A GIS-Based Suitability Model for Frac Sand Mining in West-Central Wisconsin

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ABSTRACT

Frac sand mining is an important new industry in western Wisconsin. The round, strong, quartz grains are used in the "fracking" process to enhance oil and natural gas extraction. Frac sand companies are seeking to mine the Jordan and Wonewoc formations in Wisconsin.

This project utilizes geologic and geographic data to guide the siting of potential frac sand mines in Trempealeau and Buffalo counties, Wisconsin. Criteria used to evaluate potential areas for sand mining include: distance from major roads and railroads, overburden thickness, water table depth, sand unit thickness and elevations, and pre-existing mine site locations. Data was collected from the Buffalo and Trempealeau Land Conservation offices and the WDNR.

The data was analyzed using ArcMap software. ArcGIS tools were used to interpolate the collected data and produce a heat map/index model of potential frac sand mine site locations. The "hottest" locations on the map are the most attractive for a frac sand exploration.

INTRODUCTION

Frac sand is used in the hydraulic fracturing (fracking) process to enhance oil and gas recovery in the petroleum industry (Fig. 1). Recent technological advances have made fracking easier, so the demand for high-quality sand has increased dramatically over the last few years. As a result, more frac sand mines have been proposed and opened in west-central Wisconsin because of the valuable, round, strong sand grains present in the region (Fig. 2, WDNR, 2012a). This type of sand is found in the Jordan, Wonewoc, and St. Peter formations (Fig. 3).

The study area, Trempealeau and Buffalo counties, is at the center of the frac sand exploration boom (Fig. 4). The Wonewoc and Jordan formations are present in the area. These units are Cambrian, fine- to coarse-grained quartz arenites (Mahoney et al., 1997). The purpose of this project was to use Geographic Information Systems (GIS) software and geological data to identify suitable areas for sand exploration in Trempealeau and Buffalo counties.

Figure 1. Fracking method used to extract natural gas. Sand, water, and chemicals are injected under pressure into shale to open and maintain fissures in the rock. Oil or natural gas then flows more easily through the fissures into the well, which enhances oil/gas recovery. From http://www.bbc.co.uk/news/science-environment-17726538.

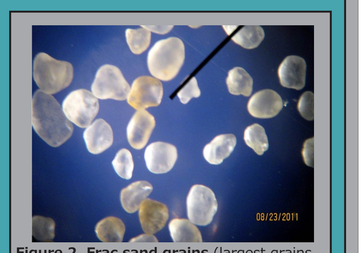


Figure 2. Frac sand grains (largest grains are 0.8 mm in diameter). Mining companies typically want sandstone containing strong, well rounded quartz grains between 0.2 and 0.8 mm diameter. From Kent M. Syverson.

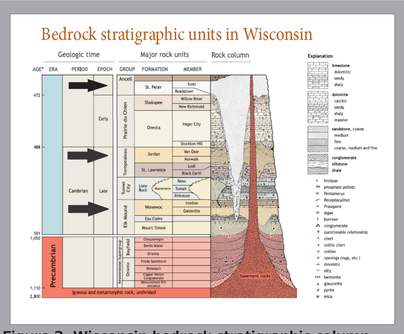


Figure 3. Wisconsin bedrock stratigraphic column. Displays geologic units in Wisconsin from Precambrian to Mid-Ordovician in age (modified from WGNHS, 2011). Arrows point to the Wonewoc, Jordan, and St. Peter formations, the major frac sand units in Wisconsin.

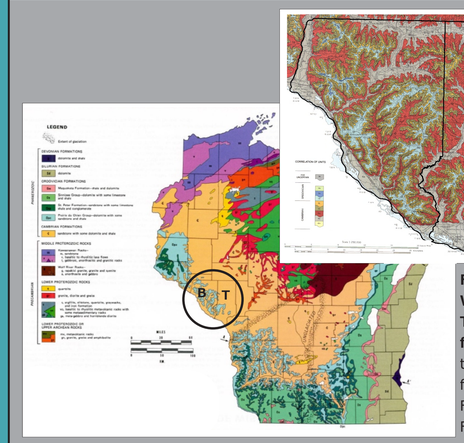


Figure 4. Bedrock geology of Wisconsin (B = Buffalo and T = Trempealeau counties, modified from UW-Extension, 1995). On the enlarged geologic map modified from Brown (1988), Wonewoc Formation is red and the Jordan Formation is gold.

