PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Jade Star Lackey
Symposium Convener
Pomona College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

ISSN# 1528-7491

The Consortium Colleges   The National Science Foundation   ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2013

Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA 91711

Christina Kelly
Proceedings Layout & Design
Scripps College

Keck Geology Consortium Member Institutions:
Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College, Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University, Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2012-2013 PROJECTS

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE: SHUMAGIN ISLANDS AND KENAI PENINSULA, ALASKA
Faculty: *JOHN GARVER*, Union College, *CAMERON DAVIDSON*, Carleton College
Students: *MICHAEL DELUCA*, Union College, *NICOLAS ROBERTS*, Carleton College, *ROSE PETTIETTE*, Washington & Lee University, *ALEXANDER SHORT*, University of Minnesota-Morris, *CARLY ROE*, Lawrence University.

LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON
Faculty: *NICHOLAS BADER & KIRSTEN NICOLAYSEN*, Whitman College.
Students: *REBECCA RODD*, University of California-Davis, *RICARDO LOPEZ-MALDONADO*, University of Idaho, *JOHNNY RAY HINOJOSA*, Williams College, *ANNA MUDD*, The College of Wooster, *LUKE FERGUSON*, Pomona College, *MICHAEL BAEZ*, California State University-Fullerton.

BIOGEOCHEMICAL CARBON CYCLING IN FLUVIAL SYSTEMS FROM BIVALVE SHELL GEOCHEMISTRY - USING THE MODERN TO UNDERSTAND THE PAST
Faculty: *DAVID GILLIKIN*, Union College, *DAVID GOODWIN*, Denison University.
Students: *ROXANNE BANKER*, Denison University, *MAX DAVIDSON*, Union College, *GARY LINKEVICH*, Vassar College, *HANNAH SMITH*, Rensselaer Polytechnic Institute, *NICOLLETTE BUCKLE*, Oberlin College, *SCOTT EVANS,* State University of New York-Geneseo.

METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND OLD MODELS
Faculty: *ZEB PAGE*, Oberlin College, *EMILY WALSH*, Cornell College.
Students: *MICHAEL BARTHELMES*, Cornell College, *WILLIAM TOWBIN*, Oberlin College, *ABIGAIL SEYMOUR*, Colorado College, *MITCHELL AWALT*, Macalester College, *FREDY, AGUIRRE*, Franklin & Marshall College, *LAUREN MAGLIOZZI*, Smith College.

GEOLOGY, PALEOECOLOGY AND PALEOCLIMATE OF THE PALEOGENE CHICKALOON FORMATION, MATANUSKA VALLEY, ALASKA
Faculty: *CHRIS WILLIAMS*, Franklin & Marshall College, *DAVID SUNDERLIN*, Lafayette College.
Students: *MOLLY REYNOLDS*, Franklin & Marshall College, *JACLYN WHITE*, Lafayette College, *LORELEI CURTIN*, Pomona College, *TYLER SCHUETZ*, Carleton College, *BRENNAN O'CONNELL*, Colorado College, *SHAWN MOORE*, Smith College.

CRETACEOUS TO MIOCENE EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX: ASSESSING THE SLIP HISTORY OF THE SNAKE RANGE DECOLLEMENT AND SPATIAL VARIATIONS IN THE TIMING OF FOOTWALL DEFORMATION, METAMORPHISM, AND EXHUMATION
Faculty: *MARTIN WONG*, Colgate University, *PHIL GANS*, University of California-Santa Barbara.
Students: *EVAN MONROE*, University of California-Santa Barbara, *CASEY PORTELA*, Colgate University, *JOSEPH WILCH*, The College of Wooster, *JORY LERBACK*, Franklin & Marshall College, *WILLIAM BENDER*, Whitman College, *JORDAN ELMIGER*, Virginia Polytechnic Institute and State University.

