Initial Steps to Integrating Sub-Daily SWAT Model and LID Practices for Large-Scale Application: A Case Study in Iowa, U.S.

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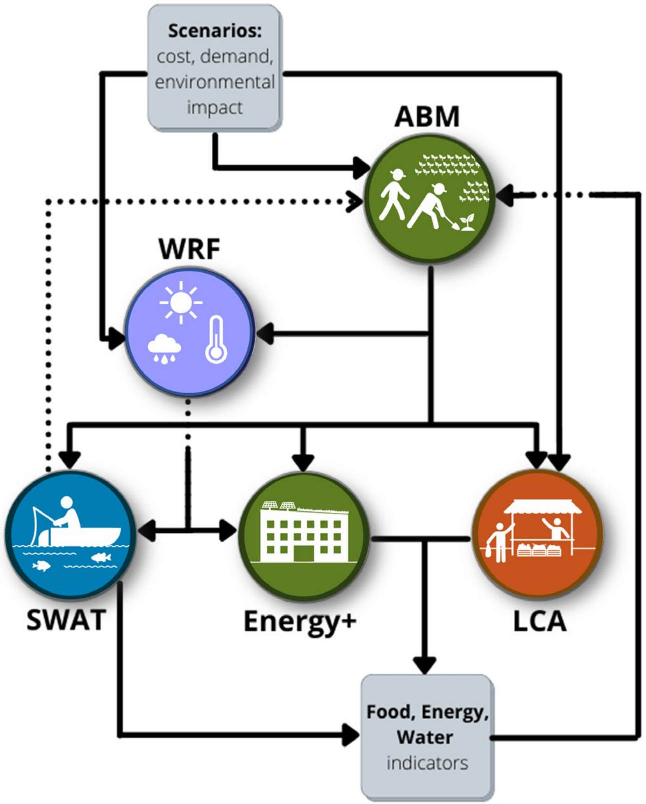
Iowa UrbanFEWS

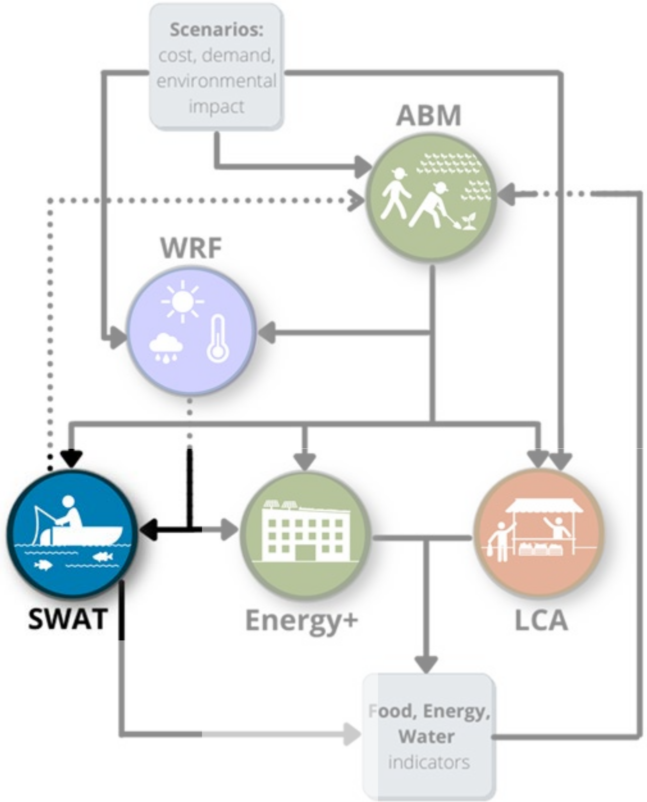
Iowa Urban FEWS – OVERVIEW

The project is focused on **developing sustainable food production systems** in the Des Moines–West Des Moines, IA Metropolitan Statistical Area (DMMSA). Multiple models are being integrated (co-simulation approach) to evaluate the impact of **converting cropland, peri-urban and/or urban landscapes to table food production**, in DMMSA transboundary and urban subareas.



SWAT model within the Iowa **UrbanFEWS**:

- Quantify crop growth.
- Hydrological cycling.
- Nutrient and sediment cycling and transport for cropping systems and associated management practices.
- Simulate future climate and land use change scenarios and characterize streamflow, nutrient, sediment load conditions, and yields production.



Main Goal:
This study integrates **sub-daily precipitation** to the Soil and Water Assessment Tool (SWAT) model on **large-scale application**, focusing on the implementation of **Low Impact Development** (LID) practices, specifically green roofs and rain gardens, within the Des Moines River Basin, Iowa, U.S.

