Green Fund Project
Final Report

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Faculty Advisor (if applicable):
Project Title: **SIU water data analytics for building a sustainable water use culture**
Project ID #: **23SP106**
Award Date: **04/19/2023**
Completion Date: **04/30/2024 (Report submission date)**
Total Funds Used: **$ 9,592**

1. **Provide a summary of your project/project experience.**

This project has the purpose of developing supporting tools to encourage SIU communities to save water use and help the SIU's Facilities and Energy Management (FEM) improve their water/energy monitoring capabilities by testing and providing machine learning models for water use prediction and anomaly detection. In this regard, the major project activities have been (1) collecting water/power use data (including climate data) with SIU FEM's collaboration; (2) analyzing the relationships between SIU's water and power usage; (3) developing multiple machine learning models for water usage forecasting and anomaly detection using the Python programing tool; (4) training and testing the machine learning models and comparing their performances in water usage forecasting and anomaly detection; (5) advancing the water usage forecasting and anomaly detection models to be potentially incorporated into a dashboard or mobile app for informative feedback to SIU communities; and (6) conducting a survey on the water-saving effects of the informative feedback on water usage.

All tasks' progress has been smooth and completed successfully. The advanced water usage forecasting model predicts water usage at a specific (target) time that the user inputs (Figure 1a). Then, it compares the predicted water usage from one, two, and three days and one week prior to the target time and provides a message to encourage the user to save water (Figures 1b and 1c). The advanced anomaly detection model detects anomalies in SIU water usage for the period of a water usage dataset that a user (FEM) provides to the model. Then, it provides the list of the dates and times for the anomalies suspected during the dataset period (Figure 2).

At this point, to the best of our knowledge, there are no effective and active promotions or campaigns for saving water in the SIU. Considering the water-saving survey results (see Section 2), we believe these two advanced models can be greatly useful and support a dashboard or mobile app as core models to encourage SIU communities to save water and help SIU's FEM monitor SIU water usage and water system.

During the project year (one year), three graduate students (Kriti Acharya, Binod Ale Magar, and Veerendra Reddy Ayaluri) participated in the project activities. They received training on responsible conduct of the project, learned how to work with Python coding and machine learning modeling, and performed the project tasks related to water usage forecasting, anomaly detection, and water-saving surveys. Through their project activities, they learned how their skills and knowledge can be applied and contribute to the SIU's water sustainability.

We have participated in various outreach programs and implemented promotion activities, such as 2024 Engineering Day and 2024 Saluki Water Workshop, to introduce this project and its outcomes and promote SIU's sustainability efforts. In addition, we will present at the EWRI (World Environmental & Water Resources Congress) conference in May 2024 to disseminate our project outcomes. This conference presentation will give insights into water-saving strategies on the demand side to academia and industry.

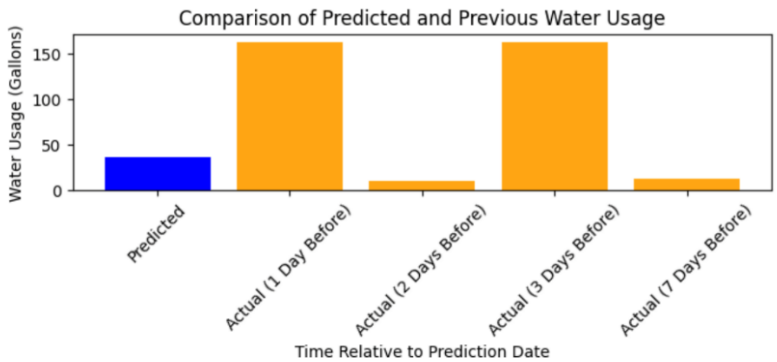
Thus, the project outcomes and activities we have made over the project year will help enhance SIU communities' awareness about water saving for water sustainability and encourage them to take small actions to participate in saving water. They will also assist the SIU's FEM in monitoring and managing the SIU water supply system and contribute to promoting our SIU's efforts for campus sustainability to the SIU and regional communities.

```
Enter Date and Time (YYYY-MM-DD HH:MM):  2023-06-13 03:00
```

(a) The user input to predict water usage at a target date and time

```
Enter Date and Time (YYYY-MM-DD HH:MM):  2023-06-13 06:00
Predicted water usage for 2023-06-13 06:00 is 36.71608734640705 Gal
Actual water usage for 2023-06-12 06:00 is 163.03951799562 Gal
Actual water usage for 2023-06-11 06:00 is 10.81778792388 Gal
Actual water usage for 2023-06-10 06:00 is 162.52438523734 Gal
Actual water usage for 2023-06-06 06:00 is 12.878318957 Gal

Great news! Your water usage at the time would be less than the recent average.
Keep saving water!! :)
```