THE ROLE OF GROUNDWATER IN THE FLOODING HISTORY OF CLEAR LAKE, WISCONSIN
Faculty: *SUSAN SWANSON*, Beloit College, *JUSTIN DODD*, Northern Illinois University.
Students: *NICHOLAS ICKS*, Northern Illinois University, *GRACE GRAHAM*, Beloit College, *NOA KARR*, Mt. Holyoke College, *CAROLINE LABRIOLA*, Colgate University, *BARRY CHEW*, California State University-San Bernardino, *LEIGH HONOROF*, Mt. Holyoke College.

PALEOENVIRONMENTAL RECORDS AND EARLY DIAGENESIS OF MARL LAKE SEDIMENTS: A CASE STUDY FROM LOUGH CARRA, WESTERN IRELAND
Faculty: *ANNA MARTINI*, Amherst College, *TIM KU*, Wesleyan University.
Students: *SARAH SHACKLETON*, Wesleyan University, *LAURA HAYNES*, Pomona College, *ALYSSA DONOVAN*, Amherst College.

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: David Dethier, Williams College, Will Ouimet, U. Connecticut.
Students: CLAUDIA CORONA, Williams College, HANNAH MONDRACH, University of Connecticut, ANNETTE PATTON, Whitman College, BENJAMIN PURINTON, Wesleyan University, TIMOTHY BOATENG, Amherst College, CHRISTOPHER HALCSIK, Beloit College.

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Keck Geology Consortium: Projects 2012-2013
Short Contributions— Clear Lake, Wisconsin Project

THE ROLE OF GROUNDWATER IN THE FLOODING HISTORY OF CLEAR LAKE, WISCONSIN
Faculty: *SUSAN SWANSON*, Beloit College, *JUSTIN DODD*, Northern Illinois University.

SEDIMENTOLOGICAL EVIDENCE OF A PERSISTENT GROUNDWATER-DOMINATED SYSTEM IN DUCK LAKE, WI OVER THE PAST 8000 YEARS
NICHOLAS F. ICKS, Northern Illinois University
Research Advisor: Justin P. Dodd

LAKE BUDGET ANALYSIS TO UNDERSTAND GROUNDWATER FLOODING OF A SEEPAGE LAKE NEAR MILTON, WI
GRACE GRAHAM, Beloit College
Research Advisor: Susan Swanson

RECENT LAND USE AND VEGETATION CHANGES RECORDED BY NITROGEN AND CARBON ISOTOPE VALUES OF LAKE SEDIMENT CORES FROM SOUTHERN WISCONSIN
NOA KARR, Mount Holyoke College
Research Advisor: Al Werner

SEEPAGE CONDITIONS AND WATER BUDGET ANALYSIS OF DUCK LAKE IN MILTON, WISCONSIN
CAROLINE LABRIOLA, Colgate University
Research Advisor: Jeni McDermott

GROUNDWATER FLOW AND DISTRIBUTION OF SUBSURFACE MATERIALS IN THE IMMEDIATE VICINITY OF CLEAR LAKE, WISCONSIN
BARRY CHEW, California State University – San Bernardino
Research Advisor: Erik Melchiorre

THREE DIMENSIONAL ANALYSIS OF THE HYDROSTRATIGRAPHY NEAR CLEAR LAKE, WISCONSIN
H. LEIGH HONOROF, Mount Holyoke College
Research Advisor: Alan Werner

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

KECK Geology Consortium
Learning Science Through Research
Published by Keck Geology Consortium

Short Contriubtions
26th Annual Keck Symposium Volume
6 April, 2013
ISBN: 1528-7491

GROUNDWATER FLOW AND DISTRIBUTION OF SUBSURFACE MATERIALS IN THE IMMEDIATE VICINITY OF CLEAR LAKE, WISCONSIN

BARRY CHEW, California State University – San Bernardino
Research Advisor: Erik Melchiorre

