DEVELOPING A GEOGRAPHIC INFORMATION SYSTEM TO MANAGE AIRPORT OPERATIONS AND REDUCE CONFLICTS BETWEEN WILDLIFE AND AIRCRAFT

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ABSTRACT

Wildlife collisions with aircraft are a serious economic and safety problem in the United States and throughout the World. With the increasing amount of aircraft movement and wildlife populations, wildlife hazards in airport settings are receiving more attention than ever.

When humans began sharing airspace with wildlife, collisions with aircraft became a safety concern as aircraft and wildlife met in space and time. Wildlife management is a multi-dimensional problem where current methods include multiple management techniques. This heightened attention has risen awareness of the FAA approved Wildlife Hazard Management Plans for airports. Technical advances can assist wildlife management to further reduce wildlife-aircraft conflicts by allowing a 'systems' management approach in a Geographic Information Systems (GIS) context.

The objective of this work was to identify and review current technologies and to develop a three-dimensional template GIS that supports wildlife management plans and airport operations. The template GIS will provide guidance for airport officials when wildlife management techniques are needed to supplement or replace traditional management practices and methods.

INTRODUCTION

Wildlife collisions with aircraft are a serious economic and safety problem in the United States. With increasing air traffic and wildlife populations (**Figure 1**) dealing with wildlife hazards at airports is becoming a U. S. Federal Aviation Administration (FAA) safety priority.

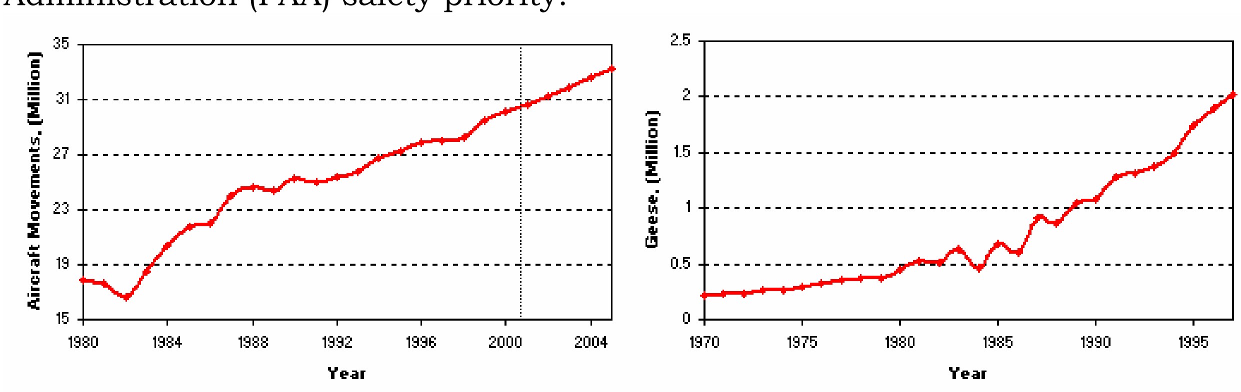

Figure 1: Aircraft movement and geese population increases.

When humans began sharing airspace with wildlife aircraft collisions became a safety issue as aircraft and wildlife met in space and time. To understand the problem of wildlife collisions with aircraft, it is important to first consider the spatial and temporal dynamics of both aircraft and wildlife. Wildlife-aircraft collisions are reported for animals such as gulls, geese, deer, coyotes, and even alligators and turtles (**Table 1**). Most attention is directed toward bird/aircraft collisions (bird strikes) because birds and aircraft both move through the atmosphere. This review will use the term *wildlife* to recognize that wildlife other than birds have been involved in collisions with aircraft.

Table 1

Wildlife groups according to the FAA National Wildlife Strike Database for Civil Aviation (August, 2000).