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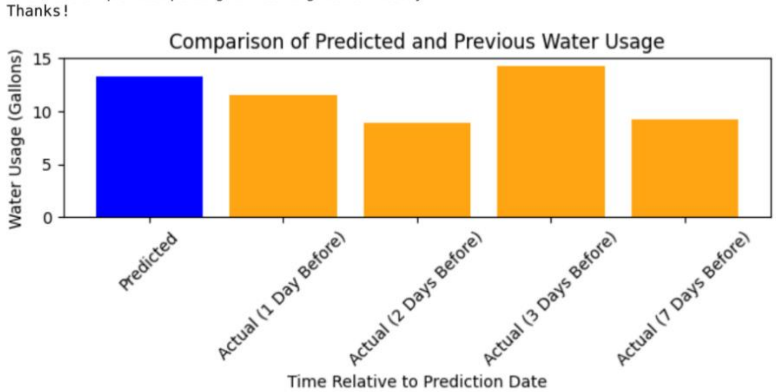
(b) Model output in the case that the predicted water usage is less than the recent average

```
Enter Date and Time (YYYY-MM-DD HH:MM):  2023-06-13 03:00
Predicted water usage for 2023-06-13 03:00 is 13.34322627134771 Gal
Actual water usage for 2023-06-12 03:00 is 11.5904870613 Gal
Actual water usage for 2023-06-11 03:00 is 8.88604008033 Gal
Actual water usage for 2023-06-10 03:00 is 14.29493404227 Gal
Actual water usage for 2023-06-06 03:00 is 9.27238964904 Gal

Oops!! Your water usage at the time would be higher than the recent average.
What about participating in saving water today?
Thanks!
```



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(c) Model output in the case that the predicted water usage is higher than the recent average

Figure 1. Water usage prediction model

```
Warning!!
At the following times, Anomalies were detected in our water system.
Please check the system.

0     2023-01-01 00:00:00
37    2023-01-02 13:00:00
168   2023-01-08 00:00:00
172   2023-01-08 04:00:00
177   2023-01-08 09:00:00
Name: Date, dtype: datetime64[ns]
```

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Figure 2. Water usage anomaly detection model output

2. **Provide a summary of your results (environmental, social, and/or economic) including quantifiable data as appropriate (ex. # of individuals reached, lbs. diverted from landfill, energy saved, etc.).**

We developed water usage prediction and anomaly detection models using machine learning, which can serve as supporting tools to provide informative feedback to SIU communities and FEM for SIU's water-saving encouragement and water system monitoring. The project findings conclude that the developed water usage prediction and anomaly detection models can significantly contribute to increasing the SIU communities' interest in SIU sustainability programs, encouraging them to participate in water saving activities, and enhancing the SIU FEM's monitoring capacity for water usage anomalies.

(1) Significant results

The major findings resulting from this project are presented below.

<u>Finding 1: Water and power usages show moderately/strongly positive correlation.</u>

We analyzed the correlation between water and energy usage in SIU. Due to the data availability for both water and energy usage on the same time scale, the Student Center building was selected to analyze the water-energy correlations. We used the Pearson coefficient and Spearman rank coefficient for quantitative indices to measure water-energy-usage correlation. Figure 3 shows the scatter plot of power vs. water usage of the Student Center building. The indices were calculated as 0.71 for the Pearson coefficient and 0.59 for the Spearman rank coefficient. This result shows that power and water usage in the Student Center building has a moderately/strongly positive correlation, based on the ranges provided by Bhandari (2021), Stefano et al. (2021), Darawati et al. (2022). In this context, we believe power (or energy) usage can be regarded as a critical feature variable to evaluate and predict water usage in a building. The application of this finding would be limited to the Student Center building. In addition, it was observed that the correlations varied depending on the range of water usage in the dataset – e.g., lower correlations were produced for the datasets including low water usage (excluding high water usage) in the Student Center building. Thus, further analysis of the water-energy-usage correlation for other buildings in SIU is needed, which requires the installation of additional sensors and meters for SIU's water and energy usage data.

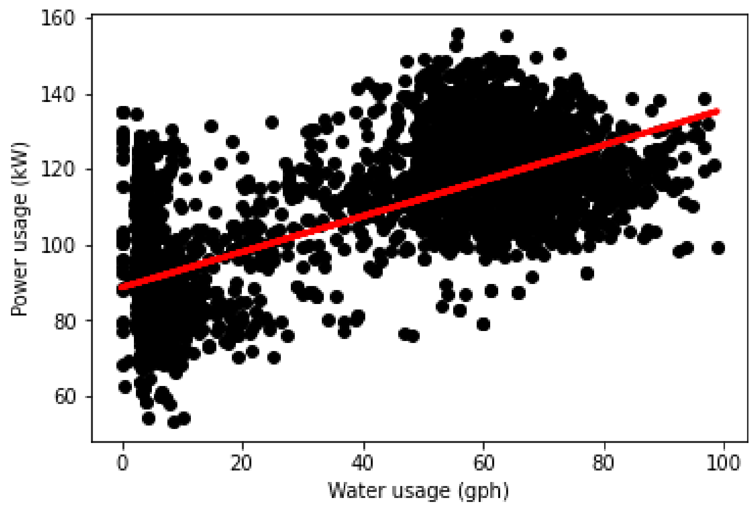


Figure 3. Plot of power vs. water usage in the Student Center building

Using multivariate regression analysis, we also investigated the significance of power usage, temperature, wind, and dew point in determining and predicting water usage for the Student Center building. As a result of p-value analysis, the variables power usage and temperature had significance in predicting the water usage, while the wind and dew point variables were not significant. The standardized beta coefficient showed power usage had a higher significance than the temperature variable. In this regard, we believe that, given data availability, power usage and temperature can be regarded as effective features to predict water usage.