INTRODUCTION

The recent long-term flooding that was experienced in the vicinity of Clear Lake and three surrounding kettle lakes was due, in part, to record precipitation that occurred between 2006 and 2008. Long-term flooding did not occur, however, at other kettle lakes within this glaciated region of southern Wisconsin. In 1971, when the USGS created a topographic map for the area, the surface level of Clear Lake was at 804 feet above mean sea level (USGS, 1971). Apparently, nobody expected the lake level to rise much higher than this, and some homes were built close to the lake. By June 2008, lake levels had risen so high that a few homes were flooded, and some septic tanks, wells, and docks were underwater. More precipitation occurred in 2009, raising lake levels even higher. On July 17, 2009, the Wisconsin Department of Natural Resources (WDNR) observed a lake level of 815.67 feet above sea level (asl) on their staff gage. The highest lake level observed by the WDNR since the flooding began was a level of 816.27 feet asl on August 9, 2010. It is not yet known why the lake level continued to rise several months after the last major precipitation event in 2009. On July 17, 2012, a lake level of 811.41 feet asl was observed on the WDNR staff gage by the Keck research group. Some docks were still submerged, and the group noted that the top of a well casing that had been previously submerged, on the north side of Clear Lake, was barely above the lake surface. On October 12, 2012, the WDNR observed that the lake surface level was at 810.51 feet asl. These data reveal that the lake level has been dropping very slowly since August 9, 2010.

These kettle lakes are seepage lakes, meaning that they have no inlet or outlet, and that their principle source of water is precipitation or runoff, supplemented by groundwater from the immediate drainage area. As previously stated, these lakes remained flooded long after the last major precipitation event and cessation of the resulting runoff. Thus, it is hypothesized that groundwater is the controlling factor in this sustained flooding. Testing of this hypothesis requires knowledge of water table levels and the locations of aquifer materials, namely sand and gravel, and of aquitard materials, namely clayey sediments and clay. Thus, the focus of this project is to determine water table levels and the distribution of subsurface materials in the immediate vicinity of Clear Lake in order to gain a better understanding of their effect on the behavior of groundwater and the recent persistence of high water table levels. The glaciated terrain in this area of southern Wisconsin is part of the Horicon Member of the Holy Hill Formation, and is made up of a mixture of layers and lenses of glacial till and meltwater deposits consisting of sand, silt, clay, and gravel (Syverson and Mickelson, 2011). To accurately locate the distribution of aquifer and aquitard materials, and to determine water table levels around the area, requires analyzing a substantial amount of well data.

METHODS

Well data were collected from two types of wells: monitoring wells and private wells. These data were used to create a fence diagram to depict water table levels and the distribution of subsurface materials in three dimensions. This three-dimensional hydrogeologic model makes it easier to visualize the spatial relationships between Clear Lake, the surrounding water table, and subsurface materials. The well data were also used to create a water table map.

Monitoring Wells

Four monitoring wells were drilled: two on the north side of Clear Lake and two on the southwest side of Clear Lake, north of Duck Lake. The wells were drilled using the Wisconsin Geological & Natural History Survey (WGNHS) drill rig (Fig. 1). A 4.25-inch hollow-stem auger was used, which allowed split-spoon sampling of sediments to be done. A water table monitoring well was installed at both locations, in addition to a piezometer. On the southwest side of Clear Lake, the shallower well, Monitoring Well 1A (MW1A), was drilled to 35 feet below ground level (bgl) and a 10-foot screen was installed between 33.7 and 23.7 feet to monitor the water table. Next to MW1A, a 43-foot-deep piezometer, MW1B, was drilled and a 2-foot screen was installed between 39.5 and 37.5 feet bgl. Two-inch I.D. PVC pipe was used for casing and screen on all four wells.

Figure 1. Well MW2B being drilled north of Clear Lake with the Wisconsin Geological & Natural History Survey drill rig.

