

Interdisciplinary Research in Ecology using GIS Technique at Kimmes – Tobin

William Bajjali¹, Donald Davidson¹, and Mary Balcer¹

1-Department of Biology & Earth Sciences, University of Wisconsin - Superior, Belknap & Catlin, PO Box 2000, Superior, WI 54880.

Abstract

The study of the water chemistry and distribution of aquatic plants in the 14 ponds in the Kimmes Tobin in Douglas County, Wisconsin revealed that there are various type of plants inhabitant the shallow ponds. The source of water in the ponds that originated from the rain and surface runoff has been geochemically shifted from calcium dominant to magnesium dominant. The shift was attributed to the interaction between aquatic root plants, microorganism, and red clay that dominated the bottom of the lake. Nitrate as main nutrients in the water for the plants has been also modified due to the adsorption of NO_3^- by the plant. This cause the water to rise up and be classified as alkaline and hyperalkaline. The GIS have been as an excellent tool in studying the spatial distribution of aquatic plants in the ponds and creating a DEM using the IDW and kriging.

Introduction

Fall 2005, the Department of Biology and Earth Sciences offered an interdisciplinary course in ecology and limnology (BIOL 420) for a group of undergraduate students. Three professors from the department were involved in this course. Two instructors are biologists and the third is hydrogeologist and GIS expert. Number of students majoring in biology, ecology & aquatic biology, plant sciences, and have minor in applied geographic information systems (GIS) minor, and physical environment science participated in this research.

The course was aimed to enhance the students to carry a real-world project using an advance GIS technique. Teach the students to conduct field work, obtain a spatial data about the plants, water quality, and insects of the Kimmes Tobin wetland. The collected data integrated, analyzed, and interpreted in GIS environment. The research approach was to answer questions related to the type of habitat and their distribution in the wetland, the depth of water in the ponds and its water quality.

Kimmes – Tobin Setting

Many wetlands in Wisconsin have been destroyed by development and construction of highways and Kimmes-Tobin is one of them (Fig.1). The wetland was destroyed by the construction of State Highway 35 and U.S. Highway 53.

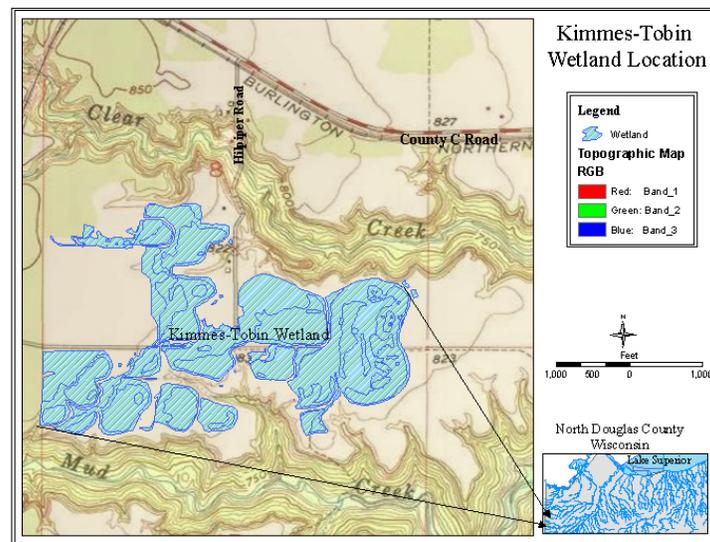


Fig. 1 Kimmes-Tobin Location in Northwest Wisconsin

Kimmes-Tobin contains 14 small shallow ponds, where the variation in their surface water elevation varies between 10 to 16 feet. The elevation of wetland varies from 820 ft to 850 feet. The water content of the ponds relies completely on precipitation and surface runoff. The 10-year precipitation average in Foxboro and city of Superior, located in close proximity to the wetland, was estimated to be 28.78 and 28.55 inches Fig.2. Inflow of surface water enters the main system principally from the west end and exits from the southeast end (DOT, 1997). A detail description

about the wetland hydrology, plants, animals, and delineation process can be found in (Davidson et. al., 2007).

