Assessing aquifer vulnerability to seawater intrusion using GALDIT method:

Application to the Portuguese Aquifer of Monte Gordo

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PROBLEM DEFINITION

- Continued human interference with the coastal hydrologic system has led to pollution of coastal groundwater aquifers by salt water.

- Change in groundwater levels with respect to mean sea elevation along the coast largely influences the extent of seawater intrusion in the fresh water aquifers.

- The smaller the drop in groundwater levels, the lesser the sea water intrusion in the aquifers. In other words, **the magnitude of change in sea level would have the identical effect on seawater intrusion if the groundwater levels were held constant**.

- In the **geological past**, sea levels have changed with changes in natural climatic conditions several times, during the glacial and interglacial periods.

- However, in the **geological present**, the climate is largely influenced by human interference in the form of air and water pollution and this has led to an imbalance in atmospheric heat. The effect of this thermal imbalance is seen in the melting of polar ice caps leading to a rise in sea level. Coastal infrastructures, tourism, and other economic activities are also at risk in costal areas.

PROBLEM DEFINITION

- The aim of the present investigation is to study the impacts of **sea level rise** on the extent of **surface inundation along the coast** and **sea water intrusion** into the coastal aquifers in Southern Portugal´s Algarve coastal zone, using the **GALDIT method** developed by CHACHADI and LOBO-FERREIRA (2001);
- Comparing this results with the ones given by the study developed for North Goa coast, presented in CHACHADI and LOBO-FERREIRA (2005).

DEFINITION OF GROUNDWATER VULNERABILITY TO SEA WATER INTRUSION

- Following the basics concepts presented in LOBO-FERREIRA and CABRAL (1991) for the definition of **groundwater vulnerability to pollution**, we believe that the most useful definition of vulnerability to seawater intrusion is one that refers to the **intrinsic characteristics** of the aquifer, which are relatively static and mostly beyond human control.

- **Groundwater vulnerability to sea water intrusion** can to be defined as:

"the sensitivity of groundwater quality to an imposed groundwater pumpage or sea level rise or both in the coastal belt, which is determined by the intrinsic characteristics of the aquifer"

SUGGESTED SYSTEM OF VULNERABILITY EVALUATION AND RANKING - GALDIT INDEX

Most important mapable factors that control the seawater intrusion:

- **G**roundwater Occurrence (aquifer type; unconfined, confined and leaky confined).
- **A**quifer Hydraulic Conductivity.
- Height of Groundwater **L**evel above Sea Level.
- **D**istance from the Shore (distance inland perpendicular from shoreline).
- **I**mpact of existing status of seawater intrusion in the area.
- **T**hickness of the aquifer, which is being mapped.

The acronym **GALDIT** is formed from the highlighted and underlined letters of the parameters.

SUGGESTED SYSTEM OF VULNERABILITY EVALUATION AND RANKING - GALDIT INDEX

- A **numerical ranking system** to assess seawater intrusion potential in hydrogeologic settings has been devised using **GALDIT factors**.

- The basic assumption made in the development of the tool include:

  "that the bottom of the aquifer(s) lies below the mean sea level".

- The system contains three significant parts: (1) **weights**, (2) **ranges** and (3) **importance ratings**:

(1) Indicator weights: represent the relative importance of the indicator to the process of seawater intrusion. A group of people (geologists, hydrogeologists, environmentalists, etc) was asked to weigh these indicators in the order of importance to the process of seawater intrusion. The most significant indicators have weights of 4 and the least a weight of 1. Those weights must be considered as constants and may not be changed.

SUGGESTED SYSTEM OF VULNERABILITY EVALUATION AND RANKING - GALDIT INDEX

(2) Assigning of **importance rates** to indicator variables using a scale of 2.5 to 10 - each of the indicators is subdivided into variables according to the specified attributes to determine the relative significance of the variable in question on the process of seawater intrusion (higher importance rating indicates high vulnerability to seawater intrusion).

