# Colorado River Water Resources Vulnerability: Project for Hill Country Conservancy: FINAL REPORT

Daniel Zavala Araiza [dz2675] GIS in Water Resources

## INTRODUCTION

Vulnerability maps are a tool that has been used over the years to help identify and classify regions and water resources based on their potential to get polluted. For both ground and surface water, it is important to determine which areas are keen to contamination, especially when conservancy efforts are intended and possible pollution could have serious effects in water quality / quantity of nearby urban areas.

### *Objective*

The objective of this project was the development of a tool based on geographical information that is useful in determining which water resources are more vulnerable to pollution. In other words, which parts or parcels of land are more valuable in terms water management in order for conservancy efforts to focus on maintaining and preserving them. The area of interest for the project is the Colorado River Watershed within the Hill Country.

### *Hill Country Conservancy*

Hill Country Conservancy (HCC) is a nonprofit organization that focuses on setting up conservation easements. They work with land owners, attorneys, and government to establish land preservation agreements with the idea of conserving a property in its natural state. HCC is interested in land conservation for a couple of reasons, including preserving the natural landscape, biodiversity, and water. It is this last objective where vulnerability mapping plays an important role. Identifying those areas with a major potential to get polluted could help HCC make decisions on particular regions where they should focus their conservation efforts, looking for land preservations agreements in those areas whose pollution would have a greater impact in the aquifer and in the water resources in general. Figure 1 shows the area where HCC works, it is interesting that almost all the Edwards aquifer falls into that area, highlighting the importance of determining possible pollution that could impact aquifers and other water resources in the region.

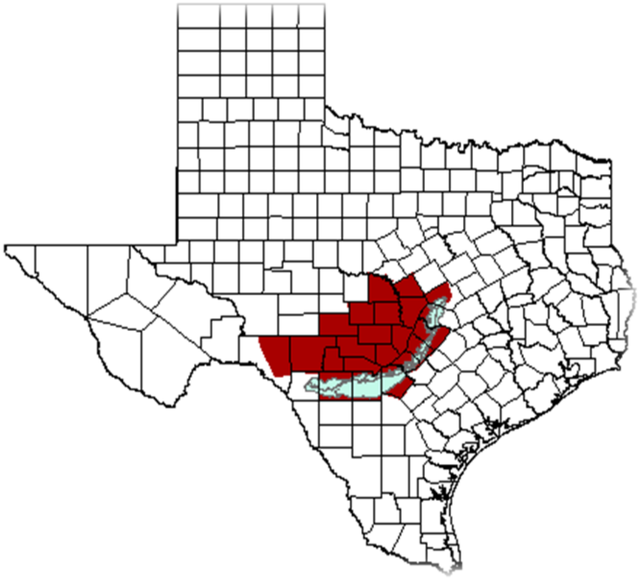

Figure 1 – Texas map showing the region where HCC works and the Edwards Aquifer.

### *Background*

A water resource system can be evaluated in terms of reliability, resiliency and vulnerability (Hashimoto, et al, 1982). The first of these terms, reliability is a measurement of the possibility of the system to fail. Resiliency is related to the ability of the system to recover from failure, while vulnerability refers to the consequences and effects that a failure would cause on the system. Speaking in a broader sense, these failures could include many types of impacts and stresses that are commonly part of water resources systems. In terms of land conservation and sustainability it is of great importance to develop an index that measures the magnitude of these effects. Focusing on the latter of the terms described above, one of this "failures" that affects a water system could be the introduction of pollutant species into a surface or ground water system. In this case, reliability would tell how likely it is for a particular system to get polluted, resiliency would take into account the ability of the system to recover from the stress caused by the introduction of the pollutant, and vulnerability would deal with the effects that the pollutant would have on the system. All three are of great importance for water resources management, but if the focus in on land preservation, and then what is the most important is a prevention approach, with the objective of sustaining water quality and quantity of a region. In this case, vulnerability would be the most important of the three, providing information of which areas are more susceptible to "failure", and not their possible ability to recover from it.

Based on geological and hydrological data, it is possible to classify different areas in order to determine both, ground and surface water vulnerability in terms of human impact, development, and pollution (Massone, et al, 2010). When talking about vulnerability mapping and not water resources systems in general, vulnerability can be defined as a group of intrinsic characteristics that determines the sensitivity of ground and surface water to contamination by human activities. Thus, many characteristics both, geological and hydro geological could be taken into account in order to establish a ranking system based on how likely it is for a particular area to get polluted.

This potential of water resources to get polluted refers to zones where soil layers do not provide protection to a rapid transfer of pollutant species. In the case of groundwater vulnerability, aquifers would be of great importance and interest (Gogu and Dassargues, 2000).

It is important to make the distinction between intrinsic vulnerability and specific vulnerability. Intrinsic vulnerability refers to pollution potential as a whole, independent of the nature of the contaminants, without trying to focus on any particular type or source, and is the approach followed in this project. On the other hand, specific vulnerability takes into account a particular pollutant, thus the way to generate this type of mapping is completely different. In the case of specific vulnerability, the generated tool is known as risk mapping, instead of vulnerability mapping, and it could include a detailed analysis of point sources. One example of this application would be for oil spills or leakage of a pollutant, where one of the most important characteristics that would have to be taken into account is the residence time of the specie in the different soil layers.

A coupled analysis using both, vulnerability and risk mapping, could be very useful to get a complete picture in terms of water resources management for a specific community. If there is little or no knowledge of a particular source of pollution or a specific pollutant, the importance of vulnerability arises, as a first approach to categorize and define specific regions or areas where a more detailed study should take place.

