CONNECTING EXPERT FIELD RESEARCH WITH CONCEPTUAL LEARNING: A USER-DRIVEN 3D GEOVISUALIZATION INTERFACE TO EXPLORE TEMPORAL AND SPATIAL PROPERTIES OF TRANSIENT GROUNDWATER RESPONSES

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Abstract: *In this paper we introduce and discuss a new approach to the visualization of transient groundwater responses on hillslopes in an effort to support improved conceptual understanding of complex hydrological processes. This project provides an alternative geovisualization interface that enables experts and students to perceive this complex phenomenon, while still using conventional data from existing sources. Our interactive geovisualization interface combines groundwater measurement locations, time, surface and bedrock topography, and groundwater levels in a systematic and comprehensible way. This interface supports interactive hypothesis-testing by allowing users to explore characteristics of these data at different locations in a 3D virtual scene, using temporal brushing controls, and simultaneously displays the data in conventional ways. This cross-platform geovisualization interface is intended to be accessible to a wide audience for education, research and the communication of environmental issues to the public.*

Keywords: 3D geo visualization, interface design, multi temporal, transient groundwater responses, hillslope hydrology, hydroviz, hydrobar, hydrosurface, QTVR

INTRODUCTION

Subsurface stormflow occurs when water moves laterally down a hillslope through soil layers, often as saturated flow over the bedrock or another impermeable layer. It is an important contributor to streamflow and is also responsible for the transport of labile nutrients into surface water bodies (Weiler et al., 2005). Unlike groundwater in riparian zones, saturation at the soil-bedrock interface on hillslopes is often only present for a few hours to a few days after rainfall events (Peters et al., 2003; Tromp-van Meerveld and McDonnell, 2006) and is thus difficult to measure and visualize. Water table responses on hillslopes are also highly spatially variable and are in part controlled by the bedrock topography. Tromp-van Meerveld and McDonnel (2006) found that transient groundwater developed on shallow soil parts of the hillslope during smaller events but that with increasing rainfall bedrock depressions on the hillslope filled, water spilled over microtopographic relief in the bedrock surface, and the subsurface saturated areas became connected. When connectivity was achieved, the instantaneous subsurface stormflow rate increased more than fivefold.

Understanding transient saturation patterns at the soil-bedrock interface and hydrological connectivity of hillslopes and riparian zones is thus pertinent for understanding subsurface stormflow processes and the timing and amount of streamflow that will be produced by rainfall events. It is also important for understanding and predicting the effects of land use change (forestation/deforestation, urbanization, etc) on streamflow, pollutant transport, and thus sustainable development of water resources. It is therefore important not only for hydrologists but also for citizens and planners to better understand the dynamics of transient saturation at the soil-bedrock-interface. However, this is difficult due to the temporary nature of the processes on hillslopes and because groundwater is normally hidden from view. These problems are compounded by the large spatial variation in responses (both in magnitude and timing) and the fact that we can only make point observations of an inherently volumetric phenomenon.

A GEOVISUALIZATION APPROACH TO HYDROLOGICAL REPRESENTATION

Transient groundwater is a challenging phenomenon to understand, communicate and visualize. It is volumetric (i.e. it has three spatial dimensions), and it is spatially and temporally dynamic. Typical approaches to representing transient saturation at the soil-bedrock interface in the hydrological research community have included: (1) time series data of groundwater levels from a number of point locations (e.g., Peters et al., 2003); (2) cross sections of transects (e.g., Buttle et al., 2004; Carlyle and Hill, 2001); and (3) plan-view maps showing whether saturation is present or the height of the water table (e.g., Tromp-van Meerveld and McDonnell, 2006).

There are limitations to each of these methods to represent transient groundwater responses. Time series graphs do not intuitively represent the spatial aspects of the data. 2D transects and plan-view maps only show the water levels at a few (key) times and thus do not adequately represent the temporal dynamics of transient hydrological events. None of these common representations show combined (or linked) visualizations of spatial and temporal variability of the perched water table response. In short, these methods provide limited temporal and spatial ‘transects’ or ‘snapshots’ of phenomena that might be better understood if they were represented, visualized and explored in three dimensions.

