

3D Cartographic Animation: Visualizing Disaster on the Columbia River

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Abstract:

This paper describes techniques used to create a 3D cartographic animation using ArcGIS® 3D Analyst™. Cartographic animation is a form of dynamic visualization that can be used to depict the re-enactment of complex phenomena. Typically the viewer is shown “key frames” of an event in the form of static maps or artistic renderings. Animation fills in the details between these “key frames” thus assisting the viewer to interpret an event or process. A case study depicting Lake Lewis, in the Pasco Basin of Washington, during the Glacial Lake Missoula Floods of the last ice age, the greatest scientifically documented floods to have taken place in North America, is used to test and demonstrate 3D cartographic animation techniques.

Introduction

The Glacial Lake Missoula Floods (also referred to as the Ice Age floods) have been described as “the greatest scientifically documented floods known to have occurred in North America” (National Park Service, 2001). Lake Lewis, a temporary lake formed by these flood waters, covered thousands of square miles in what is now south-central Washington State, and reached depths of 900 feet.

In order to help the viewer understand a dynamic phenomenon such as this, it should be depicted in an animated manner, using dynamic visualization techniques. This way the cognitive or interpretive load on the viewer is reduced. Dynamic geovisualization can be defined as the use of animated, computer-generated images for the display of geographic data. One form of dynamic visualization is the 3D cartographic animation.

Advances in both computer hardware and software have given cartographers powerful desktop tools that can be used to support dynamic visualization. One such tool is the ArcGIS® 3D Analyst™. This paper describes a project undertaken to explore the use of this tool to create a 3D cartographic animation using Lake Lewis during the Glacial Lake Missoula Floods as the case study.

The Case Study

This case study was chosen based on current local and regional interest in the Ice Age floods. The audience selected for this animation was members of the general public and perhaps educators and their students. It was assumed this audience would have no special training in hydrology or geology but may have a layman’s understanding of the Ice Age floods. It was further decided the animation would depict the flood path, spatial extent and duration of a Lake Lewis event (of which there were several).

Background Work

With the objectives of the animation in mind, Lake Lewis hydrology was determined to be the critical data required for this study. A survey was made of books written for the lay Ice Age Flood enthusiast, which also included technical reference bibliographies. Two books, Cataclysms on the Columbia (1986) and On the Trail of the Ice Age Floods (2006), were found to be the most useful. These books provided well written descriptions of flood events including specific mention of Lake Lewis. However, neither book included the detailed hydrologic data that would be required to create an animated visualization of Lake Lewis.

The focus of the research then moved to articles in professional journals dealing with Glacial Lake Missoula hydrology. References for this type of article were obtained from the two books already cited and discussions with professionals familiar with the Ice Age floods and flood literature. Each article was first reviewed for the critical data and then for references to additional articles. Using this methodology, a study entitled Erosion potential from Missoula floods in the

Pasco Basin, Washington (Craig and Hanson, 1985), containing a table of lake surface elevations for a complete Lake Lewis event was discovered.

The tabular data from this study was used to create a time series animation that met the stated objective to depict the spatial extent and duration of a Lake Lewis event. The objective to show the flood path was met by interpreting information from a combination of sources (Craig and Hanson, 1985; Allen and Burns and Sargent, 1986; Bjornstad, 2006).

While searching for the "critical" data, books and articles were found that contained descriptive contextual information about the floods. The information from these context sources has been combined to create the following event description.

Overview of the Glacial Lake Missoula Floods

During the last ice age a lobe of the Cordilleran ice sheet dammed the Clark Fork River in what is now the panhandle of Idaho creating Glacial Lake Missoula. The ice dam may have reached a height of 2,000 feet creating a lake which covered approximately 3,000 square miles or an area twice the size of Rhode Island and holding an estimated 500 cubic miles of water. Periodically the ice dam would fail sending a flood of ice- and dirt-filled water rushing down the Columbia River drainage (see figure 1) at speeds of up to 80 mph and with a rate of flow approximately 10 times the combined flow of all the worlds' rivers (Bjornstad, 2006).



Figure 1 - Geography of the Glacial Lake Missoula Floods. Route of flood from the ice dam to the Pacific Ocean shown in red.

Within hours of the ice dam failure flood waters would begin to converge on the Pasco Basin in south-central Washington State. Having only one outlet from this basin at Wallula Gap, the water would backup creating a huge temporary lake called Lake Lewis. From Wallula Gap the water continued down the Columbia River creating Lake Condon and Lake Allison as it encountered other constrictions to its flow. In the end the water would follow the Columbia River to the Pacific Ocean. It is believed that over a 2,000 year period, between 13,000 and 15,000 years ago, 40 to 100 of these floods took place (Allen and Burns and Sargent, 1986; Bjornstad, 2006).