There have been a couple of approaches to vulnerability mapping, the most used is the EPA DRASTIC model (Aller, et al, 1985, and EPA, 2011) , which takes seven parameters to rank vulnerability: **D**epth to water, **N**et recharge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone media, and **H**ydraulic Conductivity of the aquifer. The ranking system is based on a weighted sum of these parameters; the importance of each parameter relative to the rest was decided rather arbitrarily based on the experience of the researchers. Important assumptions under the DRASTIC method are that once the pollutant is in the ground surface, it will be flushed into the ground water by precipitation, and that the pollutant has the mobility of water (Sener, et al, 2009).

In many cases, DRASTIC is not the best approach, with mixed results in many parts of United States. Another calibrated probability map was suggested by USGS (USGS, 1999), taking into account land use, soil drainage, and depth to water.

After DRASTIC, there have been many approaches that modify either the parameters involved in the model, or the weight of each parameter. Besides DRASTIC, other vulnerability mapping methods include SINTACS, PI and COP (Yildirim, et al, 2007). SINTACS is really similar to DRASTIC, but gives different importance to the parameters. For example, for SINTACS aquifer properties such as conductivity and aquifer media are much more important than depth to water. The PI model focuses on parameters that reflect two main parameters: **P**rotective cover (thickness, permeability, lithology), and **I**nfiltration conditions (conductivity, vegetation). Finally the COP model, which stands for **C**oncentration of flows, **O**verlying layers, and **P**recipitation, takes as the most important parameters texture, thickness, lithology and Karts features. A comparative study was made for these three methods (Yildirim, et al, 2007), showing that for a specific area with specific meteorological and hydro geological characteristics, an specific method would work best in mapping vulnerability.

There is no consensus between hydro geologists of the best way to approach vulnerability mapping, with great differences in the parameters used and the importance of each parameter, though one of the agreements is that the effectiveness of a method can vary from one natural environment to another, thus vulnerability is a relative dimensionless property with no direct way of measuring it (Gogu and Dassargues, 2000). In many cases, the choice and quantification of parameters has no rigorous experimental background support, and the selection is based more on a theoretical basis (Van Stempvoort, et al, 1993): the consequence is that the weighting of the parameters is arbitrary and selected specifically for the local environment or zone where it will be applied.

## METHODOLOGY

In order to develop the tool for HCC two approaches to vulnerability were considered: ground and surface water vulnerability. The DRASTIC method was used as the base method to develop the tool, however, it has been considered that using the seven parameters from DRASTIC could be redundant, and not so many parameters are need to get the same precision and effectiveness in classifying regions in terms of vulnerability (Yildirim, et al, 2007).Therefore, for both, ground water and surface water, the selected parameters were: (1) Soil thickness, (2) soil conductivity, (3) slope, and (4) vegetation. The difference between ground water and surface water are the way these parameters are ranked in terms of the least and the most vulnerable, and the importance of each parameter in the weighted sum that defines the final vulnerability map. Data was collected for each parameter and a layer was generated ranking each parameter separately from 0 to 100. Being zero the least vulnerable, and 100 the most vulnerable in each case. After this classification for each layer, all the layers were part of the weighted sum that resulted in the vulnerability map. For ground water, the first step was generating and equally weighted map, consequently, different relative values were given to the parameters and a sensibility analysis was carried out to test the importance of each parameter in the classification of land as vulnerable.

*Soil thickness* is a measure of how much water can be absorbed; of how much filtration can occur in a specific piece of land. The thicker the land is the least vulnerable it will be for pollutants to migrate and reach groundwater systems. *Soil KSAT*, or soil conductivity gives information of the ability of water (and pollutant) to flow through the soil. This parameter is the main difference between the ground water and surface water vulnerability mapping; in the case of ground water, a low KSAT value means that the region is least vulnerable, but in the case of surface water, it is completely the other way around. *Slope* addresses how likely is water to runoff, steep slopes translate into most vulnerable regions, because the steeper the slope, the more likely that water will run off to a body of water. Finally, the vegetation information is important because it answers the question of how much water will be impeded by the type of vegetative cover in each place, for this parameter, the ranking system was based on the amount of ground cover, where least ground vegetation makes the region more vulnerable, and regions with a lot of ground cover are classified as the least vulnerable.

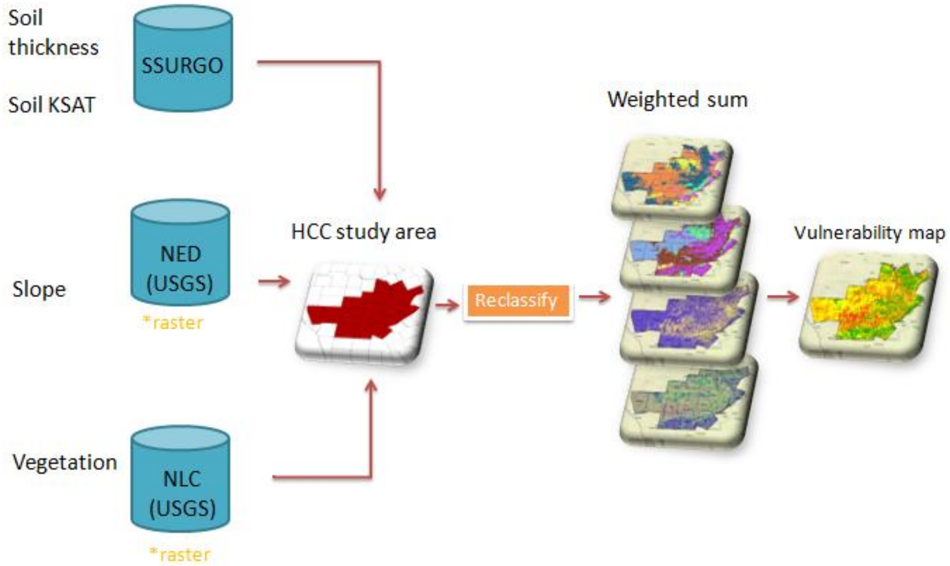

Figure 2 – General process followed to create the vulnerability maps.