METHODS

-Data were acquired from WDNR and county land conservation offices. Domestic well logs (records of the sediment and rock encountered during drilling for water), major roads, railroads, depth to water table, and county boundaries were obtained from WDNR (2012b,c). Current and proposed mine locations in Buffalo and Trempealeau counties were determined from NR-135 reclamation plans filed in county land conservation offices.
-Linear distances from major roads and railroads were calculated (Fig. 7, heat map, see Appendix).
-Well logs were geocoded (digitally located on a map) in the study area, and ~1900 out of ~5000 wells were offset from the road to the most probable well location (Fig. 5).
-Well log data were used to determine stratigraphic-unit thicknesses in Buffalo and Trempealeau counties.
-**Rasters** with the thickness of each geologic unit and the overburden were developed using **spatial interpolation** (see Appendix) in the Geostatistical Analyst Extension (Figs. 8, 9).
-Each criterion (raster) was reclassed and combined into a suitability index. For example, more overburden is considered a "bad" criterion and therefore was assigned a lower value, less overburden is considered a "good" criterion and was assigned a higher value.
-A raster calculation was used to develop **index rasters** for each county of the best potential frac sand exploration targets (Figs. 6, 7, 8, 9, 10, 11).

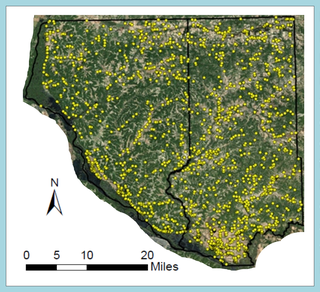


Figure 5. Geocoded well log locations (n=1877). Each well was manually moved to the nearest likely address. Each well includes a description of material encountered during drilling; these data were used to interpret the geologic units in each well. This geologic data and the well point locations were later used for spatial interpolation.

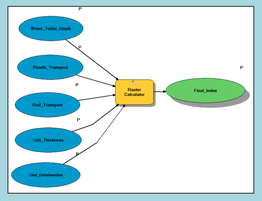
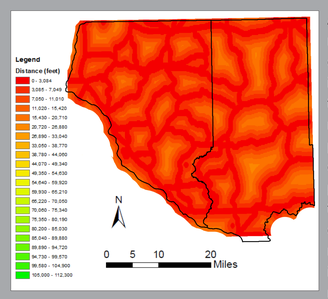


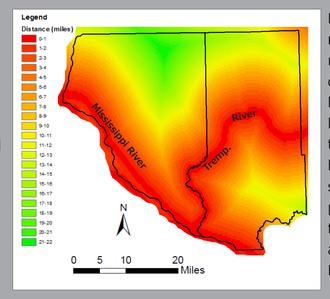
Figure 6. Data flow model. Model displaying tools and datasets used to create the Jordan and Wonewoc formation index rasters. Blue ovals represent input data, the green oval represents the resulting raster after raster calculator tool (yellow) has been run.

RESULTS

Figure 7. Transportation

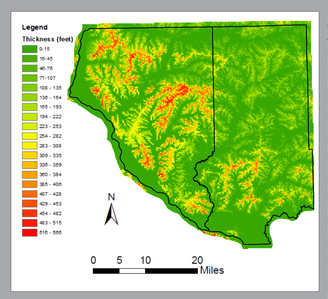


A. Proximity to major roads. Each color band is an even interval of feet from the road. Red zones represent close proximity to state and county highways, the preferred for material transport. Longer distances to major roads result in increased costs to the mine operators.

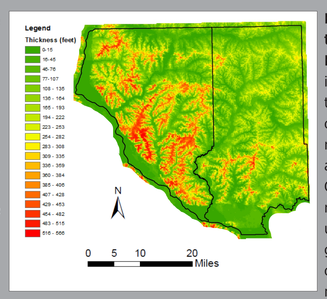


B. Proximity to major rail lines. Red represents short distances to a rail line. A nearby rail line reduces truck transport costs between the mine site and loading points. Rail lines follow the Mississippi and Trempealeau River corridors.

Figure 8. Overburden Thickness

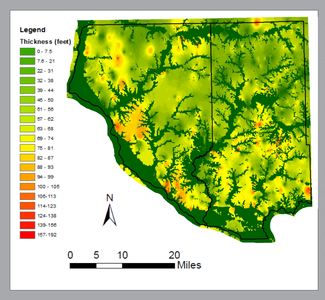


A. Overburden above the Jordan Formation. Red indicates the greatest thickness of overburden, green represents least amount of overburden. Overburden has to be removed to expose the underlying valuable geologic unit. Thin overburden reduces mining costs.

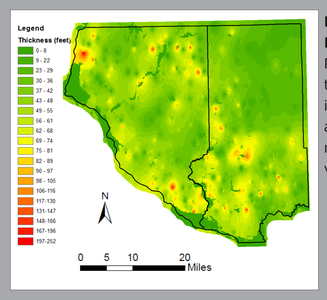


B. Overburden above the Wonewoc Formation. Red indicates the greatest thickness of overburden, green represents least amount of overburden. Overburden has to be removed to expose the underlying valuable geologic unit. Thin overburden reduces mining costs.

Figure 9. Geologic Unit Thickness



A. Jordan Formation thickness. Red indicates the thickest areas, dark green represents areas without Jordan Formation. Mining companies prefer to mine the upper, coarse-grained part of the Jordan Formation where the unit is thickest.