(3) Decision criterion is the total sum of the individual indicator scores obtained by multiplication of values of importance ratings with the corresponding indicator weights.

Higher values of importance ratings of the variable, corresponds to more vulnerable aquifers to seawater intrusion.

A more detailed description of the **GALDIT index methodology** is available in a former application to the Bardez aquifer in Goa, India (http://www.teriin.org/teri-wr/coastin/newslett/coastin4.pdf and http://www.teriin.org/teri-wr/coastin/newslett/coastin7.pdf) and it will be presented in the **second Part of this paper**, *i.e.* CHACHADI and LOBO-FERREIRA (2005), also published in the Proceedings of this *4th Interceltic Colloquium.*

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO

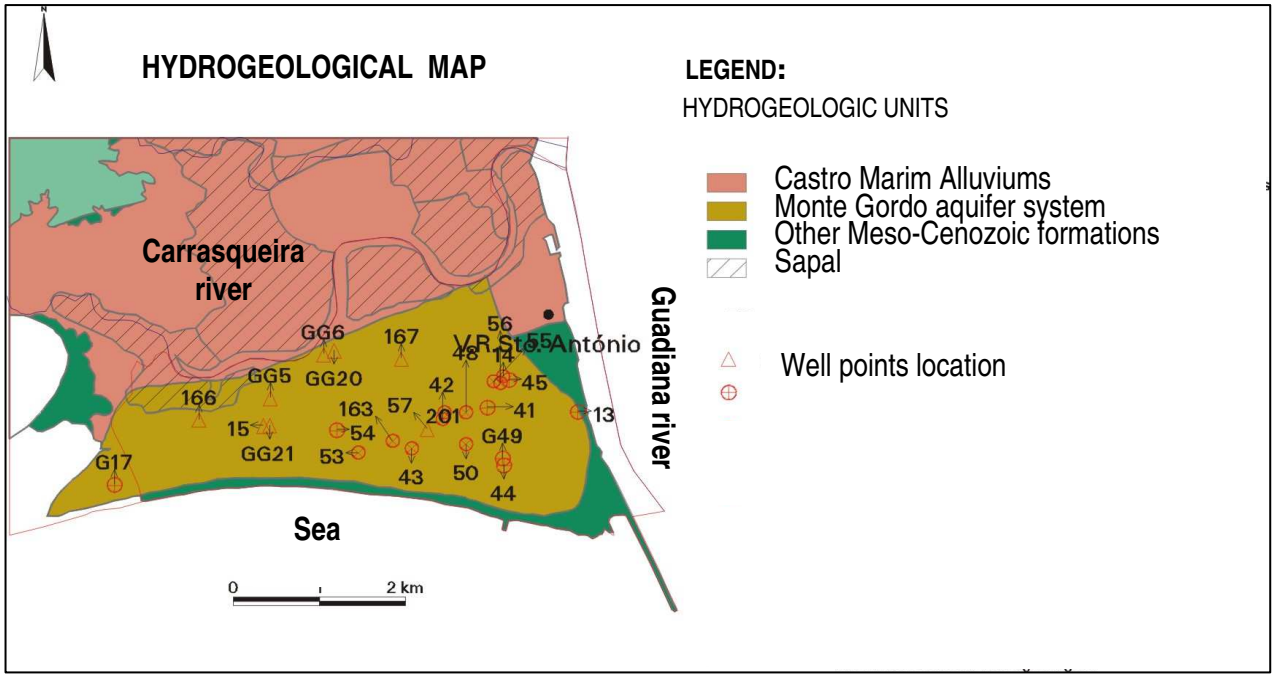
Aquifer system of Monte Gordo

- is extending from Vila Real de Santo António, in Southern Portugal's Algarve region, to Praia Verde;
- total area of approximately 10 km^2 (extension of about 5 km long by 2 km as average width);

Lithological formations (SILVA, 1984):

- sands, located along the coast line in a narrow strip of **sands dune** - this is an environment protected area occupied by pine trees.
- sands of different grain sizes with important argillaceous and organic components to the North of this region, corresponding to **old dune systems and alluvial materials**.