Figure 2 shows the basic process that was followed to obtain the vulnerability map. Data for each parameter was obtained from different sources, and using either, the clips function in

ArcGIS or the extract by mask, the HCC study area was selected. If the dataset for a particular layer was not raster but polygon, it was converted to raster, so that all the different layers were rasters. Using the reclassify tool, each layer was ranked according to their particular characteristics, and finally the weighted sum between the layers produced the vulnerability maps.

To obtain the different datasets used in the four selected parameters, the Geospatial Data Gateway from the United States Department of Agriculture was used[1]. Datasets were first filtered for the state of Texas, and then using ArcGIS, the working area limited to the HCC working region. For calculating the slope, the 30 meter National Elevation Dataset (NED) from the U.S Geological Survey (USGS) was used, for this parameter, the initial selection, instead of being state wide, involved just selecting the specific counties that include the HCC working region, facilitating the amount of information that would be processed. Once the NED was obtained for the area of interest, the slope tool from ArcGIS was used to calculate the slope for each grid cell as a previous step before the reclassification.

The vegetation layer is based on the National Land Cover (NLC) dataset from the USGS. This is a raster dataset, where each grid cell is numerically classified based on the type of vegetation. For example, 21 refer to developed, open space, 41 to deciduous forest, and 72 to grassland. This coding system was used to reclassify the layer in terms of ground cover in order to establish the vulnerability ranking.

Both soil thickness and soil KSAT are soil properties, they were obtained from the Soil Survey Geographic (SSURGO) Database. This is a data base that contains the information in to main sections: spatial data (polygons) and tabular data. The tabular data contains a long list of soil attributes of physical and chemical soil properties. They are provided in relational tables thus data base management knowledge is necessary in order to join the attributes contained in the tables with the spatial information (USDA, 1995). Example of the complexity of this process is that each map (spatial) unit consists of three components, for each component there are 60 properties and 84 data elements, additionally there are six possible soil layers, each with 28 soil properties. Extracting the desired parameters becomes a difficult and time consuming process involving the use of some data base software, such as *Microsoft Access*, formatting tables, and using the join/ relate function in *ArcGIS*. An alternative to this approach was found. The first step is to download a Microsoft Access template file that orders all the attributes in tables that afterwards can be imported to ArcMap[2]. An extension for ArcMap called *Soil Data Viewer* was created the Natural Resources Conservation Services of the USDA, it facilitates the whole

---

[1] Geospatial Data Gateway, United States Department of Agriculture, http://datagateway.nrcs.usda.gov/ , accessed November 2011.

[2] The Microsoft Access Template can be downloaded from: http://soildatamart.nrcs.usda.gov/Templates.aspx.

process of importing soil attributes to ArcGIS. Once it is installed, it is possible to open the data viewer from ArcMap, and with a friendly interface select the desired attributes and associate them to the corresponding spatial data (USDA, 2011)[3]. Soil thickness and soil KSAT layers can be easily extracted using this procedure, obtaining two polygon layers that were converted to raster and reclassified in terms of vulnerability.

After having all the four layers reclassified in terms of vulnerability (figure 3), the next step was to add them up; the first approach was to give equal value to each of the layers. Consequent approaches involved giving different relative values to the layers and analyzing the sensibility of the region to each of the parameters.