These are just the sorts of challenges that let to the emergence of geovisualization as a subfield of geographic research in the early 1990s (see MacEachren, 1994). Over the past fifteen years or so, an international cohort of geovisualization researchers have pursued a multitude of research directions to develop the technology, methods, theory and applications of dynamic and interactive 2D, 2.5D, 3D geovisualization (see MacEachren, 1995; MacEachren and Kraak, 2001; Fairbairn et al., 2001; Slocum et al, 2001; Dykes et al., 2005). From these efforts, several key objectives of a geovisualization research approach have emerged: (1) to help users reveal unknowns in complex datasets; (2) to support exploration of data; and (3) to better understand the perceptual and cognitive implications of geovisualization design (Slocum et al., 2001)

Static 2D cartography cannot easily visualize volumetric, dynamic phenomena in a way that adequately represents their complexity or dimensionality (both real and abstract). MacEachren and Kraak (2001) highlighted how traditional representation methods are challenged by very large, multivariate geospatial data sets that include three spatial dimensions (e.g, volumetric atmospheric data) and time. However, we can apply concepts from geovisualization and geospatial interface research to improve our ability to represent and visualize transient hydrological phenomena. The design of such geovisualizations requires careful consideration of how we convey a 3D volumetric phenomenon, and how it changes through time, when the information is ultimately going to be delivered via a 2D computer screen. Good geovisualization design must incorporate thoughtful representation of the data, at the same time as using various perceptual design techniques (such as visual depth cues) to help users perceive the groundwater case study. By adding animation and dynamic object behaviors, we can convey state changes over time. By making such geovisualization tools interactive, we can deliver visualization interfaces that are user-driven, supporting informal exploratory hypothesis-testing. By doing so, we aim to improve users’ ability to perceive, understand and explore the structure, spatial and temporal dimensions of transient groundwater events.

SCOPE AND OBJECTIVES OF PROJECT

In this project we introduce and discuss the implementation and application of these geovisualization and interface design techniques to the visualization of transient groundwater responses, in an effort to support improved conceptual understanding of complex hydrological processes. Special attention was paid to the design of the visualization. In particular, we aimed to implement a geovisualization that assisted users’ perception of the volumetric structure and dynamic/temporal dimensions of transient groundwater responses.

A combination of common GIS and non GIS tools were used for processing data into a collection of visualization products. This was done using existing high spatial and temporal resolution field data. We then explored new ways to provide users with opportunities to interact with these visualizations of data in a way that provided more complete representations of transient groundwater events, by linking previously isolated modes of visualizing key variables (such as discrete 2D hydrographs).

The interface we designed allows users to interactively control and browse through time (temporal brushing) and different visualization viewpoints. As a result, this geovisualization allows non-expert users to test informal hypothesis about relationships between precipitation inputs, hydrological responses at different locations, and the variation in responses over time for the given dataset.

By implementing these new geovisualizations and geospatial interface designs we aim to demonstrate: i) how careful geovisualization design factors; and ii) consideration of how new ways to interact with geovisualizations of groundwater phenomena may provide a simple methodology for interactive geovisualization of transient groundwater responses that could be applied to other datasets using the same procedure and readily available tools.

CASE STUDY

The Panola Mountain Research Watershed (PMRW) is a 0.41 km^2 mixed deciduous/coniferous forested watershed in the Panola Mountain State Conservation Park (84°10'W, 33°37'N), located 25 km southeast of Atlanta, USA (Fig. 1). The climate is humid continental to subtropical. Annual precipitation averages 1240 mm and is distributed relatively uniformly throughout the year. Total precipitation during the study period for this work (Feb 28, 2009 00:00-March 3, 2009 23:55) was 89 mm. Total precipitation in the week prior to the study period was 34 mm. The dominant bedrock at PMRW is the Panola Granite (granodiorite composition). Soils are predominantly ultisols developed in colluvium and residuum, which intergrade to inceptisols developed in colluvium, recent alluvium, or in highly eroded landscape positions. Streamflow in the PMRW is dominated by runoff from the bedrock outcrops, which make up ~10% of the watershed, and groundwater from the riparian zone, augmented by hillslope water when the watershed is wet (Burns et al., 2001).

The 12 by 18 m study site for this work includes the lower half of the hillslope, right above the riparian zone. The site is located 8 m from the ephemeral stream in the western part of the watershed. The surface topography is planar while the bedrock topography is very irregular (Fig. 1). Soil depth in this study hillslope varies from 0.3 to 7.1 m. The average slope is 21°.

