Technical Report Documentation Page

1. Report No.
SWUTC/15/600451-00027-1

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Forecasting the Impacts of Shale Gas Developments on Public Health and Transportation Systems on Both Sides of the Mexico–U.S. Border

5. Report Date
August 2015

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
Report 600451-00027-1

9. Performing Organization Name and Address
Texas A&M Transportation Institute
Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTRT12-G-UTC06

12. Sponsoring Agency Name and Address
Southwest Region University Transportation Center
Texas A&M Transportation Institute
Texas A&M University System
College Station, Texas 77843-3135

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
Supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program

16. Abstract

The activities completed for this project includes the literature research on the Eagle Ford formation, the review of public-health and transportation related variables to shale gas developments, and the definition of the project collaborative site at Prof. Medina-Cetina’s Stochastic Geomechanics Laboratory SGL server https://stochasticgeomechanics.civil.tamu.edu/wiki/projects/bngis/BN__GIS.html.

Also, a collection of spatial data from the Eagle Ford Shale, including transportation infrastructure, geology, hydrology, demography, and well production was gathered. In this project, researchers developed an improvement of the proposed Bayesian Network for the regional assessment of environmental and social risk (i.e., transportation infrastructure and public health) by enhancing the BN+GIS Model for Environmental Sensibility assessment including a Surface Water variable. This required the improvement and optimization of the code producing BN+GIS results to reduce computational time. Afterward, researchers attained results on the implementation of enhanced BN+GIS model in the Barnett Shale Play. Consequently, researchers completed a paper to be submitted in the ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems named “Bayesian Networks and Geographical Information Systems for Environmental Risk Assessment for Oil and gas Site Developments.”

Following up this activity, researchers defined the objectives, hypothesis, and methodology for a parametric sensitivity analysis on the BN+GIS Model used for Risk Assessment on the Barnett Shale. Additionally, researchers developed an investigation about commercially available simulators (software) used for estimating production in unconventional reservoirs.

17. Key Words
Bayesian Networks, Risk Assessment, GIS, Environmental Impact

18. Distribution Statement
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National Technical Information Service
Alexandria, Virginia

19. Security Classif.(of this report)
Unclassified

20. Security Classif.(of this page)
Unclassified

21. No. of Pages
33

22. Price

Form DOTF 1700.7 (8-72) **Reproduction of page authorized**

Forecasting the Impacts of Shale Gas Developments on Public Health and Transportation Systems on Both Sides of the Mexico–U.S. Border

by

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Final Report SWUTC/15/600451-00027-1

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August, 2015

ACKNOWLEDGEMENT

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center.

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The activities completed for this project were:

- Literature research on the Eagle Ford formation.
- Review of public-health related variables to shale gas developments.
- Review of transportation related variables to shale gas developments.
- Definition of the project collaborative site at Prof. Medina-Cetina's Stochastic Geomechanics Laboratory SGL server: https://stochasticgeomechanics.civil.tamu.edu/wiki/projects/bngis/BN__GIS.html.
- Data collection of spatial data located in the Eagle Ford including transportation infrastructure, geology, hydrology, demography, and well production.
- Improvement of the proposed Bayesian Network (BN) for the regional assessment of environmental and social risk (i.e., transportation infrastructure and public health).
- Investigation about commercially available simulators (software) used for estimating production in unconventional reservoirs.
- Planning for journal publications stemmed from the BN+GIS related projects.
- Enhancement of BN+GIS Model for Environmental Sensibility assessment by including the Surface Water variable.
- Attainment of results on the implementation of enhanced BN+GIS model in the Barnett Shale Play.
- Completion of paper to be submitted in the International Journal of Information Science named "Bayesian Networks and Geographical Information Systems for Environmental Risk Assessment for Oil and gas Site Developments."
- Improvement and optimization of the code producing BN+GIS results to reduce computational time.
- Definition of objectives, hypothesis, and methodology for a parametric sensitivity analysis on the BN+GIS Model used for Risk Assessment on the Barnett Shale.
- Implementation of enhanced BN+GIS model in the Barnett Shale Play using a different set of parameters.

PROBLEM

The Oil and Gas (O&G) industry has developed a series of new technologies to respond to the demands of early stage operations (Yu 2010). Recent discoveries of natural reserves in unconventional O&G plays over the United States have triggered the implementation of new Environmentally Friendly Drilling (EFD) systems (Yu 2010). However, there is no current decision-making system that can facilitate the definition of optimal EFD’s capable of optimizing cost, environmental impact, and public perception that can provide the best technical solution to a given site development. This research introduces the use of prognostic and diagnostic analysis of Bayesian Networks (BN) and Geographical Information Systems (GIS) to generate Risk index maps that can account for some of these decision criteria. This new system will be referred as “BN+GIS.”

APPROACH

The present work aimed at collecting several layers of data on shale gas developments on both sides of the Mexico-US. border, with the objective of implementing a Bayesian Decision Network model along with a Geographical Information System to map the region state of risk. An exhaustive data collection took place on the American side collecting spatial information on geology, hydrology, demographics and infrastructure, but researchers were not able to collect data on the Mexican side, despite several attempts with different state and federal agencies. As a result, the data collection on the American side was extended to the Barnett Shale area to test the Bayesian decision-model, where a preliminary mapping of risk was completed successfully.

Data collection and the implementation of the proposed analysis were conducted in two study areas within Texas: the Eagle Ford Play and the Barnett Shale. The proposed Bayesian Network decision model included environmental variables, using publicly available data from government sources. For Eagle Ford, in addition to environmental variables, demographic, infrastructure (transportation), and surface water bodies maps were also collected.

METHODOLOGY

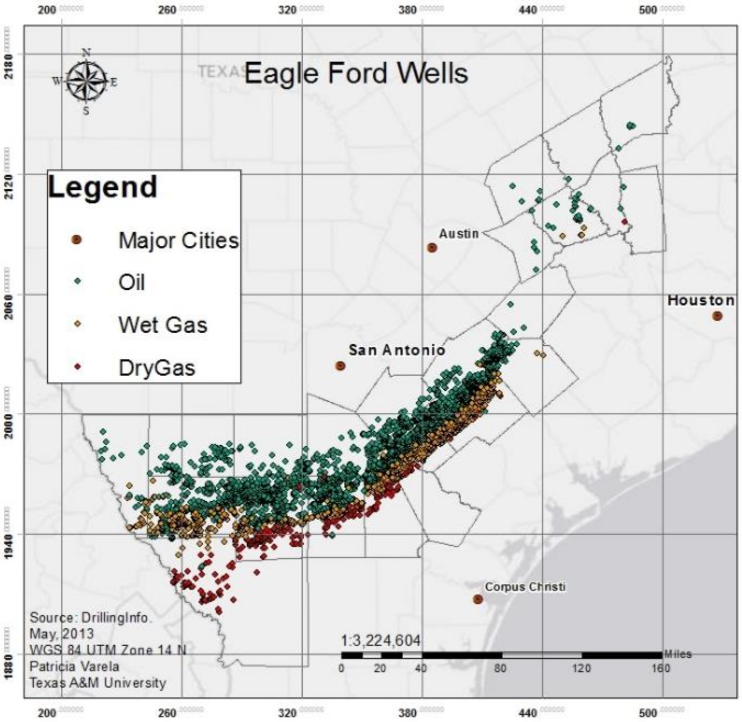
The methodology followed by the researchers was:

1. Data gathering and statistical characterization in order to obtain the proper initial conditions for the project purposes using ArcGIS.
2. Discretization of the data using a squared-grid, which will be the resolution of the output maps.
3. Spatial analysis of a buffered selection made around each grid element.
4. Computation of a Bayesian Network for Risk assessment for prognosis and diagnoses analyses.
5. Data assimilation and analysis of risk-related maps on ArcGIS and on haptic technology.

This methodology was implemented through the scripting of a code using the Python programing language, capable of managing spatial commands from ArcMap ESRI products.

SPATIAL DATABASE

Data collection on the Eagle Ford (EF) Shale included well maps processed from the DrillingInfo website (2013). This dataset was obtained in shapefile format and contains public information about the production and completion methods used in the Eagle Ford play since its initial development. The search was made in the geographical domain defined by O&G districts 1 to 5 with production dates from January 2000 to March 2013. Those districts include the counties that the Railroad Commission of Texas (2013) uses to define the location of the Eagle Ford Play. The downloaded data were manipulated to extract wells located within the Eagle Ford reservoir, which constitutes the foundation for further environmental and social risk analysis. Maps generated were re-projected to the WGS 1984 UTM Zone 14N using ArcMap (Figure 1).

