Report for 2001IA1521B: Estimation of the Nutrient Load to Clear Lake from Groundwater Using Analytic Element and Parameter Estimation Models

- Conference Proceedings:
  - Simpkins, William; Keri Drenner; and Tamara Ewoldt. 2001. Characterizing groundwater-lake interaction: a tool for understanding long term phosphorus input for lake restoration. Abstracts of the 63rd Midwest Fish and Wildlife Conference, Dec. 12, 2001, Des Moines, IA. p. 31.

Report Follows:

Problem and Research Objectives:

Although the inputs of nitrogen (N) and silica (Si) are important for aquatic life, phosphorus (P) is the principal limiting nutrient in freshwaters. Assessment and control of P losses in agricultural areas is now of broad interest, because agricultural landscapes lose more P than undisturbed lands. Although lakes have been impacted by excess nutrients, the contribution from groundwater to lakes is rarely estimated. It has been assumed that P is sorbed to sediment and that transport of P in groundwater is limited. However, evidence is accumulating that P occurs in groundwater in agricultural areas (Rodvang and Simpkins, 2001).

The groundwater flow system in contact with a lake must be known in order to estimate the load of nutrients into a lake. Traditionally, groundwater discharge into lakes has been estimated using seepage meters, along with hydraulic head and hydraulic conductivity (K) measurements that are used in Darcy's Law calculations. These data are essentially point measurements that must then be extrapolated to large areas of shoreline where measurements are lacking. Discharge measurements from seepage meters are notoriously variable and generally work best in lakes with clean sandy bottom sediments. Hydraulic head and K measurements are also often difficult to measure in lake sediments. Groundwater modeling has proven to be a valuable tool in understanding groundwater-lake interaction. Recent research has shown that the Analytic Element (AE) method is applicable to groundwater-lake systems (Haitjema, 1995; Hunt and Krohelski, 1996; Hunt et al., 1998; Hunt et al., 2000). The AE model can be calibrated and the model solution constrained by coupling the results of the AE model with a parameter estimation model, such as UCODE (Poeter and Hill, 1998).

The purpose of this study is to apply the AE modeling method to Clear Lake, a 1400-ha recreational lake in north central Iowa, for the purpose of estimating groundwater discharge and recharge from the lake. The proposed research continued the groundwater part of the *Clear Lake Diagnostic and Feasibility Study (CLDFS),* a large interdisciplinary study that is funded by the Iowa Department of Natural Resources (DNR) to Dr. John Downing of Iowa State University (ISU). The objectives of the proposed study are to:

1) simulate shallow groundwater flow near Clear Lake using an Analytic Element model;
2) calibrate the model using a parameter estimation model;
3) estimate groundwater discharge to the lake with the calibrated model and compare with estimates from seepage meters and Darcy's Law to find representative values of discharge;
4) calculate nutrient load from groundwater to the lake using representative discharge (from the model and field data) and nutrient concentration (from monitoring wells) data.

Methodology:

Piezometer (monitoring well) nests installed at 11 sites on the perimeter of the lake in summer 2000 were used in this study. They were installed at depths between 3 and 31 ft (0.9 and 9.5 m) using hollow-stem augers. Coordinates (X-Y) and absolute elevation of the standpipes (and the USGS lake stage gage) to within 1 cm were obtained from a professional surveyor using GPS and total station equipment. Hydraulic conductivity (K) was estimated in the shallow piezometers using falling and rising-head slug tests during summer 2001. Hydraulic head was measured monthly and lake-stage data was retrieved in digital form from the U.S. Geological Survey. Additional temporary piezometers were installed in the eastern part of the watershed in November 2001 using a Geoprobe. Locations and elevations of those piezometers were surveyed in using GPS technology. A Windows-based, AE model, GFLOW 2000 (version 1.2), was used to simulate the groundwater flow system and to calculate groundwater discharge into and out of the lake. Input data included elevations of stream and drainage tiles, K values, and estimates of groundwater recharge. Because the model does not explicitly incorporate lakes, Clear Lake was given a very high K value to simulate that effect, as suggested by Hunt et al. (2000) and Anderson et al. (2002). An unpublished glacial geologic map (based on digital soil survey data) from the Iowa Geological Survey Bureau was used to identify geological units that could affect flow in the vicinity of the lake. Creek discharges were also measured at approximately 25 points within the model domain to provide additional calibration points for the model.

