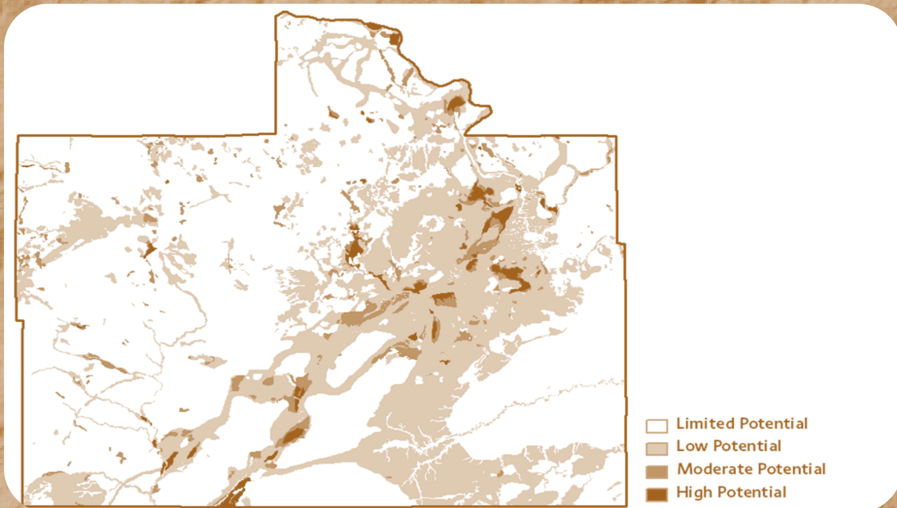
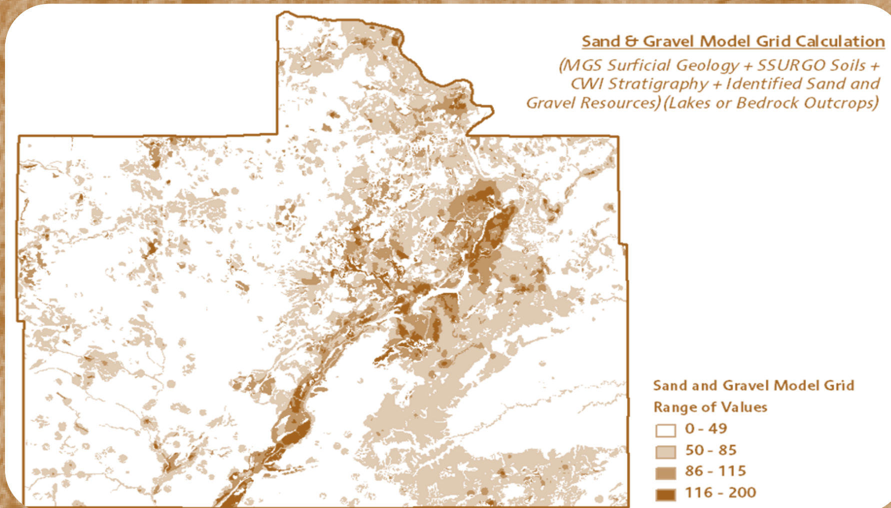
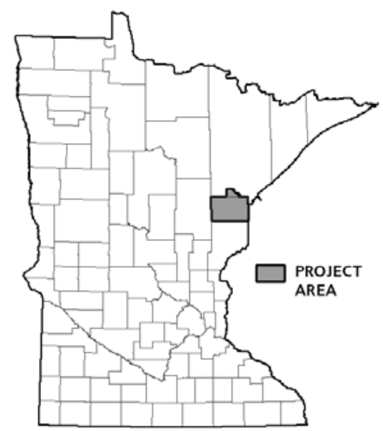




GIS MODELING OF SAND AND GRAVEL RESOURCE POTENTIAL

Development and Assessment of a GIS Based Model to Identify Sand and Gravel Resource Potential to Assist in the Acceleration of Aggregate Resource Mapping by the Minnesota Department of Natural Resources

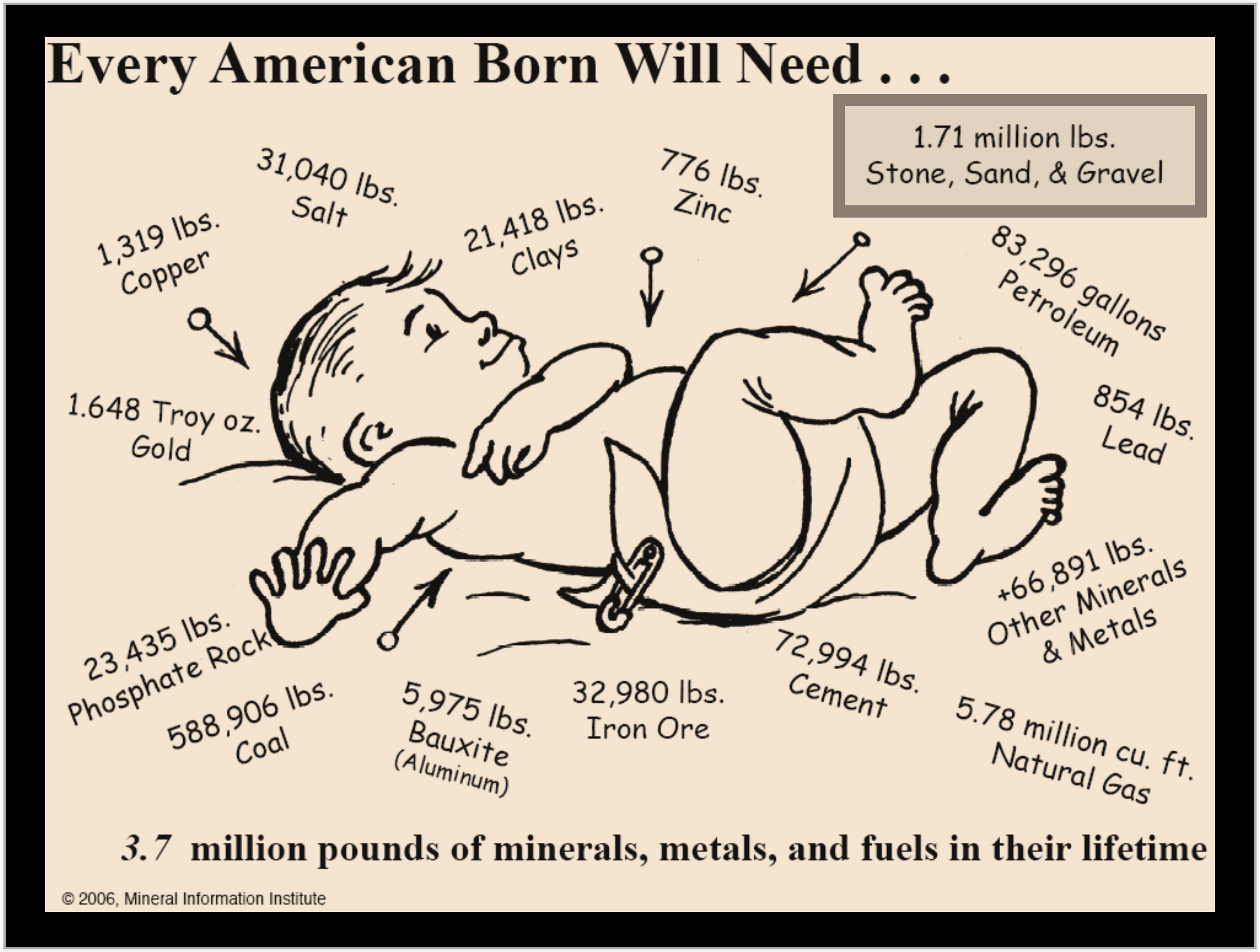
Kevin J Hanson – M.S. in GIS Candidate
Saint Mary's University of Minnesota
Department of Resource Analysis



Presentation Content

- The Basics on Sand and Gravel and DNR Aggregate Resource Mapping Program
- Development and Application of a GIS Model Using Existing Spatial Datasets to Model Sand and Gravel Resource Potential
- Applying a Cell-by-Cell Comparison Analysis of Completed Sand and Gravel Model to the Published Sand and Gravel Resource Potential Map in the Same Area (Carlton County, MN)

Background: Knowing What We Consume…



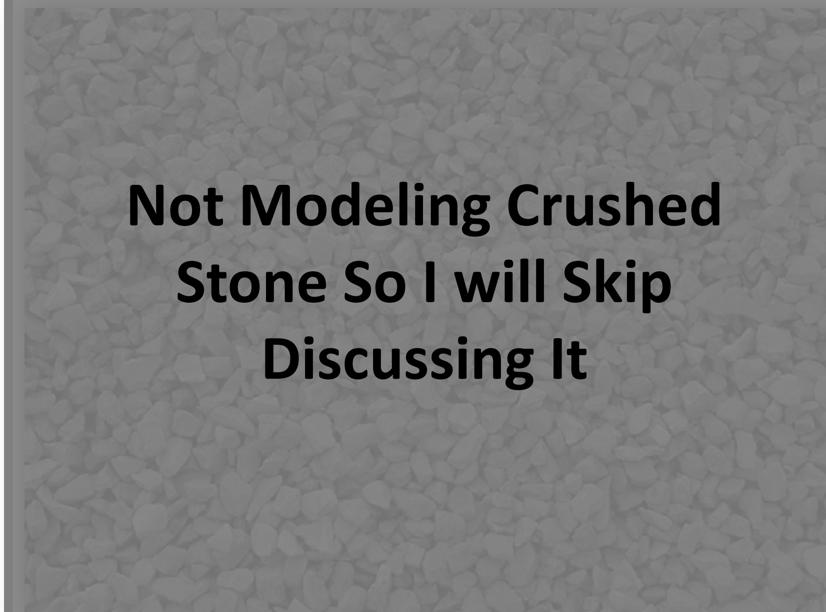
Source: Minerals Information Institute, 2006 - www.mii.org

What are Construction Aggregates?

Sand and Gravel

- ❑ Naturally occurring sediment (Glacial)
- ❑ Sorted and deposited from flowing water
- ❑ Mined from glacial outwash deposits
- ❑ Melting and retreating of glaciers from the last ice age.