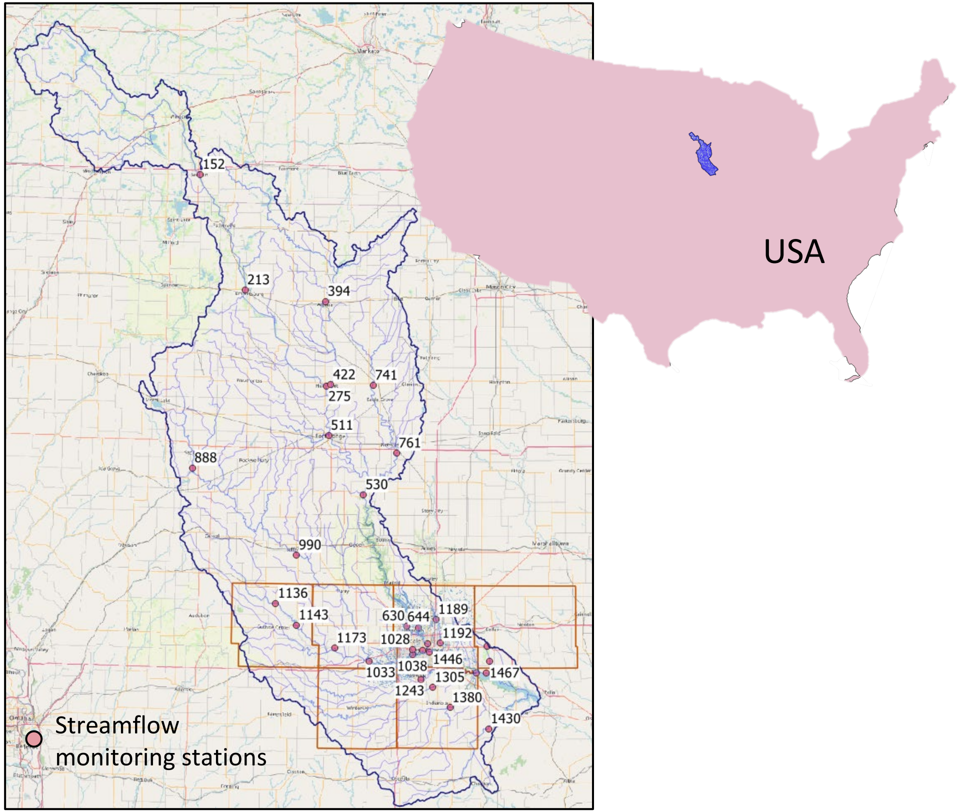
a) **Green roofs** are examined with diverse table **food vegetation covers** to evaluate their impact on surface runoff.

b) The SWAT model was executed through **cloud computing services** to improve simulation time, and scale out capabilities.

STUDY AREA

Des Moines River Basin (DMRB) 31,892 km²

- **Land use**: soybean and corn fields representing together 70%; urban is ~3%
- **Soil type**: Loamy Wisconsin Glacial Till (tile drainage represent 54%).
- **Precipitation and evapotranspiration**: 873 mm and 670 mm (annual average 1985-2018 – PRISM dataset).

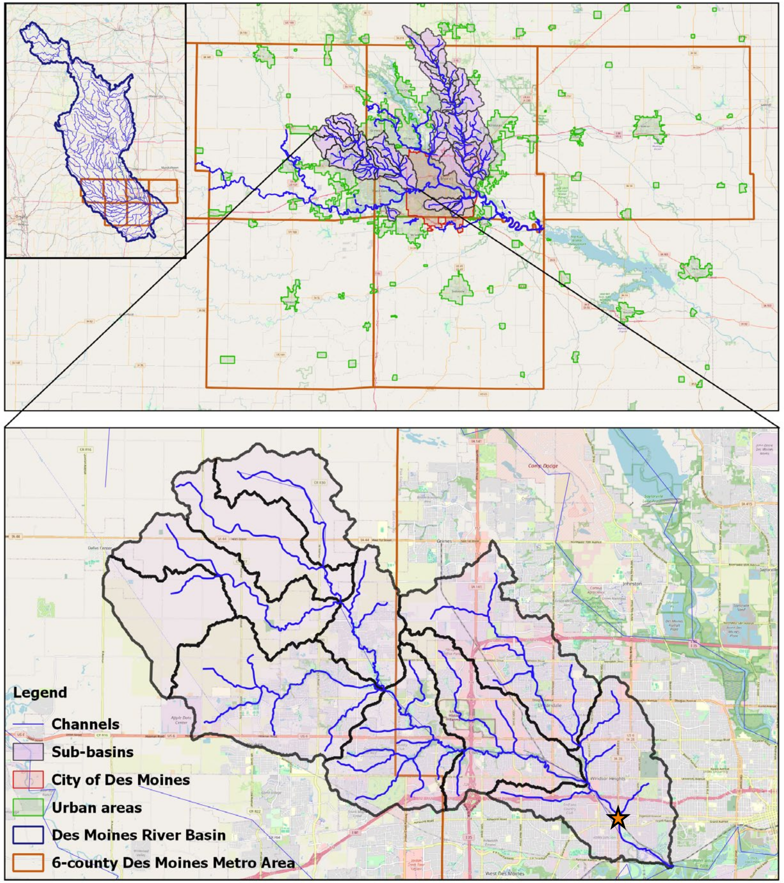


STUDY AREA

The DMMSA, which is the largest urban area in Iowa, served as approximate boundaries for choosing the areas to be replaced by fruits and vegetables due to:

- The focus of the Iowa UrbanFEWS project.
- **Available data indicating areas suitable for growing fruits and vegetables.**

A Sub-Basin of 211.7 km² and 40.7% of urban land use is used to test the data.