(Reference cited)

- Bhandari P (2021) Correlation Coefficient | Types, Formulas & Examples. Scribbr, Amsterdam, the Netherlands. See https://www.scribbr.com/statistics/correlation-coefficient.
- Stefano, A., Leal, A., Richiusa, S., Trang, P., Comelli, A., Benfante, V., ... & Russo, G. (2021). Robustness of pet radiomics features: Impact of co-registration with MRI. *Applied Sciences*, *11*(21), 10170.
- Darawati, A. S., Ladin, M. A., Rusli, R., Yazid, M. R. M., Abbil, A., & Yahia, H. A. (2022). E-hailing Utilisation Analysis in Kota Kinabalu City Centre. *International Journal of Business and Technology Management*, *4*(4), 54-62.

Finding 2: Overall, the RF model showed the best performance in the prediction of water usage for SIU buildings.

We evaluated the performance of machine learning models in predicting water usage at the building scale. We tested Random Forest (RF), Support Vector Machine (SVM), Artificial Neural Networks (ANN), and Recurrent Neural Network (RNN, Long short-term memory). Considering data availability, the features considered in the water usage prediction models were seasons and time (hours), water consumptions over the last 24 hours and one week prior to the target time, temperature, precipitation, wind speed, and relative humidity. The hourly data for the features were obtained from SIU FEM's database. Due to the limited availability of hourly data, we applied the machine learning models to five buildings – Agriculture Building, Allyn Building, Parkinson Laboratory, Plant Biology Greenhouse & Conservatory, and Eileen E. Quigley Hall in the SIU. The models' performance was evaluated using the statistical indicators including Root Mean Square Errors (RMSE), Mean Absolute Error (MAE), and Coefficient of Determination (R-squared). As the values of error-type indicators are lower and the value of R-squared is higher, the models can be evaluated to have better prediction performance. Table 1 shows the results from the performance analysis using the statistical indices. As seen in Table 1, overall, the RF model showed the best performance in the water usage prediction for the five buildings. The models' performance varies with the buildings, but the ANN and RNN models also showed good performance.

Table 1. Machine learning models' performance in water usage forecasting

Building	Model	RMSE	MAE	R^2
Agriculture	RF	27.25	13.68	0.775
	SVM	36.38	18.16	0.599
	ANN	28.53	15.48	0.7538
	RNN	27.76	14.9	0.766
Allyn	RF	9.12	4.43	0.708
	SVM	11.085	4.89	0.569
	ANN	9.317	4.85	0.696
	RNN	9.37	4.79	0.69
Parkinson Lab	RF	75.47	18.339	0.4211
	SVM	89.94	21.55	0.17785
	ANN	76.89	21.772	0.399
	RNN	79.16	20.97	0.3632
Plant biology	RF	32.3	11.82	0.5452
	SVM	47.46	12.36	0.018
	ANN	32.53	13.2	0.53877
	RNN	32.36	12.85	0.5435
Quigley Hall	RF	72.36	36.3	0.8648
	SVM	100.14	55.98	0.7414
	ANN	73.06	38.44	0.8624
	RNN	73.57	37.833	0.8604

Finding 3: The efforts to build reliable, class-balanced water usage data are needed for better performance of the anomaly detection models.

For anomaly detection, we tested RF (Random Forest) and Autoencoder (AE) models. The model features included water usage data, seasons, and time (hours). Due to the limited availability in anomaly data, we assumed and created the anomaly data through random manipulation of the SIU water usage data from a 3% increase to a 20% increase in water usage for randomly selected time periods in the dataset. The models' performance was evaluated using statistical indicators including accuracy, recall, precision, and F-1 score (Parajuli and Shin 2024). Table 2 shows the results from the performance analysis for the anomaly scenario with 10% increase in water usage for random time periods. As seen in Table 2, both models showed good performance in accuracy. However, they had significantly low performance in precision (i.e., among total predicted anomaly events/hours, how many of them are actual anomaly events/hours), recall (i.e., how many of the actual anomaly events/hours the model captures), and F-1 score (the harmonic average of precision and recall values). It is considered that this occurred due to the class imbalance (i.e. significantly unequal distribution of classes – normal and anomaly – in the real-world training dataset) and the missing data leading to low reliability and high variance of hourly aggregated data. Thus, there is a need to make efforts to reduce missing data and observation errors in SIU water usage, maintain water usage monitoring with multiple meters in a building, and build class-balanced datasets in the long term by labeling data suspected to be anomalies.

Table 2. Machine learning models' performance in anomaly detection

Building	Model	Accuracy	Precision	Recall	F-1 score
Agriculture	RF	0.933	0.204	0.077	0.112
	AE	0.894	0.027	0.025	0.026
Allyn	RF	0.930	0.096	0.035	0.051
	AE	0.892	0.009	0.008	0.008
Parkinson Lab	RF	0.949	0.563	0.315	0.404
	AE	0.895	0.033	0.030	0.032
Plant biology	RF	0.947	0.527	0.273	0.359
	AE	0.893	0.028	0.026	0.027
Quigley Hall	RF	0.932	0.175	0.070	0.100
	AE	0.894	0.027	0.025	0.026

(Reference cited)

- Parajuli, U., & Shin, S. (2024). Identifying failure types in cyber-physical water distribution networks using machine learning models. *AQUA—Water Infrastructure, Ecosystems and Society*, 73(3): 504-519. jws2024264.

(2) Project products

The purpose of this project was to develop supporting models using machine learning algorithms to encourage SIU communities' participation in saving water and help the SIU FEM's monitoring of SIU water usage. In this regard, the final products of this project are the Python-based machine learning models for water usage forecasting (Figure 1) and anomaly detection (Figure 2). The Python codes for both models are available on PI Shin's GitHub (https://github.com/happysm79/2023GreenFundProject).