Crushed Stone

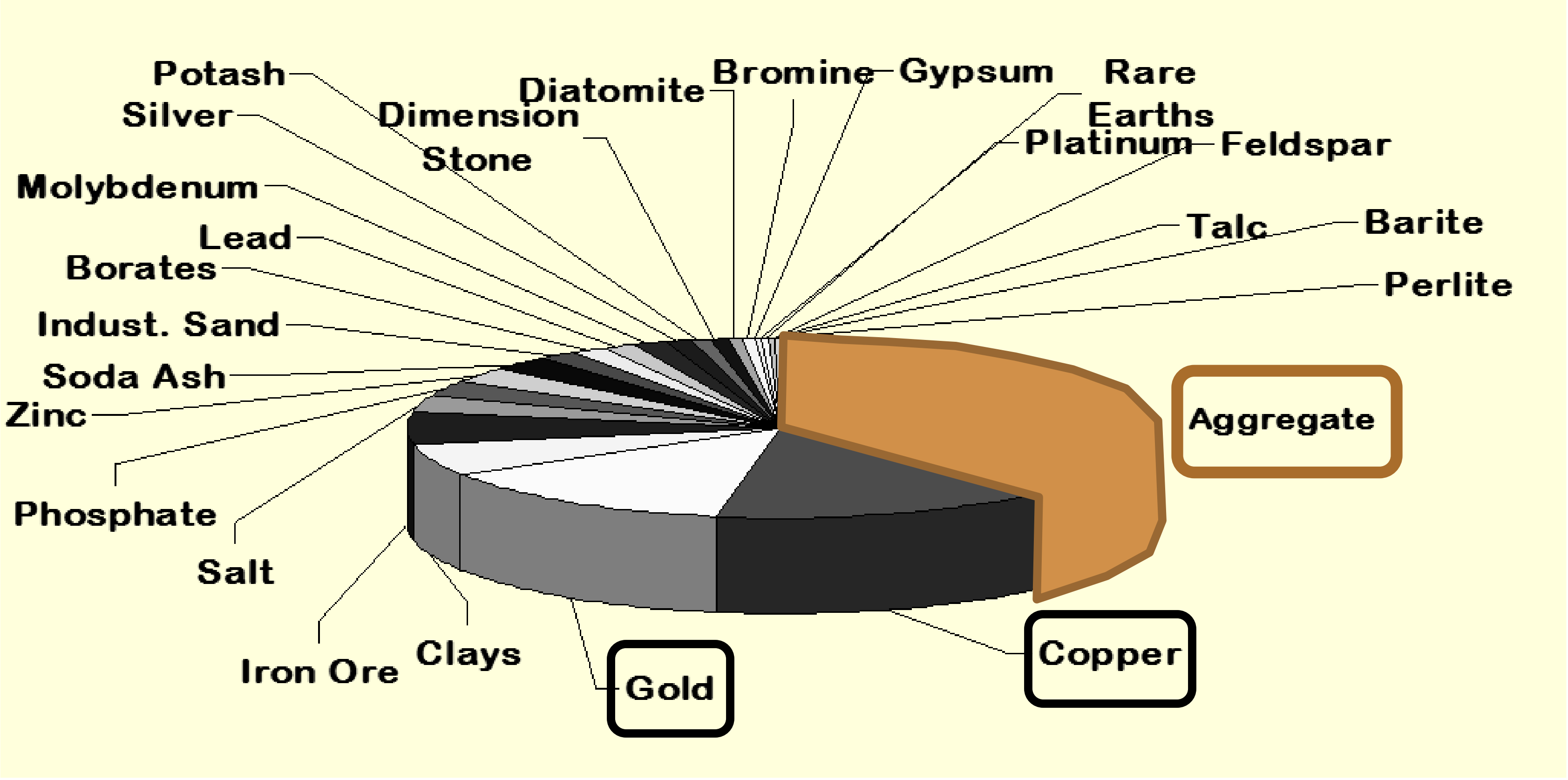


Not Modeling Crushed Stone So I will Skip Discussing It

- ❑ Product of mechanically breaking down bedrock like granites, quartzites, basalts, and limestones.
- ❑ Distribution determined by two factors; the type of bedrock and how close the bedrock is to the surface.

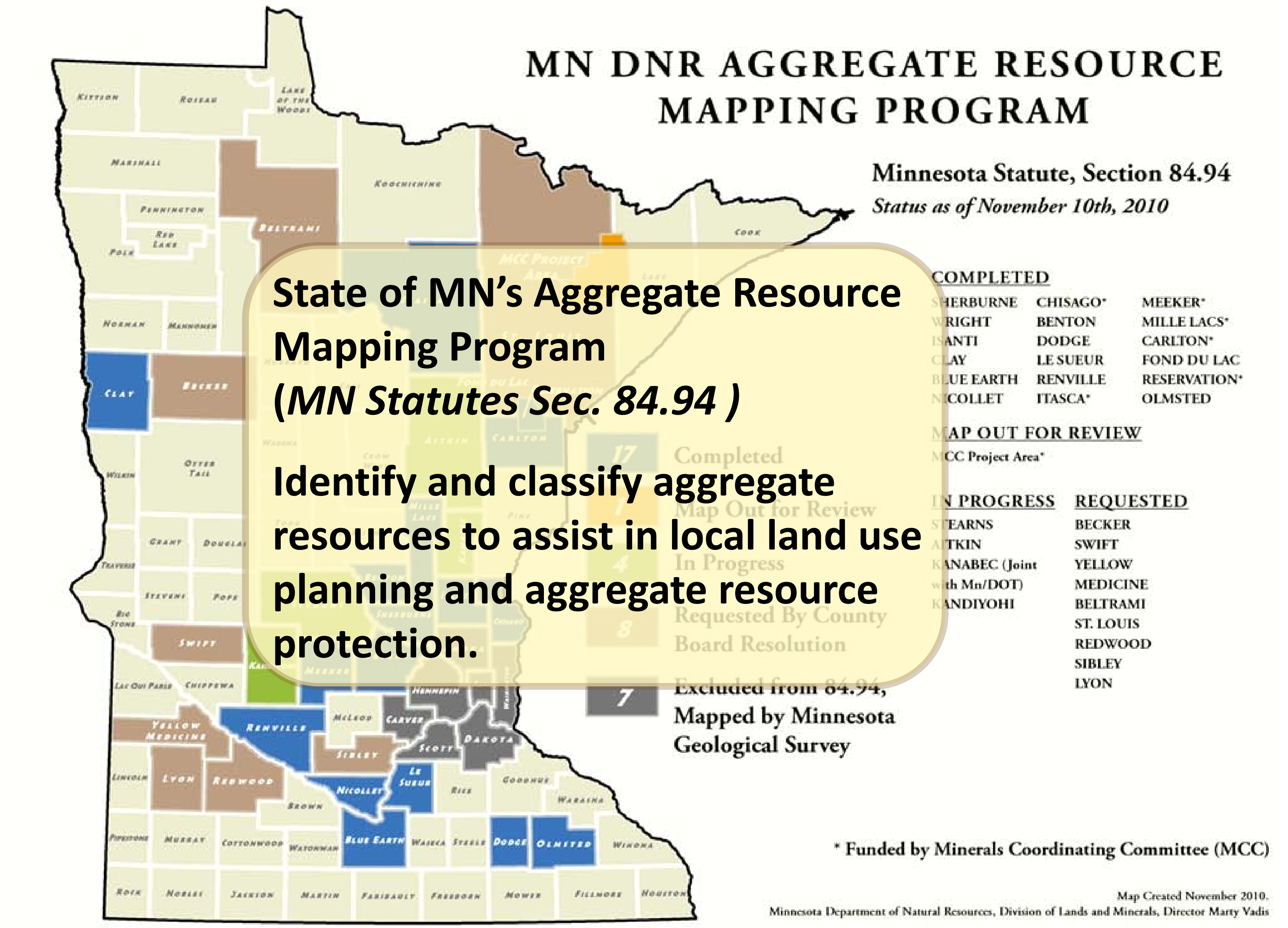
The Worldwide Construction Aggregate Industry

Largest Non-Fuel Minerals Industry in the World (Value and Volume)



Source: USGS – Miscellaneous Reports & Talks

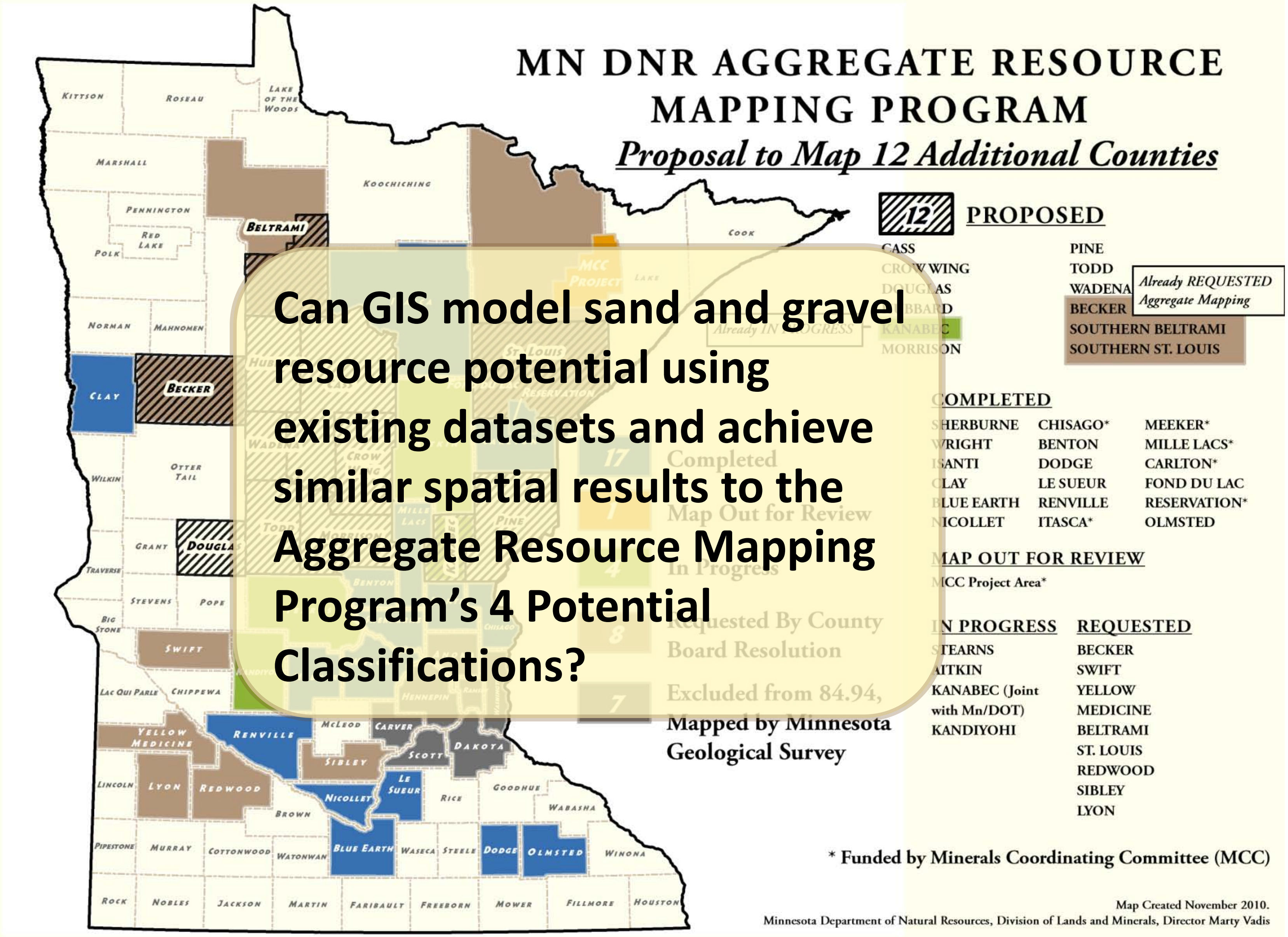
Current Aggregate Resource Mapping Program Status



State of MN's Aggregate Resource Mapping Program
(*MN Statutes Sec. 84.94*)

Identify and classify aggregate resources to assist in local land use planning and aggregate resource protection.