Dedicated polyethylene tubing was installed in each piezometer to facilitate groundwater sampling. Groundwater was sampled and analyzed for total P, dissolved P, total N, Si, pH, electrical conductivity, NO_3-N, and Cl on a monthly basis. Standard methods of analysis were employed by the Water Research Laboratory, Department of Animal Ecology, at Iowa State University, for determination of total P (persulfate digestion and spectrophometric method), dissolved P (spectrophometric method), total N (second derivative spectroscopy method), and Si (molybdate reactive method) concentrations, pH, and electrical conductivity. Samples were analyzed in triplicate. Determination of NO_3-N, Cl, and SO_4 concentrations were made by ion chromatography in the Department of Geological and Atmospheric Sciences at Iowa State University. Nutrient and contaminant loads from groundwater to Clear Lake were calculated from estimates of groundwater inflow and outflow and estimates of the concentrations of nutrients (primarily P, N, and Si) and Cl in groundwater. Nutrient load per time was calculated by multiplying discharge (L^3/T) by concentration (M/L^3). Because of Clear Lake's nature as a flow-through lake, nutrients will be added to the lake in areas of inflow and lost from the lake in areas of outflow.

Principal Findings and Significance:

The GFLOW model was run until reasonable agreement was reached with the hydraulic heads measured in the piezometers around the lake and lake stage. Values of K used for this model were 2×10^{-4} m/s and recharge was 10 percent of mean annual precipitation (3.2 in/yr). The K values for this model were judged too high for the till areas around the lake. Clear Lake is set within the Algona-Altamont Moraine Complex containing till; however, a large outwash deposit occurs on the eastern edge of the lake (bounded by orange or lighter gray border in Figure 1). It is approximately aligned with the Clear Creek outlet and leads into what appears to be an outwash fan east of the City of Clear Lake. Subsequent runs included a more conductive zone on the east end (Figure 1). Assigning a K value of 3.5 x 10^{-3} m/s to the outwash allowed K values in the till in the rest of the watershed to be lowered to 5.3 x 10^{-5} m/s. Although this is still a high value for till, it is in keeping with K values estimated from slug tests at the lake. Using a recharge value of 81.3 mm/yr (3.2 in/yr or 10 percent of mean annual precipitation), the final model produced heads similar to those observed in the field (Figure 1) and produced inflow and outflow in the areas indicated by field data. The maximum departure from the field data was 0.55 m and the mean absolute difference was 0.27 m. Flux inspection lines were drawn along areas that the model shows to be inflow and outflow zones. The results suggest that groundwater inflow (discharge) to Clear Lake is approximately 7.9 x 10^3 m^3/d and groundwater outflow is approximately 8.9 x 10^3 m^3/d. Although these values are higher than those suggested by the Darcy's Law analysis, they are within the same order of magnitude (Table 1). They are significantly higher than the seepage meter estimates. Parameter estimation using UCODE has met with only moderate success in improving these parameter estimates and that work continues. A new version of GFLOW2000 (version 1.3) was released in April 2002 that allows the lake to be modeled as a lake with a specified stage. Preliminary simulations indicate that parameter values will change slightly in this new model. The newer version using the additional calibration points will be discussed in the final report.

Table 1. Comparison of groundwater discharge values estimated by the three methods.

Method	**GW Inflow (m^3/d)**	**GW outflow (m^3/d)**	**Net (m^3/d)**
Seepage meters	5.4E+05	None	5.4E+05
Darcy's Law	4.7E+03	-6.2E+03	-1.5E+03
AE GW Model	7.9E+03	-8.9E+03	-1.0E+03

