# KARST TERRAINS: VADOSE ZONE, SINKHOLE HAZARD & GROUNDWATER VULNERABILITY

Water in the City of Tshwane; 23 & 24 January 2014

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## Hazard (Dolomite Land)

- Event
  - Occurrence of sinkhole/surface subsidence
    - Anticipated size = small, medium, large and very large

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Inherent Hazard

Potential for an event to develop within specific land use and dewatering or water ingress situation.

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**Inherent hazard**

- Susceptibility of an area to an event
  - Low, medium, high – wrt size & water ingress or drawdown

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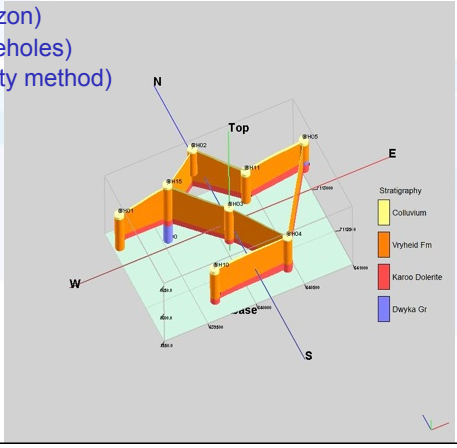
## Susceptibility determination

***Composite Model***

Inherent Hazard Classes

**Site specific**:

- geomorphology
- geology (stratigraphic horizon)
- profile characteristics (boreholes)
- geophysical probing (gravity method)
- hydrogeological data

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## Geomorphology

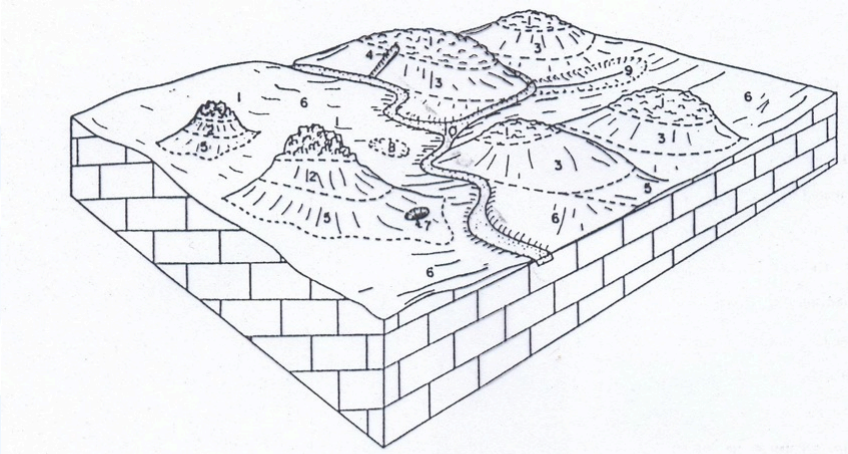

Figure 3.2: Block diagram of the Kromdraai Land System

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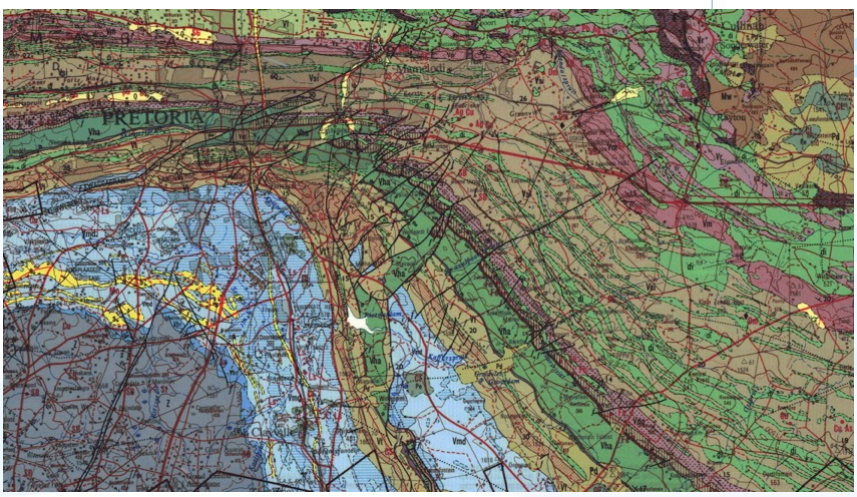
## Geology