As described earlier, the water usage forecasting model predicts water usage at a specific time by a user's request and compares the predicted water usage with the past (1, 2, and 3 days and one week prior to the input time). If the predicted usage is higher than the past average, the model provides a message promoting participation in water saving, with the predicted and past water usage (Figure 1c) – "*Oops!! Your water usage at the time would be higher than the recent average. What about participating in saving water today? Thanks.*". If the predicted usage is lower than the past average usage, the model displays a message encouraging to maintain the user's water saving (Figure 1b) – "*Great news! Your water usage at the time would be less than the recent average. Keep saving water!!* 😊".

The anomaly detection model analyzes information about suspected anomalies in water usage and their occurrence dates/times. If there is any anomaly (e.g., abnormal water usage data due to pipe leaks) in the observed water usage, the model provides a message suggesting SIU FEM to check the water system in the target building, with the list of the dates and times for the anomalies suspected during the dataset period (Figure 2).

We believe the developed water usage forecasting model can serve as a core model in a user-friendly dashboard or mobile app to encourage SIU communities to participate in water conservation efforts, and the anomaly detection model can contribute to enhancing the SIU FEM's capability of SIU water system monitoring.

(3) Sustainability impacts

We have investigated the potential impacts of our products through a survey on water saving (Figure 4). The main questions are listed:

- How aware are you of the concept of water sustainability?
- Have you actively participated in any water-saving practices in your daily routines at SIU?
- If you answered "Yes" to the above question, what actions have you taken personally to save water or reduce your water usage?
- If you were notified that your current water consumption exceeds that of the last three days, would you be willing to reduce your usage?
- If you were informed that your current water consumption is more than the average usage of others, would you be willing to reduce your consumption?
- Are you aware of any ongoing water conservation projects or programs at SIU?
- Would you be open to participating in any water saving projects or programs that SIU has planned?
- Would you be interested in learning more about techniques and practices for conserving water within the SIU?
- Do you support SIU investing in upgrading water infrastructure or adopting water-saving technologies?

Many SIU members including faculty, staff, and graduate/undergraduate students in diverse academic backgrounds have responded to the survey. Among the respondents, about 51% responded that they are making no specific efforts to save water. However, more than 85% responded that they are willing to reduce their water usage if they are notified that their water consumption exceeds that of the last three days. In addition, more than 85% of respondents showed their willingness to reduce their water consumption when they are informed that their water consumption is higher than the average usage of others.

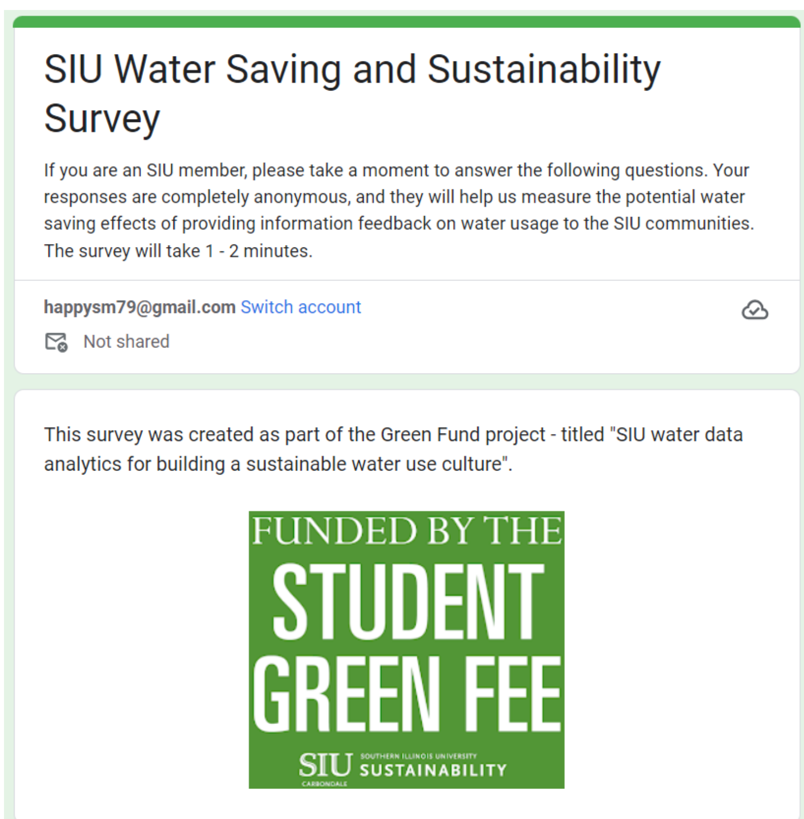


Figure 4. SIU water saving survey

In this context, we believe that the developed models – which provide informative feedback on water users' water consumption and messages encouraging water saving – can contribute significantly to the SIU water users' participation in water-saving activities. Previous studies such as Inman and Jefferey (2007), Fielding et al. (2013), and Quesnel and Ajami (2017) reported that the promotion and awareness programs for water saving/conservation can contribute to a reduction in water consumption up to 10 to 20%. Based on this reference, we approximately estimated the water saving effects for the five buildings – Agriculture Building, Allyn Building, Parkinson Laboratory, Plant Biology Greenhouse & Conservatory, and Eileen E. Quigley Hall in the SIU, as presented in Table 3. The saved amount of water was calculated as 10 ~ 20% of the current water usage in the buildings. The water rate data was obtained through phone enquiry with the City of Carbondale. As noted in Table 3, considering the water saving survey results, we believe that SIU water saving promotions/programs using the developed product of this project can create substantial effects on encouraging SIU communities to save water and drawing their attention to water sustainability activities.

