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THE APPLICATION OF GIS IN SUPPORT OF LAND ACQUISITION FOR THE PROTECTION OF SENSITIVE GROUNDWATER RECHARGE PROPERTIES IN THE EDWARDS AQUIFER OF SOUTH-CENTRAL TEXAS

DAN STONE
ESRI – San Antonio, 14100 San Pedro Avenue Suite 210, San Antonio, Texas 78232 USA
GEARY M. SCHINDEL
Edwards Aquifer Authority, 1615 North St. Mary's Street, San Antonio TX, 78215 USA

In May 2000, the City of San Antonio passed a $45 million bond issue to purchase land or conservation easements of sensitive land in the recharge zone of the Edwards Aquifer in south central Texas. The Edwards Aquifer is the primary source of water for over 1.7 million people in the region. The application of geographic information systems (GIS) methods allowed for the objective comparison of all properties within the recharge and contributing zones of the aquifer for possible purchase. A GIS matrix was developed and applied in the process of prioritizing sensitive karst lands.

The San Antonio segment of the Balcones fault zone section of the Edwards Aquifer is one of the most productive karst aquifers in the United States. Located in south-central Texas, the San Antonio segment extends from the groundwater divide in Kinney County (Brackettville), east through Bexar County and the City of San Antonio, then northeast to the groundwater divide in Hays County (near the town of Kyle). The Edwards Aquifer is the primary source of water for over 1.7 million people in the greater San Antonio area and supports a broad base of agricultural, municipal, industrial, and recreational uses (EAA 2001). The need to protect the water quality of the Edwards Aquifer was highlighted in 1987 when the U.S. Environmental Protection Agency designated the Edwards as the first "Sole Source Aquifer" in the United States. Various state, regional, and local regulatory programs have been initiated to protect water quality in the Edward's region.

In May 2000, the citizens of San Antonio passed a $65 million sales tax initiative to collect 1/8 cent sales tax up to $65 million to purchase open space within the city and for land acquisition for aquifer protection in Bexar County. Approximately $40.5 million from the sales tax initiative will be used to directly purchase land or conservation easements for aquifer protection. Another $4.5 million will be put aside for operations management. The San Antonio City Council directed city staff to develop a process to allow for the fair and adequate selection and evaluation of eligible properties.

GEOLOGIC SETTING

The Edwards Aquifer is named after and contained in the Lower Cretaceous Edwards Limestone. Secondary porosity and permeability, resulting from both meteoric water and deep circulation mixing corrosion, have dominated the flow regime. The Edwards Limestone and associated units range from 130 m to over 270 m thick with an average thickness of ~180 m. A series of faults in the Balcones fault zone has exposed the Edwards Limestone at the surface along the boundary between the dissected Edwards Plateau (Texas Hill Country) and the Gulf Coastal Plain. En echelon faulting has dropped the Edwards Limestone to great depth below the surface along the aquifer's southern and eastern boundary (Maclay 1995).

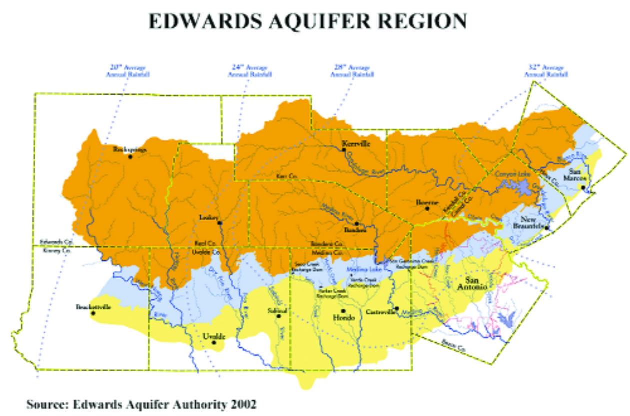

Figure 1. Edwards Aquifer region.

