MONITORING GIS ANALYSIS AND SIMULATIONS OF NATURAL AND ANTHROPOGENIC DIGITAL TERRAIN CHANGE IMPACTS ON WATER AND SEDIMENT TRANSPORT IN THE AGRICULTURAL FARMS

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ABSTRACT:

The research effort focused on the acquisition of new knowledge about the complex interactions that occur between natural processes and anthropogenic activities to improve current understanding of topographic and land cover change impact on landscape processes. The method has been developed for a comprehensive spatio-temporal analysis of sand dune evolution. First, a set of features that can be used as indicators of dune evolution was identified and methods based on surface analysis using principles of differential geometry developed. Specific thresholds for extraction of the features such as dune crests, ridges, slip faces and active dune areas were introduced. The proposed methodology can be used to assist quantifying various aspects of complex evolution of a sand dune field that included rotation, translation and deflation, evolution of new slip faces and transformation from crescent to parabolic dunes. Complex interactions between human impacts and natural processes were identified: the impact of a large number of visitors freely moving over the dune has proven to be minimal, on the other hand, the naturally expanding vegetation and urban development surrounding the dune that reduced the sand supply had a major impact. It appears that the combination of climate change and indirect human activities have more significant impact than the direct interaction. Quantification of dune evolution provided critical information for park management and selected results of the research will be included in the visitor's center. The developed methodology is general and can be applied to other areas that include migrating sands providing valuable information for management of such areas and a range of additional applications.

1. INTRODUCTION

Natural processes and human activities drive changes in landscapes that are not always compatible with each other. The changes often create conflicts between economic development and the need to preserve natural resources. Integration of new mapping and monitoring technologies, process based models and Geospatial Information System (GIS) analysis provides an opportunity to monitor and model the landscape evolution at high spatial and temporal resolutions, predict the possible impacts of human activities and explore options to minimize the negative consequences. Airborne laser scanning (e.g. LiDAR), Real-Time Kinematic GPS (RTK-GPS), sonar surveys, and multispectral remote sensors provide greatly enhanced capabilities to gather 3-D georeferenced data for large areas at unprecedented speed, recurrence interval, and spatio-temporal resolution. Terrain models based on such data provide critical information for areas with rapidly changing topography that is typical of many coastal regions, as well as for areas with intensive development, typical for rapidly expanding urban areas. The capacity to acquire such geospatial data currently by far exceeds the capability to analyze and apply the data for improving understanding of dynamic landscapes or for a wide range of decision making tasks.

The underlying problem is related to the fact that such geospatial data sets are several orders of magnitude larger than those for which current GIS tools were designed, and they have different spatial distributions and properties than data acquired by traditional methods. Therefore, methods for processing of this type of data and new types of landscape process simulation are being developed that can take advantage of the rich information available in this geospatial data for solving land management problems such as landscape modification for damage prevention or mitigation, pollution control, or hazard prevention.

2. ANALYSIS AND MODELING OF COASTAL TOPOGRAPHIC CHANGE

In the area of coastal topographic change we are now focusing on Bald Head Island that is experiencing massive changes due to a combination of the effects of natural impacts and human activities.

New set of LiDAR data with higher densities and better vegetation penetration for 2008 year were acquired and used for coastal analysis.

The research has compared the pattern and rate of recent coastal erosion with the long-term averaged rates that are used for coastal management indicating significant acceleration of erosion in certain sections of the island and highlighting the short-term erosion rates to be considered when making coastal management and development decisions. (Figure 1).