Wildlife Group	# Reported Collisions	% Total Reported Collisions
Amphibians	2	0.01 %
Birds	13,692	43.51 %
Mammals	769	2.44 %
Reptiles	37	0.12 %
Unknown	16,967	53.92 %

Wildlife collisions to aircraft have been a concern since the first fatal bird collision was reported on April 3, 1912 (Cleary, 1998; Cleary and Dolbeer, 2000). In 1960, the greatest loss of life due to a wildlife collision occurred in Boston, MA where an Electra 188 ingested a flock of starlings in its engines, causing a crash that killed 62 passengers and crew (Bird Strike Committee, 2001). Bird and other wildlife collisions annually cause over $300 million in damage to U.S. civil and military aviation operations, and endanger the lives of aircraft crew and passengers (Cleary and Dolbeer, 2000; Bird Strike Committee, 2001). Although the economic costs of wildlife collisions are high and the cost of human lives best illustrate the need to reduce these conflicts, the response to the wildlife collision hazard has been mixed. Past wildlife hazard abatement has focused on airport habitat management and application of harassment techniques to discourage wildlife (Cleary, 1998).

Reporting wildlife collisions is not required by the FAA although some airlines require it of the pilots, aircrew, and maintenance personnel. The FAA maintains a birdstrike database for civilian aircraft that includes entries from 1983 to present, **Figure 2,** with the highest quality data produced by improved reporting after 1990 (Cleary and Dolbeer, 2000; FAA, 2000). As of August 10, 2000 the FAA database included reports on over 31,000 incidents, ranging between 1,800 and 5,000 reports per year (Cleary and Dolbeer, 2000; FAA, 2000). Because collision reporting is voluntary it is estimated that less than 20 percent of all wildlife-aircraft collisions are reported (Wright, 1997; Dolbeer, 1998; Cleary and Dolbeer, 2000; Linnel et al., 1999).

Wildlife Management

Wildlife management by definition is *the application of ecological knowledge to populations of vertebrate animals and their plant and animal associates in a manner that strikes a balance between the needs of the those populations and the needs of people* (Bolen and Robinson, 1999). Wildlife management is a complex endeavor that attempts to deal with wildlife in a changing physical environment, which is affected by complex federal, state, and local regulatory environments (Cleary and Dolbeer, 2000). Effective wildlife management will ultimately depend on the ability to understand and predict wildlife-habitat relationships (Van Manen and Pelton, 1997).

Habitat modification, along with harassment, is the most common airport wildlife management approaches. Habitat is modified to alter food, water, and cover availability to make the airport less attractive to wildlife (Cleary, 1998; Dolbeer et al., 1989; Beklova, 1979; Mecham, 1999; Dolbeer, 1984; Belant, 1997; Belant et al.; 1996). Although local habitat modification may be effective, this approach will not deal with all wildlife hazards. For example, local habitat modification will have limited effect on wildlife migration across aircraft flight paths. Further, it is unusual that an airport can modify habitat beyond airport boundaries so mobile species still present a hazard to flight operations (Dolbeer et al., 1993).

Wildlife Management and Technology

The advancement of technology is providing new tools for wildlife management. Instead of shooting, frightening, or poisoning wildlife, it is possible to improve detection and recognition techniques so that aircraft can better avoid wildlife collisions. New technologies include radar, infrared thermal imagery, computer mapping, and database management (BASH, 2001). Over the past 20 years, the Bird Aircraft Strike Hazard (BASH) Team of the U.S. Air Force has been using advanced technologies to develop products that improve the safety of military flight operations. One of the first products of the BASH Team was the Bird Avoidance Model (BAM). The present BAM is a GIS based web-available predictive bird avoidance model that has coverage for the conterminous U.S. and incorporates multiple user profiles associated with low-level (low altitude) military operations (**Figure 2**).