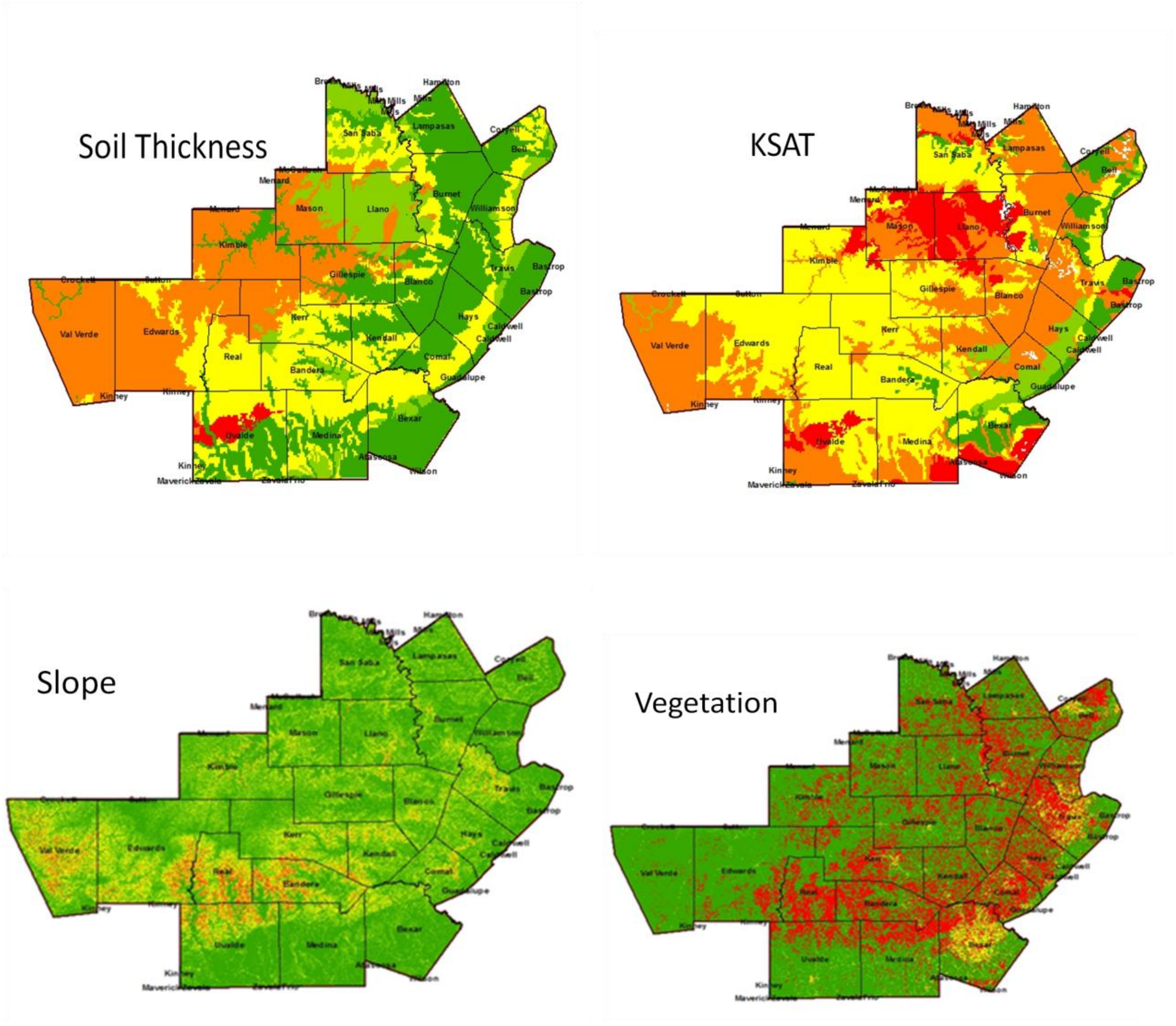

Figure 3 – Each of the four layers, reclassyfied in terms of (groundwater) vulnerability, the green color shows the least vulnerable regions, the red color corresponds to the most vulnerable regions.

---

[3] The Soil Data Viewer can be downloaded from: http://soils.usda.gov/sdv/download.html.

## RESULTS AND DISCUSSION

For each of the vulnerability maps, regions were classified into four main categories: low, moderate, high and very high vulnerability. Figure 4 shows the ground water vulnerability final map, considering that all the parameters have the same weight in the model.

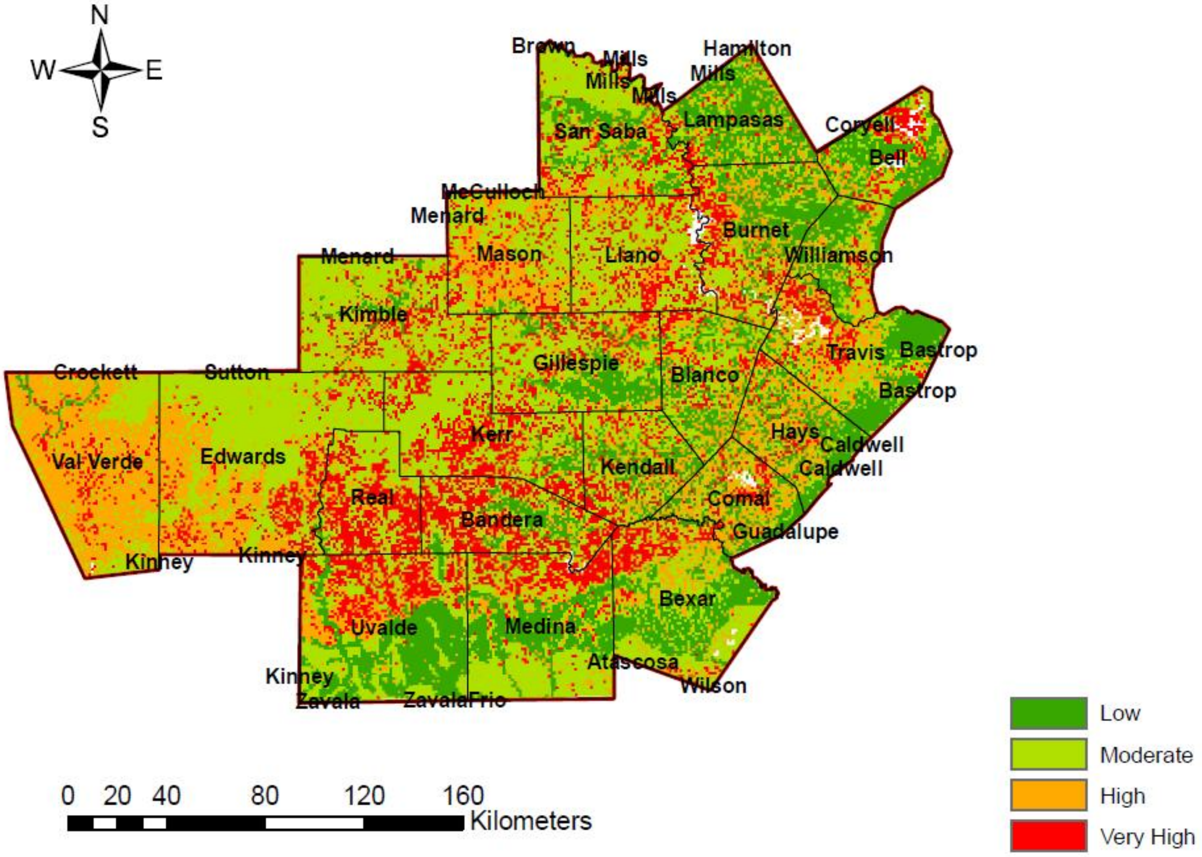

Figure 4 – Ground water vulnerability map; equal weight.

