Natural Heat Storage in a Brine-Filled Solar Pond in the Tully Valley of Central New York

Introduction

The Tully Valley, located in southern Onondaga County, New York, has a long history of unusual natural hydrogeologic phenomena including mudboils (Kappel, 2009), landslides (Tamulonis and others, 2009; Pair and others, 2000), land-surface subsidence (Hackett and others, 2009; Kappel, 2009), and a brine-filled sinkhole or “Solar pond” (fig. 1), which is documented in this report. A solar pond is a pool of salty water (brine) which stores the sun’s energy in the form of heat. The saltwater naturally forms distinct layers with increasing density between transitional zones (haloclines) of rapidly changing specific conductance with depth. In a typical solar pond, the top layer has a low salt content and is often times referred to as the upper convective zone (Lu and others, 2002). The bottom layer is a concentrated brine that is either convective or temperature stratified dependent on the surrounding environment. Solar insolation is absorbed and stored in the lower, denser brine while the overlying halocline acts as an insulating layer and prevents heat from moving upwards from the lower zone (Lu and others, 2002). In the case of the Tully Valley solar pond, water within the pond can be over 90 degrees Fahrenheit (^{o}F) in late summer and early fall. The purpose of this report is to summarize observations at the Tully Valley brine-filled sinkhole and provide supplemental climate data which might affect the pond salinity gradients insolation (solar energy).

Seasonal views of the Tully Vallely solar pond.

U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2013–1266
December 2013

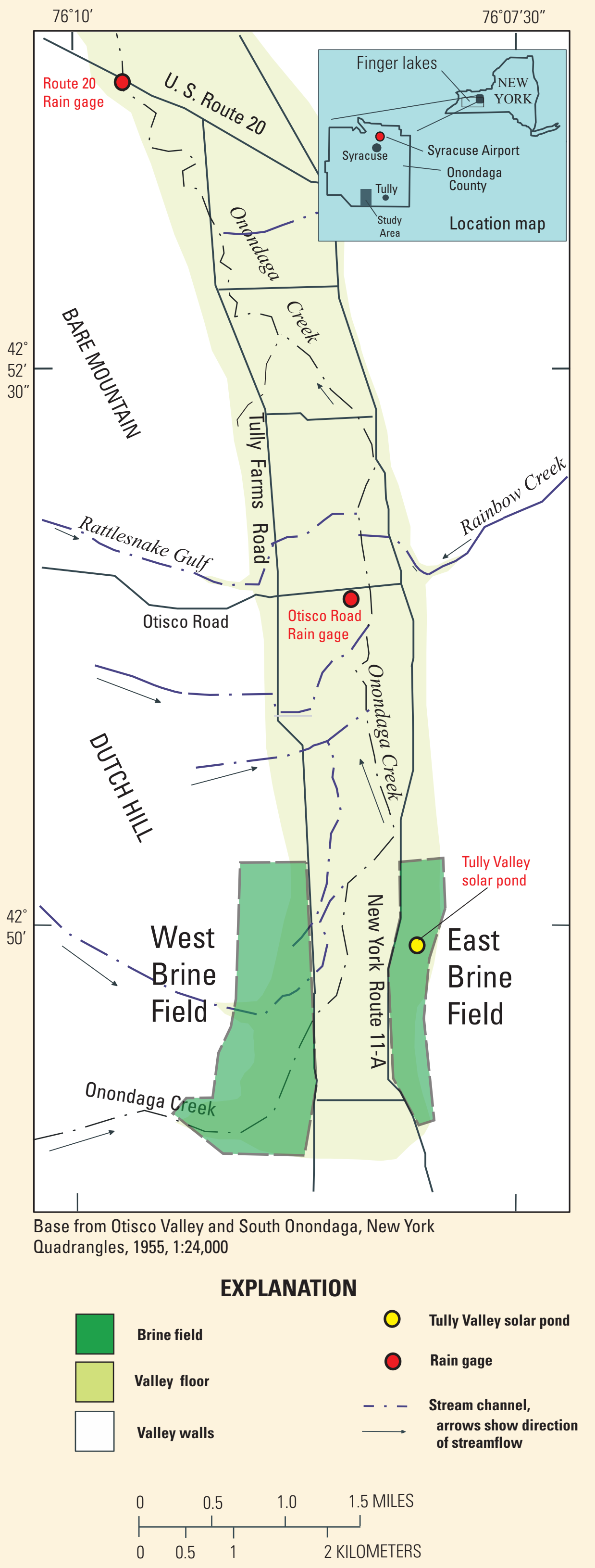


Figure 1. Physiographic features in the Tully Valley, Onondaga County, New York.

Thermal Energy from Brine Ponds

When thermal energy of brine increases with increasing salinity so does the overall density of the brine, which increases overall enthalpy of the system. (Dittman, 1977). Within the last 40 years, brine-filled ponds have been studied for heat storage and for supplying thermal energy for power generation and desalination (Lu and others, 2002; TERI, undated). The largest operational solar pond for electric generation had an area of 2.25 million square feet (ft^2), produced 5 megawatts (MW) of power, and was located near the equator in Beit HaArava, Israel; this site operated between 1974 and 1988 (Faiman, undated). Solar ponds have been used for electrical power generation and heating and cooling around much of the world (Faiman, undated; TERI, undated). In the late 1990s the U.S. Bureau of Reclamation funded “Thermal Desalination using MEMS (Multi Effect, Multi Stage) and Salinity-Gradient Solar Pond Technology” through the University of Texas at El Paso (Lu and others, 2002) The research summarized the efficiencies and economics of solar ponds used for desalination and the operation and maintenance of salinity-gradient solar ponds. The El Paso Solar Pond Project found economic viability in low-cost ponds of 2.5 acres and larger and were estimated to produce medium-grade, thermal energy (120 to 200 °F) at costs competitive with systems driven by natural gas, especially in areas associated with inland desalination projects (Salinity Gradient Solar Technology, undated).

Full-scale experiments were also conducted by the Ohio State University (OSU) in conjunction with the Department of Agricultural Engineering Greenhouse at the Ohio Agricultural Research and Development Center. The OSU design (12-foot diameter by 4-feet-deep tank) met all the winter heat requirements for a 2,000 ft^2 home or a 1,000 ft^2 greenhouse (Fynn and Short, 1983). Wherever the research and application, the approach is particularly attractive for rural areas to meet the needs of well-insulated homes and low temperature agricultural applications (Fynn and Short, 1983).