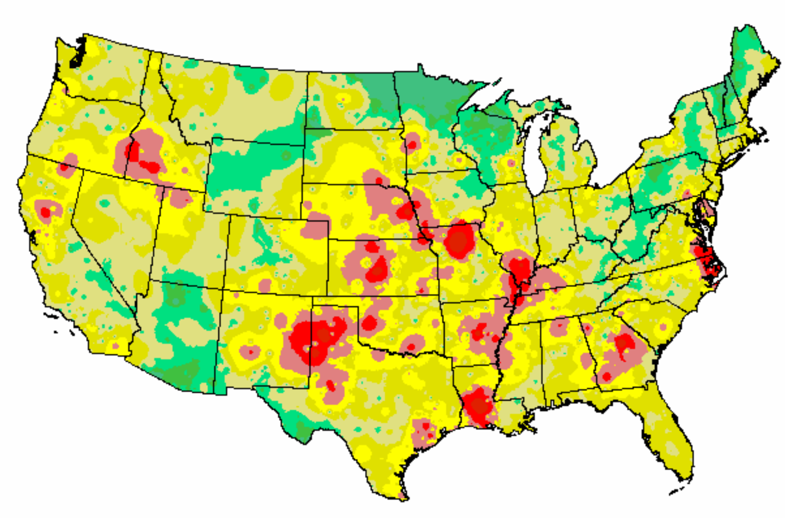

Figure 2: BAM hazard surface (BAM). Graduated colors represent varying degrees of hazard.

Along with the BAM, the BASH Team also developed the Avian Hazard Advisory System (AHAS) that incorporates BAM and NEXRAD weather radar data into a predictive model for bird migration and soaring. AHAS is able to process NEXRAD radar to identify bird presence and track movement. AHAS provides near real-time information for large-scale bird movements. The AHAS is currently available for the eastern one-third of the U.S..

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Geographic information systems (GIS) have emerged as a key technology to manipulate and analyze spatial data to assist decision makers in understanding and managing environmental systems. The GIS is a robust tool for managing spatial information while preserving geographic relationships among datasets. A GIS allows a user to query, build, and manipulate geographical databases while preserving a systems-view approach.

As the *systems* management approach is adopted in an airport setting, it will be important to consider how wildlife management at airports can be addressed in a GIS-based system. As a starting point, wildlife management can consider risk attributes and risk factors. A risk attribute is a landscape feature that is associated with an organism, which because of its behavior, size, or other characteristics, creates a risk of an aircraft collision, a risk factor (Schaeffer, 2000). An example of a wildlife risk attribute would include forested areas, water bodies, conservation sites, prairies, or built environments such as bridges, food processing plants, or landfills. Risk factors such as ducks, deer, geese, gulls, etc. would then be the wildlife associated with these attributes. Using the risk attribute/risk factor differentiation, it is possible to build a system that uses the GIS to identify the location of risk attributes in relation to the airport and aircraft operations, and then use information on risk factor (species or organism) behavior or other characteristics to relate spatial and temporal issues of collision potential.

METHODS AND MATERIALS

The development of the WHAS GIS required information from multiple sources. Integration of multiple data sources and programs was accomplished through commonly used software, data management, and GIS development techniques.

AIRPORT SELECTION

The University of Illinois Willard Airport (CMI) was selected for the template GIS. CMI was chosen due to its close proximity and because personal contacts, geo-spatial information, technical support, and existing data on habitat and wildlife were available. Land use and habitat features near CMI include agricultural land (corn and soybeans), quarry, urban development, two golf courses, prairie grasses, standing water, and streams. CMI does not have a Wildlife Management Plan although birds, deer, rodents, and fox are potential hazards. According to the FAA National Wildlife Strike Database (NWSD), CMI has eight reported strikes between 1991 and August 2000.

RISK ATTRIBUTE AND RISK FACTOR DETERMINATION

A list of risk attributes and risk factors was developed for the University of Illinois Willard Airport. Bird species were selected from the *Field Guide to the Birds East of the Rockies* (Peterson, 1980) and from the FAA National Wildlife

Strike Database (NWSD). Animals other than birds were chosen from the FAA NWSD and the *Mammals of Illinois* guide (Hoffmeister, 1989).

Risk attributes were determined from landscape information. Landscape features were identified from aerial photographs (orthophotos), satellite thematic imagery, and maps developed from the Illinois Natural History Survey, Illinois State Geologic Survey, and the University of Illinois Natural Resource and Environmental Science Department (Illinois Geographic Information System).