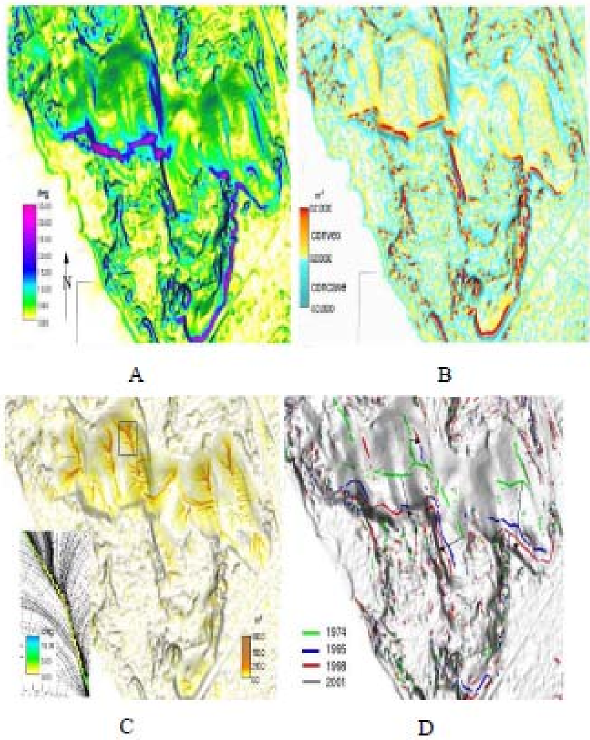

Figure 1. Topographic parameters derived from the 1 m resolution, 2008 DEM: (A) slope (slip faces in red/magenta); (B) profile curvature (convex crests in red); (C) uphill slope line density (ridges in brown), inset shows individual slope lines perpendicular to contours merging on a ridge overlaid by grid cells with slope values used to compute the average windward ridge slope; (D) extracted crests for 1998 (green), 2002 (blue), and 2004 (red) draped over the 2006 surface showing horizontal migration of the Jockey's Ridge dune complex.

3. HYDROLOGIC ANALYSIS OF WATERSHEDS BASED ON IFSAR AND LIDAR DATA

GIS methodology for effective comparison of accuracy of stream network extracted from Digital Elevation Models (DEMs) based on comparison with field measured Global Position System (GPS) data was developed. The methodology was applied to have a quantitative comparison of the accuracy of the stream extraction algorithms used to generate river and stream networks from Interferometric Synthetic Aperture Radar (IFSAR) derived digital elevation models in Panama and for mapping of the first and second order streams based on LiDAR

data in the Neuse river watershed. Different techniques were evaluated in terms of the locating both low-order streams and higher-order Rivers plus building the correct topology of the stream networks (e.g., accurate location and properties of stream confluence points, as well as identification of stream origins). Assessment of stream extraction accuracy is particularly important for the Chagres River Basin because there has not been an extensive mapping of the river channels and the analysis output which provides the "best-available" map of the river network.

Also the preliminary comparison of available USGS and local government stream data with GPS measurements demonstrates lack of accurate stream data even in such a developed and often mapped area as upper Neuse river basin, proving the importance of finding more accurate approaches to stream mapping, e.g. using LiDAR-based DEMs, than commonly used digitization from ortho-photos and limited ground surveys. In addition, the LiDAR data capture subtle topography in floodplains without well defined channel network, therefore alternative approaches for flow routing in such areas are investigated. For applications that require identification of wetlands, a process based approach is investigated. This approach allows us to map locations with standing water and subtle dry ridges providing information important for tasks related to mobility and safety (Figure 2.). The least cost algorithm applied to the same data extracts a potential channel network providing useful information for designing an optimal, cost effective drainage network if the area needs to be drained.

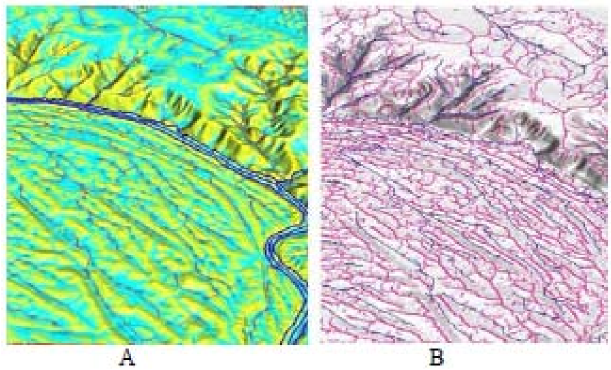

Figure 2. LiDAR data capture subtle topography in floodplains without well defined channel network; (A) water depth pattern computed by path sampling method with diffusion term; (B) potential channel network derived by shortest path algorithm provides useful information which is possible path through the floodplain can be found by further processing the ridge map layer (red), Blue lines are potential channels.