Tully Valley Solar Pond

The Tully Valley solar pond is the result of a former solution mining well discharging concentrated brine into a sinkhole that formed in a natural bed of lacustrine clay. This sinkhole formed in the early 1950s due to land-surface subsidence as a result of solution-brine mining in the southeastern end of the Tully Valley (fig. 1) between the 1890s and the mid-1980s (Hackett and others, 2009). The discharging brine well was sealed in the early 1990s, and the salty pond was discovered during a routine field survey of several sinkholes in the former brine mining area in June 2007. While constructed solar ponds are generally shallow, approximately 10 feet deep and usually have three distinct specific conductance layers, the Tully Valley solar pond is more complex because of its greater depth (approximately 21 feet) and has six distinct layers, which are described later.

Profiles of water temperature, specific conductance, and salinity (See appendix 1; available separately at *http://pubs.usgs.gov/of/2013/1266/*) were made over the deepest part (center) of the pond and were initially collected monthly beginning in June 2007. (Note: All specific conductance readings are listed at 25 degrees Celsius (°C) throughout this report.) A Yellow Springs Instrument Model 30 Temperature, Conductivity, Salinity meter [1] was used to collect all profile data. The sonde cable was marked every foot for consistent depth readings, and the instrument was calibrated against known standards several times each year and did not require any recalibration throughout the data collection period. After the first year, profile measurements were made about every 2 months, and data collection ceased in July 2010. These profile measurements were made at the pond surface and 1-foot increments to the bottom of the pond (21 feet). Figure 2 illustrates the 27 periodic, specific conductance profiles over the 40-month period of study. The figure indicates how little the specific conductance zones changed in relation to precipitation, evapotranspiration, and seasonal fluctuations of air temperature, solar irradiance, water clarity, and heat loss to the ground and the atmosphere over this time.

A fresher-water layer (designated S1–Stable Layer 1) was found between the pond's surface and a 2-foot depth; specific conductance varied seasonally between 5,700 and about 20,000 microsiemens per centimeter (uS/cm). Layer S1

[1] Use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

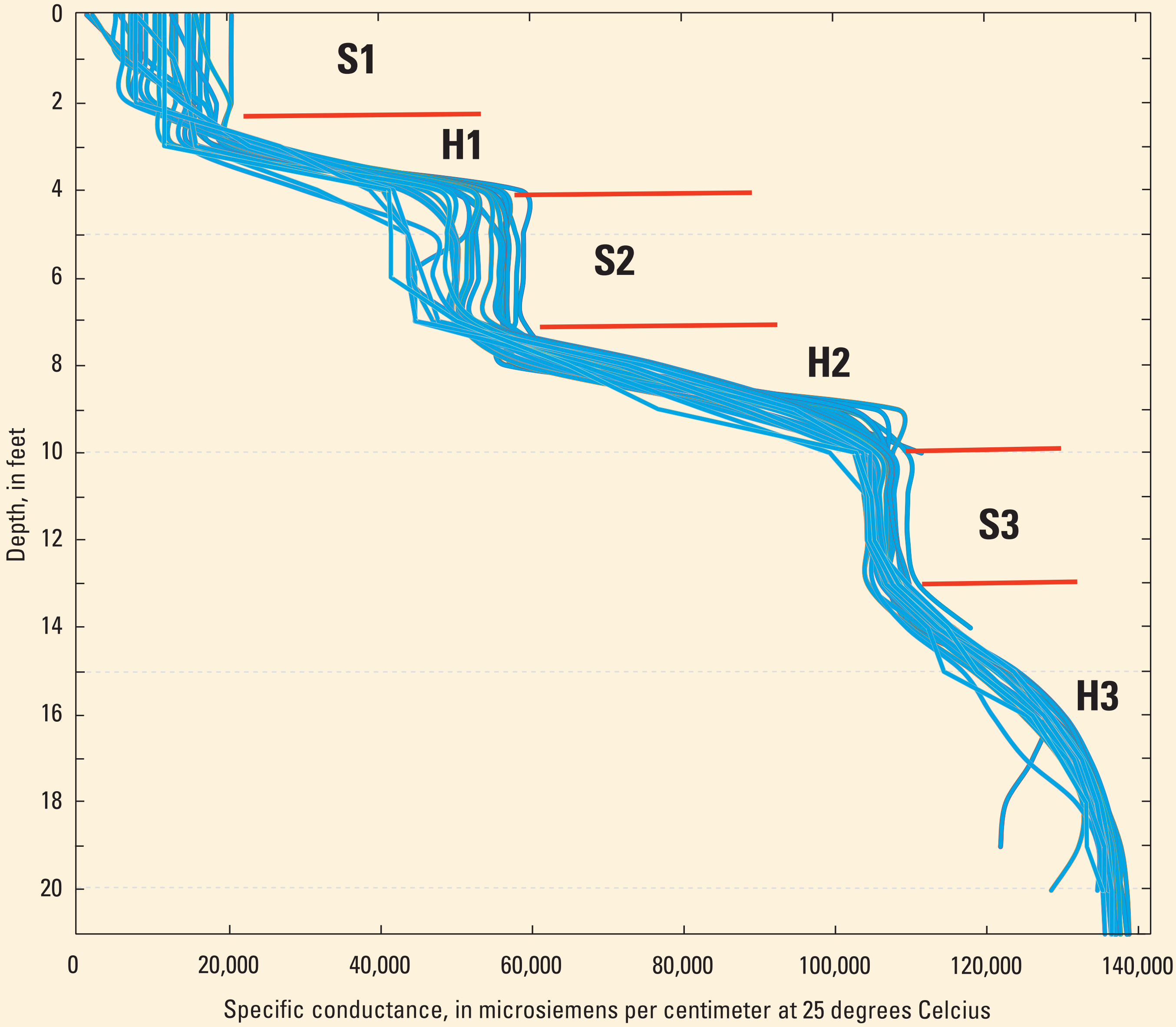


Figure 2. Specific conductance profiles in the Tully Valley solar pond defined from 27 sets of field observations between June 2007 and July 2010, showing the stable (S) and halocline (H) specific conductance layers in the pond.

is directly affected by evapotranspiration and precipitation at the pond's surface, which in turn, can change the pond's surface elevation and thus surface area. The first halocline layer (designated H1–Halocline Layer 1) is a layer of rapidly changing conductivity with depth and is found between 2 and 4.5 feet deep. Layer H1 acts to partly insulate the layers below, and the specific conductance values in H1 transition from about 20,000 to nearly 40,000 µS/cm. The next layer (S2) is between 4.5 and 7 feet and has specific conductance values that seasonally vary from 40,000 to 60,000 µS/cm. The second halocline layer (H2) is between 7 and about 10 feet, with specific conductance values that are relatively constant but vary by depth between 60,000 and just over 105,000 µS/cm, providing insulation for the layers below; the H2 layer has more consistent conductivity than the H1 layer above based upon the compact nature of the 27 profiles collected in this layer. The third stable layer (S3) from 10 to about 13 feet has a rather narrow and consistent range of conductivity from 105,000 to 115,000 µS/cm. The bottom halocline (H3) displays a uniform specific conductance profile from 115,000 to nearly 140,000 µS/cm where the densest brine in the pond is found.