Moreover, water supply consumes energy to pump, pressurize, treat, and heat water. As noted in Finding 1, water and power consumption are positively strongly correlated. Thus, saving water will contribute to reducing greenhouse gas emissions in cases where the energy is supplied by fossil-fueled generating units.

Table 3. Approximate estimation of annual water saving, water bill saving, and avoided carbon emission

Building	**Annual water saving (*m^3/yr*)**	**Annual water bill saving ($/yr)**	**Avoided carbon emission (kgCO2eq/yr)**
Agriculture	197 - 394	469 - 1,312	18 - 36
Allyn	52 - 104	124 - 347	5 - 10
Parkinson Lab	398 - 796	947 - 2,651	37 - 73
Plant biology	73 - 145	173 - 484	7 - 14
Quigley Hall	805 - 1610	1,914 - 5,359	74 - 147

(Reference cited)

- Inman, D., & Jeffrey, P. (2006). A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal*, *3*(3), 127-143.
- Fielding, K. S., Spinks, A., Russell, S., McCrea, R., Stewart, R., & Gardner, J. (2013). An experimental test of voluntary strategies to promote urban water demand management. *Journal of environmental management*, *114*, 343-351.
- Quesnel, K. J., & Ajami, N. K. (2017). Changes in water consumption linked to heavy news media coverage of extreme climatic events. *Science advances*, *3*(10), e1700784.

(4) Insights towards SIU sustainability

The water saving survey showed that about 90% of respondents were not aware of any ongoing water conservation programs at SIU. However, about 53% and 44% of the respondents indicated strong and moderate interest, respectively, in participating in water saving projects or programs that SIU implements. Also, it was investigated that about 90% of the respondents support projects or investments to upgrade SIU water infrastructure systems for water conservation and use efficiency.

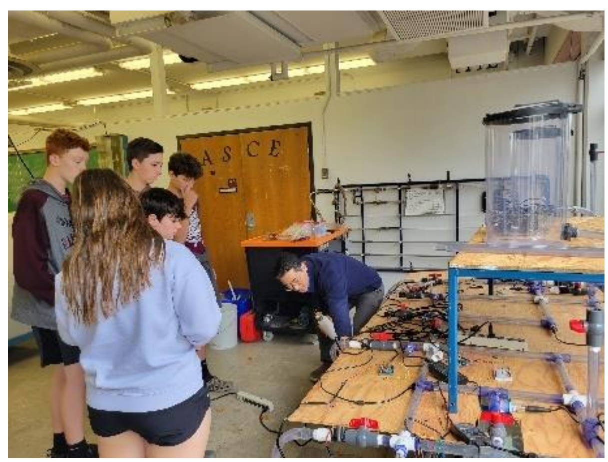
We identified the SIU communities' willingness to save water with the potential effects of informative water usage feedback on their behavioral change in water use. In addition, we confirmed the SIU communities' interests in water saving projects/programs and water infrastructure improvement for SIU sustainability. In this regard, we suggest collaborative development of water saving projects/programs from various perspectives of infrastructure, water resources and supply and water demand from the building level to the university and city levels and diverse promotional activities for the water saving projects/programs through apps, campaigns, media, and newsletters (SIU Today).

3. **Summarize how your project promoted the Green Fee/Sustainability on campus including, but not limited to, flyers created, screenshots of website, signage, etc. Please include website links, if applicable. (Reminder: you are required to promote your project using at least 2 items from the awardee website promotion list.)**

(1) Outreach activities

We have been actively engaged in various outreach activities at the School, College, and University levels. For example, PI Shin participated in an outreach event - the 2024 Saluki Water Workshop for the K-12 students in Southern Illinois on April 18, 2024. PI Shin presented about the urban water cycle and discussed the roles of the community and engineer (e.g., water saving and anomaly detection) in making a more sustainable water cycle under climate and socioeconomic changes. During the presentation, PI Shin presented our efforts to help the water engineers with our ongoing projects, including the SIU Green Fund project, which helped promote this Green Fund project to the public. In addition, with similar activities to the Saluki Water Workshop, we have participated in the Song San Jr. High Global Campus Program at the University level and Engineering Day 2024 and School lab tours by local high school students (e.g., Benton Middle School) at the College/School level. These outreach activities of PI Shin and his students contributed to increasing the understanding of how the small activity of the people in water saving can help improve water sustainability.

(a) Son San Jr. High Global Campus program
(07/18/2023)



(b) Benton Middle School visit
(10/26/2023)

(c) Engineering Day 2024
(02/22/2024)

(d) 2024 Saluki Water Workshop
(04/18/2024)

Figure 5. Outreach activities with the Green Fund project promotion

(2) Class activities

PI Shin taught UNIV 101 Saluki Success (Section 061) in Fall 2023. In this course, he provided students with information about SIU resources for their academic, social, and professional success. As one of such resources, he introduced the SIU Sustainability and its activities such as Green Fund projects, Green Fee, recycling programs, and Pumpkin Smash. He also introduced this Green Fund project to the students to encourage their participation in water saving and SIU sustainability programs. In addition, PI Shin also teaches CE 474 course (Water Resources Engineering). He presented about this project's purpose and tasks and incorporated the analysis of water saving effects on water supply systems into the lecture materials for team project's topics. We believe that the PI Shin's class activities contributed to increasing the students' interest in water-saving efforts and water sustainability programs at SIU.