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO (cont.)



- the structure of the aquifer system corresponds to an E-W basin, overlaying an impermeable substratum constituted by silts and clays, of unknown thickness, considered as old alluviums; underlying this level the Pliocene sandstone appear.

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO (cont.)

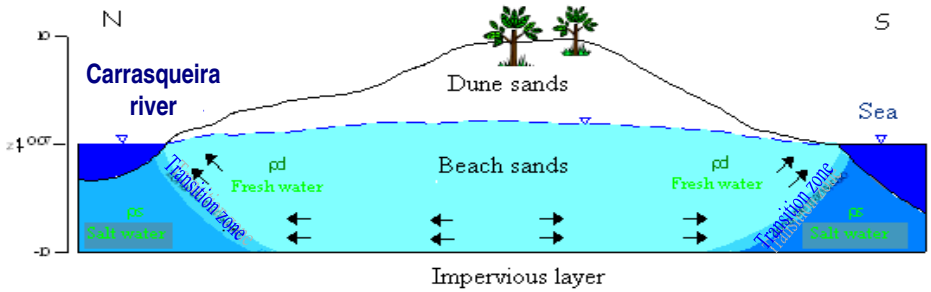
Hydrogeologic characteristics:

- unconfined porous aquifer;
- saturated zone corresponds to a sandy level - ≈ 12 meters of thickness;
- sand dune system occurs at the surface - thickness depends on the topography, ≤ 10 meters of thickness.

Saltwater-freshwater interfaces:

- along the Carrasqueira and Guadiana rivers (the rivers side it was considered a brackish water zone, with 5 g/L of salinity);
- along the coastal zone (the oceans side it was considered with high salinity content, of about 36 g/L).

N-S conceptual cross-section of the aquifer



GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO (cont.)

6 GALDIT parameters were evaluated:

Parameter G: Groundwater Occurrence (Aquifer Type)

- It is an unconfined aquifer so a GALDIT rating of **7.5** was assigned.

Parameter A: Aquifer Hydraulic Conductivity

- values range from 28 m/day to 76,3 m/day (as referred by SILVA, 1984);
- values for the aquifer area were interpolated the using a kriging method; near the coastal line and near the alluvial areas adjacent to the Carrasqueira and Guadiana rivers smaller values were assigned;
- this values were used as input data for a groundwater flow and transport model developed for this aquifer by DIAMANTINO *et al.* (2003);
- after calibration the initial hydraulic conductivity distribution was slightly rearranged and those calibrated values were then used for the GALDIT index computation.

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO (cont.)

Parameter L: Height of Groundwater Level above Sea Level

- values were provided by the groundwater model calibration for the study area in steady state regime (*cf.* DIAMANTINO *et al.*, 2003; LOBO-FERREIRA *et al.,* 2003); this is considered as the **first scenario** of Height of Groundwater Level above Sea Level.

Two additional scenarios were considered:

1) potential rise in sea level of 0,25 m

2) potential rise in sea level of 0,5 m

These scenarios may be considered as equivalent to scenarios of decreases of regional groundwater level, due to overexploitation, of the same order of magnitude.

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO (cont.)

Parameter D: Distance from the Shore

- three perpendicular distances (*i.e.* 500, 750 and 1000 m) were calculated from the coastal line in the Southern part of the aquifer, and from the rivers banks of Carrasqueira, in the Northern part, and Guadiana, in the Southeast part of the aquifer;
- surface waters in these rivers are brackish, so seawater intrusion vulnerability in these areas has the same practical negative effects as those of the coastal zone.