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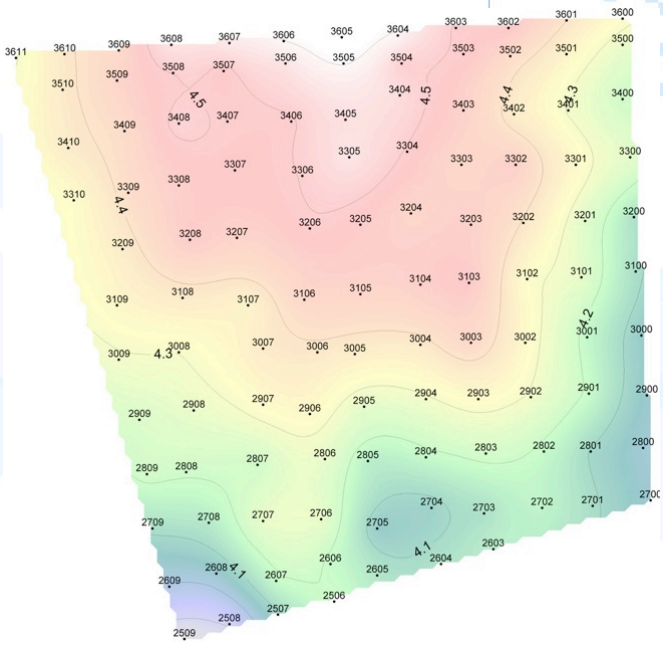
## Geophysics

## Gravity Survey



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## Profile

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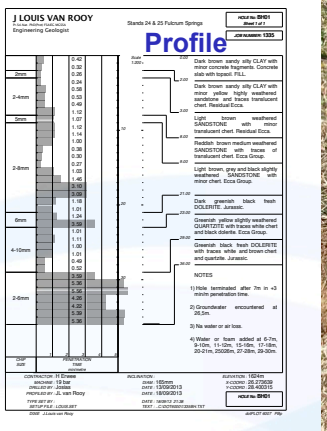
## Profile


J LOUIS VAN ROOY
Engineering Geologist

Stands 24 & 25 Fulcrum Springs

HOLE No. BH01

JOB NUMBER: 1335

Dark brown sandy silty CLAY with minor concrete fragments. Concrete slab with topsoil. FILL.

Dark brown sandy silty CLAY with minor yellow highly weathered sandstone and traces translucent chert. Residual Ecca.

Light brown weathered SANDSTONE with minor translucent chert. Residual Ecca.

Reddish brown medium weathered SANDSTONE with traces of translucent chert. Ecca Group.

Light brown, grey and black slightly weathered SANDSTONE with minor chert. Ecca Group.

Dark greenish black fresh DOLERITE. Jurassic.

Greenish yellow slightly weathered QUARTZITE with traces white chert and black dolerite. Ecca Group.

Greenish black fresh DOLERITE with traces white and brown chert and quartzite. Jurassic.

NOTES

1) Hole terminated after 7m in +3 minute penetration time.

2) Groundwater encountered at 26.5m.

3) No water or air loss.

4) Water or foam added at 6-7m, 9-10m, 11-12m, 15-16m, 17-18m, 20-21m, 25/26m, 27-28m, 29-30m.