The region shared by the Real, Bandera, Uvalde and Medina counties has the biggest extension for the very high vulnerability classification. Over 40% of the analyzed region has a high or very high vulnerability (Figure 5). 10.37 % of the HCC region has a very high vulnerability, concentrated mainly in the counties mentioned before, but also in a small region in the north, in the Burnet and Llano counties. Another region that should be observed cautiously is the Val Verde County; almost all its territory has a high vulnerability ranking with a few very high spots.

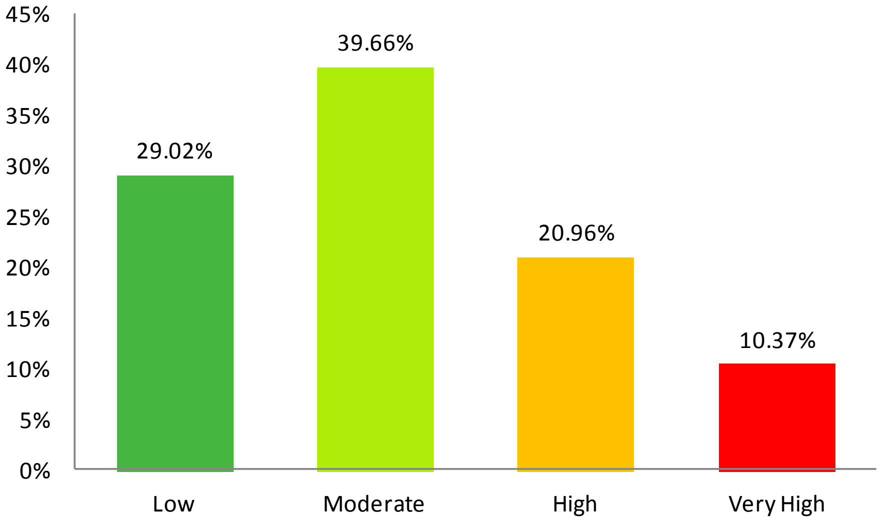

Figure 5 – Percentage of land that falls into each vulnerability category.

As a way of analyzing the real impact that the most vulnerable zones could have on water systems, two important aquifers are overlaid to the ground water vulnerability map showed in figure 4: the Edwards aquifer (major aquifer) and the Hickory Aquifer, a minor aquifer (Figure 6).

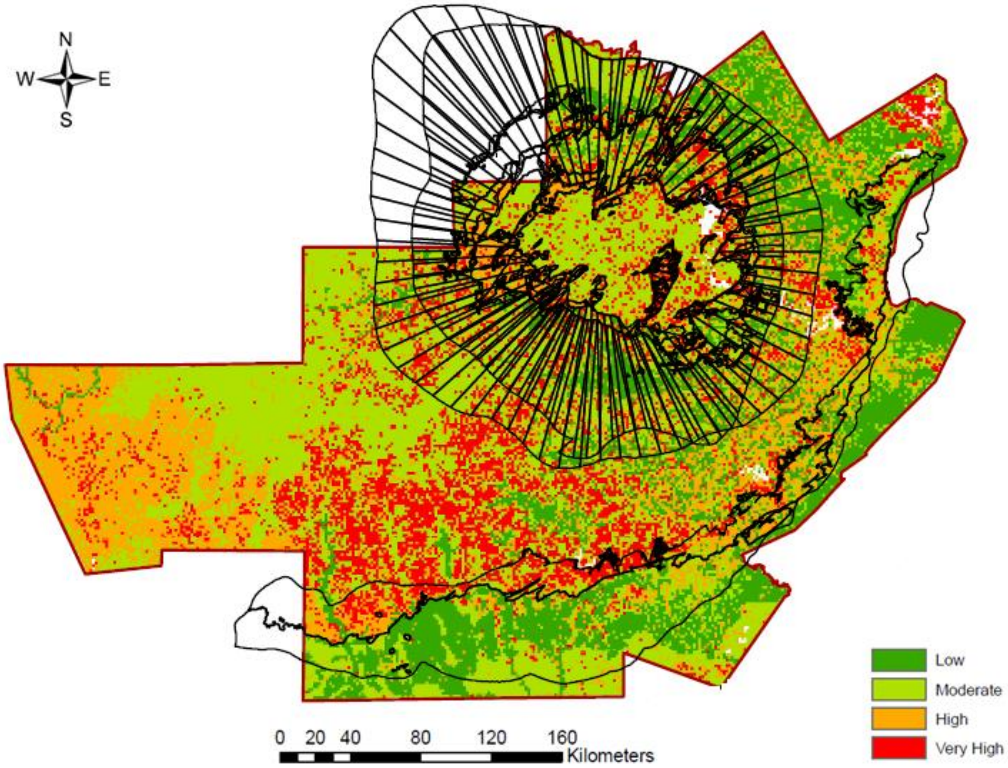

Figure 6 – Ground water vulnerability map showing the Edwards and Hickory Aquifer.

Part of the very high vulnerability region in the south intersects the Edwards aquifer, highlighting the importance of conservation in that area. Also, looking at the very high vulnerability spots in the north, they fall inside the region of the Hickory aquifer, making it also another important and valuable region in terms of conservancy because of the great potential of getting polluted.

