Aquifer Vulnerability Project Report for the Keweenaw Bay Indian Community Reservation and Encompassing Watersheds

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EXECUTIVE SUMMARY

The Inter-Tribal Council of Michigan, Inc (MITC) conducted the "Aquifer Vulnerability Project" to provide Keweenaw Bay Indian Community (KBIC) with information where the physical environment offers more or less groundwater protection in the vicinity of the L'Anse Indian Reservation. The geographic extent of the project was centered on KBIC's L'Anse Reservation in Baraga County, Michigan and extended to the outer boundaries of the Silver, Falls, Sturgeon, and Lake Drainage watersheds.

The premise of an aquifer vulnerability study is that the physical environment can provide different levels of aquifer protection depending on the depth and type of material in and around groundwater. This project utilized the DRASTIC methodology to assess aquifer vulnerability. DRASTIC evaluates the hydrogeologic variables affecting groundwater, including **D**epth to water, net **R**echarge, **A**quifer media, **S**oil media, **T**opographic slope, **I**mpact of the vadose zone, and hydraulic **C**onductivity. Depth, recharge, aquifer media, impact of the vadose zone, and hydraulic conductivity values were obtained from 604 sample wells and the geologic information contained in each well's log. Topographic slopes were derived from USGS Digital Elevation Models (DEMs) and soils information was derived from USDA soil type delineations. Each variable was ranked according to the extent to which it affects aquifer vulnerability as outlined in the attached matrix showing the DRASTIC ranking schemes. Following the ranking of sample location values, each hydrogeologic variable (depth, aquifer media, etc.) was weighted according to the extent to which it affects aquifer vulnerability.

The objective of the "Aquifer Vulnerability Project" was to produce a map showing varying aquifer vulnerability conditions in and around the Keweenaw Bay Indian Community to aid decision making. The following report states how aquifer vulnerability values were reached leaving the map to communicate the Project results.

DATA INVENTORIED AND ACQUIRED

The data necessary to conduct the "Aquifer Vulnerability Project" were obtained from a variety of sources. The first and largest inventory component of the Project began by collecting sample well locations that could be used to determine depth to water, recharge, aquifer media, impact of the vadose zone, and hydraulic conductivity throughout the Project area. Well information obtained from KBIC Natural Resources was a starting point for sample wells but many more wells were needed. The next step was to acquire the State's GIS coverage of wells in Baraga and Houghton counties provided by Michigan's Center for Geographic Information (MCGI). The preliminary well coverage can be downloaded from MCGI's website: *http://www.mcgi.state.mi.us/mgdl/?rel=thext&action=thmname&cid=2&cat=Drinking+Water+Wells*. In addition to the digital well logs, hardcopy well logs were obtained from the Michigan Department of Environmental Quality's (MDEQ) Wellogic database and their online archive of scanned well logs. The sources above comprise the origin of the sample wells used in the Project.

The second largest inventory component was the acquisition of soils data necessary for the DRASTIC evaluation. Neither Baraga nor Houghton counties had completed soils data in digital format in a scale suitable for the Project's scale. Soil Survey Geographic (SSURGO) data was a minimum of one year from completion. Further research concluded the only suitable digital soils data available for Baraga County was from the State of Michigan in Microstation design files in State Plane NAD27. The soils data for Baraga County was acquired from John Spitzley with MCGI. No digital soils data was available for Houghton County. The portion of the study area in Houghton County would require digitizing hardcopy soil delineations. Hardcopy soils maps of Houghton were requested from Glenn Lambert with the Natural Resource and Conservation Service.

The remainder of the digital spatial data was available for download from MCGI. Digital data acquired included digital elevation models (DEMs), public land survey boundaries, 1998 aerial photography, watershed boundaries, roads, streams, political boundaries, bedrock geology, and digital 1:24,000 topographic maps.