The Formation of Lake Lewis



Figure 2 – The Formation of Lake Lewis. The red lines show the route of the flood waters during a Columbia River flood. The dashed black lines show the approximate boundary of the Channeled Scablands.

There were two types of Glacial Lake Missoula floods, those that were confined to the valley of the Columbia River and those that crossed the channeled scablands. The Okanogan lobe of the Cordilleran Ice sheet was the controlling factor in the type of flood. If the lobe was not occupying the Waterville Plateau (see figure 2) then all (or almost all) of the flood water would be contained in the Columbia River Valley and be referred to as a Columbia River flood (Craig and Hanson, 1985; Bjornstad, 2006). During this type of flood all of the water that formed Lake Lewis would come through Sentinel Gap (see figure 2) and generally follow the course of the Columbia River to Wallula Gap.

If the Okanogan lobe was blocking the Columbia River valley the flood waters would flow through multiple channels across the Channeled Scablands and be referred to as a Scabland flood (Craig and Hanson, 1985; Bjornstad, 2006). Regardless of the route taken by the floodwater, it has been calculated that the flow of water that reached Wallula gap was almost twice as much as could drain through (Bjornstad, 2006). This hydraulic constriction would cause water to backup creating a type of hydraulic dam behind which Lake Lewis would form. As the flood waters sought alternative routes around the constriction they flooded the Yakima, Walla Walla and Snake River valleys. As the temporary lake subsided the water that had flowed up these river valleys would drain back and flow out through Wallula Gap.

The Craig and Hanson study documents a Lake Lewis event during a Columbia River flood. The simulated flood lasted 10 days and reached a maximum lake surface elevation of 333 meters (above present day mean sea level) and was used as the basis for this case study.

Selecting the Visualization Environment

The 3D Analyst extension to ArcGIS offers two environments that can be used out-of-the-box to create dynamic geovisualizations, ArcGlobe™ and ArcScene™. Following a review of vendor recommendations and personal experimentation ArcGlobe™ was selected as the environment for this project.

The key factors in this decision were the extents of the study area and the ability of ArcGlobe to work with cached data for fast navigation and display. The animation capabilities in ArcGlobe™ and ArcScene™ are essentially the same except in ArcScene™ a layer can be animated to move along a path and the background settings can be animated. While these capabilities are significant ArcGlobe's ability to work with large data sets made it a better choice for this case study.

Project System Architecture

The system used for this project was a Dell™ Optiplex GX 270 with a single Pentium 4 (2.8GHz) processor, 3 Gigabytes of RAM (PC3200), a Walton Chaintech SA5200 (NVIDIA® GeForce™ FX 5200, AGP 8X, 256MB DDR memory, VGA interface) graphics card and dual analog monitors. The system software included the Windows XP (SP2) operating system and ESRI® ArcGIS® version 9.2 with the 3D Analyst™ extension.

Creating the Visualization

The complexity of a visualization project can be underestimated when considering only the scope of the project or the amount of data to be processed (Ervin and Hasbrouck, 2001). For example, the task of turning forty numeric lake elevation values into data sets that can be used in a geovisualization is deceptively simple. However, the actual process requires the creation, naming and storage of a seamless digital elevation model (DEM) before the first lake

elevation contour can be generated. Each lake elevation contour must then be stepped through a process that transforms it from simple line to polygon then lake surface in the geovisualization.

The creation of the individual lake surfaces marks the end of one task and simultaneously provides the data necessary to begin the next task of creating the time series animation. Thus the project progresses step by step from task to task. Clearly the management of a visualization project can be enhanced through the use of structured methodology.

One systematic method for managing visualization projects has been presented as a series of five interrelated stages: data management, data assembly, visual mapping, rendering and display (wood et al., 2005). These five stages of the visualization process have been described as a "pipeline" with data sets flowing from one stage to the next to create the visualization. However, implementation of this process has shown that it would be more appropriate to view the visualization process as a circular (iterative) rather than a straight line process. Each iteration is followed by a review of the output which either brings the end of the project or new ideas that can be implemented in the next iteration. In this manner the project goes through a refining process until the desired results are achieved.

The following sections illustrate how the five steps of the visualization process have been incorporated in this project.

Stage 1 - Data Management

The essential tasks of the data management stage are: selection of a data model, identification of required data and the collection of raw data.

Data Model Selection

The term data model refers to the structure of and relationship between data sets. Typically these data sets are thought of as tables in a relational database, however, they can also be the layers used to create a geovisualization. A data model provides the framework that guides the selection of data sets for a given purpose.

