Groundwater Flow Model of the Silver River Watershed
Keweenaw Bay Indian Community, Baraga County, MI

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Executive Summary

The Keweenaw Bay Indian Community (KBIC) of Baraga County, MI obtained Clean Water Act funds to characterize the Silver River watershed, which is part of the Lake Superior Basin in Michigan's Upper Peninsula. A cooperative agreement was established between the KBIC and a student "enterprise" group at Michigan Technological University called Aqua Terra Tech (ATT). ATT was tasked with characterizing the hydrogeological conditions in the watershed and with developing of computer model of the surface and subsurface hydrology. Seasonal home water well levels, shallow seismic refraction, and bedrock outcrops were measured, recorded and mapped by the students and incorporated into a hydrological model using the Groundwater Modeling Systems Software, GMS 5.1. The result of the project is a conceptual model of the regional surface and groundwater flow for the KBIC to utilize for community planning.

Background

Aqua Terra Tech (ATT), an enterprise engineering design student group at Michigan Technological University has completed a collaborative project with the Keweenaw Bay Indian Community (KBIC) to characterize the pristine rural Silver River watershed on the L'Anse Indian Reservation in the Upper Peninsula of Michigan. This project started in the fall of 2000 under the supervision of Dr. John S. Gierke, Ph.D., P.E. Various Civil, Environmental and Geological Engineering students have worked on this project through ATT and senior design. Components of this project included conducting field observations and creating a conceptual computer model of the region surrounding the Silver River watershed.

The geology of the Silver River watershed region is composed of glacial and unconsolidated alluvial deposits overlying intrusive and metamorphic bedrock (Sweat, 1998). Soil types include sandy to silty loams and till based on USDA classification, with some organic soil layers. The watershed area is 64 m^2, with the ground cover being mostly forested with hardwoods, some conifers and swampy areas. The surface topography is generally hilly, with elevation gradients less than sixty degrees from vertical (Kremer, 2001).

Data Sources

The data input into the conceptual model comes from a variety of sources. These sources include field observations; water well drilling borehole records; daily average precipitation data; USGS stream gage data, Digital Elevation Model (DEM), and topographic maps, and USCS Soil Classification data.

Field Observations

The fieldwork utilized for this project includes seasonal water level observations from home drinking water wells from fall 2000-2004, seismic refraction surveys to observe the water table and bedrock elevations, and bedrock outcrop locations. For the water level measurements, a sounder instrument was lowered into the well to measure the water table elevation from the ground surface. When possible, water levels were observed in the same wells from season to season to look at long term variation of the groundwater flow. The seismic refraction surveys were performed at various locations throughout the watershed to expand the geologic data coverage and decrease the error of extrapolation of the water table and bedrock elevations. The surveys were conducted with a 12-channel SmartSeis Seismograph, and locations were verified using a Trimble Global Positioning System (GPS). The bedrock outcrop locations were mapped using the GPS.

USGS Data

The USGS stream gage data from the Silver River was used to compare the observed river flow rates to the model calculated flow rates. This is public data and can be accessed at http://waterdata.usgs.gov/mi/nwis/.

The topography of the ground surface input into the model is from a DEM gridfile, from the Michigan Geographic Data Library (http://www.mcgi.state.mi.us/mgdl/). The original projection was Michigan GeoRef, which was converted into the UTM NAD27 coordinate system with units of feet. The purpose of these elevation values is to represent accurate spatial relationships of the surface water and geologic features. USGS 7.5 Minute Quadrangle maps were used as a visual backdrop for the computer simulated watershed.

Soil Records

Subsurface information was taken from water well drilling logs (boreholes). These logs contain geologic information including depths to bedrock, rock and soil types and hydrogeologic information (SWL and well performance). The borehole records came from the KBIC NRD, Michigan Western Upper Peninsula Public Health Office, and Michigan Department of Environmental Quality Electronic Database (http://www.deq.state.mi.us/well-logs/). Information from paper copies of logs was input into the model to create the conceptual static water level and bedrock layers.

Different soil types allow precipitation infiltration at different rates and accommodate different vegetation types. The STATSGO soil information is generalized surface soil maps that can be used to represent different recharge areas in the regional flow model.