GIS SOFTWARE

Environmental Systems Research Institute (ESRI) of Redlands, CA developed the GIS software selected for this project. ArcView® GIS is a widely used program and data developed by private, state, and federal agencies are commonly Arc® compatible.

GIS DATA

The GIS data was obtained from state, federal, and military agencies. This included the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), U.S. Fish and Wildlife Service (USFWS), National Imagery and Mapping Agency (NIMA), Illinois Geographic Information System (IGIS), Illinois Natural History Survey (INHS), Illinois State Geologic Survey (ISGS), Illinois Department of Natural Resources (IDNR), FAA Flight Data Center, National Climatic Data Center (NCDC), and the National Oceanic and Atmospheric Administration (NOAA). Private institutions included Geo Insight International Inc. (BAM developers) and GeoComm International Corporation.

Two-dimensional data was converted into three-dimensional files that would reflect the spatial dynamics of wildlife and aircraft. This was completed by creating TINs (Triangulated Irregular Networks) from the USGS Digital Elevation Models (DEMs) and by extruding height attributes (tree heights, building stories) from two-dimensional data. The remaining two-dimensional layers were overlaid on the three-dimensional TIN base layer, creating a three dimensional view where the scene is dictated by the elevations of the TIN.

RESULTS AND DISCUSSION

To demonstrate the usefullness of a GIS in a wildlife-aircraft context, a template GIS was created for Willard Airport. The template GIS incorporated data from multiple sources and allowed analysis within a single interface. The GIS supported better visualization, better analysis of spatial problems, and the development of predictive capabilities for the three dimensional environment of airports, which is needed to reduce wildlife-aircraft hazards.

Support of the template GIS was accomplished through data integration. Risk attributes and risk factors were identified, GIS layers were obtained, and the template GIS was incorporated into three-dimensions. The following sections review significant findings for the implementation of an airport GIS.

RISK ATTRIBUTES AND RISK FACTORS

The risk attributes developed for Willard Airport are unique to that airport where the risk attribute identification used a general list to produce a site-specific listing. The attributes are not unique, but the site specificity coupled with attributes in the specific spatial position are unique.

In addition to risk attributes, site-specific risk factors were also developed. The risk factor matrix for Willard Airport was developed as an autecology matrix that identifies the species, habitat, breeding status, and the peak appearance months for birds at Willard Airport. As species abundance and distribution change with habitat modifications, wildlife conservation efforts and acclimation, the autecology matrices will also require modification.

THE TEMPLATE GIS

Using the risk attributes identified for Willard Airport it was possible to begin developing geographically referenced information for the GIS. GIS layers were not available for each risk attribute desired, but a list of critical layers obtained for Willard Airport are presented in **Table 2.**

Table 2

Risk attribute GIS data layers for Willard Airport. (* Created = created from digital orthophotos, ** Created = created from FAA National Database for Civilian Wildlife Strikes, IGIS = Illinois Geographic Information System).

Risk Attribute GIS Data Layer Name	Obtained?	Source
Golf courses	Yes	* Created
Streams	Yes	IGIS
Waterways	Yes	IGIS
Flood zones	Yes	IGIS
Permanent water bodies	Yes	IGIS
Wetlands	Yes	IGIS
Feedlots	Yes	IGIS
Intermittent lakes	Yes	IGIS
State wildlife management areas	Yes	IGIS
Land use	Yes	IGIS
State parks	Yes	IGIS
State forest	Yes	IGIS
State fish & wildlife	Yes	IGIS
State conservation	Yes	IGIS
Nature preserve	Yes	IGIS
Federal land	Yes	IGIS
Natural areas	Yes	IGIS
Landfills	Yes	IGIS
Trees	Yes	* Created
FAA wildlife collisions	Yes	** Created
Water/sewage treatment plants	No	N/A
Rookeries	No	N/A
Fish plants	N/A	N/A
Fish piers	N/A	N/A
Abattoirs (slaughterhouses)	N/A	N/A

Several layers were used in the template GIS that were not identified as risk attributes. These layers were used to create a comprehensive template that incorporated features near Willard Airport that supported the systems view to wildlife management **Table 3.**

Table 3

General GIS data layers for Willard Airport. (* Created = created from digital orthophotos, ** Created = created from aircraft tracking data, USAF BAM = United States Air Force Bird Avoidance Model, FAA = Federal Aviation Administration, IGIS = Illinois Geographic Information System, USGS = United States Geological Survey).

