Precision Water Management in Western Great Plains irrigated agriculture

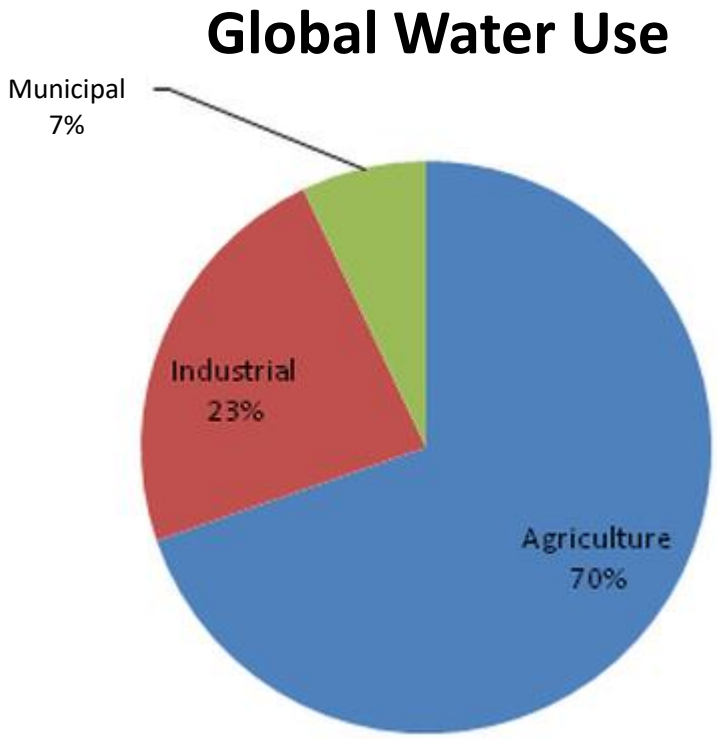
Dr. Raj Khosla, Professor of Precision Agriculture

Colorado State University

Outline

- Importance of water in the Western Great Plains
- Aspects of Spatio-Temporal variability for precision water management
- Precision Irrigation and technology
- Innovative soil moisture sensing
- Complexity of writing “dynamic” prescriptions for water management
- Current and future approaches

Agriculture… largest consumer of fresh water…



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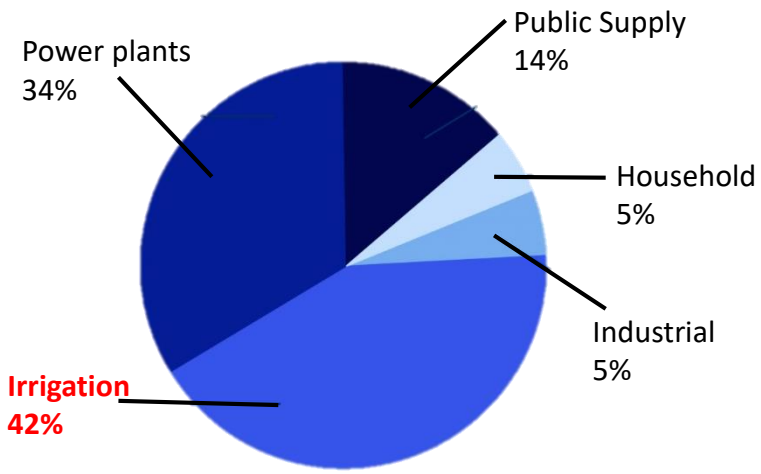
https://www.ers.usda.gov/media/9165/june17_datafeature_schaible_photo.jpg