On the north side of Clear Lake, another water table monitoring well (MW2A) was drilled to 39 feet with a 10-foot screen installed from 38.4 to 28.4 feet bgl. A piezometer (MW2B) was drilled to 50 feet and screened from 48.3 to 46.3 feet bgl. A split-spoon sampler was driven down inside the auger to take samples of sediments at both locations. Two-foot-interval samples were taken down to 35 feet in MW1A and down to 39 feet in MW2A. Samples could not be taken any deeper due to water pressure forcing sand up inside the auger. Deeper drilling was therefore done with a wooden plug in the bottom of the auger and no sediment sampling. The samples were examined for grain size and shape, sorting, density/consistency, moisture content, Munsell color, and whether or not they reacted to HCl. Samples were bagged and kept for further analysis in the lab if needed.

After well construction was completed, volumes of filter packs and saturated depths of well casings were calculated for well development. Standard practice for well development is to bail out ten times the volume of water as that contained within the filter pack and the saturated depth of the well casing combined, to remove any sediment in the well (WI Legislature, Ch. NR 141). The four wells were developed using bailers lowered down the wells repeatedly until the appropriate amount of water was removed and the water became clear (Fig.2).

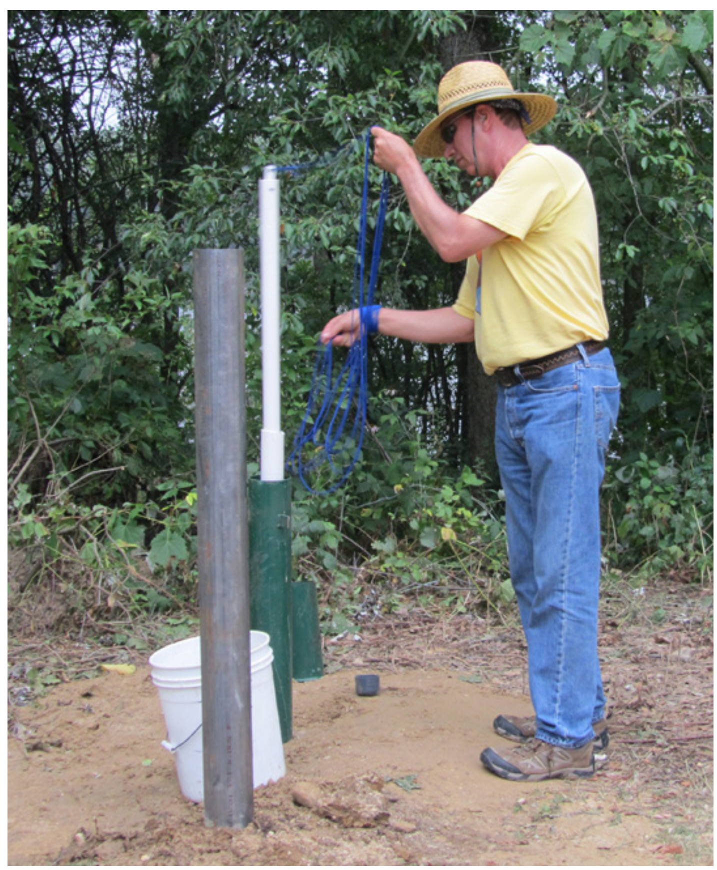

Figure 2. Development of well MW1B using a bailer.a

After well development was completed, water levels in all four monitoring wells were measured and recorded. State of Wisconsin Monitoring Well Construction and Development forms were completed for all wells and submitted to the WDNR. Water levels in these wells continue to be monitored by the WGNHS. It was noted that the water table dropped in 2012 at a rate consistent with the slow drop in the level of Clear Lake.

Private Wells and Water Table Map

Well logs were obtained for 269 private wells (WGNHS, 2004; WDNR, 2012), which are all located within about a 2-mile radius of Clear Lake. Geospatial data from the Rock County Planning, Economic, and Community Development Agency and plat map information from the Rock County GIS Website were employed to find properties by owner name (Rock County GIS Website, 2008). Wells with usable data that were also locatable were plotted on maps with notations of their respective static water level elevations. Water levels in six wells owned by local residents were measured using a sonic water level meter and a reel-type water level meter with an electronic sensor. The elevations of the top of the well casings were measured using a Trimble GPS unit, and water level elevations calculated, recorded, and plotted on the maps.