B. Wonewoc Formation thickness. Red indicates the thickest areas, green indicates thinnest areas. The thickest regions are the most valuable for mining.

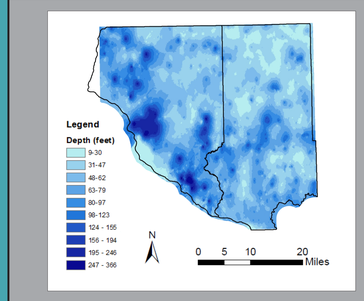
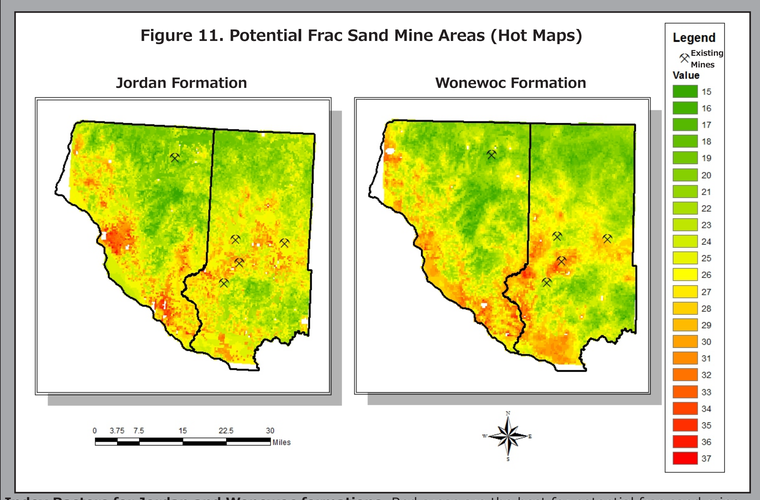


Figure 10. Depth to Water Table

Each well log includes the depth to water table. This was used to interpolate water table levels within the study area.



Index Rasters for Jordan and Wonewoc formations. Red areas are the best for potential frac sand mine sites, green would be the least viable locations. Mining symbol represent pre-existing frac sand mines. The index rasters are a result of reclassifying the criteria in raster calculator so that transportation, material thickness, water table depth, and amount of overburden dictate which areas are the "hottest" (most optimal) for mine sites.

CONCLUSIONS

-The final heat maps strongly coincide with access to rail transport, as do the pre-existing mines in the study area associated with the Wonewoc Formation (Figs. 7B., 11).
-Buffalo County has many "hot" areas for Jordan Formation sand prospecting (Fig. 11).
-Factors contributing to errors include:
  -Lack of detail in well log descriptions. Insufficient information may lead to ambiguity in naming a formation correctly and determining thicknesses. For example, upper and lower sandy units may be grouped into one description of "Nonfirm brown sand," making it difficult to determine where one unit ends and another begins.
  -Uncertainty in manually located wells after geocoding.

APPENDIX: DEFINITIONS OF SELECTED TECHNICAL TERMS

-Raster- sampling of one or many continuous attributes on a rectangular array of equally sized cells to capture imagery, thematic, surface, or picture data.
-Index raster- a raster storing a color map (heat map in this case), where each color is assigned a value based on categorical data.
-Spatial Interpolation- this method uses values at observed locations to estimate the variables at unobserved locations in geographic space.

BIBLIOGRAPHY

Batten, W. G., and Zaporozec, A., 2000, Generalized water-table elevation map of Buffalo County, Wisconsin, Wisconsin Geological and Natural History Survey, Miscellaneous Map 50.
Brown, B.A., 1988, Bedrock geology of Wisconsin: West-Central Sheet: Wisconsin Geological and Natural History Map 88-7, scale 1:250,000. http://wisconsingeologicalsurvey.org/pdfs/M104_web.pdf
Mahoney, J.B., Havholm, K.G., Runkel, A.C., and Hooper, R.L., 1997, Late Cambrian shelf sedimentation, Upper Mississippi Valley, Wisconsin and Minnesota (abbreviated version); in Mudrey, M.G., ed., Field Trips in Wisconsin and Adjacent Areas of Minnesota; 31st Annual Meeting of the North-Central Section of the Geological Society of America, p. 51-67.
WDNR, 2012a, Silica Sand Mining in Wisconsin, 42 p., http://dnr.wi.gov/topic/mines/documents/silicasandminingfinal.pdf
WDNR, 2012b, DNR Public GIS FTP directory, ftp://dnrftp01.wi.gov/geodata/.
WDNR, 2012c, water well and related data files, CD ROM, produced January 2012.
WGNHS, 2011, Bedrock stratigraphic units in Wisconsin, Wisconsin Geological and Natural History Survey, Educational Series 51, 4 p.
UW-Extension, 1995, Bedrock geology of Wisconsin: Wisconsin Geological and Natural History Map 1, http://wisconsingeologicalsurvey.org/sample.htm