General GIS Data Layers	Obtained?	Source
BAM Predictive Risk Surface	Yes	USAF BAM
Highways	Yes	IGIS
Roads	Yes	IGIS
Buildings	Yes	* Created
Digital Elevation Model (DEM)	Yes	USGS
Military Airfields	Yes	USAF BAM
Military Heliports	Yes	USAF BAM
Airports	Yes	FAA
Municipalities	Yes	IGIS
Townships	Yes	IGIS
Counties	Yes	IGIS
Utility	Yes	IGIS
Rail roads	Yes	IGIS
NEXRAD stations	Yes	* Created
Digital Orthophoto Quadrangles	Partial	USGS
Digital Raster Graphics	Partial	USGS
Aircraft tracking data	Partial	** Created

The aircraft tracking theme (**Table 3**) is an important component of the template GIS because it displays crucial hazard areas where wildlife collisions can occur. Overlying the aircraft tracking data with the other themes within the template GIS allows the systems view analysis of looking beyond the airport boundaries. Approach, departure, and other flight path (aborted landing, touch-and-go, etc.) information is required for each runway.

ArcView® 3-D Analyst was used to provide a basis for three-dimensional analysis. The USGS Digital Elevation Models and TINS were incorporated for visualization purposes within 3-D Analyst®. The purpose of a TIN was to establish an elevation reference for the project area. Certain themes do not contain a third dimension (ex. lakes, streams, nature preserves, NEXRAD stations, etc.) so these themes must be assigned a "base height" from an established surface. An arbitrary base height can be assigned (as apposed to assigning the base height to the TIN surface), but this can hinder analyses because height/elevation attributes of trees and buildlings are often recorded as heights (stories, feet, or meters) instead of elevations. Thus, by assigning a base height to the TIN surface for our study area, we are able to display two-dimensional data in a three dimensional context (ie. because the TIN was selected as the base height surface, a two-dimensional stream theme will still flow downhill because the stream network will ly ontop the TIN surface). **Figure 3** is a 3-D view that includes a typical approach and departure from Willard Airport including buildings, trees, streams, and land use themes.