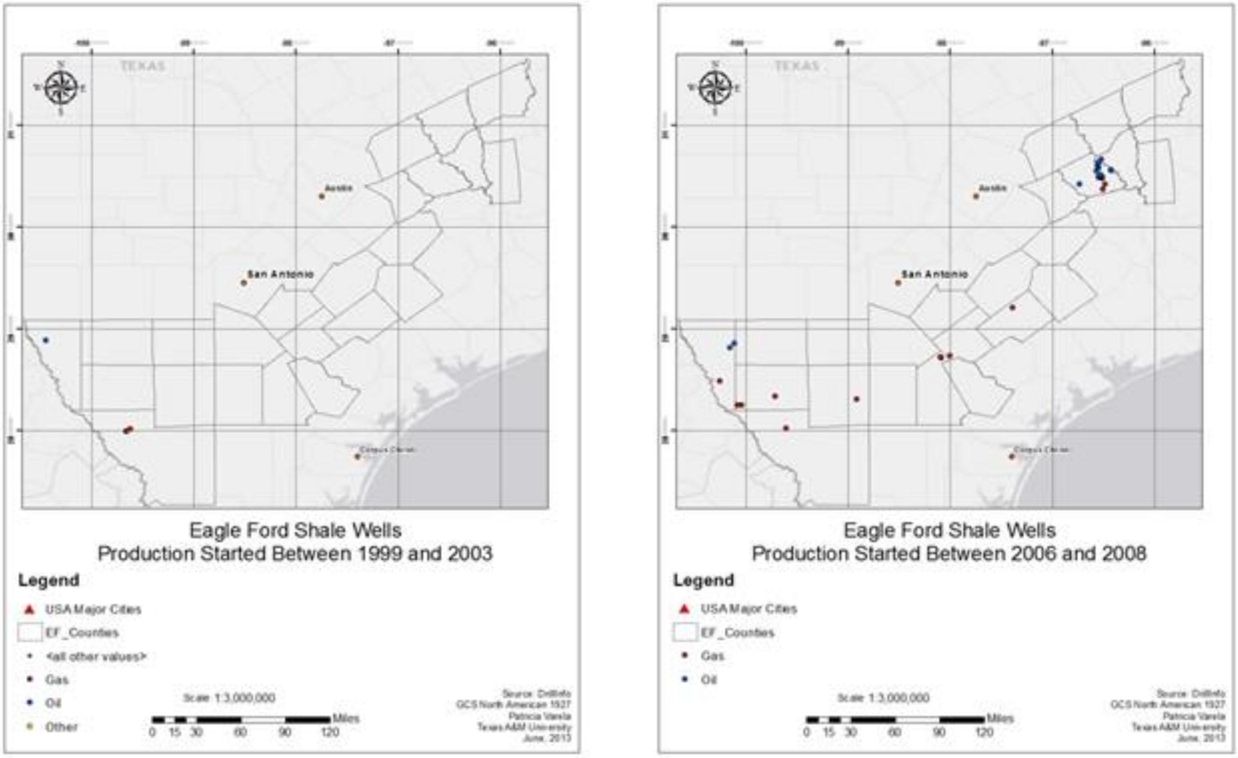


Source: DrillingInfo, 2013. Completion and Production Wells Data.

Figure 1. Eagle Ford Wells and Counties.

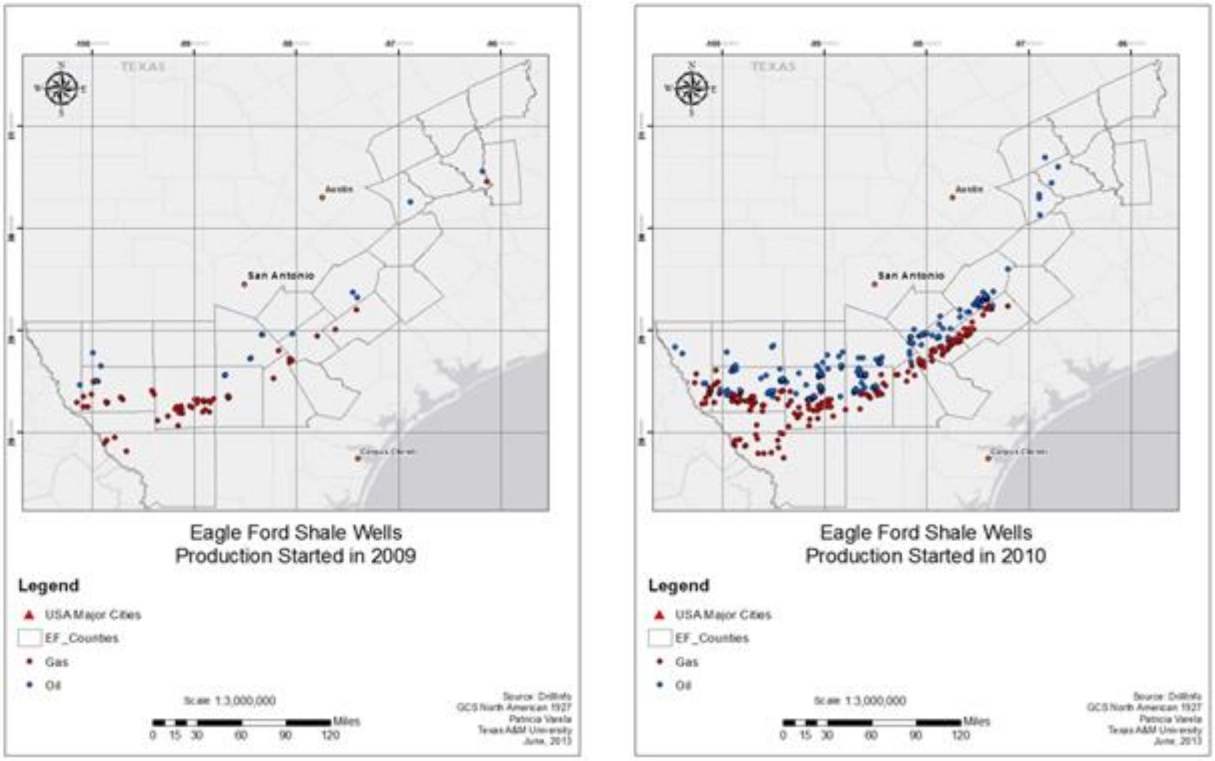
To distinguish between wet and dry gas production, researchers used a field from the table of contents of the well's shapefiles named cumulative Gas and Oil Ratio (GOR). GOR is the ratio of volume of gas to the volume of oil produced in a well. If GOR is higher than 50,000 scf/B, then the hydrocarbons (HC) produced can be defined as Dry Gas (Schlumberger 2009). Based on these data, the total well count sums up to 5,371 within the Eagle Ford counties, where 3,980 wells (74.1 percent) produce oil, 1118 wells (20.8 percent) produce wet gas, and 273 (5.1 percent) produce mainly dry gas. The spatial distribution of the HC fluids shows that most of the production on the Eagle Ford play has been within the oil window at the northwestern section of the formation (Dawson 2000). It also was observed that the Eagle Ford Formation can be found at shallower depths towards the northwest of the play where it yields oil, and down-dips reducing its thickness towards the Gulf coast, where it yields gas.

The Eagle Ford reservoir has been developed for more than 10 years, but it was not until 2010 that the amount of land leases and drilled wells had a significant increase. Figure 2 to Figure 4 show a temporal sequence of the start-production date of the wells targeting the Eagle Ford reservoir. These emphasize the rapid drilling development in South Texas and set the hypothesis of the corresponding social, economic, and environmental impacts.


Eagle Ford Shale Wells
Production Started Between 1999 and 2003

Eagle Ford Shale Wells
Production Started Between 2006 and 2008

Figure 2. EF Production Wells 1999–2003 and 2006–2008.


Eagle Ford Shale Wells
Production Started in 2009

Eagle Ford Shale Wells
Production Started in 2010

Figure 3. EF Production Wells 2009 and 2010.

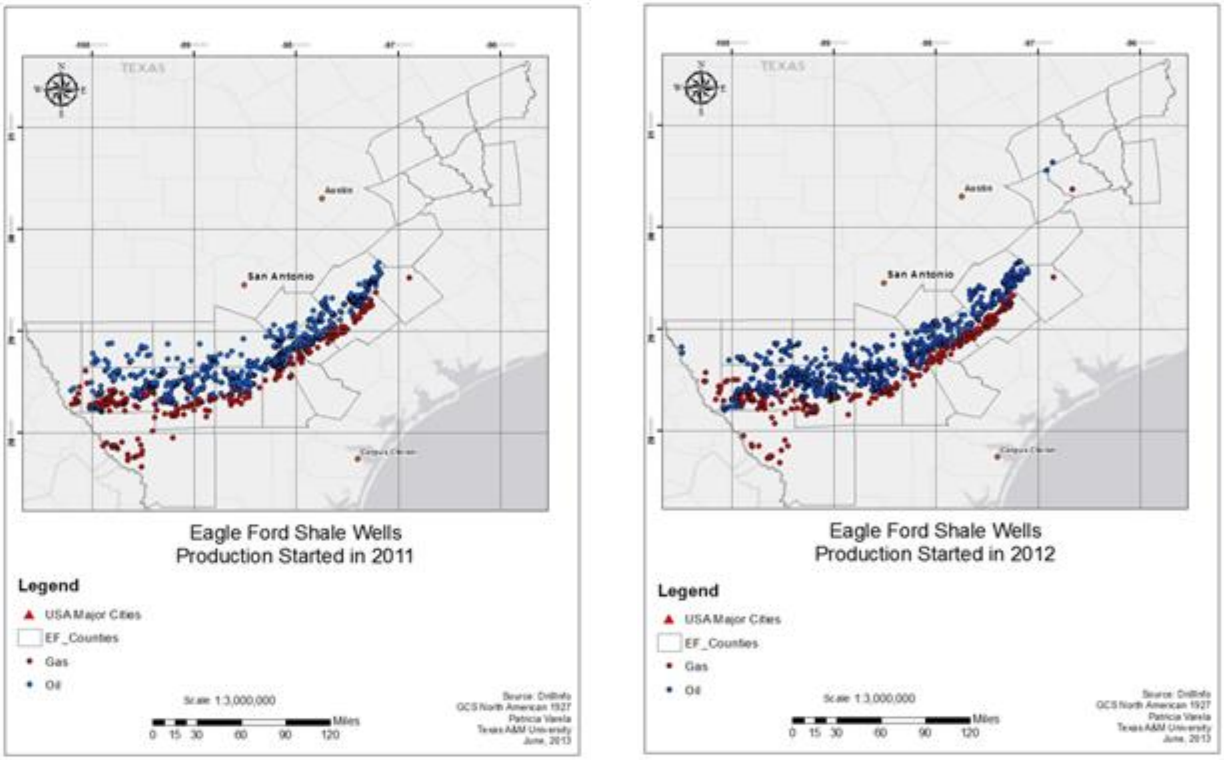


Figure 4. EF Production Wells 2011 and 2012.

