AUTOMATED UPDATES TO 2D HYDROLOGIC MODELS FOR OPEN-PIT MINING

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Abstract Open-pit mines exhibit complicated hydrologic and sediment transport processes that impact the surrounding environment. Building and calibrating an initial hydrologic model that models these processes is a challenge, and updating this model poses further challenges. Hydrologic models of open-pit mines must be frequently updated because of constant changes to the topography, land use, pumping stations, and settling ponds surrounding the open-pit mine. The Gridded Surface Subsurface Hydrologic Analysis (GSSHA) 2D hydrologic model, developed by the US Army Corps of Engineers (USACE) Engineer Research and Development Center, can be used to analyze the complicated processes in an open-pit mine, among other things. The Watershed Modeling System (WMS) software, developed by Aquaveo, provides graphical tools to develop a GSSHA model and view the model output. We have developed an automated modeling wizard in the WMS that assists GSSHA modelers in updating the topography, land use, pumping stations, settling ponds, and associated model parameters for open-pit mine hydrologic models. This paper describes the procedures followed in automatically updating these model parameters using this wizard.

INTRODUCTION

Open-pit mines exhibit complicated hydrologic and sediment transport processes that impact the surrounding environment. Building and calibrating an initial hydrologic model that models these processes is a challenge, and updating this model poses further challenges. Hydrologic models of open-pit mines must be frequently updated because of constant changes to the topography, land use, pumping stations, and settling ponds surrounding the open-pit mine. This study included developing a semi-automated wizard-based approach for updating hydrologic models in watershed areas surrounding open-pit mines.

The Gridded Surface Subsurface Hydrologic Analysis (GSSHA) hydrologic model, developed by the USACE’s Engineer Research and Development Center, was used to model the watershed areas surrounding the open-pit mines described in this study. GSSHA “is a physics-based, distributed, hydrologic, sediment and constituent fate and transport model. Features include two dimensional (2D) overland flow, 1D stream flow, 1D infiltration, 2D groundwater, and full coupling between the groundwater, shallow soils, streams, and overland flow” (Downer and Ogden, 2015). Because GSSHA offers so many processes that can be modeled, it offers an ideal solution for modeling the complex hydrologic processes surrounding open-pit mines.

The Watershed Modeling System (WMS) software, developed by Aquaveo, provides graphical tools to develop a GSSHA model and view the model output. We used WMS to
collect the necessary data and to build, run, and calibrate GSSHA models for this study. Then we read and view the GSSHA results in WMS. Aquaveo developed an automated modeling wizard in WMS that assists GSSHA modelers in updating the topography, land use, pumping stations, settling ponds, and associated model parameters for open-pit mine hydrologic models.

The model study area was the watershed areas surrounding three large open-pit coal mines in Indonesia. Several watersheds surround these mines, and water quality and erosion in the surrounding watersheds are a concern. Aquaveo built and calibrated separate GSSHA models for each of the watersheds surrounding the mines. Aquaveo then tested the wizard on each of these models to determine its usefulness in automatically updating the models of the watersheds surrounding the mines. This paper gives an overview of the model development and shows how the WMS wizard is used to automatically update the hydrologic models for the watersheds surrounding the open-pit mines. The techniques used in this wizard can be used to automatically update other types of hydrologic models and could possibly be used to auto-generate GSSHA hydrologic models sometime in the future.

METHODS

This section first gives an overview of the models that were developed and then describes the processing required to update the various types of data for each of the models in the WMS wizard.

Model Overview: 21 different GSSHA models were built and calibrated to represent the watershed areas surrounding 3 different yet closely-spaced open-pit coal mines. Techniques involved in setting up the initial GSSHA models using WMS are described elsewhere (see Nelson and Smemoe, 2015). A photo of one of the open-pit mines is shown in figure 1.

Ponded water, loose sediment, and drainage are a major problem in the areas surrounding these open-pit mines. Because of the impacts of the mine, there are some areas surrounding the mines where erosion is a major concern (figure 2).

The watershed models determined areas with large amounts of sediment erosion and deposition, areas with high channel velocities, and determined the impacts of sediment mitigation efforts, including adding sediment settling ponds (figure 3) at the downstream end of the watersheds.
Figure 1 One of the open-pit coal mines

Figure 2 An eroded culvert crossing close to one of the mines
Figure 3 A series of sediment settling ponds surrounding one of the open-pit mines.

A plan view of the GSSHA-computed water depths after a storm event is shown in figure 4.
Figure 4 Computed water depths in one of the watersheds surrounding the open-pit mine.

A similar example of the GSSHA-computed erosion/deposition map is shown in figure 5.
Figure 5 Aerial map showing computed sediment erosion (red-tinted areas) and deposition (blue-tinted areas) in one of the watersheds surrounding the open-pit mine.

The WMS mine wizard can be used to update changing model inputs for the 21 existing GSSHA models and outputs many useful model parameters that are described in the section on model output.

**Update Elevation Data:** An image showing the GSSHA model update wizard with each of its steps is shown in figure 6.
You can use the Update Elevation Data step of the wizard to read updated elevation data, if necessary. The updated elevation data is used to delineate the watershed and update the 2D Grid elevations in the GSSHA model. When delineating a watershed, it is important to determine flow directions and flow accumulation values from the elevation data, and this step includes an option to compute these grids from the elevation data.

