Integrating Remote Sensing and Spatiotemporal Statistics to Develop Prescription Maps for Variable Rate Irrigation Systems

Principle Investigator:	Dr. Neil C. Hansen, Department of Plant and Wildlife Sciences
BYU Co-Investigators:	Dr. Ruth Kerry and Dr. Ryan Jensen, Geography Department
	Dr. Matthew Heaton, Department of Statistics
	Dr. Bryan Hopkins, Department of Plant and Wildlife Sciences
Research Collaborators:	Mr. Ryan Christensen, Christensen Farms
	Dr. Colin Campbell, Meter Environment, Inc.

Abstract

Irrigated agriculture consumes a large majority of global fresh water. Increasing water scarcity due to population growth and climate change creates an urgent need to improve irrigation efficiency. Scientists and industry experts have developed variable rate irrigation systems (VRI) which use global positioning technology to precisely deliver water in spatially varying patterns. Adoption of VRIs is limited because over-simplified application approaches fail to produce economically valuable outcomes. To remedy this, we propose to combine scientific expertise in soil and irrigation science, drone and satellite based remote sensing, and spatio-temporal statistics to create and solve a viable algorithm in three steps. First, we will develop a spatial data layer of soil water holding capacity with high-resolution that is temporally constant using soil and crop yield maps, soil sampling, remotely sensed imagery, and digital elevation models. Second, we will model spatially and temporally varying soil water levels and in-season crop response from remotely sensed images, a distributed network of soil sensors, energy balance equations, meteorological data, and irrigation inputs. Finally, we will combine results from steps 1 and 2 to provide a spatially complete assessment of irrigation water needs across fields in real time (Step 3). This information will be provided to VRIs to govern irrigation decisions and efficiently manage scarce water resources. Potential sources for continued funding beyond this BYU IDR include a Western SARE Research and Education Grant, the Terrestrial Hydrology Program at NASA, and the Binational Agricultural Research and Development Fund (BARD).

The pilot study will be conducted at Christensen Farms in Grace, ID. The left image shows the center-pivot sprinkler that waters both a crop field and a golf course. The right image shows GPS receivers, controllers, and nozzles on the existing variable rate irrigation system.

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Background

Irrigated agriculture produces 40% of the world's food and fiber and is the single largest user of world freshwater resources (Evans et al., 2013; Postel, 1999; Schaible and Aillery, 2012; Abdullah, 2006). Because irrigation is also a large consumer of energy, irrigated agriculture is at the center of the water-food-energy nexus, a concept illustrating the development interdependence of global food, energy, and water supplies. As population expands and economies develop, the increased demand for all three resources intensifies competition for the limited water supply. Agriculture faces the challenge of increasing production without increasing water consumption. To help meet this challenge, this project integrates crop and irrigation science with remote sensing and spatiotemporal statistics for improved water and energy efficiency of irrigated agricultural systems.

The center-pivot sprinkler is one of the most prevalent systems for irrigated crop production, with more than 14 million hectares (35 million acres) of sprinkler irrigated farmland in the U.S. alone (USDA Census of Agriculture, 2013). In this system, the sprinkler system rotates around a central, pressurized water supply point, creating large, circular irrigated fields, each commonly about 50 ha in size (125 acres). Current center-pivot sprinkler systems apply water in a spatially uniform pattern over the entire field, ignoring within-field variation in soil properties, relief, evaporation, and crop growth (King et al., 2006). While the aim of uniform water application is to reduce crop yield variability, high levels of spatial variation in crop growth and yield are still widely observed (Daccache et. al., 2014; Longchamps et al., 2015). With spatially uniform irrigation, the observed variation in crop growth and yield means that some areas of the field get too much water and other areas get too little water. Over-irrigating wastes water and energy and leads to environmental problems from runoff or leaching. Under-irrigating leads to inefficient water and energy use because crop stress leads to poor yields.

A developing technology to improve irrigation efficiency is variable rate irrigation (VRI), which uses global positioning technology on center-pivot sprinklers to precisely deliver water according to within field variation of crop needs (Evans and King, 2012; Evan et al., 2013). Early VRI systems were developed by scientists from the U.S. Department of Agriculture (Evans and King, 2012; McCarthy et al., 2010) and were later demonstrated on a small number of commercial farms through cost-sharing programs. In research applications, significant water savings have been documented from VRI systems (Liakos et al., 2017; O'Shaughnessy et al., 2016) and VRI systems are now being produced commercially by various companies (see for example: Lindsay Corporation; Reinke; Valley Irrigation). However, adoption of VRI systems by farmers is currently very limited. One reason for limited adoption of VRI is a poor understanding of how to apply the available technology to field-specific needs in a way that achieves economically important improvements in water and energy efficiency.

Effective application of VRI technology requires the solution of a complicated spatio-temporal problem for every single irrigation event during the growing season. Embedded in the problem are questions such as: 1) what is the average amount of irrigation needed for the field, 2) what parts of the field require more or less than the average, and 3) how much more or less? The solution to this problem is a prescription map that can be used to program the VRI system. Irrigation companies and some agricultural consultants have developed approaches to create VRI prescription maps, but the approaches used to date have over-simplified the process to a degree that the potential benefits of VRI are frequently not evident. In this project, we will combine scientific expertise in soil and irrigation science with remote sensing and spatio-temporal statistics using statistical models and machine learning algorithms to create effective VRI prescription maps.

Long and Short Term Project Goals

Our research team seeks to publish and patent a systematic, high-tech approach to develop VRI prescription maps that improve water and energy use in an economically important way. A robust solution will require an interdisciplinary research approach over multiple site-years representing a range of crop, soil, and climate conditions. In addition, long-term success depends on collaboration with the irrigation, field-sensor, and remote sensing industries. The proposal has assembled a unique, interdisciplinary team around a compelling research problem. We are committed to achieve the long-term goal and believe that this pilot project will provide the proof-of-concept we need for success in future grants and sponsorship.

Keeping the long-term goals mentioned above in mind, this proposal will focus on short-term goals that can be accomplished under the scope and time frame of the IDR. Specifically, this research will apply modern research methods to (1) collect and analyze field and remote sensing data to develop a high-resolution map of water holding capacity (the total amount of water the soil can hold) throughout the field, (2) use weather and remote sensing data, or alternatively a distributed sensor network, to develop spatio-temporally dynamic maps of crop water use, and 3) develop VRI prescription maps that match spatially variable needs within the field.

Research Approach

The research activities of this IDR will center around a pilot-study for an existing 380-m long, state-of-the-art VRI system on a 22-hectare (54-acre) commercial farm field owned and operated by Christensen Farms in Grace, Idaho. Namely this IDR will develop methodology to generate a VRI prescription map for each irrigation event during the cropping season for this field (Figure 1). Broadly speaking, this methodology will consist of, first, gathering appropriate data via modern remote sensing techniques and ground-level equipment and (ii) synthesis of the data into irrigation prescription maps via statistical analysis. Consider each step in turn.