Thermal storage capacity is most prevalent in the deeper layers and is apparently related to the degree of brine saturation, solar irradiance, and water clarity in the S1, H1, and S2 layers. Heat loss occurs at the perimeter of the pond from all layers and back to the atmosphere from only the S1 layer.

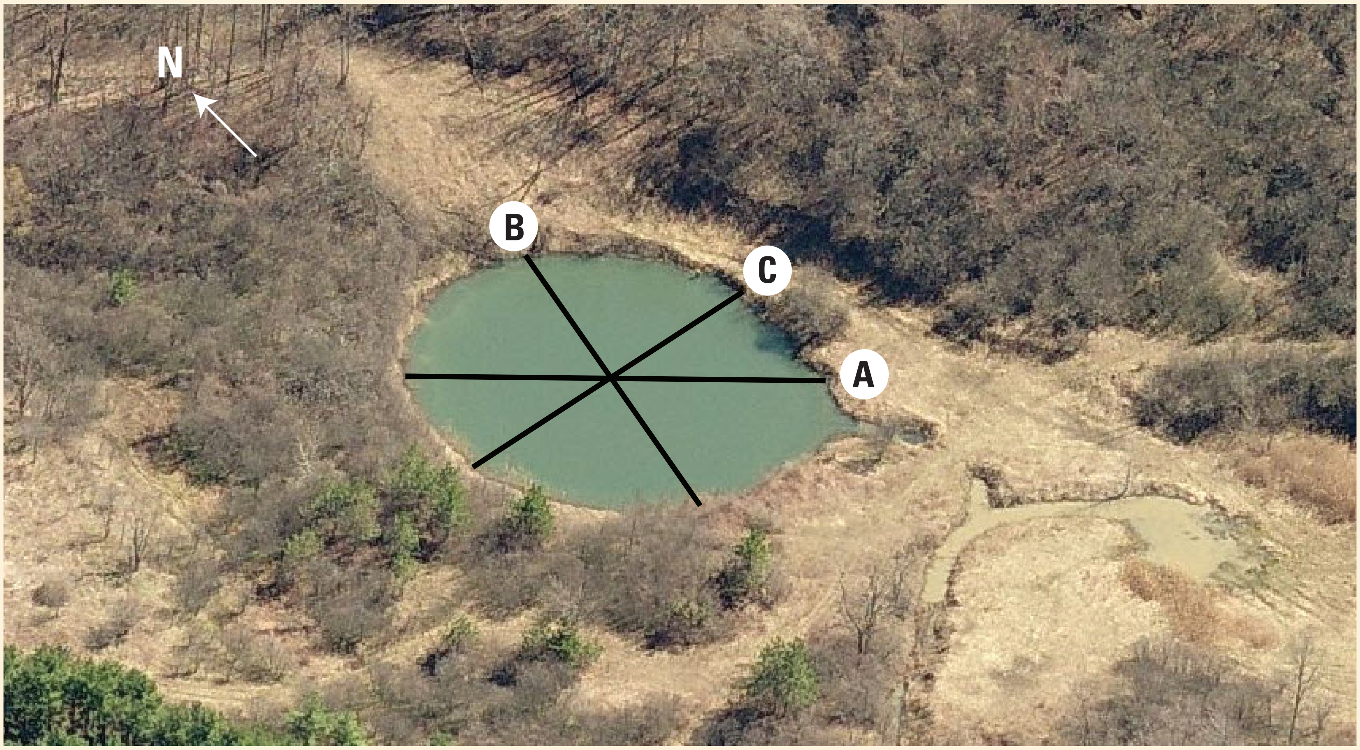
Pond Geometry and Clarity

Three acoustic surveys of the pond (fig. 3) were made on April 10, 2008, to determine the shape and calculate the volume of the pond. The pond was found to be a relatively flattened half-sphere with an average surface diameter of 170 feet with an average maximum depth of 21.4 feet. Surface area of the pond was about 22,800 ft^2, and the volume of the pond was about 324,000 cubic feet.

Water clarity is an important factor for solar irradiance entering the pond. Beginning in October 2008, Secchi disk transparency data were collected to understand how water clarity changed over time. It was found that the deepest Secchi disk observations (>11 feet) occurred in the early spring through mid-summer, while from summer into the fall, clarity diminished to approximately 6 feet, and by early winter with or without ice cover, clarity was reduced to 5 feet or less. Also, usually during the summer, an iridescent sheen was periodically reported floating on the water surface. This sheen was not petroleum based but most likely produced by iron bacteria within the pond as the sheen was easily "broken" into plates whereas a petroleum-based sheen that would immediately flow back together.

Solar Irradiance

The sun emits electromagnetic radiation, (the primary type reaching the earth's surface being infrared radiation),



Imagery by Pictometry International Corporation

Figure 3. Aerial picture of the Tully Valley solar pond taken April 2007, showing the location of the three acoustic transects for determination of the pond geometry.

which is measured at the earths' surface in units of watts per square meter (W/m^2). The warming of the ground, water, and atmosphere is the direct result of the infrared radiation interacting with the earth's atmosphere and land/water surfaces. The amount of the heating is variable due to the location on the earth's surface (latitude), length of the day-night cycle, position of the sun relative to the earth's surface (seasonality), weather (clouds), and atmospheric pollution.

