RECLAMATION

Managing Water in the West

Technical Memorandum No. 86-68220-12-09

Construction and Testing of a Soil Temperature Modification Unit for Climate Change Studies in Remote Areas

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Abstract

Data from a pilot study, in which solar energy was used for subsurface heating, suggests that such an approach may be useful for modifying soil temperatures. Direct and indirect solar energy was harvested with a water heated collector and a photovoltaic powered pump. Soil temperature data were collected. Average soil temperature increased 1.15^{o}C over ambient temperatures. The small inexpensive energy system performed as predicted over the approximate 4 month study and increased growing degree days by about 5%. The system supplied sufficient heat to mimic warming trends that could affect plant communities under conditions of future climate change.

Introduction

Methods to artificially increase soil temperatures are needed for study of potential impacts of climate change on variables such as: soil nutrients (Hantschel et al. 1995), plant communities (Farnsworth et al. 1995), and soil fauna (Briones et al. 2009). Buried heating cables (Farnsworth et al. 1995, Briones et al. 2009) or electric lamps suspended above the ground (Harte et al. 1995) have been used for this purpose; however, power source requirements limit the ability to experimentally alter soil temperatures in more remote natural environments. Soil temperatures at isolated sites in Europe have been heated during the night with retractable plastic covers (Beier et al. 2004) operated with solar powered motors. These covers, however, likely affect other variables such as wind speed and light regime and could have unintended impacts on studied plant communities.

Our interest was in development of methodology for study of warming impacts on riparian zone environments that might be in remote, non-powered environments. The possibility of flood damage would preclude placement of extensive structures in the riparian environment. Requirements were that soil warming equipment would be solar powered, allow for interaction with groundwater, resilient to flooding, and capable of heating soil to ca. 2°C above ambient temperature. Low cost and ease in construction and transport were also considerations.

Methods

Two 31.5 X 44 cm solar panels (8W) were used to charge a lead acid rechargeable battery (12V-4AH) that powered a water pump (DC 12-20 V). The pump was submerged in a black 13.2 L bucket which served as a passive solar collector that heated the water. Tubing (1.3 cm I.D.) was connected (inlet and outlet) from the solar collecter to a bottomless 19 L plastic bucket (28.5 cm I.D. and 36.5 cm height) where it was formed into a helical (4 revolutions) shaped heat exchanger wrapped along the inside of the bucket. The bottomless bucket was set in the ground so that the top of the bucket was level with the ground surface and then filled with soil (0.023 m^3). The pump was set to run for 4 hr each day from ca 10:30-14:30 and continuously cycled water from the solar collector and through the heat exchanger during that time.

A single HOBO™ temperature logger (15 minute logging period) was placed into soil (20 cm depth) in each of the paired bottomless buckets. It was hypothesized that the soil temperature modification unit would increase soil temperatures relative to a nearby reference unit (separated by 20 cm) that consisted of just the soil-filled bottomless bucket placed in the ground.

Soil temperatures between the reference (unheated) and solar (heated) units were compared graphically. Temperature measurements were initiated on May 17th and the solar unit was started on June 3rd. The solar pump was stopped on August 22nd and logging continued until August 29th when HOBO's were removed from the soil. This pattern allowed for comparisons of soil temperatures with and without solar heating.

Growing degree days (GDD) (celsius) were calculated for reference and solar heated soils by subtracting the base temperature (0^oC) from the daily average temperature and then summing for the period June 3-August 22.

The absence of replicate units precluded the use of statistical methods for comparing reference and solar heated soils.