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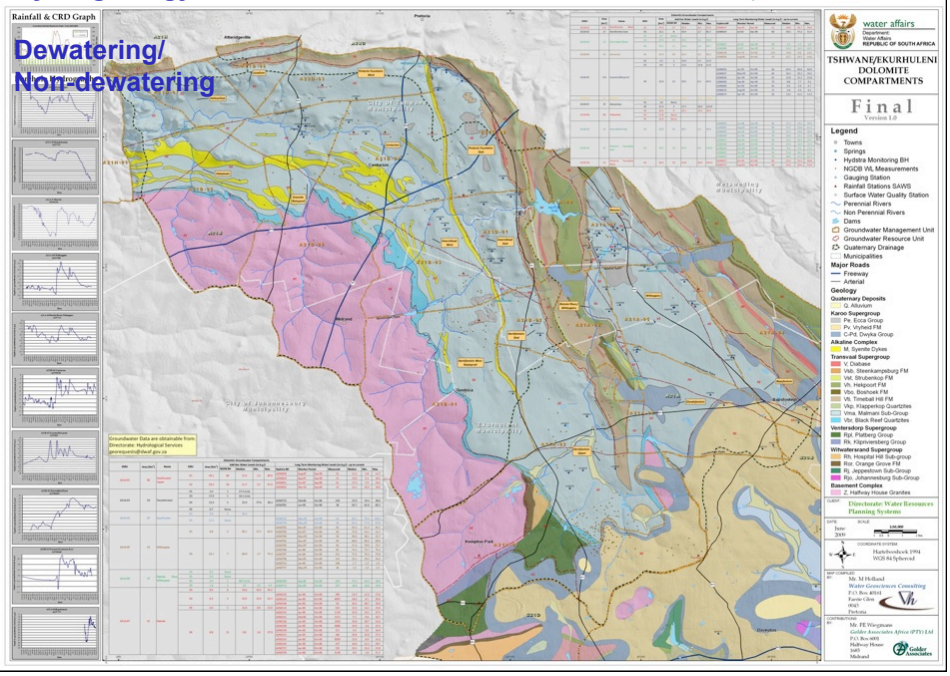
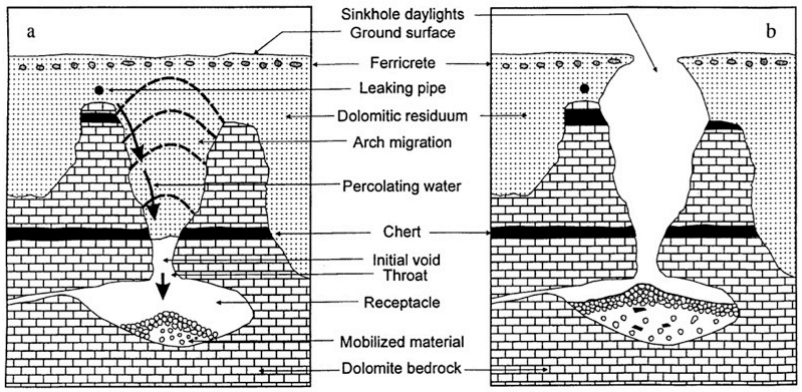
## Hydrogeology




**Dewatering/ Non-dewatering**

## Susceptibility determination

- Specifically:
  - Receptacle development and bedrock morphology
  - Mobilization potential and agents
  - Blanketing layer properties



## Planning & Development

Assign appropriate land use to each Inherent Hazard Class.

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## Planning & Development

Assign appropriate land use to each Inherent Hazard Class.

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## Planning & Development

**Dolomite Risk Management Plan.**

Water precautionary measures.
Foundation designs.
Monitoring
Maintenance
Vigilance

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## Vulnerability (Groundwater)

- Groundwater context:
  - Susceptibility of an aquifer to droughts (quantitative)
    Likelihood of borehole drying up during droughts due to increased stress on low-yielding groundwater sources & reduced recharge (Calow *et al* 1996).
  - Susceptibility of an aquifer to contamination (qualitative)
    Likelihood for contaminants to reach a specified position in the groundwater system after introduction at a location above the uppermost aquifer (NRC 1993).

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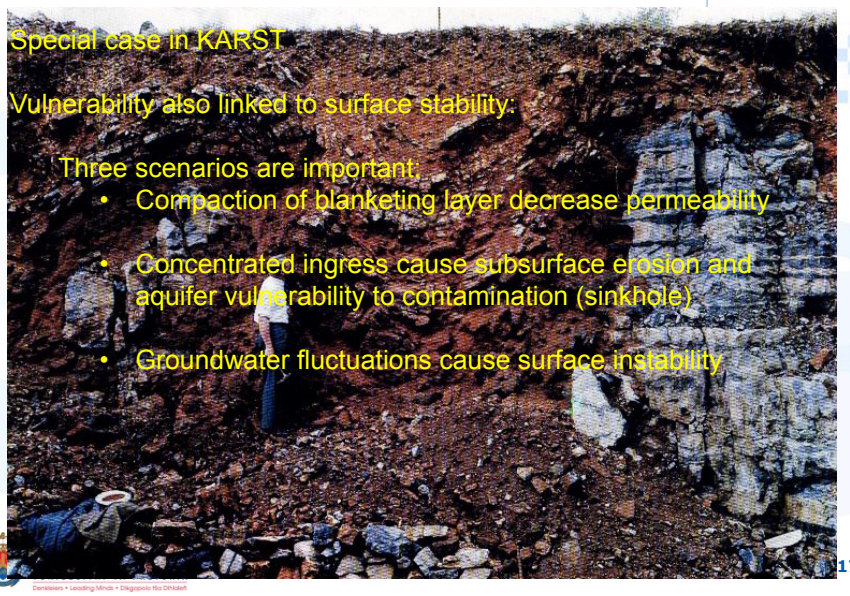
## Vulnerability