Solar irradiance for the Tully Valley solar pond was estimated from data collected at the Syracuse International Airport (J. Rennells, Northeast Regional Climate Center, written commun., 2012), approximately 15 miles north of the Tully Valley. The 2007–2010 monthly means of solar irradiance are shown in figures 4A–C. In 2007–08 the mean monthly irradiance was slightly above the 30-year (yr) normal for the first half of the period, then moderated on either side of the average for the second half (fig. 4A). In 2008–09 solar irradiance generally followed the 30-yr normal for the period (fig. 4B). In 2009–10 solar irradiance from June 2009 to February 2010 was below average whereas the rest of the period was generally above normal except for June 2010 (fig. 4C).

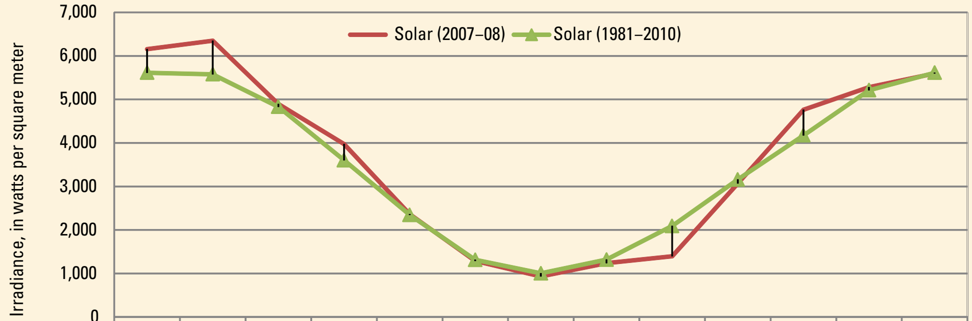
Air Temperature

For the Tully Valley (greater Syracuse, NY. region) the average mean temperature is 48.2 °F, and annual average low and high temperatures range from 17 °F to 84 °F (National Climatic Data Center, 2012). Summer daytime temperatures are usually between 70 and 80 °F with occasional 90 °F and above temperatures, whereas winter low temperatures can range between 0 °F and -10 °F. The average central New York freeze-free growing season is between 150 and 180 days long (National Climatic Data Center, 2012).

Air temperature, collected at the Syracuse Hancock International Airport for the period of 2006–2010, is shown in figures 5A–C and provides a means to estimate monthly mean air temperatures for the Tully Valley (maximum, minimum, and mean values). A 30-yr normal temperature for 1981 to 2010 (National Climatic Data Center, 2012) provides a

View of the Tully Valley Solar Pond looking north during the Fall of 2009.

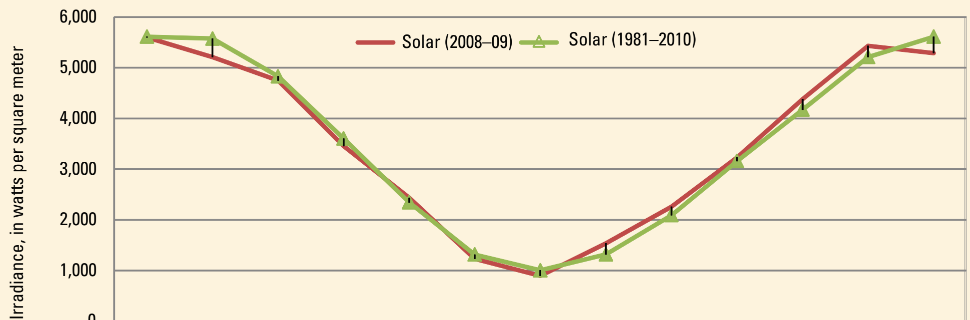
A. **Monthly mean solar irradiance 2007–2008**



	JUNE 2007	JULY 2007	AUG. 2007	SEPT. 2007	OCT. 2007	NOV. 2007	DEC. 2007	JAN. 2008	FEB. 2008	MAR. 2008	APR. 2008	MAY 2008	JUNE 2008
Solar_Mean	6155	6348	4893	3973	2362	1287	933	1236	1398	3071	4761	5279	5598
Solar (1981–2010)	5613	5576	4830	3603	2345	1314	1004	1317	2091	3160	4175	5211	5613

Month

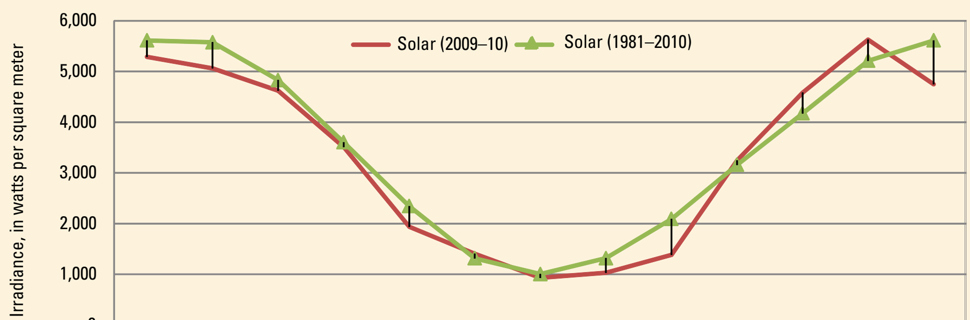
B. **Monthly mean solar irradiance 2008–2009**



	JUNE 2008	JULY 2008	AUG. 2008	SEPT. 2008	OCT. 2008	NOV. 2008	DEC. 2008	JAN. 2009	FEB. 2009	MAR. 2009	APR. 2009	MAY 2009	JUNE 2009
Solar_Mean	5598	5210	4749	3454	2433	1231	897	1535	2258	3232	4381	5432	5290
Solar (1981–2010)	5613	5576	4830	3603	2345	1314	1004	1317	2091	3160	4175	5211	5613

Month

C. **Monthly mean solar irradiance 2009–2010**

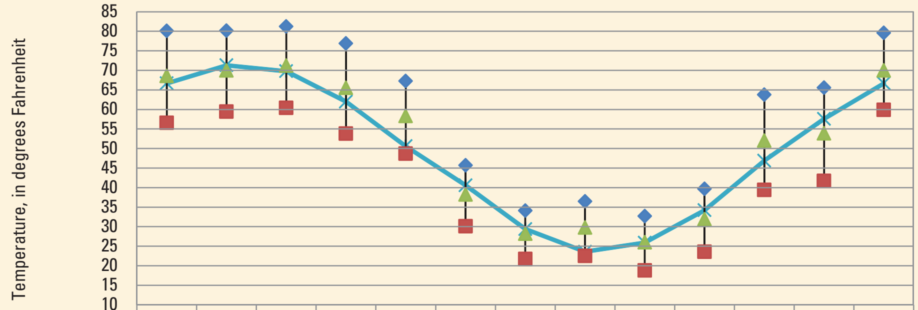


	JUNE 2009	JULY 2009	AUG. 2009	SEPT. 2009	OCT. 2009	NOV. 2009	DEC. 2009	JAN. 2010	FEB. 2010	MAR. 2010	APR. 2010	MAY 2010	JUNE 2010
Solar_Mean	5290	5061	4623	3510	1939	1406	932	1029	1385	3244	4584	5629	4748
Solar (1981–2010)	5613	5576	4830	3603	2345	1314	1004	1317	2091	3160	4175	5211	5613