Top U.S. Freshwater Use



Public supply
Power plants
Irrigation
Industrial
Aquaculture

CLIMATE CENTRAL

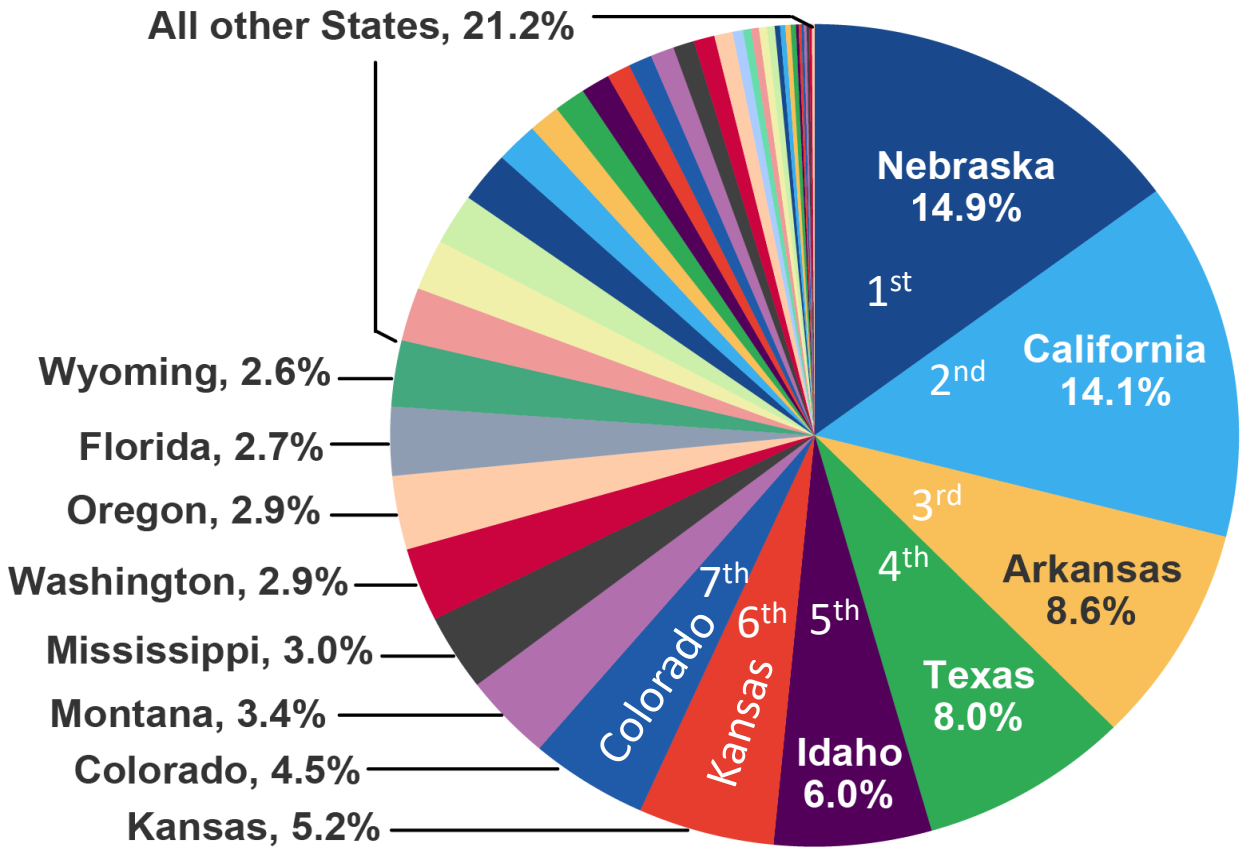
Source: 2015 USGA National Water Census. Produced 3/20/2019

The 17 Western States

Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx

Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service, *2012 Census of Agriculture*, State data.



Note: The 13 leading States (10 Western, and Arkansas, Mississippi, and Florida) accounted for 78.8 percent of U.S. irrigated acres, including harvested cropland, pasture, and other lands (but excluding horticulture under protection).

How do we use water in Colorado?

Live Radio · KUNC
Colorado Edition

News Programs Series Support About Search

Water Is Leaving Colorado Farmland For The City — But Will It Ever Return?

By LUKE RUNYON, MATT BLOOM & ESTHER HONIG • JUN 13, 2018

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A grain silo serves as an advertisement for new homes in Windso development.

LUKE RUNYON / KUNC

An old water cliché tells us that "water flows uph
money." It's an adage born out of people's frustra
who benefits when water moves around in the W
popularized by author Marc Reisner's 1986 book
Desert."

Holiday Gift Guide — page 18

North Forty News

December 2012 www.northfortynews.com Volume 20 Number 9 FREE

The community newspaper for Wellington, north Fort Collins and northern Larimer County, Colorado

Moose in the morning

Larimer County reaches out to fire survivors

By Kate Hawthorne
North Forty News

Water squeeze

Fort Collins cuts irrigation to farmers

By Jeff Thomas
North Forty News

With the city of Fort Collins' water resources expected to be extremely stressed next summer, farmers in the 111-year-old Wellington-based Northern Poudre Irrigation Company expect to be the first to be left high and dry.

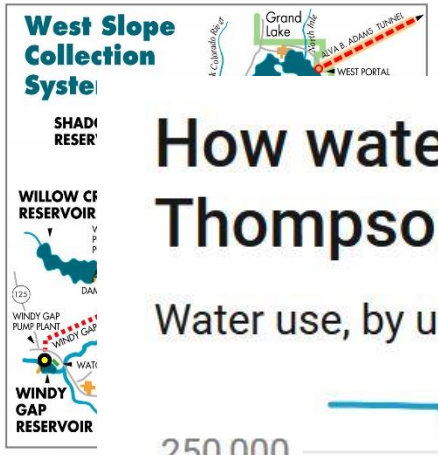
"The horrible thing is that when Fort Collins was here buying up all these shares, they told us this water would always be available (for lease)," said one east Larimer County farmer, who wished to remain anonymous. "I didn't sell anything to the city, but that's what they told neighbors to reassure us all."

The city owns about 35 percent of the NPIC shares, and much of that water comes from the Colorado Big Thompson Project (CBT), a source the city is seeking to conserve. On average the amount of CBT water the city leases shareholders in this former farmers' cooperative constitutes about 25 percent of the company's overall available water, said NPIC Operations Manager Steve Smith.

"I think the farmers, if they are astute about this situation — given the drought — they will probably cut back on the number of acres they are irrigating," Smith said. He said there really aren't any options for water users in the NPIC service area, which lies between the foothills and the Weld County line, north from the Cache la Poudre River to about Larimer County Road 76.

