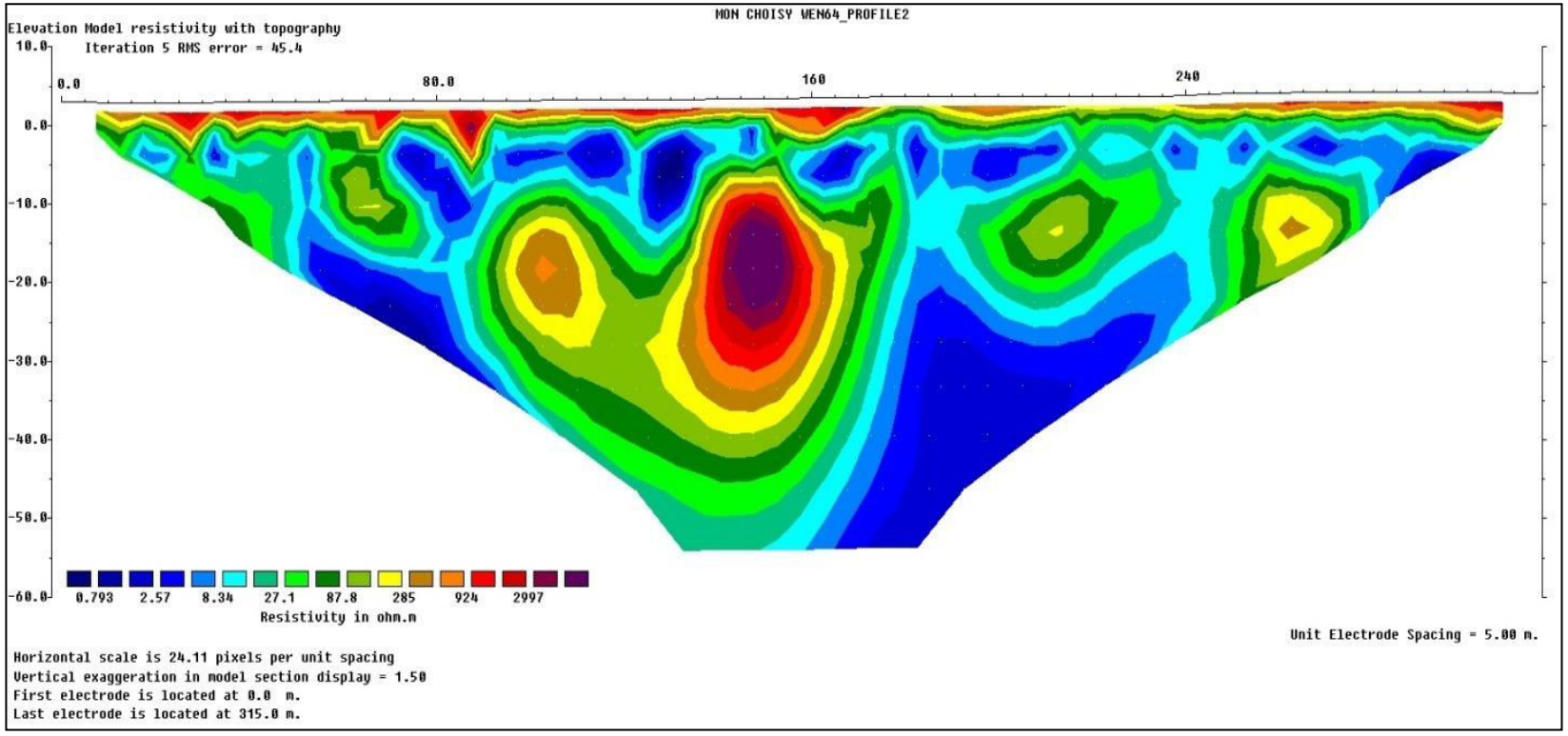
Methodology – Survey at Mont Choisy



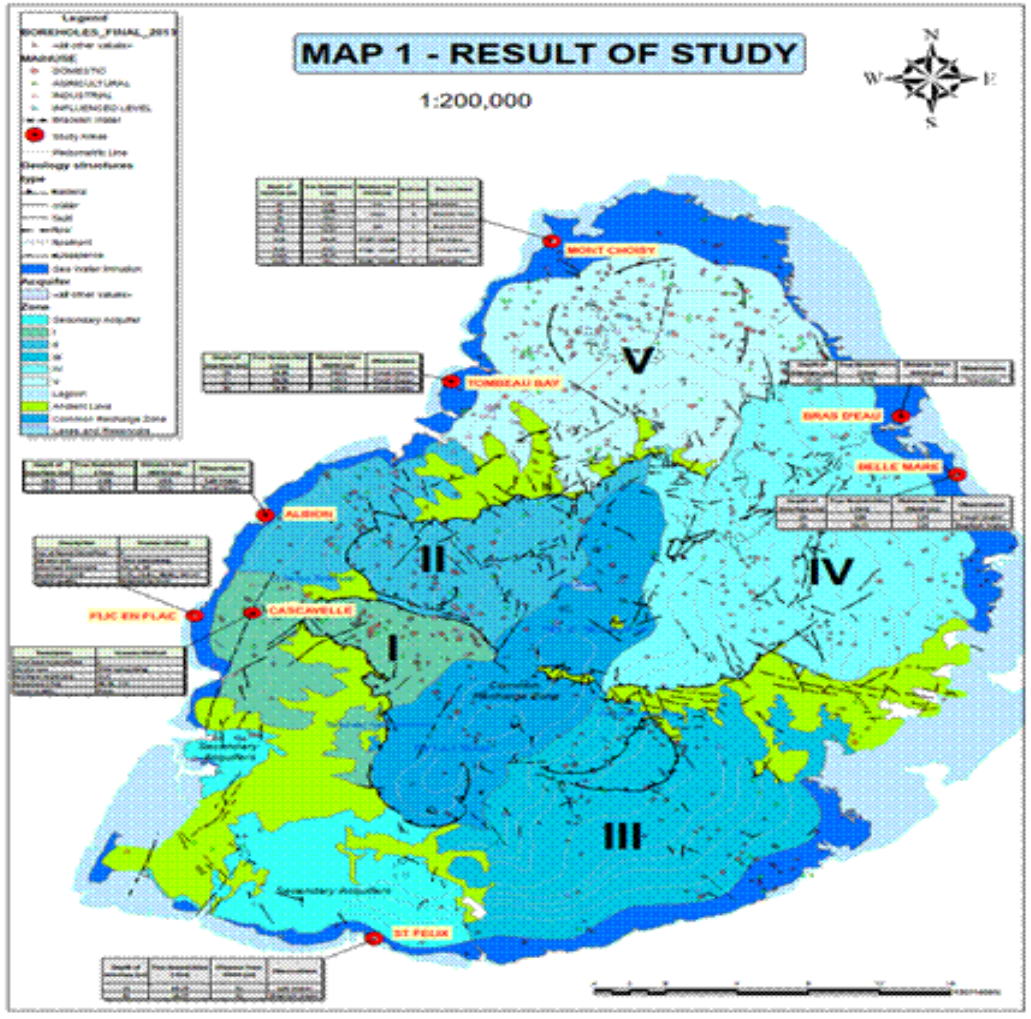
Results & Discussion – Mont Choisy :Perpendicular to the coastline



Results & Discussion – Mont Choisy :Parallel to the coast line



Results


MAP 1 - RESULT OF STUDY
1:200,000
N
W
E
S
MONT CINDSY
TOMBEAU BAY
BRAS D'EAU
BELLE MARE
ALBION
CASCAVELLE
FLIC EN FLAC
ST FELIX
I
II
III
IV
V