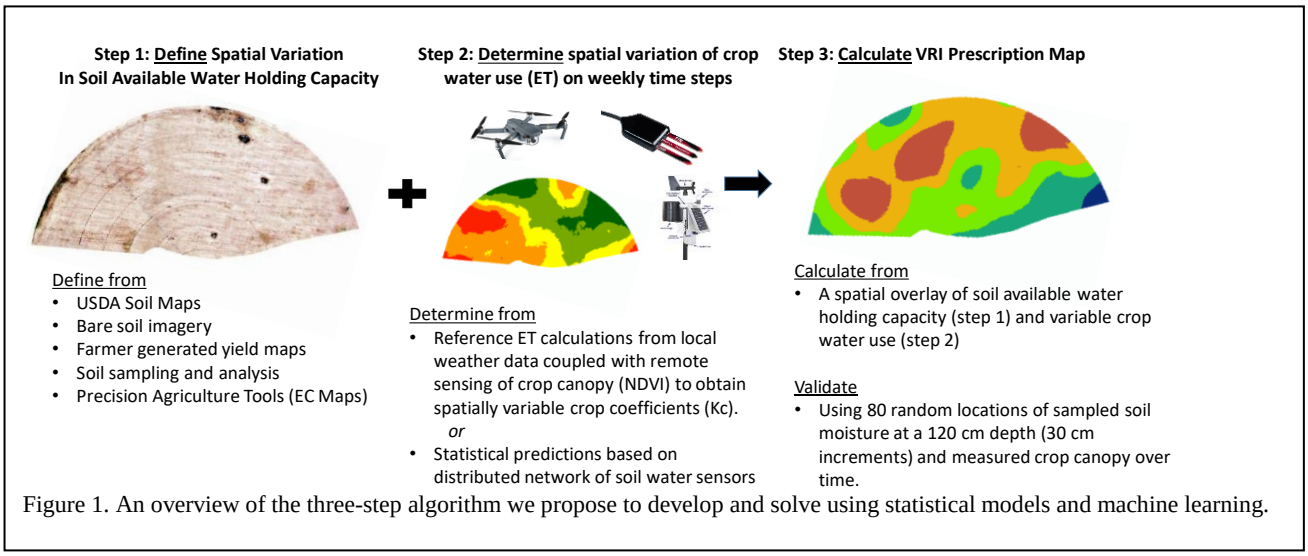

Figure 1. An overview of the three-step algorithm we propose to develop and solve using statistical models and machine learning.

Field Data Collection. Soil samples will be collected four times in each of two growing seasons from 80 sample locations from a nested grid in the field and will be analyzed for soil water content. Canopy cover will be analyzed at the times and locations using a light-bar system. Spatial maps of crop yield will be obtained from our farm collaborator. A distributed network of soil moisture sensors will track soil moisture from a more limited set of locations in real time. Sensors and technical support will be provided by our collaborator from Meter Environment, Inc.

Remote Sensing Data Collection and Analysis. Small Unmanned Aerial Systems (sUAS; i.e. "drones") enable rapid, low-altitude (e.g., < 122 meters above ground level), and fine spatial resolution (e.g., pixels < 5cm) image acquisition and analysis. The potential for environmental remote sensing using sUAS was effectively argued by Tomlins (1983) over 30 years ago, reiterated by Laliberte et al., (2007), and more recently explored by Jensen (2017). Use of sUAS is gaining in popularity in agriculture for crop monitoring and problem diagnosis. Some farmers, including our farm collaborator, own and operate sUAS, but most hire professionals to conduct flights and analyze images. For larger areas or when lower resolution imagery is adequate, satellite remote sensing platforms can also provide useful information. In this study, remote sensing data will be collected using several sUAS (DJI Mavic Pro, DJI Inspire 1, and DJI Phantom 4 NIR) flown by project personnel and also by orbital satellite platforms (e.g., Landsat 8). Orbital satellite data will be acquired that were imaged as close to the date of the sUAS data flights as possible. This will be done using the USGS Earth Explorer website (https://earthexplorer.usgs.gov) where multiple satellite datasets are usually available days after they are imaged. Coupling sUAS data with standard satellite data will allow us to determine the capacity of data acquired on both types of platforms for determination of the crop canopy information needed to estimate crop water use. Vegetation indices from these data will be compared with values calculated from the sUAS. This comparison will help us determine the utility of orbital remote sensing data to aid in water conservation in precision irrigation systems.

Statistical Analysis of Collected Data. Generating VRI prescription maps poses several intriguing statistical challenges: 1) simultaneous and cohesive analysis of multiple data types (e.g. field measurements, remote sensing and historical data), 2) exploiting spatial relationships to predict water capacity and availability at locations in the field where no observed data is available, and 3) empirically defining regions where water capacity and availability is similar. To address these challenges, we will employ state-of-the-art statistical methods such as Bayesian modeling for merging multiple data types, Gaussian processes for spatial prediction and hierarchical clustering to define contiguous spatial regions with similar irrigation needs (see, for example our previous work in Messick et al. 2017). Importantly, the employed statistical methods will be developed in a way that allow large datasets to be analyzed in real time with computing systems likely to be connected to variable rate irrigation systems.

Expected Project Outcomes

The key outcome of this project will be a proof-of-concept approach for developing VRI prescription maps based on interdisciplinary study at a pilot site. This will provide a strong foundation for the grant and contract support needed to expand our result to a more comprehensive solution that is robust over variable crop, soil, and environmental conditions. While working toward the long-term goal, we expect to achieve the following shorter-term outcomes during the timeframe of this project.

Scholarly Outcomes. Project personal (faculty and students) will present disciplinary components of the project at the following scientific meetings: American Society of Agronomy, American Association of Geographers, American Society for Photogrammetry and Remote Sensing, Soil Science Society of America, Crop Science Society of America, International Conference for Precision Agriculture, European Conference for Precision Agriculture, and Joint Statistical Meetings of the American Statistical Association. Further, we expect to develop the following disciplinary manuscripts:

Anticipated publication title	Target Journal
Spatial variation of crop water productivity	Agronomy Journal
Modelling within field variation of soil water content to support variable rate irrigation decisions	Irrigation Science
Comparison of required spatial, spectral, and temporal resolutions for use of both sUAS and orbital platforms in making variable rate irrigation decisions	GIScience & Remote Sensing
Potential for estimating crop canopy with the Greenness Vegetation Index	Applied Remote Sensing
Spatial hierarchical clustering to designate watering zones for variables rate irrigation systems	Journal of Agricultural, Biological and Environmental Statistics

BYU Inspiring Learning Initiative. This project will support the experiential and inspired learning initiative at BYU. Namely, our research plan involves scientific training and leadership of 3 graduate students and involvement of 6 or more undergraduate students. Student teams will meet weekly with their disciplinary advisor and monthly with the full project team. All students will get the opportunity to be involved with the interdisciplinary aspects of the project such as, collecting field data at our case study site in Idaho, supporting data collection using the sUAS, cleaning and organizing big data and performing the associated statistical analysis. The research team members will all be involved in mentoring students from each representative department and college.

BYU Curriculum. Topics from this project will be integrated into existing and future course curriculum. For example, the research done as part of this IDR will be instrumental in the creation of a new "Correlated Data Analysis" class within the statistics department that will be available to all students (not just those directly involved in the project). The course will cover modern techniques for analyzing correlated data in space and time.

Plans for Pursuing External Funding

Our team plans to seek funding support from both competitive research grants and cooperative research contracts as shown here.