The framework of a data model can be very structured as in the case of the ArcHydro or the Spatial Data Structure for Infrastructure and Environment (SDSFIE) data models. However, a data model can also be more abstract such as the four essential elements of landscape visualization.

The four essential elements of landscape visualization – landform, plants or vegetation, water and atmosphere (Ervin and Hasbrouck, 2001), was chosen as the data model. The use of this data model presented a flexible but guided approach to the selection of data sets for this project.

Identification and Collection of Raw Data

Data sets were identified and collected based on the textual and analytical descriptions of a Lake Lewis event and the landscape visualization data model. Other factors that were also considered were - degree of realism and level of detail (LOD).

The purpose of this visualization did not require a verisimilar or geospecific degree of realism (i.e. orthoimagery draped) representation. Therefore, while both geospecific and geotypical (rendered) surface coverings are used, the degree of realism being sought is geotypical.

Level of Detail (LOD) refers to the fact that objects depicted in a visualization may be represented with varying amounts of detail depending on their distance from the viewer (Ervin and Hasbrouck, 2001). Therefore, it was necessary to acquire data sets of varying LOD for the same spatial extents.

The following is a sample of data sets collected for use in this study.

Landform

Landform is the foundation upon which the visualization rests and its depiction requires both a physical form and surface covering (Ervin and Hasbrouck, 2001).

Physical Form

Five types of physical form data were collected for use in this project: GTOPO30, USGS 1:250000 DEMs, USGS National Elevation Data Set files and USGS 10 meter DEMs.

GTOPO30 is a global DEM with a resolution of 30 arc seconds (approximately 1 kilometer) (ESRI ArcGIS 9.2 Data & Maps media kit, Image Data, 2005). USGS 1:250000 DEMs cover the contiguous United States with a resolution of 3 arc seconds <<http://edcftp.cr.usgs.gov/pub/data/DEM/250/>>. The National Elevation Data set contains data for the United States in a seamless raster format with a resolution of 1 arc second <<http://seamless.usgs.gov>>. The USGS 10 meter DEMs cover the contiguous United States with a resolution of 1/3 arc second and were obtained as individual files <<http://gis.ess.washington.edu>> and as 1 degree buffered blocks <<http://www.or.blm.gov/gis>>.

Surface Covering

The application of a surface covering to the physical form completes the landform and provides context to the viewer. Orthoimagery and custom raster images were used as surface coverings in this project.

The Orthoimagery was obtained from the National Agriculture Imagery Program (NAIP) in the form of compressed county mosaics (CCM) in MrSID format with 1 meter resolution <<http://datagateway.nrcs.usda.gov/GatewayHome.html>>. The custom raster images used for surface covering were created by combining data

sets from a variety of geographic information sources such as <<http://wagda.lib.washington.edu>> and <<http://wagic.wa.gov/washdat.htm>>.

Vegetation

In this case study vegetation will be depicted through the colorization of the surface covering.

Water

Lake Lewis is the primary focus of this visualization, however, the depiction of the regions principle rivers and the Cordilleran ice sheet are also important elements. Lake Lewis surface elevations have been taken from tabular data in the Craig and Hanson study (Craig and Hanson, 1985, p. 106). Polygons representing the Columbia, Snake, Yakima and Walla Walla rivers have been obtained from a variety of sources, while required flow lines for the rivers have been digitized from Digital Raster Graphics files <<http://www.or.blm.gov/gis>>. Cordilleran ice sheet data, including extents and ice depths, have been found in scientific literature (Waitt and Thorson, 1983, p. 54).

Atmosphere

The simulated flood used as the basis for this visualization takes place over a 10 day period (Craig and Hanson, 1985, p. 106). Time passing will be depicted through changes in ambient lighting, and sky and surface coloring.

Spatial Domain

The spatial domain of the study area includes the maximum extent of Lake Lewis, the southern margins of the Cordilleran Ice sheet and the glacial dam failure point. This region lies between 45 and 49 degrees North Latitude and 115 and 121 degrees West longitude (see figure 3).