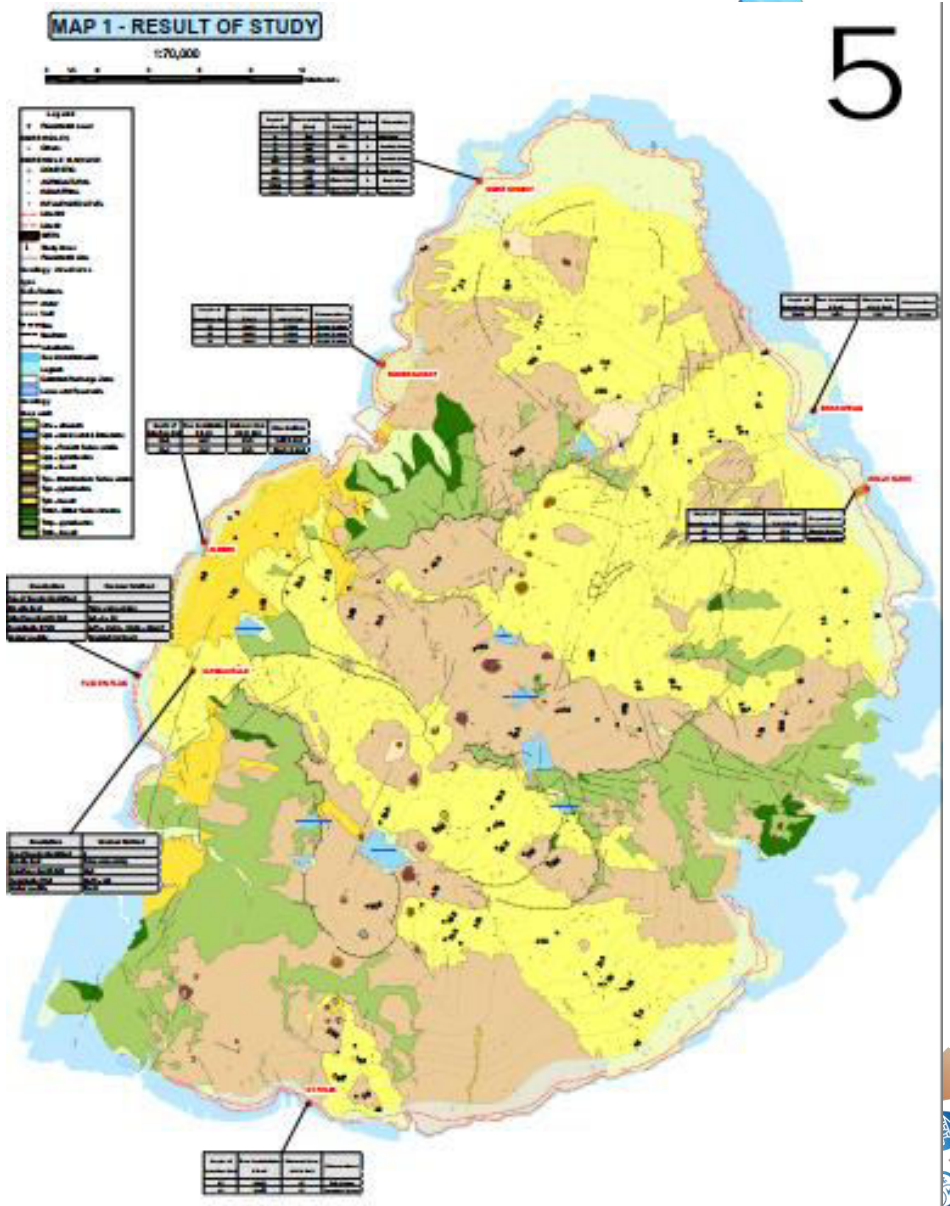
Validation of Data

- **Physico-chemical data from CWA**

SN	Site	CWA Borehole code	Depth (m)	Distance (km)	Resistivity (Ωm)	Calculated Conductivity (µS/cm)	CWA Boreholes Conductivity (µS/cm)
1.	Albion				2.68 22.9	3731.34 436.68	Data not available
2.	St Felix	BH387	36.58	2.5	63.29 18.77	158.00 532.76	588.00
3.	Tombeau Bay	SW233	25.00	1.5	28.85 30.86 16.67	346.62 324.04 599.88	791.00
4.	Cascavelle	BH946	70.00	10	48.78 125.00	205.00 80.00	332.00 292.00
5.	Flic-en-Flac	BH247A	45.72	9.5	2.75 23.81 38.89 342.47	3636.36 419.99 257.13 29.19	338.00, 332.00 340.00,292.00 344.00,303.00
6.	Mon Choisy	BH1	48.77	9,7	789.00 13.08 19.20 11.20 13.57 58.38 67.70 36.73 28.10	12.67 764.52 520.83 892.85 736.91 171.29 147.71 272.25 355.87	218.00, 261.00
7.	Bras D'Eau	BH11A	39.62	4.6	0.74	13513.51	185.00, 163.00
8.	Belle Mare	BH815	132.00	2.6	100.00 10.71	100.00 933.70	320.00,317.00

