**Tennessee Valley Energy**

*Assessing the Hydrothermal Outputs of Nuclear Power Plants Along the Tennessee River with NASA Earth Observations*

**Project Team**

***Project Team:***

Lisa Dong (Project Lead)

Jessica Ding

Rachel Smith

Samuel Tatum

***Advisors & Mentors:***

Dr. Jeffrey Luvall (NASA Marshall Space Flight Center)

Dr. Robert Griffin (The University of Alabama in Huntsville)

Maggi Klug (The University of Alabama in Huntsville)

Helen Baldwin (NASA SERVIR)

Christine Evans (The University of Alabama in Huntsville)

**Project Overview**

***Project Synopsis:***Nuclear power plants use water to dissipate waste heat. This water is discharged back into the river at a higher temperature which can negatively affect the biodiversity of aquatic ecosystems. The Environmental Protection Agency (EPA) requires nuclear plants to comply with water temperature regulations to ensure the preservation of these ecosystems. In collaboration with the Tennessee Valley Authority (TVA), this project used Earth observations to highlight spatial and temporal variation in river surface temperature at the Browns Ferry Nuclear Plant (BFNP) and the Sequoyah Nuclear Plant (SNP) on the Tennessee River.

***Abstract:***

Aquatic ecosystems are susceptible to biodiversity loss due to increased water temperatures, which can select for heat-tolerant species and lead to a loss of locally adapted species that have a narrow temperature range. Regulations concerning heated effluent from nuclear power plants are administered by the Environmental Protection Agency (EPA) in order to avoid damage to surrounding ecosystems. This project utilized thermal infrared data from NASA’s Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and Landsat 8 Thermal Infrared Sensor (TIRS) along the Tennessee River to help improve river temperature predictive models used by the Tennessee Valley Authority’s Browns Ferry Nuclear Plant (BFNP). To do this, the team highlighted spatial and temporal variation in river surface temperature as a result of seasonal change, flow rate, ambient air temperature, and plant power output. Results from the BFNP study area indicated that from 2013 to 2018, the change in water temperature between upstream and downstream locations (ΔT) increased by 3.546°F (p<0.01) and from 2018 to 2019, the ΔT decreased by 2.22°F (p<0.01). However, it is unclear if this variation can be attributed to the BFNP expansion. The results also demonstrated that river flow rate had the greatest impact on ΔT (p<0.001), while air temperature and power output did not significantly affect ΔT. These visualizations provided a new perspective on the behavior of thermal effluent at different locations along the Tennessee River, at different flow rates, and after the BFNP power upgrade.

***Keywords:***

remote sensing, Terra ASTER, Landsat 8 TIRS, ISS ECOSTRESS, TVA, nuclear power plant, freshwater surface temperature

***National Application Area Addressed:*** Energy

***Study Location:*** Tennessee Valley (TN and AL)

***Study Period:*** January 2013 to September 2019

***Community Concerns:***

* The Browns Ferry Nuclear Plant (BFNP) draws water from the Tennessee River to cool its active nuclear reactor units. Changes in the water temperature surrounding nuclear plants could result in a loss of locally adapted species and lead to changes in species distribution and habitat ranges of aquatic organisms
* The TVA currently monitors river temperature using in situ temperature stations to ensure that temperatures do not exceed regulatory limits set by the National Pollutant Discharge Elimination System (NPDES) permit. If the water temperature exceeds the NPDES limit, the TVA reduces the thermal output of one or more units in order to maintain compliance. Increasing temperature trends, as well as BFNP’s recent expansion, could lead to more frequent shutdowns of reactor units.
* The TVA loses approximately 1 million dollars each day that a reactor unit is offline. Operation of additional cooling measures also results in financial loss to the TVA due to the increase in energy consumption.

***Project Objectives:***

* Visualize yearly and seasonal water surface temperatures through time-series maps to identify surface temperature spatial variation over time
* Compare satellite performance between BFNP and Sequoyah Nuclear Plant (SNP)
* Analyze river flow rate, air surface temperature, and power output impacts on water surface temperatures through statistical analyses
* Improve the TVA’s effluent model by showing spatial variation in river surface temperature
* Illustrate the feasibility of using NASA Earth observations to monitor water surface temperatures through a tutorial

**Partner Overview**

***Partner Organization:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC** | **Partner Type** | **Boundary Org?** |
| **Tennessee Valley Authority,**  **Hydrothermal Group** | Colleen Montgomery, Civil Engineer;  Lana Bean, Manager of the National Environmental Policy Act Program | End User | Yes |

***Decision-Making Practices & Policies:***

The Clean Water Act (CWA), administered by the EPA, is a federal law which sets pollution discharge limits for United States surface waters. The NPDES and CWA regulations include thresholds for 1-hour average temperature to not exceed 93 °F; daily average temperature to not exceed 90 °F; and limit for daily average temperature rise relative to ambient to not exceed 10 °F. The TVA’s Hydrothermal Group is in place to monitor and control rise in temperature due to BFNP discharge. If water temperature exceeds regulation standards, the TVA employs additional cooling systems or reduces the thermal output in order to remain below regulatory temperature thresholds. At BFNP, water temperature is collected at five temperature stations (two upstream, three downstream) with temperature readings taken at depths of 3, 5, and 7 feet. In addition, the TVA has taken measures to predict future temperature fluctuations using flow, meteorological, and river temperature data from 2006-2012 using the Delft3D model made by Deltares. As a result of increasing heat trends (from the data within the six-year period of 2006-2012), the TVA predicts further measures will be required to ameliorate rising temperatures. While remote sensing applications can help to supplement the data collection and monitoring already in place, *in situ* data being collected by the TVA is indispensable for proper regulatory compliance. Nevertheless, remote sensing applications can provide a cost-effective and efficient way to supplement TVA’s extant data.