Grant Program	Funding Limit	Deadline	Comments
United States – Israel Binational Agricultural Research and Development Fund (BARD)	$310,000 for a 3-year grant.	Annually mid-September	This program requires collaboration among U.S. and Israeli scientists. We have already established an Israeli team to work with and we will submit a proposal in 2018.
NASA Terrestrial Hydrology Program	Not listed in official documents	Annually mid-July	This program has the scientific objective to use remote sensing to develop a predictive understanding of the role of water in land-atmosphere interactions and to further the scientific basis of water resources management. We plan to submit a proposal in July, 2019.
Agriculture and Food Research Initiative Foundational Competitive Grants Program (AFRI)	Range of budgets listed, most around $400,000 for 3-year projects	Annually with June, July or August due dates. Letters of intent due in May.	This program seeks to sustainably increase agricultural productivity and availability of safe and nutritious food while significantly reducing water use and preserving water quality. We will submit a proposal in 2019.

We have identified these other grant programs with related priorities and will pursue them as we are able: National Science Foundation, Hydrologic Sciences Program; Water Resources Research National Competitive Grants Program, U.S. Geological Survey; Western Sustainable Agricultural Research and Education Grant, USDA.

Project Timeline

Year	Jan - Mar	Apr - Jun	Jul - Aug	Sept – Dec
2018	Pre-award activities Coordination with farm cooperator Create nested grid sampling array Bare soil imagery Identify sources for weather data Student recruiting	Crop planting/initial soil sampling Create static maps of soil water holding capacity. Install sensor network Satellite and drone based images. Create and test initial VRI prescription maps	Two mid-season sampling and imaging trips. Spatio-temporal analysis Analysis of sensor data Draft BARD Proposal	Harvest/final soil sampling and imaging trip. Progress review and evaluation Progress report Submit BARD Proposal
	---------- Weekly mentoring meetings ---------- ---------- Monthly team meetings ----------			
2019	Automation and testing of algorithm. Draft NASA and AFRI Proposals	Repeat of 2018 field activities Test and validate VRI prescription maps Review NASA and AFRI Proposals. AFRI Letter of Intent	Repeat of 2018 field activities Test and validate VRI prescription maps Submit NASA and AFRI Proposal	Harvest/final soil sampling and imaging trip. Draft Final Report Identify future sites and collaborators.
	---------- Weekly mentoring meetings ---------- ---------- Monthly team meetings ----------			
2020	Graduate Students-Thesis Defense Manuscript and Final Report Submission			

Project Members and Responsibilities

The VRI concept is not new. Scientists and industry have already developed VRI equipment and remote sensing tools are widely available for agricultural uses. The primary reason VRI adoption is limited is that information from all relevant disciplines has not been effectively integrated into practical solutions. For these reasons, our interdisciplinary team is uniquely positioned to make a viable VRI system.

Interdisciplinary Research Team

Name	Department/College	Project Roles
Dr. Ruth Kerry	Geography / Family Home and Social Sciences	Dr Kerry's researches spatial sampling issues and use of remotely sensed data in geostatistical research. She will provide guidance on soil sampling and data interpolation.
Dr. Matt Heaton	Statistics / Physical and Mathematical Sciences	Dr. Matthew Heaton's expertise is spatio-temporal statistical analysis, with a strong background in climate research. He will advise graduate and undergraduate students and they will be responsible for the statistical analysis to produce the static and temporally dynamic maps of soil water use.
Dr. Bryan Hopkins	Plant and Wildlife Sciences / Life Sciences	Dr. Bryan Hopkins is a soil scientist and crop production specialist. He has extensive experience with field-based research with collaborating farmers. He will coordinate the project team on field data collection.
Dr. Ryan Jensen	Geography / Family Home and Social Sciences	Dr. Ryan Jensen is an expert in applying GIS and remote sensing to natural resource problems. Together with graduate and undergraduate students, he will direct the remote sensing components of this study. He is an FAA Certified Remote Pilot and is licensed to fly sUAS to acquire aerial sUAS imagery for research and/or commercial purposes.
Dr. Neil Hansen	Plant and Wildlife Sciences/Life Science	Dr. Hansen has a successful track-record in directing large, multi-disciplinary projects and will serve as the project P.I. As an irrigation scientist, he will oversee the team on the irrigation management components of the project.

Citations

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Project Budget

Category	Year 1	Year 2	Total
Graduate Student Wages (contract)	$31,500	$32,445	$63,945
Undergraduate Student Wages (hourly)	$12,750	$13,133	$25,883
Travel	$9,300	$9,579	$18,879
Supplies	$6,250	$4,000	$10,250
Total	$59,800	$59,157	$118,957

Budget Justification

Total Request: $118,957

Wages: $89,828

Graduate students (contract) - $63,945. Two M.S. students will be supported on the project at half-time appointments (20 hrs./week). Contracts in year 1 will be $5,250 for each of three semesters and increased by 3% in year 2. One student will be in the Statistics Department, advised by Dr. Heaton. The second student will be in the Department of Plant and Wildlife Sciences, co-advised by Dr. Hansen and Dr. Jensen.

Undergraduate students (hourly) - $25,883. Funds are requested for two, part time undergraduate, mentored research students. Each student will work about 10 hours per week during fall (14 weeks) and winter (14 weeks) and 30 hours per week during the summer (12 weeks), for a total of 640 hours. Hourly pay will be $10/hr. in year 1 and will increase by 3% in year 2.

Domestic Travel: $18,879
The pilot study will be located on a farm in Grace, Idaho. We have budgeted for six project personnel (faculty, graduate students, and undergraduate students) to each participate in 5 overnight work trips per year to the research site. Trips will be in a rented pick-up truck with one-way distance of 220 miles and will involve soil and crop sampling and remote sensing missions. In year 1, total cost of each trip will be $1,100 ($314-mileage, $450-hotel, $336 per diem) with a 3% increase in year 2. The budget also includes reasonable estimates for two graduate students and two undergraduate student to participate in a professional conference one time during the two-year project.

Supplies: $10,250

The study will involve soil sampling on four dates at 90 field locations and 4 depths for 1,800 samples per year. Analysis cost for soil moisture determination is $1.75/sample in year 1. $2,400 is needed in year 1 to purchase soil moisture sensors and $1450 is requested for publication costs in year 2.

List of Supportive Materials

Curriculum Vitae for Project Participants

Current and Pending Support Documents for Project Participants
(note: Dr. Kerry has not current or pending grants to report)

Endorsement from Dr. Brock McMillan, Chair, Department of Plant and Wildlife Sciences

Support letters from Project Collaborators

Dr. Colin Campbell, Meter Environment

Mr. Ryan Christensen, Christensen Farms

NEIL C. HANSEN

Curriculum vitae

Brigham Young University, Department of Plant and Wildlife Sciences
701 East University Parkway Drive, 4105 LSB, Provo, UT 84602
Phone: (801) 422-2760 Email: neil_hansen@byu.edu

EDUCATION

Ph.D. - Soil Physics - University of Minnesota, St. Paul, MN - 1998

M.S. - Agronomy - Brigham Young University, Provo, UT - 1994

B.S. - Agronomy, Brigham Young University, Provo, UT - 1992

EXPERIENCE

2017 - Present	Professor, Dept. Plant and Wildlife Sciences, Brigham Young Univ.
	Affiliate Professor, Dept. Soil and Crop Sciences, Colorado State Univ.
2013 – 2017	Associate Professor, Dept. Plant and Wildlife Sciences, Brigham Young Univ.
2004 - 2013	Associate Professor, Dept. Soil and Crop Sciences, Colorado State Univ.
1998 - 2004	Assistant Professor, Dept. of Soil, Water, and Climate, Univ. of Minnesota

PUBLICATIONS

Peer Reviewed Journal Articles and Book Chapters:

Carroll, D.A., Hopkins, B.G., DeJonge, K. and **Hansen, N.C.** 2017. Water stress indices of maize with controlled deficit irrigation and variable nitrogen supply. Irrigation Science 35:1-12.