Precipitation Data

Average daily precipitation records from the Baraga Precipitation Observation Station were used along with soil information to determine the precipitation recharge rate of the watershed. This data is compiled by the National Climate Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html). A Thornthwaite-Type Water Monthly water Balance Model was used to calculate recharge and hydraulic conductivity rates.

Conceptual Model Components

Model Genesis

The watershed model is created using GMS 5.1 watershed modeling software. Throughout the model development, an upgrade from GMS 4.0 allowed for increases in the computing ability and GIS data input. All of the information input into the model is incorporated into separated layers called coverages. Each of the layers can be selected depending on the desired visual output. The majority of the information was input by hand, and when possible imported using spreadsheets and geographic information systems (GIS) software, ArcView GIS3.3. The model is based on two layers: glacial drift and bedrock layers. The bedrock layer is assumed impermeable to the groundwater flow. The bedrock and glacial drift layers are constructed from the borehole information. Over 200 boreholes were input into the model.

The surface water components of the model include rivers, lakes and watershed boundaries. Ephemeral streams were not included in the model for several reasons. The ephemeral streams have a very high seasonal variation which is assumed to average into a static flow value. There is insufficient data to calibrate the calculated stream flow, so the flow from the ephemeral streams is included in the larger river flow. The rivers are established by creating arcs in GMS by tracing a USGS topographic map image backdrop. Inland lakes and the shoreline of Lake Superior are represented as constant head boundaries. The watershed boundaries for the regional model and the sub-watersheds included were determined based on topographic divides. These boundaries were not incorporated in the flow calculations to prevent restriction of groundwater flow according to the topography. Within the region, there are ten watersheds, including the Silver River watershed. The Silver River watershed is divided into seven sub-watersheds based on the tributary stream distribution. This regional approach was used based on previous work in the Zebra Creek watershed, which would not converge on a solution without surrounding regional information.

The ground surface elevations were input through a DEM, based on the UTM NAD1927 coordinate system, with map units set to feet. The DEM originally had a resolution of 100ft grid squares, and this was thinned by taking every tenth elevation point to accommodate GMS computing ability. This yielded a resolution of approximately ¼ x ¼ mile grid squares. The DEM was converted to a triangular irregular network (TIN) layer which was easier for GMS to run simulations with compared to the large DEM file. These elevations allowed GMS to calculate surface water and groundwater flow directions and rates with appropriate spatial distribution.

Groundwater flow also varies based on the hydraulic conductivity of the soil and recharge rates from precipitation. Based on the different soil types according to the STATSGO soil information, regions of for soil types were established in the model. Hydraulic conductivity and recharge were allowed to vary across the region. However, because of the model resolution, GMS was unable to reach a solution using the soil regions. The final model is based on a constant recharge rate and varying hydraulic conductivities.

Model Validation and Numerical Results

As the data was input to the model, simulations of groundwater flow were checked for error, run and checked against observed data. Based on the simulation results, more information was utilized to get the most accurate model possible. This additional information included a flow budget, data from the USGS Silver River gaging station, and comparison to a surface water model using HMS and HEC RAS programs.

The home water well water elevations are not included in the model calculations, but are used to compare calculated water table elevations, or heads. The water level distribution of the Silver River region is shown in Figure 1. Larger figures are found at the end of this report. The home water wells are represented by the relative error compared with the calculated water level elevation. Green error bars are within the specified allowable range of values, yellow error bars are less than 200% error, whereas red error bars represent greater than 200%. Typically, the red wells are outside the Silver River subshed.

