Appendix I: Conceptual Groundwater Model

The Groundwater Modeling Process. The first step of the modeling process is to define the problem, which was covered in section 1.3 Purpose of Study for the St. Regis Site (Fetter, 2001; Reilly, 2001). Defining the problem can be helped by literature review, preliminary analyses, and data collection (Reilly, 2001). Literature review and data collection are still ongoing for the St. Regis Site. The next step of the modeling process is to develop a conceptual model.

To develop a conceptual model, first define the geographic setting by specifying the geographic coordinates and acquiring both the geographic location and facilities maps (Fetter, 2001; Reilly, 2001). It is also helpful to establish the time structure of the model during this stage (Fetter, 2001; Reilly, 2001). These have all been determined for the St. Regis Site. The time structure of the model will be from 1957 to 2017.

The second stage in developing a conceptual model is to collect aquifer property, geometry, and geology data for the study area. This includes determining the number of layers in the aquifer, the elevation of each layer surface, and the geologic stratigraphy (Fetter, 2001; Reilly, 2001). For each layer the thickness, extent, hydraulic conductivity, and porosity will be found (Fetter, 2001; Reilly, 2001). Extent and thickness are important for establishing the aquifer geometry. Determining the glacial geology is also essential to understanding the geology so glacial material type, porosity, and glacial layer thickness must be specified (Fetter, 2001; Reilly, 2001). For the St. Regis Site, these are being determined by the data from wells around the 125-acre study area and the surrounding areas.

Determining the hydrologic setting is the next stage in developing a conceptual model. The hydrologic boundaries must be specified and be set as flow or no flow boundaries and the type of boundary if it is a lake, river, or wetland (Fetter, 2001; Reilly, 2001). The head values must be found at all open flow boundaries (Fetter, 2001; Reilly, 2001). Wells will greatly affect the hydrologic setting, so the location, number, and type of wells need to be found for the study area (Fetter, 2001; Reilly, 2001). Infiltration parameters, surface discharges, storage, precipitation, and recharge areas must be determined for the study area (Fetter, 2001; Reilly, 2001). These will be determined for the St. Regis Site as data collection continues.

The final stage in developing a conceptual model is specifying the contaminant properties (Fetter, 2001; Reilly, 2001). The contaminant history in the study area must be established (Fetter, 2001; Reilly, 2001). The chemical character of the contaminants and their interactions with the aquifer must be ascertained (Fetter, 2001; Reilly, 2001). Anything that could be affecting the contaminants must be considered such as land use, precipitation, or engineering structures (Fetter, 2001; Reilly, 2001). Dioxin detection was discussed in the Literature Review Section 1.4.5. The contaminants pentachlorophenol and creosote need to be researched for the St. Regis Site.

Once the conceptual model is completed, the third step of the modeling process is to choose a mathematical model (Fetter, 2001; Reilly, 2001). Assumptions must be defined (Fetter, 2001; Reilly, 2001). The aquifer must be specified as confined or unconfined and as steady-state or non-steady state (Fetter, 2001; Reilly, 2001). Elements such as wells, sinks, or sources must be considered (Fetter, 2001; Reilly, 2001). The algorithm must be determined (Fetter, 2001; Reilly, 2001). For a confined steady-state aquifer, analytical methods, such as the Laplace equation, should be used (Fetter, 2001). For an unconfined non-steady state aquifer, numerical methods, such as the Boussinesq equation, should be used (Fetter, 2001). A mathematical model will need to be chosen for the St. Regis Site.

The fourth step of the modeling process is Calibration (Fetter, 2001; Reilly, 2001). This is an important step to ensure the accuracy of the model. This can be achieved by using history matching, sensitivity analyses, or independent data sets (Fetter, 2001; Reilly, 2001).
Once the model is calibrated the fifth step is that problem can be assessed using the model and the results can be analyzed (Fetter, 2001; Reilly, 2001). Then the final steps are that the problem can be re-evaluated considering the results and the model can be adjusted and run over many times until the results are as accurate as possible (Fetter, 2001; Reilly, 2001). Then the model will be complete (Fetter, 2001; Reilly, 2001).

Model Type. For the St. Regis Site, a solute-transport groundwater model will be an ideal model to help find the contamination plumes. Data needed for this type of modeling will be flow-model data, distribution of effective porosity, aquifer dispersion factors, fluid-density variations, and natural concentrations of solutes distributed throughout the study area. The location of the contamination source and the strength of the contamination must be known. For the specific contamination solutes, retardation factors within specific rocks and soils of the study area must be found. The flow-model will be used to compute the rate of fluid movement and the direction of fluid movement. Solute-transport equations are added onto the flow model to obtain movement and retardation values of the contaminant solutes (Fetter, 2001).