4. SIMULATION OF TERRAIN CHANGE IMPACT ON WATER FLOW AND SEDIMENT TRANSPORT USING PROCESS-BASED MODELING AND ANALYSIS GIS

The objective of this research is to evaluate the capabilities to predict spatial pattern and magnitude of water flow and sediment transport in landscapes undergoing substantial changes in topography and land cover using GIS-based modeling. The fact that the spatial range of land use change impacts which is well beyond the affected site requires that the models capture not only the specific processes at individual locations or for given structures, but also can simulate the combined effects of spatially distributed landscape changes and control measures at a larger spatial scale. Advances in geospatial technologies, including high resolution mapping, monitoring and GIS create new opportunities for significant improvements in the development of comprehensive modeling tools designed for land management applications.

To evaluate the capabilities of the current models (Figure 2.) to predict spatial patterns and magnitudes of water flow and sediment transport in rapidly changing landscapes the selected models (WEPP, GeoWEPP and SIMWE) were applied to two sites:(i) Centennial Campus site that is undergoing transformation from a secondary forest to urban land use and (ii) a small watershed at NCSU Sediment and Erosion Control Research and Education Facility (SECREF).

The first site has been monitored and modeled in collaboration. Digital landscape models were created at each of the site for different stages of development and various combinations of conservation and sediment control measures using highresolution GIS and CAD data. The WEPP model was calibrated using leveraged funding and applications focus on simulations using the observed and design storms (for 2 years and 10 years). The preliminary results of the modeling confirm the results of monitoring efforts that the current standard design of sediment control measures does not provide adequate sediment control. These results suggest a need for re-evaluation of the assumptions underlying the existing rules for sediment basin design, consideration of measures to bring the site conditions closer to the assumptions and incorporation of spatial aspects into the design. Spatial simulation for phased construction (only part of the site is disturbed at any time) demonstrated that the effectiveness of this approach is highly site specific.

The number and type of measures required is greatly dependent on configuration of terrain and grading. Phased development may well require the same number of structures as without phased development the additional costs due to scheduling of the construction is resulted.

Finally, the use of 'Illuminating Clay' as a 'Tangible GIS' is being explored as a novel approach for the real-time design and evaluation of various alternatives for land management and sediment control. The concept of this novel concept is to create an interactive environment for real-time simulation that combines traditional visualization with a flexible 3D model (i.e., the tangible interface). Simulations 'react' in real time to changes made on the surface of a reliable physical model: As the surface is modified, it is laser scanned, and the model is recomputed with results of the land modification action projected back to the model so there is a perception of real-time change. Various algorithms for modeling surface flow are evaluated and the one that provides a good balance between accuracy/realism and computational speed will be implemented by modifying a relevant GRASS GIS code.

This effort improve the understanding of impacts of terrain and land use on water and sediment flow and provide insights into our capabilities to predict these impacts and design effective control measures. It will also contribute to the development of new technology that has a potential to fundamentally change the ways to interact with landscape simulations and we make decisions that require understanding of landscape structure and processes.

5. TECHNOLOGY TRANSFER

Upgraded and enhanced spatial interpolation and topographic analysis module was released with GRASS 6.0. Spatially distributed and sediment transport models were upgraded to GRASS 6.0. , but have not been included in the official release as more research and development is needed to migrate this tool from research applications to a routine use. (Figure 3, 4.).