A digital elevation model was built to better understand the impact of transportation infrastructure within the footprint of the Eagle Ford play, and the corresponding hillshade highlights the existing surface geomorphological features (Figure 5). This figure shows little variation on the topographic and geomorphological features across the study area.

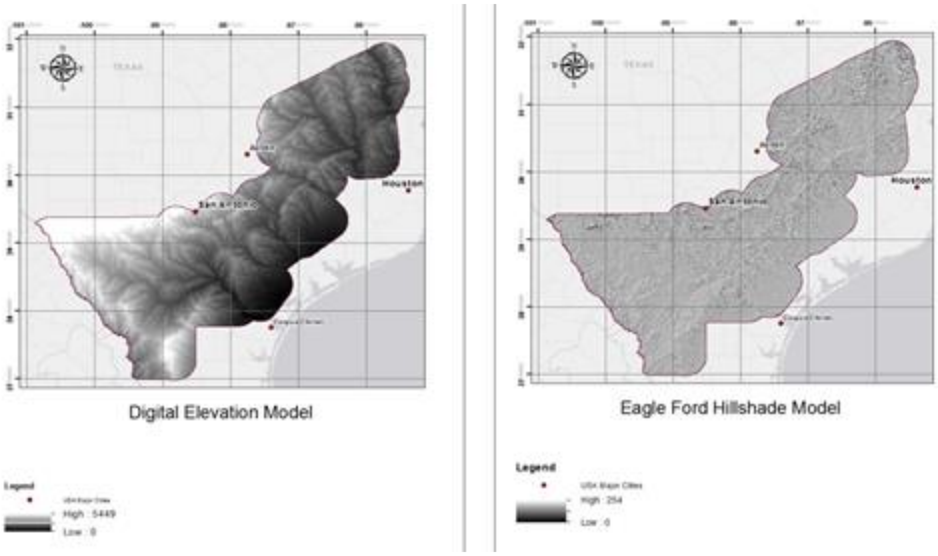


Figure 5. EF Digital Elevation Model and Hillshade.

The data retrieved from DrillingInfo contains information about the interval targeted for production purposes. This information is thought as a proxy for potential production and the transportation impacts that can be anticipated within the next 20 to 30 years in the region. This interval is defined as the "gross pay" thickness, and it was mapped using the Kriging interpolation technique available in ArcMap. Figure 6 shows maps indicating the top and bottom of this interval, while Figure 7 shows an isopach map, where the dark shades reflect higher thickness. The top and bottom surfaces show how the Eagle Ford Formation deepens toward the Gulf of Mexico.

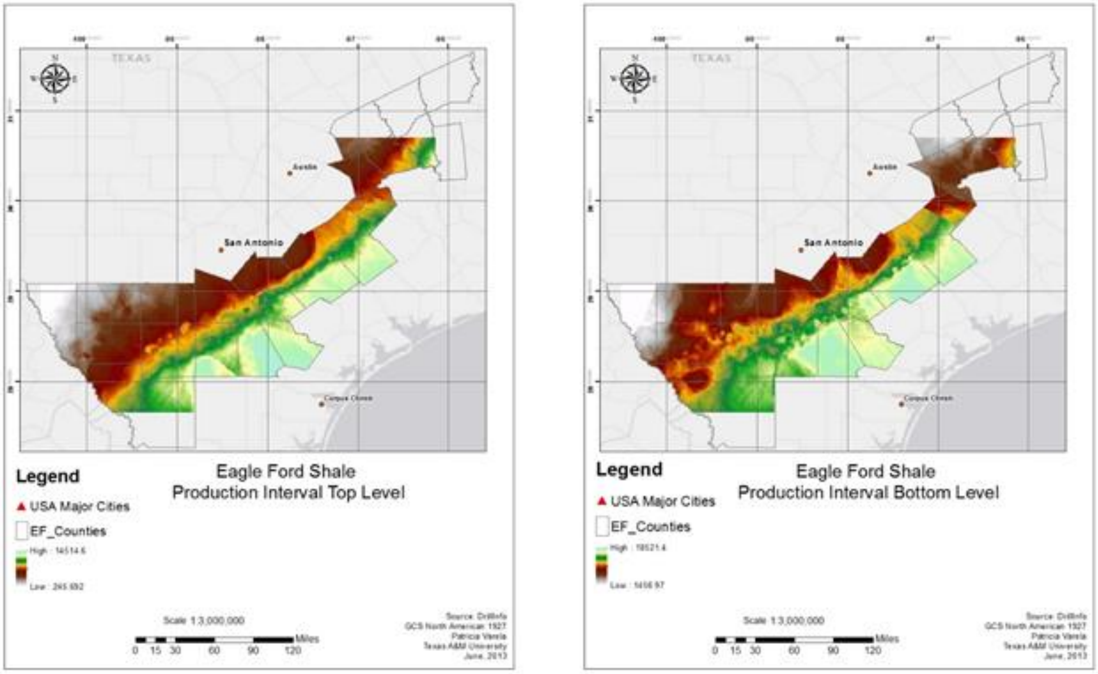


Figure 6. EF Reservoir Top and Bottom Production Interval Surface.

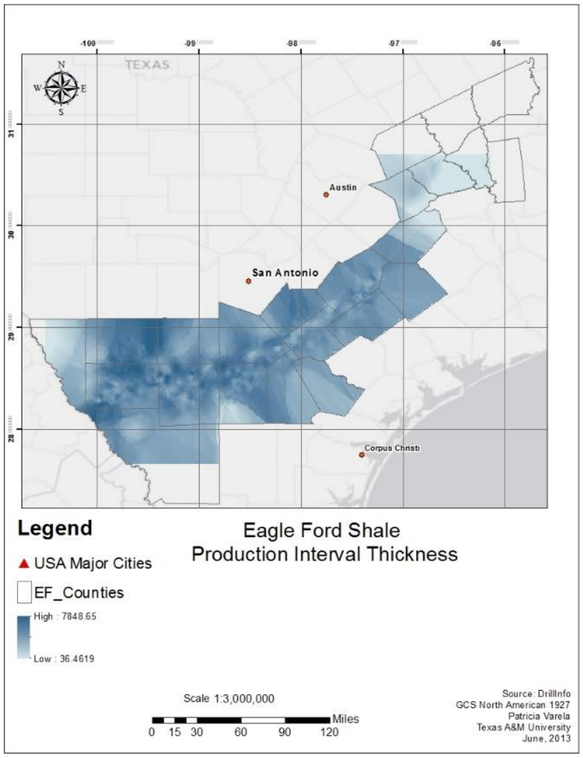


Figure 7. EF Production Interval Thickness.

For a better assimilation of some of these large scale features, and for a better interpretation of production potential, some of these maps were visualized and manipulated in ArcScene to obtain 3D images (Figure 8 and Figure 9). This data is intended to be used for the spatial data assimilation process using haptic devices (in collaboration with current sponsor Grupo Plenum).

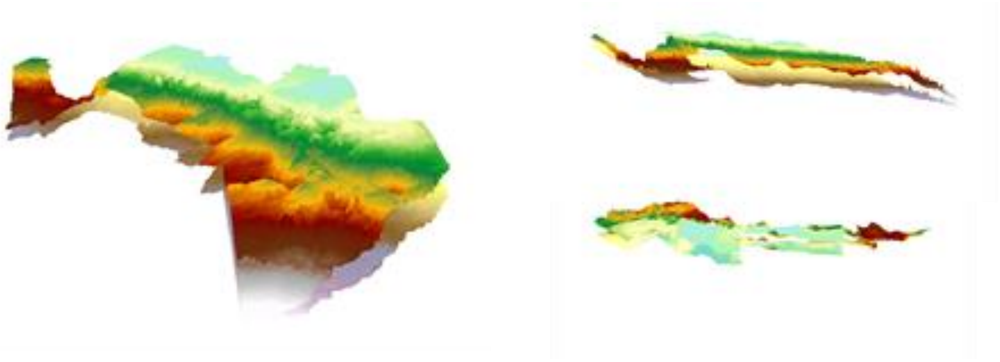


Figure 8. Visualization 3D of Eagle Ford Top and Bottom Production Interval.

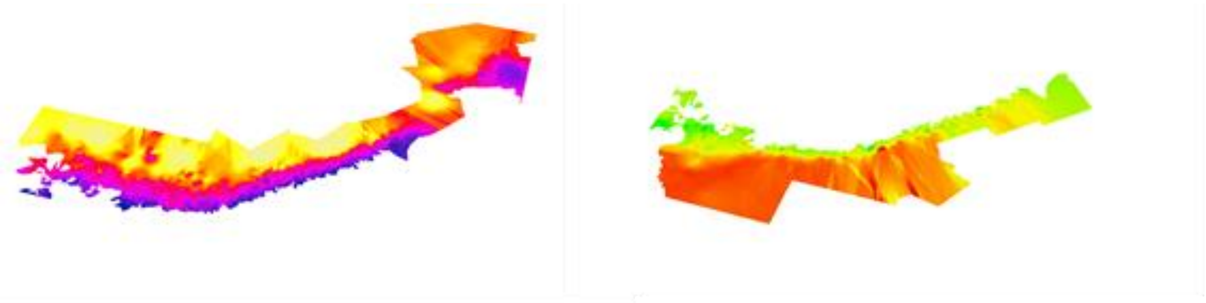


Figure 9. Visualization 3D of Eagle Ford Oil Gravity (Left) and Gas Specific Gravity (Right).