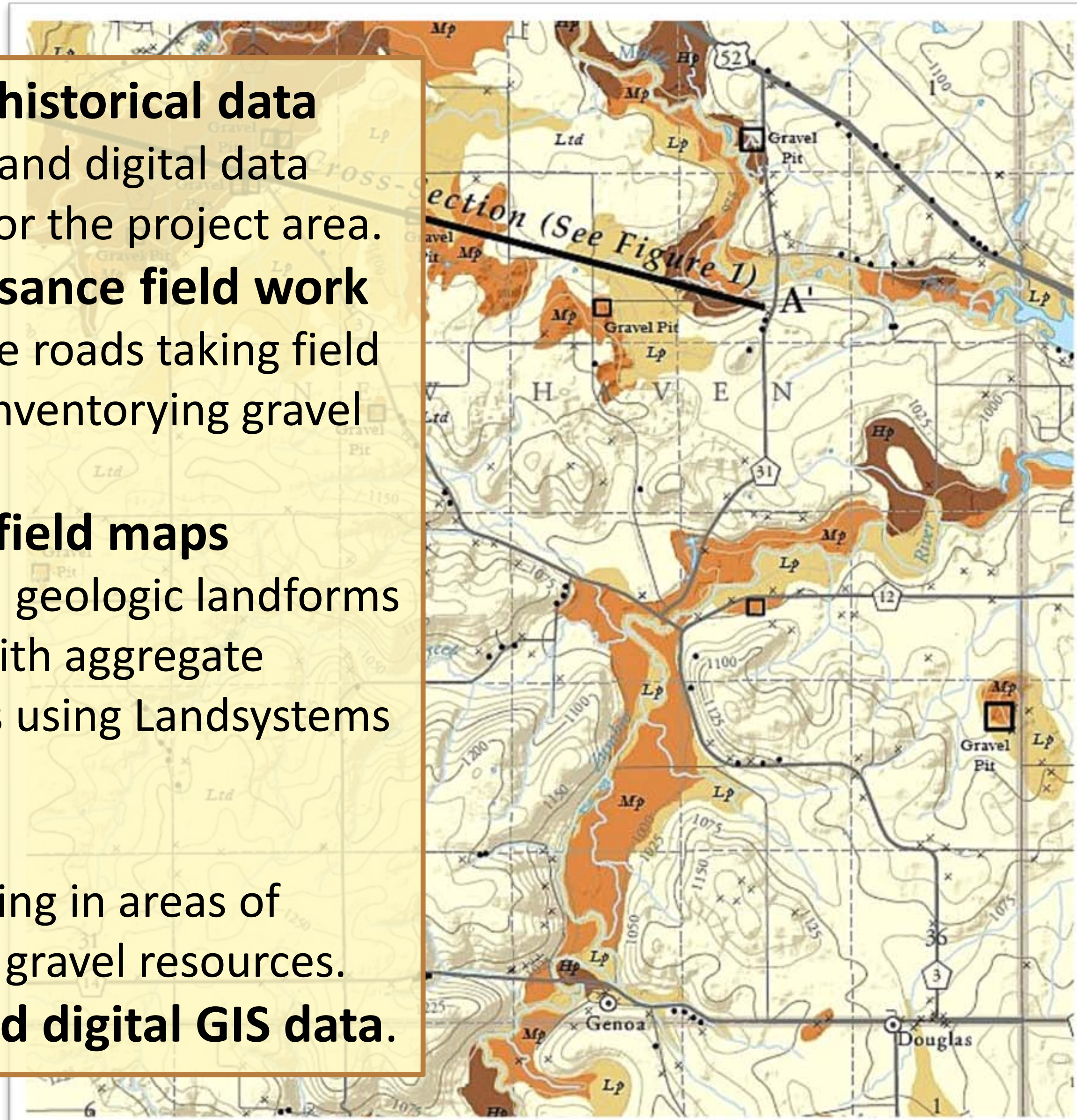
ACCELERATION….Proposal to Map 12- County Area



Can GIS model sand and gravel resource potential using existing datasets and achieve similar spatial results to the Aggregate Resource Mapping Program's 4 Potential Classifications?

MN DNR's Current Aggregate Mapping Methods (Simplified)

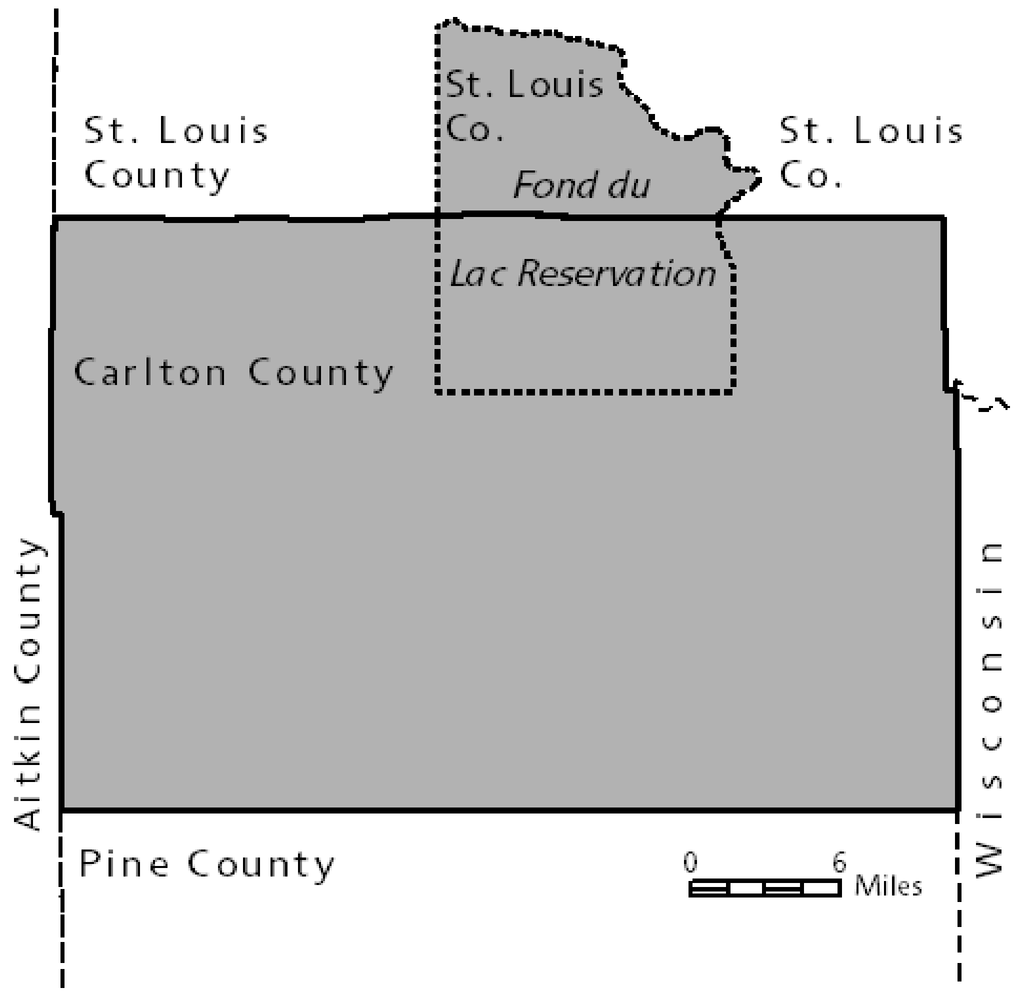
- ❑**Collect digital and historical data**
  - ▪Literature review and digital data (GIS) compilation for the project area.
- ❑**Conduct reconnaissance field work**
  - ▪Drive all accessible roads taking field observations and inventorying gravel pits.
- ❑**Start constructing field maps**
  - ▪Delineate surficial geologic landforms and label (point) with aggregate resource attributes using Landsystems Approach.
- ❑**Fieldwork- drilling**
  - ▪Confirmation drilling in areas of probable sand and gravel resources.
- ❑**Complete maps and digital GIS data**.

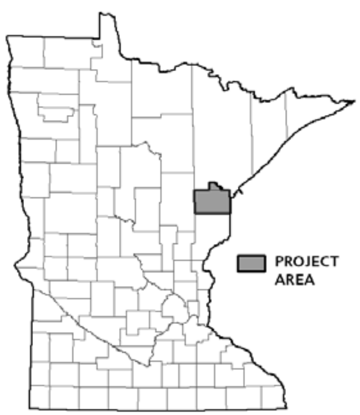


Developing the GIS Model for Sand and Gravel Resources

Selecting a project area to develop and apply the GIS model

- Carlton County, MN and Fond du Lac Reservation
- Mapped by Aggregate Mapping in 2009
- Use the published map to compare with the GIS model at a 10-meter raster cell level.





Development of GIS Model: GIS Vector Dataset Inputs

A total of 5 grids were developed and applied into the GIS model using existing vector datasets.

1. ***Surficial geology*** of Carlton County and Fond du Lac Reservation by Minnesota Geological Survey (MGS) (polygons)
2. ***SSURGO Soils*** of Carlton County, including, Southern St. Louis County (polygons)
3. ***County Well Index*** (CWI) stratigraphy data (points)
4. ***Gravel Pits, Sand Pits, and Prospects***; historic and current (points)
5. Merged Layer: ***MGS Bedrock Outcrops*** and ***Lakes*** greater than 5 acres (Polygons)

To create each grid **the vector datasets were compiled and reclassified using ArcGIS Desktop with the aid of an aggregate geologist (Friedrich, H.)**

Development of GIS Model: GIS Vector Dataset Inputs

Grid 1: Surficial Geology – From Vector to Raster

Surficial Geology maps delineate glacial landforms such as eskers, end moraines, and outwash channels. Some landforms have a higher probability to contain significant sand and gravel resources than others.

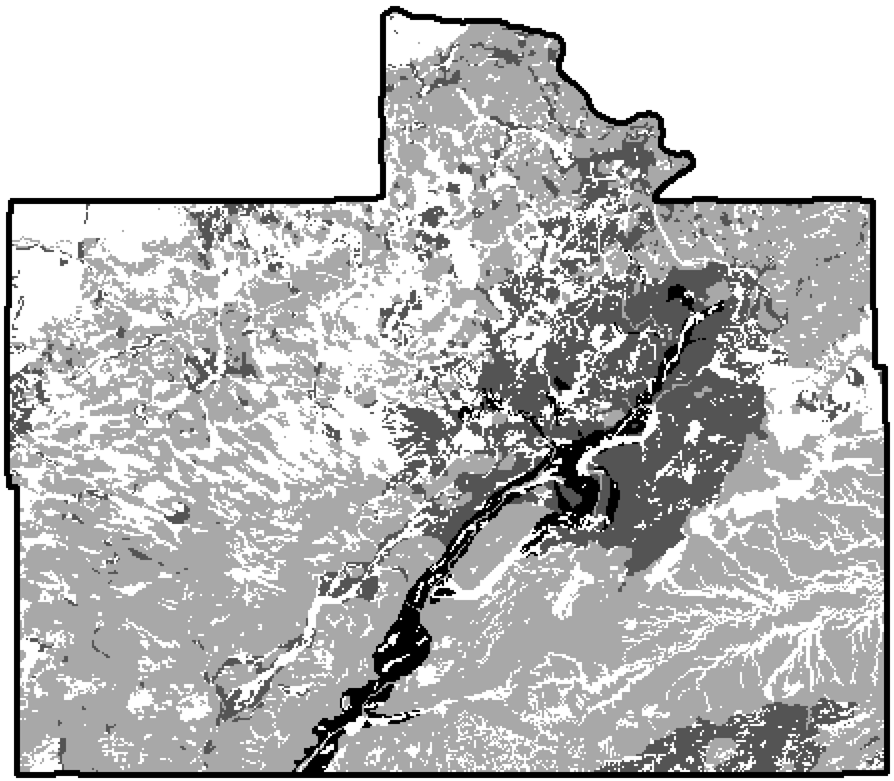
The Minnesota Geological Survey's surficial geology mapping units (Scale: 1:100,000) for model's project area were reclassified and ranked with a value between 0 and 10 by the aggregate geologist as the mapping units relate to sand and gravel resource potential.