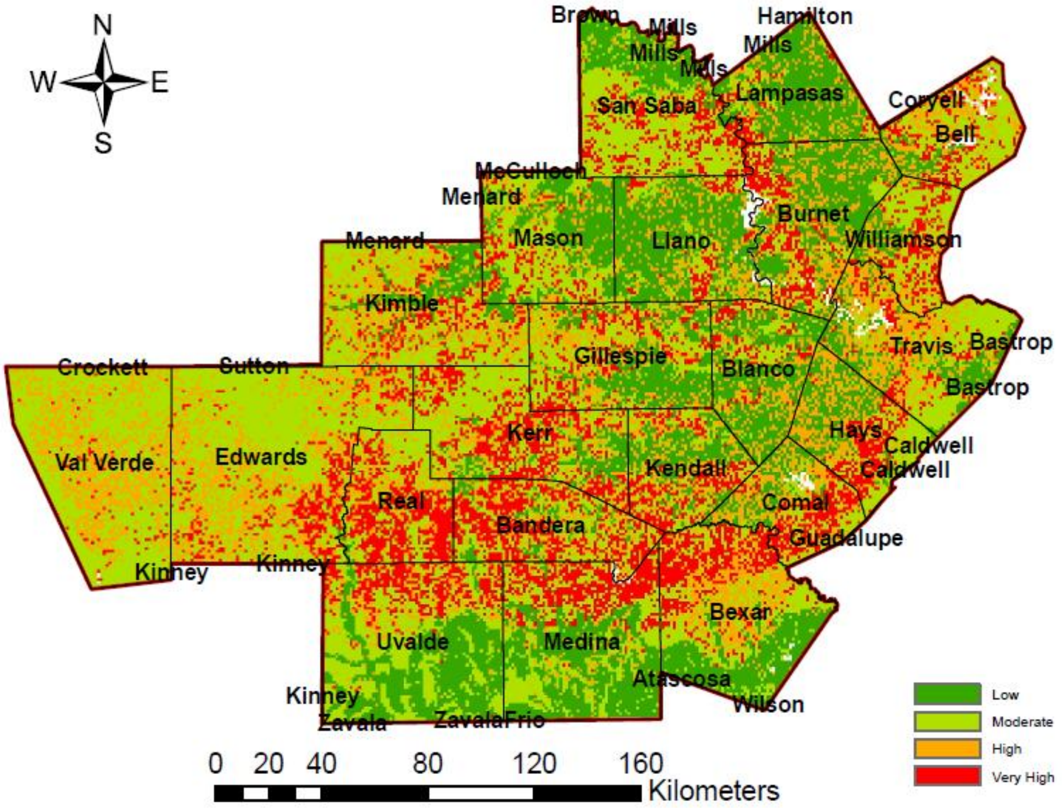

Figure 7 – Equal weight surface vulnerability map.

The same approach of the equal weight method was used to generate a surface water vulnerability map, which is shown in figure 7.The difference between the groundwater vulnerability map (figure 4), and the surface water vulnerability map is the reclassification of the soil KSAT, and now for surface water, the low KSAT values are translated to the most vulnerable regions. The result is that there is an increase in the percentage of the highly vulnerable regions from the surface water vulnerability map, to what was obtained for the ground water vulnerability map. Now, almost 15 % of the land is classified with very high vulnerability (figure 8), almost five percentile points more than in the case of ground water vulnerability. In spatial terms, there are no important changes in the classification. The most vulnerable regions have a similar localization for both ground, and surface water. There is a reduction in the percentage of land considered of high vulnerability, and a small increase of the moderate classification: when comparing the surface water vulnerability map to the original ground water vulnerability map.

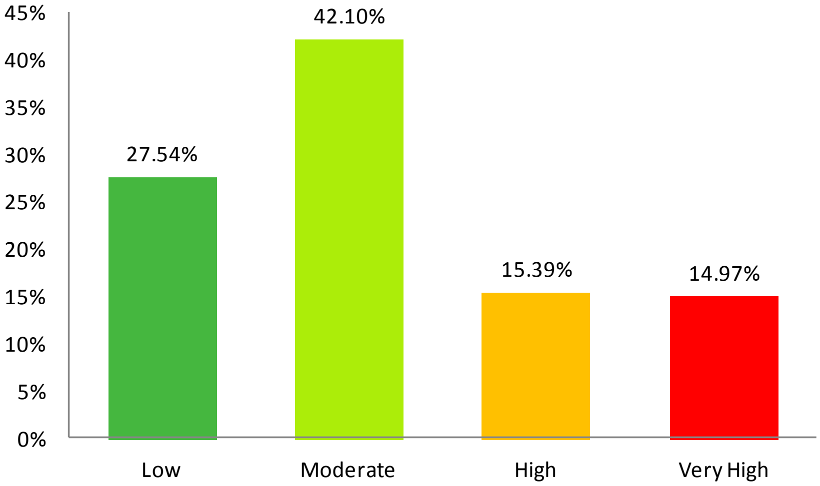

Figure 8 – Percentage of land that falls into each vulnerability category, for the surface water vulnerability map.