This technology was presented at the Offshore Technology Conference (OTC) 2014 conference in Houston (the largest oil and gas conference in the world), where this project was presented to close to 150 attendees. A subset of images was prepared for this report, as shown in Figure 10.

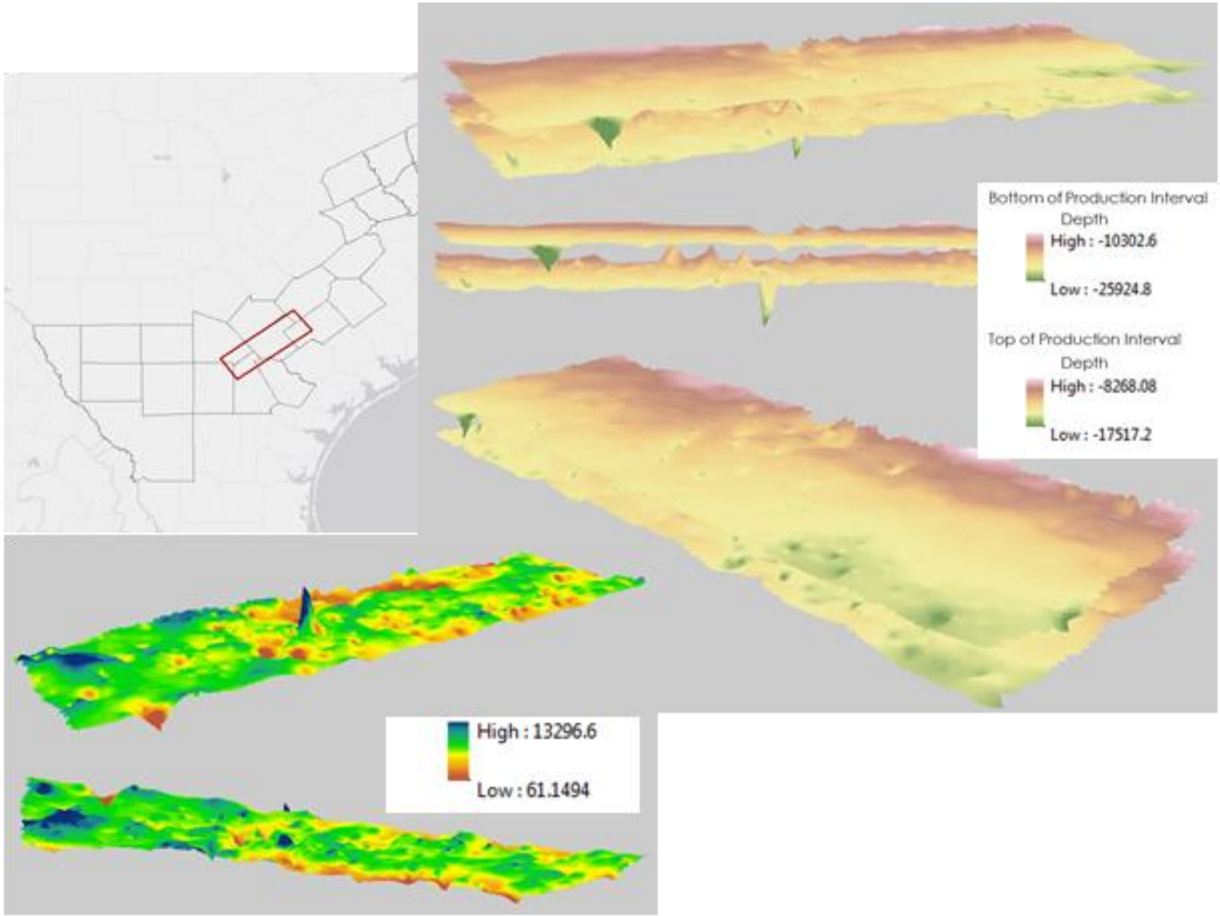


Figure 10. Visualization 3D of Selected Study Area (Red Box) of Top and Bottom Production Interval and Thickness.

One proxy variable for assessing public health risk was demographic information of Eagle Ford. The demographic data was collected on a preliminary collaboration with the Texas A&M Census Research Data Center (TAMU-RDC). Figure 11 shows the demographic distribution on the study area at a Census Tract level for the 2000 and 2010 national census. These figures show distinct changes on the treatment of spatial demographics (non-constant delimitation of population) and at the same time, a significant change on the population. This spatial irregularity along with the coarse time resolution of the demographic population (census data updates every 10 years) made it difficult to capture the known rapid demographic change in the region. However, this effort triggered a continuous collaboration with the TAMU-RDC to further explore other health variables that can be correlated with the spatial demographic changes (not included in this report).

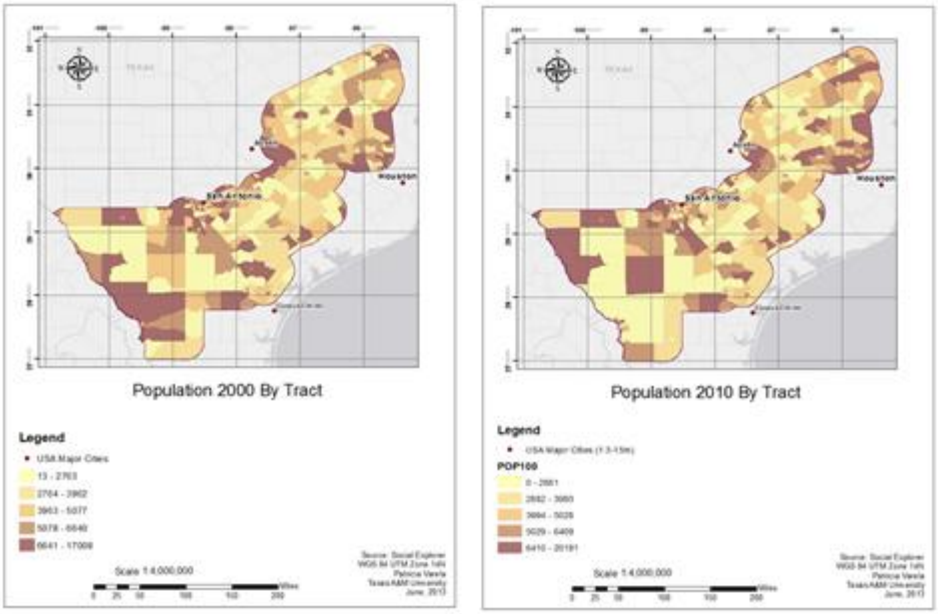


Figure 11. Eagle Ford 2000 and 2010 Population by Census Tracts.

Similarly, maps of transportation networks, aquifers, surface water, ecoregions, and land use/land cover (LULC) were other sources of spatial data collected on the Eagle Ford play. These are presented in Figure 12, Figure 13, and Figure 14, respectively. Further work effort is required to integrate this information into the probabilistic Risk mapping methodology (described in the next section).

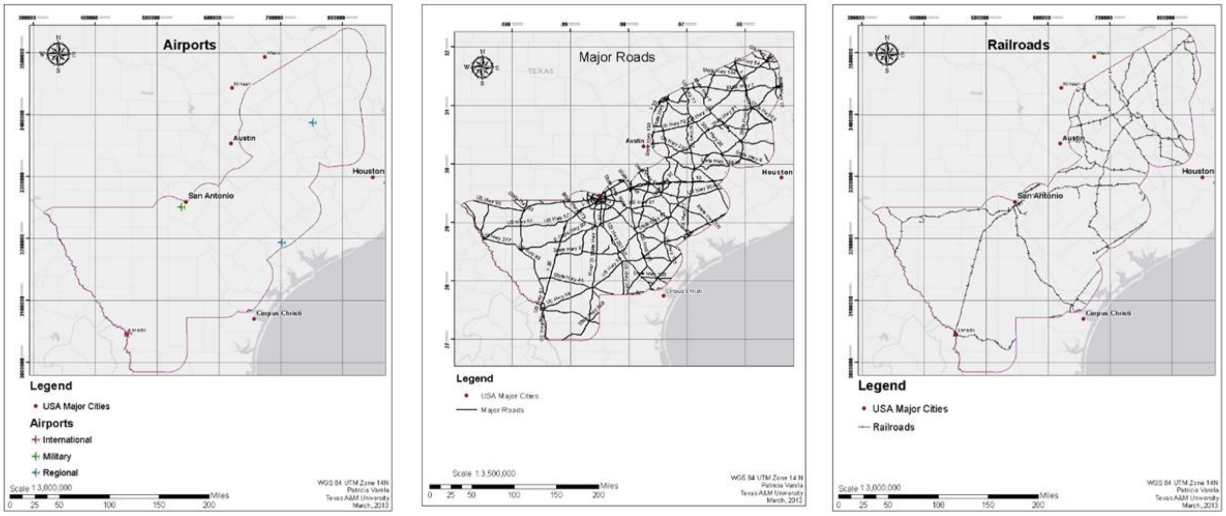


Figure 12. Airports, Major Roads, and Railroads of Eagle Ford Play.