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Pearson, C.H., Brummer, J.E., Beahm, A.T., and **Hansen, N.C**. 2014. Kura clover living mulch for furrow-irrigated corn in the intermountain west. Agronomy Journal 106:1324-1328.

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Sherrod, L.A., Ahuja, L.R., **Hansen, N.C.,** Ascough, J.C., Westfall, D.G., and Peterson, G.A. 2014. Soil and rainfall factors influencing yields of a dryland cropping system in Colorado. Agronomy Journal 106: 1179-1192.

Lloyd, G., **Hansen, N.C.**, Sherrod, L., Inman, D, and Peterson, G.A. 2013. Constraints and capabilities of no-till dryland agroecosystems as bioenergy production systems. Agronomy Journal 105:364-376.

RECENT GRANTS

Connecting the Biocycling of Watershed Phosphorus with Synoptic Surface Water Sampling in the Upper Strawberry River Watershed. PI: N.C. Hansen. Utah Division of Wildlife Resources. $17,651. 2016.

Decision Support Tools, Drought Tolerance, and Innovative Soil and Water Management Strategies to Adapt Semi-arid Irrigated Cropping Systems to Drought. Project Director (PD): N.C Hansen, BYU; Co-director: Francesca Cotrufo, CSU; Co-leaders: Keith Paustian, Raj Khosla, Louis Longchamps, Jose Chavez, Allan Andales, Robin Reich. USDA, NRCS Conservation Innovation Grant Program. $882,924. 2014-2017. (Hansen direct spending authority $156,154).

Soil Testing and Phosphorus Risk Indexing in the Wallsburg Watershed. PI: N.C. Hansen. Utah Department of Environmental Quality. $14,000. 2014-2015.

Matthew J. Heaton, Ph.D.

Department of Statistics
Brigham Young University
223 TMCB
Provo, UT 84602

Email: mheaton@stat.byu.edu
Phone: (801) 422-7249
Web: mheaton.byu.edu
Fax: (801) 422-0635

EDUCATION

- Doctor of Philosophy: Statistical Science; Duke University; May 2011
  – Thesis: Kernel Averaged Predictors for Space and Space-time Processes
  – Committee: Alan E. Gelfand (chair), David L. Banks, Merlise A. Clyde, and David Holland
- Master of Science: Statistics; Brigham Young University; August 2007
  – Thesis: Temporally Correlated Dirichlet Processes in Pollution Receptor Modeling
  – Committee: C. Shane Reese, William F. Christensen, and Scott Grimshaw
- Bachelor of Science: Statistics; Brigham Young University;

PROFESSIONAL EXPERIENCE

- Assistant Professor; Brigham Young University; July 2013-Present.
- Post-graduate Scientist; National Center for Atmospheric Research; August 2011-July 2013.

MOST RELEVANT PUBLICATIONS

- Collins, G.Q., **Heaton, M.J.**, Hu, L., and Monaghan, A.J. "Physically Constrained Spatiotemporal Kriging of Remotely Sensed Land Surface Temperature" in preparation for *Journal of the Royal Statistical Society Series C*.
- Collins, G.Q., **Heaton, M.J.**, Hu, L., and Monaghan, A.J. "Spatio-temporal, Multi-resolution Modeling to Infill Missing Areal Data and Enhance the Temporal Frequency of Infrared Satellite Images," in press at *Environmetrics*.
- Gibson, K, **Heaton, M.J.** and Neeley Tass, E.S., "Identifying Crash Risk Factors on an Interstate Network," in press at *Statistical Modelling: An International Journal*.
- Mortensen, J., **Heaton, M.J.** and Wilhelmi, O.V. "Urban Heat Risk Mapping of Houston, Texas using Multiple Point Patterns" in press at *Journal of the Royal Statistical Society Series C*.
- Messick, R.M., **Heaton, M.J.** and Hansen, N. (2017), "Multivariate Spatial Mapping of Soil Water Holding Capacity with Spatially Varying Cross-Correlations" *Annals of Applied Statistics* 11(1), 69-92.
- **Heaton, M.J.**, Christensen, W.F., and Terres M. A. (2017), "Nonstationary Gaussian Process Models using Spatial Hierarchical Clustering from Finite Differences," *Technometrics* 59(1) 93-101.
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- **Heaton, M.J.** and Peng, R.D. (2014), "Extending Distributed Lag Models to Higher Degrees," *Bio- statistics* 15(2), 398-412.

RESEARCH GRANTS

- "CAREER: Practical Approaches to the Analysis of Multivariate Point Pattern Data," (2017) submit- ted to the National Science Foundation CAREER Grant Series (Role: Sole PI; Amount: $418,119).
- "Modeling Environmental Impacts on Bronchiolitis in the Presence of Spatial Uncertainty," (2014) submitted to National Institutes of Health R03 Grant Series (Role: P.I.; Amount: $125,250).
- "Focus Crash Types and Risk Factors" (2014), Federal Highway Administration (Role: PI; Amount:
  $149,222).
- "Collaborative Research: Scalable Statistical Validation and Uncertainty Quantification for Large Spatio-Temporal Datasets" (2013), National Science Foundation, Computational and Data-Enabled Science and Engineering in Mathematical and Statistical Sciences (Role: P.I. for BYU portion; Amount:
  $201,000).

RECENT STUDENT ADVISING EXPERIENCE

Year Graduated	Student	My Role	Student Position Upon Graduation
TBD	Ben Terrazas[†]	Research Mentor	Not yet completed
TBD	Kaden Maughn[†]	Research Mentor	Not yet completed
TBD	Shelby Taylor[†]	Chair	Not yet completed
2018	Wyatt Clegg	Research Mentor	Not yet completed
2018	Ben Tingey[†]	Research Mentor	Not yet completed
2018	Gavin Collins[†,‡,<,*]	MS Chair	Not yet completed
2018	Sierra Pugh[†,<]	MS Chair	Not yet completed
2017	Christian Davis[†]	Chair	BYU MS
2017	Spencer Galbraith	MS Chair	Walmart
2017	Kaitlin Gibson[†,<]	MS Chair	TaxHawk
2016	Dalton Bagley[†]	Research Mentor	Health Catalyst
2016	Rachel Messick[*,§]	MS Chair	Visible Equity
2016	Jacob Mortensen[‡]	MS Chair	Simon Fraser University (Ph.D.)
2016	Cameron Faerber	MS Chair	GroupSolver