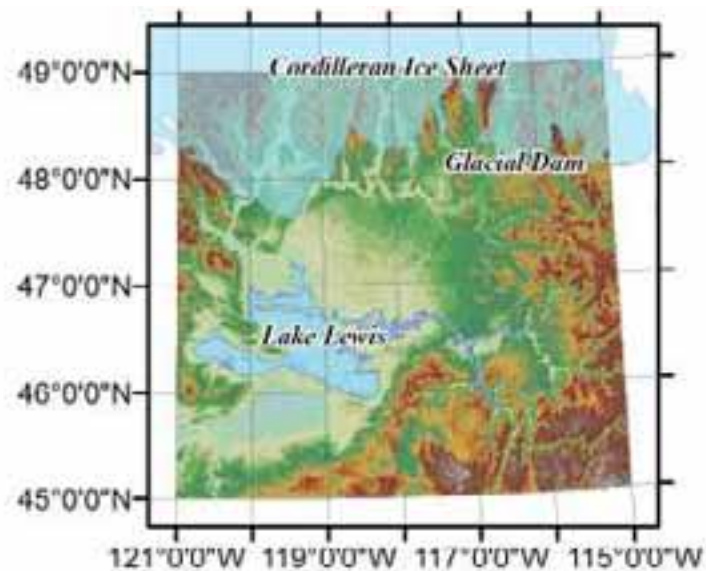


Figure 3 – Case Study Spatial Domain

Stage 2 – Data Assembly

The essential task in this stage was to process the raw data for use in the animation. It was also at this stage that a preferred projection and coordinate system was selected.

Using ArcGlobe™ as the geovisualization environment was the deciding factor in the selection of a projection for this case study. The ArcGlobe projection for data above 45 degrees north latitude (such as the data for this study) is a custom coordinate system called World_Cube. Projecting data sets into World_Cube will avoid the overhead of on-the-fly reprojection (“ArcGIS 3D Analyst – Designing”, 2004).

Following are examples of the processing necessary to assemble acquired data sets for use.

Landform

Physical Form

The required 1:250000 DEMs were identified using textural descriptions and illustrations of the Glacial Lake Missoula floods and Lake Lewis (Allen and Burns and Sargent, 1986). Each DEM was downloaded, unzipped and, using the ArcGIS ArcView ArcToolBox tools, converted from USGS DEM format to GRID format. The GRID files were then merged together and projected into the required coordinate system using ArcToolBox tools.

The National Elevation Dataset files come in GRID format so no conversion was required. Following the download and unzipping of each file they were merged using the ArcToolBox mosaic tool - then the entire mosaic was projected into the desired coordinate system.

Surface Covering

Having determined the spatial extent and visual content of a given surface covering the necessary data sets were assembled in an *.mxd* file in ArcMAP. A *.tif* image was exported from ArcMAP with a companion world file.

Water

Lake Lewis surface polygons have been developed using data from a table of surface elevations (Craig and Hanson, 1985, p. 106). A spreadsheet was created which converted the tabular data from feet to meters (rounded to the nearest whole meter). In ArcGIS ArcView 3D Analyst a file containing the contour lines for each lake elevation was created using the 1:250000 DEM GRID file as the surface. In ArcView the lines within the contour file were closed so they could be converted from lines into polygons in ArcGIS ArcInfo. The polygon files would usually contain several polygons, some of which represented “donut holes”. Each polygon file was simplified to a single polygon. An attribute called “elevation” was added to the polygon remaining in each file and populated with the surface elevation in meters.

The GRID file analyzed to obtain the contours from which the elevation polygons were created identified an issue. In the vicinity of both Sentinel Gap and Wallula Gap the river channel and river surface elevation have been effected by hydroelectric dams and their reservoirs. Surfaces reflecting the pre-dam river channel and water surface elevation will need to be created. At this time lake surface elevation polygons have been generated for time steps 6 through 31 in the Craig and Hanson study which represent lake surfaces.

Stage 3 - Visual Mapping

The visual mapping stage begins with the creation of a narrative summary of the proposed visualization. Given that this animation is to depict the flood path, spatial extent and duration of the flood - the following summary was developed.

Create a dynamic visualization which illustrates the path of a Glacial Lake Missoula flood from a point upstream of Sentinel Gap, through the Pasco Basin and continuing to a point downstream of Wallula Gap. Depict the rise and fall of Lake Lewis over a ten day period by displaying lake surface elevations, and indicate time passage by showing the transition from night to day. Use ground cover and sunrise/sunset parameters appropriate for the month of April (present day) in the study area. During the visualization, the camera will move as required to enhance the experience of the viewer.

Using the above narrative as a guide, a script for the visualization was developed. The script included four sections: staging, camera, animation, and output. Staging contains a list of required data sets. Camera defines the location of the observer (camera placement), the location of the target (where the camera is pointing), and any observer and/or target movement. In the animation section animated sequences are prioritized, named, objectives stated and a description given. Finally, the output method is identified.