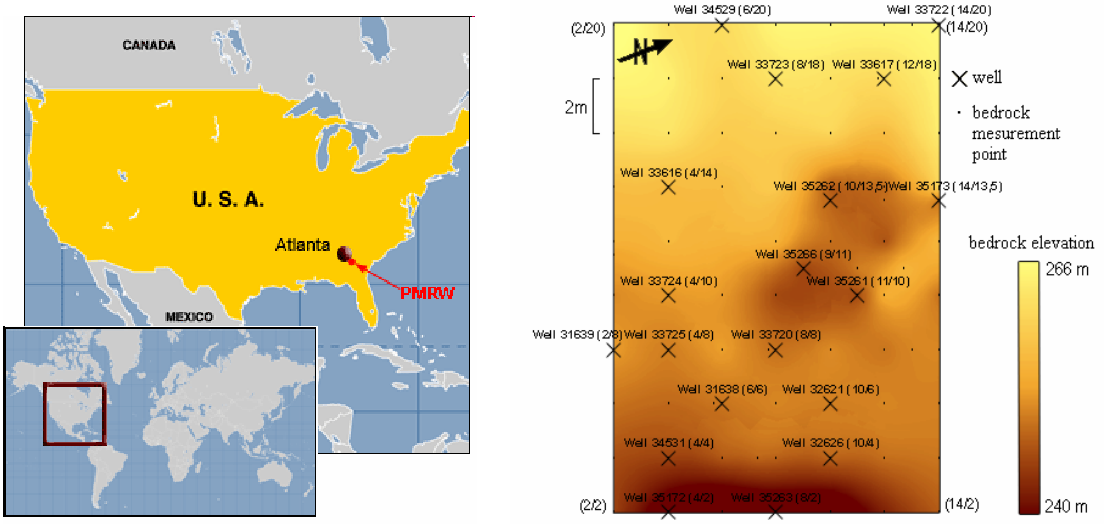

Figure 1. Location and map of the study site

DATA

Groundwater levels were measured in nineteen 51 and 32 mm diameter PVC piezometers installed at the soil-bedrock interface. The water level in the piezometers (i.e. the height of the water level above bedrock) was measured at 5-minute intervals with Odyssey Capacitance water level recorders (Dataflow Systems, Christchurch, New-Zealand). Rainfall was recorded at one-minute intervals from several tipping bucket gauges in and adjacent to the watershed. The tipping bucket rainfall data series were combined to yield one rainfall time series for the watershed. Discharge was determined from a stage-discharge rating curve using stage measurements recorded by a data-logger. The stage was sensed using a potentiometer and a float-counterweight system in a stilling well, which was connected to a compound 90° V-notch weir

(Peters et al., 2003). The study area was surveyed on a ~2 x 2 m grid. Soil depth was determined with a small hand auger at 82 locations.

METHODS

There were three distinct elements to our interactive hydrological visualization development: 1) compute and generate data assets to adequately represent transient groundwater responses (outlined in the introduction) for our case study using the data described in the previous section; 2) design of the geovisualizations to maximize information content, perception of structure and relationships for this groundwater case study; and 3) design and implement ways to allow users to interact with these visualizations of transient groundwater data, supporting exploratory informal hypothesis testing.

Generating data assets

Several data assets are key to this visualization project (Fig. 2): A digital bedrock model (i.e. topography of bedrock without soil) (DBM) of the study site; a digital elevation model (DEM) of the ground surface of the study site; temporally-indexed precipitation and groundwater level data; and interpolations of groundwater surface geometry at each indexed time step.

The first step for this project was to produce a digital bedrock model (DBM) and a digital elevation model (DEM) of the study site (Fig. 1), transforming the local grid (used to reference measurements at the field site) into the Universal Transverse Mercator projection (UTM) with real elevation values. With the help of the kriging method (spherical, ordinary, cell size 0.048) in ArcGIS Spatial Analyst, the DEM and DBM were created. Kriging was chosen because it is a common method in geological modeling (Childs, 2004). The advantage of kriging is that it pays attention to spatial variability, conserving the spatial correlation of the topography and that it is capable of incorporating underlying trends not apparent in the raw gridded data (Huang, 1998). Furthermore, kriging calculates the error of estimation, which can be useful to evaluate the results.

The piezometer-based water level data were refined from a raw temporal resolution of twelve 5-minute intervals per hour, to a single interval per hour, on the hour. The eleven 5-minute-interval time steps between hourly intervals were removed. This resulted in a more manageable dataset containing water level values for all 19 piezometers, for 144 one-hour intervals.