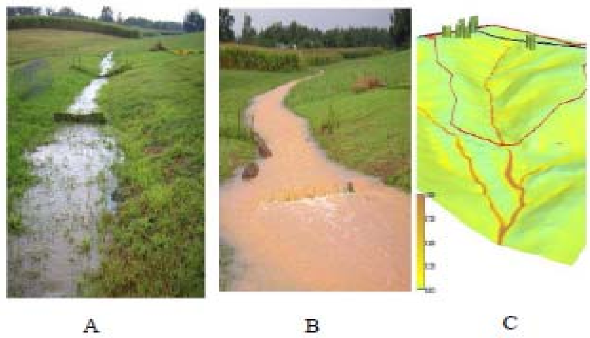

Figure 3. Using simulations to investigate optimal location and size of check dams to minimize the sediment pollutions and risk of gully formation. (A): field location of small check dams/filters aimed at reducing sediment transport. (B): filters are overflow and destroyed during a storm and sediment moves freely downstream. (C): simulation of spatial pattern of sediment flow and water depth without check dams.

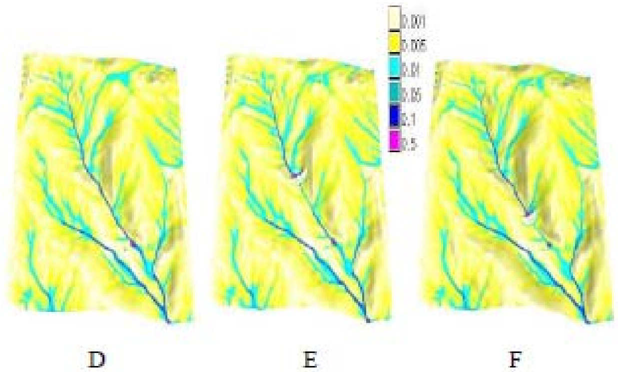

Figure 4. Using GIS modeling to investigate optimal location and size of check dams to reduce the sediment pollutions and risk of gully formation. (D): Simulation of spatial pattern of sediment flow and water depth without check dams. (E): simulated water depth for the location of impermeable, large check dams and (F): also simulated water depth for different location of impermeable, very large check dams.

CONCLUSION

Both modeling and simulation demonstrate that the higher spatial and temporal resolutions of terrain data can provide better understanding of some unexpected consequences of development and creates opportunities for adopting more sustainable approaches to coastal and urban landscape management. They also illustrate the current capabilities of open source geospatial technology for topographic data processing, analysis, modeling and visualization.(Figure 5.)

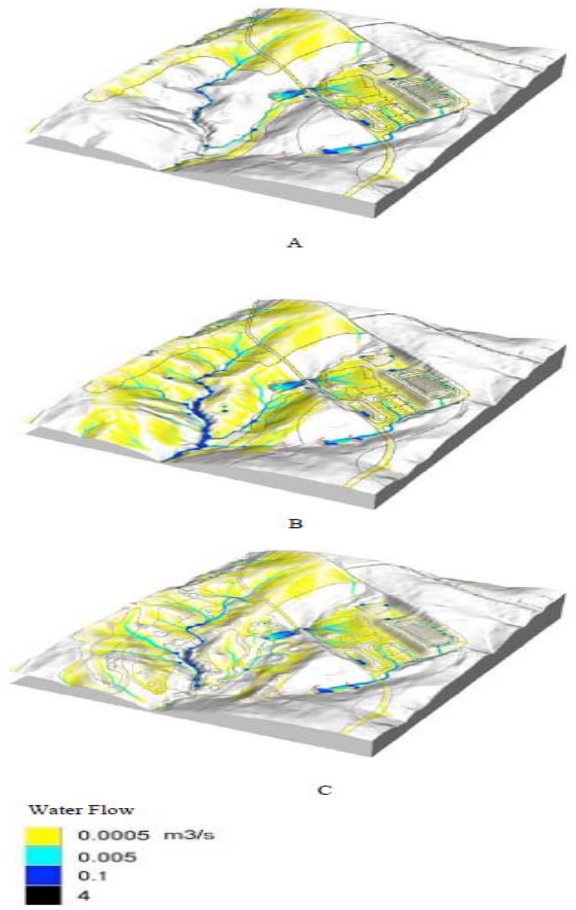

Figure 5. Spatial pattern of water discharge (A): for the current conditions. (B): during development of golf control measures are implemented in addition to the mandatory stream buffer. (C): after the golf course is finished, the water flow was simulated in GRASS GIS using an experimental module.

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