Sample Script

Title: Disaster on the Columbia – Lake Lewis and the Ice Age Floods

Narrative

[Include the narrative summary in this section of the script]

Staging

Landform – physical
GTOPO30 and Lake_cube

Landform – surface covering
Lakelewis_gray_1200dpi.tif

Water

The group layer "Lake Elevation Polygons Cube" containing lake surface polygons for time steps 6 through 31 will be used to display the rise and fall of Lake Lewis. Use a simple polygon fill (custom blue, RGB: 15,165,206) as the lake surface covering. To provide context to the viewer display centerlines of present day rivers and streams in Washington State and a polygon representing the Cordilleran ice sheet.

Atmosphere

In ArcGlobe set the background globe property to transitional color mode. The space color will be set to black (RGB: 0,0,0) and the sky color will be set to "big sky blue" (RGB: 0,178,255). Set the transitional zone with an upper limit of 108km and a lower limit of 103km.

Camera

The initial location of the observer will be to the west of the Yakima Valley inundated by Lake Lewis and at sufficient height to have an oblique view of Lake Lewis at its maximum extent. The initial target location will be a point just east of Rattlesnake Mountain. From the initial location the camera will move in a closed circular path, keeping as much of the lake in view as possible at all times. In addition, other methods of camera animation such as zooming and panning will be evaluated with each animation sequence and incorporated into the final integrated visualization as required to enhance the viewer's experience.

Animation

Rise and Fall

Objective: Depict the rise and fall of Lake Lewis over a ten day period by displaying lake surface elevations.

Lake surface elevation data sets displayed in a time series can be used to show the rise and fall of Lake Lewis.

Flood Path

Objective: Illustrate the path of a Glacial Lake Missoula flood from a point upstream of Sentinel Gap, through the Pasco Basin and continuing to a point downstream of Wallula Gap. There are three aspects of the flood path that must be shown: the initial flood wave, the use of new channels as existing ones are inundated as the lake rises, and the flow reversal of the Yakima, Snake and Walla Walla rivers.

The initial flood wave will take place between the beginning of time step 1 and the end of time step 2 (note: all references to time steps are based on Craig and Hanson, page 106, 1985). During time step 3 the hydraulic dam forms and the lake surface begins to rise. As the surface of Lake Lewis rises and falls (time steps 3 - 37) the channels used by the flood water will adjust, as will the flow reversal for the three rivers.

Given that no simulation data is available to illustrate the flood path it will be necessary to present this information diagrammatically (Ervin, 2004). A time series of flow lines can be utilized to indicate direction and path of moving water.

Night and Day

Objective: Indicate time passage by showing the transition from night to day

The flood visualization will begin with time step 1 starting at midnight of day one and ending at 6AM, and each of the succeeding time steps will cover a period of 6 hours. Given spring as the selected time of year for the visualization, sunrise will be around 6AM and sunset around 6PM.

Output

The animation will be exported as an .avi file called Lake_Lewis_10days.

End of Sample Script

The script governs the second task in the visual mapping stage - the incorporation of data sets into the visualization framework. When a data set is added into the ArcGlobe framework (table of contents) its role in the document must be established. In addition, a caching method and a level of detail must be implemented for each data set.

The role of the data set will be categorized as either an *elevation*, *draped* or *floating* layer. Elevation layers provide a source of base height for other layers. Draped layers use other layers as elevation sources. Floating layers are used to show objects that are not placed on the elevation surface.

There are three data caching methods used in ArcGlobe: on-demand, full, and partial. On-demand takes place as the data set is navigated around, full involves generating and saving data tiles, and partial refers to generating data tiles for a chosen level of detail ("ArcGIS 3D Analyst – Designing", 2004).

Level of Detail refers to the scales between which data tiles have been generated for a data set.

Table 1 – Sample data set configuration settings in ArcGlobe

Data Set	Layer Role	Data Caching Method	Level of Detail From/To
GTOPO30	elevation	partial	Globe to Counties
lake_cube	elevation	partial	Counties to Metropolitan Area
Lakelewis_gray_1200dpi.tif	draped	partial	Counties to Cities
Lake Elevation Polygons	draped	partial	Countries to City Blocks