Results and Discussion

Soil temperatures--It appeared that the solar powered unit achieved some degree of soil heating (Figure 1). Differences between the reference and solar soil temperatures (average of the daily average temperatures) were -0.44^oC before initiation of heating, 1.15^oC during heating, and -0.78^oC post-heating. Peñuelas et al. (2007) considered an increase in soil temperature of $0.5\text{-}1.5^oC$ to successfully mimic predicted warming effects that will likely occur over the next 20-30 years. Augmented temperatures in the present study resulted in an increased GDD in the solar soil unit (1986 GDD) by 4.9% over the unheated reference soil (1893 GDD) for the 80 day period. This is similar to the GDD increase of 3-16% that Peñuelas et al. (2007) documented in their study. This level of warming resulted in changes in plant species richness and above ground net primary productivity at some sites (Peñuelas et al. 2007).

Figure 2 presents a portion of soil temperature data in 15 minute increments. These data show the effect of pump timing on soil temperature, with soil heating starting at pump initiation and increased temperatures being maintained even after the pump has been turned off. Peak temperatures occurred at around 16:00 hours, about 1.5 hrs after the timer stopped the pump. This may have been caused by passive exchange of heated water that continued even after powered exchange was halted. Temperatures tended to decline after 16:00 but were still higher than ambient soil temperatures until the following morning at about 4:00-5:00.

It appeared that there may have been a slight daily cooling effect that occurred before inititation of solar heating, with water in the collector and tubing acting as a heat sink during the early morning (e.g., Figure 2), chilling the soil slightly. Minimum values from the heating period were lower in solar heated soil (16.25^oC vs. 17.46^oC, n=7488). Maximum values, as expected, were higher in solar heated soil (30.77^oC vs. 27.82^oC, n=7488). The box and whisker plots demonstrate this variability graphically (Figure 3). With this system, then, temperatures were higher in solar heated soil in late morning through early the next day and temperatures were slighly lower during early morning (ca. 4:00-11:00).

Cost--Expenditures were minimal for the solar heating units with $150 costs for solar panels, solar powered pump, battery, and timer. Part of the reason for low cost was that this is an off-the-shelf item designed for home use. Other additional costs for buckets and tubing were estimated at ca. $50. This low level of expense should allow for implementation of numerous “replicates” in the floodplain environment.

Improvements/questions—This initial study left unanswered questions such as the sort of edge effects that might occur, and at what maximum depth soil temperature is affected. The relatively small size of the heated soil container would place limits on the extent of plant communities that could be studied.

More temperature control could be obtained by running the pump for longer periods of time with thermostat control for both high and low temperatures.

Conclusions

Soil temperatures were succesfully modified in a manner consistent with projected climate changes. The solar powered warming equipment was of relatively low cost and would be suitable for placement in riparian zones with groundwater interaction. Design improvements could potentially be achieved with temperature control related to pumping.

Acknowledgements

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Literature Cited

Beier, C., B. Emmett, P.Gundersen, A. Tietema, J. Penuelas, M. Estiarte, C. Gordon, A. Gorissen, L. Llorens, F. Roda, D. Williams. 2004. Novel approaches to study climate change effects on terrestrial ecosystems in the field: drought and passive nighttime warming. Ecosystems 7(6):583-597.

Briones, M.J., J.J. Ostle, N.P. McNamara, and J. Poskitt. 2009. Functional shifts of grassland soil communities in response to soil warming. Soil Biology and Biochemistry 41(2):315-322.

Farnsworth, E.J., J. Nunez-Farfan, S.A. Careaga, and F.A. Bazzaz. 1995. Phenology and growth of three temperate forest life forms in response to artificial soil warming. Journal of Ecology 83(6):967-977.

Hantschel, R.E., T. Kamp, and F. Beese. 1995. Increasing the soil temperature to study global warming effects on the soil nitrogen cycle in agroecosystems. Journal of Biogeography 22(2/3):375-380.

Harte, J., M.S. Torn, F.-R. Chang, B. Feifarek, A.P. Kinzig, R. Shaw, and K. Shen. 1995. Global warming and soil microclimate: results from a meadow-warming experiment. Ecological Applications 5(1):132-150.