(3) Water-saving survey

We have implemented a survey (https://forms.gle/eTMgnMXgpgjABhvj6) targeting the broad SIU communities to investigate the potential water-saving effects of providing information feedback on their water usage (Figure 4). The survey states that "This survey was created as part of the Green Fund project – titled 'SIU water data analytics for building a sustainable water use culture'". Thus, we believe this survey served as one of the tools to inform the SIU communities about this Green Fund project. In addition, one of the questionnaires is "Are you aware of any ongoing water conservation projects or programs at SIU?". We anticipate that such question motivates the SIU communities to be more interested in water-sustainability projects or programs in the SIU.

(4) Project webpage in PI's SCIENSE Laboratory website

PI Shin has updated his ***SCIENSE*** (**S**mart and **C**onnected **I**nfrastructure **E**ngineering **S**yst**E**m) Laboratory website - https://sites.google.com/view/sangmin-shin/home. He created a project webpage (Figure 6) on the lab website to inform the research, academia, industry, and public communities about this project and its tasks - https://sites.google.com/view/scienselab-research-project2/green-fund-project. This project webpage introduces our Green Fund project for water saving (project abstract) and shows the Green Fee Marker to indicate the project funding source. The project outcomes, including publications, data, and models, will be shared under the data security policy of SIU within one year of being generated. The project webpage helps promote SIU's efforts on the Green Fee/Sustainability to all the webpage visitors.

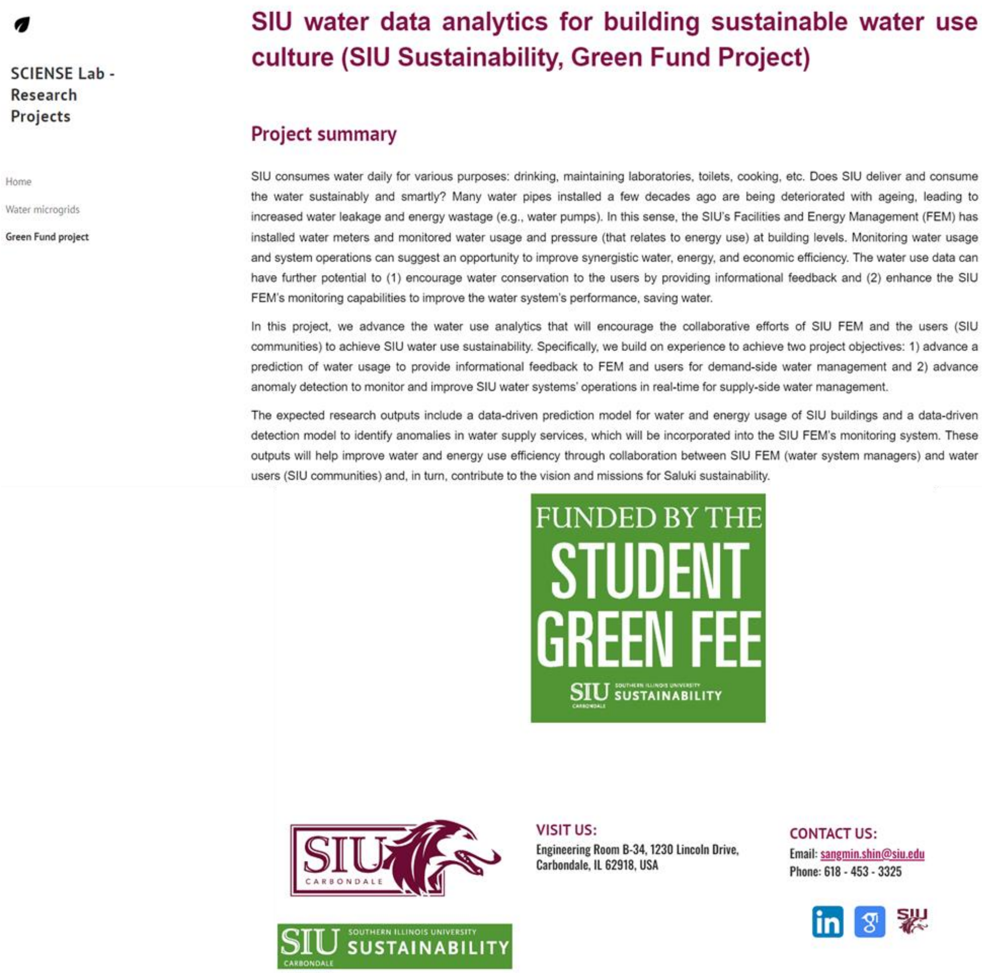


Figure 6. The webpage for this Green Fund project

(5) Conference

We will attend a conference to disseminate and promote this project outcome to the communities in academia and industry – 2024 World Environmental & Water Resources Congress (EWRI). The EWRI conference will be held in Milwaukee, Wisconsin, on May 19 – 22, 2024. We will introduce this SIU Green Fund project and present the project outcomes (focusing on water demand forecasting) at the conference (Figure 7). We will also meet relevant professionals in academia and industry to discuss and get feedback on the SIU Green Fund project outcomes.