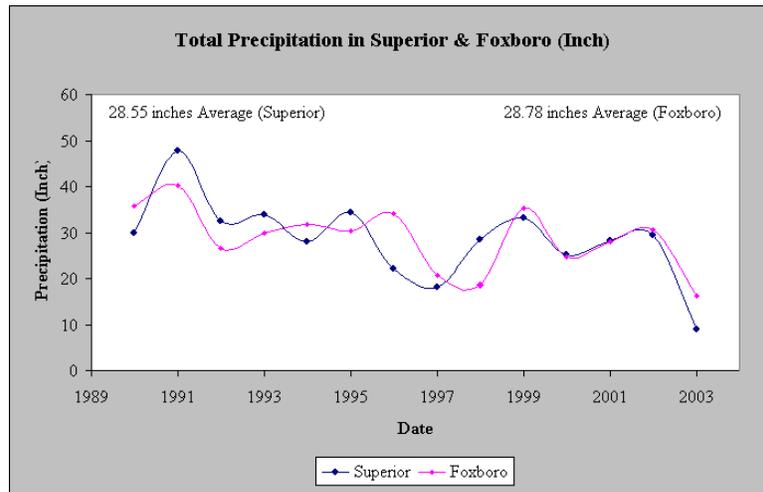


Fig. 2 Total Precipitation in the Superior and Foxboro area, Douglas County

Methodology

In order to conduct the interdisciplinary research more than a simple set of methods were applied to obtain spatial database related to the ecosystem of the study area. The approach that has used in this study is to involve students to utilize ways and methods have learned in the classroom and laboratory entirely in the field. The assumption was that there is hidden unknown information, requiring be revealing and explaining.

To study and identify the diversity of plants, vegetation, and flora various sampling transects and quadrat techniques were used.

GPS instruments were used to collect the spatial locations and elevations. The Garmin GPS and ArcPAD-GPS are used to gather many sites from different locations on the land and on the ponds of the wetland. Boat was used to sample the chemistry of the water and the depth of the ponds.

GIS approach

GIS analysis provides meaning to the collected database. After integrating the diverse collected database from the field and the digital data files of the wetland into the GIS system, three steps were taken to perform the spatial analysis:

I - Data Collection and Conversion

The handheld Garmin GPS and ArcPAD-GPS are used to gather the spatial location of the wetland. ArcPad is software for mobile GIS and field mapping applications using handheld and mobile devices. The ArcPad is used to record the perimeter of the whole

wetland and the area of the land and ponds of Kimmes-Tobin wetland. The sketches were important part of the data collection process as they become part of the project record.

The handheld Garmin GPS was used primary to capture the coordinate system of the sites needed in the project. The error discrepancies of the latitude and longitude are taken into consideration with plus and minus 30 feet. The data points gathered were in two different formats, the Garmin produced data in database (dbf) format and the ArcPad in shapefile format. The dbf file of Garmin GPS was integrated into GIS and converted into shapefile format.

II - Prepare the data for analysis

A variety of GIS approaches have been used in this study to integrate the different databases into the GIS environment.

1-Projection: Both the GPS-Garmin and ArcPAD produced data registered in geographic coordinate and World Geodetic System of 1984 (WGS84) Datum.

In order to align the collected GIS data with an existing aerial photograph registered in Douglas County Projection (DCP), the data were projected into DCP. Map projection is a mathematical formula where the 3-D earth's transform into a 2-D or plane surface (Robinson et al 1995). DCP has the following parameters:

Projection: Transverse Mercator
Ellipsoid: GRS 80
Datum: NAD83
Units: meters

Parameters:

1. Origin of Longitude: W 91° 55'
2. Origin of Latitude: 45° 53'
3. False Easting: 59131.3183 meters
4. False Northing: 0.0041 meters
5. Scale factor on Central Meridian: 1.0000385418

2-Geoprocessing: The clip function was used in order to extract the captured points that were associated with the wetland. This was done by using the boundary of the wetland digitized from the aerial photograph. This is a useful step in GIS to create a new theme needed for analysis.

3-Vector Conversion onto Raster: In order to perform spatial analysis, the study area containing the point elevations converted from vector format into a raster format (grid). Therefore, part of the active landfill area that contains the point elevations were saved as an independent GIS layer. The layer then converted into raster in order to make the analysis possible and to restrict the interpolation surface to the boundary of the new created raster. This step is significant in order to carry out the analysis on a selected set of cells. This means that processing will only occur on the cells that are located in the new

layer that has been converted into grid.

Spatial Analyst and Geostatistical Analyst were used to save certain steps in order to process the data for the analysis. Raster analysis was required to generate many grids, which was important in order to have the same resolution.