Peñuelas, J., P. Prieto, C. Beier, C. Cesaraccio, P. DeAngelis, G. De Dato, B.A. Emmett, M. Estiarte, J. Garadnai, A. Gorissen, E. K. Láng, G. Kröel-Dulay, L. Llorens, G. Pellizzaro, T. Riis-Nielsen, I.K. Schmidt, C. Sirca, A. Sowerby, D. Spano, and A. Tietema. 2007. Response of plant species richness and primary productivity in shrublands along a north-south gradient in Europe to seven years of experimental warming and drought: reductions in primary productivity in the heat and drought year of 2003. Global Change Biology 13:2563-2581.

Figure 1. Pattern of soil temperatures over time for heated (solar) and ambient (reference) soils.

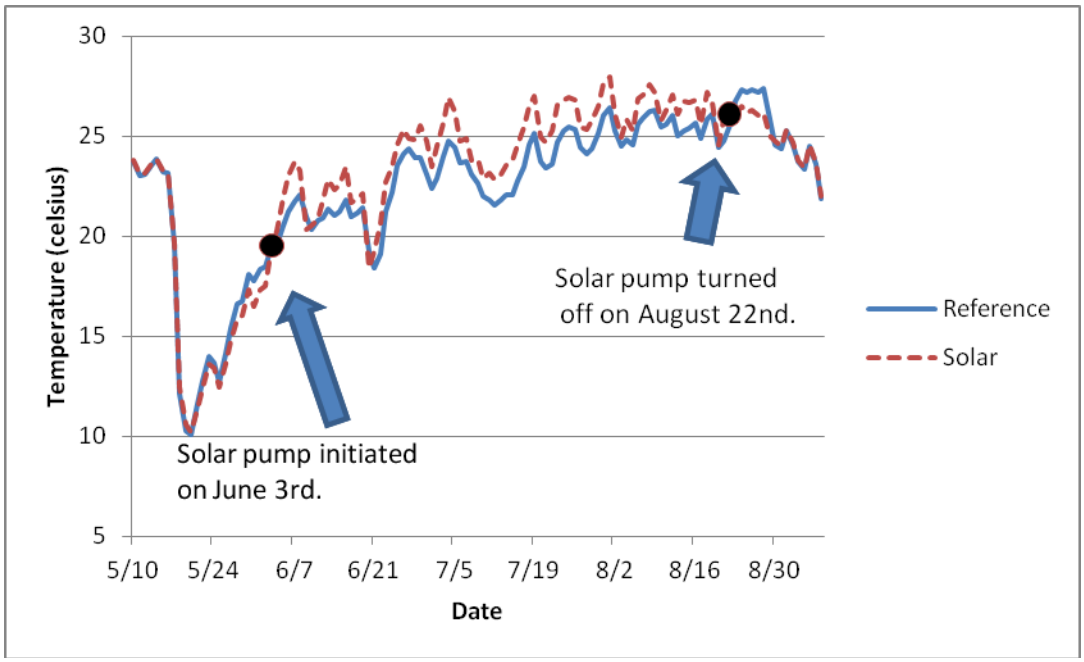


Figure 2. Diurnal patterns in heated (solar) and ambient (reference) soils.