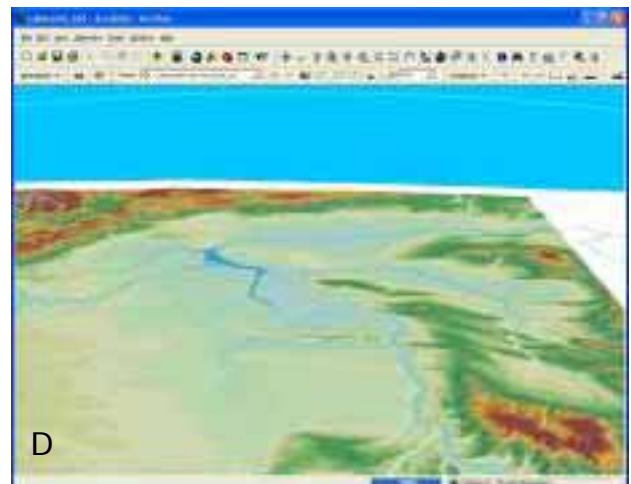
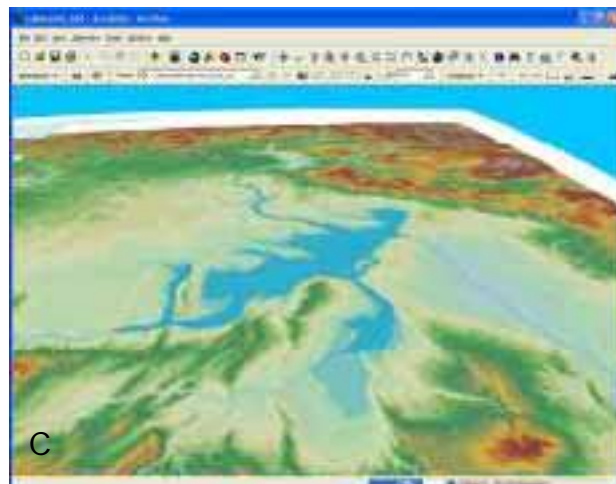
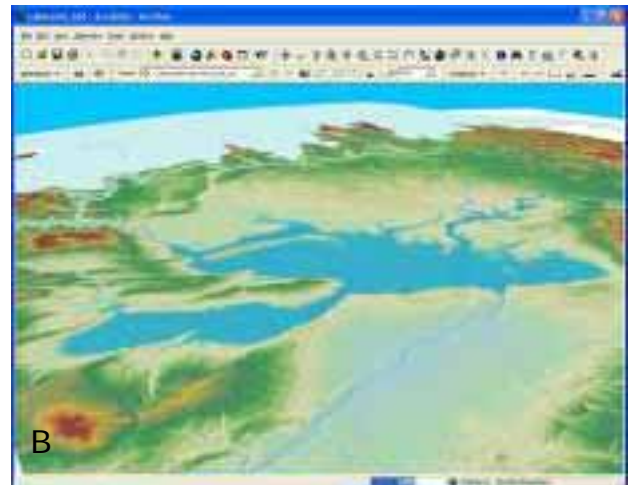
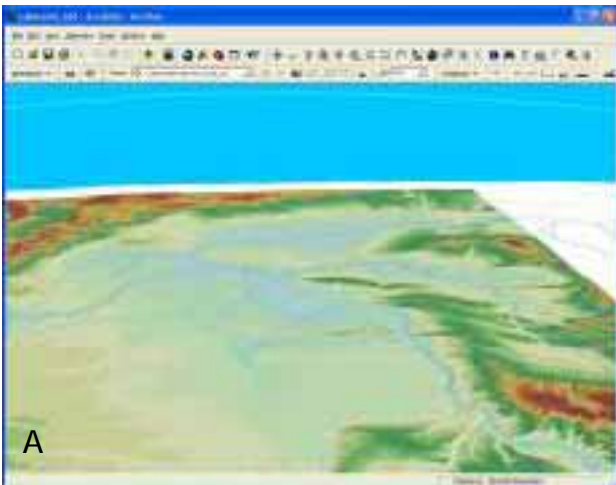
Stage 4 - Rendering

In the rendering stage the animation sequences in the script are adapted to the animation capabilities of ArcGlobe. Following are the adaptations written for the previously cited script. (It should be noted that as an animation sequence is completed it is carried independently through to the output stage - this provides a portable version that can be supplied to subject matter experts for review and comment.)

Rise and Fall

[Include the animation objective and description from the script]

Initially this animation will be staged using only the Lakelewis_gray_1200dpi.tif, and camera settings with a fixed observer and target. As the development of the animation progresses a full color surface covering and other context layers will be added along with camera animation.