SPATIAL DATA COMPILATION AND STANDARDIZATION

Spatial data standardization began with geographically pinpointing sample wells from hardcopy format. Sample wells were located using township, range, section, quarter quarter section and/or address information printed on the well log. Aerial imagery was used in conjunction with the above information to locate each sample site. Only well logs with quality well location information and lithology were used. Geographically referenced hardcopy sample wells were merged with MCGI digital wells for Baraga and Houghton counties into one file and clipped to Project extent boundaries. A total of 604 sample wells were ultimately compiled within the sample well data layer.

Baraga soils were converted within ARC/INFO Workstation from Microstation soil quads in State Plane NAD27 to ArcView shapefiles. The quads were cleaned and merged into one file for Baraga County and reprojected into the Michigan Georef projection. The soil layer was then clipped to the Project's extent. The soil's attribute table was modified to contain the soil type as indicated in the Soil Survey of Baraga County Area, Michigan.

The Project contained a small area of land within Houghton County that had to have soil delineations digitized from two hardcopy maps. The soils were digitized using

ARC/INFO. The soil's attribute table was modified to contain the soil type as indicated in the Soil Survey of Houghton County Area, Michigan. The resulting soils layer was merged with the Baraga soils layer and cleaned for overlap and slivers. The final soils layer had good spatial integrity and was ready to be ranked and later converted to a raster layer for mathematical operations to be performed between layers.

Digital elevation models for Baraga and Houghton counties were converted from Interchange files to ARC/INFO GRIDS and were merged within ARC/INFO. The boundary between the two layers was cleaned to eliminate gaps. The resulting DEM was then clipped to the Project's extent. The layer was then ready to be ranked and undergo mathematical operations to be performed between layers.

The remainder of the acquired spatial data from MCGI was converted into ArcView shapefile format using ARC/INFO. The data was already in the Michigan Georef projection. The aforementioned spatial data was brought into an ARC/INFO 8.3 project for analysis and for cartographic output of analysis results.

CATEGORIZE/RANKING SPATIAL DATA ACCORDING TO AQUIFER VULNERABILITY

The following narrative describes how the seven hydrogeologic variables in the "Aquifer Vulnerability Project" using the DRASTIC methodology were ranked.

D*epth to Aquifer*

The Depth to Aquifer component of the Project was derived from the 604 sample wells located within the Project's boundaries. Each well was analyzed to determine the approximate depth of the groundwater from the surface. Calculating vulnerability for multiple aquifers at one sample locations was beyond the scope of this project. The groundwater targeted for vulnerability ranking was that being used by the well.

A majority of the wells within the Project's boundaries were rock wells developed in Jacobsville Sandstone or Michigamme Slate. Groundwater depths in these wells were assumed to be located at the static water level indicated on the well log or in some cases at the top of the Jacobsville Sandstone or Michigamme Slate. The top of the consolidated material was used in cases where the static water level was shallower than the top of the Jacobsville or Michigamme.

The depth to aquifer in the wells in unconsolidated material was calculated using the static water level in unconfined conditions. In wells that had confined groundwater, the depth of the bottom of the confining layer was used to measure depth to aquifer. Following the depth to aquifer determination for both rock and non-rock

DRASTIC Ratings for Depth to Water (DRASTIC Weight 5)	
Water table depth (feet)	DRASTIC rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
>100	1

wells described above, the well was placed into one of the following depth to aquifer classifications.

Depth ranking values between wells were calculated by means of Spline interpolation. Spline estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations. There are two Spline methods: Regularized and Tension. The Tension method was used because it tunes the stiffness of the surface more closely to the character of the hydrogeologic conditions. It creates a less-smooth surface with values more closely constrained by the sample data range. For Tension, a weight parameter defines the amount of tension placed on the surface being created. The higher the weight, the coarser the surface. A tension weight of 15 was used in the depth to aquifer interpolation. The number of points used in the calculation of each interpolated cell was set at four sample wells. More input points would have caused interpolated cell values being more heavily influenced by distant wells. Finally, the cell size of the surface was set to the standardized 26.35 meter^2 to match that of the DEMs.