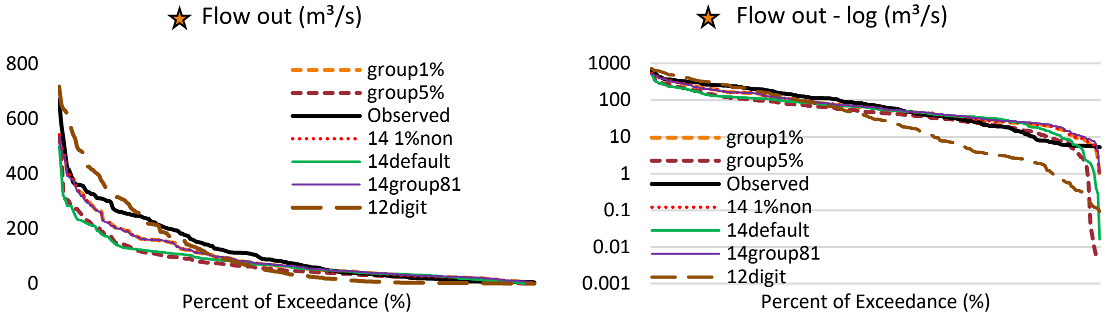
SWAT discretization

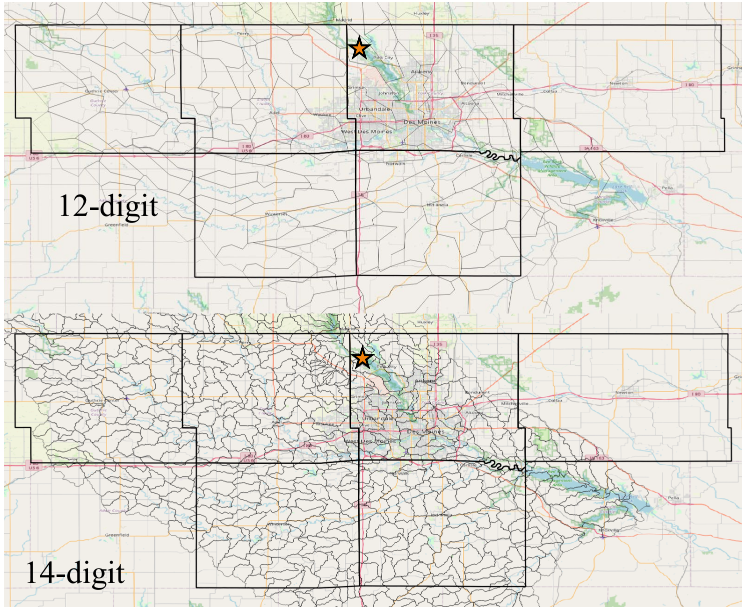
Improving SWAT spatial variability by increasing subbasin number (HUC 12-digit to HUC 14-digit)

- Simulation of the SWAT Des Moines River Basin using the HUC14 scale with an average area of ~22 km² (8 mi²). Note: HUC12 scale is, on average, 98 km² (38mi²).

	12-digit	14-digit
Number of subbasins	356	1477
Number of Hydrologic response units (HRU)	15225	**243,682**
Average simulation time daily (12 years)	~30 min.	**~3 days**

- Reduce the number of HRUs to 81,914. This will reduce the simulation time to ~1 day and maintain the minimum area needed for tile-drain allocation.
- Some testing to reduce HRU size





Sub-daily precipitation

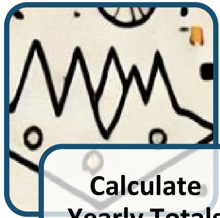
Data files: sub-daily time step (1 hour)

ERA5-Land <https://www.ecmwf.int/en/era5-land>

- The dataset is available for public use for the period from 1950 to 5 days before the current date.
- ERA5-Land provides hourly high resolution information of surface variables.
- The data is a replay of the land component of the ERA5 climate reanalysis with a spatial resolution: ~9km grid spacing.

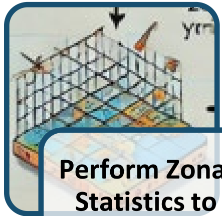
Sub-daily precipitation

ERA5-Land – Bias correction



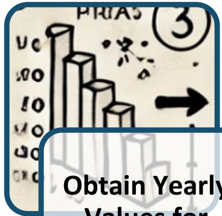
Calculate Yearly Totals for PRISM and ERA5Land for Each HUC

Input: PRISM Data, ERA5Land Data, HUC boundaries



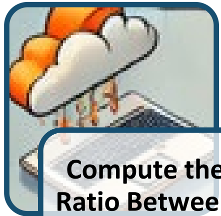
Perform Zonal Statistics to Average Grid Cells within Each HUC

Process: Calculate averages



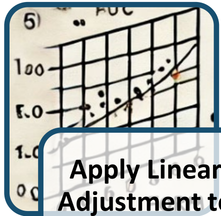
Obtain Yearly Values for PRISM and ERA5Land

Output: Yearly totals for PRISM, Yearly totals for ERA5Land



Compute the Ratio Between PRISM and ERA5Land Yearly Totals

Process: Calculate ratio (PRISM/ERA5Land)