Month

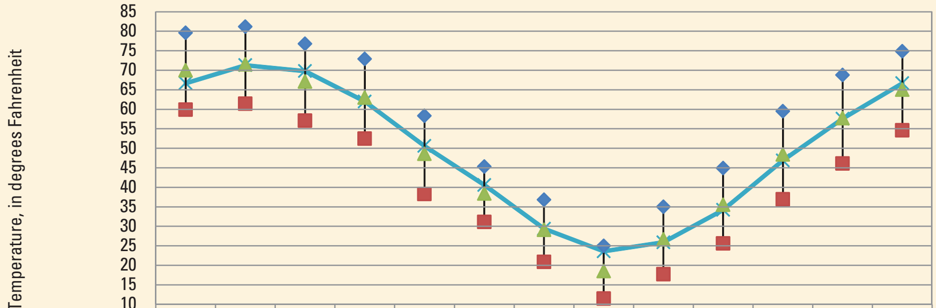
Figure 4. Long-term normal monthly solar irradiance recorded at the Syracuse, New York, airport (1981–2010) versus average monthly solar irradiance at the Syracuse airport for: *A,* June 2007 to June 2008; *B,* June 2008 to June 2009; and *C,* June 2009 to June 2010.

A. Maximum, mean, and minimum monthly air temperature 2007–2008



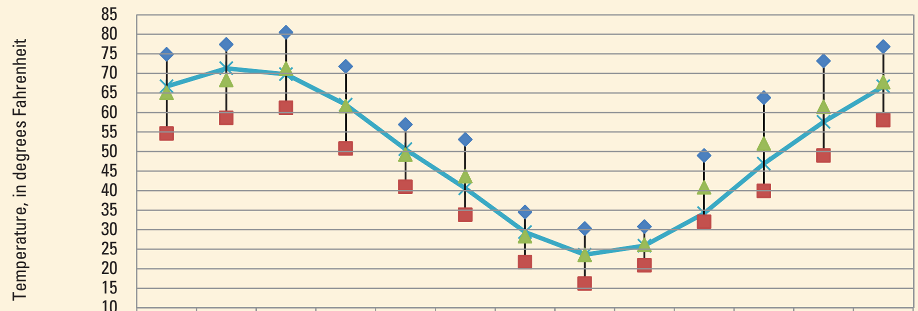
	JUNE 2007	JULY 2007	AUG. 2007	SEPT. 2007	OCT. 2007	NOV. 2007	DEC. 2007	JAN. 2008	FEB. 2008	MAR. 2008	APR. 2008	MAY 2008	JUNE 2008
Temp_Maximum	80.1	80.2	81.3	76.9	67.3	45.7	34.1	36.5	32.7	39.7	63.8	65.6	79.6
Temp_Minimum	56.6	59.4	60.4	53.8	48.7	30.1	21.7	22.5	18.8	23.6	39.4	41.7	59.9
Temp_Mean	68.6	70.0	71.2	65.5	58.3	38.2	28.2	29.8	26.0	31.9	52.0	53.9	70.0
Temp. (1981–2010)	66.7	71.3	69.8	62.0	50.6	40.6	29.4	23.6	25.9	34.2	46.9	57.6	66.7

B. Maximum, mean, and minimum monthly air temperature 2008–2009



	JUNE 2008	JULY 2008	AUG. 2008	SEPT. 2008	OCT. 2008	NOV. 2008	DEC. 2008	JAN. 2009	FEB. 2009	MAR. 2009	APR. 2009	MAY 2009	JUNE 2009
Temp_Maximum	79.6	81.2	76.8	72.9	58.3	45.3	36.8	25.0	35.0	44.9	59.5	68.8	74.9
Temp_Minimum	59.9	61.4	57.1	52.5	38.3	31.1	20.9	11.5	17.7	25.6	36.9	46.1	54.6
Temp_Mean	70.0	71.5	67.1	63.0	48.6	38.4	29.1	18.5	26.6	35.5	48.4	57.7	65.0
Temp. (1981–2010)	66.7	71.3	69.8	62.0	50.6	40.6	29.4	23.6	25.9	34.2	46.9	57.6	66.7

C. Maximum, mean, and minimum monthly air temperature 2009–2010



	JUNE 2009	JULY 2009	AUG. 2009	SEPT. 2009	OCT. 2009	NOV. 2009	DEC. 2009	JAN. 2010	FEB. 2010	MAR. 2010	APR. 2010	MAY 2010	JUNE 2010
Temp_Maximum	74.9	77.4	80.5	71.8	56.9	53.1	34.5	30.30	30.80	49.00	63.80	73.2	76.9
Temp_Minimum	54.6	58.6	61.2	50.8	41.0	33.8	21.7	16.20	20.90	32.00	39.90	49.0	58.0
Temp_Mean	65.0	68.3	71.2	61.6	49.2	43.7	28.3	23.50	26.10	40.80	52.00	61.4	67.7
Temp. (1981–2010)	66.7	71.3	69.8	62.0	50.6	40.6	29.4	23.6	25.9	34.2	46.9	57.6	66.7

Figure 5. Long-term normal monthly air temperatures recorded at the Syracuse, New York, airport (1981–2010) versus maximum, average, and minimum monthly air temperatures at the Syracuse airport for: *A,* June 2007 to June 2008; *B,* June 2008 to June 2009; and *C,* June 2009 to June 2010.

comparison to each of the 13-month cycles shown in figure 5. Mean temperatures for 2007–08 follow the 30-yr normal temperature curve with warmer autumn days in September and October 2007, and warmer January and April 2008 temperatures (fig. 5A). Temperatures during 2008–09 follow the 30-yr temperature cycle with the exception of colder days for the month of January 2008 (fig. 5B). The 2009–10 monthly mean temperatures followed the 30-yr normal until spring 2010 with higher than normal average daily temperatures for March through May 2010 (fig. 5C).