Special case in KARST

Vulnerability also linked to surface stability:

Three scenarios are important:

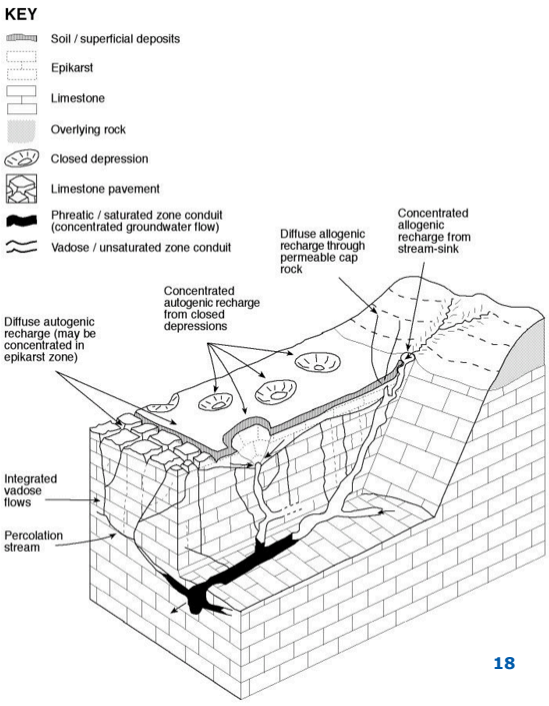
- Compaction of blanketing layer decrease permeability
- Concentrated ingress cause subsurface erosion and aquifer vulnerability to contamination (sinkhole)
- Groundwater fluctuations cause surface instability





## Vulnerability

Conceptual model of karst aquifer (Gunn 1986)



## Vulnerability

- Past attempts in RSA:
  - Lynch et al (1994)
  - Foster (1987)
  - Van Schalkwyk & Vermaak (2000)
  - WRC (AVAP)
- But not KARST specific
- WRC funded research project involved the development of vulnerability mapping in Karst terrains – specifically in the COHWHS (Leyland 2008).



## Vulnerability Mapping

- European karst approach investigated:
- COP Method (Vias et al 2003)
  - Carbonate rock aquifers
  - Determination of protection offered by the vadose zone against contaminant event.
- Locally adjusted to VUKA (Leyland 2008)

## Vulnerability Mapping

- VUKA Vulnerability Index:
  - Combination of three maps:
    - Overlying layers map
    - Concentration of flow map
    - Precipitation map

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## VUKA Method

- Overlying layers map
  - Protection provided by unsaturated zone
    - Soil type & thickness
    - Lithology