Surficial Geology Reclassification as followed:

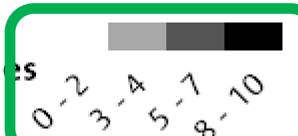
Limited Sand and Gravel Potential = 0-2
Low Sand and Gravel Potential = 3-4
Moderate Sand and Gravel Potential = 5-7
High Sand and Gravel Potential = 8-10

Development of GIS Model: GIS Vector Dataset Inputs

Grid 1: Surficial Geology – From Vector to Raster



Surficial Geology Grid:
Sand and Gravel Ranked Index Values
See table 1 for value descriptions



Map Label	General Description	Model Rank Index
water	water feature	0
Qhp	peat, other organic sediments	0
outcro	bedrock Outcrop	0
Qab	till deposits	1
Qat	till deposits	1
Qwf	off-shore silt and clay lake deposits	1
Qal	lacustrine deposits	3
Qct	till deposits	3
Qit	till deposits	3
Qkt	till deposits	3
Qll	lacustrine deposits	3
Qlt	till deposits	3
Qmt	till deposits	3
Qha	floodplain alluvium	4
Qmw	wave-washed till	4
Qul	sand, silt, and clay lake deposits	4
Qac	till, sand and gravel complex	5
Qcc	till, sand and gravel complex	5
Qd7	diversion channel deposits	5
Qmc	till, sand and gravel complex	5
Qws	near-shore and deltaic sand deposits	4
Qd2	diversion channel deposits	6
Qlo	outwash	6
Qmo	outwash	6
Qt	terrace deposits	6
Qwg	shoreline deposits	6
Qai	ice-contact deposits	7
Qao	outwash	7
Qci	ice-contact deposits	7
Qco	outwash	7
Qd3	diversion channel deposits	7
Qd6	diversion channel deposits	7
Qd8	diversion channel deposits	7
Qlc	till, sand and gravel complex	7
Qmi	ice-contact deposits	7
Qd4	diversion channel deposits	9
Qd5	diversion channel deposits	9
Qd9	diversion channel deposits	9
Qli	ice-contact deposits	10

Development of GIS Model: GIS Vector Dataset Inputs

Grid 2: SSURGO Soils– From Vector to Raster

SSURGO Soils Database provide the most detailed level of soils information for identifying near surface sediments as well as the parent material of the soils. The parent material in general is the surficial geology.

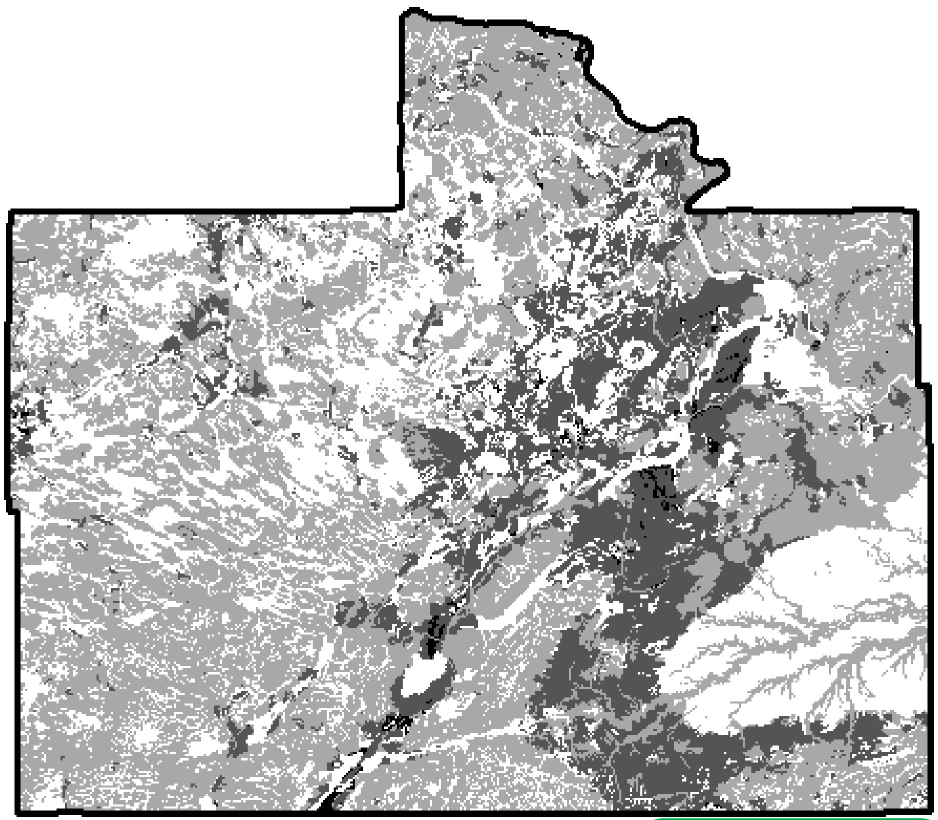
The SSURGO Soil mapping units for this model's were describing the parent group material & geomorphic description (1:20,000). The units were reclassified & ranked (0-10) by the aggregate geologist as the mapping units relate to sand & gravel resource potential.

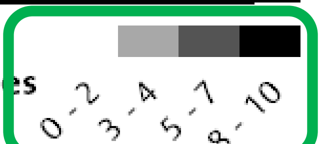
SSURGO Reclassification as followed:

Limited Sand and Gravel Potential = 0-2
Low Sand and Gravel Potential = 3-4
Moderate Sand and Gravel Potential = 5-7
High Sand and Gravel Potential = 8-10

Development of GIS Model: GIS Vector Dataset Inputs

Grid 2: SSURGO Soils– From Vector to Raster





SSURGO Soils Grid:
Sand and Gravel Ranked Index Values
See table 2 for value descriptions

Parent Group Material Unit	Model Rank Index
bedrock outcrops	0
herbaceous organic material	0
water features	0
clayey lacustrine deposits	1
clayey till	1
herbaceous organic material over loamy	1
mossy organic material	1
organic material	1
organic material over dense loamy till	1
organic material over glaciofluvial	1
organic material over loamy material over dense loamy till	1
organic material over loamy till	1
organic materials mixed with alluvium	2
alluvium	3
friable loamy till over dense loamy tilll	3
herbaceous organic material over sandy	3
loamy and or silty material over loamy till	3
loamy and or silty material over loamy till	3
loamy material over dense loamy till	3
loamy till	3
silty lacustrine deposits	3
silty lacustrine deposits over loamy till	3
silty material over loamy till	3
stratified lacustrine	3
eolian sands	4
glaciolacustrine deposits	4
sandy material over loamy till	4
sandy outwash over clayey lacustrine	4
sandy outwash over loamy till	4
loamy material over sandy outwash	5
sandy outwash	5
loamy drift over sandy and gravelly	6
loamy material over gravelly outwash	6
sandy and gravelly outwash	10

Development of GIS Model: GIS Vector Dataset Inputs

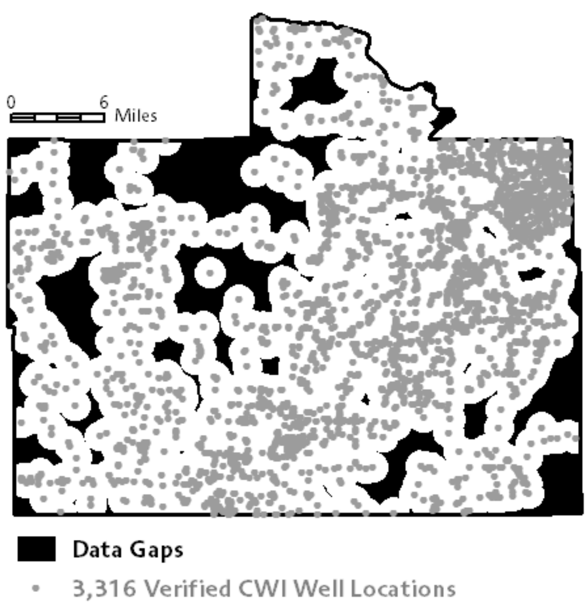
Grid 3: CWI Stratigraphy – From Vector to Raster

- **<u>CWI Statigraphy</u> table contains subsurface geologic information on water wells (primarily) drilled in Minnesota. Drill depths very from around 20 feet > 5000+ feet (exploration).**
- **Database for this project area consisted of 16,049 stratigraphy records.**
- **Each record represents a three dimensional space (subsurface elevation calculated) with a material attribute (clay, sand and gravel, etc.).**
- **There were 1,696 unique driller descriptions of the material. These driller descriptions were reclassified to 73 unique material descriptions.**
- **The 73 unique material descriptions were reclassified & ranked (0-10) by the aggregate geologist as the mapping units relate to sand & gravel resource potential**

Development of GIS Model: GIS Vector Dataset Inputs

Grid 3: CWI Stratigraphy – From Vector to Raster

- Table to right shows reclassified CWI stratigraphy materials and Model Rank Index
- Map at right shows the well locations and data gaps.
- NOTE these records resemble cylinders of varying thicknesses, materials, and depth from surface.
- This is just step 1 in a number of steps to model the CWI stratigraphy in the project area.



CWI Stratigraphy Material	*Model Rank Index*
bedrock	0
clay	0
drift or no record	0
kaolin	0
mud	0
peat or organics	0
sandy clay/loam	0
shale	0
silt	0
silt and boulders/clay/sand	0
top soil	0
clay and boulders/cobbles/gravel/sand/ silt	1
cobbles and clay/mud/silt	1
gravel and mud	1
loam	1
sand and clay/mud/silt	1
till	1
gravel and clay	2
gravel and organics	2
gravel and silt	2
gravel, clay, and rocks	2
sand	2
hardpan	3
gravel and hardpan	6
sand and rocks	6
sand, gravel, and silt	6
boulders and gravel	8
boulders with cobbles/sand	8
boulders with sand and gravel	8
cobbles and gravel	8
cobbles and sand/boulders	8
cobbles with sand and gravel	8
gravel and boulders/cobbles/rocks	8
sand and boulders	8
sand and cobbles	8
sand with gravel	8
gravel	10
gravel and sand	10
sand and gravel	10

Development of GIS Model: GIS Vector Dataset Inputs

Grid 3: CWI Stratigraphy – From Vector to Raster

RELATEID	DEPTH_TOP	DEPTH_BOT	DRLLR_DESC	LITH_PRIM	LITH_SEC	LITH_MNOR	STRAT_MAT	SMR	TSM	OSM	OSM_DESC	OSMR	NONSIGV	CWI_SFV
0000544817	63	121	CLAY	CLAY			Clay	0	58	63	51-100	0.25	0	0
0000493878	0	8	SILTY SAND	SAND	SILT		Sand and Silt	1	8	0	0-15	1	1	8
0000641564	38	51	BLACK SAND GRAVEL SMALL ROCKS	SAND	GRVL	COBL	Sand and Gravel	10	13	38	31-50	0.5	1	65
0000711282	0	22	SAND & GRAVEL	SAND	GRVL		Sand and Gravel	10	22	[illegible]	0-15	[illegible]	1	220
0000407949	0	20	SAND	SAND			Sand	2	20	0	0-15	1	1	40
0000567922	0	30	SAND & GRAVEL	SAND	GRVL		Sand and Gravel	[illegible]	[illegible]	0	[illegible]	1	1	300
0000604582	25	30	GRAVEL	GRVL			Gravel	10	5	25	16-30	0.75	1	37.5
0000177611	26	45	COARSE SAND	SAND			Sand	2	19	26	16-30	0.75	1	28.5
0000493888	63	64	SHALE	BDRK			Bedrock	0	1	63	51-100	0.25	0	0
0000626444	63	75	SAND SILT	SAND	SILT		Sand and Silt	1	[illegible]	63	51-100	0.25	0	0
0000114023	25	44	COARSE GRAVEL	GRVL			Gravel	10	19	25	16-30	0.75	1	142.5
0000565053	25	[illegible]	CLAY	[illegible]			Clay	[illegible]	[illegible]	25	[illegible]	[illegible]	1	0
0000664692	38	50	SAND GRAVEL	SAND	GRVL		Sand and Gravel	10	12	38	31-50	0.5	1	60
0000613397	38	54	ROCK & MUD SAND	COBL	MUDD	SAND	Cobbles and Mud	[illegible]	[illegible]	38	31-50	0.5	1	8
0000546191	39	60	SAND & COARSE GRAVEL	SAND	GRVL		Sand and Gravel	[illegible]	[illegible]	39	[illegible]	0.5	1	105
0000445589	38	80	SAND & CLAY	SAND	CLAY		Sandy Clay	0	42	38	31-50	0.5	1	0
0000664983	25	55	CLAY GRAVEL	CLAY	GRVL		Clay and Gravel	1	30	25	16-30	0.75	1	22.5
0000613353	62	75	COARSE SAND & GRAVEL	SAND	GRVL		Sand and Gravel	10	13	62	51-100	0.25	1	32.5

CWI Stratigraphy Final Value (CWI_SFV) = SMR * TSM * NONSIGV * OSMR

Next we summarize using ArcGIS attribute table options all the stratigraphy records on the relate id (many) and sum the CWI_SFV value for the entire well.