***R**echarge*

Like the Depth to Aquifer component, Recharge was derived from analyzing each of the 604 sample well logs. Material in and above the groundwater at each sample location was studied to evaluate Recharge values. The consolidated material in the Project area is well cemented, has low permeability, and is generally confined according to the USGS (Groundwater Atlas of the United States Iowa, Michigan, Minnesota, Wisconsin HA 730-J – Jacobsville and crystalline-rock aquifers). Based upon the USGS assessment, rock wells were given the lowest recharge classification of 0-2 inches a year and assigned a value of 1 in DRASTIC.

Of the 604 sample wells, relatively few were set in unconsolidated material. Wells in the unconsolidated material were assigned the slightly higher classification of 2-4 inches a year based on the Project area's estimated average recharge of 2 inches a year. Few wells were estimated to have a moderately higher than average recharge based on relatively shallow depth and highly permeable overburden.

DRASTIC Ratings for Net Recharge (DRASTIC Weight 4)	
Recharge (in/yr)	DRASTIC rating
0-2 (Jacobsville & Michigamme)	1
2-4	3
4-7	6
7-10	8
>10	9

Recharge ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer narrative. A tension weight of 15 and values from four neighboring sample sites were used to calculate the value of each 26.35 meter^2 cell.

***A**quifer Media*

Like the Depth to Aquifer and Recharge components, Aquifer media was derived from analyzing each of the 604 sample well logs. The process of determining aquifer media was performed in conjunction with the Depth to Aquifer step. Once the placement of groundwater was identified within a well log's lithology, the aquifer media according to the well driller was readily identifiable (i.e. sandstone, slate, sand, gravel, etc.). Overlay of well location with mapped bedrock types provided additional support for aquifer media determination. Jacobsville Sandstone was given a DRASTIC ranking value of 4 (DRASTIC: Massive Sandstone value range = 4-9). Jacobsville was given the least vulnerable ranking because of its high degree of consolidation. Michigamme Slate was given a DRASTIC ranking of 3 (DRASTIC: Metamorphic/igneous value range = 2-5). Michigamme Slate was given the average ranking for metamorphic/igneous consolidated material. The remaining aquifer media found in the Project area was fine sand, sand, and sand and gravel. These materials were ranked 6, 7, and 8 respectively according to the DRASTIC methodology.

DRASTIC Ratings for Aquifer Media (DRASTIC Weight 3)	
Aquifer material	DRASTIC rating
Massive shale	2 (1-3)
Metamorphic/igneous	3 (2-5)
Weathered metamorphic igneous	4 (3-5)
Glacial till	5 (4-6)
Bedded sandstone, limestone, shale	6 (5-9)
Massive sandstone	6 (4-9)
Massive limestone	6 (4-9)
Sand and gravel	8 (4-9)
Basalt	9 (2-10)
Karst, limestone	10

Aquifer Media ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer and Recharge narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

***S**oil Material*

Soil Materials ranking values were derived from 1:24,000 USDA Soil Survey delineations and soil types. Each soil type was placed in a DRASTIC soil material category and assigned the corresponding DRASTIC rating shown to the right.

The Soil Material layer was based upon continuous 1:24,000 spatial data rather than interpolation between sample well locations performed with the first three hydrogeologic variables.

DRASTIC Ratings for Soil Media (DRASTIC Weight 2)	
Soil Material	DRASTIC rating
Thin or absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Nonshrinking and non-aggregated clay	1

T*opographic Slope*

Topographic Slope ranking values were derived from USGS digital elevations models (DEMs). Slope was calculated as a percent within ARC/INFO GIS. The resulting slope layer was reclassified according to established DRASTIC ratings found in the adjacent matrix.

The Topographic Slope layer was based upon continuous 1:24,000 spatial data rather than interpolation between sample well locations performed with the first three hydrogeologic variables.

DRASTIC Ratings for Topography (DRASTIC Weight 1)	
Slope (%)	DRASTIC rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

I*mpact of the Vadose Zone*

Like the Depth to Aquifer, Recharge, and Aquifer Media components of the Aquifer Vulnerability Project, Impact of the Vadose Zone was derived from analyzing each of the 604 sample well logs. The material in the vadose zone of each sample well was identified following the placement of groundwater within the well's lithology. The material that significantly characterized the unsaturated zone was ranked according to established DRASTIC values shown in the matrix to the right. In instances where more than one material made up the vadose zone, the material's rankings were averaged together to produce a final vadose zone value.

