Image processing of outcrop LiDAR scans for use in heterogeneity models

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Abstract

The development of models that represent heterogeneity at varying scales is vital for modeling dispersion in groundwater. Dispersion, the result of varying velocities in a flow field, is, in part, due to material heterogeneity. In order to represent the influence of heterogeneity at the outcrop scale, a series of millimeter-scale point spaced terrestrial lidar scans have been taken of sediments located in braided stream exposures west of Albuquerque, New Mexico. Scans are projected onto an x-y plane and converted to a high resolution TIFF image. Using the mean and standard deviation of the "stacked" images, the data are processed through a series of filters to enhance textural information and distinguish between lithologies. The product, a TIFF image representing the lithology of the scanned area, is converted to a grid with numerical color values for each lithology (e.g. sandstone, gravel). Lithologies are assigned reasonable hydraulic conductivity values. Groundwater flow and transport time are simulated using MODFLOW and RWHet respectively. Simulations show that flow and solute transport are focused by cross-bedding into the coarser-grained units. Flow may be focused into some areas in finer-grained beds as well, if the adjacent gravel bed has been cut. Thus, the majority of the flow may be focused into a smaller volume of the material making up the aquifer. These solute transport simulations result in non-Fickian flow, characterized by focused flow along pathways with early breakthrough and tailing.

LiDAR: LIght Detection And Ranging

LiDAR unit with controller and power supply

Laser aimed at outcrop with millimeter scale point spacing

Collects data as intensity of the reflected pulse and presents it as an XYZ point cloud

Raw range accuracy 7 mm @ 100 m

Raw positional accuracy 8 mm @ 100 m

Battery powered and portable

Dr. Tim Wawrzyniec using the scanner in the field

Jed Frechette with the scanner in the field

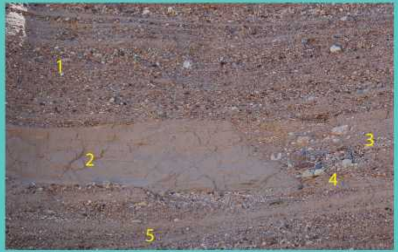


Photo of the section scanned for this work. These are braided stream deposits from the Arroyo Ojito Formation in the Sand Hill area west of Albuquerque, New Mexico. Lithologies presented are: (1) cross-bedded sand and gravel, (2) horizontally laminated medium sands, (3) gravelly cross-bedded sands, (4) cobble lag deposit, and (5) cross-bedded sand and gravel

Lidar analysis and image segmentation:

Multiple scans are collected of the outcrop (7) at 2 mm point spacing

Point clouds from the repeated scans are projected onto one grid and a mean intensity value and a standard deviation of the intensity is calculated for each pixel

The standard deviation of intensity is processed using Photoshop and ENVI to amplify the textural information -

- Color scale is adjusted by changing the contrast and brightness
- Darker or lighter sections are adjusted using burning and dodging tools
- Horizontally skewed filters were applied to enhance the continuity of the lithologies while preserving the interbedding
- Cobbles were masked from the mean intensity image and overlaid onto the standard deviation image for the Sand Hill image

The result is an image with segmented lithologies and three numeric color values, black - 0, gray - 127, and white - 255, or blue, yellow, and pink, in this case, as the colors are displayed here

The numeric values are changed using Idrisi, to black = 1, gray = 2, and white = 3 (or 2 if no gray value), and the image is converted to an ASCII matrix of grid values which are loaded into MODFLOW and MODPATH

Sand Hill cell size is 2 mm. The size of the final figure is (X,Y) = (280,150) in cm

Hanford Site cell size is 5mm. The size of the final figure is (X,Y) = (819, 132) in cm

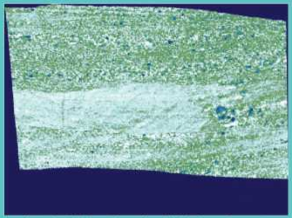


Image of mean intensity data. Image is the mean of repeated "stacked" scans of the same region. The zero data points are removed and the intensity data are projected onto an XY plane.