III - Spatial Interpolation

Two geostatistical approaches Inverse Distant Weighting (IDW) and Kriging were used to interpolate the depth of water in the one of the ponds in the study area. Spatial interpolation is simply defined as a process to estimate unknown values from points with known values. The models generate prediction surfaces and also uncertainty surfaces, giving an indication of how the predictions are. In this study the unknown elevation values of the bottom of the pond at a location with no GPS measurement were estimated through two interpolation techniques from known elevation values measured at various locations. The Geostatistical Analyst extension in ArcGIS was used for performing the analysis. The two models were used to create interpolated grid based on the measured depth of certain sites. A reclassification function for each of the interpolated elevation grid was defined. A new value is assigned to each class based on the range of the elevation in the study area.

Inverse Distance Weighting (IDW)

Inverse distance weighting is very popular techniques in GIS and considers one of the simplest interpolation methods. There are a variety of methods that use weighted moving averages of points within a zone of influence. Interpolation techniques in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location (Fisher et al 1987). In general the simplified formula for IDW is

$$V_0 = \frac{\sum_{i=1}^n \left(\frac{V_i}{D_i^2} \right)}{\sum_{i=1}^n \left(\frac{1}{D_i^2} \right)}$$

Where, V_0 is the predictable value at a point 0, V_i is the V value at control point i, D_i is the distance between control point i and 0, n is the number of known values used in the evaluation.

The weights are a decreasing function of distance and the user has control over the mathematical form of the weighting function. The size of the neighborhood can be expressed as a radius or a number of points.

III.2.2 Kriging

Kriging is another strong method for spatial interpolation. It is the estimation procedure used in geostatistics using known values and a semivariogram to determine unknown

values. The procedures involved in kriging incorporate measures of error and uncertainty when determine estimations. Based on the semivariogram used, optimal weights are assigned to unknown values in order to calculate unknown ones (Webster and Oliver 1990). Since the variogram changes with distance, the weights depend on the known sample distribution.

A powerful set of kriging techniques with varying degrees of sophistication have been implemented in GIS. The most popular approach using the ordinary kriging is applied in this study.

The first step in this technique is to construct a variogram from the set of the data point to be interpolated. Two variograms exist: an experimental and a model variogram. The experimental variogram is found by calculating the variance of each point (v) in the set with respect to each of the other points and plotting the variances versus distance (d) between the points.

Once the experimental variogram is computed, the next step is to define a model variogram. A model variogram is a simple mathematical function that models the trend in the experimental variogram. Once the model variogram is constructed, it is used to compute the weights used in kriging. The basic equation used in ordinary kriging is as follows:

$$K(d) = \frac{1}{2n} \sum_{i=1}^n (Z(x_i) - Z(x_i + d))^2$$

Where d is the distance between known points, n is the number of pairs of sample separated by d; Z is the attribute value (elevation of known points). The equation indicates that the semivariance is expected to increase as d increases.

Results and Discussion

Vegetation and Flora

Identification of representative plant species and their relative frequency and prevalence indices was made, and a general vegetation map was developed. Figure 3 shows that scrub-shrub, wet meadow, shallow marsh, deep marsh, and aquatic bed species all were present in Kimmes-Tobin. The wetland types determined by water level and dominant species as follow:

Shallow Marsh: Standing water less than 6 inches deep. Dominated by four emergent obligate species: *Scirpus atrovirens*, *Scirpus cyperinus*, *Typha angustifolia* and *Typha latifolia*

Deep Marsh: Water depth 6 inches to 4 feet. Dominated by three obligate species: *Potamogeton foliosus*, *Potamogeton natans* and *Sparganium americanum*.

Aquatic Bed: Water depth 6 inches to 4 feet. Dominated by two submerged aquatic species which are obligates: *Calligeron giganticum* and *Potamogeton foliosus*

Wet Meadow: No standing water but moist soils. Dominated by *Carex gynandra* and *Phalaris arundinacea* both are facultative wetland, and one obligate *Scirpus cyperinus*.

Scrub Shrub: Wet soil and some standing water. Dominated by *Alnus rugosa* and *Salix* sp. both are facultative wetland.