Generally, the Edwards Aquifer is divided into three zones: the drainage zone or contributing zone, the recharge zone, and the artesian zone (Fig. 1) (EAA 2002). Surface streams forming on the contributing zone (the dissected Edwards Plateau), flow south or east and cross the Edwards Limestone outcrop (recharge zone) (Fig. 2). During low flow conditions, most surface water is captured by the aquifer as it crosses the outcrop. In addition, rainfall that occurs directly on the recharge zone also enters the aquifer. Groundwater entering the aquifer generally flows south and east into the artesian zone. In the artesian zone, regional flow paths are from west to east where the aquifer discharges at two primary springs – Comal Springs and

San Marcos Springs. Comal Springs is the largest spring in the southwest with an average discharge of 8.3 m³/s. However, wells tapping the aquifer in the artesian zone withdraw >500,000,000 m³ of water each year. Residence time of water in the aquifer ranges from a few hours or days to many years depending upon depth of circulation, location, and related aquifer parameters (Maclay 1995).

Water quality in the aquifer is generally very high; however, human activities in the contributing and recharge zone have resulted in degraded water quality in some areas. Of particular concern is the northern growth of San Antonio onto the recharge zone. Land use is quickly changing from ranching to mixed residential and commercial development. Wells that exceed safe drinking water limits are generally associated with point contamination sources such as releases from above or underground storage tanks.

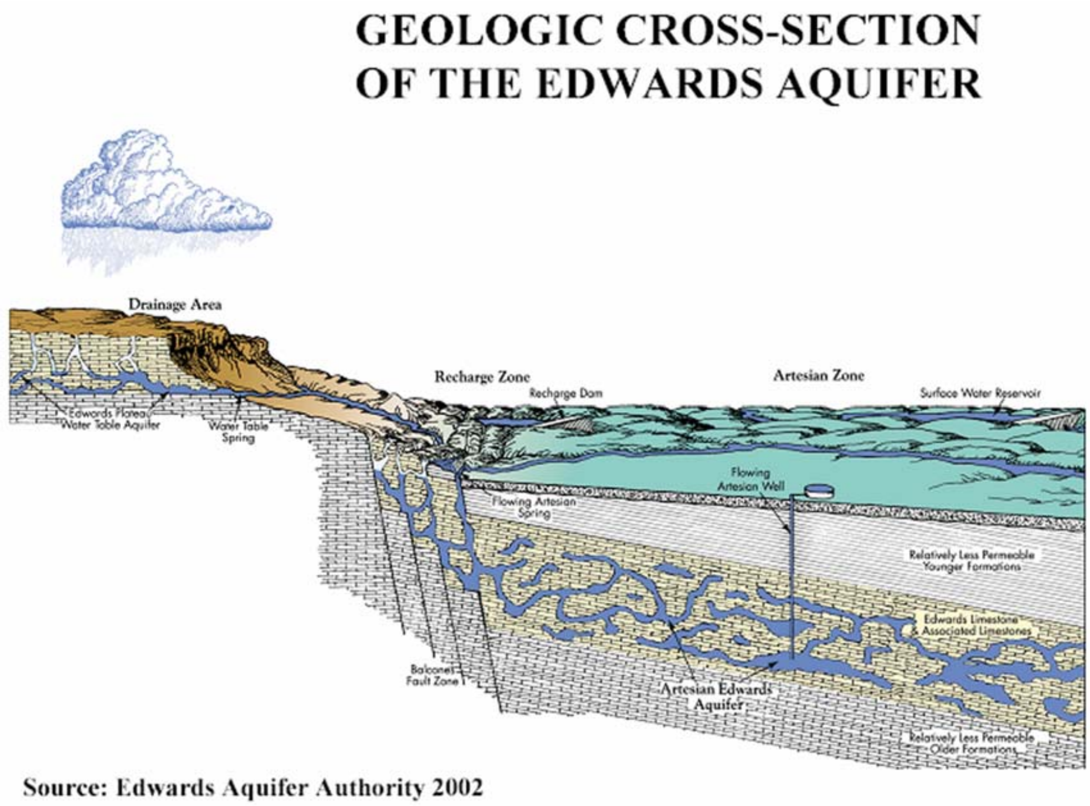

Figure 2. Geologic cross-section of the Edwards Aquifer.

PROPOSITION 3

On May 6, 2000, the citizens of San Antonio passed a "Parks Development and Expansion Venue Project Proposition" (Proposition 3) to raise $65 million through a 1/8 cent sales tax increase for the acquisition of open space over the Edwards recharge zone and linear parks along Salado and Leon Creeks. Of the four propositions in the May election, only Proposition 3 passed. A total of $40.5 million was reserved for the purchase of land or conservation easements over the recharge and contributing zones of the aquifer. Another $4.5 million was created for a maintenance endowment fund for management of acquired properties and easements.