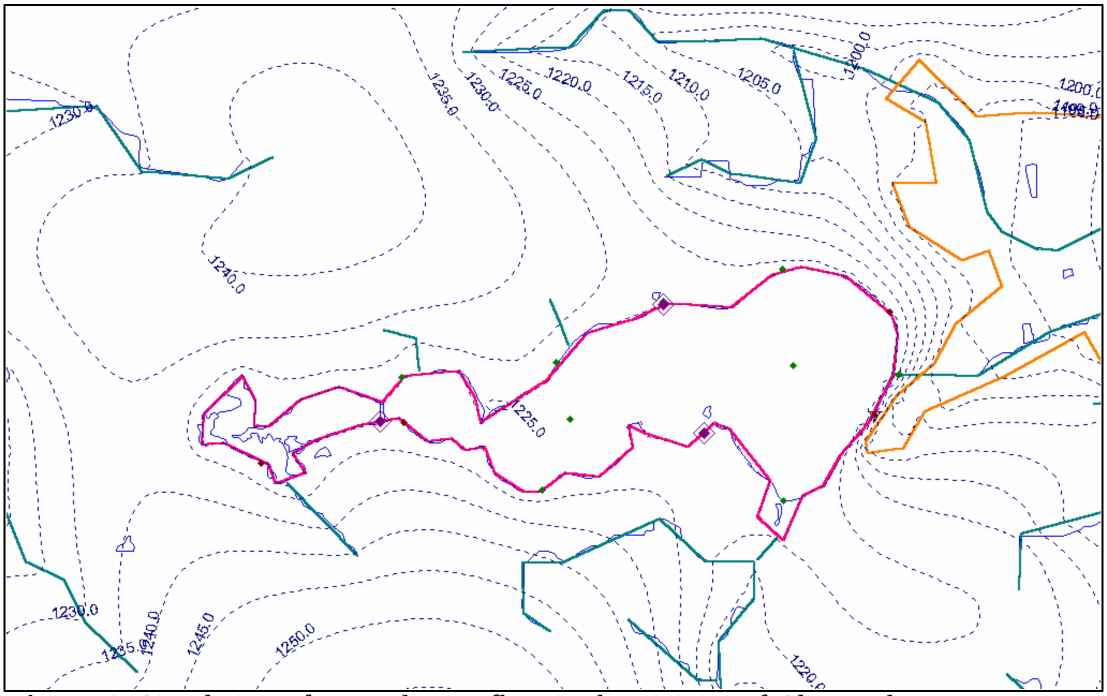

Figure 1. Simulation of groundwater flow in the vicinity of Clear Lake using GFLOW2000 (version 1.2). Contour interval is 5 ft. Outwash deposit is outlined in orange (lighter gray). Original calibration points (piezometers) shown as diamonds.

Total P concentrations were similar to that reported by Simpkins et al. (2001) with a mean value of 237.7 µg/L and a standard deviation of 232.9 µg/L (Table 2). Because some very high concentrations skew the distribution, the median value of 172.9 µg/L may be a better measure of the central tendency. Most of the total P is apparently in the form of dissolved P. In contrast to P, concentrations of Total N were considerably less (Table 2). The mean, standard deviation and median values are 1.1, 1.57 and 0.8 mg/L, respectively. The lack of NO_3-N in these samples is consistent with the lack of dissolved O_2 and use of alternate electron acceptors in the system. Concentrations of SiO_2 were within the range common for groundwater systems at near-neutral pH in these materials (Table 2). Mean, standard deviation, and median concentrations were 40.4, 14.3, and 37.3 mg/L, respectively. Chloride concentrations in groundwater ranged from 1.0 to 73.1 mg/L, with a mean of 17.1 mg/L. The mean Cl concentration in Clear Lake is about 16 mg/L. Because there is no known natural source of Cl in the glacial sediment, its origin must be anthropogenic. Potential sources include agricultural fertilizers, septic systems and road de-icing salts and solutions. Preliminary nutrient loads to Clear Lake for the major nutrients and Cl (calculated using groundwater discharges from the model) are given in Table 3. Work continues to refine water quality statistics and nutrient load estimates to the lake.

Table 2. Statistics for Total P, Total N, and SiO_2 concentrations in groundwater from 32 piezometers. Total P concentrations in µg/L. Total N and SiO_2 concentrations in mg/L.

Analyte	N	Mean	Median	Std. Dev.	SE Mean	Min.	Max.
Total P	219	237.7	172.9	232.9	15.7	< 0.01	1783.1
Total N	219	1.1	0.8	1.57	0.11	0.001	11.54
SiO_2	219	40.4	37.3	14.3	0.96	17.6	131.3

Table 3. Summary calculations of nutrient and contaminant load to Clear Lake.

Flow direction	Q (m^3/d) from Part I	Nutrient or contaminant	Median conc. (mg/L)	Load (kg/d)
In	7.9E+03	Total P	0.173	1.37
	"	Total N	0.8	6.32
	"	Silica (SiO_2)	37.3	294.70
	"	Cl	14.3	112.98
Out	-8.9E+3	Total P	0.174	-1.54
	"	Total N	1.31	-11.66
	"	Silica (SiO_2)	38.7	-344.47
	"	Cl	15.4	-137.08

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