Environment and Natural Resources Trust Fund
2019 Request for Proposals (RFP)

Project Title: **ENRTF ID:** 113-BH

Simulating and Exploring Drought Scenarios at Reduced Scale

Category: H. Proposals seeking $200,000 or less in funding

Sub-Category: B. Water Resources

Total Project Budget: $ 199,640

Proposed Project Time Period for the Funding Requested: June 30, 2022 (3 yrs)

Summary:

water evaporation from differently saturated soil will be reproduced in a wind tunnel to better model the effect of wind, terrain roughness and solar radiation under controlled laboratory conditions.

Name: Michele Guala

Sponsoring Organization: U of MN

Title: Associate Professor

Department: St. Anthony Falls Laboratory

Address: SAFL, 2 third ave SE
Minneapolis MN 55414

Telephone Number: (612) 625-9108

Email mguala@umn.edu

Web Address http://www.cege.umn.edu/directory/faculty-directory/guala.html

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

New evaporation models will be integrated with weather forecast to guide irrigation strategies under various drought scenarios

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

____ If under $200,000, waive presentation?

SIMULATING AND EXPLORING DROUGHT SCENARIOS AT REDUCED SCALE

I. PROJECT STATEMENT

Water conservation strategies depend on the outcome of evaporation and transpiration models. The former accounts for solar radiation and wind turbulence, controlling water vapor flux at the soil surface. The latter accounts the water absorbed and released to atmosphere by plants. Plants play a complex role because they take water from the ground through their roots system, but they also shelter the soil from wind and sun, thus regulating evaporation fluxes. This interaction led to the formulation of integrated evapotranspiration models, quantifying the net effects of vegetated areas on the water balance. Since plant species varies a lot in foliage, yield, water uptake and spatial density, while continuously adapting to seasonal and local micro-meteorological conditions, evapotranspiration models have inherent limitations. There are ongoing, statewide efforts to map Minnesota plants, track invasive species, and assess anthropic effects such as urbanization expansion in rural areas. All those contribute to water uptake directly, e.g. by increasing surface temperature or by enhancing transpiration, or indirectly, e.g. by changing wind patterns near the ground. Estimating the net water vapor fluxes under those conditions can be extremely challenging.

We propose here to start a systematic laboratory study on soil evaporation, and to build the fundamental knowledge necessary to tackle progressively more complex environment.

While we do not attempt to include plant transpiration, we aim to reproduce all the thermal and mechanical effects induced by sparse and dense canopies within the diurnal cycle. This will provide a well-controlled baseline for next-gen study of plant physiology that will be scalable to real atmospheric conditions. Such baseline is necessary to support ecology-oriented studies in future assessment of drought potential and evaluation of water conservation strategies.

The proposed research activities include quantification of water loss due to evaporation on bare soils (activity 1) and sub-canopy terrains (activity 2) through experiencing diurnal and nocturnal thermal stratification consistent with average spring and summer microclimates in southern Minnesota.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: bare soil evaporation — Budget: $100,000

The experimental research activities will be carried out in the Saint Anthony Falls Laboratory wind tunnel, which is designed to reproduce the wind and temperature conditions achieved in the atmospheric surface layer. Different soil compositions, saturation levels, wind intensities and air temperatures will be tested to develop evaporation models that will be available to anyone with internet access. Water losses will be measured by humidity sensors in a soil box embedded in the wind tunnel floor and directly by weight loss of the box. A solar-equivalent radiating lamp to simulate the diurnal cycle and a thermal camera for assessing spatio-temporal changes of surface temperature will be added to the tunnel to recreate and monitor land-atmosphere interactions.

Outcomes and Products:	**Completion Date**
1. Dataset of evaporation experiments on bare soil	*January 2020*
2. A set of evaporation scenarios under increasing temperatures	*June 2021*
3. Web based model integrating temperature and wind conditions from weather forecast	*June 2022*

Activity 2: Sub-canopy soil evaporation — Budget: $99,640

The sheltering effect of trees on soli evaporation will be reproduced using a permeable foam layer simulating foliage. This will allow changing the foam permeability, thus the penetration of wind within the canopy. In our model the key parameter controlling the soil sheltering effect will be the drag coefficient of the tree ensemble, estimated from the velocity deficit above the canopy. Two set of experiments will be performed, one with an infinite canopy covering the entire wind tunnel floor, one with a canopy patch covering also the inlet portion of the wind tunnel. These two regimes will add the drag coefficient and the distance to the canopy to the weather-based input parameter space for our evaporation model. Once this is achieved, vegetation and land use maps (from Geographic, Information Systems, GIS) can be integrated into a unified evaporation model.