[†] – Began research as an undergraduate
[‡] – NSF Graduate Fellow Honorable Mention
[t>] – NSF Graduate Fellow Applicant
[*] – NASA Space Grant Consortium Fellowship Recipient
[J] – ORCA Grant Recipient
[§] – 3MT Competition Winner

BRYAN GENE HOPKINS
CURRICULUM VITAE

RANK: Professor, Brigham Young University

DEPARTMENT: Plant and Wildlife Sciences

OFFICE LOCATION: 5115 LSB
Provo, UT 83602

OFFICE PHONE: 801-422-2185
FAX: 801-422-0008

EMAIL: hopkins@byu.edu
WEB: http://lifesciences.byu.edu/home/FacStaff/default.aspx?ID=293

EDUCATION:

Degrees:

1995	Ph.D.	Agronomy	Kansas State University, Manhattan, KS
1991	M.S.	Agronomy and Horticulture	Brigham Young University, Provo UT.
1990	B.S.	Agronomy and Horticulture	Brigham Young University, Provo UT.
1988	A.A.	Horticulture	Ricks College, Rexburg, ID

Certificates:

1991-present	Certified Professional Soil Scientist (CPSSc),	Soil Science Society of America,

EXPERIENCE:

Academic Appointments:

Environment Science of Managed Landscapes, Professor, Brigham Young University, Provo, UT, 50% teaching/45% research/5% citizenship, 10 month appointment
*2012-present Professor & Director of BYU Environmental Analytical Lab
*2007-2012 Associate Professor

Soil Scientist and Cropping Systems Specialist, University of Idaho, Idaho Falls, ID, 80% extension/20% research and citizenship, 2001-2007

Research Assistant/Lab Manager, Kansas State University, Manhattan, KS, 1991-1995

Research/Teaching Assistant, BYU, Provo, UT, 1990-1991

Non-Academic Employment:

Director of Education Division & Lab Consultant, Servi-Tech, Inc., Blackfoot, ID, 1998-2001

Laboratory Director/Agronomist, Stukenholtz Laboratories, Twin Falls, ID, 1997-1998

Laboratory Director/Agronomist, Servi-Tech, Inc., Hastings, NE, 1995-1997

SCHOLARSHIP:

Publications Summary

	Hopkins' Graduate Student First Author	Hopkins' Undergraduate Student First Author	Other Graduate Student First Author	Other Undergraduate Student First Author	Hopkins First Author	Co-author	Total
Refereed Journal	14	3	13		13	5	48
Edited Journal		1			2	3	6
Book Chapters					4	4	8
Bulletins					12	8	20
Conf. Proceedings	14	10	5		36	6	71

SELECTED REFEREED JOURNAL PUBLICATIONS:

Hopkins, B.G., K.J. Fernelius, N.C. Hansen, and D.L. Eggett. 2018. AVAIL phosphorus fertilizer enhancer: Meta-analysis of 503 field evaluations. *Agron. J.* file:///C:/Users/bryangh/Downloads/agronj2017.07.0385.pdf

LeMonte, J.J., V.D. Jolley, T.M. Story, and **B.G. Hopkins**. 2018. Assessing atmospheric nitrogen losses with photoacoustic infrared spectroscopy: Polymer coated urea. *Plos One* (accepted)

Carroll, D.A., II., N.C. Hansen, **B.G. Hopkins**, and K.C. DeJonge. 2017. Leaf temperature of maize and crop water stress index with variable irrigation and nitrogen supply. *Irrig. Sci.* 35(6): 549-560. DOI: 10.1007/s00271-017-0558-4

Fernelius, K.J., M.D. Madsen, B.G. Hopkins, S. Bansal, V.J. Anderson, D.L. Eggett, and B.A. Roundy. 2017. Post-fire interactions between soil water repellency, soil fertility and plant growth in soil collected from a burned Piñon-Juniper woodland. *J. Arid Env.* 144: 98-109. DOI:org/10.1016/j.jaridenv.2017.04.005.

Katseanes, C.K., M.A. Chappell, **B.G. Hopkins**, B.D. Durham, C.L. Price, B.E. Porter, and L.F. Miller. 2017. Multivariate soil fertility relationships for predicting the environmental persistence of 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitro-1,3,5-tricyclohexane (RDX) among taxonomically distinct soils. *J. Environ. Manage.* 203: 383-390. DOI: https://doi.org/10.1016/j.jenvman.2017.08.005

Summerhays, J.S., V.D. Jolley, M.W. Hill, and **B.G. Hopkins**. 2017. Enhanced phosphorus fertilizers (Carbond P® and AVAIL®) supplied to maize in hydroponics. *J. Plant Nutr.* 40: 2889-2897. DOI:10.1080/01904167.2017.1384007. Available at: http://www.tandfonline.com/doi/full/10.1080/01904167.2017.1384007

Buck, R.L**., B.G. Hopkins**, B.L. Webb, and V.D. Jolley. 2016. Depth of ion exchange resin capsule placement impacts on estimation of nitrogen and phosphorus bioavailability in semi-arid, low fertility soils. *Soil Sci.* 181: 216–221. DOI:10.1097/SS.0000000000000165

LeMonte, J.J., V.D. Jolley, J.S. Summerhays, R.E. Terry, and **B.G. Hopkins**. 2016. Polymer coated urea in turfgrass maintains vigor and mitigates nitrogen's environmental impacts. *Plos one* 11: e0146761. DOI:10.1371/journal.pone.0146761

Geary, B., J. Clark, **B.G. Hopkins**, and V.D. Jolley. 2015. Deficient, adequate and excess nitrogen levels established in hydroponics for biotic and abiotic stress-interaction studies in potato. *J. Plant Nutr*. 38: 41-50. DOI:10.1080/01904167.2014.912323

Hopkins, B.G., D.A. Horneck, and A.E. MacGuidwin. 2014. Improving Phosphorus use efficiency through potato rhizosphere modification and extension. *Am. J. Potato Res.* 91: 161-174. DOI:10.1007/s12230-014-9370-3.

Hopkins, B.G. 2013. Russet Burbank potato phosphorus fertilization with dicarboxylic acid copolymer additive (AVAIL®). *J. Plant Nutr.* 36: 1287-1306. DOI:10.1080/01904167.2013.785565

Madsen, M.D., E.G. Coronel, and **B.G. Hopkins**. 2013. Soil surfactant products for improving hydrologic function in post-fire water-repellent soil. *Soil Sci. Soc. Am. J.* 77: 1825-1830. DOI:10.2136/sssaj2012.0305

Madsen, M.D., S.L. Petersen, K.J. Fernelius, B.A. Roundy, A.G. Taylor, and **B.G. Hopkins**. 2012. Influence of soil water repellency on seedling emergence and plant survival in a burned semi-arid woodland. *Arid Land Res. Manag.* 26: 236-249. DOI:10.1080/15324982.2012.680655

Barben, S.A., **B.G. Hopkins**, V.D. Jolley, B.L. Webb, B.A. Nichols, and E.A. Buxton. 2011. Zinc, manganese and phosphorus interrelationships and their effects on iron and copper in chelator-buffered solution grown Russet Burbank potato. *J. Plant Nutr.* 34: 1144-1163.