**Update Outlet/Settling Pond Locations:** Sometimes, the locations of the settling ponds are changed or new settling ponds or embankments are added to the watershed that change the flow and may require the watershed outlet point and the watershed boundary to be changed. Because of this, we added a step to the wizard to assign a new outlet location. If a drainage coverage (layer) already exists in the model, WMS copies this coverage to a new drainage coverage. If no drainage coverage exists, WMS creates a new drainage coverage so the outlet can be added to that coverage. When assigning a new outlet location, WMS deletes all the geometric data in the coverage and the watershed boundary is re-computed when the watershed is delineated in the next step.

**Watershed Delineation:** This step determines the watershed boundary based on the flow directions and accumulations and the outlet point in the active drainage coverage.

**Update 2D Grid:** The Create 2D Grid step is used to update or create a 2D grid for running GSSHA from the delineated watershed boundary. In this step, you select a grid cell size or number of cells, assign an optional depression coverage, and assign an optional coverage containing GSSHA structures (such as detention basin outlets) and select a button to create a 2D grid and initialize your GSSHA model parameters.
WMS does the following when you select the Create 2D Grid button:

1. Convert the delineated drainage coverage to a GSSHA coverage.
2. Intersect the stream arcs (polylines) in the GSSHA coverage with the depression coverage (if this option is on) and split the stream arcs at the intersections.
3. Redistribute stream vertices so the vertex spacing matches the specified 2D grid cell size.
4. Smooth any stream arcs that are outside of depression coverage polygons. If no depression coverage exists, WMS removes all adverse slopes on the streams.
5. Combine the stream arcs so they are no longer split at the intersections of polygons in the depression coverage.
6. Assign default stream attributes to all the streams (Trapezoidal channel with the following attributes: Manning’s n = 0.03, depth = 3 m, width = 4 m, and side slope = 0.5).
7. If the option to assign structures from an existing GSSHA coverage is selected, WMS copies the embankments, detention basin nodes, and pumps and their attributes from the selected GSSHA coverage to the new GSSHA coverage.
8. Creates a 2D grid filling the watershed boundary polygon at the specified cell size.
9. Initializes the GSSHA model data and copies the previously defined GSSHA model job control information over to the new GSSHA model.

**Update GSSHA Parameters:** This step of the wizard is used to specify the GSSHA land use and soil type parameters assigned to the land uses and soil types in WMS. These parameters are later assigned to the GSSHA model after updating the land use and soil data assigned to your model. Default parameter files can be read and used from other projects to parameterize values in the active GSSHA model.

**Update Land Use/Soil Data:** The define land use and soil data step converts GIS shapefiles to data in the WMS Map module. WMS uses the boundary of the watershed in the GSSHA coverage to clip the shapefile data for the selected files.

**Update Index Maps:** The index maps step is used to generate GSSHA index maps from the polygons in the WMS land use and soil type coverages. After WMS defines the GSSHA index maps, it generates GSSHA mapping tables from the index map ID’s and the GSSHA land use and soil type parameters defined in the GSSHA Parameters step of the wizard.

**Update Embankment Locations:** The embankment locations step is used to layout or change the locations of GSSHA embankment arcs within a watershed. These embankment arcs could represent structures such as hauling roads, detention basin embankments, or settling pond embankments.
**Update Pumping Stations:** The pumping locations step of the wizard is used to delete or add pumping stations and to define the pumping rates. Pump stations are where water or sludge is transferred from the open-pit mine to the watershed. These pumping stations can be a major source of sediment load in each of the watersheds surrounding the mines.

**Update Rainfall:** The model rainfall occasionally needs to be updated to forecast future sediment loads and water depths in each of the watersheds surrounding the open-pit mines.

**Output:** Several output parameters that are useful for managing the watersheds surrounding the open-pit mine are exported from the model after running the model. Some of the parameters that are output include:

1. Simulation input parameters, such as pumping rates, model duration, and watershed area.
2. General simulation results at each user-specified output point, such as peak flow, runoff volume, volume of water pumped, and total infiltration.
3. Information about the settling ponds, such as their initial storage, volume of rainfall in the ponds, volume of runoff to the ponds, and the peak discharge from the ponds.
4. A sediment summary, including the maximum and average erosion rates, the total sediment eroded and deposited in various parts of the watershed, and sediment concentrations.
5. Discharge and runoff volume are also computed at each user-specified output location in the model.
6. An erosion/deposition plan view map is computed and displayed as part of the output.

**DISCUSSION, CONCLUSION, AND FUTURE WORK**

Open-pit mines can impact their surrounding watersheds in various ways. The GSSHA model can be used to model some of these impacts on the environment. Some of these impacts include sediment erosion, sediment deposition, and flooding from settling pond embankments and hauling roads. WMS can be used to develop GSSHA models, and the open-pit mine wizard in WMS allows you to update these GSSHA models in a semi-automated fashion.

This paper provided an overview of the GSSHA hydrologic models surrounding three open-pit coal mines and shows how the WMS wizard can automatically update the hydrologic models for the area surrounding the open-pit mine. We would like to extend the techniques used in this wizard to automatically update other types of GSSHA hydrologic models and perhaps to auto-generate hydrologic models for any watershed of interest.
REFERENCES