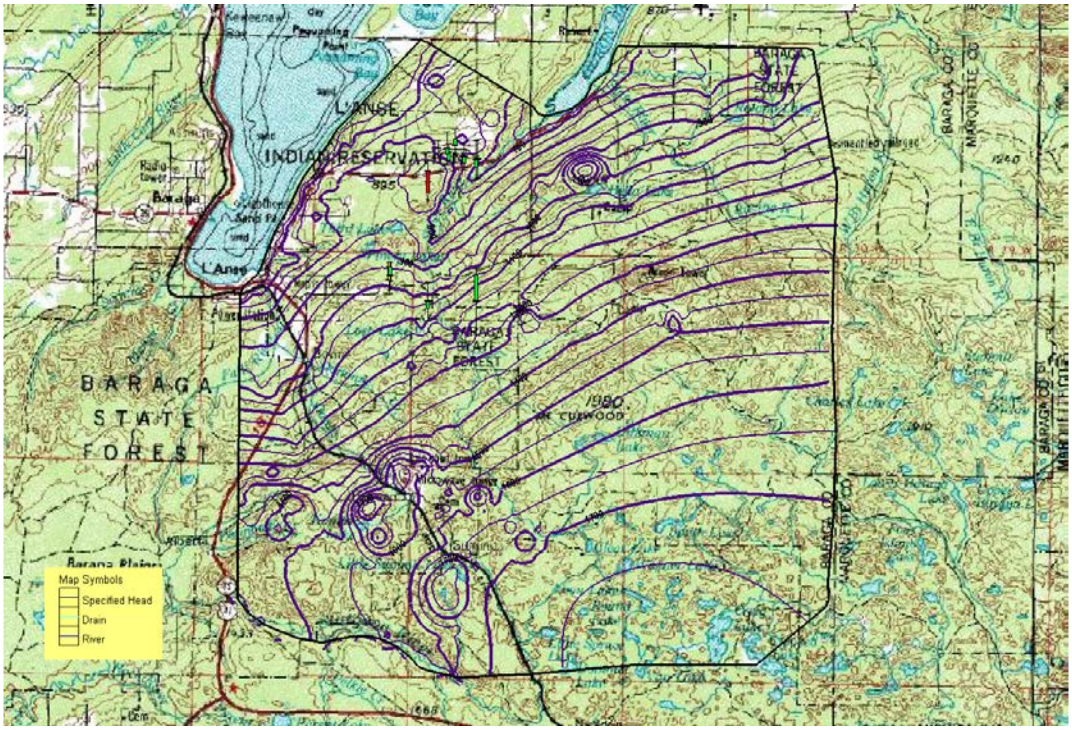

Figure 1. Silver River watershed groundwater table elevation contours. The circular features occur in areas of rapid change in ground surface elevation as well as a higher density of inland lakes.

Figure 2 illustrates the regional groundwater flow direction with flow vectors. The flow vectors are generated independent from the groundwater table elevation contours. Groundwater flow occurs perpendicular to the contour lines, and this shows that the results GMS calculates for the groundwater flow directions are reasonable. A second validation to the relevance of the groundwater flow direction is the watershed boundary images. Groundwater generally flows according to the surface topography, and the generated flow vectors align with the surface watershed boundaries. The flow vectors also show how the groundwater flows in and out of the rivers.