Hopkins, B.G., J.W. Ellsworth, T.R. Bowen, A.G. Cook, S.C. Stephens, V.D. Jolley, A.K. Shiffler, and D. Eggett. 2010. Phosphorus fertilizer timing for Russet Burbank potato grown in calcareous soil. *J. Plant Nutr.* 33: 529-540. DOI:10.1080/01904160903506266

Ryan R. Jensen, Ph.D.

Education

2000	Ph.D. **Geography**, Minor: **Botany**, concentration in **Interdisciplinary Geographic Information Systems**, University of Florida, Gainesville, Florida.
1997	M.S. **Geography**, Brigham Young University, Provo, Utah.
1996	B.S. **Cartography and Geographic Information Systems**, Brigham Young University, Provo, Utah.

Professional Appointments

2013 – Present	Professor, Department of Geography, Brigham Young University
2012 – Present	Chair, Department of Geography, Brigham Young University
2007 – 2012	Associate Professor of Geography, Department of Geography, Brigham Young University
2005 – 2007	Associate Professor of Geography, Department of Geography, Geology, and Anthropology, Indiana State University (Tenured).
2005 – 2007	Director, Center for Remote Sensing and Geographic Information Systems, Indiana State University.
2005 – 2007	Adjunct Professor, Department of Life Sciences, Indiana State University
2000 – 2005	Assistant Professor of Geography, Department of Geography, Geology, and Anthropology, Indiana State University (Tenure track)
2002 – 2007	Associate Director for Forest Research, Center for State Park Research, Indiana State University.
2002 – 2007	Undergraduate Advisor, Department of Geography, Geology, and Anthropology, Indiana State University

Professional Certification and License

2008 – Present	Certified Geographic Information System Professional (GISP)
2017 – Present	FAA certified Part 107 Remote Pilot

Relevant and Recent Peer-Reviewed Journal Articles

Boswell, A., S. Petersen, B. Roundy, R. Jensen, D. Summers, and A. Hulet. 2017. "Rangeland monitoring using remote sensing: comparison of cover estimates from field measurements and image analysis." *AIMS Environmental Science* 4(1):1-16. DOI: 10.3934/environsci.2017.1.1

Roundy, D.B., A. Hulet, S.L. Petersen, B.A. Roundy, R.R. Jensen, J.B. Hinkle, and L. Crook. 2016. "Estimating pinyon and juniper cover across Utah using NAIP imagery." *AIMS Environmental Science* 3(4):765-777. DOI: 10.3934/environsci.2016.4.765

Westover, M., R. Baxter, J. Baxter, C. Day, R. Jensen, S. Petersen, and R. Larsen. 2016. "Assessing Greater Sage-Grouse selection of brood-rearing habitat using remotely-sensed imagery: Can readily available high-resolution imagery be used to identify brood-rearing habitat across a broad landscape?" *PloS ONE* e0156290. doi: 10.1371/journal.pone.0156290

Jamison, A., E. Tuttle, R. Jensen, G. Bierly, and R. Gonser. 2015. "Spatial ecology, landscapes, and the geography of vector-borne disease: a multi-disciplinary review." *Applied Geography* 63:418-426.

Hulet, A., B.A. Roundy, S.L. Petersen, S.C. Bunting, R.R. Jensen, and D.B. Roundy. 2014. "Utilizing National Agriculture Imagery Program data to estimate tree cover and biomass of pinon and juniper woodlands." *Rangeland Ecology & Management* 67(5):563-572.

Hulet, A., B.A. Roundy, S.L. Petersen, R.R. Jensen, and S.C. Bunting. 2014. "An object-based

image analysis of pinyon and juniper woodlands treated to reduce fuels." *Environmental Management* 53(3):660-671.

Jensen, R.R., R.A. Gonser, and C. Joyner. 2014. "Landscape factors that contribute to animal-vehicle collisions in two northern Utah canyons." *Applied Geography* 50:74-79.

Hulet, A., B.A. Roundy, S.L. Petersen, R.R. Jensen, and S.C. Bunting. 2014. "Cover estimations using object-based image analysis rule sets developed across multiple scales in pinyon-juniper woodlands." *Rangeland Ecology & Management* 67(3):318-327.

Hulet, A., B.A. Roundy, S.L. Petersen, R.R. Jensen, and S.C. Bunting. 2013. "Assessing the relationship between ground measurements and object-based image analysis of land cover classes in pinyon and juniper woodlands." *Photogrammetric Engineering & Remote Sensing* 79(9):799-808.

Hall, T.R., R.R. Jensen, and D.D. McLean. 2013. "Learning in the geoscience classroom: Q-methodology, learning, styles, and individual preferences." *Journal of Geoscience Education* 61(1):120-128.

Jensen, R.R., P.J. Hardin, and A.J. Hardin. 2012. "Classification of urban tree species using hyperspectral data." *Geocarto International* 27(5):443-458.

Jensen, R.R., P.J. Hardin, and A.J. Hardin. 2012. "Estimating urban leaf area index of individual trees with hyperspectral data." *Photogrammetric Engineering & Remote Sensing* 78(5):495-504.

Young, S.G. and R.R. Jensen. 2012. "Statistical and Visual Analysis of Human West Nile Virus Infection in the United States, 1999 – 2008." *Applied Geography* 34:425-431.

Im, J., J.R. Jensen, R.R. Jensen, J. Gladden, J. Waugh, and M. Serrato. 2012. "Vegetation cover analysis of hazardous waste sites in Utah and Arizona using hyperspectral remote sensing." *Remote Sensing* 4:327-353.

Jensen, R.R., A.J. Hardin, P.J. Hardin, and J.R. Jensen. 2011. "A new method to correct push-broom hyperspectral data using linear features and ground control points." *GIScience & Remote Sensing* 48(3):416-431.

Hardin, P.J. and R.R. Jensen. 2011. "Small-Scale Unmanned Aerial Vehicles in Environmental Remote Sensing: Challenges and Opportunities." *GIScience & Remote Sensing* 48(1):99-111.

Hardin, P.J. and R.R. Jensen. 2011. "Introduction - Small-Scale Unmanned Aerial Systems for Environmental Remote Sensing." *GIScience & Remote Sensing* 48(1):1-3.

Jensen, R.R., P.J. Hardin, and M.W. Jackson. 2010. "Spectral Modeling of Population Density: A Study of Utah's Wasatch Front." *Photogrammetric Engineering & Remote Sensing* 76(7):797-806.