Upon passage of Proposition 3, the San Antonio City Council instructed City staff to create a process for the fair and adequate evaluation of properties. City staff proposed and the City Council approved the creation of two committees: the Scientific Evaluation Team (SET) and the Conservation Advisory Board (CAB).

The purpose of the SET was to develop a "scientific data matrix" outlining and prioritizing the characteristics of the area for use by the CAB in property evaluation. This group was composed of representatives from public agencies and one private environmental consulting firm as follows: Texas Parks & Wildlife, Edwards Aquifer Authority, San Antonio Water Systems, City of San Antonio Public Works Department, City of San Antonio Parks & Recreation Department, United States Geological Survey, University of Texas San Antonio, National Resources Conservation Service, San Antonio River Authority, and George Veni and Associates.

The Conservation Advisory Board was created to review the SET's scientific data matrix, establish additional criteria to be considered for land acquisition (i.e., property size, cost, proximity to other public property, open space linkages, etc.), transmit the final matrix to the land agents, evaluate properties identified by the land agent, make recommendations for land purchases to the Planning Commission and City Council, and to work with City staff to determine appropriate park land use intensity after purchase. The CAB is composed of representatives from the following groups: Texas Parks & Wildlife, Edwards Aquifer Authority, San Antonio River Authority, San Antonio Water Systems, City of San Antonio Public Works Department, City of San Antonio Parks & Recreation Department, Open Space Advisory Board (conservation community representative), Parks and Recreation Advisory Board (neighborhood representative), and a business representative.

The City of San Antonio (COSA) staffed the SET and the

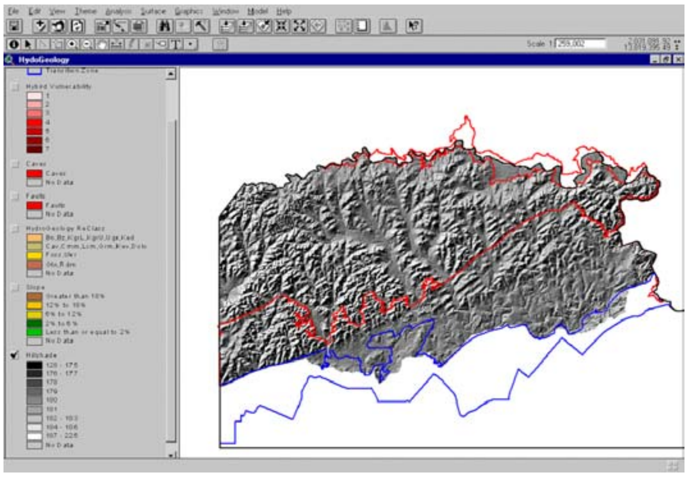

Figure 3. Digital elevation model (DEM) of the study area.

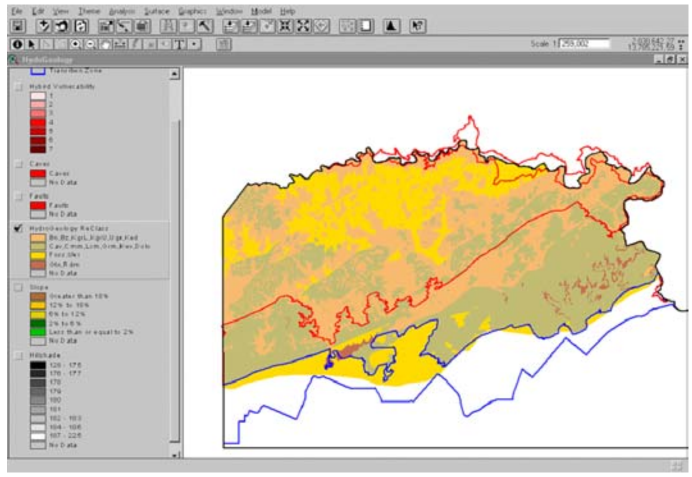

Figure 5. Geologic classifications.