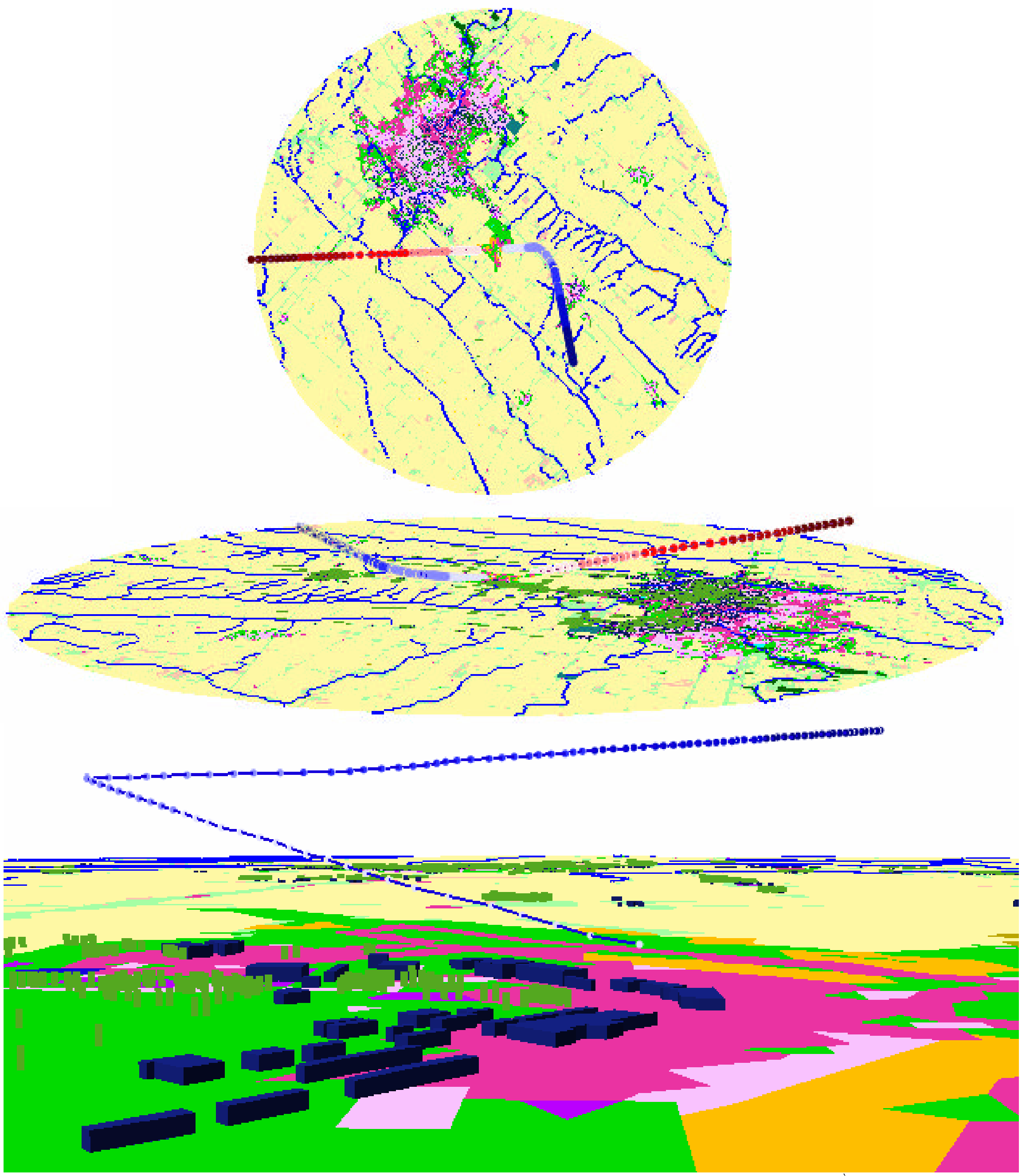

Figure 3: Three-dimensional scene created in ArcViews 3-D Analyst© for a typical approach and departure from Willard Airport. Note the three-dimensional buildings, trees, and flight paths.

GENERAL DISCUSSION AND FUTURE APPLICATIONS

The created GIS data and data from private and federal agencies require a scale with higher resolution than the BAM. The BAM operates at a 1km resolution while the template GIS requires a scale less than 30-meters to effectively display and analyze most data. Also, the BAM was developed for low altitude military operations and cannot be directly correlated to civilian aircraft that utilize airspace between ground-level and 35,000-feet. Digital Orthophoto Quadrangles (DOQ) require a finer resolution, between one-to-three meters to display an effective base map. Small-scale data will improve the analysis and predictive capabilities of the airport GIS and therefore enhance wildlife management.

In 1986, Major et al. developed a three-dimensional statistical computer simulation of bird flocks and aircraft to model predator-prey interactions. The simulated interactions between aircraft and small flocking birds were an approach to investigating such interactions and reducing wildlife collisions. Although not in a GIS context, their methodology could be applied to a GIS that could incorporate interactions between wildlife and aircraft, and be applied to aircraft operations around the airfields, particularly during take-off and landing maneuvers.

The next phase of this application will include a model integrated with the template GIS. The model will include all the risk attributes and risk factors previously explained and it will link wildlife species and their movements, attractants, abundance and weight, with aircraft tracking data to assign hazard values in a three-dimensional hazard envelop.