Ruth Kerry: Department of Geography, Brigham Young University
ruth_kerry@byu.edu

Education

2004, University of Reading, United Kingdom
PhD Soil Science and Precision Agriculture - full scholarship
1997, University of Reading, United Kingdom
MSc in Soil Spatial Analysis and Land Evaluation, Pass with Distinction - full scholarship
1995, University of Oxford, St Hugh's College
BA/MA Honours in Geography II(i)

Professional Experience since PhD

Fall 2017-Fall 2022: Affiliate Assistant Professor
Auburn University, Crop, Soil and Environmental Sciences Department
Fall 2014-present: Affiliate Collaborator
Brigham Young University, Department of Geography
Fall 2008 – Winter 2014: Associate Lecturer, Classes: Quantitative Methods, Mentored Research
Brigham Young University, Department of Geography
September 2007 – August 2008: Visiting Scholar
Grant F. Walton Center for Remote Sensing and Spatial Analysis, Rutgers University, New Jersey
January-July 2005, June-September 2007, May-August 2009, May-August 2010, May-August 2012
Visiting Scholar, ***University of Cambridge, Department of Geography***
2004-2008: Part-time faculty, Classes: Quantitative Methods; Landforms; Climatology
Brigham Young University Department of Geography

Most Relevant Publications

Edited Volumes/Books

Escola, A. and *Kerry, R*. IN PREPARATION. Sensing Approaches for Precision Agriculture. Part of the Springer series: ***Progress in Precision Agriculture*.**

***Kerry, R*. Guest Editor. IN PREPARATION. Special Issue: Papers from ECPA 2017, *Precision Agriculture*.**

Kerry, R., Oliver, M. A. & Haining, R. P. Guest Editors 2010. Special Issue: Geostatistical Methods in Geography: Applications in Physical Geography. *Geographical Analysis*. 42:2.

Kerry, R. Guest Editor. 2008. Special Issue on Spatial Variation in Precision Agriculture. *Precision Agriculture*. Volume 9.

Peer-reviewed Book Chapters

Kerry, R., Oliver, M. A. & Frogbrook, Z. L. 2010. Sampling I. In: M.A. Oliver (ed.) *Geostatistical Applications for Precision Agriculture*. Springer. pp. 35-64.

Goovaerts, P. & *Kerry, R.* 2010. Use of ancillary data in precision agriculture. In: M.A. Oliver (ed.) *Geostatistical Applications for Precision Agriculture*. Springer. pp. 167-194.

Peer-reviewed Journal Articles

Nabiollahi, K., Golmohamadi, F., Taghizadeh-Mehrjardi, R., *Kerry, R*. & Davari, M. 2018. Assessing the effect of slope gradient and land use change on soil quality degradation through digital mapping of soil quality indices and soil loss rate. *Geoderma*, 318: 16-28.

Nabiollahi, K., Taghizadeh-Mehrjardi, R., *Kerry, R*. & Moradian, S. 2017. Assessment of soil quality indices for salt-affected agricultural land in Kurdistan Province, Iran. *Ecological Indicators*, 83: 482–494.

Kerry, R., Goovaerts, P., Giménez, D. & Oudemans, P. 2017. Investigating temporal and spatial patterns of cranberry yield in New Jersey fields. *Precision Agriculture*, 18 (4), 507-524.

Kerry, R., Ortiz, B., Ingram, B. R. & Scully, B. T. 2017. A Spatio-Temporal Investigation of Risk Factors for Aflatoxin Contamination of Corn in Southern Georgia, USA using Geostatistical Methods. *Crop Protection*. 94, 144-158.

Mirzaee, S., Ghorbani-Dashtaki, S., Mohammadi, J. & *Kerry, R*. 2017. Modeling WEPP erodibility parameters in calcareous soils in northwest Iran. *Ecological Indicators*. 74, 302–310.

Akbarzadeh, A., Ghorbani-Dashtaki, S., Naderi-Khorasgani, M., *Kerry, R*. & Taghizadeh-Mehrjardi, R. 2016. Monitoring and assessment of soil erosion at micro-scale and macro-scales in forests affected by fire damage in northern Iran. *Environmental Monitoring and Assessment*, 188, 699.

Ostovari, Y., Ghorbani-Dashtaki, S., Bahrami, H., Naderi, M., Dematte, J. & *Kerry, R*. 2016. Modification of the USLE K factor for soil erodibility assessment on calcareous soils in Iran. *Geomorphology*, 273, 385-395.

Kerry, R., Goovaerts, P., Giménez, D., Oudemans, P & Muñiz, E. 2016. Investigating geostatistical methods to model within-field yield variability of cranberries for potential management zones. *Precision Agriculture*, 17, 243-273.

Taghizadeh-Mehrjardi, R., Nabiollahi, K. & *Kerry, R*. 2016. Digital mapping of soil organic carbon at multiple depths using different data mining techniques in Baneh region, Iran. *Geoderma*, 266, 98-110.

Kerry, R., Goovaerts, P., Rawlins, B. G. & Marchant, B. P. 2012. Disaggregation of legacy soil data using area to point kriging for mapping soil organic carbon at the regional scale. *Geoderma*, 170:347-358.

Kerry, R. & Oliver, M. A. 2011. Soil Geomorphology: Identifying Links between Processes and the Scale of Spatial Variation using the Variogram. *Geomorphology*, 130:40-54.

Haining, R. P., *Kerry, R* & Oliver, M. A. 2010. Geography, Spatial Data Analysis and Geostatistics: An Overview. *Geographical Analysis*. 42:1, 7-31.

Kerry, R, Rawlins, B. G., Oliver, M. A. & Lacinska, A. M. 2009. Problems with determining the particle size distribution of chalk soil and some of their implications, Geoderma, 152:324-337.

Kerry, R. & Oliver, M. A. 2008. Determining nugget:sill ratios of standardized variograms from aerial photographs to krige sparse soil data. *Precision Agriculture*, 9, 33–56.Kerry, R. &

Kerry, R. & Oliver, M. A. 2007. Sampling requirements for variograms of soil properties computed by the method of moments and residual maximum likelihood. *Geoderma*, 140:4, 383-396

Kerry, R. & Oliver, M. A. 2007. Mapping Soil Structure using Ranked Observations and Indicator Kriging. *Geoderma* 140:4, 397-416.

Kerry, R. & Oliver, M.A. 2004. Average variograms to guide soil sampling for land management. The International *Journal of Applied Earth Observation and Geoinformation*, 5, 307-325.

Kerry, R. & Oliver, M.A. 2003. Variograms of ancillary data to aid sampling for soil surveys. *Precision Agriculture*, 4, 261-278.

Citizenship/Professional Membership:

Editorial Board Member
Precision Agriculture Journal

Scientific Committee Member
Pedometrics 2017, Wageningen, Netherlands
9th, 10th and 11th European Conferences on Precision Agriculture, Spain, Israel and UK
Fellow of the Royal Geographical Society (RGS) – by election
Member of the Association of American Geographers (AAG)
Member of the Soil Science Society of America (SSSA)
Member of British Society of Soil Science (BSSS)
Member of the International Association for Mathematical Geology (IAMG)

CURRENT & PENDING SUPPORT

Name: Bryan Hopkins

Instructions:
Who completes this template: Each project director/principal investigator (PD/PI) and other senior personnel that the Request for Applications (RFA) specifies
How this template is completed:

- Record information for active and pending projects, including this proposal.
- All current efforts to which PD/PI(s) and other senior personnel have committed a portion of their time must be listed, whether or not salary for the person involved is included in the budgets of the various projects.
- Provide analogous information for all proposed work which is being considered by, or which will be submitted in the near future to, other possible sponsors.