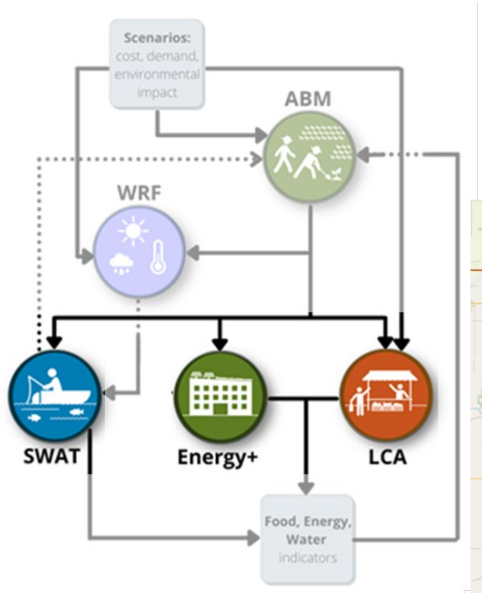


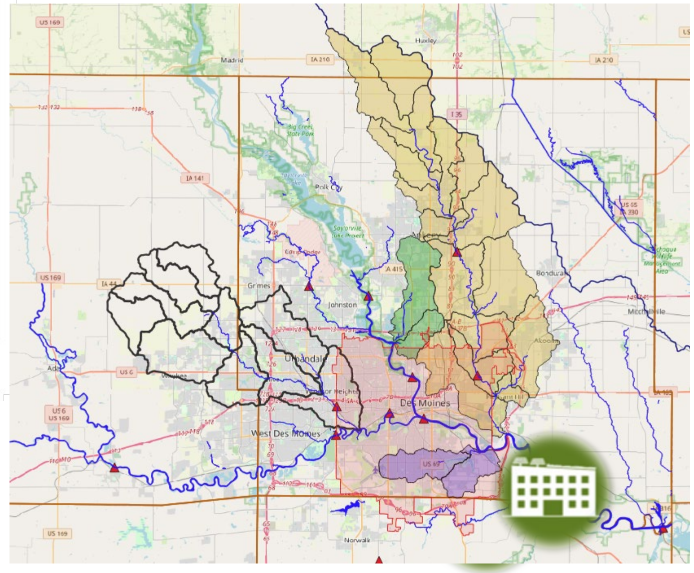
Apply Linear Adjustment to Hourly ERA5Land Data

Process: Adjust ERA5Land data using the ratio

ERA5Land Becomes Hourly Form of PRISM Yearly Data

Low impact development (LID)





- The sub-daily LID setup will be used in the SWAT-LCA-Energy+ co-simulation
- Energy+ is only for the City of Des Moines boundaries, and also simulates the green roofs.
- LCA receive SWAT and Energy+ to calculate the environmental impacts of converting the crop land. (estimated yields for green roofs)

Low impact development (LID)

Infrastructure tested:

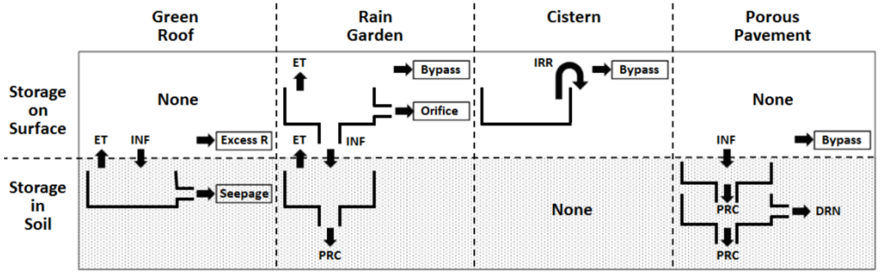
- Green Roof (map location)
- Rain Garden (locally common)

Evapotranspiration occurs on the soil surface and through vegetated grasses so that soil water content would decrease. An actual evapotranspiration rate is calculated using a crop coefficient method:

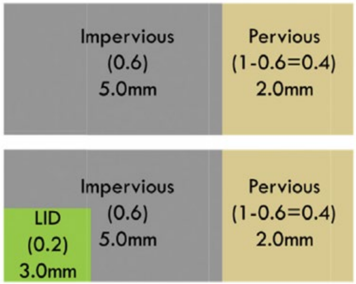
$$ET = k \cdot PET \quad (3)$$

where *ET* the actual evapotranspiration rate (mm/hour), *k* is the crop coefficient, and *PET* is the potential evapotranspiration rate (mm/hour). The crop coefficient is determined by a user considering types of vegetation planted, and it is set to a constant parameter in the model for the simplicity assuming that typical green roofs drain well with amended soils used as soil beds. Soil

Storage Type	Green Roof	Rain Garden	Cistern	Porous Pavement
Amended soil layer	O	O	X	O
Surface storage	X	O	O	X
Gravel bed layer	X	X	X	O
No. Storages	1	2	1	2



A Urban HRU (area = 1.0)



Q_total = Q_per×(1-A_imp) + Q_imp×A_imp
= 2.0mm×(1-0.6)+5.0mm×0.6=**3.80**mm

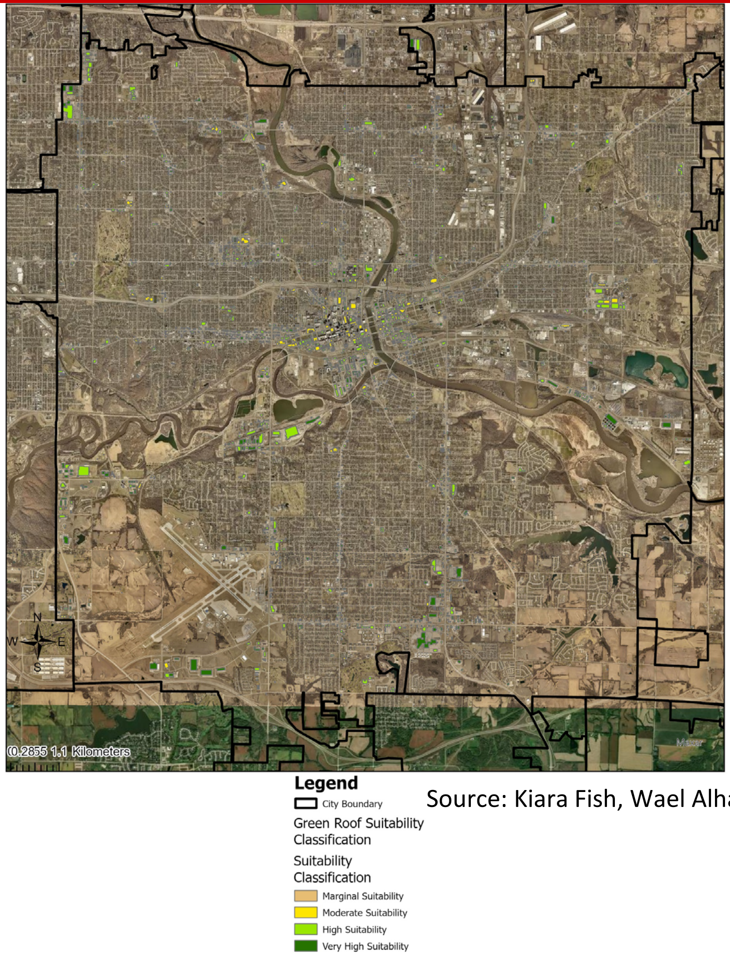
Q_total = Q_per×(1-A_imp) + Q_imp×A_imp×(1-A_LID) + Q_LID×A_imp×A_LID
= 2.0mm×(1-0.6)+5.0mm×0.6×**(1-0.2)**+**3.0mm×0.6×0.2**=**3.56**mm