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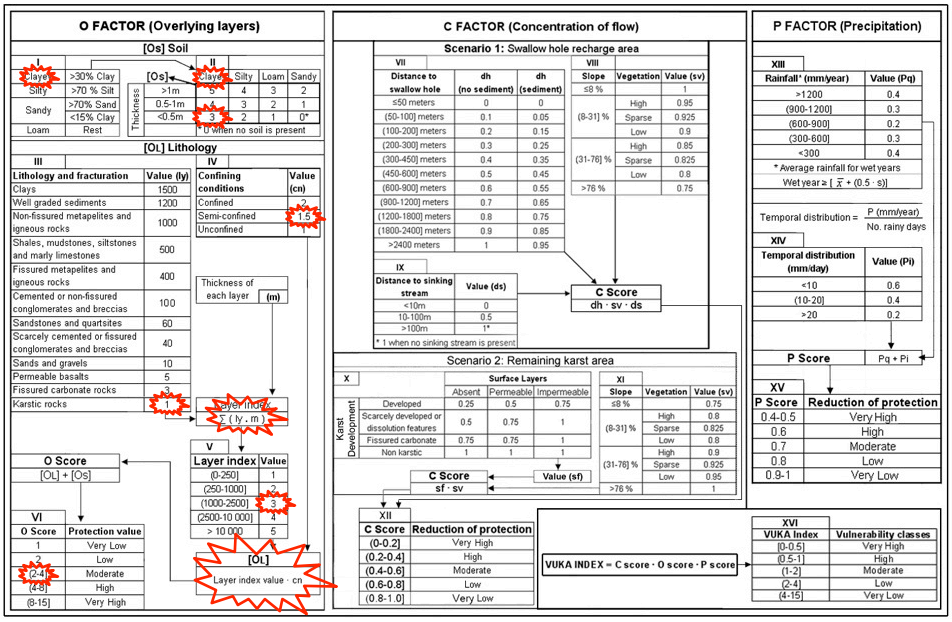
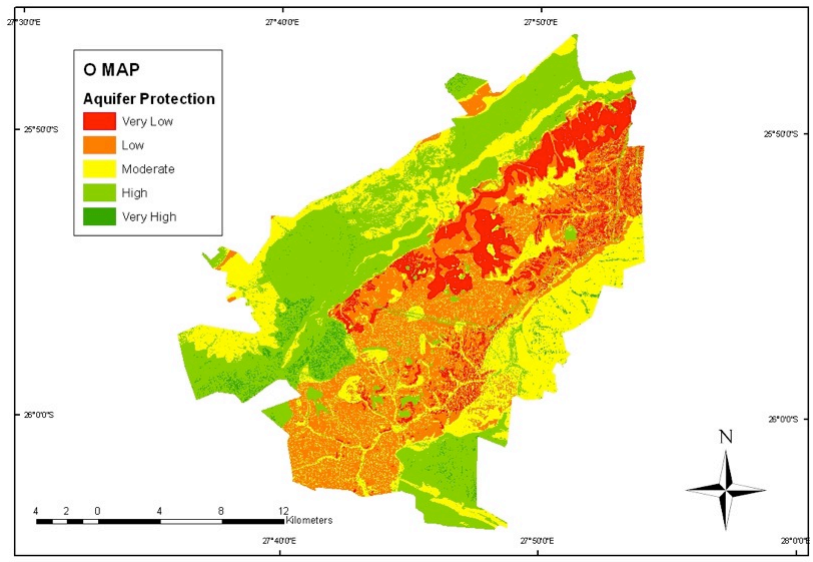
## VUKA Method




## Overlying layer (O Factor) map for the COHWS



## VUKA Method

- Concentration of flow map
  - Swallow hole recharge
  - Remaining karst

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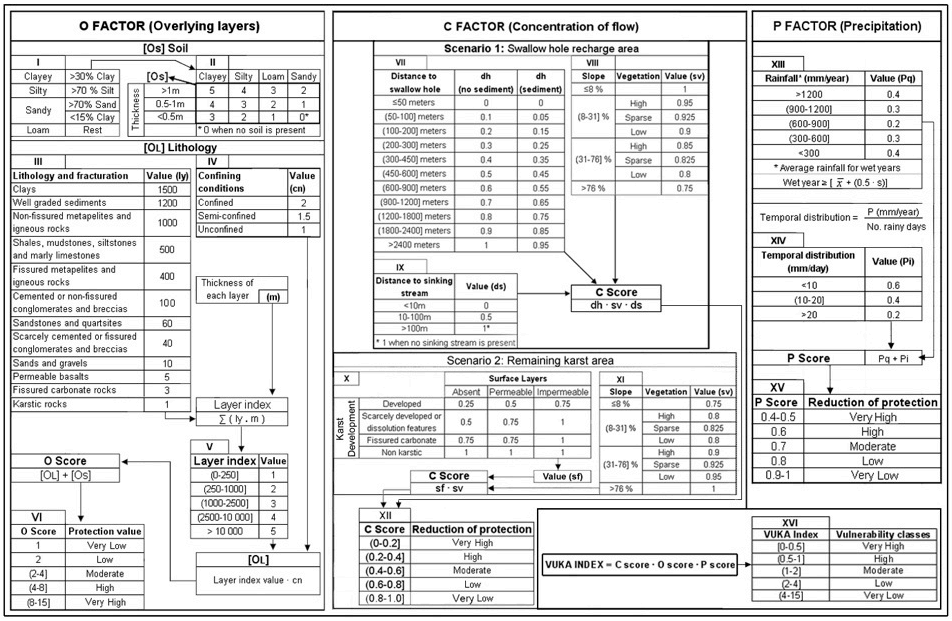
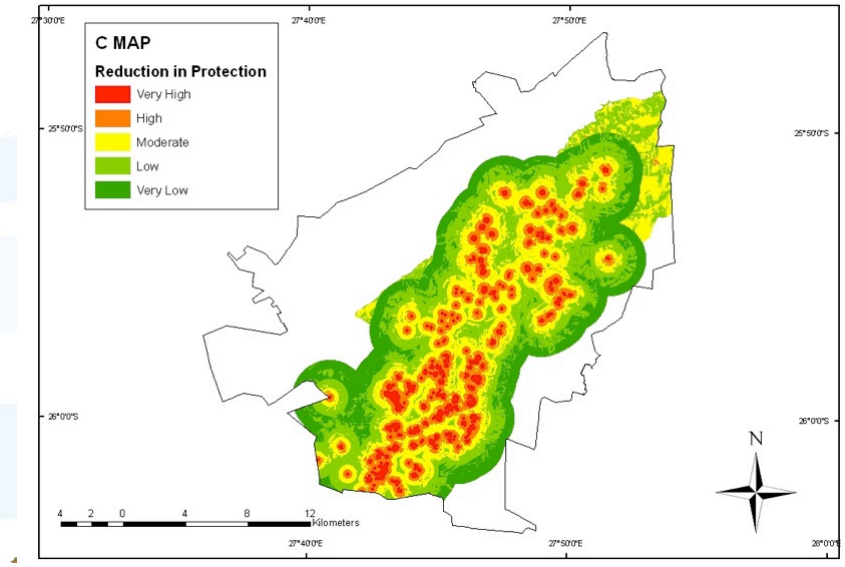
## VUKA Method