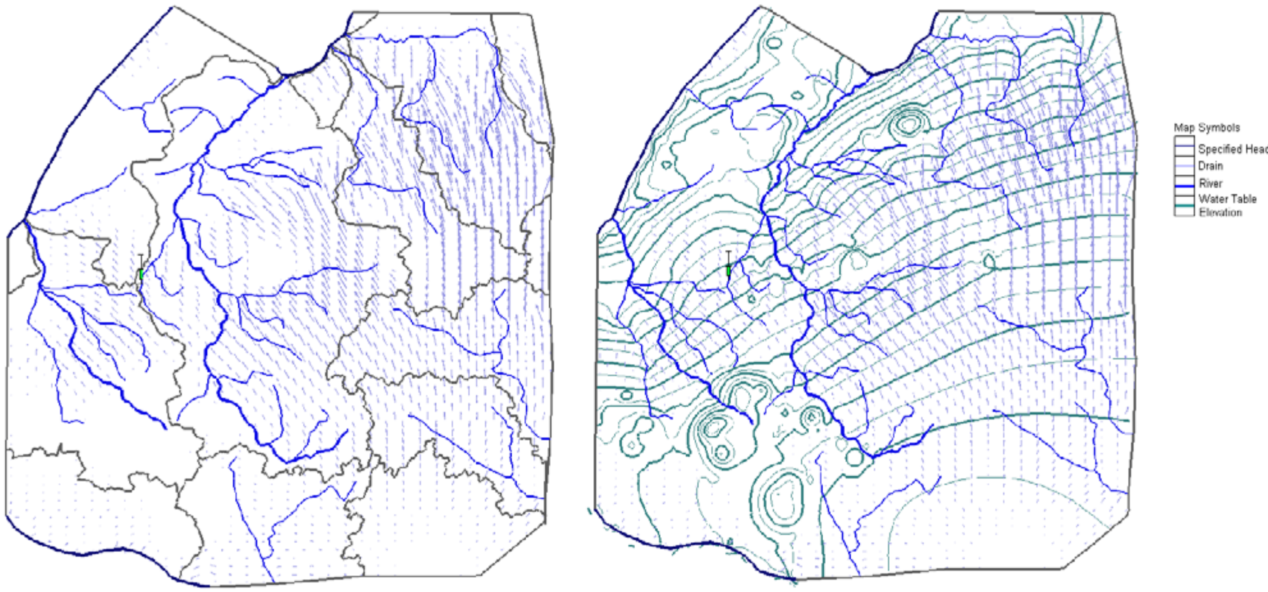

Figure 2. Regional groundwater flow of the Silver River watershed and surrounding areas. The flow vectors generally align with the watershed boundaries. Deviation of flow is likely caused by variation in the subsurface that is not expressed on the surface.

A flow budget was created in GMS to compare the total inflows to the total outflows of the watershed as well as their percentage comparison, which was within 0.00015%. Table 1 shows the ratio of groundwater to surface water discharge into Lake Superior. Based on a USGS study of Lake Michigan, direct groundwater flow into the Great Lakes is typically around 8% of the indirect groundwater flow (Grannemann et al.). Direct groundwater flow includes groundwater going directly from the aquifer into the lake, while indirect flow is groundwater discharged into a surface water body and eventually discharged into the lake. Table 1 gives a ratio of direct to indirect groundwater flow into Lake Superior, which is 5.7%. Though this value is lower than that found for Lake Michigan, it is expected because the aquifers surrounding Lake Michigan typically have higher permeabilities.

Table 1. Flow budget of flow into Lake Superior for regional watershed model.

Groundwater flow (ft^3/d)	Surface water flow (ft^3/d)	Ratio
1,320,000	23,050,000	5.7%

Data from the USGS gaging station was used to calculate observed flow rates from both the groundwater model and the HEC RAS surface water model. The calculated surface water flow rate from the HEC RAS modeling program was compared with the GMS observed flow rate. Although the HEC RAS program does not take into account the evapotranspiration and groundwater flow data, after correction for evapotranspiration the two flow rates for the USGS gaging station location were within 20% of each other. The USGS gaging station was chosen to represent the total surface water flow for the entire watershed because the flow of all subbasins is assumed to flow through the gaging station. Figure 3 shows the correlation of the HEC-HMS surface water flow value locations to those in GMS.

Table 2. Comparison of flow rate results between the HMS and GMS models, as well as adjusted HMS results. The flow through the USGS Gage represents the total flow from all subbasins.

Location	HEC Flow (cfd)	HEC Adjusted (cfd)	GMS Flow (cfd)	Ratio	Adjusted Ratio	% Difference Between Models
USGS Gage	**20206995**	**7216784**	**8965381**	**2.25**	**80.5%**	**19.5%**
Gomanche Creek	1376441	491586	658000	2.09	74.7%	25.3%
East Branch	4779341	1706908	1820106	2.63	93.8%	6.2%
South Sub-basin	5777218	2063292	1040511	5.55	198.3%	98.3%
Junction 1	10556636	3770227	2860617	3.69	131.8%	31.8%
Junction 2	13865602	4952001	4394466	3.16	112.7%	12.7%
Junction 3	18800841	6714586	7963961	2.36	84.3%	15.7%