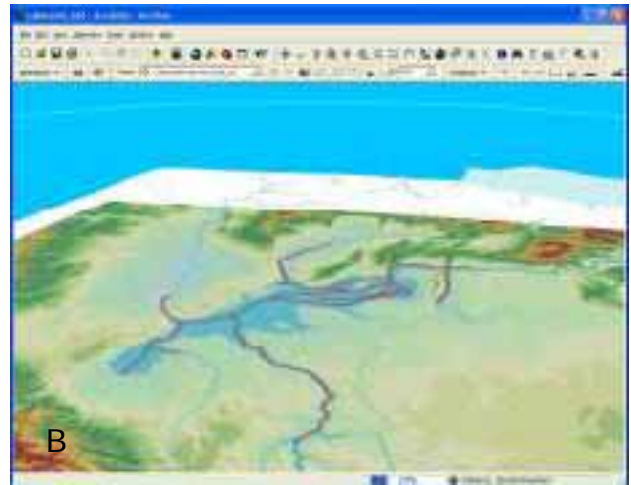
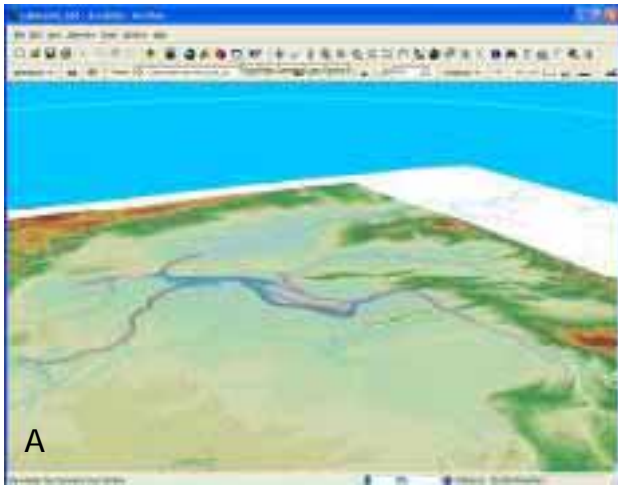
Frames from a rendering simulating the Rise and Fall of Lake Lewis viewed during a circumnavigation of the lake.

The depiction of the rise and fall of the lake surface elevation will be shown using a group layer animation. The layers will become visible one at a time with each layer blending into the next and using the maximum fading time.

Flood Path

[Include the animation objective and description from the script]

The initial flood wave, the water finding new channels and river flow reversal can be indicated through the use of flow lines. The flow lines will be symbolized using color and arrowheads to show the direction and path of the flood waters.



Frames from a rendering showing the Flood Path indicated by the red lines.

The flow lines will be integrated into the Rise and Fall animation sequence as data sets placed in the group animation so they are seen briefly before the new lake level is shown.

Night and Day

[Include the animation objective and description from the script]

The animation begins just after midnight on day one of the flood scenario. Table 2 shows the sky, surface and ambient lighting conditions that must be synchronized to depict the transition from night to day during a flood "day".

Table 2 – Lighting conditions during a flood "day"

	Midnight to Dawn	Sunrise	6am to 6pm	Sunset	Sunset to Midnight
Sky	Black	Transition	Blue	Transition	Black
Surface	Black and White	Transition	Color	Transition	Black and White
Ambient Light	Low Light	Transition	Full Light	Transition	Low Light

The transition of the sky will be animated by setting the background properties of the globe to transitional color mode, establishing a narrow transition zone and then moving the observer through that zone. The transition of the surface from black and white to color is accomplished using two copies of the same layer, one symbolized in color and the other in black and white, in a group layer animation. The change in ambient lighting must be made programmatically.

The Global properties will be set to enable sun lighting on an absolute sun position of 46.5 degrees North Latitude and 119.5 degrees West Longitude.

Upon the completion of an animation sequence the rendering will be presented to professionals in the fields of geology and hydrology for review of content.

The final step in the rendering process is the integration of the individual animation sequences into a single unified visualization using the Animation Manager.

Stage 5 - Display

The display method selected for the completed animation will be a file exported in *.avi* format, distributed for use on desktop systems. This method was chosen because it allows each viewer to have an individualized, interactive experience using readily available desktop programs. The viewer can play the animation - stopping or repeating it as required thus enhancing their interpretive experience (Tversky and Morrison and Betrancourt, 2002).

Conclusions

This project was begun thinking of an action packed animated presentation showing the thundering flood waters sweeping through central Washington. The adaptation of this vision to the realities of hardware, software, and staff capabilities has been an interesting learning experience. While the animation being created is different than the one initially envisioned, upon completion it will provide a means for viewers to "experience" details about Lake Lewis not shown in static maps or artistic renderings.

Several software packages for the simulation of floods have become available since the Craig and Hanson study was published in 1985. It would be interesting to take the approach outlined in this paper and expand it to create a dynamic visualization of a complete Glacial Lake Missoula flood with data provided from one of these "next generation" applications.

It was demonstrated through this project that it is possible to create a dynamic visualization using out-of-the-box capabilities of ArcGIS® 3D Analyst™. However, it is possible to extend these capabilities through custom development. In the future, where limitations are found (particularly in the areas of animation and rendering) the development of customized extensions will be explored.

There were three key elements to the process presented in this paper: the use of the landscape visualization data model, the implementation of the five stages of visualization in an iterative manner and the use of a script to capture a specific visualization concept and add structure to the creative process. These same elements can be used and adapted to any dynamic visualization project.