Conceptual Model for the St. Regis Site. For the St. Regis site the problem defined is that the soil and groundwater contaminated with Creosote (specifically Polycyclic Aromatic Hydrocarbons [PAHs]), Pentachlorophenol (PCP), and Dioxins. The soil is more contaminated than the groundwater. Every time it rains or snow melts the soil contaminants are leeching into the groundwater as precipitation passes through. There are 12 extraction pump out wells at the St. Regis Site. However, as discussed earlier and seen in Figure 7, the surface topology and drainage are not being considered and water is draining to lower points away from the extraction wells in OU1 and OU3. This means the dangerous contaminants are likely flowing into the unconfined aquifer and Pike Bay, a lake used widely by locals and tourists for fishing and recreation.

The geographic setting is defined by the Study Area Superfund Boundary. The Study Area Superfund Boundary is the LLDRM recognized area for the St. Regis Site is 1.71247 square kilometers (423.16 acres). It is in the Township, Range, Direction, and Section T145 R 31 W SECT 15 and T145 R 31 W SECT 16. The latitude and longitude coordinates of the five corners are the following:

NW corner 47.3775513616944, -94.6120348682155
NE corner 47.3773958306692, -94.5881507150606
SE corner 47.3738327117942, -94.5868939102924
S corner 47.3669868330332, -94.5979719394479
SW corner 47.3700263426037, -94.6139120598002

Within the Superfund Boundary the1984 OU areas were 0.505857 square kilometers (125 acres). In 2018 the OU areas are approximately 0.70249 square kilometers (173.6 acres). Several maps of these areas and the surrounding areas have been acquired. The time structure of the model will be from the start of operations in 1957 to the end of the precipitation recharge data 2017.

According to 1991 and 1996 studies there are four major hydrogeologic units for aquifer below the Study Area. These include an unconfined aquifer, an upper confining unit of clay and till, a confined aquifer, and a lower confining unit of clay and till (Stark, Busch, & Deters, 1991; Lindgren, 1996).

The unconfined aquifer saturated thickness could range from 0 to 34 meters (105 ft) but is mostly about 4.5 m (15 ft) to 9.1 m (30 ft) (Stark, Busch, & Deters, 1991; Lindgren, 1996). The ranges for layer thickness from Stark and Lindgren for the upper confining unit of clay and till, the confined aquifer, and the lower confining unit of clay and till are very wide and need to be more specific for an accurate model. The same goes for the hydraulic conductivity, horizontal hydraulic conductivity, and transmissivity for all four aquifer layers. Further research is needed to ensure the accuracy of these numbers before running the model.

The quaternary geology and geomorphic landform association of the St. Regis Site Study Area includes DHE - End Moraine (Des Moines Lobe--Sugar Hills Moraine) in the northwest region, DSS - Stagnation Moraine (Des Moines Lobe--Big Stone Moraine) in the northeast region, DO - Outwash - Undivided as to Moraine Association in the central region including the entire Superfund Boundary area, and WIG - Ground Moraine (Wadena Lobe--Itasca Moraine) on the western edge as well as southeast and southwest regions (Maeder & Rader, 2014; Jirsa et al., 2011). The Lithology of the Study Area is non-calcareous till in the northwest, western edge, southeast, and southwest regions, calcareous till in the northeast region, and sand and gravel in the central region including the entire Superfund Boundary area (Maeder & Rader, 2014; Jirsa et al., 2011). This means this glacial geology will have a high porosity. The Hobbs and Goebel Lithology is Diamicton for the corners and Sand for the central region (Maeder & Rader, 2014; Jirsa et al., 2011; Hobbs, Goebel, & Lively, 1982). The Glacial Lobe of the Study Area is Des Moines from the Early Wisconsinan glacial stage for the northern and central regions and the Wadena Lobe from the Late Wisconsinan glacial stage in the southeast and southwest regions (Maeder & Rader, 2014; Jirsa et al., 2011). The Deposit Type is Glacial Moraine in the corners of the Study Area and Glaciofluvial Apron in the central region (Maeder & Rader, 2014; Jirsa et al., 2011). The texture modifier for the entire Study Area and Superfund Boundary area is Clayey (Maeder & Rader, 2014; Jirsa et al., 2011). These sediments were deposited during the last glaciation (Maeder & Rader, 2014; Jirsa et al., 2011). The Pre-Cambrian Bedrock for the entire

Study Area and Superfund Boundary area is Bemidji batholith (Maeder & Rader, 2014; Jirsa et al., 2011). Data about the glacial layer thickness needs to be found for the St. Regis Site.

Soil data was retrieved from the Gridded Soil Survey Geographic (gSSURGO) for Database for Beltrami, Cass, Hubbard, and Itasca Counties, Minnesota hosted on the United States Department of Agriculture's Natural Resources Conservation Service Geospatial Data Gateway. There are six soil layer profiles, ranging from 10 cm above the surface to 203.2 cm below the surface, were created using soil survey data for Beltrami, Cass, Hubbard, and Itasca Counties (Nyberg,1987; Neuenfeldt, 2000; Richardson, 1997; Larson & Rolling, 1997). Each soil profile layer includes a color, description of soil type, infiltration rate in cm/hr, hydraulic conductivity K value, and porosity value. There are 13 soil polygons of 12 types of soil within the Superfund Boundary area.