## Concentration of flow layer (C Factor) map for the COHWHS

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## VUKA Method

- Precipitation map
  - Reduction of natural aquifer protection
    - Rainfall amount
    - Temporal distribution

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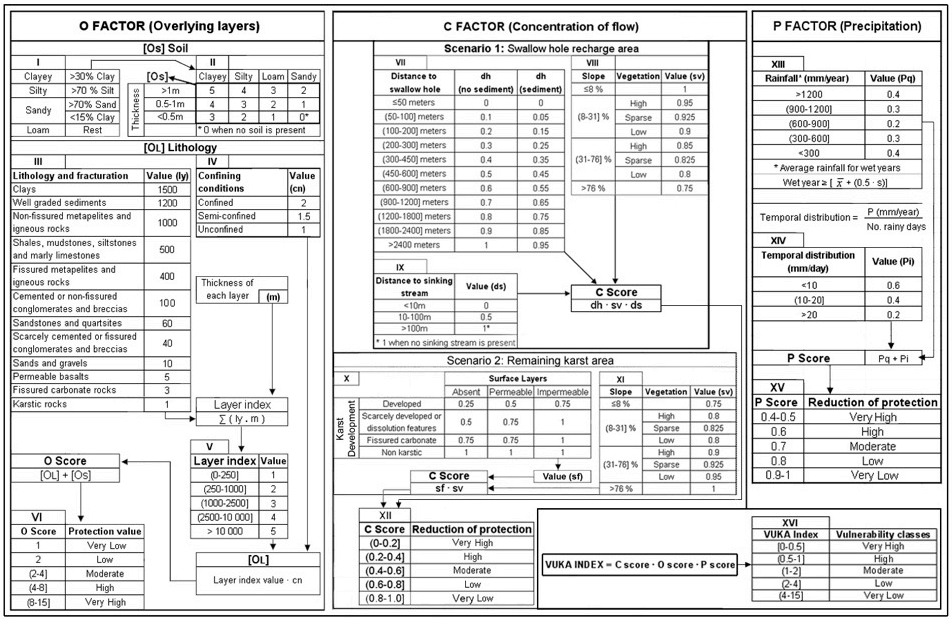
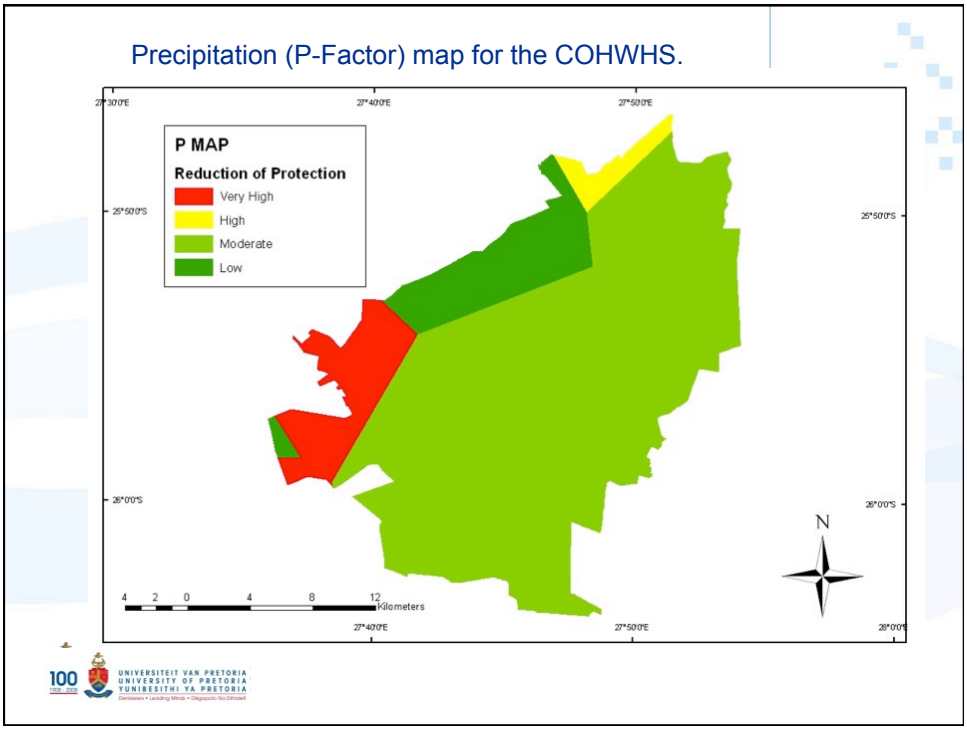
## VUKA Method