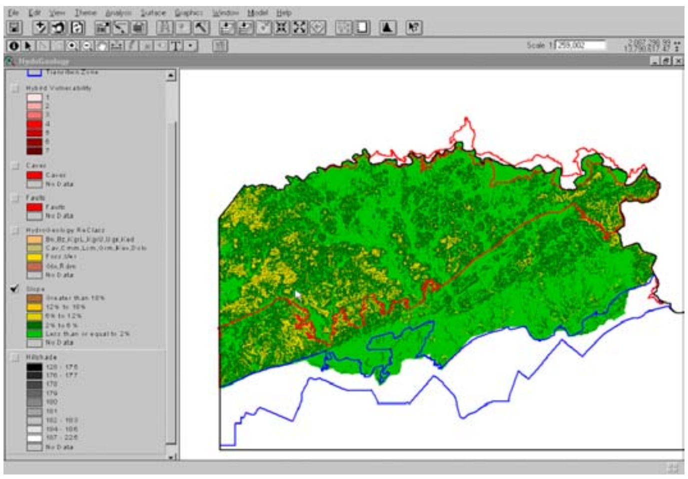

Figure 4. Calculated slope ranking.

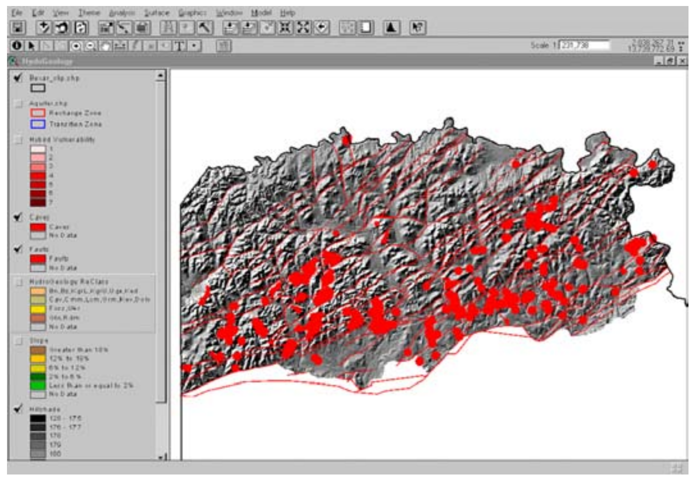

Figure 6. Buffered faults, sinkholes, and caves.

CAB. Susan Crane, a landscape architect with COSA was named project manager. In addition, COSA contracted with software developer ESRI to provide Geographic Information System (GIS) support.

The first meeting of the SET addressed various methods to rank and score individual properties. However, it was determined that this offered no guidance to the land agents in preselection of properties and potentially wasted considerable time and money. In addition, the scoring of individual properties could be very subjective, especially if properties would not or could not be compared to a larger population set. The SET Committee determined that developing a matrix using GIS offered the best solution to this problem and allowed for the objective comparison of all properties within the recharge and contributing zones.

The use of GIS allows spatial information to be stored in a computer based on different themes or layers. A layer is data organized by subject matter. For example, land surface elevation data can be grouped together into a single layer. As relevant data sets are identified and gathered, the GIS technology allows the various layers to be queried to determine relationships, or quantified for scoring and ranking purposes. For example, the process can be used to indicate all properties within 60 m of an existing park that are at least 24 hectares in size, and contain specific geologic formations.

The SET then identified the variables, criteria for inclusion of the datasets, and weighting for each layer for use in the spatial model. Three primary data categories were selected for inclusion in the model: geologic, biologic, and watershed data. Each major category contained a number of subcategories. It was also necessary for each dataset to cover the entire study area. Advances in computational power and existing datasets allowed a 1-m data cell resolution.