Now we have a new field of the total material value for each well. This is a one-to-one relationship allowing for easy 2D interpolation modeling

Field Headings Code Definitions

RELATEID - Unique id for CWI database. Represents one well drilled.
DEPTH_TOP - Depth from the beginning of the stratigraphic record to well surface
DEPTH_BOT - Depth to bottom of the stratigraphic record
DRILLR_DESC - Driller's description of the stratigraphic material
LITH_PRIM - MGS reclassification of driller's description for primary material
LITH_SEC - MGS reclassification of driller's description for secondary material
LITH_MINOR- MGS reclassification of driller's description for minor material

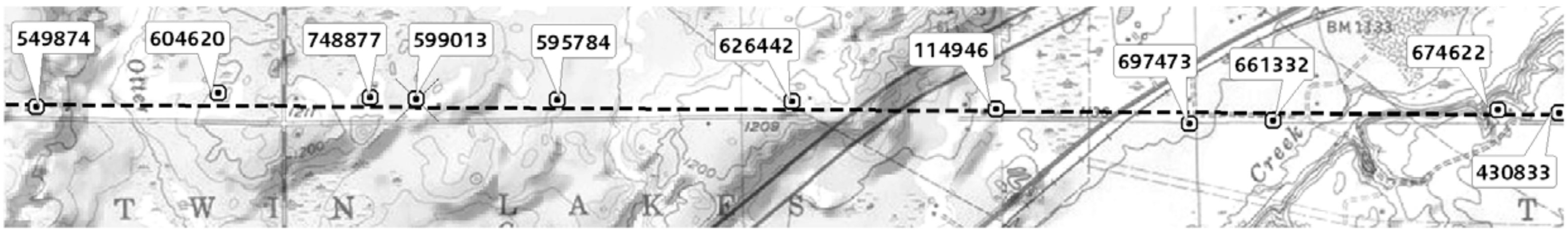
STRAT_MAT - Reclassification of MGS reclassifications of stratigraphic material(s)
SMR - Stratigraphic material rank of STRAT_MAT (0-10 scale).
TSM - Thickness of stratigraphic material (DEPTH_BOT - DEPTH_TOP)
OSM - Overburden of stratigraphic material (DEPTH_TOP)
OSM_DESC - Description of overburden into five classifications
OSMR - Numeric reclassification of the OSM_DESC field
NONSIGV - Non-significant value. '0' is populated for materials with a SMR <5 that have greater than 50 feet of OSM. '1' is populated for all other records.
CWI_SFV - CWI stratigraphy final value (=SMR*TSM*NONSIGV*OSMR)

Dark Field Headings Illustrate New Fields Created for this Study. (exp., STRAT_MAT, SMR)

Development of GIS Model: GIS Vector Dataset Inputs

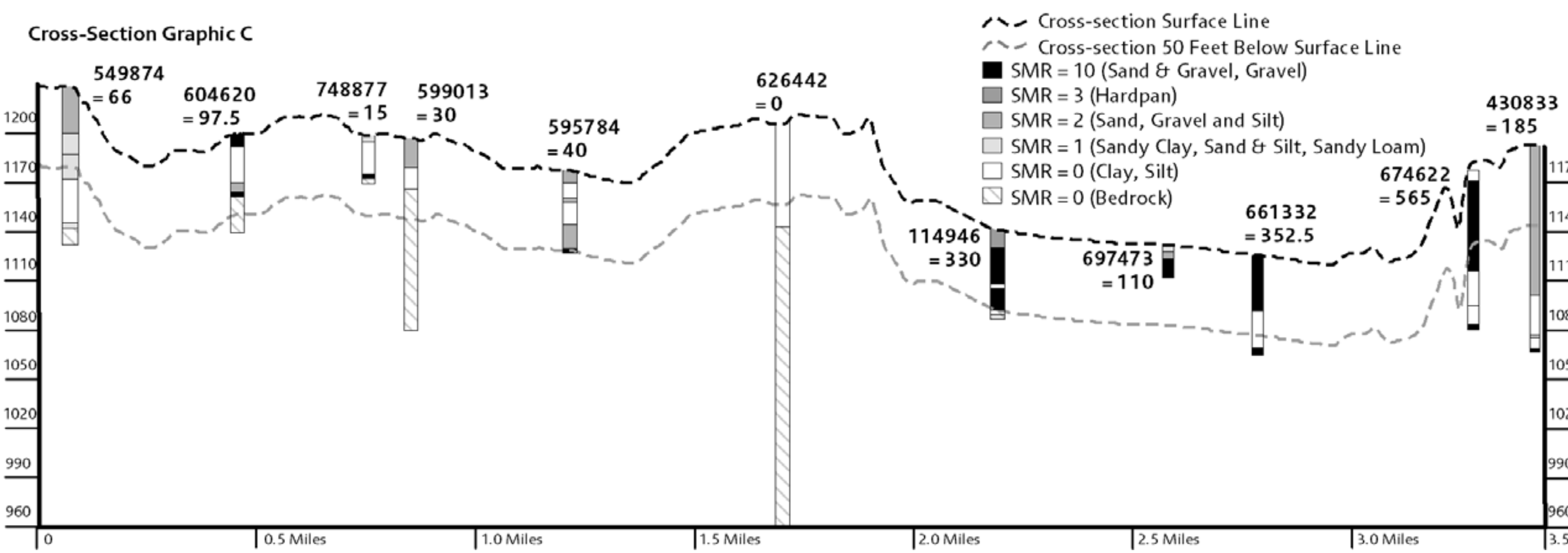
Grid 3: CWI Stratigraphy – From Vector to Raster

Cross-Section Graphic A



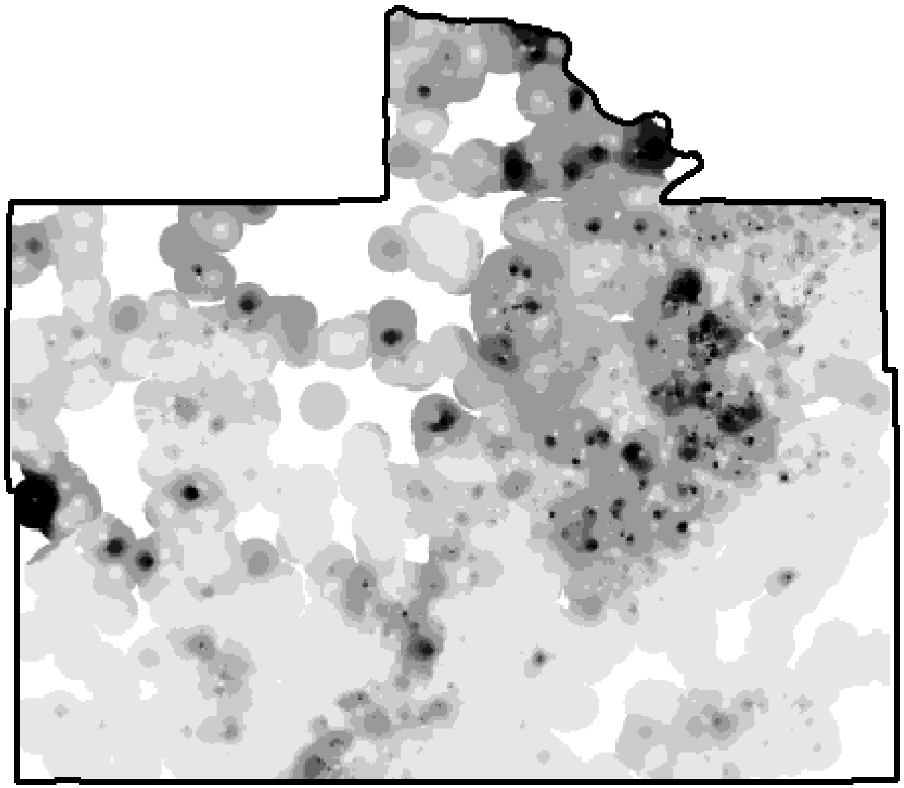
Cross-Section Graphic B

Cross-Section Graphic C

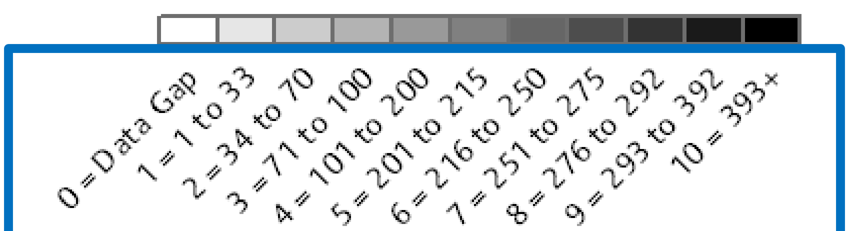


Development of GIS Model: GIS Vector Dataset Inputs

Grid 3: CWI Stratigraphy – From Vector to Raster



CWI Stratigraphy Grid: Interpolated Grid Values Ranked



Limited Potential = 0-2
Low Potential = 3-4
Moderate Potential = 5-7
High Potential = 8-10

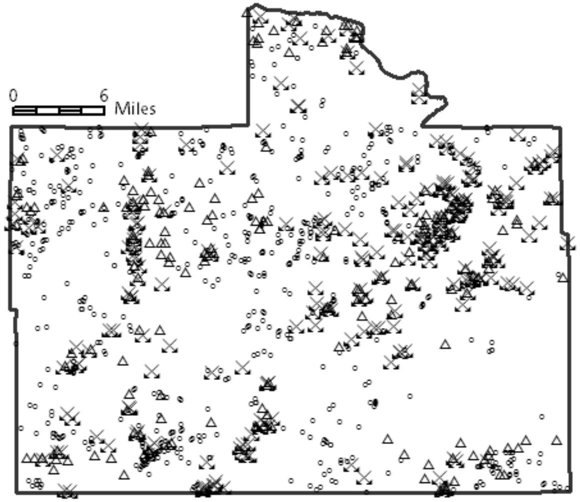
Intersect Analysis:
Mean SFV Value within Four Classifications of Completed Aggregate Resource Map

Limited Potential = 33
Low Potential = 85
Moderate Potential = 216
High Potential = 292

Development of GIS Model: GIS Vector Dataset Inputs

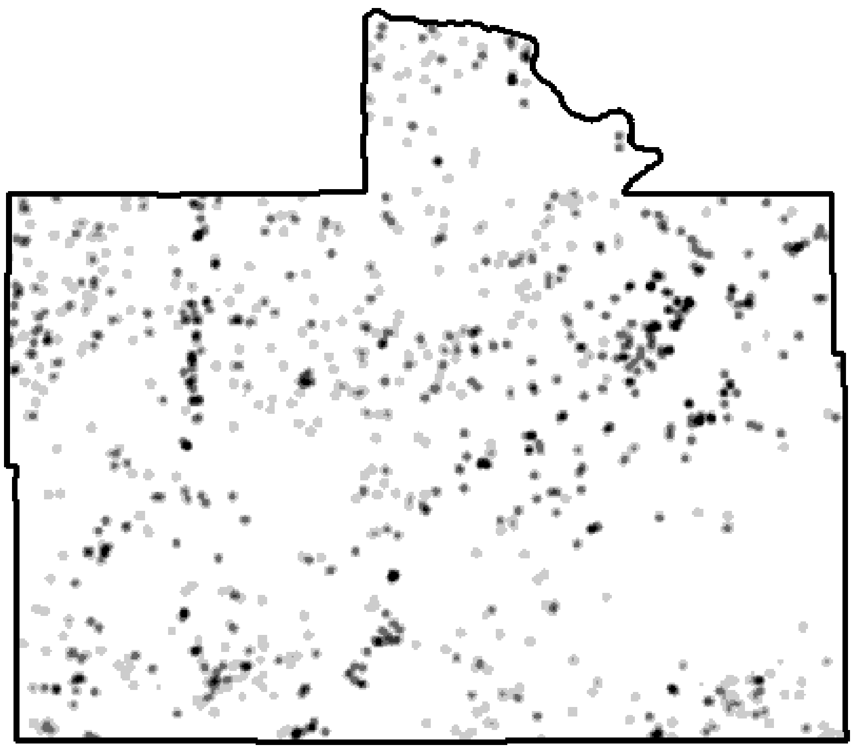
Grid 4: Identified Sand & Gravel Res. – From Vector to Raster

- ❑ <u>Identified sand and gravel source points</u> of current and historic gravel pits, sand pits, prospects, and aggregate related SSURGO spot features
- ❑ These features (points) were modeled into a 10-meter grid using the kernel density tool in ArcGIS. The sources of these range from USGS, Mn/DOT ASIS database, and SSURGO.
- ❑ Kernel Density calculates the density of a point in a circular neighborhood around the inputted features. With this type of density analysis the user can weight their inputted features.