Ninety-one wells within a mile of Clear Lake were plotted on a 1:6,000 scale map for use in creating both the water table contour map and the fence diagram. Wells were color-coded by the decade in which they were drilled in order to help determine if variations in reported static water levels between neighboring wells were due to changes in water levels at different times or other factors. Some variations were attributed to errors or differences in methods by the drillers. Water levels reported for wells drilled in 2008, or after, were about 10 feet higher, on the average, than older reported levels, as were the levels in the monitoring wells and private wells which were measured in July 2012. In order to ensure results consistent with the 804-foot lake level on the 1971 USGS map, which was used to create the water table map, high water table levels that were measured after the flooding began in 2008 were not used. Water table contour lines were drawn on the map in places where there were enough well data (Fig. 3). Data from eighty of the ninety-one wells on the map were used to draw the contour lines; the other eleven were not deemed usable for this purpose.

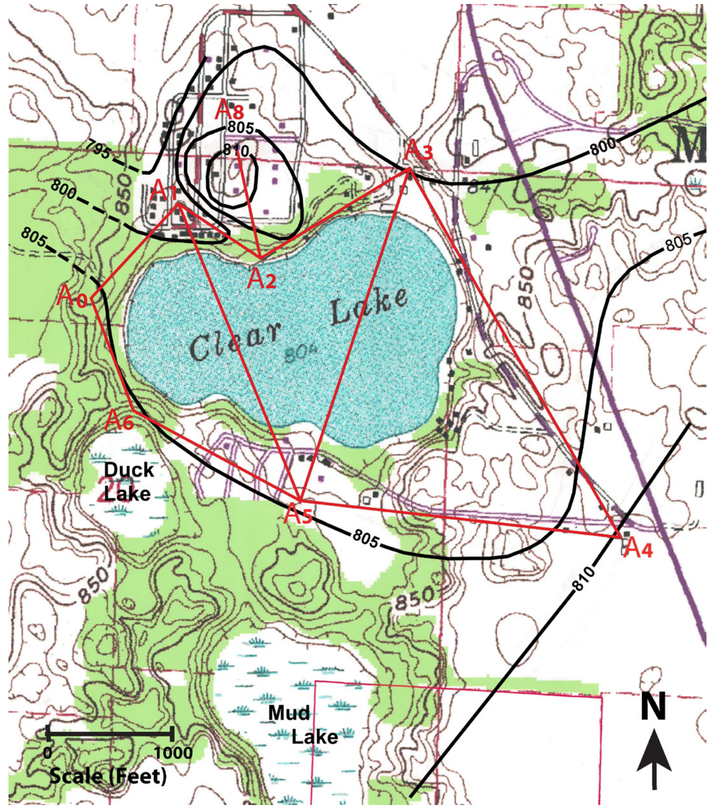

Figure 3. Water table contour map. Black lines represent water contour lines at 5-foot intervals. Red lines and typing represent fence diagram cross-section lines and endpoints.

Nine hand-drawn cross-sections were drafted and used to form a fence around and through Clear Lake. Lake-bed contour lines used to make the cross-sections that extend across the lake were obtained from a bathymetric map of the lake (Graham, 2013). Cross-section endpoints were labeled A_0 through A_8. Lines and endpoints are colored red on Figure 3. These cross-sections were then used to create a hand-drawn fence diagram (Fig.4). To create the cross-sections and fence diagram, data from 21 wells were used, including water table levels and varying depths of sedimentary materials reported on the well logs. Sedimentary materials were divided into two groups: aquifer materials (sand and gravel), and aquitard materials (clayey sediments, and clay). These were plotted on the diagrams in terms of their elevations above sea level and correlated in the areas between wells to depict what was deemed the most realistic interpretation.