Source: Her, Y., Jeong, J., Arnold, J., Gosselink, L., Glick, R., & Jaber, F. (2017). A new framework for modeling decentralized low impact developments using Soil and Water Assessment Tool. Environmental Modelling & Software, 96, 305-322. https://doi.org/10.1016/j.envsoft.2017.06.005

Low impact development (LID)

A literature review revealed a selection of green roof urban agriculture criteria:
Minimum roof surface area (1000 ft^2, 93 m^2)
Maximum building height (100 ft)
Surface slope (<5°) (Eckelman et al., 2017).

Calculated % of suitable area for each building and a suitability score was assigned for categories including building area and building height which resulted in the raster map showing the suitability of roofs in Des Moines.

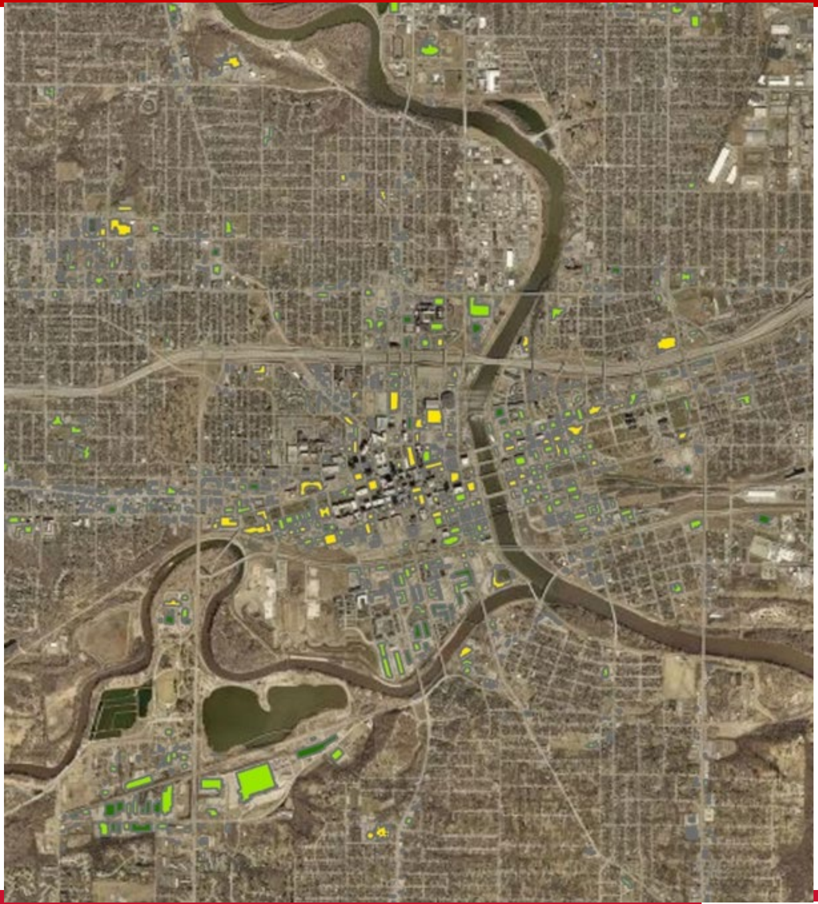


Source: Kiara Fish, Wael Alhaj

Low impact development (LID)

which vegetables were the most environmentally intensive.
Snap Bean, 31, the most water and energy-intensive
Head Lettuce, 7, is the least intensive and environmentally.
When selecting vegetables for green roof agricultural production there must also be a consideration for rooting depth.

Small-Scale	
Head lettuce	7
Carrot	8
Leaf lettuce	8
Onion	9
Tomato	10
Cabbage	11
Pumpkin	15
Squash	16
Sweet corn	17
Cucumber	18
Potato	19
Bell pepper	19
Romaine lettuce	23
Pea	25
Cauliflower	25
Broccoli	27
Spinach	27
Snap bean	31



SWAT – Azure Workflow

Scalable deployment of HUC 14 SWAT simulations

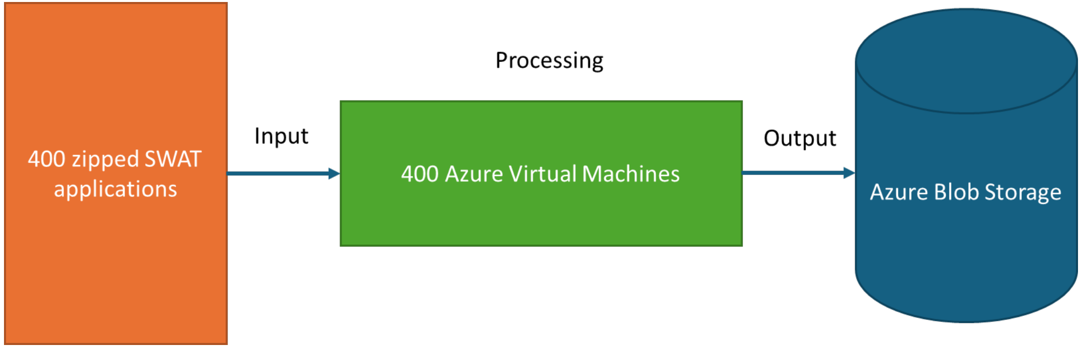
Azure Services Used

Azure Batch

- Job Scheduling Engine
- Large variety of Virtual Machines (VM)
- 2.7 GHz Clockspeed
- Time taken
  - HUC14 (3years) = 24h 08m 27.28s
  - HUC12 (22 years) = 37m 8.92s
- Machines cost $0.19/ hour
- 4GB memory (SWAT typically does not use more than 4GB observably)
  - Can extend up to 8 GB Memory + as we scale with multiple SWAT simulations