Geologic datasets

The following geologic criteria were selected for use in the GIS model: terrain slope, stratigraphy, mapped faults, caves and sinkholes, and soils. The United States Geological Survey (USGS) had just completed a 2-year study of the recharge zone and created a dataset using the above listed layers. However, this data set was limited to the recharge zone only. At the

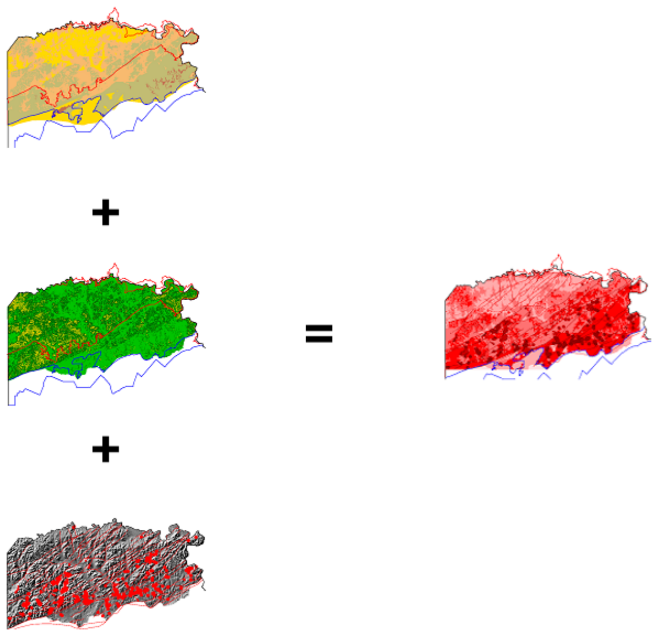

Figure 7. Vulnerability model spatial overlay process.

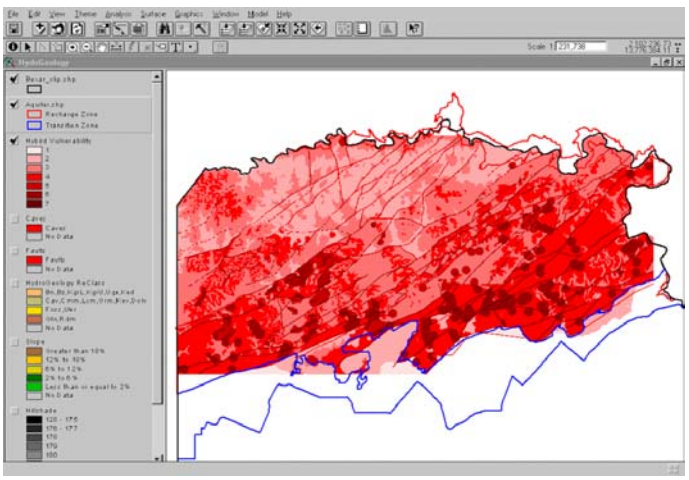

Figure 8. Vulnerability model showing areas of highest permeability in darker red.

request of the SET, the USGS prepared a new hybrid-data set that included the contributing zone.

Table 1. Slope Classification

Class	Rating
Greater than 18%	1
Greater than 12% and less than 18%	3
Greater than 6% and less than 12%	5
Greater than 2% and less than 6%	9
Less than or equal to 2%	10

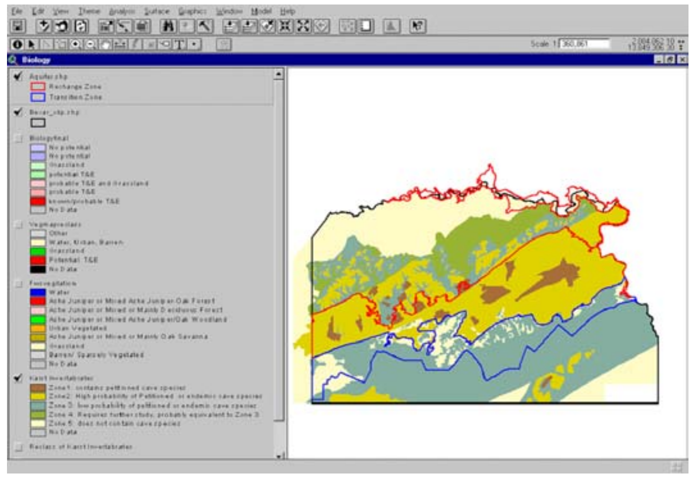

Figure 9. Endangered karst invertebrate classification zones.