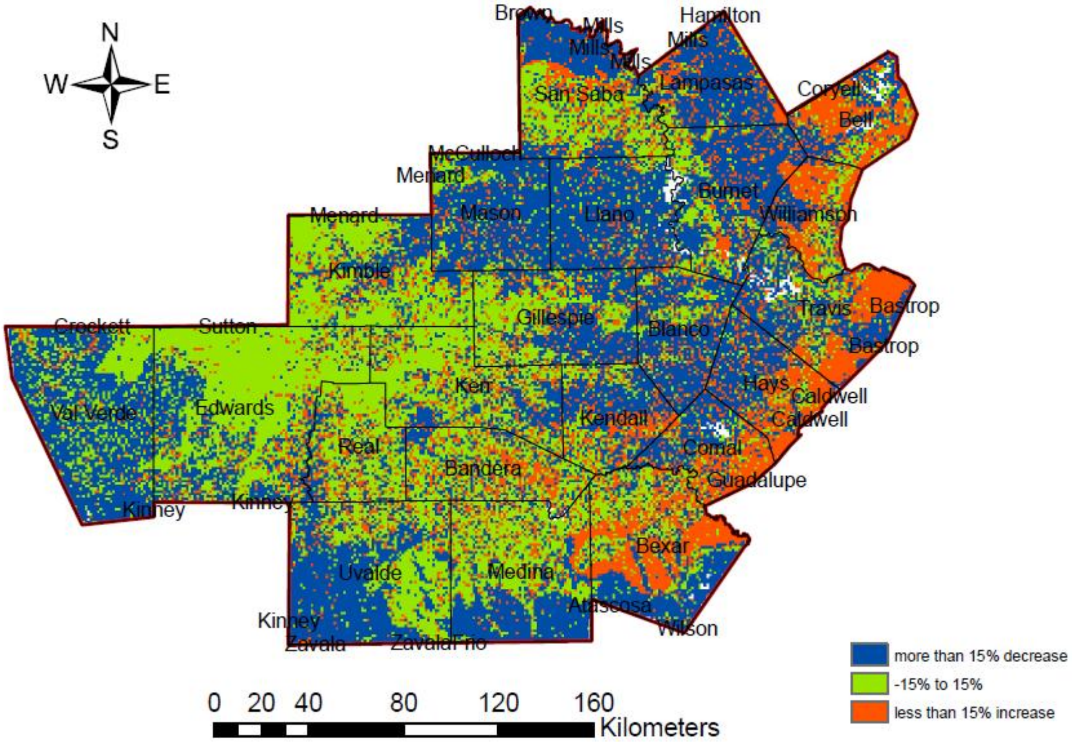

Figure 9 – Map showing the percentage increase or decrease between groundwater vulnerability and surface water vulnerability.

As a last step of the analysis comparing groundwater to surface water vulnerability, a new layer was created using the raster calculation. The increase or decrease in vulnerability was calculated, using the groundwater map as the base map (figure 9). There is a great extension of land that shows a decrease in vulnerability; however the counties to the east show an important increase in vulnerability. Considering that surface water had more very high vulnerability regions, it is expected that the zones with increments should be more abrupt, compared to many zones that show decrements but not so drastic.

For the sensitivity analysis, the first step was to make each of the layers be three times as important as any other layer, trying to see individually what effect they had in the final vulnerability map. For this analysis, the groundwater vulnerability map was used as the base map.

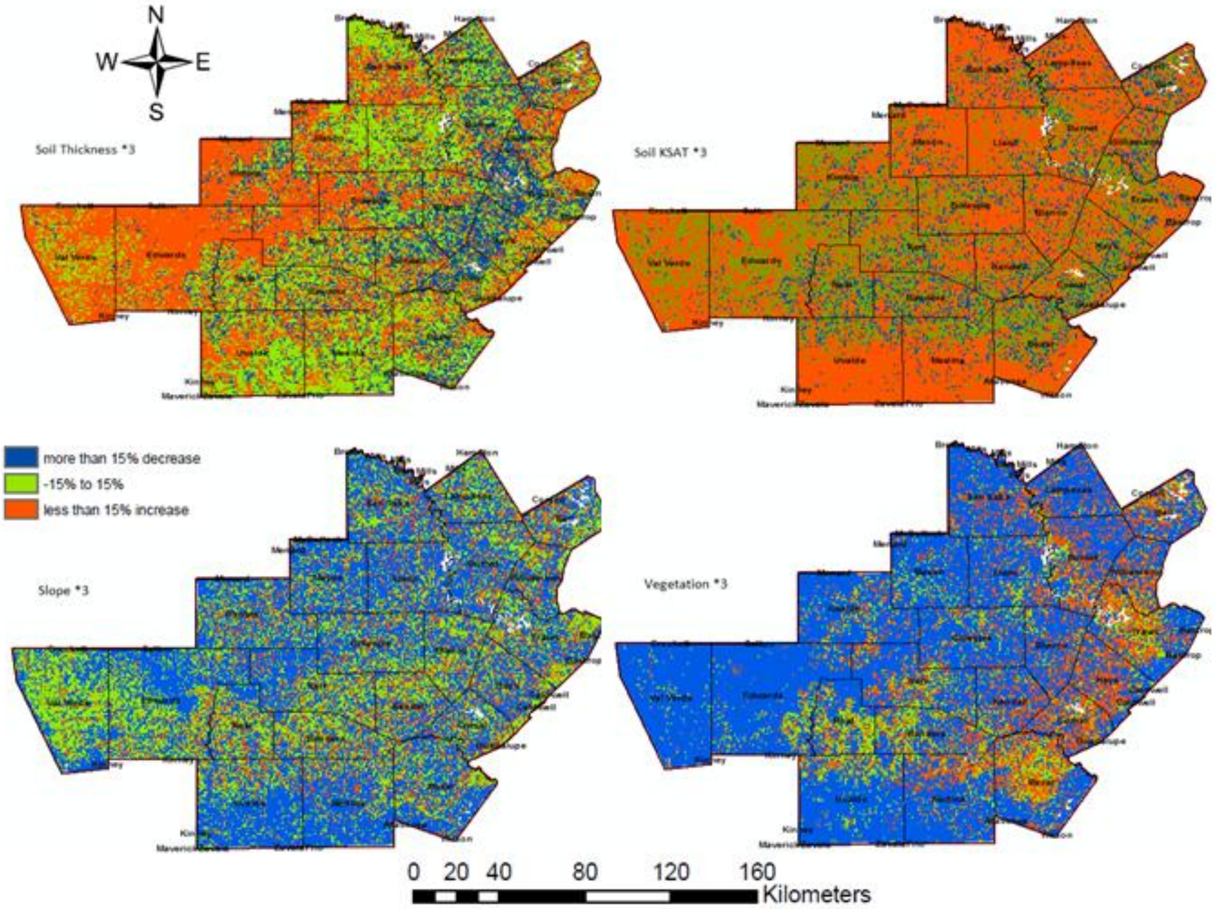

Figure 10 – Sensibility analysis giving different weight to each parameter.