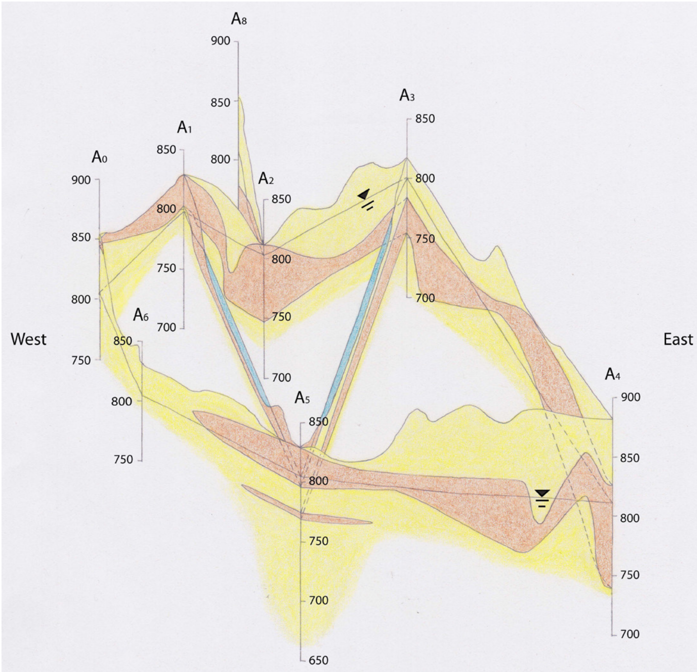

Figure 4. Fence diagram of Clear Lake area depicting distribution of subsurface materials and water table levels. Black triangle symbols identify the water table level line. Brown areas depict aquitard materials (clay). Yellow areas depict aquifer materials (sand and gravel). Blue areas depict water in Clear Lake. Elevations are in feet above sea level. See Figure 3 for scale and location.

RESULTS

Monitoring Well Water Levels

The water levels in monitoring wells 1A and 1B were first measured on July 20, 2012. The water levels in water table well, MW1A, and the piezometer, MW1B, had the same hydraulic head of 811 feet asl, as did Clear Lake and Duck Lake at the same time. These wells are located between the two lakes and therefore, no vertical gradient existed between the lakes and the wells. A slight horizontal gradient was indicated by northward groundwater flow at this location as seen in Figure 3.

Water levels in the other two monitoring wells were first measured on July 24, 2012. The water levels in water table well MW2A and piezometer MW2B had the same hydraulic head of 810 feet asl, thus no vertical gradient existed between the water levels in the two wells. A horizontal gradient sloping to the west was indicated by the westward flow of groundwater at this location as seen in Figure 3.

Water Table Map

The contour lines drawn on the water table map (Fig. 3) show the overall flow of groundwater to be in a north-northwesterly direction. The 810-foot contour line in the southeastern area of the map, combined with other contour lines, shows a flow from the southeast toward Duck Lake and Clear Lake. Flow becomes more complicated immediately north of Clear Lake where the water table again rises to 810 feet, under a hill, and flows away from that hill in all directions, including back southward toward the lake. No contour lines were placed in the southwestern area of the map due to lack of enough well data in that immediate area.

Distribution of Subsurface Materials

The fence diagram (Fig. 4) shows the distribution of subsurface materials. The diagram shows that significant clay layers exist around and under the lake, but no clay is present in the shallow subsurface on the southwest and west sides of the lake. A thick clay layer is present around the south, east, and north sides of the lake and it extends to or under the lake in some areas. In the middle of the lake, it appears that two clay layers exist, one that extends from the northwest side to the south side and one that extends from the northeast side to the same point on the south side.