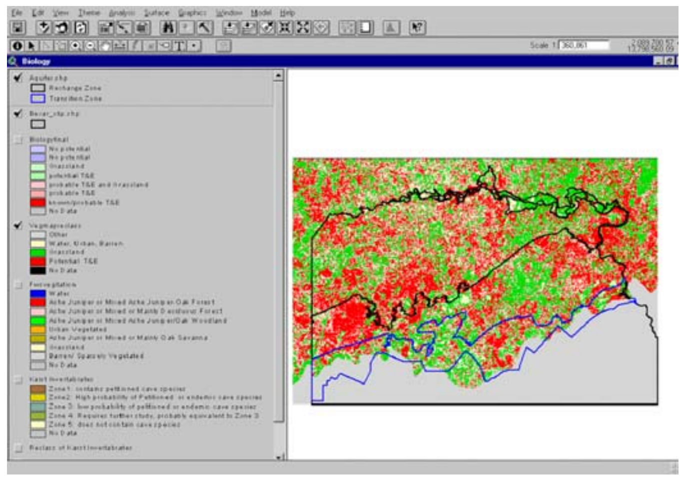

Figure 10. Vegetation habitat classification for the Golden-Cheeked Warbler.

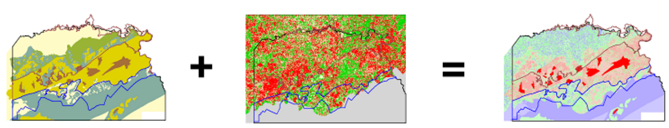

Figure 11. Biological model spatial overlay process.

TERRAIN SLOPE

Slope plays an important roll in controlling rainfall runoff with the greatest slope having the least potential for infiltration. Properties with little or no slope would have the greatest potential for infiltration and would therefore be more important to protect through purchase. The GIS was able to analyze the Digital Elevation Model (DEM) and calculate the differences in elevation between every square meter in the data set (McCoy & Johnston 2001). Using the criteria established for slope in Table 1, it was easy to calculate a ranking of slope for

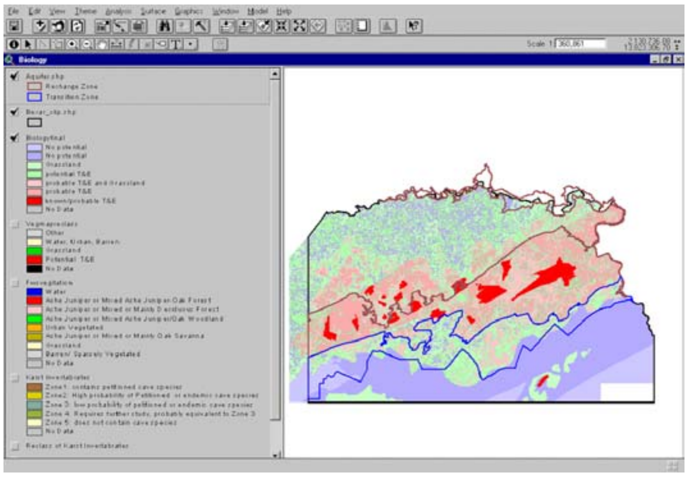

Figure 12. Biological model showing areas of highest potential for threatened and endangered species in dark red.

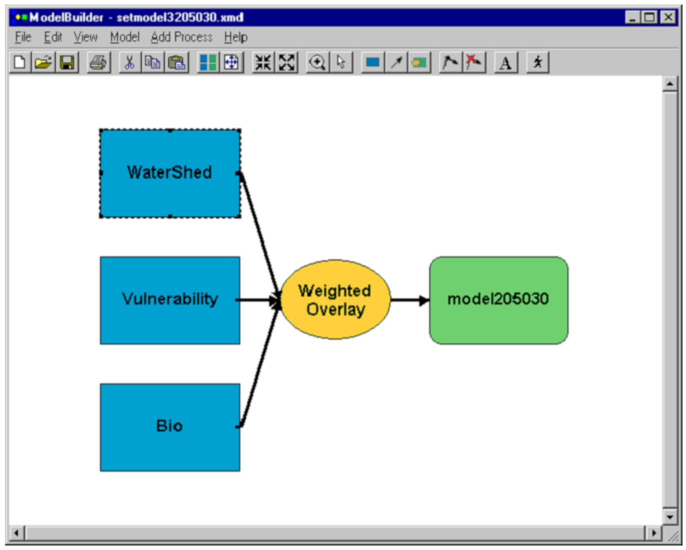

Figure 13. Model Builder diagram of the final SET model.

the region. Figure 3 shows the DEM for the study area. The resulting slope calculation by the GIS is displayed in Figure 4. Areas indicated in light green have relatively flat slopes and are indicative of highest rating.