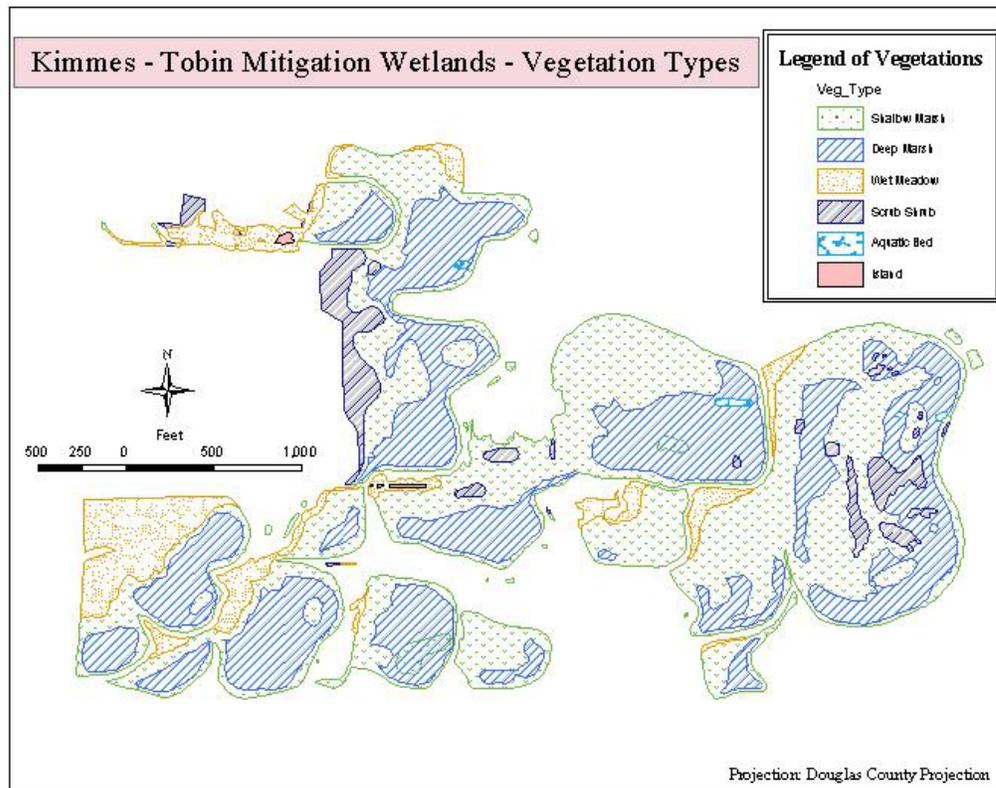


Fig. 3 Location of Pond No. 2 at Kimmes – Tobin

Digital Elevation Model Creation for Pond 2 using interpolation methods

Pond No 2 in the study area had been chosen to be used as an example for creating the Digital Elevation Model (DEM). The Pond is relatively big, easy to access and is divided into two sections. The western part of the pond is crowded with aquatic vegetation and the eastern part free water (Fig. 4). The captured elevation data of the pond depth from the eastern part was integrated into ArcGIS as dbf file. The file converted into shapefile and a new field was added to the attribute table and called “Depth”. The depth of the pond was recorded in centimeter with the minus sign to facilitate the interpolation of the pond’s depth. The new “Depth” field data were used in the interpolation using two methods; the IDW and ordinary of Kriging. The methods were used in order to retain actual elevation measurement in a final surface. Each method selected requires that the exact data values for the sample points are included in the final output surface.

The distance-decay principle is shown by IDW surface in Figure 5. The IDW parameters specified in ArcGIS environment are the power option, circle's radius distance for influence on the data, number of points in the ellipsoid, and output cell size. The input points are the sampled location of the elevation "elevation.shp". IDW assumes that each input point has an influence that reduces with distance. It weights the points that are closer more than the points that are located farther away. A specified number of 15 points within a specified 50 m radius is used to determine the output value for each location. The power parameter in the IDW interpolator controls the significance of the surrounding points upon the interpolated value. The optimized power value obtained was 2.63. This value generated the best trend surface model with 47.82 Root Mean Square (RMS), which is considered the best in this particular case. The result of the interpolation shows that the highest depth in the pond is in the eastern part (Fig. 5).