NAME (List/PD #1 first)	SUPPORTING AGENCY	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	Person months per year	TITLE OF PROJECT
	Active:				
Hopkins	Research & Business Development Center	250,000	1/2017 – 12/2017	0.3	Plant Nutrition and Pest Management
Petersen, Hopkins, et. al.	Department of Defense	382,269	8/2017 – 7/2018	1	UTTR – Air Force Utah Training Range Environmental Restoration and Monitoring
	Pending:				
Hopkins	Research & Business Development Center	25,000	1/2017 – 12/2017	1	Plant Nutrition and Pest Management
Geary et al.	NSF/NIH/NIFA	2,268,815	07/01/2018 – 07/31/2022	1	Data Driven Modeling of Pythium/Host Competition Dynamics

Current and Pending Support
Matthew J. Heaton

Pending

Title: CAREER: Practical Approaches to the Analysis of Multivariate Point Pattern Data
Agency: National Science Foundation
Funding Period: March 2018-February 2023
Status: Under Review Since July 2017

Title: Dynamic, Spatio-temporal Modeling of Seasonal RSV Circulation to Improve Childhood Health Outcomes
Agency: National Institutes of Health
Funding Period: September 2018-August 2023
Status: To be submitted February 5, 2018

Current:

Title: Modeling Environmental Impacts on Bronchiolitis in the Presence of Spatial Uncertainty
Agency: National Institutes of Health
Funding Period: March 2015-Feburary 2018

Title: Scalable Statistical Validation and Uncertainty Quantification for Large Spatio-temporal Datasets
Agency: National Science Foundation
Funding Period: August 2014-July 2018

Ryan R. Jensen
Pending Support

"Building Capacity for Geospatial Technologies in Tanzania: A Collaboration between Brigham Young University and the College of African Wildlife Management." To be submitted to Millennium Challenge Corporation - Foreign Assistance for Overseas Programs. Role – Principal Investigator. Proposed budget: $193,712.

Neil C. Hansen
Current Support

Decision Support Tools, Drought Tolerance, and Innovative Soil and Water Management Strategies to Adapt Semi-arid Irrigated Cropping Systems to Drought. Project Director (PD): N.C Hansen, BYU; Co-director: Francesca Cotrufo, CSU; Co-leaders: Keith Paustian, Raj Khosla, Louis Longchamps, Jose Chavez, Allan Andales, Robin Reich. USDA, NRCS Conservation Innovation Grant Program. $882,924. 2014-2017. (Hansen direct spending authority $156,154).

PLANT AND WILDLIFE SCIENCES
BRIGHAM YOUNG UNIVERSITY
PROVO. UTAH 84602-5183
(801) 422-1228 : FAX: (801) 422-0008

To: Conrad Monson and IDR Proposal Review Committee, BYU Office of Research Development

From: Brock McMillan, Chair, Department of Plant and Wildlife Sciences

Re: IDR Proposal by Dr. Neil Hansen

Date: 16 January 16, 2018

I provide my strongest possible endorsement the proposal entitled "Integrating Remote Sensing and Spatiotemporal Statistics to Create Water Conserving Precision Irrigation Systems," being led by Dr. Neil Hansen from my academic department. Dr. Hansen has assembled an excellent interdisciplinary research team, with involvement from the college of Life Sciences, the college of Family Home and Social Sciences, and the college of Physical and Mathematical Sciences. The applied research problem addressed in the proposal has a high potential impact, developing an approach to conserve water. I have complete confidence that this team will work effectively and that this grant will help them establish a project that can later obtain external support.

Dr. Hansen is a Full Professor in our department. He is an outstanding educator and a rising star in research. In particular, his work on water use efficiency and conservation is cutting-edge, high-impact research. He consistently and frequently publishes his results in top journals. Dr. Hansen has a successful track-record of obtaining funding and directing large, interdisciplinary projects. This IDR Award will aid in moving this cutting-edge research forward by taking a multi-pronged, interdisciplinary approach.

In summary, I reiterate my strongest possible support for Dr. Hansen's application for an IDR Award. I am confident in the outstanding quality and significance of his research, the quality of the team that Dr. Hansen has organized, and results and enhanced productivity that will come from this award. Please feel free to contact me if I can provide any additional information.

Sincerely,

Brock R. McMillan, Ph.D.
Professor and Chair

801-422-1228
Brock_mcmillan@byu.edu

METER

METER Group Inc. 2365 NE Hopkins Court, Pullman, WA 99163

15 January 2018

Brigham Young University
Office of Research Development
Interdisciplinary Research Origination Award Program

Dear Kristen Kellems and IDR Proposal Review Committee

I am writing to state my support for the proposal titled ***Integrating Remote Sensing and Spatiotemporal Statistics to Develop Prescription Maps for Variable Rate Irrigation Systems.*** I am a senior research scientist for Meter Group, Inc and I lead the Meter Environment division. Our company, located in Pullman, WA, is an environmental sensor company with a mission to solve meaningful problems in areas such as air and water quality, crop management, and food safety. I have been working closely with Dr. Neil Hansen and Dr. Bryan Hopkins over the last several years on projects that address water conservation in irrigated systems. This proposal is unique because of the interdisciplinary team that has been brought together to address the important challenge in application of variable rate irrigation. I am pleased to participate in the project. In hopes that the project will be funded, our company has already provided soil water sensors and telemetry for the study location in Idaho. I will provide technical and scientific support on the use of the sensors and interpretation of data. I am excited to be a part of a research team that brings together expertise in statistics, remote sensing, soil, and water to address critical world problems.

Sincerely,

Colin S. Campbell, Ph.D.
VP Environment and Senior Research Scientist
METER Group, Inc. USA

METER Group Inc.
2365 NE Hopkins Court, Pullman, WA
99163
T 509.332.2756 F 509.332.5158
E info@metergroup.com W
metergroup.com

January 15, 2018

BYU Interdisciplinary Research Origination Award Program
C/O Conrad Monson
BYU Office of Research Development

Conrad Monson,

I am Ryan Christensen of Christensen Farms in Grace, Idaho. Nine years ago, I graduated from BYU with a Landscape Management degree in the Plant and Wildlife Sciences department. Of the many tools I left BYU possessing, the desire to always be furthering knowledge and understanding of my surroundings has been the driving force of how I approach my career. When Dr. Bryan Hopkins and Dr. Neil Hansen approached me with the idea of researching how to better use my Variable Irrigation System (VRI) I considered it both an honor to be able to give something back to BYU for my time there, and a great opportunity to provide greater understanding to an emerging technology where full potential has not been reached on an application basis.

I am fully supportive of the research proposal that has been presented to me. The students, faculty, and other research participants will have full access to my VRI equipment, the field, and anything else that I can provide to make this project a success. I farm with my dad and brother, and all three of us see the value the results of this project can bring to not only us, but to an emerging technology industry where little understanding of precise application exists.

In addition to the VRI equipment and field, I will also provide drone imagery, as well as historical yield map data. I have kept accurate, calibrated yield data since 2012 and will continue to provide usable data for all crops that will be harvested over the course of the project. I have two personal drones, a DJI Mavic Pro and a DJI Inspire 1, that I will fly the field regularly to provide plant health imagery to assist in the decision making of the project. I have used the drones in my own decision making process of farm operations for two years now, and these will provide useful information going forward.

I am excited for this project and think the information learned will be very valuable as farmers seek ways to reduce use of natural resources, while at the same time increasing production to feed an ever-growing world population. I am willing to assist in anyway that I can to make this successful.

Thank you,

Ryan Christensen