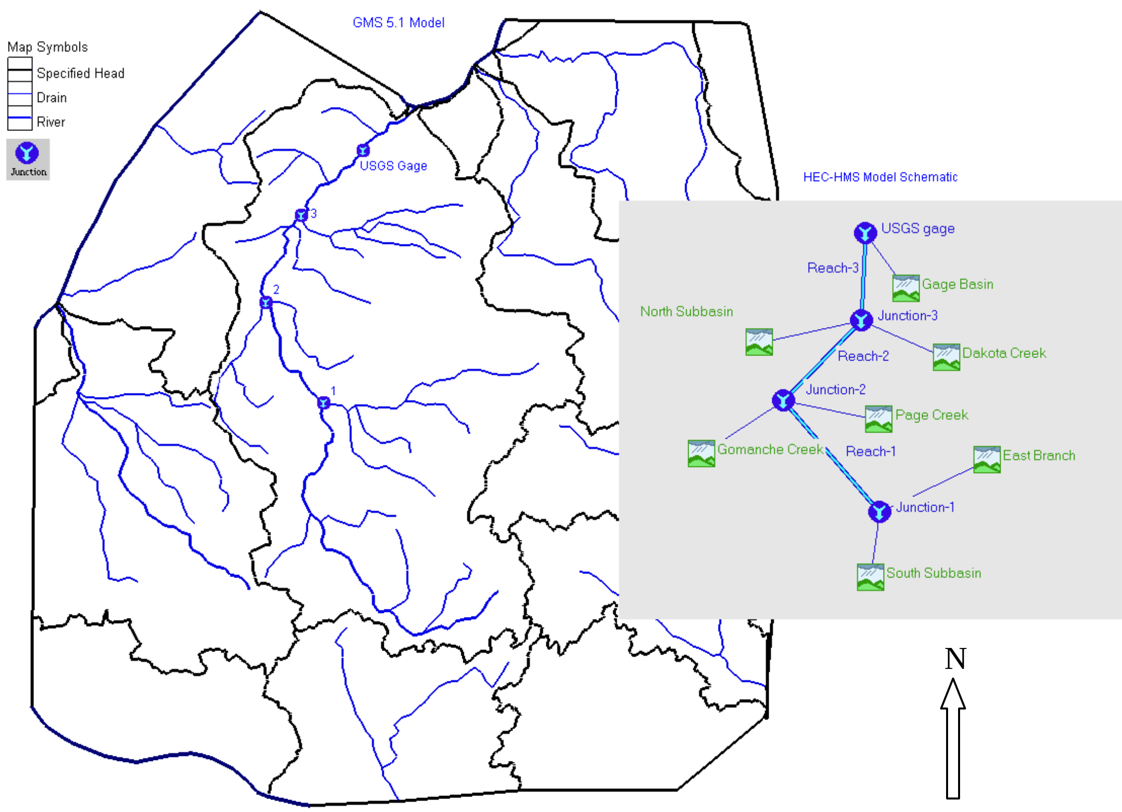

Figure 3. Computer modeled flow rate locations from the GMS 5.1 and HEC-HMS models. Flow values at the junctions are the summation of the total flow upstream of that given point, i.e. the flow through Junction 3 is the sum of all the flows from Junctions 1 and 2 and their respective tributaries.

Conclusions

The groundwater flow in the Silver River watershed region is generally to the northwest, recharging streams from the south. The model calculated water level values had relatively high error from the observed values up to 60 feet, which is most likely due to the low resolution of the elevation data. However, the model calculated groundwater flow direction and the amount of stream flow matches very closely with observed data. The GMS 5.1 model of the Silver River watershed area is a reasonable model given the constraints of the data available and the computational ability of GMS 5.1. Given the large area and variations in the subsurface, the dual layer model was chosen as the best conceptual representation of the watershed behavior.

Additional information that would supplement the model would include a higher resolution of the elevation data, additional stream flow data, and a greater distribution of geologic data in the southeast portion of the watershed. The stream flow data from the gauging station matched the calculated flow, so additional stream gauges would be helpful in modeling the variation of stream flow. Also, estimates of the recharge rates and hydraulic conductivity based on both the soil types and the subsequent geologic layers would enhance the model accuracy. Information that was not crucial to the model was soil data and seasonal water levels at this resolution. A higher resolution model could allow a more detailed variation of recharge and hydraulic conductivity based on both the soils and glacial drift.

Recommendations

Further approaches to the analysis of the watershed would be to first have more information on the recharge rate and hydraulic properties of the watershed. Currently, GMS has the capability to model a higher resolution over a smaller area with more concentrated data. In order to get a higher resolution model, sub-areas of the Silver River watershed could be modeled in greater detail. The results of each of these individual models could be linked to model the entire Silver River watershed. Pending increases in the software, further analysis could include creating a transient model that simulates seasonal variations in the water table.

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