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References

- Allen, John Eliot, Marjorie Burns, and Sam C. Sargent, Cataclysms on the Columbia. Timber Press, Portland Oregon, 1986.
- Bajwa, Hardeep, Bratt, Steve, "Building 3D Animations", ESRI International Users Conference 2004, San Diego, CA, 2004.
- Benito, G. and J.E. O'Connor, 2003, "Number and size of last-glacial Missoula floods in the Columbia River valley between Pasco Basin, Washington and Portland, Oregon," Geological Society of America Bulletin 115 (2003): 624-638.
- Bjornstad, Bruce, On the Trail of the Ice Age Floods: a Geological Field Guide to the Mid-Columbia Basin, Keokee Co. 2006
- Bodum, Lars "Modeling Virtual Environments for Geovisualization: A Focus on Representation", Dykes, MacEachren and Kraak 389-402
- Craig, R. G., and J.P. Hanson. Erosion potential from Missoula floods in the Pasco Basin, Washington. Battelle Pacific Northwest Laboratory Document PNL-5684, UC-70, 185 p. and 5 appendices. 1985
- Dykes, J., MacEachren, A.M., Kraak, M.-J., eds. Exploring Geovisualization. New York: Elsevier, 2005.
- Edsall, Robert M. and Sidney, Laura R. "Applications of a Cognitively Informed Framework for the Design of Interactive Spatio-temporal Representations", Dykes, MacEachren and Kraak 577-89
- Ervin, Stephen M., Landscape Visualization: Progress and Prospects, ESRI International User Conference, San Diego, CA, 2004.
<<http://gis.esri.com/library/userconf/proc04/doc/pap1647.pdf>>
- Ervin, Stephen and Hope Hasbrouck, Landscape Modeling Digital Techniques for Landscape Visualization. New York: McGraw-Hill, 2001
- ESRI. (2004) ArcGIS 9 Using ArcGIS 3D Analyst, USA: Author.
- (2004) ArcGIS 3D Analyst – Designing Interactive ArcGlobe Documents. USA: Author.
- "Ice Age Floods Table of Contents." Ice Age Floods Study of Alternatives and Environmental Assessment. February 2001. National Park Service. 18 April 2006
<<http://www.nps.gov/iceagefloods/>>.

Kobben, Barend and Yaman, Mustafa, Evaluating Dynamic Visual Variables Seminar held at the Escuela Universitaria de Ingeniera Tecnica Topografica, Madrid, Spain, August 30 - September 1, 1995.

30 June 2006 <<http://cartography.geog.uu.nl/ica/madrid/kobben.html> >

Kraak, Menno-Jan and Klomp, Arjen, A Classification of Cartographic Animations: Towards a Tool for the Design of Dynamic Maps in a GIS Environment, Seminar held at the Escuela Universitaria de Ingeniera Tecnica Topografica, Madrid, Spain, August 30 - September 1, 1995.

30 June 2006 <<http://cartography.geog.uu.nl/ica/madrid/kraak.html>>

Maidment, David R., ed. Arc Hydro GIS for Water Resources. California: ESRI Press, 2002.

MacEachren, Alan M. How Maps Work: Representation, Visualization and Design. New York: The Guilford Press, 2004

MacEachren, Alan M., Kraak, Menno-Jan, Verbee, Edward, "Cartographic Issues in the Design and Application of Geospatial Virtual Environments" 1999

O'Connor J.E., and Baker, V.R., 1992, Magnitude and implications of peak discharges from glacial Lake Missoula: Geological Society of America Bulletin.104 (1992): 267-279.

Peterson, Michael P., Spatial Visualization through Cartographic Animation: Theory and Practice, Proceeding of Geographic Information Systems/ Land Information Systems GIS/LIS 1994, pp. 250-58.

Technical Articles – ESRI Support. "FAQ: Does ESRI support dual or dual-core with the ArcGIS Desktop products?" Article 31903. 11/15/2006.
<<http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=31903>>

Tversky, Barbara, Morrison, Julie Bauer, Betrancourt, Mireille, Animation: can it facilitate?, International Journal Human Computer Studies (2002) 57, 247-262

Wood, Jo, et al. "Using 3D in Visualization." in Dykes, MacEachren and Kraak 295-312, 2005.

Waitt, R.B., and Thorson, R. M.1983, The Cordilleran Ice Sheet in Washington, Idaho, and Montana, in Wright, H.E., Jr. ed., Late Quaternary environments of the United States; Volume 1, The late Pleistocene: Minneapolis, Minnesota, University of Minnesota Press, p. 53-70.