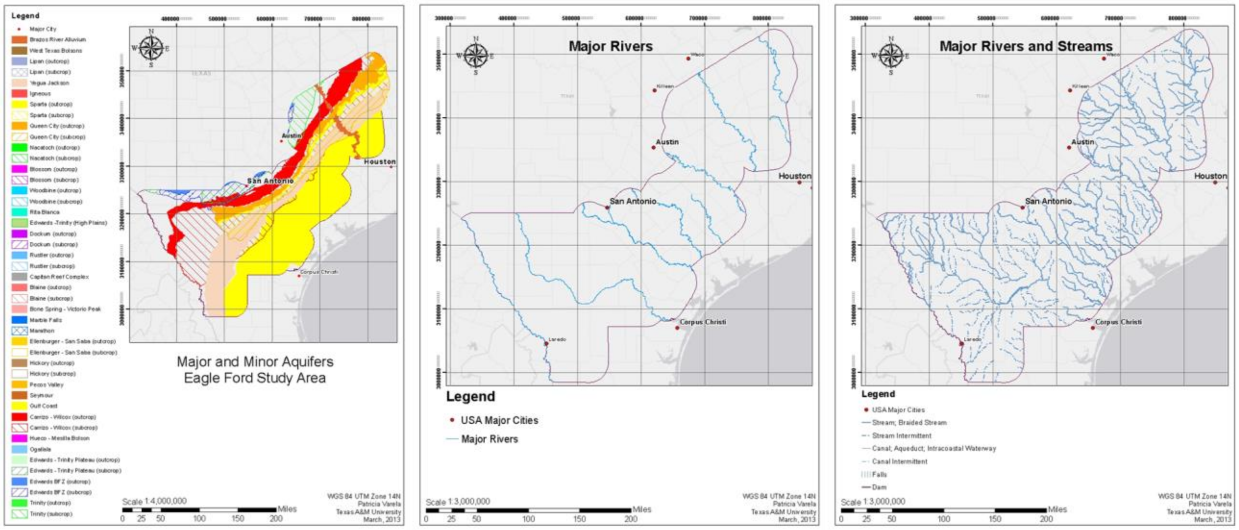


Figure 13. Major and Minor Aquifers, Major Rivers, and Streams of Eagle Ford Play.

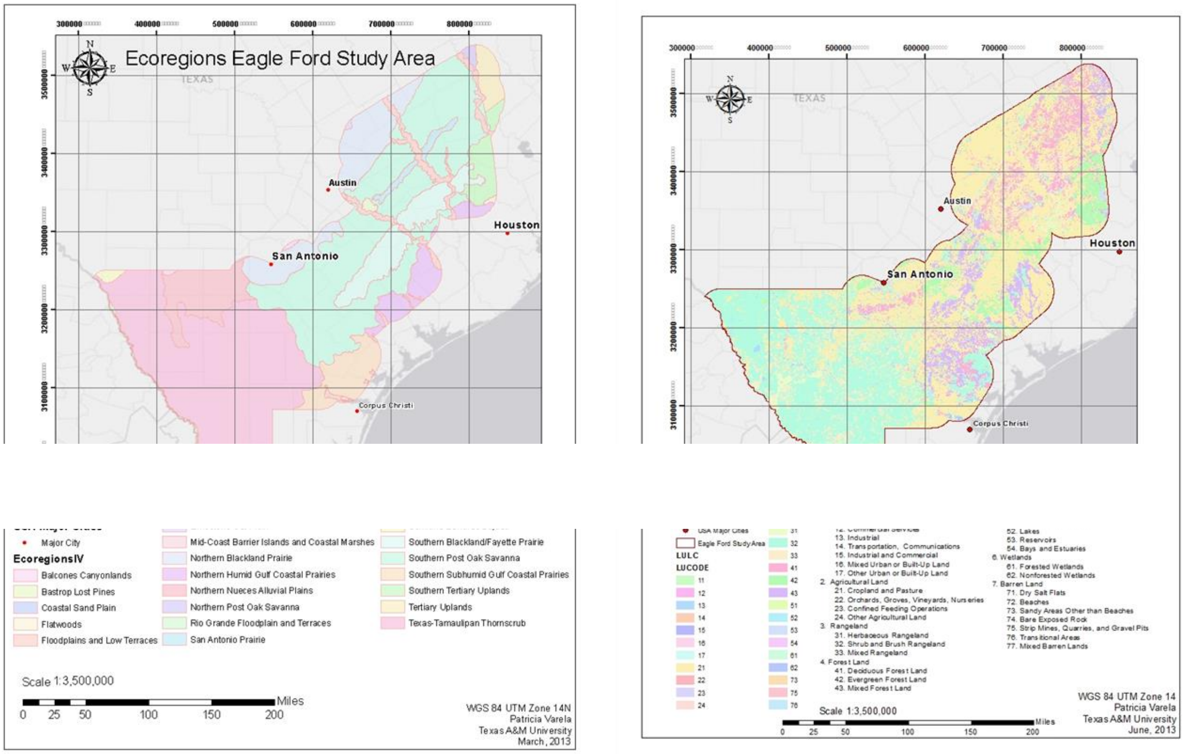


Figure 14. Ecoregions and Land Use Land Cover of Eagle Ford Play.

IMPROVED ENVIRONMENTAL BAYESIAN NETWORK MODEL

Prof. Medina-Cetina's research had originally developed a BN model addressing basic environmental variables that can be used to measure the state of risk within an energy development region. This has been applied at the Barnett Shale play (Varela 2013). Figure 15 shows the environmental BN including the aquifers, ecoregions, and LULC as hazard variables, which can propagate information to assess a risk index. In this work, this model has been extended to include a fourth variable that accounts for the surface water bodies such as streams, lakes, and swamps, among others (Figure 16), which will be used to assess the environmental impact on the Eagle Ford counties close in the vicinity of shale gas wells. Figure 17 presents the surface water map generated for the Barnet Shale.

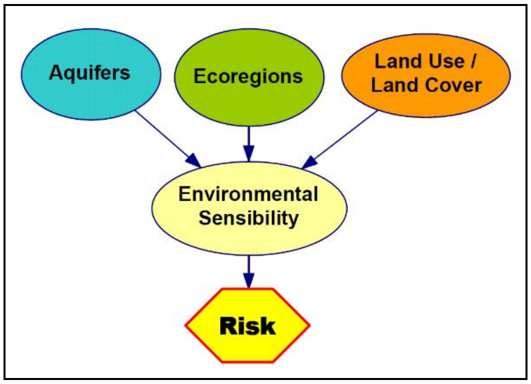


Figure 15. Environmental BN Model.

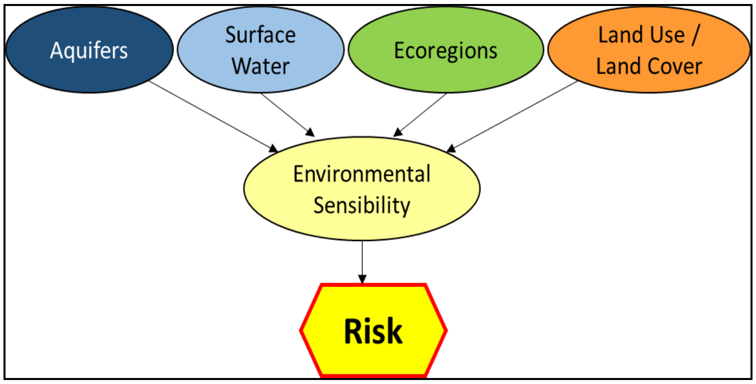


Figure 16. Enhanced Environmental BN Model.

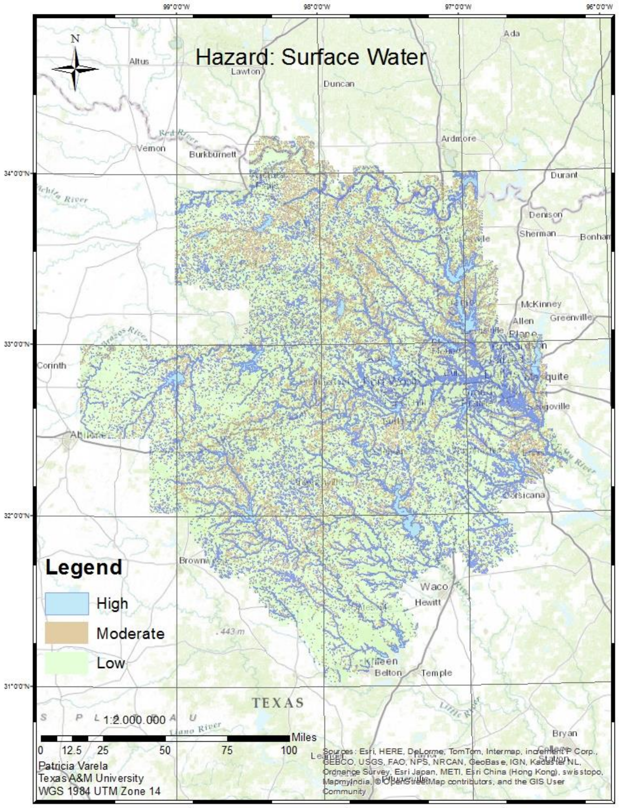


Figure 17. Surface Water Variable added to Bayesian Network.

The nodes in the improved model are defined as ordered values discretized into three levels of hazard (high, moderate, and low), which is quantified by displaying a conditional probability distribution in the form of conditional probability tables (CPT). The CPT that corresponds to the “Environmental Sensibility” (ES) node in this model was reformulated as seen on Table 1. This table shows the conditional probability distributions for the four variables with equal weight distribution among each other.

Table 1. Conditional Probability Table for Enhanced BN Model.