Soil Media Data

Description	Area (sq. km)	Soil Drainage	Soil Permeability	Soil Water Capacity	Soil Surface Runoff	Depth to Water Table Top (cm)	Depth to Water Table Bottom (cm)	Depth to Bedrock (cm)	Averate Inflitration Rate (cm/hour)	Soil Survey Source
Eagleview and Menahga soils, 1 to 8 percent slopes	26.584	Eagleview: somehwat excessively drained Menahga: excessively drained	Rapid	low	slow	no data	no data	152.4	2.35585	(Neuenfeldt, 2000, p.58-59; Larson & Rolling, 1997, p.43)
Eagleview and Menahga soils, 3 to 15 percent slopes	1.493	Eagleview: somehwat excessively drained Menahga: excessively drained	Rapid	low	slow	no data	no data	152.4	1.83198	(Neuenfeldt, 2000, p.58-59; Larson & Rolling, 1997, p.43)
Fluvaquents, frequently flooded	36.094	Poorly drained	Moderate to Rapid	high to low	very slow	0	60.96	no data	1.5113	(Richardson, 1997, p.82)
Histosols, depressional	53.402	Very poorly drained	Moderately Slow to Rapid	very high	slow	-30.48	30.48	no data	0.8763	(Larson & Rolling, 1997, p.119)
Humaquepts	16.353	Poorly drained and very poorly drained	Rapid to Moderate	low to moderate	very slow or slow	0	60.96	no data	1.97062	(Larson & Rolling, 1997, p.117)
Humaquepts, sandy	59.266	Poorly drained and very poorly drained	Rapid or Moderately Rapid	moderate or high	very slow	0	30.48	no data	2.42782	(Larson & Rolling, 1997, p.119)
Meehan loamy sand, 0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(Richardson, 1997,

Soil Media Data from the Soil Surveys of Cass County (Richardson, 1997), Beltrami County (Larson & Rolling, 1997), and Hubbard County (Neuenfeldt, 2000) by the Minnesota Agricultural Experiment Station and the USDA NRCS Forest Service

The hydrologic boundaries show how water enters and leaves the model study area. For the St Regis Site water enters the study area from precipitation as recharge. Average monthly precipitation data was available for Beltrami, Cass, Hubbard, and Itasca Counties from 1891 to 2017 from Precipitation Data Retrieval from a Gridded Database hosted by the Minnesota State Climatology Office DNR Division of Ecological and Water Resources & the University of Minnesota. Water leaves the St. Regis Site by running through streams flows as seen in Figure 7 as well as through Fox Creek and the water channel between Cass Lake and Pike Bay. Water can also exit the Study Area by evapotranspiration and by the 12 groundwater extraction wells. For the Superfund Boundary area the flow boundaries are Fox Creek on the southwestern boundary, Pike Bay on the southeastern boundary, and the water channel between Cass Lake and Pike Bay is the eastern boundary. The no-flow boundaries are the Western Boundary and the Northern Boundary. These are areas of higher ground where natural topographic divides occur. Head and flux values must be found at all open flow boundaries for the St. Regis Site.

There are 12 pump out extraction wells in the Study Area and 994 other types of wells. Of the 994 other types of wells, 666 are domestic wells where 644 are active, 14 are sealed, eight have an unknown status. The Study Area also has 138 Monitoring wells with 108 active, 28 sealed, and two with unknown status. There are two active industrial wells and three active irrigation wells. Two Environmental Bore Hole wells are active and two are sealed. Four Licensed Non-Public Supply wells are operational and one is sealed. There are nine active Municipal / Municipal Community Supply wells, 13 active Public Supply Non-Community wells, and 109 Public Supply Non-Community Transient wells (98 active, four inactive, seven sealed). Other wells in the study area include two sealed and one active observation wells, nine active recovery wells, two active remedial wells, and one sealed scientific investigation well. There are 21 test wells where one is sealed but the status of the other 20 is unknown. Five wells are labeled as “other” with four active wells and one sealed. Three wells are of unknown type and statuses. All 12 pump out extraction wells are inside the Superfund Boundary area as well as 98 other types of wells.

The last component of the conceptual model is to establish the contaminant properties. For the contaminant history, creosote was used from 1957-1985, PCP was used from 1960-1985, and some wood was treated with either chromated copper arsenate (CCA) or ammoniacal copper arsenate (ACA) between 1969 and 1973. The chemical character of the contaminants and the chemical interactions with the aquifer need to be found for the St. Regis Site.

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