Parameter I: Impact of existing status of Seawater Intrusion

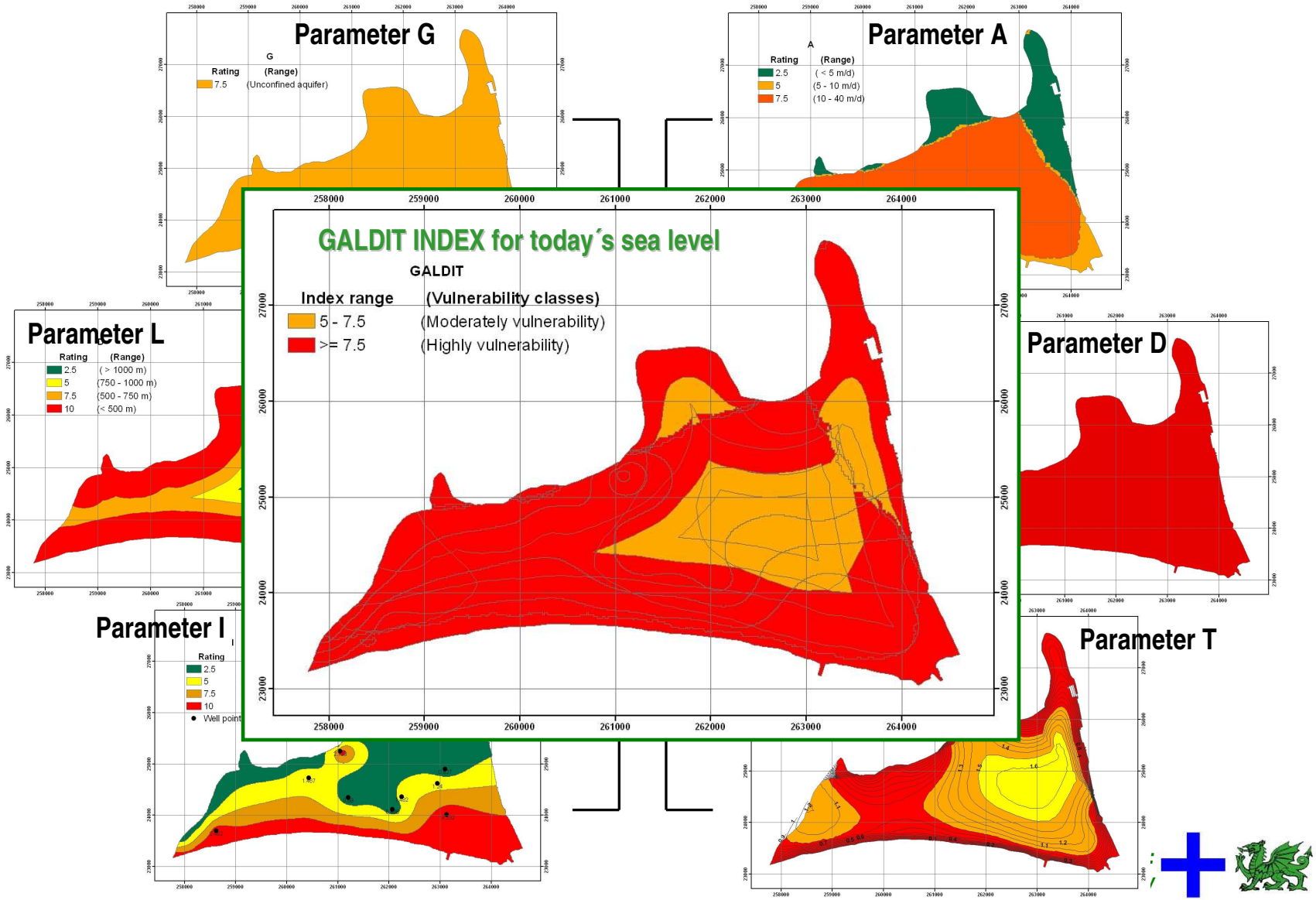
- to evaluate this parameter the **ratio of Cl^- / HCO_3^-** was determined for those wells that have available the concentrations of those two anions.

Parameter T: Thickness of Aquifer

- the study aquifer is 12 m thick, so a GALDIT rating of **10** was assigned.