Aquifers	**High**								
Surf. Water	**High**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.95	0.8	0.8	0.8	0.45	0.6	0.8	0.6	0.45
P($ES_{Moderate}$)	0.04	0.15	0.1	0.15	0.45	0.2	0.1	0.2	0.1
P(ES_{Low})	0.01	0.05	0.1	0.05	0.1	0.2	0.1	0.2	0.45

Aquifers	**Moderate**								
Surf. Water	**Low**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.6	0.2	0.2	0.2	0.05	0.1	0.2	0.1	0.05
P($ES_{Moderate}$)	0.2	0.6	0.2	0.6	0.8	0.45	0.2	0.45	0.15
P(ES_{Low})	0.2	0.2	0.6	0.2	0.15	0.45	0.6	0.45	0.8

Aquifers	**High**								
Surf. Water	**Moderate**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.8	0.45	0.6	0.45	0.15	0.2	0.6	0.2	0.2
P($ES_{Moderate}$)	0.15	0.45	0.2	0.45	0.8	0.6	0.2	0.6	0.2
P(ES_{Low})	0.05	0.1	0.2	0.1	0.05	0.2	0.2	0.2	0.6

Aquifers	**Low**								
Surf. Water	**High**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.8	0.6	0.45	0.6	0.2	0.2	0.45	0.2	0.1
P($ES_{Moderate}$)	0.1	0.2	0.1	0.2	0.6	0.2	0.1	0.2	0.1
P(ES_{Low})	0.1	0.2	0.45	0.2	0.2	0.6	0.45	0.6	0.8

Aquifers	**High**								
Surf. Water	**Low**								
Ecoregions	**High**		**Moderate**				**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.8	0.6	0.45	0.6	0.2	0.2	0.45	0.2	0.1
P($ES_{Moderate}$)	0.1	0.2	0.1	0.2	0.6	0.2	0.1	0.2	0.1
P(ES_{Low})	0.1	0.2	0.45	0.2	0.2	0.6	0.45	0.6	0.8

Aquifers	**Low**								
Surf. Water	**Moderate**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.6	0.2	0.2	0.2	0.05	0.1	0.2	0.1	0.05
P($ES_{Moderate}$)	0.2	0.6	0.2	0.6	0.8	0.45	0.2	0.45	0.15
P(ES_{Low})	0.2	0.2	0.6	0.2	0.15	0.45	0.6	0.45	0.8

Aquifers	**Moderate**								
Surf. Water	**High**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.8	0.45	0.6	0.45	0.15	0.2	0.6	0.2	0.2
P($ES_{Moderate}$)	0.15	0.45	0.2	0.45	0.8	0.6	0.2	0.6	0.2
P(ES_{Low})	0.05	0.1	0.2	0.1	0.05	0.2	0.2	0.2	0.6

Aquifers	**Low**								
Surf. Water	**Low**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.45	0.2	0.1	0.2	0.1	0.05	0.1	0.05	0.01
P($ES_{Moderate}$)	0.1	0.2	0.1	0.2	0.45	0.15	0.1	0.15	0.04
P(ES_{Low})	0.45	0.6	0.8	0.6	0.45	0.8	0.8	0.8	0.95

Aquifers	**Moderate**								
Surf. Water	**Moderate**								
Ecoregions	**High**			**Moderate**			**Low**		
LULC	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**	**High**	**Mod**	**Low**
P(ES_{High})	0.45	0.15	0.2	0.15	0.025	0.05	0.2	0.05	0.1
P($ES_{Moderate}$)	0.45	0.8	0.6	0.8	0.95	0.8	0.6	0.8	0.45
P(ES_{Low})	0.1	0.05	0.2	0.05	0.025	0.15	0.2	0.15	0.45

An Excel® spreadsheet with the information propagation in two modes, prognosis and diagnosis, was completed for the Barnet Shale. Results obtained from this are presented in Figure 18–Figure 22, and the same model is currently applied to the Eagle Ford play. Figure 18 shows the prognosis analysis, while Figure 19–Figure 22 show the diagnosis analysis. The diagnostic analysis shows the results when the value of risk is fixed, and the initial conditions are evaluated when the message is transmitted to the top of the network. In this study case, the given state of risk for environmental sensibility used was: low=50 percent, medium=30 percent, and high=20 percent. The power of this type of analysis resides in the definition of risk scenarios for a non-exceeding policy. This set of analyses was included in a publication prepared for the International Journal of Geographical Information Science titled “Bayesian Networks and Geographical Information Systems for Environmental Risk Assessment for Oil and gas Site Developments” (under review of co-authors).

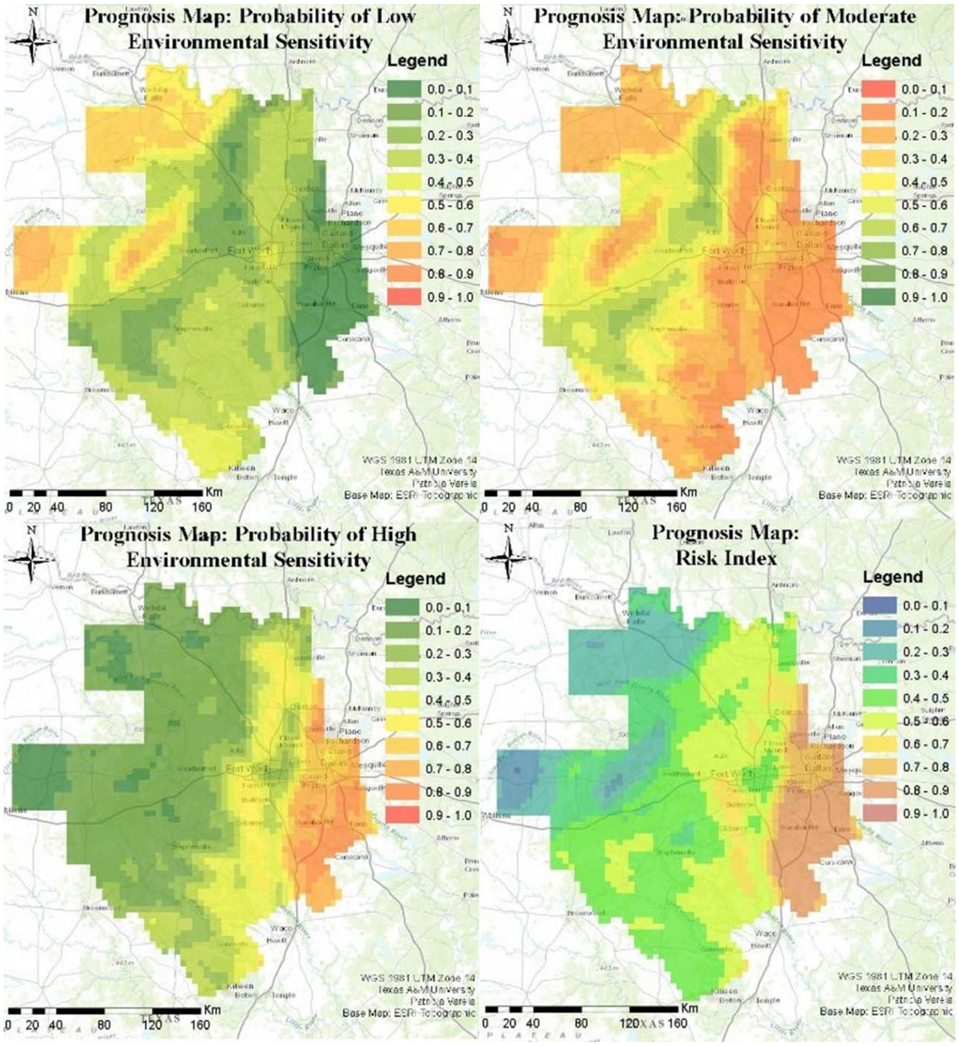


Figure 18. Result Maps for Prognosis Analysis.

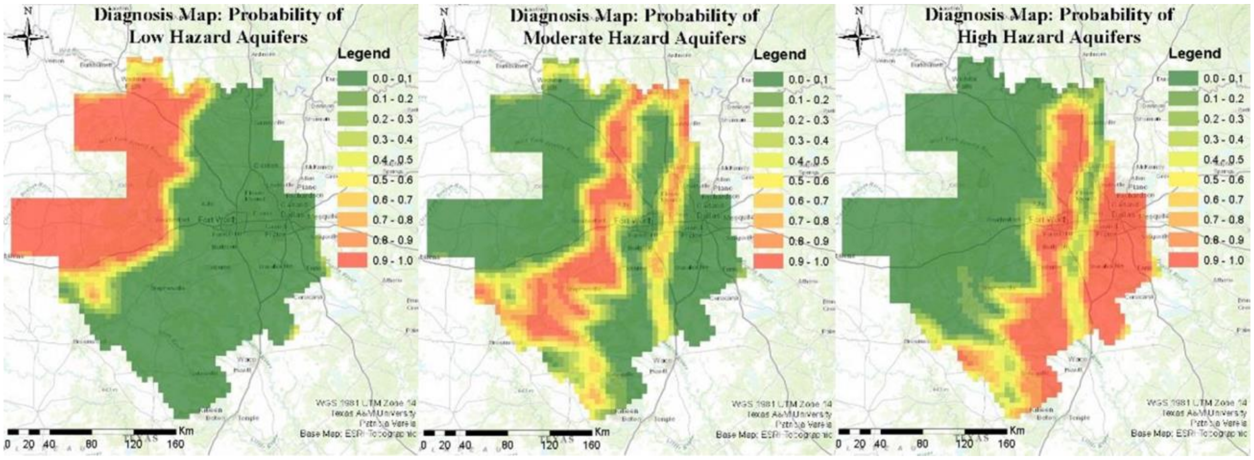


Figure 19. Result Maps for Diagnosis Analysis. Updated Probability of Aquifers Hazard.