O FACTOR (Overlying layers)
[Os] Soil
[OL] Lithology
C FACTOR (Concentration of flow)
Scenario 1: Swallow hole recharge area
Scenario 2: Remaining karst area
P FACTOR (Precipitation)
O Score
[OL] + [Os]
Layer index
∑ ( ly . m )
[OL]
Layer index value · cn
C Score
dh · sv · ds
sf · sv
P Score
Pg + Pi
VUKA INDEX = C score · O score · P score


Precipitation (P-Factor) map for the COHWHS.
P MAP
Reduction of Protection
Very High
High
Moderate
Low
27°30'0"E
27°40'0"E
27°50'0"E
25°50'0"S
26°0'0"S
N
4 2 0 4 8 12
Kilometers
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## VUKA Method

Product of the three sub-factors

| Vulnerability index | Vulnerability classes |
|---|---|
| 0 – 0.5 | Very high |
| 0.5 – 1 | High |
| 1 – 2 | Moderate |
| 2 – 4 | Low |
| 4 – 15 | Very low |

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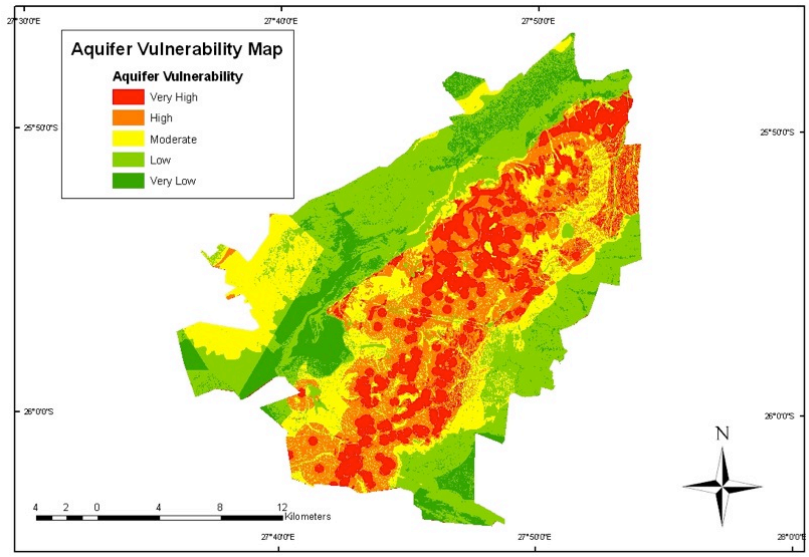