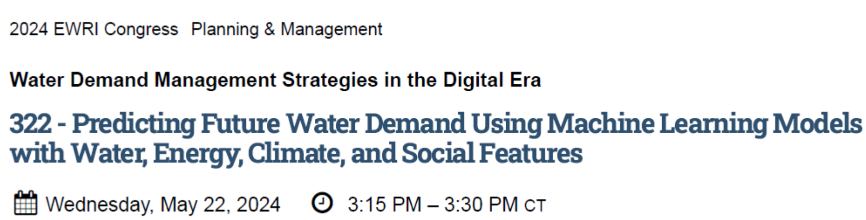


Figure 7. Presentation schedule at the 2024 EWRI conference

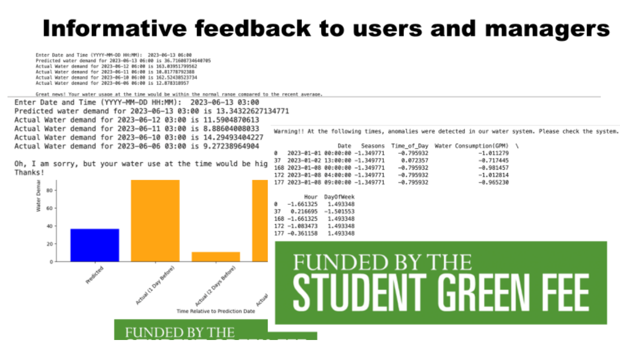
4. **Provide evidence of how you used the Green Fund Marker in your project.**

We have used the Green Fund Marker in various activities. The water usage forecasting and anomaly detection models in this project provide informative feedback on water usage and anomaly events and messages encouraging water saving and timely system-checking. As seen in Figures 1 and 2, the models display the informative feedback and messages with the Green Fund Marker to indicate the development of the machine learning models in this project was supported by the Green Fund Grant program.

Based on the project findings related to water usage forecasting and anomaly detection, we have implemented a survey targeting the SIU communities to investigate the potential water-saving effects of providing informative feedback on their water usage (Figure 4). The Green Fund Marker is positioned at the top of the survey sheet to denote that the survey was created as part of this Green Fund project.

PI Shin's SCIENSE Laboratory website introduces this SIU Green Fund project in its project webpage - https://sites.google.com/view/scienselab-research-project2/green-fund-project. The Green Fund Marker is displayed on the project webpage to indicate the support of SIU Green Fund Grant Program (Figure 6).

We participated in an outreach event – the 2024 Saluki Water Workshop – for K-12 students in Southern Illinois on April 18, 2024. As described in Section 3, PI Shin presented our efforts to help the water engineers through our ongoing projects, including this SIU Green Fund project. The presentation slides have the Green Fund Markers to introduce SIU Sustainability and the Green Fund Grant program (Figure 8).



(a) A slide showing this Green Fund project outcome

(b) A slide discussing about water saving activities

Figure 8. Presentation slides for 2024 Saluki Water Workshop

As described in Section 3, we will attend the 2024 EWRI conference to present this Green Fund project and its outcomes, which will be held in Milwaukee, Wisconsin, from May 19 to 22, 2024. The cover page of the conference presentation slides has the Green Fund Marker to state that the research in the presentation was supported by the SIU Green Fund Grant Program (Figure 9).

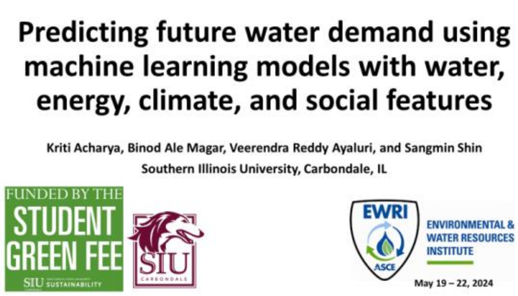


Figure 9. Cover page of EWRI conference presentation slides

We also showed the Green Fund Markers when promoting this project and outcomes on SNS (LinkedIn), as shown in Figure 10.

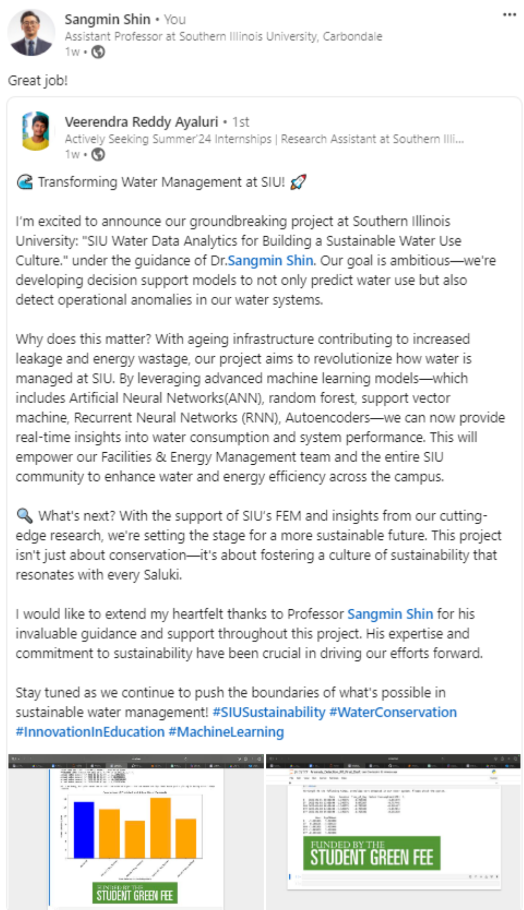


Figure 10. LinkedIn post showing the Green Fund Marker

5. **Is there anything you would do differently if you were to do a similar project in the future? If so, please describe.**