Since GIS layers contain attribute tables that descriptively explain the respective theme, hazard values will be assigned to each attribute. These hazard attribute values will be included on each attribute and on each theme that will contribute to the wildlife-aircraft model. The hazard values are numbers that define the degree of hazard of the risk attribute and risk factor. For example, the land use theme may have attritbutes of water, forest, and pavement, with hazard values of 8, 10, and 1, respectively (1=low hazard, 10=high hazard). The model will draw on these hazard values and relate them to other risk attributes, risk factors, and aircraft tracking data to develop a three-dimensional hazard envelop that predicts a wildlife hazard to aircraft.

The output of the model will then be incorporated into the GIS. **Figure 4** is a view of the potential three-dimensional GIS after the integration with the model. The usefulness of the model/GIS marriage is two fold. First, it will allow aircraft operations to pick optimum travel paths for aircrafts. These optimum travel paths will be used for wildlife-aircraft collision reduction. **Figure 4** is an example that shows which approach path is optimal for wildlife conflict avoidance. Second, the GIS will allow the user to make decisions on develpement and wildlife management that effect wildlife-aircraft collisions. The GIS will allow the user to modify land use to model habitat modification and determine if the modifications will promote or reduce wildlife-aircraft collisions. The user will change the land use attribute (ie. change a forest into a parking lot) and the model will predict the effect the alteration will have on wildlife-aircraft conflicts. Thus, optimal land management can be chosen through this iterative process to reduce wildlife conflicts.