Assessing aquifer vulnerability to seawater intrusion using GALDIT method: Part 1 – Application to the Portuguese Aquifer of Monte Gordo

GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO



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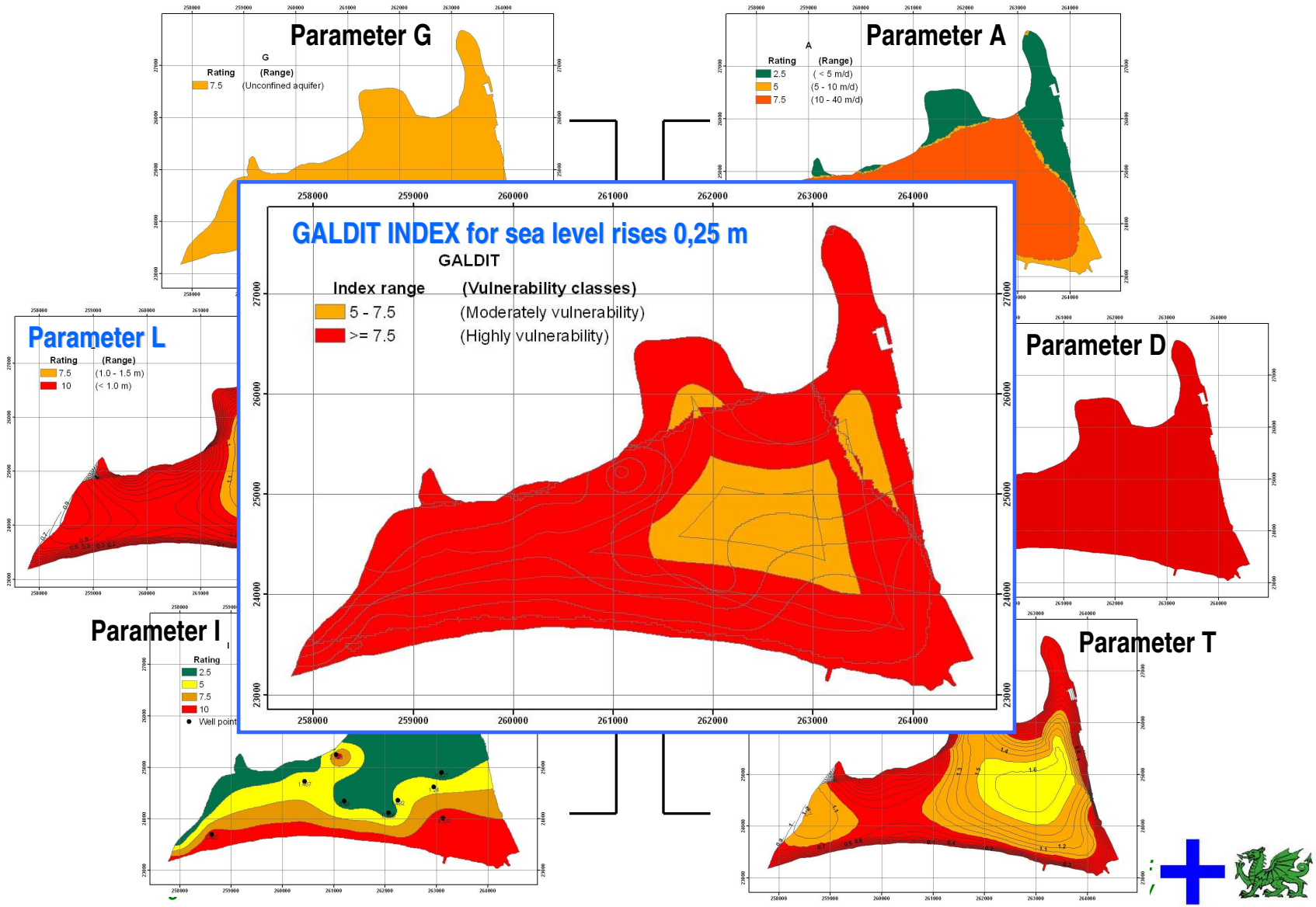