DISCUSSION

It was previously stated that wells MW1A and MW1B, located between Clear Lake and Duck Lake, have the same hydraulic head as these lakes and no vertical gradient, at least on the date of measurement. A regional water table map of Rock County (Gaffield, et al., 2002) depicts groundwater flowing from the southwest, the south, and the southeast toward Clear Lake. These flows converge in the vicinity of Clear Lake, while groundwater flows out of the area in only one direction: north-northwestward, toward Lake Koshkonong and the Rock River. The groundwater flow directions are consistent with the results obtained in Figure 3, which also shows more complicated, localized flow. For example: just north of Clear Lake, groundwater flows from an elevation of 810 feet down to lake level. The 6-foot water table difference between 810 feet and 804 feet is a large change in hydraulic head for such a short distance, and some of this flow is southward. These results provide clear evidence of groundwater and surface water interactions.

Clay layers under and around the lake also affect the flow of groundwater in the immediate vicinity of the lake. The fence diagram (Fig. 4) shows that there is a thick clay layer north of the lake that may impede groundwater flow. The only large areas of the lake where groundwater can flow into or out of the lake unimpeded by clay layers is the area on the southwest and west sides, and the area on the northeast side.

Figure 4 shows a significant clay layer extending from the south side of the lake, around the east side, on around the north side. This clay is at the water table level for most of its length. It is not certain whether or not this clay extends all the way to and/or under the lake on the southeast side because well data for wells closer to the lake, on the southeast side, were not available. But, it is quite possible that it does extend that far. It is also possible that this clay significantly restricts inflow and outflow of groundwater to the lake in much of the area on the southeast and east sides of the lake.

CONCLUSION

It has been shown that groundwater is converging on the Clear Lake area from multiple directions, but only flowing out in one direction. It has also been shown that groundwater flow is being impeded by clay layers in the immediate vicinity of Clear Lake. It appears likely that the combination of these conditions is causing groundwater retention in the area, and that groundwater retention is the controlling factor in the sustained flooding. If more time and money were available, it would be beneficial to drill more wells to obtain more data and conduct further research. Well data is lacking along the south, southeast, and east shorelines of the lake. It would be most beneficial to drill wells close to the shoreline of the lake, from the south side at Blackhawk Beach, on around the southeast side, and on up the east side.

ACKNOWLEDGEMENTS

I thank the Keck Geology Consortium, project directors Sue Swanson and Justin Dodd, and the Clear Lake Improvement Association for making this project possible. I give special thanks to Clear Lake area property owners who gave us access to their properties, to Tom and Arra Lasse for their generous hospitality, to Roman and Joyce Szymberski for their support and for letting us drill wells on their property, and to the WGNHS for drilling and well construction. And last, but not least, I thank Sue Swanson and Erik Melchiorre for their advice and technical support.

REFERENCES

Gaffield, S., Gotkowitz, M., and Bradbury, K., 2002, Delineation for zones of contribution for municipal wells in Rock County, Wisconsin: Final report, Wisconsin Geological and Natural History Survey Open-File Report 2002-02, 47 p.

Graham, G., 2013, Lake budget analysis to understand groundwater flooding of a seepage lake near Milton, WI, *in* Proceedings of the Twenty-sixth Annual Keck Research Symposium in Geology: Pomona College, Claremont, CA.

Rock County GIS Website, 2008, Rock County GIS Map Viewer: http://199.233.45.152/Rock/ (August 2012).

Syverson, K.M., and Mickelson, D.M., 2011, Holy Hill Formation, *in* Syverson, K.M., Clayton, L., Attig, J.W., and Mickelson, D.M., eds., Lexicon of Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

U.S. Geological Survey, 1971, Milton, Wisconsin Quadrangle 7.5 Minute Series Topographic Map, product no. 262460, scale 1:24,000, 1 sheet.

Wisconsin Department of Natural Resources, 2012, Scanned images of Wisconsin Well Constructor's Reports: Rock County, 1990-present, updated every 6 months.

Wisconsin Geological and Natural History Survey, 2004, Scanned images of Wisconsin Well Constructor's Reports: Rock County, 1936-89: Wisconsin Open-File Report 2001-02 RO, CD-ROM.

Wisconsin Legislature, Chapter NR 141: Groundwater monitoring well requirements: http://docs.legis.wisconsin.gov/code/admin_code/nr/141 (July 2012).