Outcomes and Products:	**Completion Date**
1. Dataset of evaporation experiments with canopies of different permeability	*Aug 2021*
2. Model for soil evaporation within and downwind of canopies with given drag properties	*Mar 2022*
3. GIS (vegetation map -land use)–weather forecast integrated model for soil evaporation	*June 2022*

III. PROJECT STRATEGY

A. Project Team/Partners

The proposed research requires expertise in experimental fluid mechanics, micrometeorology, and atmospheric science (**Michele Guala,** Associate Professor, Department of Civil Environmental and Geo-Engineering, and Associate Director of Research at the Saint Anthony Falls Laboratory, UMN), hydrology, remote sensing and land-atmosphere interactions (**Ardeshir Ebtehaj,** Assistant Professor, Department of Civil Environmental and Geo-Engineering, UMN).

B. Project Impact and Long-Term Strategy

What is the benefit for Minnesota citizens, agencies and legislators?

Answer questions.

1) Are we prepared to face drought conditions? How much more water will be used by agriculture for each degree of increased temperature? How much water do we really need, and how much can we save?

2) Provide service to farmers: how does different soil compactness respond to wind intensity and air temperature?

3) Water irrigation: how much water should be provided per unit area in early growth season based on real-time weather forecast? Under initial saturated soil conditions, how long will it take for a seed at known depth to perceive dry soil?

4) What is the water conservation rate as a function of orchard spacing and porosity? Can we come up with alternative and more efficient irrigation strategies?

Improve stream and lake water quality.

Optimal irrigation means reduced water flow in ditches, tile drainage and surface runoff. An indirect benefit is related to reduced runoff due to more conservative irrigation strategies. If soil evaporation is mitigated and less water is required for the same crop yield, less water will be collected in ditches and tiles drainage resulting in reduced erosion and transport of nitrates and phosphates to stream and lakes. Especially during the growing season, limiting the runoff flux to water bodies, especially lakes, will limit nutrients availability for algal species and will have the potential to improve statewide water quality.

The rationale for developing a web-based GIS system is to facilitate public engagement and increase farmers' knowledge about the ways they can sustainably reduce water use and increase crop yield.

Promote Minnesota excellence at very competitive costs.

Only one other wind tunnel in USA is equipped for soil evaporation studies, at the Colorado School of Mines, but has a smaller cross section and does not allow setting the thermal stability condition of the incoming turbulent flow. We have an opportunity to make advancement at a federal level on a research theme that should resonate with rural Minnesota.

Long term strategy. Experiments in the SAFL wind tunnel have been recently performed by a team led by the UMN's Department of Bioproducts and Biosystems Engineering using oat plants. The goal was to predict stem deflection under varying wind and stem density (in fact a canopy patch). It is thus possible to have plants in the wind tunnel. The long term strategy (beyond this proposal) is to move from bare soil and a synthetic canopy model to grass patches, simulating early growth season and adding a transpiration component to our evaporation model.

2019 Detailed Project Budget

Project Title: SIMULATING AND EXPLORING DROUGHT SCENARIOS AT REDUCED SCALE

IV. TOTAL ENRTF REQUEST BUDGET: $199.640 for 3 years

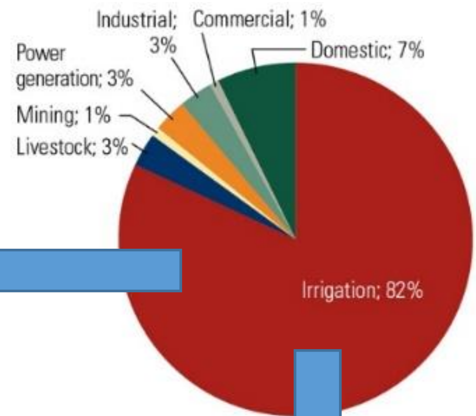
BUDGET ITEM	AMOUNT
Personnel:	
Prof. Michele Guala, PI (75% salary, 25% benefits); 7% FTE , 2 weeks per year for 3 years: Dr. Guala is the associate director of SAFl. He brings critically important expertise in experimental fluid dynamics and atmospheric boundary layer, and he will co-supervise the PhD student.	$ 23,330
Prof. Ardeshir Ebtehaj, PI (75% salary, 25% benefits) 7% FTE , 2 weeks per year for 3 years: Dr. Ebtehaj is an expert in hydrology, mathmethical modeling and land-surfac einteractions . He will co-supervise the PhD student.	$ 20,887
Staff Engineer Christopher Feist (78% salary, 22% fringe): 7% FTE (2 weeks per year) . will help the PhD student to build the wind tunnel setup for evaporation tests, including mounting IR camera and solar radiation lamp. He will also help building web-interface for modeling	$ 15,267
Graduate student (59% salary, 41% fringe): One graduate students will be supported for tuition (3 years) and salary (2.5 years). He will be performing experiments, processing data and formulating the evaporation model.	$ 126,656
Equipment/Tools/Supplies: (see below)	$ -
supplies: General supplies are requested for repairment of hotwire (flow measurement) probes, and for the construction of canopy model: Year 1,2 ($1,000), Year 3 ($500). These costs are split between**Activities 1 and 2**	$ 2,500
Equipment: infrared camera for spatial measurements of surface temperature and a solar radiation lamp to provide the sun-equivalent correct radiative heat flux (both critical for activities 1 and 2).	$ 10,000
Travel	
travel to the EOLOS meteorological field station are budgeted for Year 1,2 based on historical cost assessments.	$ 1,000
Additional Budget Items: none	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 199,640**