Precipitation

Monthly mean precipitation within the Tully Valley was collected at the U.S Geological Survey (USGS) Otisco Road rain gage (USGS site number 425129076082701) for the three assessment periods. Due to variations in weather patterns across the Tully Valley, data from the rain gage located at the USGS Onondaga Creek near Cardiff, NY (Route 20), streamgage (04237962) were also examined. The 30-yr normal monthly precipitation for the Syracuse area (1981–2010) was obtained from the National Climatic Data Center for comparison to the three, 13-month cycles (National Climatic Data Center, 2012). Figures 6A–C provide monthly precipitation differences as compared to the 30-yr normal. Most notably, average monthly precipitation for all three assessment periods was less than the long-term normal. May, June, and August of 2008 had minor amounts of precipitation (figs. 6A and B), but several months also had much above normal precipitation throughout the three assessment periods—indicative of greater climate and precipitation variability—as comparisons between the Otisco Road and Route 20 raingages confirm lower than expected precipitation for most of 2008 in the Tully Valley.

Water Quality

Water-quality samples were collected by using a Van Doren bottle sampler at the center of the solar pond at depths of 4 feet and 18 feet (Zones S2 and H3) on three occasions—December 9, 2008, September 1, 2009, and April 5, 2010. The samples in the upper and lower parts of the pond were collected and processed in a churn splitter in the field using standard USGS techniques (Wilde and others, 1999a and b) and shipped to the USGS Denver, Colorado, water-quality laboratory for analysis. The samples were analyzed for basic inorganic constituents—chloride, fluoride, bromide, sulfate, and alkalinity, total dissolved solids—calcium, iron, magnesium, manganese, potassium, silica, and sodium (table 1), and nutrients—dissolved ammonia, ammonia plus organic nitrogen, nitrite, nitrite plus nitrate, dissolved phosphorus, and orthophosphate (table 2).

Results of these analyses indicate that most inorganic constituents had greater values at the 18-foot depth with the exception of sulfate which was less concentrated than at the 4-foot depth. pH was lower at the 18-foot depth due to increased alkalinity and an increased calcium concentration than at the 4-foot depth. The nutrient analyses indicate a reduction of ammonia at the 4-foot depth due to nitrification resulting from ammonia oxidation of decomposing plant and animal matter trapped in the bottom of the pond. In addition, phosphorus was greater at an 18-foot depth as a result of dissolved phosphate run-off and decomposing plant matter at the bottom of the pond.

Water Temperature Cycling

Water temperature profiles were also collected along with the specific conductance and salinity profile data The 27 temperature profiles were then used to create isohyetal temperature diagrams for the 3 assessment periods—June to June for 2007–2008, 2008–2009, and 2009–2010 (figs. 7A–C). The isohyetal temperature diagrams show areas of similar water temperature in the solar pond over time. All three diagrams have similar characteristics—a 90 °F or higher temperature "bubble" that usually begins to form in June of each year at a depth of about 5 to 6 feet, at the bottom of halocline zone (H1), and slowly grows in size and depth over the next several months into the lower layers (S2, H2, S3, and H3).

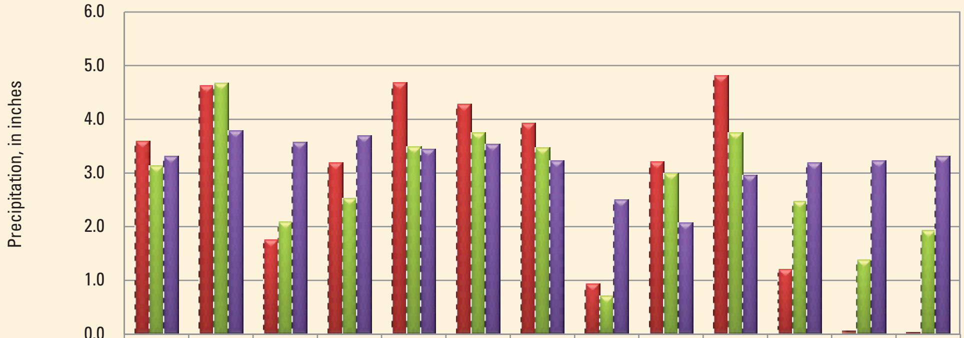
By late summer, the bubble becomes smaller and remains in the deeper H3 part of the pond through either November or December of each year. The 80 °F bubble starts slightly higher in the H1 zone and usually lasts through February of the following year in the H3 zone before it too dissipates its heat and the water temperature drops into the 70 °F range until early spring, when increasing solar irradiance begins the next heat-storage cycle. During the winter months the upper water surface cools like a regular pond with ice covering the pond surface. Colder temperatures in the 50–60 °F range persist below the upper halocline (H1) zone, but as springtime approaches, the ice melts and water temperature in the pond quickly responds to increased solar irradiance.

Conclusions

The development of a solar pond in the Tully Valley was accidental due to land-surface subsidence adjacent to discharging brine well in a former brine-field area. Although the well was sealed in the early 1990s, the resulting sinkhole was naturally lined with a thick clay deposit which prevented the dense brine from leaking out of the pond since well closure. A series of 27 specific conductance, salinit , and water temperature profiles were made between June 2007 and July 2010 to document the range of the specific conductance and temperature fluctuation that occurred within the pond

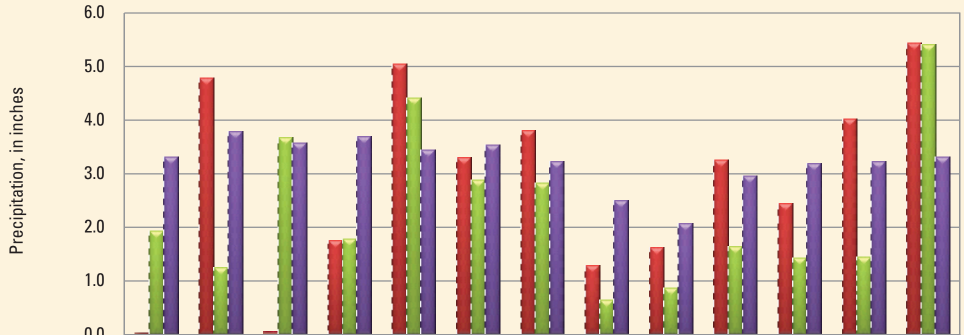
Three environmental factors were assessed which were likely to affect the ability of the solar pond to gain energy—solar irradiance, air temperature, and precipitation—all of which were measured remotely and not at the pond itself. Of the three factors, solar irradiance appears to be the primary driver of increasing water temperature change in this pond each summer. Comparing solar irradiance (fig. 4) to measured pond water