Azure Blob Storage

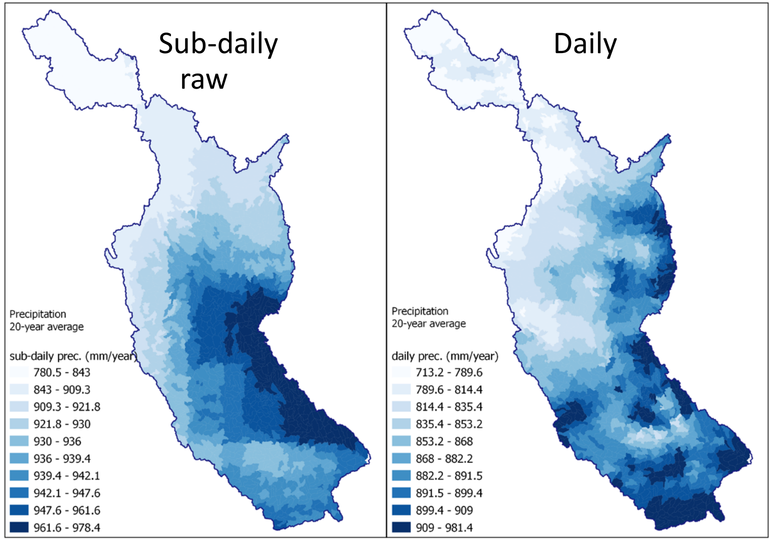
- Storage for Output



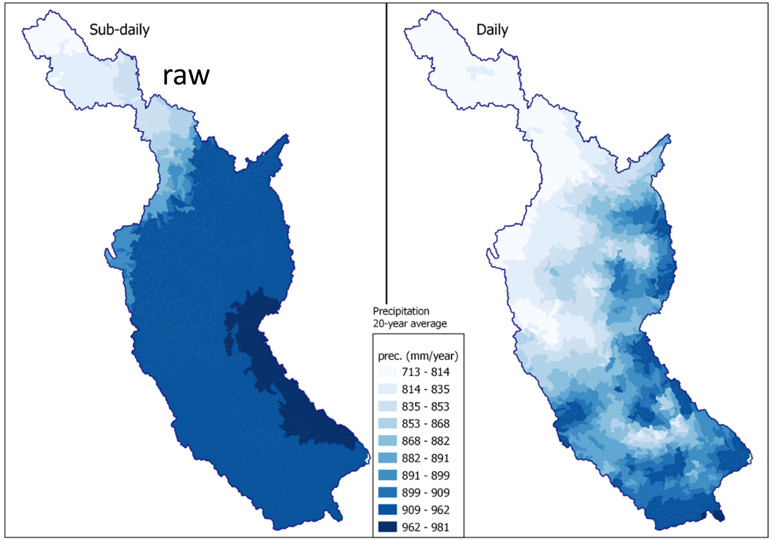
Source: Vishal Muralidharan

Sub-daily precipitation – why the bias correction (and still in process…)

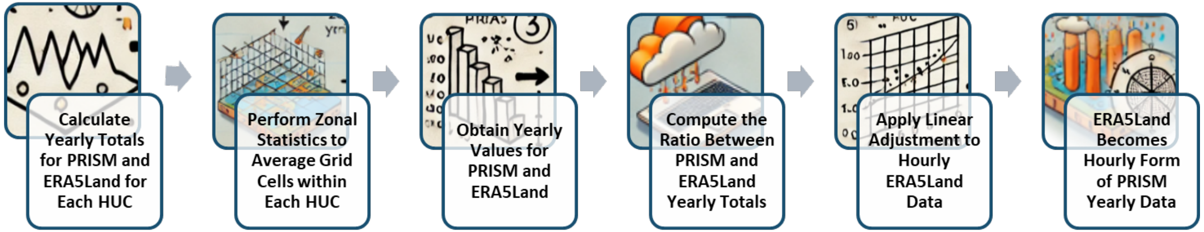
Spatial distribution of the precipitation when daily (PRISM) and sub-daily (ERA5-Land) are classified separately. (type, equal count: quantile).

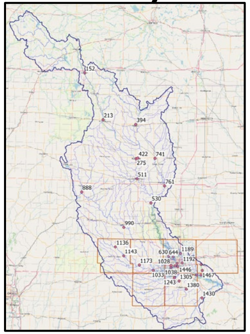


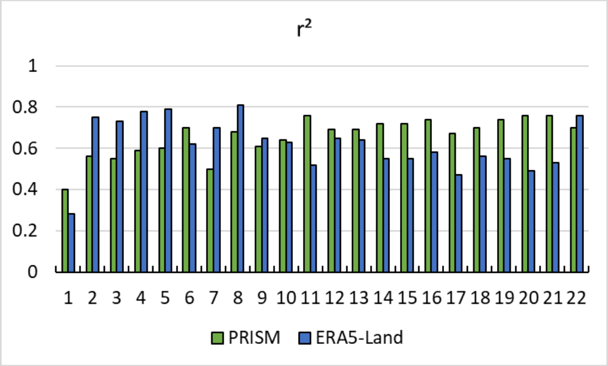
Spatial distribution of the precipitation if we classify the two data sets with the same range intervals (type, equal count: quantile).