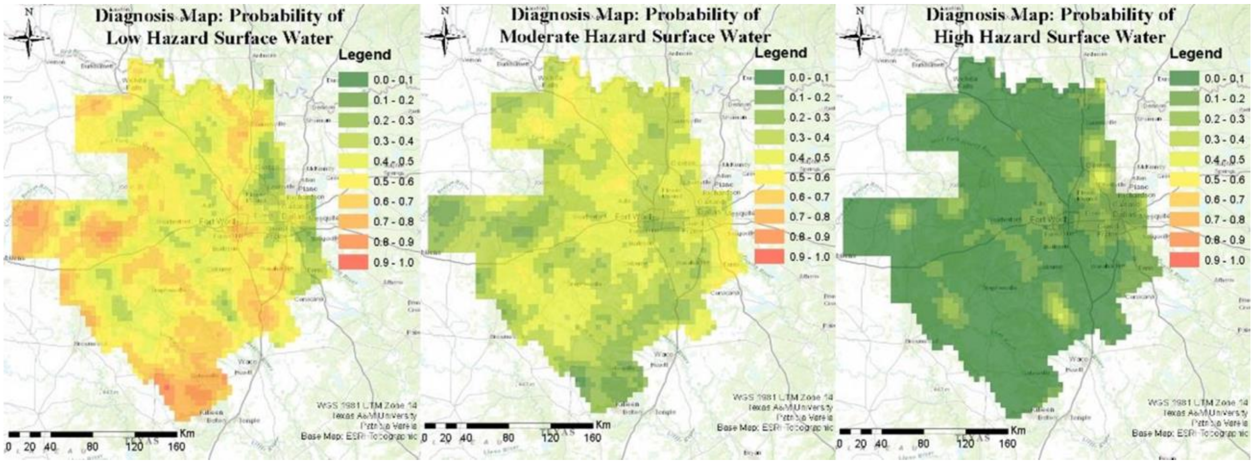


Figure 20. Result Maps for Diagnosis Analysis. Updated Probability of Surface Water Hazard.

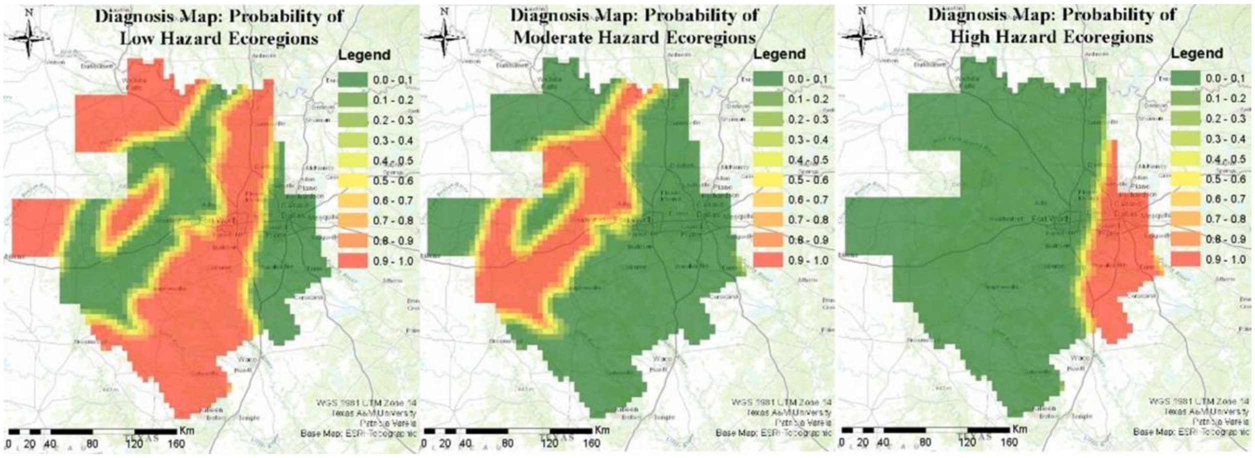


Figure 21. Result Maps for Diagnosis Analysis. Updated Probability of Ecoregions Hazard.

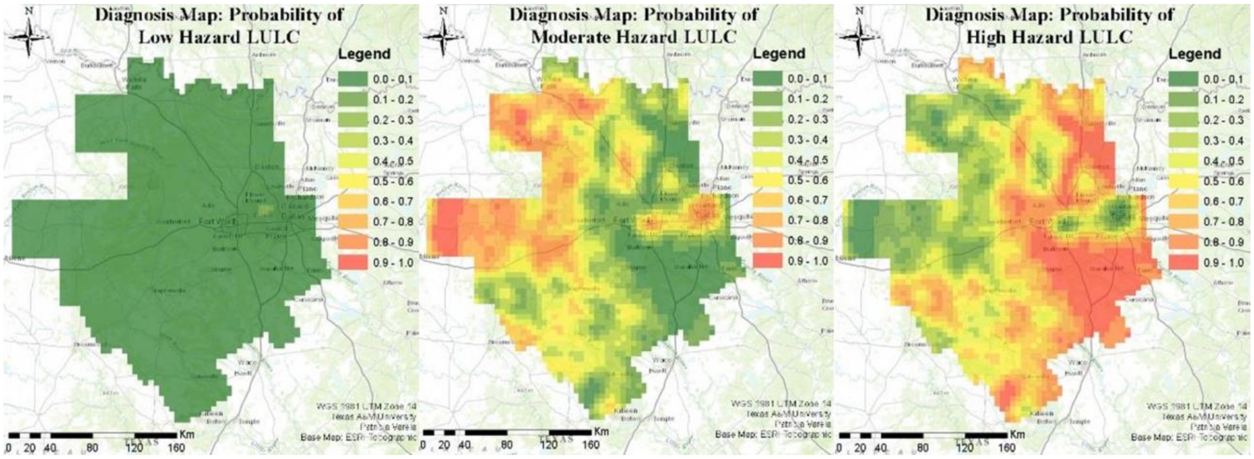


Figure 22. Result Maps for Diagnosis Analysis. Updated Probability of Land Use Land Cover Hazard.

FINDINGS

The patterns obtained in the prognosis maps for the environmental sensibility node show a significant impact on the current state of risk. The influence of aquifers and ecoregions input maps show marked elongated shapes northeastward that can be observed on the three ES maps and in the risk index map (Figure 18). The scattered appearance of the input LULC map gives the results a pattern of areas without specific delineated boundaries, providing a more realistic sense of the natural conditions. Some of the most important lakes in the surface water map are areas that are delimitating a local increase of the Risk index. Since the environmental sensibility maps sum to one, it can be seen how the ES Low map highlights the opposites areas that ES High does, while the ES Mod map complements the two extremes.

The risk map (Figure 18, bottom right) show an important influence from the input variables, as a result of the application of the utility function that weights the ES distribution. The areas with a higher risk (0.8–1.0), given the input natural conditions described for this study, are located at the eastern extreme of the Barnett Shale. Its lateral extension is approximately 60 km wide by 140 km long, occupying the settlements of East Dallas, Lancaster, Ennis, Midlothian, Ennis, Milford, Itasca, north Hillsboro, and Hubbard. This area coincides with a cluster of major rivers, with a major aquifer outcrop and the most sensitive prairies with abundant lakes and cropland zones. The highest Risk Index value is 0.88 at the Lake Ray Hubbard, and the intensity of the risk is dissipated westward, reaching the lowest intervals in the northern and western sections of the Barnett Shale counties (Albany and Lueders). In this region, the surface water is not abundant, aquifers are absent, ecoregions are mostly semi-arid prairies, and LULC is composed by moderate hazard rangelands.

The result of this diagnostic analysis is summarized in 12 maps (see Figure 19–Figure 22), representing the updated probability of the four variables to a certain level of hazard (3 states—low, moderate, high). The diagnosis analysis indicates that the variability of the fixed Risk Index does not affect the general clustering or patterns of the hazard. However, the transition zones between hazard levels (high, moderate, low) are the most sensitive areas to the variation of the required risk in diagnosis. This means that areas that are 100 percent within a hazard level are going to produce the same probability distribution after the diagnostic analysis. It is more obvious to observe these occurrences for the input variables with larger spatial features such as aquifers and ecoregions, where it can be seen that the diagnostic results match the initial conditions, but it is less evident for scattered inputs such as surface water and LULC, where more transition zones are present on the study area.

A new set of results is being computed as part of a parametric sensibility analysis. The objective of this study consists on the development of a sensitivity analysis of the model to different conditions. The hypothesis presented in this project is that the output maps of the Bayesian benchmark model will provide a variability that can be quantified and then compared to identify the areas where the uncertainties of the model are localized. Therefore, this method will provide a better understanding of the practical applicability of the model and its sensitivity to different parameters in the analysis.

The experimental design has been defined as:

- Buffer/area analysis: 2, 4, 6, 8, 10, and 12 km with a grid size of 2 km.
- Grid Size analysis: 2, 4, 6, 8, 10, and 12 km with a buffer radius of 10 km.
- Message fixed in diagnostic propagation (see Figure 23):

a. Combination 1: $ES_H = 0.1$; $ES_M = 0.2$; $ES_L = 0.7$.
b. Combination 2: $ES_H = 0.15$; $ES_M = 0.7$; $ES_L = 0.15$.
c. Combination 3: $ES_H = 0.7$; $ES_M = 0.2$; $ES_L = 0.1$.
d. Combination 1: $ES_H = 0.33$; $ES_M = 0.33$; $ES_L = 0.33$.