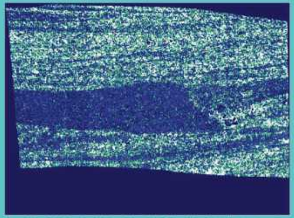
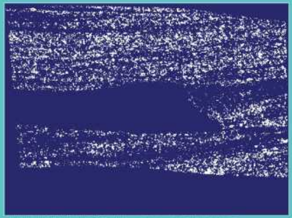
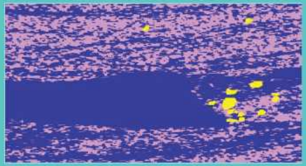


Image of the standard deviation of stacked intensity data. Textural information in this image is amplified using filters to differentiate sands from gravels and cobbles.



Standard deviation of intensity after scale change and maximum and minimum filters.



Final image after application of horizontally skewed filters and overlaying cobbles masked from the mean intensity image.

Fluvial sediments near the Hanford Site in Washington, USA. Location is Brother's Driveway.

Image of the standard deviation of intensity data. Textural information in this image is processed to differentiate sands from gravels.

Standard deviation of intensity after processing

Image before converting to text matrix and replacing numeric color values with 1 or 2. In this case, gravels are blue/purple and sands are black.

Groundwater modeling:

Each numeric value (lithology) is assigned general hydraulic conductivity values (e.g. gravel = 0.1 cm/s; sand = 0.001 cm/s)

Constant head boundaries are set and steady state solution transport is simulated using MODFLOW

Pathlines and breakthrough times for particles are generated using MODPATH

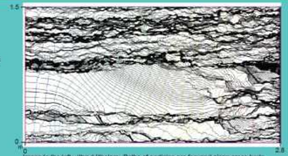
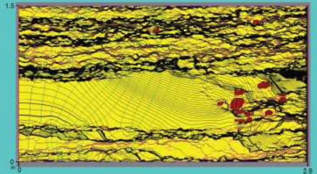
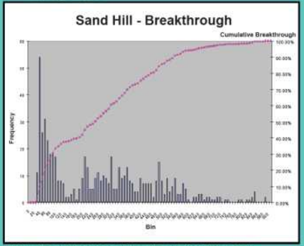


Image to the left without lithology. Paths of particles are focused along cross-beds. The heterogeneity of the outcrop may still be seen in this figure, as the particles travel mainly through the gravels.



Results of particle tracking using MODPATH. Particles were released from cells on the right side of the model. Particle travel is focused along gravel cross-beds. These data show the significance of the role of heterogeneity on the non-Fickian behavior of solute dispersion.



Particle breakthrough at the left boundary. Early breakthrough and long tailing is markedly non-Fickian due to heterogeneity.

Conclusion:

This work shows the significance of the role played by heterogeneity in solute dispersion. Heterogeneity produces variability in groundwater velocities. Particle transport and fluid flow are both focused preferentially into the gravels. Breakthrough curves show non-Fickian early arrival and tailing. This highlights the importance of heterogeneity in groundwater models and the need to develop a method to predict parameters for modeling non-Fickian solute transport.

Future work:

A code to automate the process of image segmentation for recognition of textures or identifying boundaries of lithologies

An outcrop will be scraped back and scanned in repeated sections, with the aim of building a 3D model to examine upscaling with the inclusion of heterogeneity and how much sediment character controls the direction and velocity of solute dispersion

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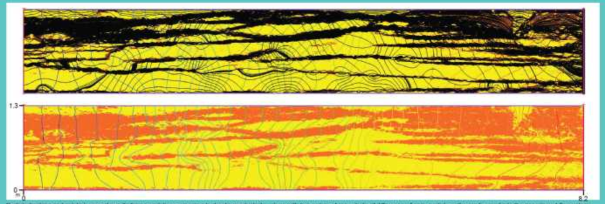
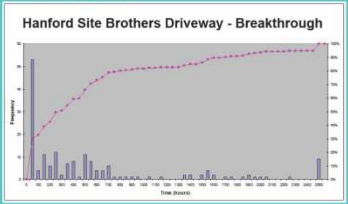
Scanning another location at Sand Hill for current work

Scraping the outcrop back to scan another layer



Particle tracking and solute transport results from simulations run using hydraulic conductivity values with two orders of magnitude of difference. Again, particle paths are focused into the gravels and flow velocities are increased within the gravels. In this figure, gravels are orange and sands are yellow.



Breakthrough curve and frequency for simulations run with two orders of magnitude of difference. Note the early breakthrough and tailing characteristic of Non-Fickian solute transport.