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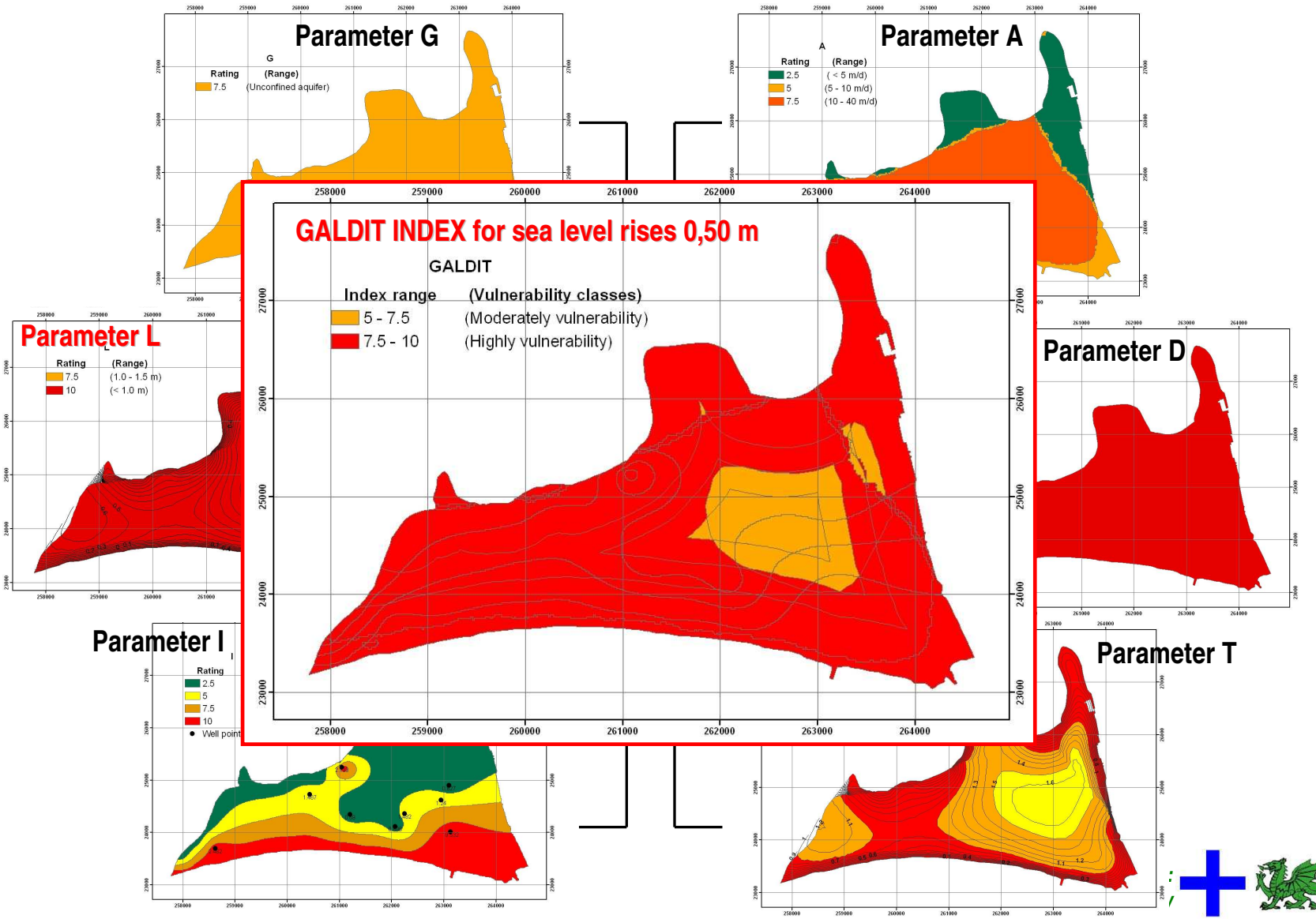
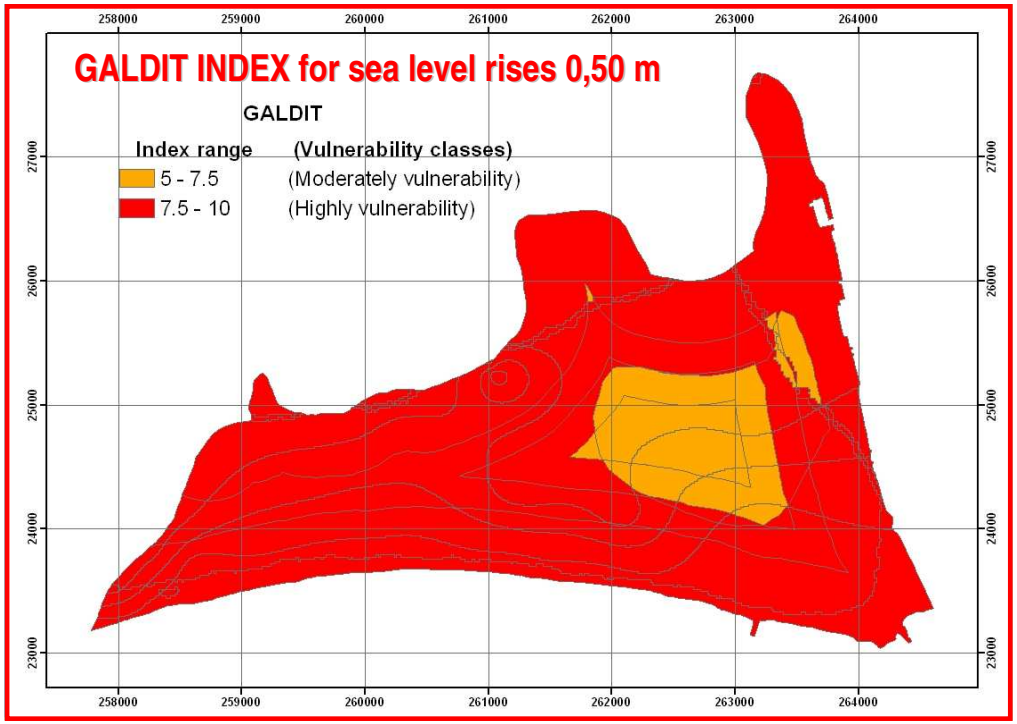