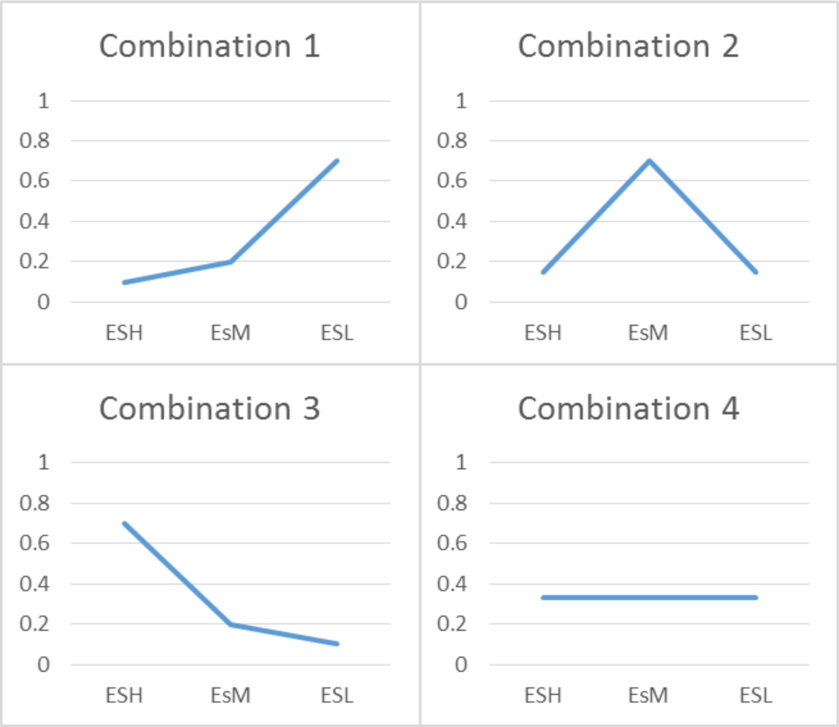


Figure 23. Probability Distribution of Fixed Node Environmental Sensibility for Diagnostic Reasoning.

Some of the results obtained for the parametric analysis of the buffer size on the BN+GIS model can be seen in Figure 24.

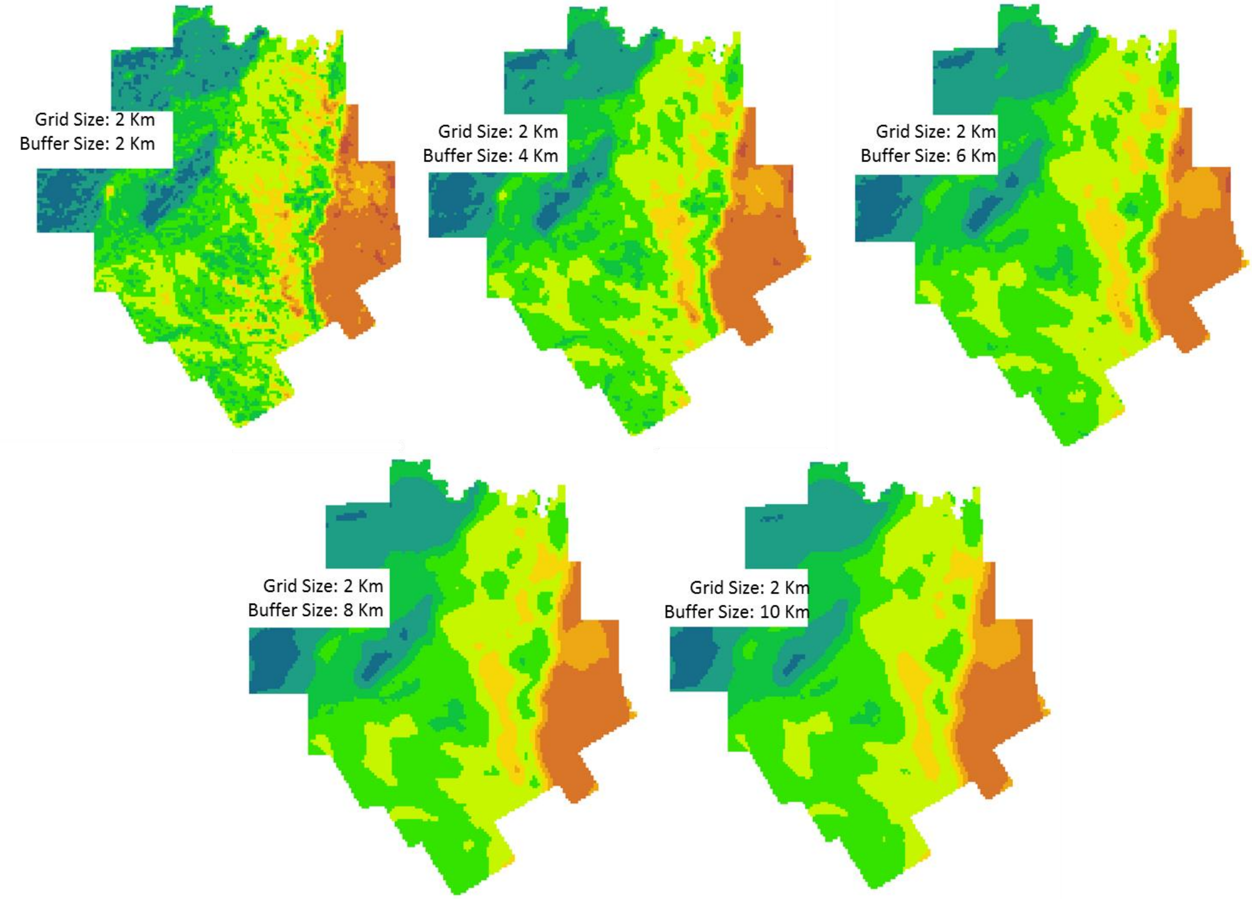


Figure 24. Barnett Shale Risk Index Maps Using 2 Km Grid and 2, 4, 6, 8, and 10 km. Buffer Analysis.

CONCLUSIONS

The benchmark Bayesian Network model proposed in this study was able to recreate multiple environmental risk scenarios following a probabilistic approach. These maps can be used for O&G industry decision makers to find the most suitable place to drill and operate, based on the variables provided by the model.

The surface water bodies, aquifers, ecoregions, and LULC maps used as input variables of the proposed model were satisfactory to assess the environmental sensibility of the Barnett Shale counties. The maps returned by BN+GIS are a symbolic representation of the environmental risk based on these four hazard variables. The model returns a 2D analysis based in the geographical distribution of the hazard’s features, as a projection of a study that combines lateral and depth information. This third dimension is incorporated to the model by the aquifers hazard, since in its definition is described as the presence or absence of an aquifer, counting as a dimension of depth. However, the interpretations that can be made using this tool are based only on the input variables, since other factors are not considered on this study. The risk assessment methodology coupled nicely with the proposed BN, since the input was defined as hazards, the conditional probability table of the ES served as the vulnerability of the model to those hazards and the utility function provided a dimension of the consequences. The methodology suggested by this proposed model resulted in a reasonable application of the BN to assess the risk.

RECOMMENDATIONS

The interpretation of the risk used on this work is strictly based on the spatial configuration of surface water, aquifers, ecoregions, and LULC given by the specific data sources used for this study. Results can be used as a powerful decision-making instrument that provides a probabilistic approach to the spatial conditions that could affect the environment, the public perception or the economic cost, given different input variables. Further work is being done in order to quantify the uncertainty of using this method.

ADDITIONAL WORK

Software Evaluation

The Computer Modeling Group (CMG) is a simulator supplier focused on the technology development for conventional and unconventional reservoirs (Figure 25). The purpose of reviewing this commercially available simulator is to link production forecasts with social and environmental forecasts. CMG has developed a series of modules that are used in different stages of the reservoir simulation process, which includes: BUILDER for the data preparation, IMEX for the simulation of conventional reservoirs, GEM for the simulation of unconventional reservoirs, STARS for the thermal reservoir simulation, CMOST for the geostatistical analysis tools, WINPROP for the laboratory and field data analysis, and 3D as a display module (Computer Modeling Group, 2013). The workflow conventionally used for these modules can be seen in Figure 26.

Figure 25. CMG Modules.

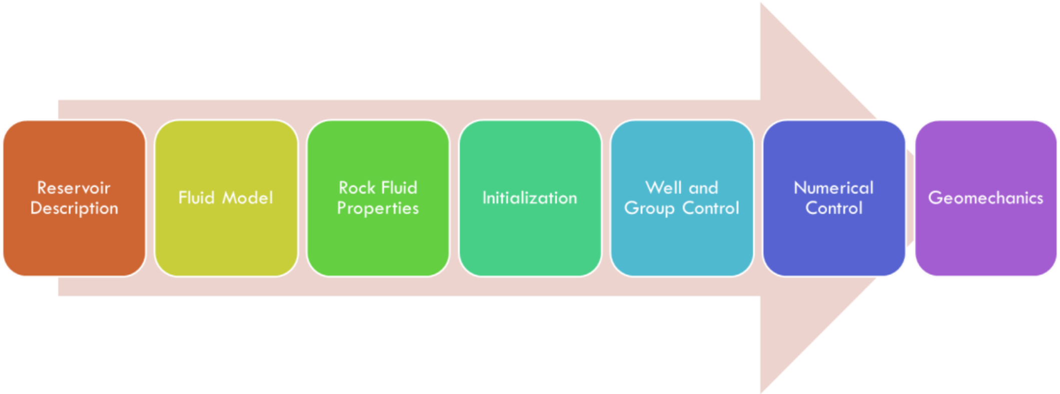


Figure 26. CMG Module's Workflow.

Funding Awards

Funding from Grupo Plenum – CONACYT (Mexico) was obtained for the second phase of the project "Stochastic Geomechanics for Shale Gas Computing." Funding from SWUTC helped to build a strong case for the extension of this project. The award for the FY2014 was $155,333.00.

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