A. Monthly mean precipitation 2007–2008



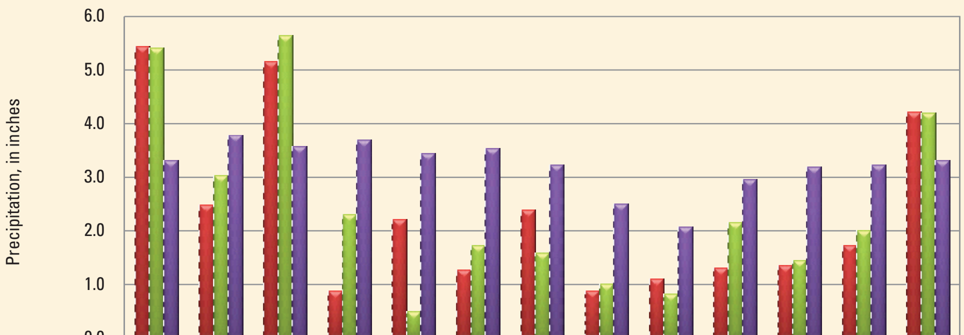
	JUNE 2007	JULY 2007	AUG. 2007	SEPT. 2007	OCT. 2007	NOV. 2007	DEC. 2007	JAN. 2008	FEB. 2008	MAR. 2008	APR. 2008	MAY 2008	JUNE 2008
Otisco Road Precip.	3.6	4.6	1.8	3.2	4.7	4.3	3.9	0.9	3.2	4.8	1.2	0.1	0.0
Cardiff Precip.	3.13	4.67	2.09	2.53	3.49	3.75	3.47	0.7	2.99	3.75	2.47	1.38	1.93
Precip. (1981–2010)	3.31	3.78	3.57	3.69	3.44	3.53	3.22	2.50	2.07	2.95	3.19	3.22	3.31

B. Monthly mean precipitation 2008–2009



	JUNE 2008	JULY 2008	AUG. 2008	SEPT. 2008	OCT. 2008	NOV. 2008	DEC. 2008	JAN. 2009	FEB. 2009	MAR. 2009	APR. 2009	MAY 2009	JUNE 2009
Otisco Road Precip.	0.0	4.8	0.1	1.8	5.1	3.3	3.8	1.3	1.6	3.3	2.4	4.0	5.4
Cardiff Precip.	1.93	1.25	3.67	1.78	4.41	2.88	2.83	0.64	0.86	1.64	1.43	1.44	5.41
Precip. (1981–2010)	3.31	3.78	3.57	3.69	3.44	3.53	3.22	2.50	2.07	2.95	3.19	3.22	3.31

C. Monthly mean precipitation 2009–2010



	JUNE 2009	JULY 2009	AUG. 2009	SEPT. 2009	OCT. 2009	NOV. 2009	DEC. 2009	JAN. 2010	FEB. 2010	MAR. 2010	APR. 2010	MAY 2010	JUNE 2010
Otisco Road Precip.	5.4	2.5	5.2	0.9	2.2	1.3	2.4	0.87	1.10	1.30	1.35	1.72	4.21
Cardiff Precip.	5.41	3.03	5.64	2.3	0.49	1.73	1.58	1	0.82	2.15	1.44	2	4.2
Precip. (1981–2010)	3.31	3.78	3.57	3.69	3.44	3.53	3.22	2.50	2.07	2.95	3.19	3.22	3.31

Figure 6. Average monthly precipitation in the Tully Valley recorded at the Otisco Road and Cardiff raingages for: *A,* June 2007 to June 2008; *B,* June 2008 to June 2009; and *C,* June 2009 to June 2010 versus the long-term normal monthly precipitation (1981–2010) recorded at the Syracuse, New York airport.

Table 1. Concentrations of selected major ions and pH in samples collected from 4-foot and 18-foot depths in the solar pond, Tully Valley, New York, December 9, 2008, September 1, 2009, and April 5, 2010.

[National Geodetic Vertical Datum of 1929. Elevation and depth are in feet. All values are in milligrams per liter except as noted. E, estimated; <, less than; --, no value; µg/L, micrograms per liter]

	12/9/2008		9/1/2009		4/5/2010	
Pond elevation	708.08		708.36		707.75	
Sample depth from surface	4	18	4	18	4	18
pH, standard units	7.1	6.9	7.1	6.7	7.4	6.7
Dissolved solids dried at 180 degrees Celsius	67,100	93,700	53,900	94,600	26,200	96,300
Alkalinity	360	860	310	872	249	980
Bromide	--	29.7	16.8	30.3	7.42	29.4
Calcium	576	869	428	919	212	845
Chloride	41,500	58,600	35,100	59,700	16,800	59,100
Fluoride	0.11	0.17	E0.07	<0.08	0.12	0.13
Magnesium	99.9	131	76	131	38.3	124
Potassium	35.2	51.5	29.6	52.9	13.4	62.2
Silica	7.63	15.2	8.71	17.4	<1.45	19.1
Sodium	25,000	35,800	19,200	35,000	9,390	33,700
Sulfate	210	32.4	168	25.1	78.7	<18
Iron, µg/L	E104	5,620	<200	4,640	<150	22,100
Manganese, µg/L	97.8	14,000	76.8	19,000	20.6	19,200

Table 2. Concentrations of selected nutrients in samples collected from 4-foot and 18-foot depths in the solar pond, Tully Valley, New York, September 1, 2009, and April 5, 2010.