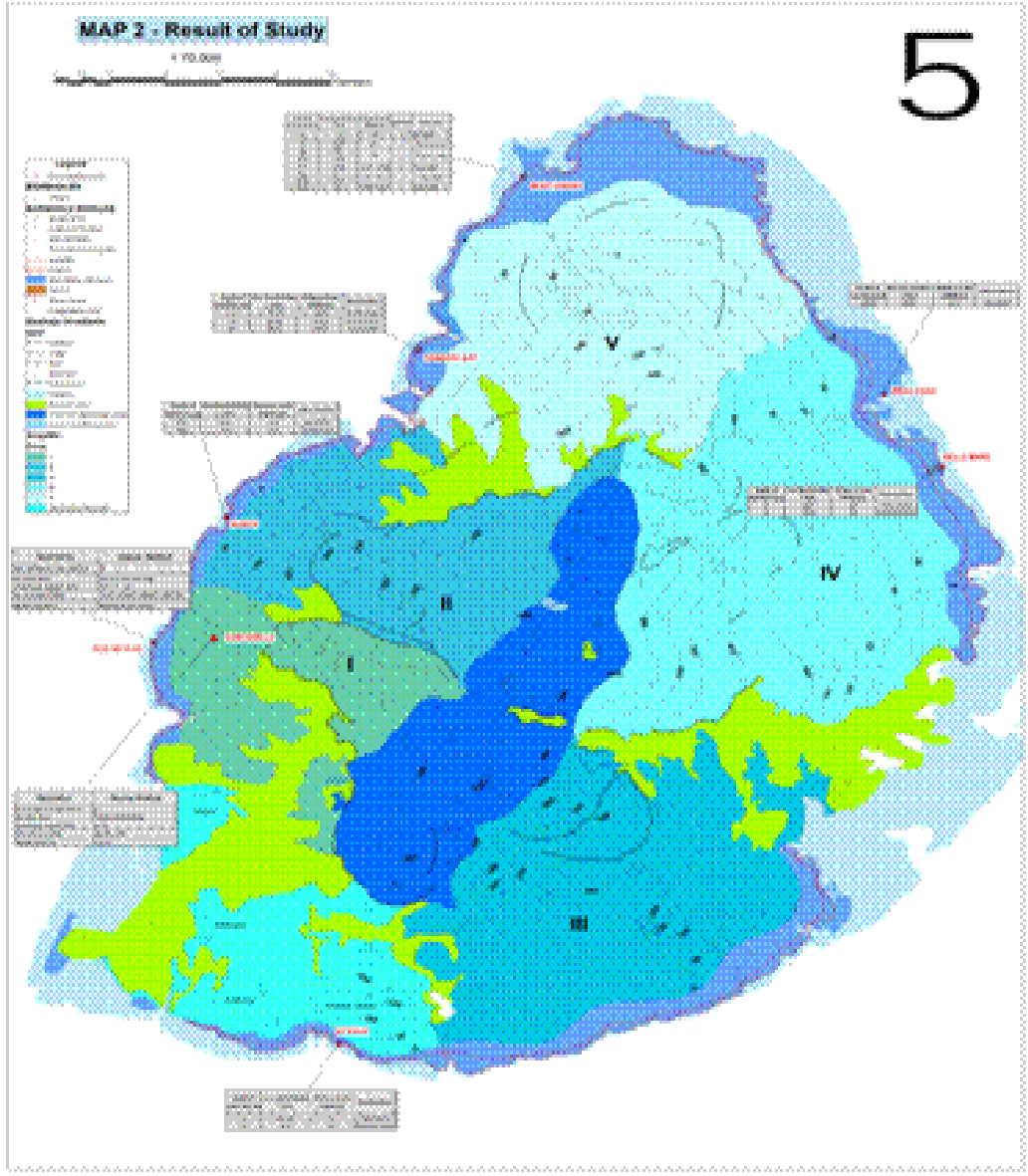
Conclusion

- **Mapping brackish water line**



Conclusion

Heterogeneous subsurface with varying permeability with zones of fresh,brackish and fresh water



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Thank you!

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