Maps, as the one shown previously in figure 9, appear in figure 10. For each parameter, a new layer was created giving it 3 times more weight than all the other parameters. The weighted sum for each case was calculated, and the percent change is shown in figure 10. The map for incrementing the importance of *soil thickness* shows the largest green area, thus it has the smallest changes with respect to the original base (equal weight) map. Soil KSAT shows that almost all the selected region increases in vulnerability by more than 15%. The opposite effect appears when, either slope or vegetation become the most important parameters; in these cases, the main consequence is a decrease of 15% or more in the vulnerability of the region. When vegetation is the most important parameter, a few spots show increments, situation that is almost not observed for slope, where most zones show decrements, and just a few zones remain with less than 15% changes. This sensitivity analysis shows that soil thickness and soil KSAT show a similar behavior in terms of vulnerability, the same thing can be said of slope and vegetation but with the opposite effect. This analysis also shows that for high vulnerability zones, soil thickness and soil KSAT would be the major contributors; that is why when the other parameters gain importance with respect to these, the final result is a decrease in vulnerability. A next step within this type of analysis would be to propose other models with different weighted parameters, the difficulty with this approach is that, as stated before, there is not enough theoretical background to select parameters and their relative importance, therefore this next step would have to be based on experience and field studies in the specific area of interest. This sensibility analysis tried to show the relative importance that play the different selected parameters, a more intensive study focused in the working region should be applied in order to make a better decision of possible ways to vary the weight of the parameters and correct the vulnerability map.

## CONCLUSIONS

Vulnerability mapping is an important tool to signal regions with high potential to get polluted. Therefore, this tool is of great value for conservancy efforts, which would help decide and categorize priority regions where these land preservation efforts should focus.

One of the main problems with vulnerability mapping is that the selection of parameters and their relative importance is a rather arbitrary process. It is based in theoretical knowledge of hydro geological properties, but there is not much consensus of which properties are the most important. The vulnerability maps developed in this project become an easy to understand tool that HCC could use coupled with their own experience to help land and water management of the region. An important further step would be to correct these maps based on field measurements and specific information about the hydro geological characteristics of the region.

The presence of important minor and mayor aquifers in the HCC working region makes it even more important to have a tool that facilitates taking decisions about where to work in future projects and which parcels of land are more important to conserve.

This intrinsic vulnerability method is useful if the objective is to look at the working region as a whole and classify sub regions of greater importance (high – very high vulnerability), a second useful tool, once the zones have been identified in terms of intrinsic vulnerability, would be to use risk mapping to address specific pollutant point sources, it is clear that for this to happen, the identification of high risk zones should be done previously, using the tool developed in this project, and then an specific analysis is necessary to determine possible pollutants, characteristics of these pollutants and possible sources.

Vulnerability mapping is a tool that could be really useful for local community's water resources management. Especially when a strategy to preserve water quality and quantity is being developed and no specific pollutants are known or involved. Vulnerability mapping can help to classify regions and pieces of land where environmental impacts could be more sensitive. Although their use should be coupled with other methods and reviewed by local experiences and knowledge, they represent a first approach to decision making in terms of sustainability projects.

## REFERENCES

Aller, Linda, Bennett, Truman, Lehr, J.H., and Petty, R.J., 1985, DRASTIC—a standardized system for evaluating ground water pollution potential using hydrogeologic settings: U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, 163

DRASTIC Index: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydro geologic Settings. EPA, http://yosemite.epa.gov/water/owrcCatalog.nsf/SingleKeyword?Openview&Keyword=Drastic+Index&count=2000, accessed November 2011.

Gogu R. C., Dassargues A. 2000. Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. Environmental Geology 39 (6) 549 – 559.

Hashimoto, T., Stedinger, J., Loucks, D., 1982. Reliability, Resiliency, and Vulnerability Criteria For Water Resource System Performance Evaluation. Water Resources Research, 18 (1), 14 – 20.

Massone, H., Quiroz Londono, M., Martinez, D., 2010. Enhanced groundwater vulnerability assessment in geological homogeneous areas: a case study from the Argentine Pampas. Hydrogeology Journal, 18, 371 – 379.

Sener E., Sener S., Davraz A. 2009. Assessment of aquifer vulnerability based on GIS and DRASTIC methods: a case study of the Senirkent – Uluborlu Basin (Isparta, Turkey). Hydrogeology Journal 17, 2023 – 2035.

United States Department of Agriculture, 1995. Soil Survey Geographic (SSURGO) Data Base: Data Use information, pp. 110.

United States Department of Agriculture, 2011. Soil Data Viewer 6.0, User Guide, pp. 62.

USGS, 1999. Improvements to the DRASTIC Ground – Water Vulnerability Mapping Method. National Water – Quality Assessment Program. 6 p.

Van Stempvoort, D., Ewert L., Wassenaar, L., 1992. Aquifer Vulnerability Index: A GIS – compatible method for groundwater vulnerability mapping. Canadian Water Resources Journal. 18 (1), 25 – 37.

Yildirim, M., and Topkaya B., (2007), Groundwater Protection: A Comparative Study of Four Vulnerability Mapping Methods. Clean 35 (6), 594 – 600.