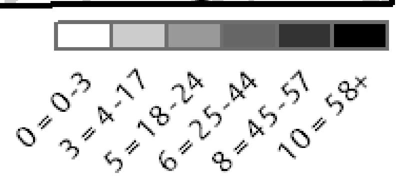


Development of GIS Model: GIS Vector Dataset Inputs

Grid 4: Identified Sand & Gravel Res. – From Vector to Raster



Kernel Density Analysis of Identified Sand Gravel Resources: Density Grid Values Ranked

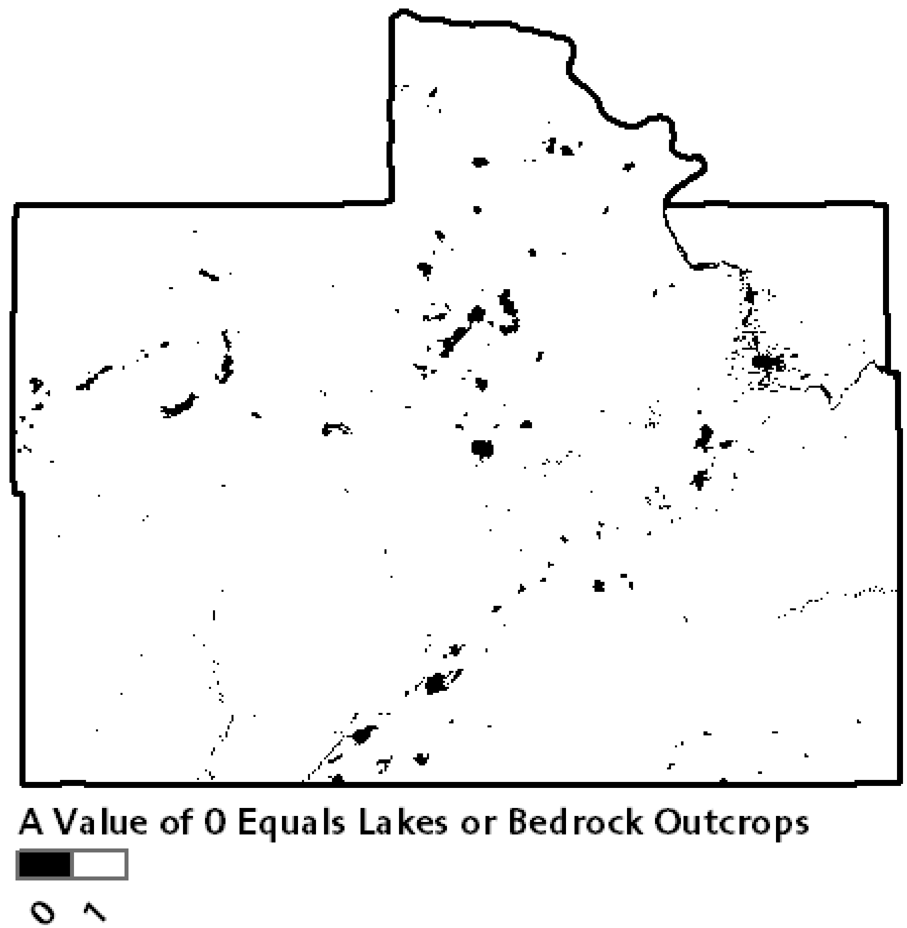


Material or Pit Type	*Source*	*Kernel Weight*
clay	MNDOT prospects	1
no gravel	MNDOT prospects	1
stony spot	SSURGO spot features	2
knoll of better drained soil	SSURGO spot features	4
sand	MNDOT prospects	4
sand pit	USGS	4
sandy	MNDOT prospects	4
sandy spot	SSURGO spot features	4
granular Class 3	MNDOT prospects	5
class 4	MNDOT prospects	6
terrace deposits	MNDOT prospects	7
not indicated	MNDOT prospects	7
class 5	MNDOT prospects	8
gravelly spot	SSURGO spot features	8
ice contact and esker deposits	MNDOT prospects	8
class 6	MNDOT prospects	9
gravel	MNDOT prospects	9
sand and gravel	MNDOT prospects	10
gravel pit	MNDOT, USGS, or SSURGO	10

Development of GIS Model: GIS Vector Dataset Inputs

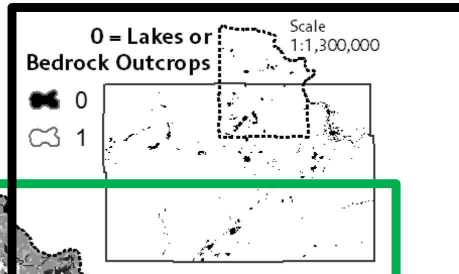
Grid 5: Bedrock Outcrops and Lakes

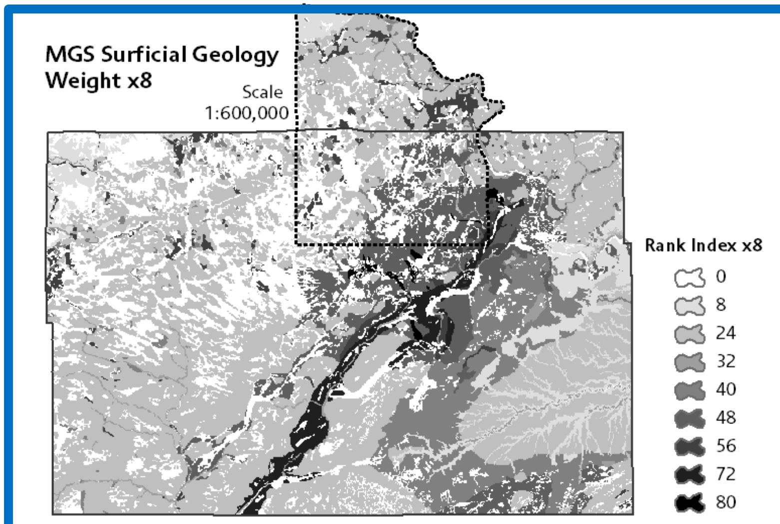
- ❑A merged vector layer of bedrock outcrops and lakes (>5 Acres) were both classified with a value of 0
- ❑There is no potential for sand and gravel resources where bedrock is outcropping and usually where there are large lakes.
- ❑These would be use to erase potential in the final model.

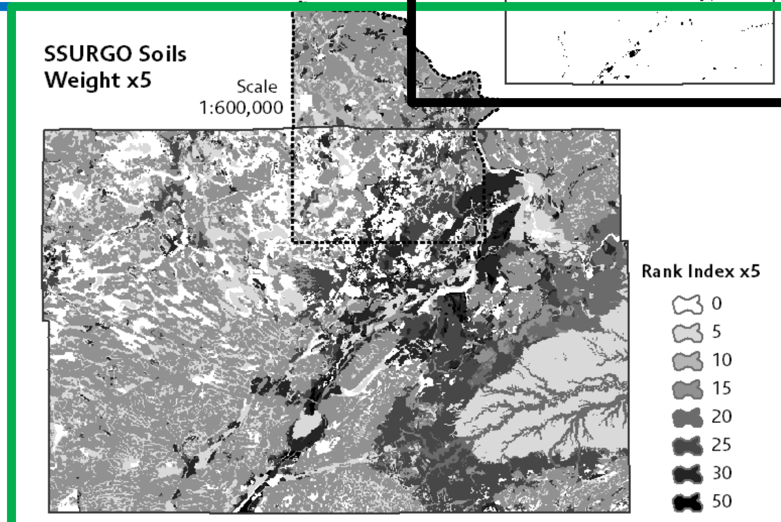


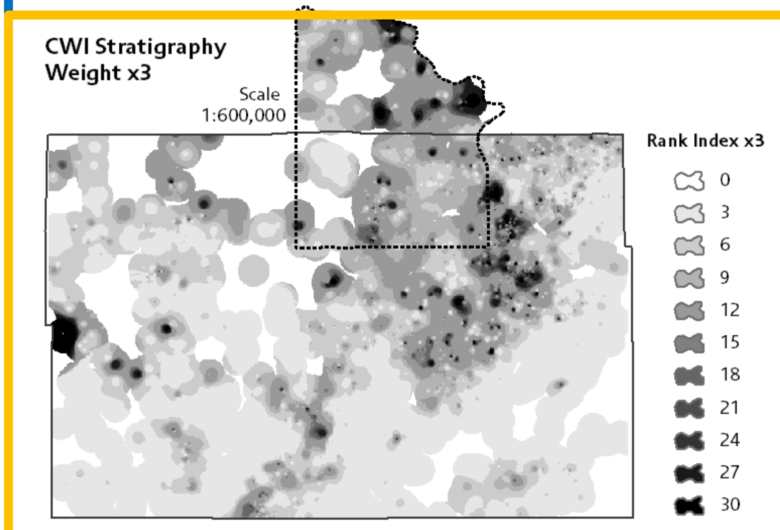
Development of GIS Model: Summing Weighted Grids

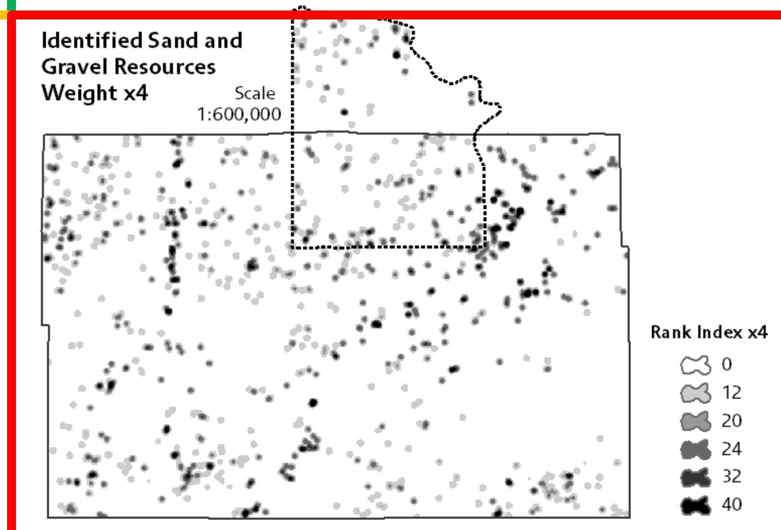
Final Grid = (Surficial Geology + SSURGO Soils + CWI Stratigraphy) + Identified Resources) (Lakes/Outcrops)