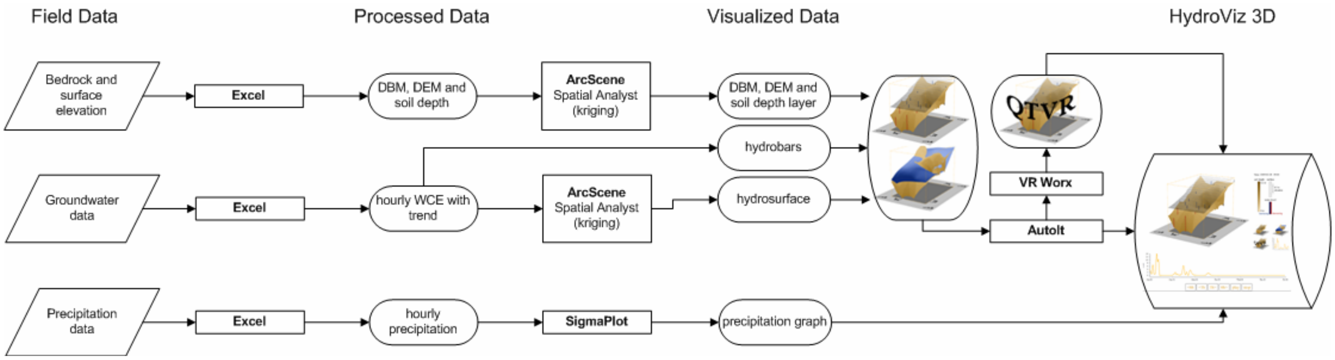

Figure 2. From the field data to the HydroViz

Water column elevations (WCE) for each measurement location were displayed using a set of vertical WCE visualization objects that we have named ‘hydrobars’. In addition to representing absolute WCE, we felt that a visualization that could differentiate between decreasing and increasing WCE levels would add value to the representation of transient groundwater. We therefore implemented a database-driven approach to codifying WCE values to give bars with decreasing and increasing water levels different colours. This was done by adding a negative algebraic sign in Excel 2007 for all decreasing values. The dataset was then imported and transformed into a Shapefile through ArcMap and exported to ArcScene. For every single time step the values of the water level were extruded by the vertical height of the measured water level above bedrock. These vertical WCE values where then visualized by placing hydrobars in the scene, stacked on top of the DBM.

For the interpolated water level layer the elevation of the bedrock at the measurement points was added to the water level values and the dataset was imported and transformed into a Shapefile through ArcMap. With help of the kriging method (spherical, ordinary, cell size 0.048) in the Spatial Analyst a groundwater level elevation model (GLM) was interpolated and imported to ArcScene. In ArcScene the layer was extruded by the z values calculated by the Spatial Analyst. From the dataset a new layer was created with the same interpolation method. A colour scheme was created with colours relative to the complete dataset and applied to this layer so that all time steps could be compared to each other.

Designing the geovisualization

Transient groundwater responses are structurally and temporally complex. As a result, we had to do more than simply render visual symbologies of spatial and temporal data. Since hydrological interpretation often requires exploration of new data and informal hypothesis-testing about observed patterns and relationships, we had to design a visualization of available data that supported an exploratory browsing of spatial and temporal structural relationships in a way that maximized spatial and temporal information, without overwhelming or confusing the user.

We paid close attention, therefore, to clearly differentiating three geovisualization elements that together enable us to meaningfully represent and perceive transient groundwater phenomena. The first element of our geovisualization was to design features that assisted and maximized the viewer’s ability to perceive the structural and spatial relationships between the variables listed in the first element. Two critical ingredients of this were strong depth cues for all variables, and an overall volumetric frame of reference with which to perceive proximity, orientation, relative position, and size of objects. The second element of our visualization was the collection of key scientific variables: digital bedrock model (DBM); digital elevation model (DEM) of the surface geometry; water column elevation (WCE) data; and an interpolated groundwater surface for each time-step, based on discrete WCE values. The third and final element of our design was to link key transient groundwater variables and their structure time – since we had data for all variables, for each of 144 discrete time steps.