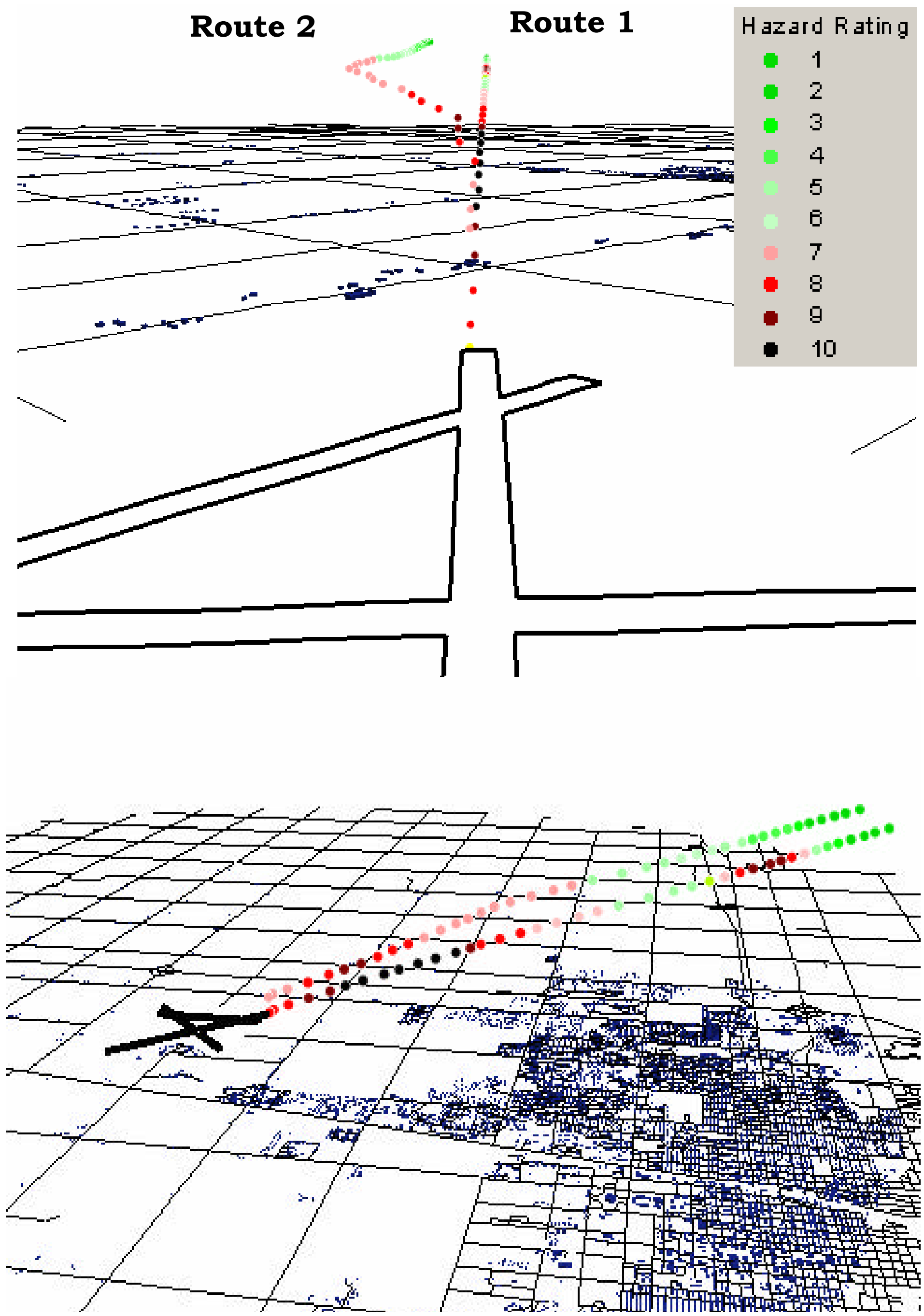

Figure 4: Output from the proposed model integration in 3-D Analyst© . Note the alternate flight routes and reduced cumulative hazard in Route 2.

CONCLUSION

The mission of the FAA is to ensure safe air travel. For this reason, the FAA is developing a systems-based effort to address wildlife safety issues at airports. The FAA recognizes that the wildlife management practices at airports require continued development because the most effective program integrates all control strategies whenever and wherever possible. This integrated approach offers maximum long-term effectiveness, immediate relief, and minimizes the need for repeat applications of lethal or costly control methods. For the above reasons, the FAA has taken preventative measures through research and development of an integrated GIS application in the wildlife-aircraft environment.

Concurrent with the trends in GIS applications and the evolving awareness of wildlife collision control at airports, it is logical to assume that airports will incorporate a GIS in wildlife management plans and assessments. It is important for airport wildlife managers to be proactive and anticipate, if possible, species' arrival or change in annual behavior weeks or even months in advance. Anticipating changes in the wildlife composition and abundance can help to plan management techniques in a more effective manner. To do so requires information on the different species' ranges (geographical distribution), life histories, demography, population dynamics, interaction with other species, and land use-wildlife linkages. Wildlife can be attracted to a site for a number of reasons and the identification of land use used by wildlife is key for effective wildlife management. Technical advances can now assist wildlife management to further reduce wildlife-aircraft conflicts by allowing this 'systems' management approach in a GIS context.

Risk Attributes, Risk Factors and Aircraft Tracking Data

A comprehensive list of risk attributes and risk factors was completed for the template GIS. The risk attributes will require constant updating as urbanization and landscape alterations continue. Risk factor updating is also required as wildlife communities continually change as new species can present hazards.

Aircraft tracking data for Willard Airport was integrated in the GIS. The aircraft tracking data is an essential requirement for the systems-based analysis.

The Template GIS and Wildlife-Aircraft Collision Abatement

The threat of wildlife-aircraft collisions is a spatial and temporal issue and is thus a good candidate for integration in a three-dimensional GIS environment. The GIS is a robust application that accounts for attribute changes and modifications associated with land use, wildlife distributions, abundance and movements, aircraft flight paths, and habitat alterations. In essence the GIS accounts for the dynamic nature of wildlife and allows for systematic modifications.

The template GIS provides a framework for choosing optimal flight paths (approach and departure), land use management, and habitat modification for wildlife at a specific airport or airspace. The GIS allows for a systems view of the wildlife-aircraft collisions at any elevation, of any attribute, and at any scale or range. The GIS created for Willard Airport is the first step towards a fully developed GIS. The next step for the GIS advancement is continuing model development of an airport-based wildlife management model.

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