***Project Benefit to End User:***

Water temperature is a significant concern when evaluating nuclear power plant effluent. NASA Earth

observations will provide the TVA with new perspectives into the behavior of thermal effluent at two

nuclear power plant locations. This project’s evaluation of NASA’s thermal infrared data will demonstrate the feasibility of using NASA Earth observations to analyze the effects of thermal emissions within the Tennessee River. The results will give context to existing TVA river temperature models, assessing the effects of seasonal variation, nuclear power plant location, and BFNP upgrades. These tools can aid the TVA in responsible effluent management, enabling responsible ecological decision making.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter** | **Use** |
| **Landsat 8 TIRS** | Surface temperature | Landsat 8 TIRS evaluated water surface temperature. |
| **ISS ECOSTRESS** | Surface temperature | ISS ECOSTRESS assessed water surface temperature. |
| **Terra ASTER** | Surface temperature | Terra ASTER approximated water surface temperature. |

***Ancillary Datasets:***

* TVA Hydrothermal Group Water Temperature Station Data, 2013-2019 – Compared hourly in situ water temperature measurements with surface water temperature obtained from Earth observations
* TVA Flow Data, 2013-2019 – Related hourly flow data past BFNP with river temperature
* TVA Meteorological Station Data, 2013-2019 – Contrasted statistical analyses from air temperature data with water surface temperature at BFNP to give context to downstream river temperatures
* TVA Power Output Data, 2013-2019 – Compared statistical analyses from the 15-minute frequency data with water surface temperature at BFNP
* USGS National Hydrography Dataset – Created study area shapefile from the waterbody shapefiles

***Software & Scripting:***

* ESRI ArcGIS Pro 2.4.1 – Raster manipulation and analysis, imagery processing, and map production
* ESRI ArcMap 10.5 – Raster Manipulation, imagery processing, and map production
* RStudio Desktop 1.2.5001 – Statistical analysis
* VassarStats – Conduct one-way analysis of variance for independent or correlated samples

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Hydrothermal Output Time Series &**  **Variable Analyses** | Landsat 8 TIRS  Terra ASTER  ECOSTRESS | This time series depicted the change in water surface temperature around BFNP seasonally as well as prior to and after expansion. The team also incorporated statistical analyses of flow rate, air temperature, and power output to explain variances. | N/A |
| **Facility Comparison Maps** | Landsat 8 TIRS  Terra ASTER  ECOSTRESS | This product compared satellite performance at BFNP and SNP. This helped the TVA assess the feasibility of implementing Earth observations at different locations. | N/A |
| **Model Comparison Maps** | ECOSTRESS  Landsat 8 TIRS | This product compared the temperatures predicted by the TVA’s model, ECOSTRESS, and Landsat to assist the TVA in improving their model. | N/A |
| **Water Surface Temperature Tutorial** | N/A | The team created a tutorial for obtaining water surface temperature with ECOSTRESS and Landsat 8 TIRS to enhance the end user’s capacity to use NASA Earth observations for their modeling research. | N/A |
| **ArcGIS Story Map: Go with the Flow** | N/A | The team created an interactive story map showcasing how Earth observations can supplement TVA’s efforts toward ecologically responsible decision making in nuclear energy production. | N/A |

**Project Handoff Package**

***Transition Plan:***  At the conclusion of the term, the team delivered the handoff package to partner POCs at the TVA via Google Drive. The team also conducted an interactive handoff, during which the DEVELOP team presented results and addressed any partner questions.

***Team POC:*** Lisa Dong, ldong003@ucr.edu

***Partner POC:*** Colleen Rice Montgomery, crmontgomery@tva.gov

***Handoff Package:***

* Hydrothermal Output Time Series & Variable Analyses
* Facility Comparison Maps
* Model Comparison Maps
* Water Surface Temperature Tutorial
* ArcGIS Story Map: Go with the Flow
* Project Summary
* Poster
* Presentation
* Technical Paper

**References**

Ficke, A. D., Myrick, C. A., & Hansen, L. J. (2007). Potential impacts of global climate change on freshwater

fisheries. *Reviews in Fish Biology and Fisheries*, 581–613. https://doi.org/10.1007/s11160-007-9059-5

Lowry, R. (2019). One-Way Analysis of Variance for Independent or Correlated Samples [Computer

software]. Retrieved from: http://vassarstats.net/anova1u.html

The Nuclear Regulatory Commission. (2017, August 16). NRC Approves Extended Power Uprate for

Browns Ferry Nuclear Plant. [Press release] Retrieved from:

https://www.nrc.gov/reading-rm/doc-collections/news/2017/17-037.pdf

*Section 404 of the Clean Water Act: An overview*. (2003). Washington, D.C.: United States Environmental

Protection Agency, Wetlands, Oceans, and Watersheds. Retrieved from:

https://www.epa.gov/cwa-404/permit-program-under-cwa-section-404