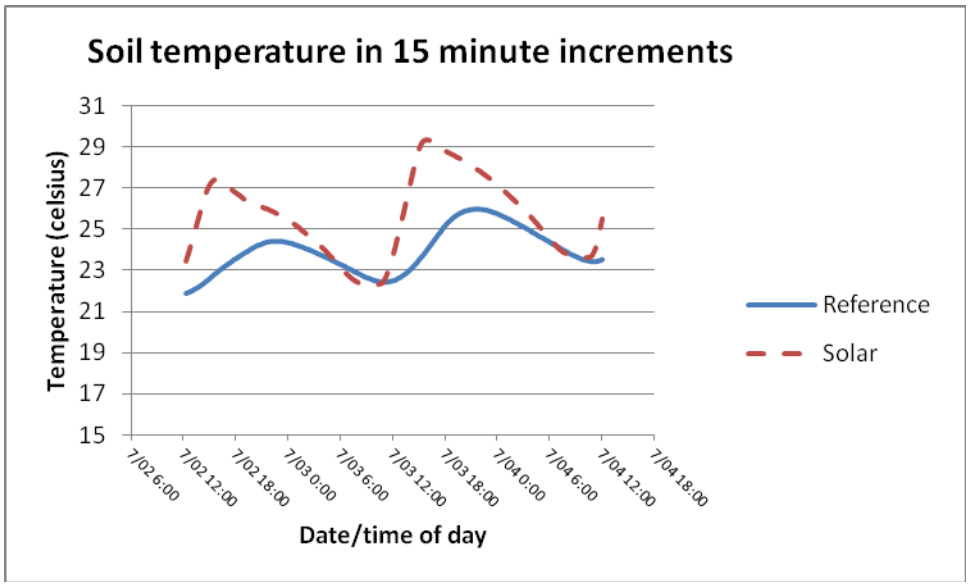
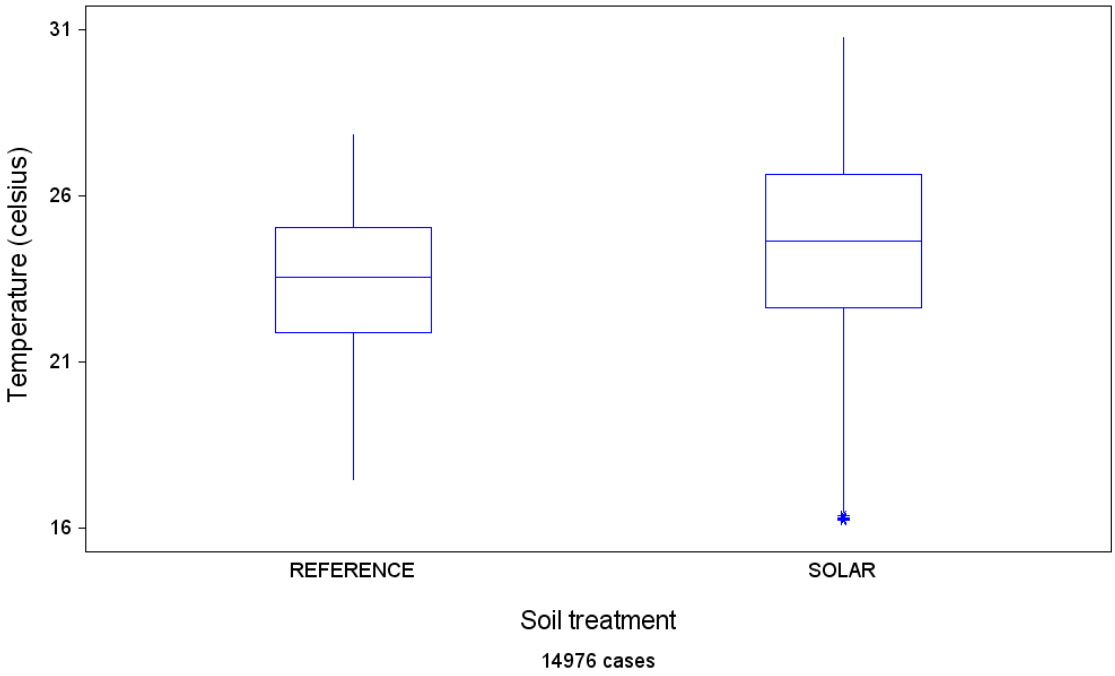


Figure 3. Temperature variability in heated (solar) and ambient (reference) soils.



PEER REVIEW DOCUMENTATION

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REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: 25 Sep 12 Review Date:
Signature

Preparer - I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Date: 9-25-12
Signature