STRATIGRAPHY

The recharge zone of the Edwards Aquifer is generally defined as the outcrop area of the Edwards Limestone and associated units (Georgetown Formation). The Edwards Limestone is composed of a number of mappable units or strata, each exhibiting varying degrees of susceptibility to dissolution processes. The location of each unit has been defined within a GIS dataset. The contributing zone is composed of the Glen Rose Limestone, the geologic unit located stratigraphically beneath the Edwards Limestone. Units within the Glen Rose also display varying susceptibility to karstification. The SET, based upon a consensus of experience, assigned each unit a classification related to its primary and secondary porosity and permeability. Under the guidance of the SET geologists, the geology was classified into the following categories with areas of higher relative permeability given a higher ranking than areas of lower relative permeability. The resulting data layer is displayed in Figure 5.

The last variable in the hybrid-vulnerability model was the inclusion of fault, sinkhole, and cave data. The SET made an assumption that all faults, sinkholes, and caves were areas of enhanced permeability and, therefore, should receive separate coverage and given a high ranking. Faults, sinkholes, and caves were identified from data provided from the USGS, the Texas Bureau of Economic Geology, the terrain model, and from the Texas Speleological Survey files. The areas around faults, sinkholes, and caves were "buffered" in the model to cover some uncertainty regarding their locations and the concern that adjacent areas may not have been identified but exhibit similar physical properties related to hydrology. Faults were given a 25-m buffer on each side, caves and sinkholes were given a 50-m buffer. Identified features are shown in red in Figure 6.

The final hybrid-vulnerability model was created through an operation known as a spatial overlay (ESRI 1997). All of the layers: Slope, Geology, Faults, Sinkholes, and Caves; were overlaid (Fig. 7) and the values for each square meter calculated for the output model. Figure 8 depicts the results of the overlay process. The dark red colors in Figure 8 are areas that have the highest score, thus meeting the majority of the geologic criteria established by the SET.

BIOLOGY

The second primary data category identified for inclusion in the model was biological criteria. The SET identified a surface biological component and a subsurface biological component for inclusion in the model. Datasets containing relevant material were provided by the Texas Parks and Wildlife and the U.S. Fish and Wildlife Service.

The SET selected the habitat of the Golden-Cheeked Warbler to represent surface biologic datasets. The Golden-Cheeked Warbler is a federally listed endangered species that only nests in mature, central Texas mixed ash juniper and oak woodlands. The species was listed because of declining populations resulting from land use changes.

In 1992, several groups petitioned the U.S. Fish and Wildlife Service to add 9 species of karst invertebrates to the list of Threatened and Endangered Wildlife. The 9 species of invertebrates are known only from caves in the northern and northwest parts of Bexar County. The SET selected the karst invertebrate dataset to represent the subsurface component for the model. In December 2000, U.S. Fish and Wildlife listed the 9 species, which includes three beetles, five spiders, and one harvestman. Figure 9 indicates the GIS coverage for the biologic subsurface datasets. The data are partitioned into 5 zones with Zone 1 (highest ranking) to Zone 5 (lowest ranking).

Table 2. Geologic Classification Based On Relative Permeability

Geologic Strata	Class
Basal Nodular (Edwards) Member Bullis Zone Lower Glen Rose Upper Glen Rose Edwards	1
Upper Glen Rose "Cavernous Zone" Edwards (Cyclic and Marine Members) Edwards (Leached and Collapsed Member) Edwards (Grainstone Member) Edwards (Kirschberg Member) Edwards (Dolomitic Member)	2
Upper Glen Rose "Fossiliferous Zone" Upper Confining Unit Undivided 3	3
Georgetown Formation Regional Dense Member (Edwards)	4

Table 3. Karst Invertebrate Zones

Zone	Classification
Zone 1	Contains petitioned cave species
Zone 2	High probability of petitioned or endemic cave species
Zone 3	Low probability of petitioned or endemic cave species
Zone 4	Requires further study
Zone 5	Does not contain petitioned species

Zone 1 containing listed cave species, Zone 2 probably containing species, Zone 3 having a low probability of containing species, Zone 4 requiring further study, and Zone 5 not containing listed species. The classification is described in Table 3.