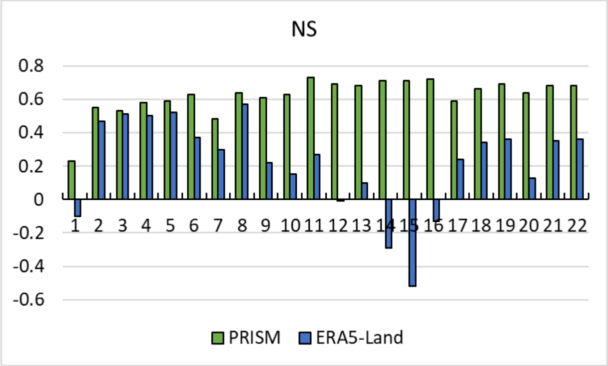


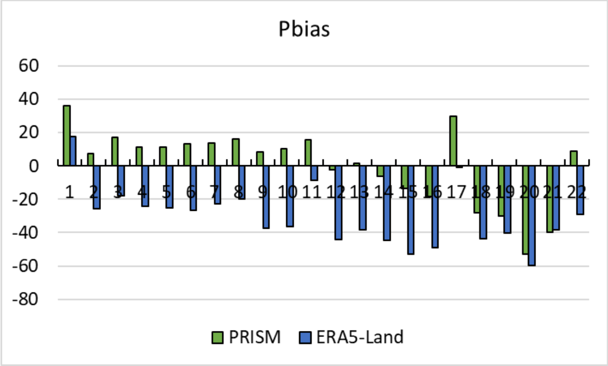
PRISM x ERA5-Land (daily accumulation for streamflow comparison)







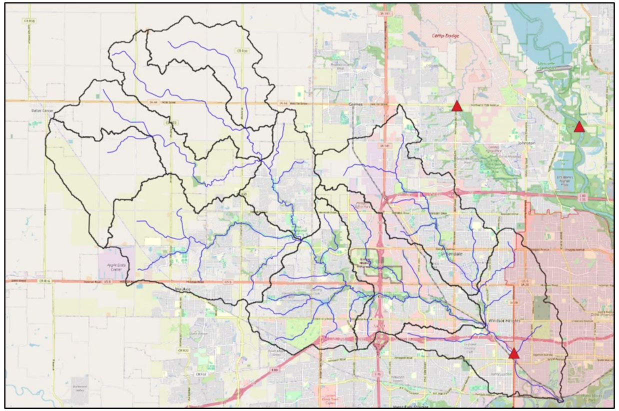


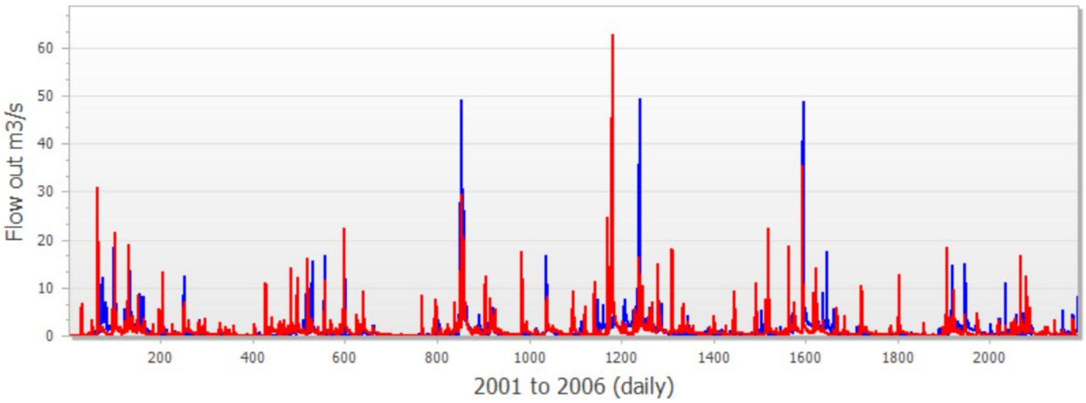


PRISM x ERA5-Land (daily accumulation for comparison)

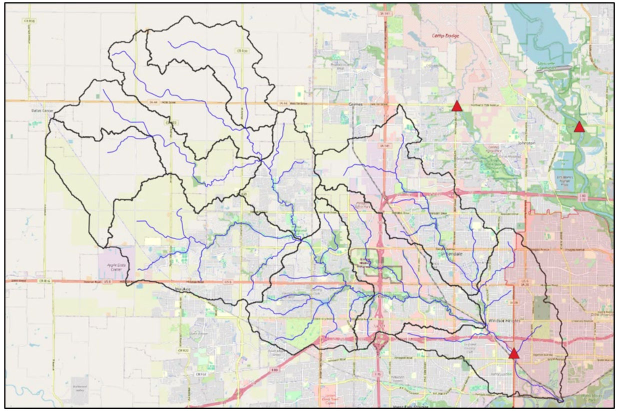
Sub-System analysis

	R2	NS	PBIAS (%)	KGE	Mean_sim(Mean_obs)
PRISM	0.52	0.41	5	0.71	1.14(1.20)
Era5land	0.55	0.22	29	0.27	1.39(1.20)





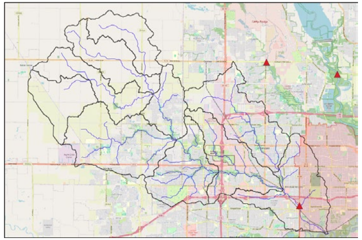
Sub-System analysis – Crop coefficient (kc)