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *none*		

SIMULATING AND EXPLORING DROUGHT SCENARIOS AT REDUCED SCALE

1) Agriculture is the major consumer of fresh water



? Evaporation

2) Minimizing water loss through evaporation is the best conservation strategy

transpiration → crop yield → OK

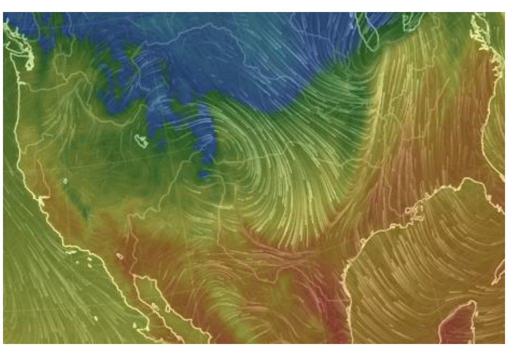
Evaporation = turbulence (wind) + heat (air temperature) + terrain complexity

3) How much water is needed ?

4) Wind tunnel experimental research

5) Validated evaporation model

SOLUTIONS:



6) Weather forecast + web-based model = optimal irrigation

PROJECT MANAGER QUALIFICATIONS

Michele Guala, Associate Director of Research St. Anthony Falls Laboratory (SAFL),
Associate Professor Department of Civil Environmental and Geo- Engineering (CEGE), University of Minnesota, Minneapolis, 55414, MN, USA

Education

Ph.D. Hydraulic Engineering, 2003, University of Padova, Italy
Laurea (BS+MS) Civil and Environmental Engineering, 1998, University of Genova, Italy

Professional experience

UMN , SAFL & Department of Civil, Environmental, and Geo- Engineering, assistant professor 2011-2017
Caltech Postdoctoral GALCIT, Caltech, Pasadena , 2008-2010, SLF, Davos Research scientist 2007,
ETH Zurich, CH Postdoctoral fellow at the Institute of Hydromechanics 2003-2006

Awards/Recognitions

Recipient of the **NSF CAREER award** "Geophysical Flow Control" (2014-2019)
Recipient of the **IREE Early Career Award** (UMN) *"Evaluating wind farm performance under realistic thermal and complex terrain conditions: the first path towards optimization"(2012-2015)*

Publications

(Relevant to this LCCMR proposal; out of a total of 57 publications→1502 citations)

1) Singh A. Howard K. , Guala M. "Scale-dependent asymmetry and intermittency in turbulent boundary layer flows", J. Fluid Mechanics, (2016)
2) Howard K., Chamorro L.P. Guala M. "A Comparative Analysis on the Response of a Wind-Turbine Model to Atmospheric and Terrain Effects", Boundary-Layer Meteorology (2016)
3) Guala M, Tomkins C. D., Christensen K.T., Adrian R.J. "Vortex organization in a turbulent boundary layer overlying sparse roughness elements " Journal of Hydraulic Research, (2012)
4) Guala M., Metzger M. and McKeon B. ``Scale interactions in the high Reynolds number turbulent boundary layer'' J. Fluid Mech., (2011)
5) Guala M., Manes C., Clifton A., Lehning M. ``A wind tunnel investigation on the saltation of fresh snow particles in a turbulent boundary layer: profile characterization and single particle statistics'' Journal of Geophysical Research - Earth (2008)
6) Hong J., Toloui M., Chamorro L.P., Guala M., Howard K., Riley S., Tucker J., Sotiropoulos F. Natural snowfall reveals large-scale flow structures in the wake of a 2.5-MW wind turbine. Nature communications 5 (2014)

ORGANIZATION DESCRIPTION: St. Anthony Falls Laboratory, University of Minnesota

The proposed research will be performed at the St. Anthony Falls Laboratory, University of Minnesota. SAFL faculty, staff and researchers have a considerable experience in conducting and analyzing laboratory and field measurements. For this research the Atmospheric wind tunnel will be used for the duration of the project. PI Guala is responsible for the wind tunnel schedule within SAFL and he is committed to allocate the necessary resources for the completion of the proposed research activities. Atmospheric data from the 130m tall meteorological tower located at UMore Park, in the Eolos Wind Research Field, will be also used to guide our wind tunnel investigation. SAFL, now under the college of science and engineering, host faculty from different departments including Earth Science and Ecology that can be beneficial for this project.

TEAM DESCRIPTION

Michele Guala will supervise the flow measurements in the wind tunnel and contribute to the atmospheric science component of this research. He will also coordinate all the research activities, co-supervise the PhD student involved, and take care of technical documentation, data management and reporting.
Ardeshir Ebtehaj is an expert in hydrology, remote sensing and mathematical modeling. He will supervise the evaporation modeling work and co-supervise the PhD student.