Vegetation data for the study area was reclassified to identify potential endangered species habitat. The SET acquired a vegetative dataset prepared cooperatively by Texas Parks and Wildlife and U.S. Fish and Wildlife Service. From the dataset, vegetation was reclassified from 8 classifications to 3 classifications. The reclassification is described in Table 3. The results of the reclassification are shown in Figure 10.

The final biology model was created through spatial overlay. The vegetation and karst invertebrate layers were combined to form the final biologic layer (Fig. 11). The result of the overlay process is shown in Figure 12. The red areas in Figure 12 represent areas that have the highest potential for threatened and endangered species.

Table 4. Reclassification of Vegetative Data Sets

Original	Reclassified
Ashe Juniper or Mixed Ashe Juniper Oak Forest Ashe Juniper or Mixed Ashe Juniper or Mainly Deciduous Forest Ashe Juniper or Mixed Ashe Juniper/ Oak Woodland Ashe Juniper or Mixed or Mainly Oak Savanna	Potential Threatened and Endangered Species
Water Urban vegetated Barren, Sparsely Vegetated	Water, Urban, Barren
Grassland	Grassland

WATERSHED

The third primary data category was a watershed component. The watershed component consisted of several variables such as property size, adjacency, and proximity of a property to other "Open Space" properties.

The SET decided to set a minimum property size for property consideration at 60 acres. The 60 acres minimum was based upon the minimum area necessary for effective wildlife management. Properties were then reclassified by property size from data provided by the Bexar Appraisal District and included parcel number, size, ownership, and appraised value including improvements.

The SET determined that properties located either adjacent to or in proximity of other open space properties were desirable. This would improve the size of wildlife habitat as well as make management of properties easier. Existing open space areas that were considered in the model were military bases, San Antonio River Authority Dam locations, and existing parks and nature areas. This layer was used to find all properties that are adjacent to these features. A 200-foot buffer was used to select all properties in proximity to these features.

THE SET MODEL

Data layers from the geologic, biological, and watershed primary data categories were combined into a spatial overlay using the GIS model builder application (Ormsby & Alvi 1999) (Fig. 13). The SET determined the weighting for primary data categories as follows: geologic (50%), biological (20%), and watershed (30%). The modeling process assigned every square meter of the study area a value based on the weighted overlay with the higher values representing the greatest number of criteria met.

The results of the modeling were divided into 8 tiers with the 3 highest tiers meeting the overall criteria developed by the SET to be considered for evaluation for purchase. Use of the GIS SET model allowed the objective evaluation of each property and provided the public an assurance that Proposition 3 funds were being spent to support the goals of the program.

CONCLUSION

GIS allows for the processing of very large and diverse data sets to meet the goals of the SET - to established scientifically based, objective criteria to evaluate properties over the drainage and recharge areas of the Edwards Aquifer. The model was used by the Proposition 3 project manager to direct land agents to pursue properties that met the objectives of the program. As land purchases are negotiated with the owners, they are evaluated by the Conservation Advisory Board. If the CAB gives a land purchase a favorable rating, the property acquisition was forwarded to the Planning Commission and City Council for review and approval.

In December 2000, the first purchase of "sensitive" land was made using funds generated by Proposition 3, a 1/8 cent sales tax that took effect in October 2000. The San Antonio City Council voted to spend almost $6.8 million to acquire 414 hectares of ranch land adjacent to Government Canyon State Natural Area in northwest Bexar County. Almost all the property lies within the recharge zone. The city is now creating a management plan for the property in cooperation with the CAB.

The Proposition 3 program continues to purchase property in the recharge and contributing zone and is now considering increasing the funding as well as the ability to purchase lands outside of Bexar County for inclusion in the program. Since December, the city has acquired 4 additional properties. A total $22.5 million was spent for 1416 hectares. Prior to the proposition program the park acreage was 3298 hectares. With the proposition program the park lands have increased 43%.

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