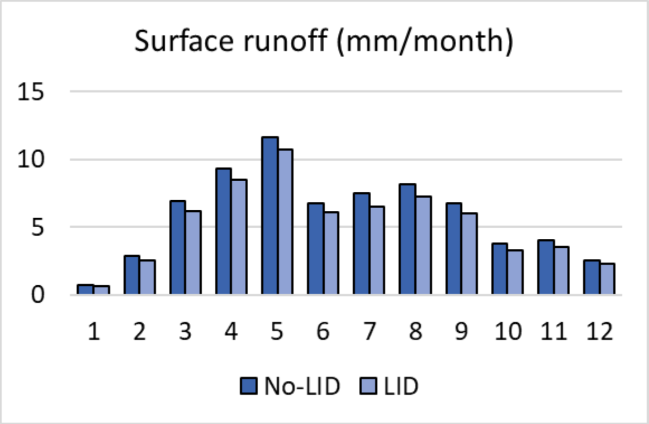


Crop type	Kc
Broccoli	0.95
Cabbage	0.95
Carrot	0.95
Cucumber	0.75
Onion	0.8
Melon	0.6
Potato	0.75
Pumpkin	0.8
Spinach	0.95
Squash	0.75
Strawberry	0.75
Sweet Potato	0.65
Tomato	0.8

- kc from literature: Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56
- Distribution of the crops is based on kc values
- Replace kc in the .lid file

Sub-System analysis – Crop coefficient (kc)





	LID (default)	LID (75)	LID (80)	LID (95)
SURFACE RUNOFF Q	63.81	63.1	62.45	61.82
LATERAL SOIL Q	103.43	103.41	103.6	103.68
GROUNDWATER (SHAL AQ) Q	152.65	152.72	152.92	153.06
GROUNDWATER (DEEP AQ) Q	11.65	11.65	11.67	11.68
DEEP AQ RECHARGE	11.65	11.66	11.67	11.68
TOTAL AQ RECHARGE	165.25	165.32	165.55	165.69
TOTAL WATER YLD	338.96	338.28	338.08	337.69
PERCOLATION OUT OF SOIL	172.89	172.96	173.2	173.35
ET	545.2	545.3	545.4	545.5

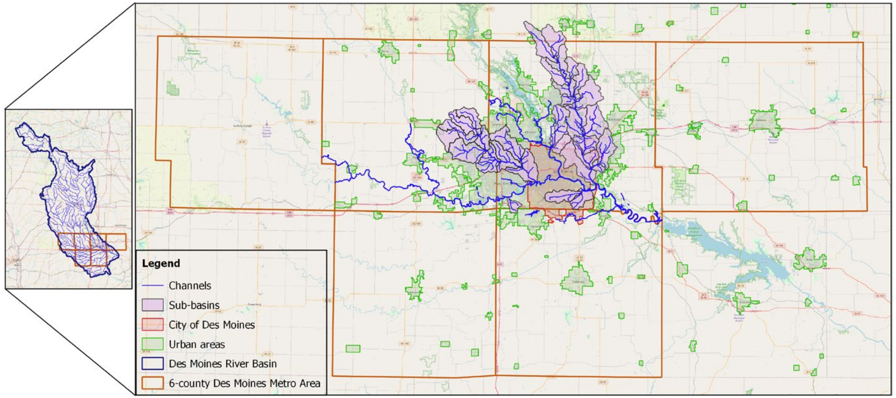
Sub-System analysis – Crop coefficient (kc)

Small-Scale	
Head lettuce	7
Carrot	8
Leaf lettuce	8
Onion	9
Tomato	10
Cabbage	11
Pumpkin	15
Squash	16
Sweet corn	17
Cucumber	18
Potato	19
Bell pepper	19
Romaine lettuce	23
Pea	25
Cauliflower	25
● Broccoli	27
● Spinach	27
Snap bean	31

Crop type	Kc
Broccoli	0.95
Cabbage*	0.95
Carrot*	0.95
Cucumber	0.75
Onion*	0.8
Melon	0.6
Potato	0.75
Pumpkin	0.8
Spinach	0.95
Squash	0.75
Strawberry	0.75
Sweet Potato	0.65
Tomato*	0.8

Highlights

- Updated bias correction is still needed, but the data is promising;
- Reducing the size of the subbasin (HUC12 to HUC14) improved the results for the raw model;
- For sub-daily simulation in a “big” basin some manual processes were needed when using SWATEditor (pcp.pcp and .lid)



Thank you!

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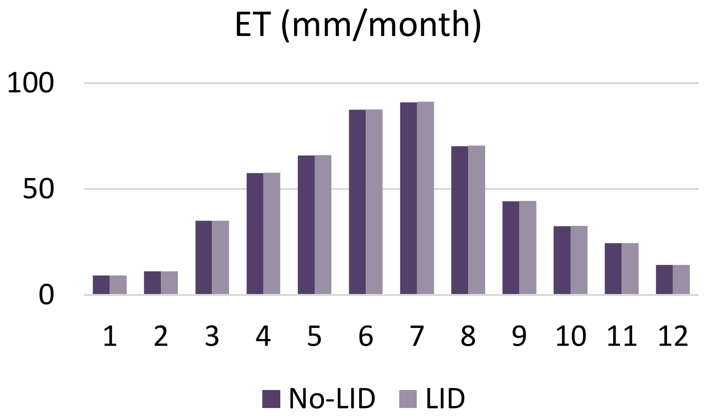
ET (mm/month)
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12
No-LID
LID