A customized wireframe box as receptacle and perceptual frame of reference

We implemented a simple but effective structural ‘receptacle’ for all of the transient groundwater data. We designed a customized wireframe box, into which all key data assets were georeferenced to each other and placed, defining the volumetric extent of the scene. The wireframe box was positioned on a plane, which was separated into an inner and an outer area, to provide depth cues and perceptual cues for scene orientation. The inner plane was delimited by the bottom face of the bounding wireframe box, and as such indicated the ‘footprint’ of the scientific data assets assembled and visualized inside it. The inner and out plane are opaque, and so avoid a common problem of scientific visualization – when data visualizations ‘float in space’, without strong, consistent depth cues. The inner and outer plane were intentionally assigned inconspicuous colours in order not to not distract users from the actual visualizations but still give some contrast to the background.

In a 3D visualization (and especially one that might be rotated) it is important to provide north arrows that can be seen from most angles. North arrows and the scale indicators were placed on all sides of the outer box. Their colours were chosen to give a clear contrast to the outer floor for an easy perception but again without distracting from the main elements. Placing a north arrow in a 3D visualization is even more important than in ordinary 2D maps, where the north is usually ‘up’. For the same reason the scale is placed at multiple locations as well. Visualizing this important scale reference information was extended to the wireframe box. We placed small spheres at regular intervals along all vertical and horizontal edges of the wireframe box, at the same spacing (2 meters) as the scale indicators on the lower plane of the visualization. Together, the features of our customized wireframe box provide important visual, structural and dimensional frames of reference to aid the user with exploration and judgment.

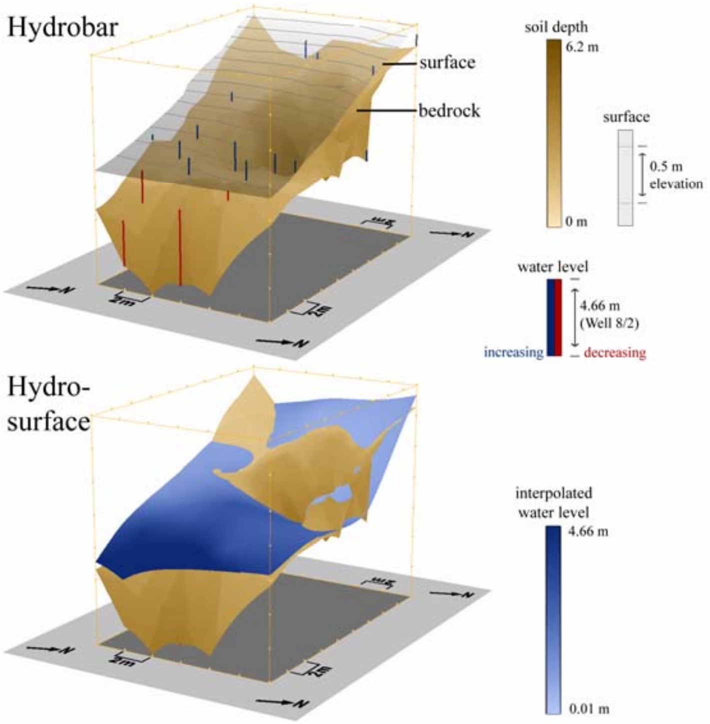

Figure 3. Design of the hydrobar and hydrosurface visualization (in the actual visualization the background is black)

Visualizing the digital bedrock model

The DBM defined the extent of the box. The lowest point of the DBM touches the lower plane, while the outer edges of the DBM are tangent to the edges of the box and follow the transparent walls, making it easy to see inside and perceive the topography and structure of the bedrock. The color scheme of the bedrock represents the soil depth. A darker color indicates a deeper soil. This is one benefit of the 3D visualization because the soil depth can be visualized at the same time as the bedrock topography just by the color and the topography from the base layer. This means that we apply multiple data dimensions (bedrock elevation and soil depth) in this layer. For the bedrock layer no shading is used because this would complicate the perception of the color scheme. A semi transparent layer with contour lines was added for the surface topography to symbolize that the bedrock normally is hidden from view.

Visualizing transient groundwater

We visualized water levels in the transient groundwater case study context in two separate ways (Fig. 3). The first approach visualized the groundwater level as vertical bars extruded up to the actual measured water level above bedrock at the different piezometer positions. Water levels that were increasing (i.e. rising water table) were colored blue and water levels that were decreasing were color-coded red. This was done to make it easy to perceive trends in individual water levels, and to identify the areas with increasing and decreasing water levels. The blue color was chosen because it is an intuitive color for water. After exploring numerous combinations, we selected red and blue in combination with the brownish tones of the bedrock because the strong visual contrast makes them easy to see and differentiate. The drawback of this visualization is that through the depth cue of relative sizing, depending of the distance from the viewer, bars of the same height appear smaller in the background than in the foreground, which could be misleading. But for clarity reasons a graduated color scheme for the bars was rejected for this project (at typical screen resolutions, subtle color graduations may be difficult to perceive). By using a three dimensional visualization we can visualize four data dimensions (in addition to the three dimensional topographic dimensions) in a straightforward way that is clear and easy to perceive. This visualization could therefore be used for informal hypotheses testing.