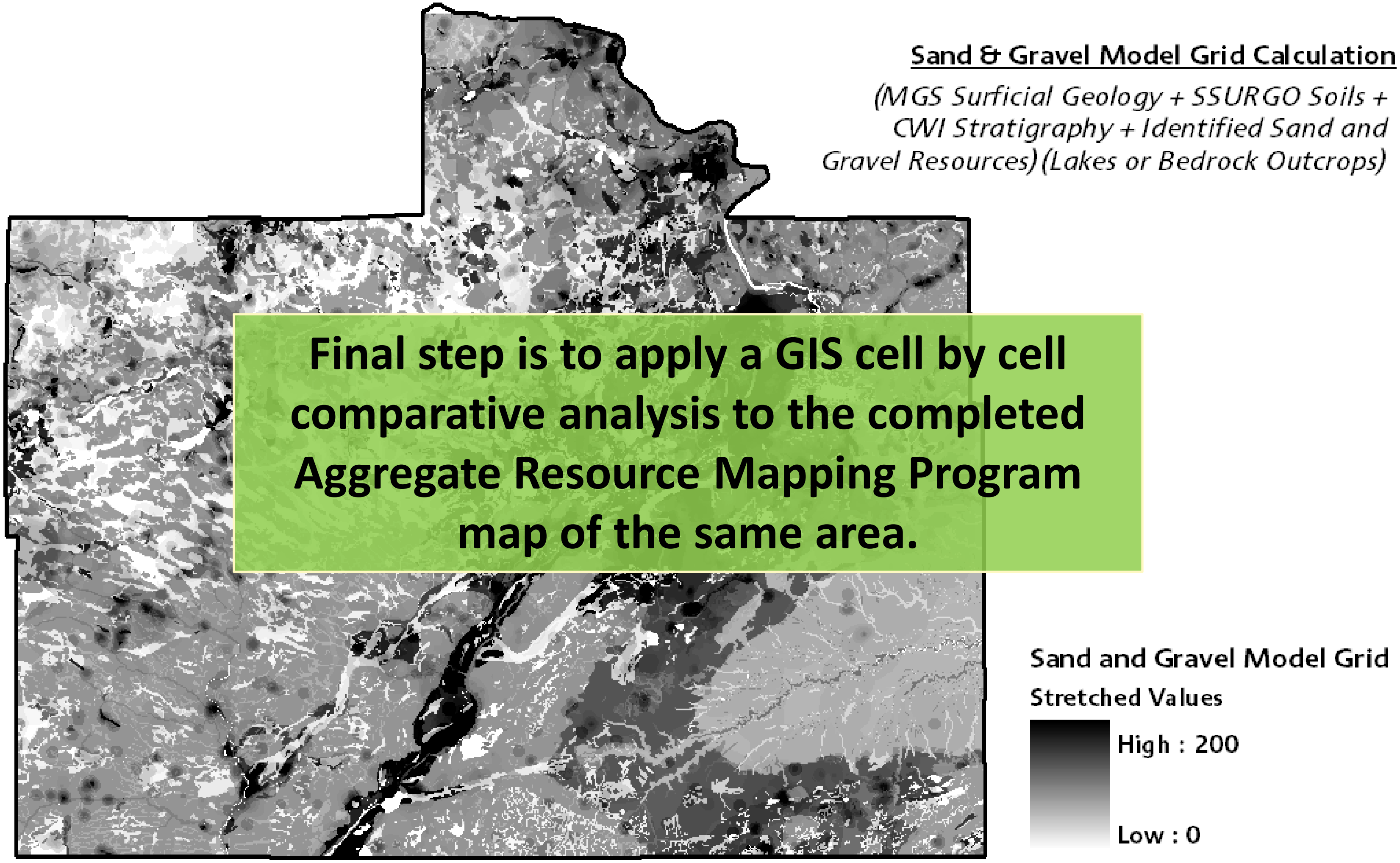






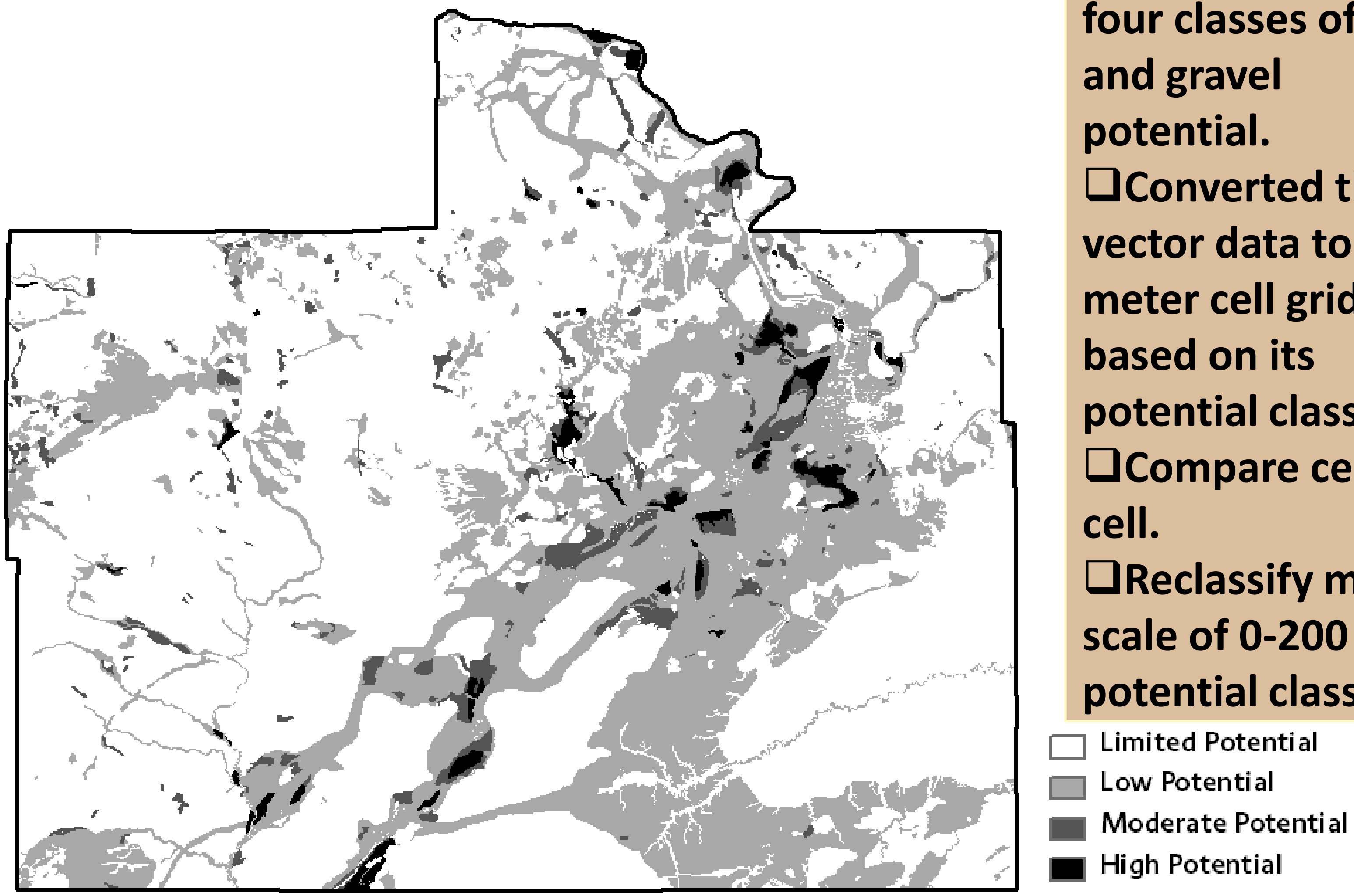


Development of GIS Model: Final Grid



Final step is to apply a GIS cell by cell comparative analysis to the completed Aggregate Resource Mapping Program map of the same area.

Development of GIS Model: GIS Grid Comparative Analysis



- Seen here is the published Aggregate Map in four classes of sand and gravel potential.
- Converted the vector data to a 10-meter cell grid based on its potential classes.
- Compare cell-to-cell.
- Reclassify model scale of 0-200 to potential classes

Development of GIS Model: GIS Grid Comparative Analysis

ARMP Potential Value	ARMP Potential Description	Final Model's Mean	Final Model's SDEV
Nonsignificant Potential			
1	Limited Potential	34	17.8
2	Low Potential	64	27.6
Significant Potential			
3	Moderate Potential	90	29.1
4	High Potential	115	27.8

- **In order to reclassify the modeled values (0-200) to the needed four classes the ArcGIS Zonal Statistics tool was applied.**
- **Zonal statistics was able to determine the mean, median, and Standard deviation for the final model cells that fell into one of the four potential classes from the completed map.**
- **This is show in the table to the left.**

Development of GIS Model: GIS Grid Comparative Analysis

ARMP Potential Value	ARMP Potential Description	Final Model's Mean	Final Model's SDEV
Nonsignificant Potential			
1	Limited Potential	34	17.8
2	Low Potential	64	27.6
Significant Potential			
3	Moderate Potential	90	29.1
4	High Potential	115	27.8

Final Sand and Gravel Model Reclassed Value	Final Sand and Gravel Model Range of Values	Percent of Total Area
1	0-49	63.17%
2	50-85	27.23%
3	86-115	7.83%
4	116-200	1.77%

- **The range of values selected for reclassification can be seen in the table at the bottom left.**
- **Zonal statistics was applied on the new reclassed modeled grid (values 1-4)**
- **The results are shown in the table below.**

ARMP Potential Value	ARMP Potential Description	Final Model's Reclassed (1 - 4) Mean	Final Model's Reclassed SDEV
Nonsignificant Potential			
1	Limited Potential	1.15	0.37
2	Low Potential	1.92	0.72
Significant Potential			
3	Moderate Potential	2.68	0.88
4	High Potential	3.35	0.78

Development of GIS Model: GIS Grid Comparative Analysis

Final Sand and Gravel Model Reclassed Value	Final Sand and Gravel Model Range of Values	Percent of Total Area
1	0-49	63.17%
2	50-85	27.23%
3	86-115	7.83%
4	116-200	1.77%

ARMP Potential Value	ARMP Potential Description	Percent of Total Area
Nonsignificant Potential		95.57%
1	Limited Potential	67.01%
2	Low Potential	28.56%
Significant Potential		4.43%
3	Moderate Potential	3.07%
4	High Potential	1.36%

- **Note the field percent total area and visually compare it to the published aggregate data in the table below. See similarities?**
- **It is very important to note how much area is taken up in the project area by nonsignificant potential (limited and low).**
- **90-95%**

Development of GIS Model: GIS Grid Comparative Analysis

ARMP Potential Value	ARMP Potential Description	ARMP Potential Percent of Total Area	Final Model's Reclassed (1-4)	Model Value Equal to ARMP Value	Model Value Not Equal to ARMP Value
Nonsignificant Potential					
1	Limited Potential	67.0%	1 (0-49)	86%	14%
2	Low Potential	28.5%	2 (50-85)	54%	46%
Significant Potential					
3	Moderate Potential	3.0%	3 (86-115)	39%	61%
4	High Potential	1.5%	4 (116-200)	54%	46%

*In total **75%** of the final model grid cell values equaled the same ARMP cells when analyzing by the four classes.*