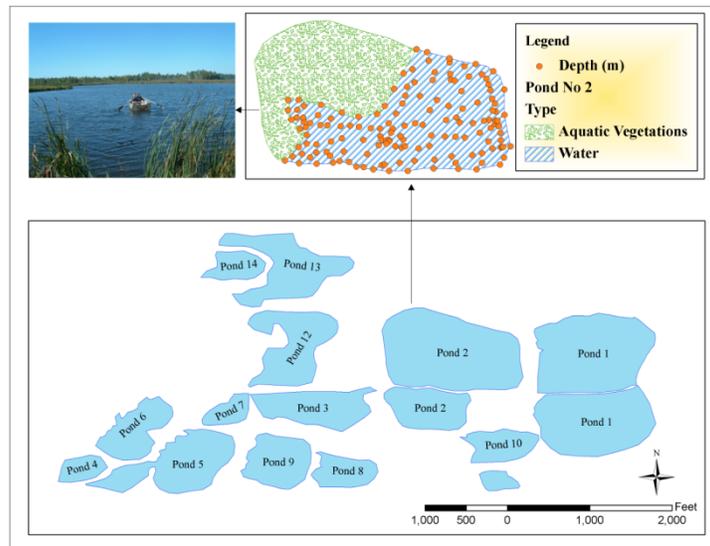


Fig. 4 Location of Pond No. 2 at Kimmes – Tobin

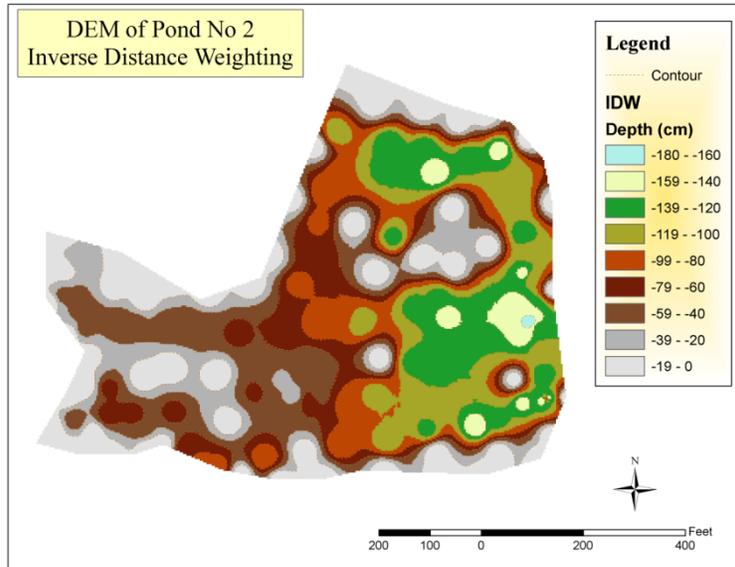


Figure 5: Inverse distance weighting surface for pond No. 2

Similar to IDW, KRIGING uses a weighting, which assigns more influence to the nearest data points in the interpolation of values for unknown locations. KRIGING, however, is not deterministic but extends the proximity weighting approach of IDW to include random components where exact point location is not known by the function. KRIGING depends on spatial and statistical relationships to calculate the surface. The two-step process of KRIGING begins with semivariance estimations and then performs the interpolation. Some advantages of this method are the incorporation of variable interdependence and the available error surface output. A disadvantage is that it requires substantially more computing and modeling time and KRIGING requires more input from the user. The result of the kriging method is illustrated in Figure 6. The smooth surface created by the kriging function provides more correct general elevation trend for the Pond No.2 than the IDW.