The second way in which we visualized transient groundwater, was to visualize groundwater surfaces interpolated from the discrete measurement locations. Again we used blue to symbolize the groundwater, with a color saturation gradient, where darker colors of blue represented a higher water level above bedrock than brighter blue colors.

Exporting the visualization from ArcScene with AutoIt

For each of the 144 time step, hydrobar and the hydrosurface visualizations were rendered from with the same point of target (POT) and point of view (POV) and exported as a .png picture via the 2D export function of ArcScene. This allowed us to keep the view constant while allowing the natural changes in the data to occur. Since this required the production of 288 separate images of the visualization to be rendered, we automated this process using the AutoIt 3.0 scripting tool (AutoIt 2010). AutoIt allowed us to automate keyboard and mouse inputs based on a simple programming syntax, and enabled us to produce all 288 images in 2.5 hours. Another advantage of AutoIt is that scripts can easily be adapted to other software because it does not depend on specific programming languages of software (like visual basic VBA and ArcObjects in ArcGIS). The use of AutoIt was a significant asset to help us produce a multi-temporal and multi-viewpoint visualization like this one. This became even more important when we took our visualization interface ideas one step further to produce an interactive QuicktimeVR scene (allowing 360-degree rotation, and 90-degree vertical manipulation of our 3D groundwater visualization) using VRWorx.

Creating of the QTVR with AutoIt and VR Worx

In addition to the visualizations and interface described above, we wanted to explore how we might be able to support freeform user manipulation and exploration of 3D groundwater visualizations. We therefore decided to implement a QuickTime Virtual Reality (QTVR) version of our 3D groundwater visualization. This type of QTVR scene is built by assembling a carefully organized arrangement of individual images of a 3D object, render from an evenly-spaced set of viewpoints, whose points of view (POV) are typically angular intervals of rotation about the horizontal and vertical axes of the 3D object. This results in a constellation of images that can then be imported into a defined image POV coordinate system to produce a QTVR object scene. We wanted to let the user explore the visualization from any POV in a hemispherical viewing space from 5-degree POV angular intervals in both the horizontal and vertical image groups. Therefore we had to render a total of 1368 POV images per time step (every 5 degrees rotation around the point of target (POT), for every 5-degree vertical elevation angle). For the entire project 24 time steps for 6 days were rendered.

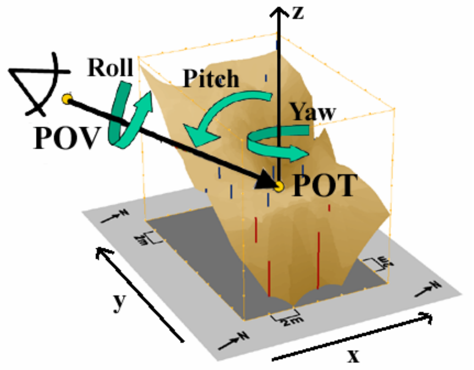

Figure 4.: Perspective view of a 3D scene (modified from Kolbe 2004)

With such a large number of images required, AutoIt was again used to automate the process of visualize them in ArcScene and exporting the images. The POT was constant in the middle of the wireframe box while the POV was circulation with a yaw of 360° and with a pitch of 90° in a 5° interval with a constant distance from the POT (Fig. 4). Beside operating ArcScene, we included a function to the AutoIt script which compiled the x,y,z variables relative to the ArcScene coordinate system out of the spherical coordinate system. For each time step AutoIt needed 6 hours to produce the images. Each set of images was compiled into a QTVR scene and saved as .mov using VR Worx.