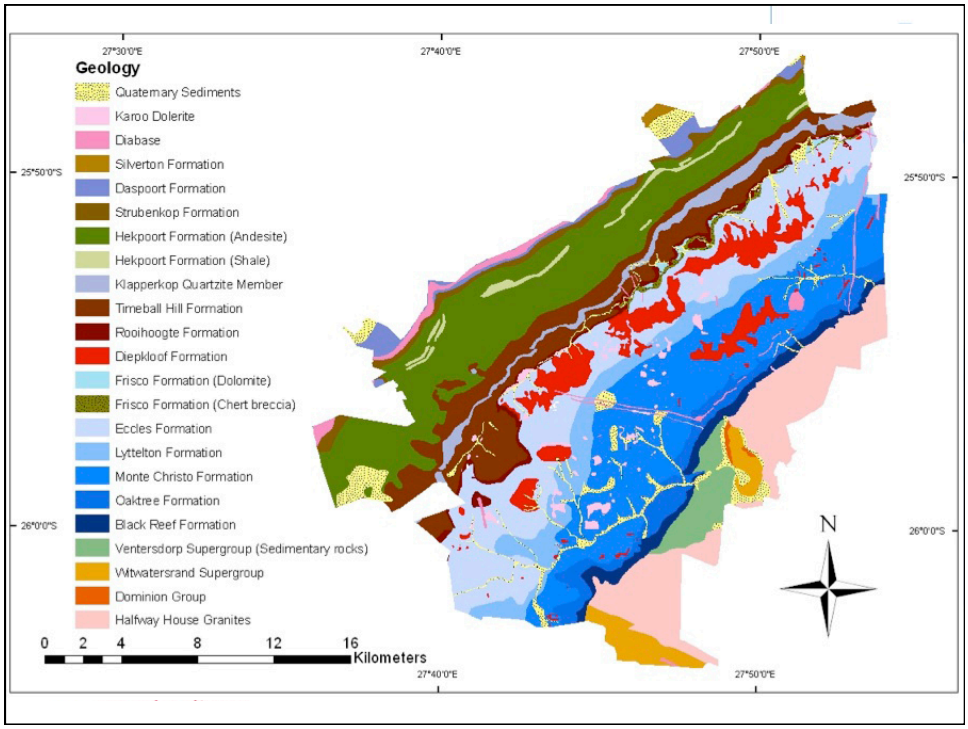


## Intergrated Dolomite Aquifer Susceptibility Characterization

| Parameter | Vulnerability mapping | Surface stability | S.I. technique |
|---|---|---|---|
| Soil type & thickness | ⊗ | ⊗ ? Blanketing layer (more detail) | Land-type data, mapping (gravity & drilling for blanketing layer) |
| Rock type | ⊗ | ⊗ | Geological maps, mapping, drilling |
| Depth to groundwater | ⊗ | ⊗ | Available data, hydrocensus, drilling |
| Depth to bedrock vs. groundwater level | | ⊗ | Gravity, drilling |
| Vegetation cover | ⊗ | | Remote sensing, mapping |
| Slope gradient | ⊗ | | DTM, topocadastral |
| Karst development | ⊗ | | Mapping |
| Karst features (historic) | ⊗ | ⊗ | Mapping |
| Rainfall | ⊗ | | Available (Weather Service) |
| Groundwater abstraction | | ⊗ | Available data |

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## Intergrated Karst Terrain Susceptibility

1. Determine aquifer vulnerability – VUKA
2. Desk study – site specific vulnerability & regional surface stability
3. If vulnerability is high/very high
   Flag site as protected
4. No further investigation or change development type

5. Favourable aquifer & surface stability

Proceed

↓



## Intergrated Karst Terrain Susceptibility

6. Inherent Hazard & Risk assessment

- Additional information:
  - Depth to bedrock/bedrock morphology
  - Mobilization potential
  - Groundwater abstraction (dewatering)

7. Inherent Hazard Class & appropriate development
   (Usually site specific)

## Intergrated Karst Terrain Susceptibility

8. Recommend appropriate groundwater management guidelines.
9. Appropriate development related to vulnerability and Inherent Hazard Class
10. Site specific decision on maximum allowable dewatering rate.
11. Risk Management plan.

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## Acknowledgements


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  - Funding of vulnerability mapping in COHWHS
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