GALDIT APLICATION TO THE AQUIFER SYSTEM OF MONTE GORDO

Comparison of the three scenarios



CONCLUSIONS (1):

1) The new method of **aquifer vulnerability mapping due to sea water intrusion** *i.e.* **GALDIT method** developed by CHACHADI and LOBO-FERREIRA (2001) has been successfully used to assess the extent of aquifer contamination due to sea water intrusion.

2) The maps derived can be used as a tool for **management of the coastal groundwater resources**. Similar applications can be done for the island aquifers so that optimal management practices can be evolved for groundwater use.

3) The maps can be prepared using GIS or if the area is small, point values of the vulnerability indices can be obtained from the equations presented in CHACHADI and LOBO-FERREIRA (2005) and then contoured using SURFER to get a vulnerability score map as done in the present study.

CONCLUSIONS (2):

4) The point values of GALDIT- index can be used in ascertaining the **wellhead protection areas** in the coastal belts to prevent seawater mixing.

5) The three scenarios application regarding the parameter L - *Height of Groundwater Level above Sea Level*, show how important it is to assess on due time the **impact of sea water level rise do to climate changes**. These figures are also important to observe the negative effects of overexploitation of aquifers, which affects regional groundwater level, causing in coastal zone salt water intrusion.

6) To complement this reasoning, on the effects of sea water rise in aquifers, the values presented before for Monte Gordo aquifer can be compared with those computed for the Bardez aquifer in Goa, India, presented in Part 2 of this paper (*also included in the Proceedings of this 4th Interceltic Colloquium*), *i.e.* in CHACHADI and LOBO-FERREIRA (2005).

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Final report available in http://www.dha.lnec.pt/nas/estudos/COASTIN.htm