For similar projects in the future, I will collaborate with SIU faculty/staff, engineers, and students in the fields of software, data science, and app design because the envisioned final product extended from this project is a user-friendly app ("SIU water saving app") with a dashboard that enables SIU FEM to provide informative feedback on water usage (predicted and observed) to SIU communities (users). The developed models for water usage prediction and anomaly detection in this project can be the core source models for the SIU water saving app. As shown in Figures 1 and 2, the developed and tested machine learning models can be used as supporting tools to predict water usage for a target date and time and detect anomalies. They also provide a message for SIU communities to encourage their water saving and help SIU FEM monitor water usage effectively. The SIU communities can search and check their water consumption through a user-friendly interface (dashboard) in the SIU water saving app. Then, the app can provide informative feedback on the SIU communities' water usage and water saving message. To create an SIU water saving app, we will collaborate with software developers, UI designers, and data scientists in the SIU who can create a user-friendly interface and incorporate our machine learning models into the water saving app. In addition, the app will be connected to an SIU water usage database, which will be managed by SIU FEM. Thus, we will also collaborate with database developers and computer scientists in the SIU to develop and manage the database and connect it to the water saving app. These collaborations will contribute to implementing this project's outcomes into practical applications for SIU's water saving programs and water system management.

6. **Provide as an attachment to the email (see email address below) a minimum of 5 digital images. A minimum of one of the five images should include a person. Images should be of high a quality as possible and be attached in jpg format, if available. Images will be used to promote interest in sustainability projects on campus and may be used on our website and in other promotional material. These can be photos of the progress of the project or the completed project. Provide captions for photos here.**

Attachment	Captions
Attachment 1	• Water usage prediction model's output in the case that the predicted water usage is less than the recent average
Attachment 2	• Water usage prediction model's output in the case that the predicted water usage is greater than the recent average
Attachment 3	• Water usage anomaly detection model's output
Attachment 4	• SIU water saving survey (cover page)
Attachment 5	• 2024 Saluki Water Workshop
Attachment 6	• Water saving Green Fund project webpage

7. **In 2-5 sentences, describe what you learned from completing the Green Fund grant process. Include a detailed response (Do not simply respond "yes" or "no.") to at least one of the following questions to help us understand how this project has impacted your overall university experience.**

This project provided us with a great opportunity to understand the correlations between water and energy usage (Figure 3), learn machine learning models for water usage prediction and anomaly detection using the Python tool (Figures 1 and 2), and indirectly identify the effectiveness of informative feedback on water usage in encouraging SIU communities to save water (Figure 4). Furthermore, as a water engineer, this project provided a valuable experience to understand how our knowledge and modeling skills can contribute to enhancing the SIU's water sustainability and positively impact the SIU communities' behaviors toward water saving.

During this project year, three graduate students actively engaged in this project's activities. They have been trained to conduct project tasks responsibly and effectively and work with data collection and machine learning modeling. They became conversant with the concepts and application of machine learning modeling and water sustainability. This project has also allowed them to improve their communication and leadership skills and learn how to write a scientific article by preparing for the conference abstract and journal papers.

- **Do you have a different understanding of sustainability now than you did at the beginning of the process?**

  PI Shin has studied water infrastructure systems for water sustainability. The students involved in this project have also learned the concept of water sustainability through their classes. However, moving beyond just conceptual understanding and application, we've come to understand the importance of the practical application of our knowledge and skills to enhance water sustainability directly or indirectly.

- **Did you apply knowledge or skills learned from courses at SIU?**

  This project's topics – water sustainability and data-driven modeling – are directly related to PI Shin's research interests, and he has studied the topics with multiple research projects. The graduate students have also taken their courses related to water resources engineering and data science. In their classes, the students have learned the concept of water sustainability in water supply and various modeling approaches using data and hydraulic simulation tools. All our knowledge and modeling skills have substantially contributed to developing this project's outcomes, improving their modeling skills, and understanding water sustainability in practice.

- **Did the completion of the Green Fund grant process help to prepare you for your future career opportunities?**

  The developed water usage prediction and anomaly detection models employ a machine learning modeling approach – a hot topic in the Civil and Environmental Engineering fields. We have studied various modeling tools such as hydraulic and hydrologic models. Through this project, we could improve our modeling skills with machine learning models, contributing to PI Shin's long-term goal – smart and connected water infrastructure systems – and the students' preparation for their academic/industrial careers in water engineering. In addition, the students will present the project outcomes at the EWRI conference (Figure 7). Their conference activities will suggest opportunities to meet professionals and engineers to discuss the project outcomes and the needs for their future career development.

8. List suggestions for the SIU Sustainability Council to improve the Green Fund Award Process here:

The Green Fund Award Process was well organized. I really appreciate all your efforts in supporting Green Fund projects (including this project) that can greatly contribute to SIU sustainability. PI Shin has also been happy that his student group and he could help make our campus more sustainable through our knowledge and skills.

A few suggestions related to the Green Fund Award could include: (1) a workshop (at the Green Fund Award Ceremony) to present the outcomes of the projects awarded in the previous year and (2) more active promotion of Green Fund Programs (e.g., Green Fund Grant Program and writing competition).