Impact of Vadose Zone ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer, Recharge, and Aquifer Media narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

DRASTIC Ratings for Vadose Zone (DRASTIC Weight 5)	
DRASTIC Ratings for Vadose Zone (DRASTIC Weight 5)	
Confining layer	1
Silt/clay	3 (2-6)
Shale	3 (2-5)
Limestone	6 (2-7)
Sandstone/Jacobsville	6/4 (4-8)
Bedded limestone, sandstone shale	6 (4-8)
Sand and gravel with significant silt & clay	4 (4-8)
Metamorphic/igneous	4 (2-8)
Sand and gravel	8 (6-9)
Basalt	9 (2-10)

H*ydraulic Conductivity*

The final hydrogeologic component evaluated by the Aquifer Vulnerability Project was the estimation and ranking of hydraulic conductivity. As with Depth to Aquifer, Recharge, Aquifer Media, and Impact of the Vadose Zone, Hydraulic Conductivity was derived from analyzing each of the 604 sample wells logs. The material identified in the Aquifer Media component was used to estimate hydraulic conductivity. The majority of wells were placed in Jacobsville Sandstone and Michigamme Slate. Jacobsville Sandstone was reported to have an estimated hydraulic conductivity of about 1 foot per day according to the USGS (Groundwater Atlas of the United States Iowa, Michigan, Minnesota, Wisconsin HA 730-J – Jacobsville and crystalline-rock aquifers). Michigamme Slate was assumed to have the same or less ability to transmit water according to well production reports (Water Resources of the Keweenaw Bay Indian Community, Baraga County, Michigan, 1998). Wells that were located in unconsolidated material were ranked according to the DRASTIC ranking scheme identified in the matrix to the right.

DRASTIC Ratings for Hydraulic Conductivity (DRASTIC Weight 3)	
Conductivity (Meters/Day)	DRASTIC rating
<4 (Fine sand, clay, slate, jacobsville)	1
4-12 (Peat)	2
12-28 (Medium sand)	4
28-40 (Till)	6
40-80 (Coarse sand)	8
>80 (Gravel, fractured)	10

Hydraulic Conductivity ranking values between sample locations were calculated by the same interpolation process described in the Depth to Aquifer, Recharge, Aquifer Media, and Impact of the Vadose narratives above. A tension weight of 15, values from four neighboring sample sites were used, and 26.35 meter^2 cells were created.

DRASTIC Score/Aquifer Vulnerability

The aquifer vulnerability determination for the area within the Project boundary was a result of weighting (multiplying by weight shown in attached matrix) each hydrogeologic variable then overlaying each layer and getting a sum of the weighted DRASTIC rankings. The weights used to heighten the significance of one variable over another were a standard DRASTIC weighting scheme (seen in the equation below and in the attached matrix). The following equation was calculated within ARC/INFO GIS using each ranked hydrogeologic layer comprised of 26.35 meter^2 cells throughout the Project study area:

DRASTIC Score = $D_r * D_5 + R_r * R_4 + A_r * A_3 + S_r * S_2 + T_r * T_1 + I_r * I_5 + C_r * C_3$

The final step for mapping aquifer vulnerability within Keweenaw Bay Indian Community's reservation area was assigning each 26.35 meter^2 cell a qualitative risk. The qualitative risk categories used was the following commonly used DRASTIC classification: DRASTIC score 1-100 = Low aquifer vulnerability, DRASTIC score 101-140 = Moderate, DRASTIC score 141-200 = High, DRASTIC score >200 = Very High.

The resulting aquifer vulnerability/DRASTIC score and the seven hydrogeologic layers were printed on 17" X 11.5" paper at a scale of 1:150,000. The spatial data were stored and printed using the Michigan GeoRef projection. Copies of the digital spatial data were burned to compact discs for use by the Keweenaw Bay Indian Community.