INTERFACE AND INTERFACE INTERACTIONS OF HYDROVIZ 3D

Visual information design is only part of the relationship between a user and information that supports the perception and development of cognitive models of phenomena. A further part of this relationship is the way in which a user accesses, explores and experiences information. In short, being able to interact with visualizations in a range of (new) ways may support new modes of perceiving and experiencing representations of phenomena under study. We explored the implementation of user-driven geovisualization interfaces by developing an integrated visualization interface that linked together the transient groundwater variables we identified at the start of this paper, and allowed the user to explore the three-dimensional structural relationships of key variables and browse these variables through time (temporal brushing). It was also our objective that the interface should be as ‘transparent’ as possible – meaning that the transient groundwater response variables and events should always be dominant and not obscured by any element of the interface design.

Design and features of the integrated HydroViz 3D transient groundwater interface

We based our design on an intended delivery mechanism of web-delivery or standalone desktop computer display. We aimed for a basic (common) screen resolution of 1280 x 1024.
The interface is divided it into four sections: Temporal menu, visualization menu, legend, and visualization (Fig. 5). The upper part of the interface is divided into the visualization on the left side and the legend and visualization menu on the right side. The lower part shows the temporal menu of the interface containing the precipitation graph for the study period.

The central element of the interface was the main visualization, using the largest portion of the interface’s visual real estate. Depending on which selection the user made in the temporal and visualization menu either the static hydrobar or hydrosurface visualization, the interactive QTVR, or a hydrograph menu is shown.

On the right side of the visualization the legend is shown. Like the visualization, the elements of the legend change dynamically depending on which visualization is selected. For example, in the hydrobar visualization, a colour scheme legend of the soil depth and the hydrobars are shown. In addition the distance between the contour lines of the surface layer is displayed. When the hydrosurface is shown a legend for the colour scheme of water depth is shown in addition to the soil depth. Since the surface and the hydrobars are not displayed in this visualization the legend for those are not displayed either. When the QTVR is loaded into the visualization part either one of those legend settings is displayed, depending on which type of visualization is shown as QTVR. When the hydrograph menu is shown a legend for the bedrock elevation is displayed. At the top of the legend the time index of the currently displayed visualization is shown.

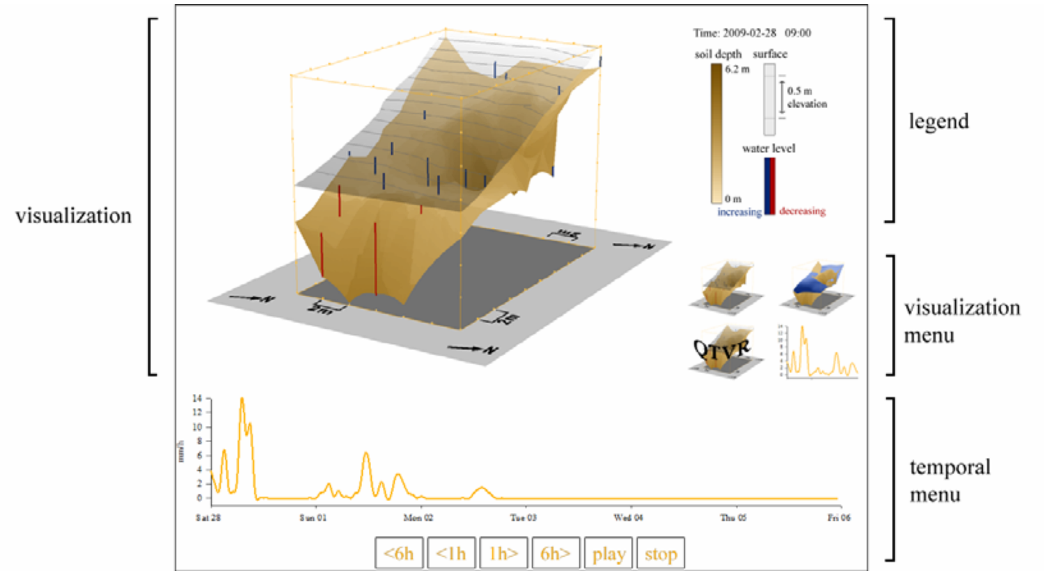

Figure 5. Transient Groundwater HydroViz Interface

The visualization menu can be found beneath the legend. Here the user can choose between the four different visualization modes. For each type of visualization there is a small clickable symbol where the user can change between the different visualization modes (hydrobar; hydrosurface; QTVR; hydrographs).