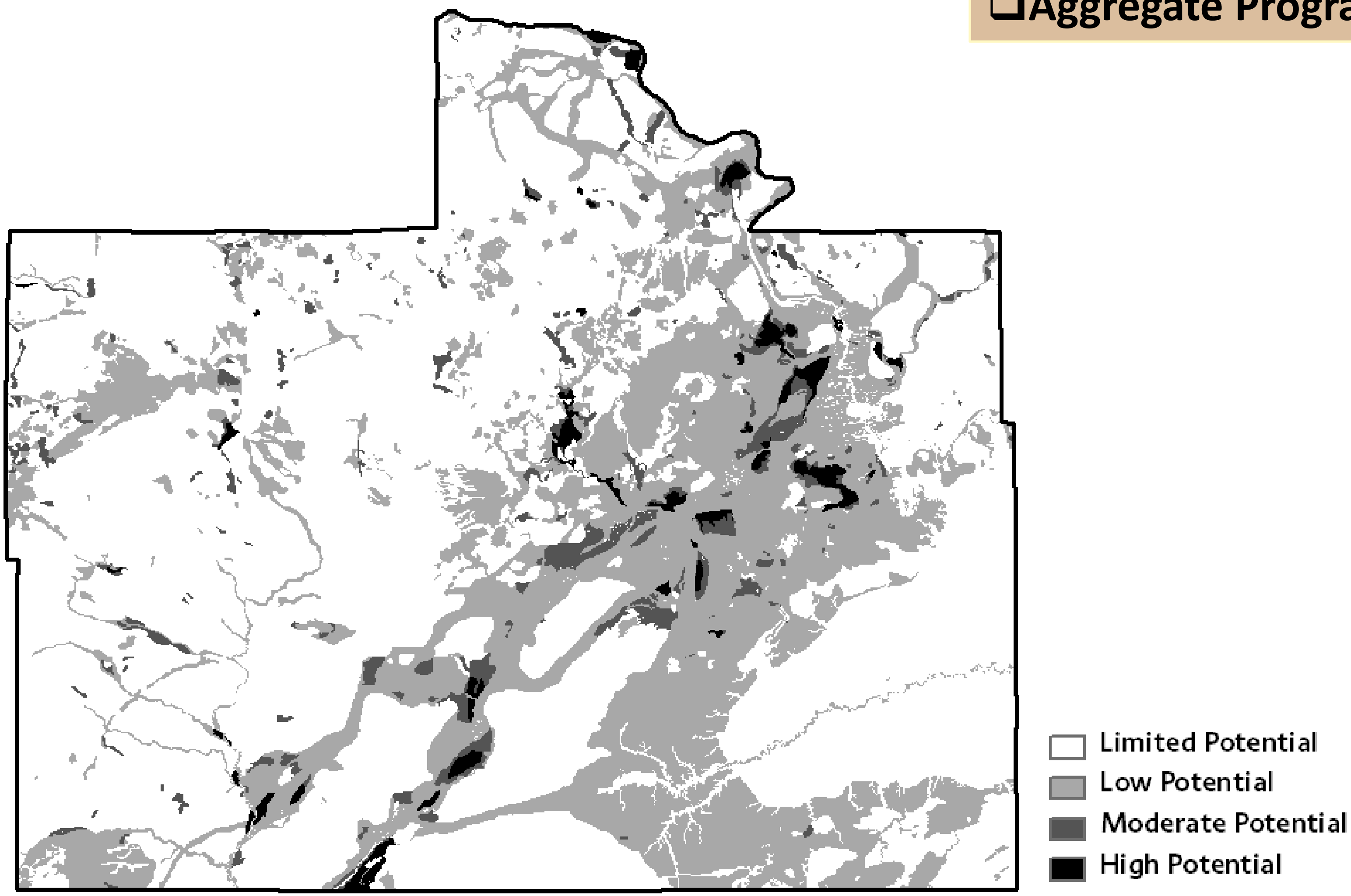
ARMP Potential Value	ARMP Potential Description	ARMP Potential Percent of Total Area	Final Model's Reclassed (1-2)	Model Value Equal to ARMP Value	Model Value Not Equal to ARMP Value
1 (1 or 2)	Nonsignificant Potential	95.50%	1 (0-85)	94%	6%
2 (3 or 4)	Significant Potential	4.50%	2 (86-200)	66%	34%

*In total **93%** of the final model grid cell values equaled the same ARMP cells when reclassifying the 4 values down to two classes (significant and nonsignificant)*

- **In order to do a cell-by-cell comparison of the model vs. the published map, ArcGIS raster calculator was applied**
- **The calculator was able to deliver a count of where the final model cell was equal to the aggregate mapping cell at the same location.**
- **Two tables were created to display the results**

Development of GIS Model: Finally the visual comparison…

- Aggregate Program

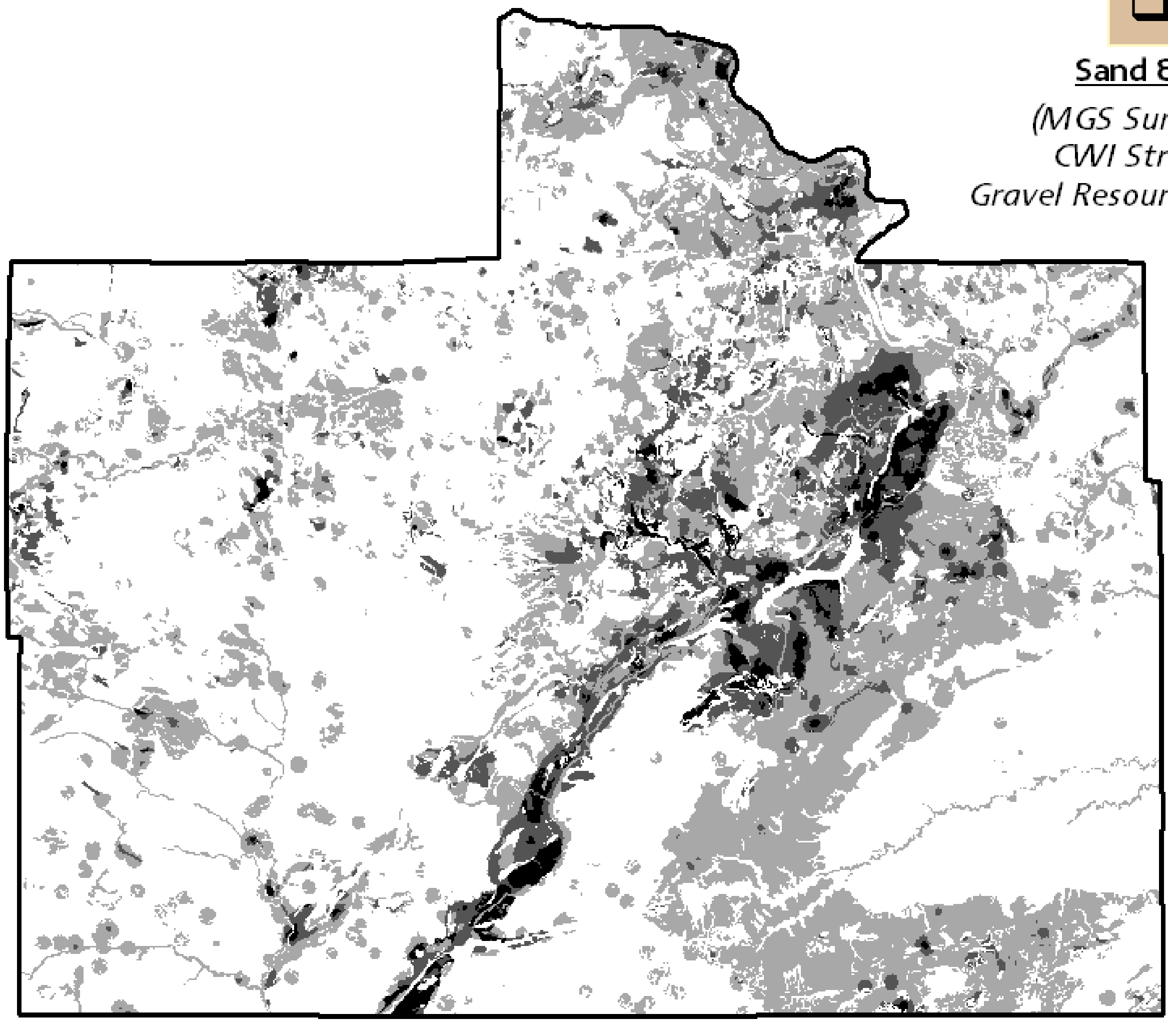


Development of GIS Model: Finally the visual comparison…

❑Sand & Gravel Model

<u>Sand & Gravel Model Grid Calculation</u>

(MGS Surficial Geology + SSURGO Soils + CWI Stratigraphy + Identified Sand and Gravel Resources) (Lakes or Bedrock Outcrops)



Sand and Gravel Model Grid

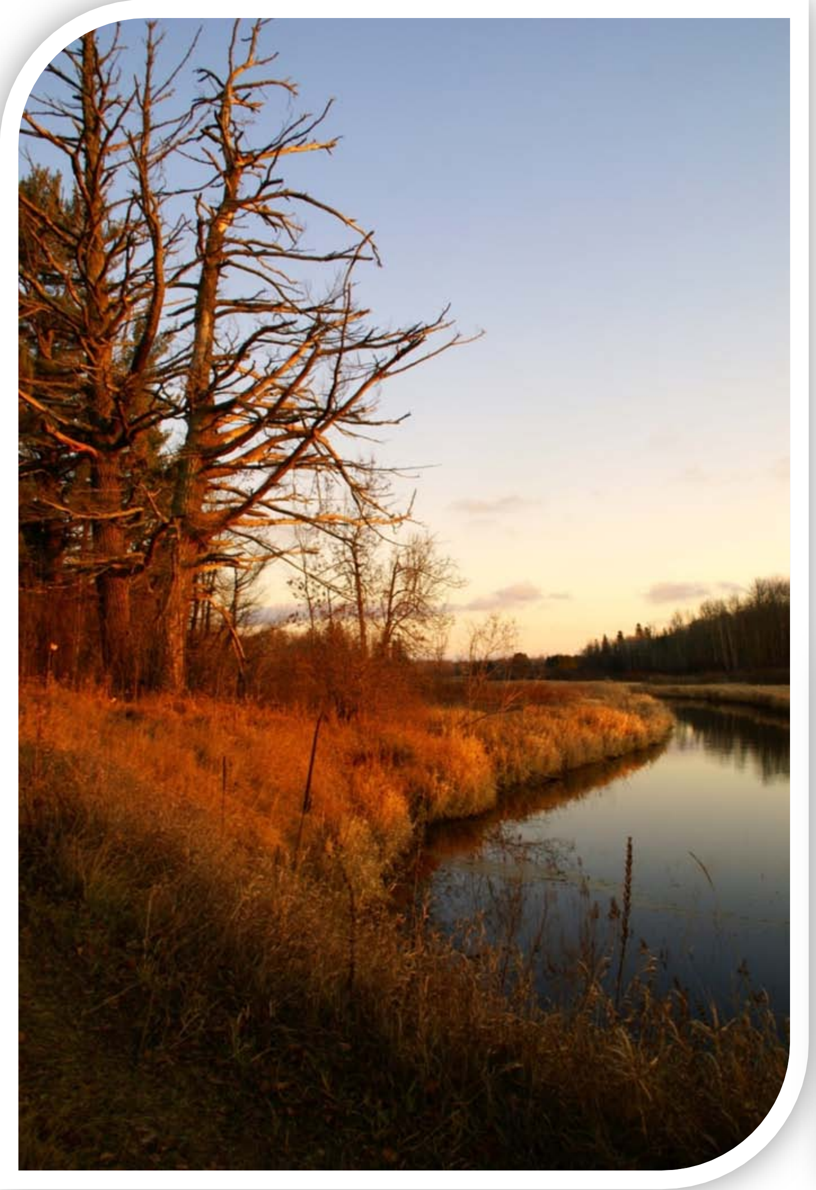
Range of Values

- 0 - 49
- 50 - 85
- 86 - 115
- 116 - 200

Development of GIS Model: Was it worth it?

- ❑The model did well, however it can not replace the level of detail in digital data creation (attributes), confirmation drilling, and the geologist expert interpretation when digitizing landforms using air photos.
- ❑The model can however, and has been, a tool to apply before the geologist begins a new project.
- ❑In a sense the model is doing a lot of the interpretive geologic leg work prior to beginning a project.
- ❑The model can be useful in the field and during drilling to focus the geologist field work and time to significant sand and gravel rich areas.
- ❑Lastly the project geologist has a modeled grid to assist with or confirm their interpretations when delineating sand and gravel potential.

Development of GIS Model: Thank You



- **QUESTIONS**
- **Thanks to the SMUMN GIS Staff for all their help**
- **Thanks to Hannah Friedrich, the aggregate geologist, who help me rank and weight the modeled grids.**