Estimation of the Groundwater Nutrient Input to Clear Lake

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Introduction

A "Diagnostic and Feasibility Study" of Clear Lake, funded primarily by the IDNR, the City of Clear Lake, Cerro Gordo County, Hancock County, the Hancock and Cerro Gordo County offices of the NRCS, and Iowa State University (cost-share) was completed in 2001. The purpose of this two-year project was to study the Clear Lake watershed and community, to determine water-quality problems and their causes, and to suggest potential remedial measures. The feasibility of remedial alternatives is still under review by the IDNR and the City of Clear Lake.

Clear Lake is third largest of 34 natural (glacial) lakes in Iowa and provides water-based recreation and fishing. It has a maximum depth of 19 feet and an average depth of 9.5 feet. Water is supplied to the lake by many small tributaries, rainfall, groundwater, and a large number of run-off sites. About 47% of the water supply flows in from a large wetland complex on the west side of the lake (Ventura Marsh). The watershed–to–lake-area ratio is only 2.3:1, and the watershed is composed of 59% cropland, 10% urban areas, 9% wetlands, 8% grasslands, 5% wooded lands, 5% roadways, 2% farmsteads, 1% pasture and 1% state parks. Clear Lake receives an elevated supply of nutrients (most notably phosphorus) from its watershed, rainfall, and groundwater, resulting in a volume-weighted average spring phosphorus concentration of 186 ug/L (ppb). The mixed agricultural and urban watershed furnishes very high nutrient loads to the lake, some of which have been deposited into the sediment layers. "Wind mixing" returns nutrients from the sediments into the water column during the warm, summer season. High nutrient inputs, coupled with the fish-, boat- and wind-induced mixing of sediments have turned Clear Lake into a eutrophic to hyper-eutrophic lake (Downing et al., 2001).

Materials and Methods

Groundwater inflow and outflow are part of the nutrient budget of Clear Lake; thus, an understanding of the geology and hydrogeology of the region is necessary to understand lake–groundwater interactions. Investigations were directed toward the following objectives:

- To determine the thickness of Quaternary units underlying the lake and overlying the regional bedrock aquifer.
- To estimate hydraulic heads in the regional aquifer and their relationship to the lake elevation and shallow groundwater flow.
- To determine the nature and types of geologic units affecting flow into and from the lake.
- To estimate groundwater discharge and nutrient load to the lake.

Groundwater discharge was estimated by three independent methods:

- Direct measurements by use of seepage meters.
- Application of Darcy's Law, using hydraulic head gradient and hydraulic conductivity data from 33 piezometers installed around the lake.
- An analytic element groundwater-flow model.

Results and Discussion

Volumetric inflow and outflow estimates from Darcy's Law and the analytic element model were very similar (Table 1). Estimates from seepage meters were much higher, presumably because they indicated inflow only. Groundwater samples from the 33 piezometers were analyzed for total P, total N, Si, alkalinity, electrical conductivity, and pH. Additional parameters (major cations and anions, trace elements, dissolved O_2, dissolved organic carbon) were measured in order to understand the geochemical environment in which the nutrients occur. The mean concentration of Total P was 173 μg/L (ppb).

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 groundwater discharge by concentration (Table 2). Because Clear Lake is a flow-through lake, nutrients are added to the lake in areas of inflow and lost from the lake in areas of outflow. Groundwater contributed only about 1.37 kg/day to the lake, which is only 7–11% of the total P budget of the lake between 1998 and 2000 (Downing et al., 2001). Reducing conditions in groundwater appear to preclude nitrate from reaching the lake, although Cl contamination from road salt appears to be significant (Simpkins et al., 2001).

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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

Table 2. Summary calculations of nutrient and contaminant load to Clear Lake.

Flow direction	Q (m^3/d)	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