The main feature of the temporal menu is a precipitation graph, which shows precipitation (in mm/h) for the study period. It was produced with SigmaPlot 11 (SigmaPlot, 2010) from the precipitation data. This provides the user with the information about when (in the time series) the majority of water was injected into the case study field site. This lets the user combine and link this information to the WCE responses of the piezometers in the visualization. At the same time we implemented an interactive precipitation graph that can be used to brush through time – a useful feature for researchers to interactively explore multiple variables in timeframes of interest. The source precipitation graph was sliced into 144 parts with

ImageReady 7 (ImageReady, 2002) matching the time steps in the visualization. Using these images almost like ‘rollovers’ (to use a web interface term), the user can mouse over any part of the precipitation graph, which results in the interface calling up the visualization for the related time step when the hydrobar or the hydrosurface visualization is chosen. When the QTVR visualization is active, clicking a specific time step calls up the related QTVR. In the hydrograph mode temporal brushing is not possible. Beneath the precipitation graph six buttons are displayed to jump six or one hour ahead and after the actual time step and a play and stop button to automatically animate through the time steps while in the hydrobar and hydrosurface visualization.

In the QTVR visualization the user is able to turn the visualization 360° around the z axis as well as rotate and explore the visualization at any 5-degree vertical interval between zero (the ‘equator’ around the 3D groundwater visualization) and 90 degrees vertical elevation (a ‘polar’ POV, looking down from above the top of the 3D visualization). In addition the user is able to zoom onto the visualization from every viewing angle (Fig. 6).

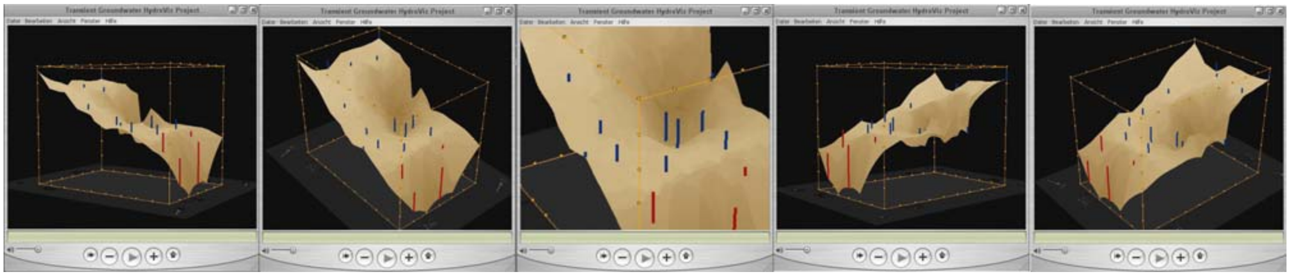

Figure 6. Screenshots of the QuickTime QTVR

The ability to move around and zoom into the visualization provides the user with more visual depth cues than a static view. In interpreting the transient groundwater response, we need to be able to validate, confirm or reject the visual and spatial relationships between represented variables at each time interval. In static views we only have static visual cues to suggest the relative size, orientation and position of objects. Being able to rotate and view such 3D visualizations from multiple angles enables us to confirm or reject perceptual hypotheses about the arrangement of key variables as components of a visualization. This is due to several useful depth cues that are activated by user manipulation of an interactive 3D interface. These include motion parallax (where objects in the background are moving slower that objects in the foreground) and interposition (objects in the background are occluded by ones closer to the user’s POV). These capabilities, supporting user-driven exploratory sense-making, may help researchers to accept or reject informal hypotheses about the transient groundwater response-related variables and spatial-temporal relationships they represent.

The entire interface was developed with html, php and JavaScript. Using a web browser based interface makes the geovisualization platform independent. Only the QuickTime player is needed to open the QTVR.

CONCLUSION

We developed a new approach to the visualization of transient groundwater responses on hillslopes in an effort to support improved conceptual understanding of complex hydrological processes. The geovisualization interface enables experts and non-expert users to perceive this complex hydrological phenomenon using conventional data from existing sources. This interactive geovisualization interface combines groundwater measurement locations, time, surface and bedrock topography and perched groundwater levels in a systematic and comprehensible way. It supports interactive hypothesis testing by allowing users to explore the characteristics of these data at different locations in a 3D virtual scene, using temporal brushing controls, and simultaneously displays the data in conventional ways. By being platform independent the interface is accessible to a wide audience for hypothesis testing and research, education, and for the communication of environmental issues to the public. This approach could be used for the visualization of other complex 3D phenomena as well.

The interface prototype described in this paper can be accessed at: http://www.geographie.uni-koeln.de/hydroviz

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