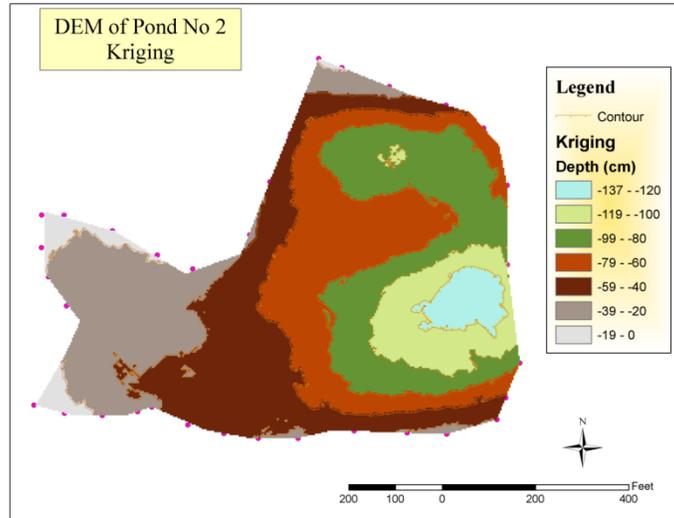


Figure 6: Ordinary Kriging surface for pond No. 2

Geochemistry of surface water in the pond

There are various factors contributing to the major constituents of the surface water in the pond. The ponds are kept full by precipitation and also by surface runoff. Therefore, the climate and landscapes of Kimmes Tobin area have a significant influence on the natural water quality conditions. Factors such as meteorology, geology, vegetation, soil, and hydrology cause surface water quality to vary extensively. The quality of water in the pond is also affected by evaporation, transpiration and aquatic plants.

The water measured to identify the chemical and physical characteristics. The water was sampled for major cations, anions, and temperature in order to be evaluated and compared against the EPA guideline.

Water Salinity

The salinity of the surface water in the ponds was found to be very low, heterogeneous, and ranging between 83 mg/l and 160 mg/l. The heterogeneity of the water salinity in the pond indicates that factors other than the surface runoff and evaporation have influenced the makeup of the water chemistry. The dissolution process in the rhizosphere of the red soil at the bottom of the pond should be considered. The rhizosphere is very active environment within which a wide range of complex reaction took place between plant root, microorganism, and soil. These processes caused change in the physical and chemical properties of the soil materials which make more elements available for uptake by plants. As explained by Heckman and Strick (1996), nutrients are absorbed by the roots of plants as cations and anions. The differential uptake of these ions can affect the pH of the rhizosphere and water. Among the most important of these ions are nitrate NO_3^- . The absorption of NO_3^- ion promotes the efflux of OH^- and raises the pH. Table 1, indicates that pH of the water is alkaline and ranges between 6.9 and 9.8, while the NO_3^- is almost zero. The molal ratio indicates that the water type of water pond is classified as

Ca-HCO₃. The water is considered fresh and suitable for different purposes including drinking.

Table 1 Chemical analysis of the water in the ponds

Site	pH	Ca	Mg	Na	K	Cl	HCO ₃	SO ₄	NO ₃	Cd	Pb	TDS	Type of Water
		mg/l							ppb		mg/l		
CANAL 01	8.3	13.0	8.3	0.7	0.1	1.5	64.0	1.0	0.0	1.0	5.0	94.6	CaHCO ₃
NO 3 - 66	8.0	12.0	8.4	1.1	0.2	0.3	58.0	1.0	0.0	1.0	5.0	87.0	CaHCO ₃
POINT 5	9.8	11.0	8.6	1.1	0.2	0.9	63.0	1.0	0.0	1.0	5.0	91.8	CaHCO ₃
Pond 01	8.8	10.0	6.9	1.2	0.3	0.6	57.0	1.0	0.0	1.0	5.0	83.0	CaHCO ₃
Pond 02	8.1	11.0	7.1	1.2	0.3	0.4	57.0	1.0	0.0	1.0	5.0	84.0	CaHCO ₃
Pond 04	8.1	18.0	14.0	2.2	0.7	0.3	110.0	1.0	0.3	1.0	5.0	152.5	CaHCO ₃
Pond 05	8.3	16.0	11.0	1.0	0.3	0.3	85.0	1.0	0.2	1.0	5.0	120.8	CaHCO ₃
Pond 06	7.8	16.0	10.0	1.4	0.6	0.3	82.0	2.0	0.0	1.0	5.0	118.3	CaHCO ₃
Pond 07	6.9	15.0	12.0	1.1	0.3	0.4	74.0	1.0	0.0	1.0	5.0	109.8	CaHCO ₃
Pond 08	7.5	26.0	11.0	1.1	0.3	0.2	114.0	1.0	0.0	1.0	5.0	159.6	CaHCO ₃
Pond 09	8.8	14.0	14.0	2.2	0.9	0.3	96.0	1.0	0.4	1.0	5.0	134.8	CaHCO ₃
Pond 10	7.4	16.0	9.2	0.9	0.4	0.4	78.0	1.0	0.0	1.0	5.0	111.9	CaHCO ₃
Pond 13	9.0	12.0	8.8	0.7	0.1	0.5	63.0	1.0	0.0	1.0	5.0	92.1	CaHCO ₃