[National Geodetic Vertical Datum of 1929. Elevation and depth are in feet. All values are in milligrams per liter. N, nitrogen; P, phosphorus; E, estimated; <, less than; --, no value]

	9/1/2009		4/5/2010	
Pond elevation	708.36		707.75	
Sample depth from surface	4	18	4	18
Ammonia plus organic nitrogen, filtered, as N	0.49	14	0.65	30
Ammonia plus organic nitrogen, unfiltered, as N	0.57	2.4	0.67	30
Ammonia, filtered, as N	0.03	12.7	0.103	27.2
Nitrate plus nitrite, as N	<0.04	0.04	<0.04	E0.02
Nitrite, as N	E0.001	0.01	E0.002	0.007
Orthophosphate, as P	<0.008	0.018	<0.008	1.05
Phosphorus, filtered, as P	--	--	<0.03	0.79
Phosphorus, unfiltered, as P	--	--	0.008	1.13

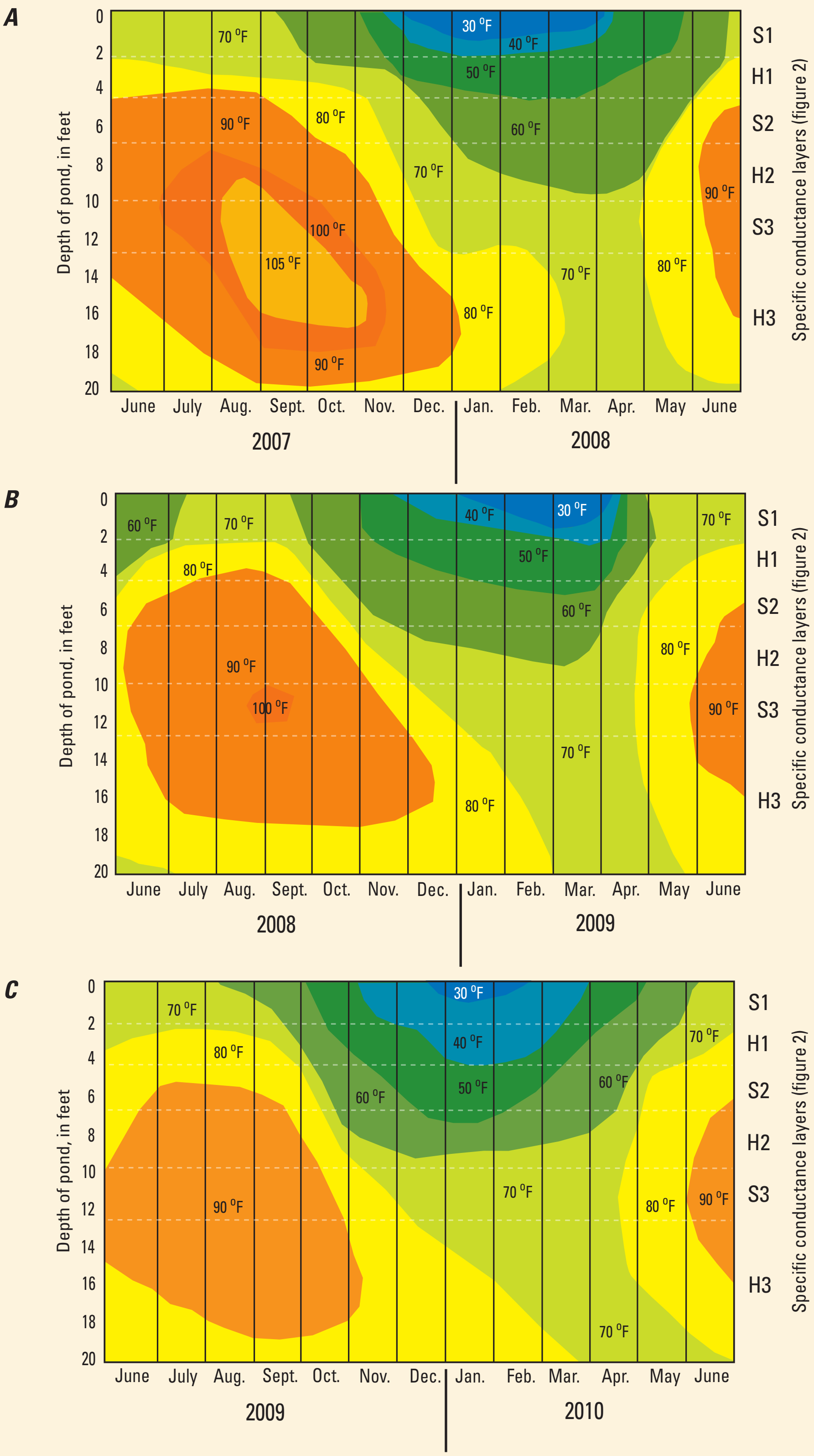


Figure 7. Isohyetal temperature plots for the Tully Valley solar pond during: *A* ,June 2007 to June 2008; *B,* June 2008 to June 2009; and *C,* June 2009 to June 2010, showing the approximate location of stable (S) and halocline (H) specific conductance layers shown in figure 2.

temperatures (fig. 7) indicates that in the summer of 2007 solar irradiance was above the Syracuse long-term monthly average, and the internal pond temperatures were as high as 105 degrees Farenheit (^{o}F), while in the summer of 2008 solar irradiance was near average and internal pond temperatures barely got to 100 ^{o}F. During the summer of 2009, solar irradiance was generally below average and internal pond temperatures were just in the 90 ^{o}F range and the 90 ^{o}F "bubble" was smaller than the preceding 2 years. Average monthly air temperature and precipitation did not appear to have any other effect on the pond temperatures as the amount of solar irradiance (sunshine) is directly related to the amount of clouds, which in turn affects air temperature and precipitation. This is consistent with solar pond research discussed previously, whereby solar ponds are closer to the earths equator, where the sun is higher, air temperatures are greater, and precipitation is much less and leads to much more efficient (higher temperature) solar ponds.

The phenomenon of solar-heated ponds was found to have been heavily researched from the 1980s through the end of the 20th century as to their utility to produce electrical power, desalinate water, and provide heat for multiple purposes. Most of this research generally occurred in areas closer to the equator (Texas, Israel), and most of this research ended by the early 2000s due to high operating costs to maintain these solar ponds, reduced funding, and other energy resources (wind and solar cells), which were apparently more efficient to manage.

The information collected at the Tully Valley solar pond indicates that solar ponds, either natural or man-made, may be useful as a renewable energy source for heating rural buildings and homes if operating costs for such ponds could be proven to be cost effective. Further research on the utility of solar ponds in colder climates is a possibility as the world moves toward renewable-resource technologies. This documentation may provide a basis for further evaluation of this technology in the higher latitudes of North America and elsewhere.

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View of the Tully Valley Solar Pond well head during the winter 2010.

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ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20131266