To construct the piper diagram, the relative abundance of cations and anions in meq/l of surface water of the pond and rain water from Wisconsin is plotted in the diagram (Fig.7). The rain data from Wisconsin are taken from published data (Peters N and Bonell J 1982). The diagram shows graphically that the pond water samples are plotted in different locations than the rain water. The clustering of the rain water samples at this position allows classifying them as calcium type of water, while the position of the pond water sample as magnesium type, with exception one sample, which is clustering with the rain water. This could be explained that the rain water after filling the pond has been shifted geochemically and the calcium concentration in the bond water become less abundance than the magnesium. This could be attributed to the adsorption of the Ca²⁺ from the root of the diverse aquatic plant. Nevertheless, the adsorption of the Ca²⁺ is not homogeneous in all the ponds. This might be attributed to various factors such as the residence time of water and the type and density of the aquatic plant in each pond

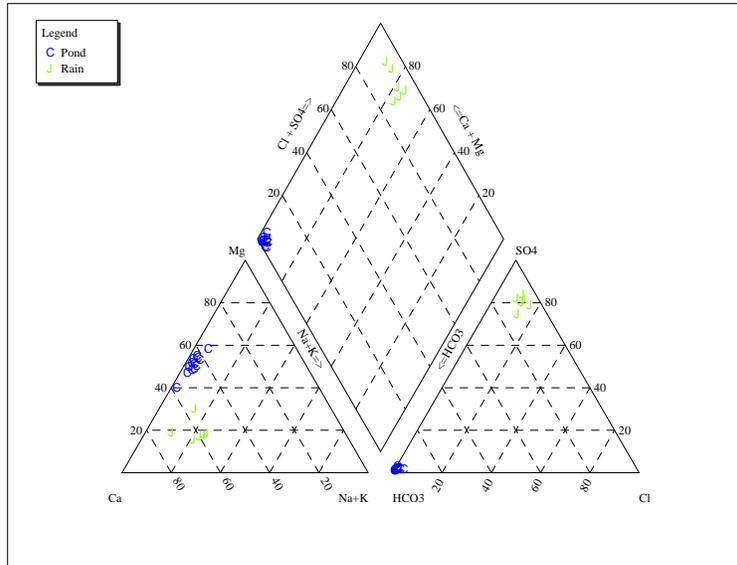


Fig.7 Piper diagram shows water of the ponds and rain from Wisconsin

Summary

Fourteen ponds in the Kimmes Tobin wetland in Douglas County, Wisconsin were studied to understand the type and distribution of the aquatic plants in these ponds and the geochemistry of the surface water. The chemistry of the rain in Wisconsin rain and surface water has provided useful information regarding the geochemical evolution of water and the interaction between the root of the aquatic plants, red clay and microorganism. The chemistry of surface water recharged by precipitation shifted from calcium type to magnesium type due to the interaction and residence time. Certain nutrients such as nitrate became completely depleted due to the adsorption by the root plants and cause the surface water to be alkaline and in other ponds to be hyperalkaline. DEM has been created for ponds 2 using the IDW and kriging in GIS environment. The participation of undergraduate students in this research generated reasonable and unrealistic expectation and helps them to work together in multidisciplinary project in creative and successful way.

Acknowledgment

The authors would like to thank University of Wisconsin – Superior for funding the research and the students who conducted the field and GIS analysis. Thanks also extended for ERA lab for their generosity of analyzing the chemical data.

REFERENCES

1. Davidson D W, Gitar R, Bajjali W, Anderson D S (2007) Past and Present Landscapes and Plant Cover of the Kimmes-Tobin Mitigated Wetlands, Foxboro, Douglas County, Wisconsin. (07-0160): 86th TRB Annual Meeting - January 21-25, 2007, Washington DC, USA
2. Department of Transportation (DOT), Final Report Kimmes – Tobin Wetland, DOT, State of Wisconsin, 1997.
3. Fisher N I, Lewis T, and Embleton B J J (1987) Statistical Analysis of Spherical Data, Cambridge University Press, 329 pp
4. Heckman J R and Strick JE (1996). Teaching Plant-Soil Relationships with Color Images of Rhizosphere pH. Journal of Natural Resources and Life Sciences Education.
5. Robinson A, Morrison J, Muehrke P, Kimmerling A, and Guphill S (1995). Elements of Cartography (6th Edition). New York: Wiley.
6. Webster R and Oliver MA (1990). Statistical Methods in Soil and Lands Resource Survey. Oxford: Oxford University Press.