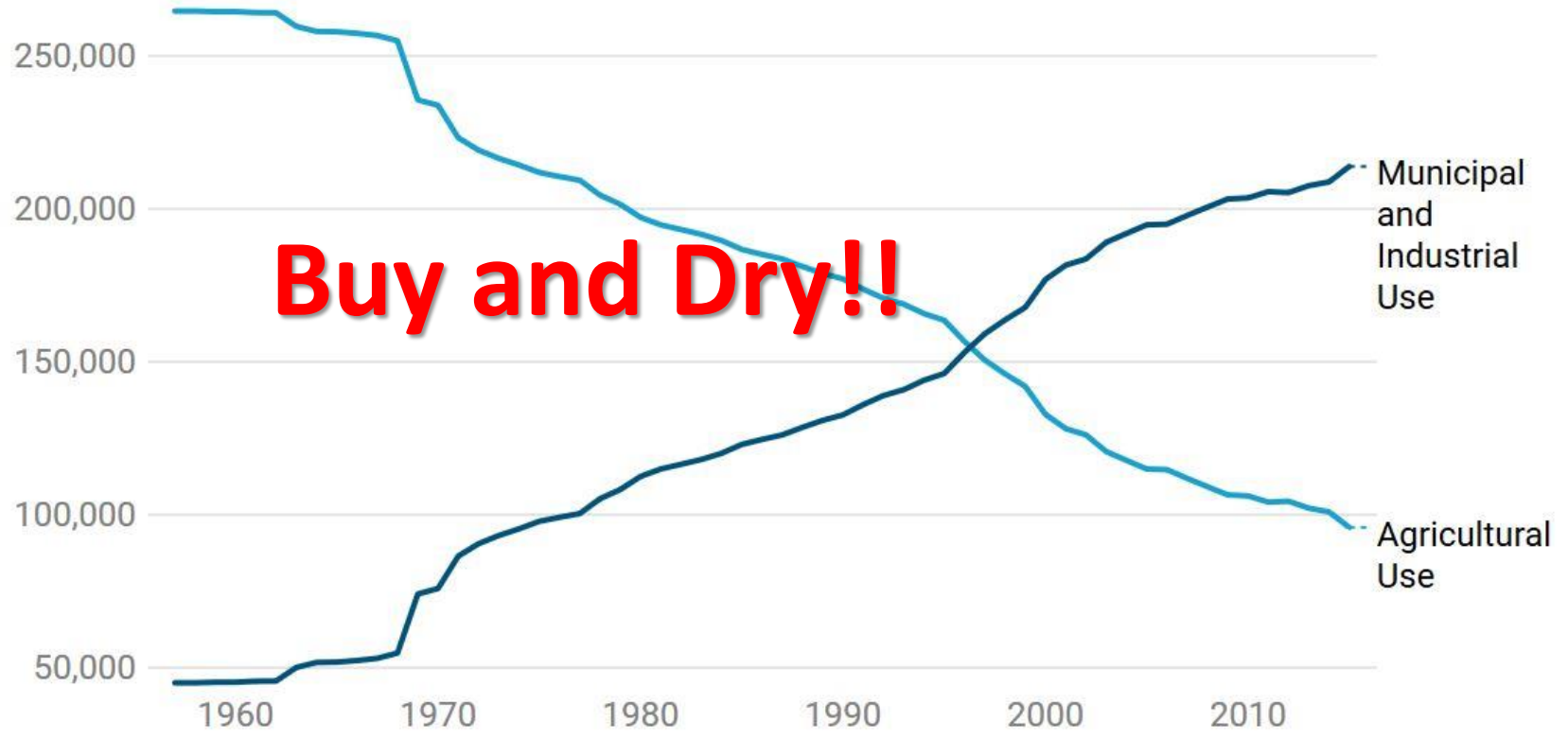
Other than the water company's rights to natural flow from the Poudre River and

Northern Colorado



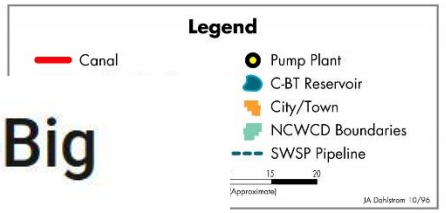
How water ownership has changed on the Colorado-Big Thompson Project:

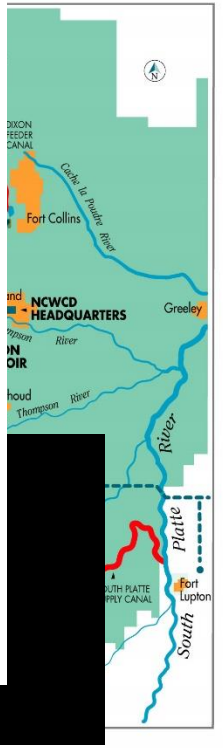
Water use, by units of Colorado-Big Thompson water



Buy and Dry!!

Chart: Ashley Jefcoat/KUNC • Source: Northern Colorado Water Conservancy Project • Created with Datawrapper





Colo

- C
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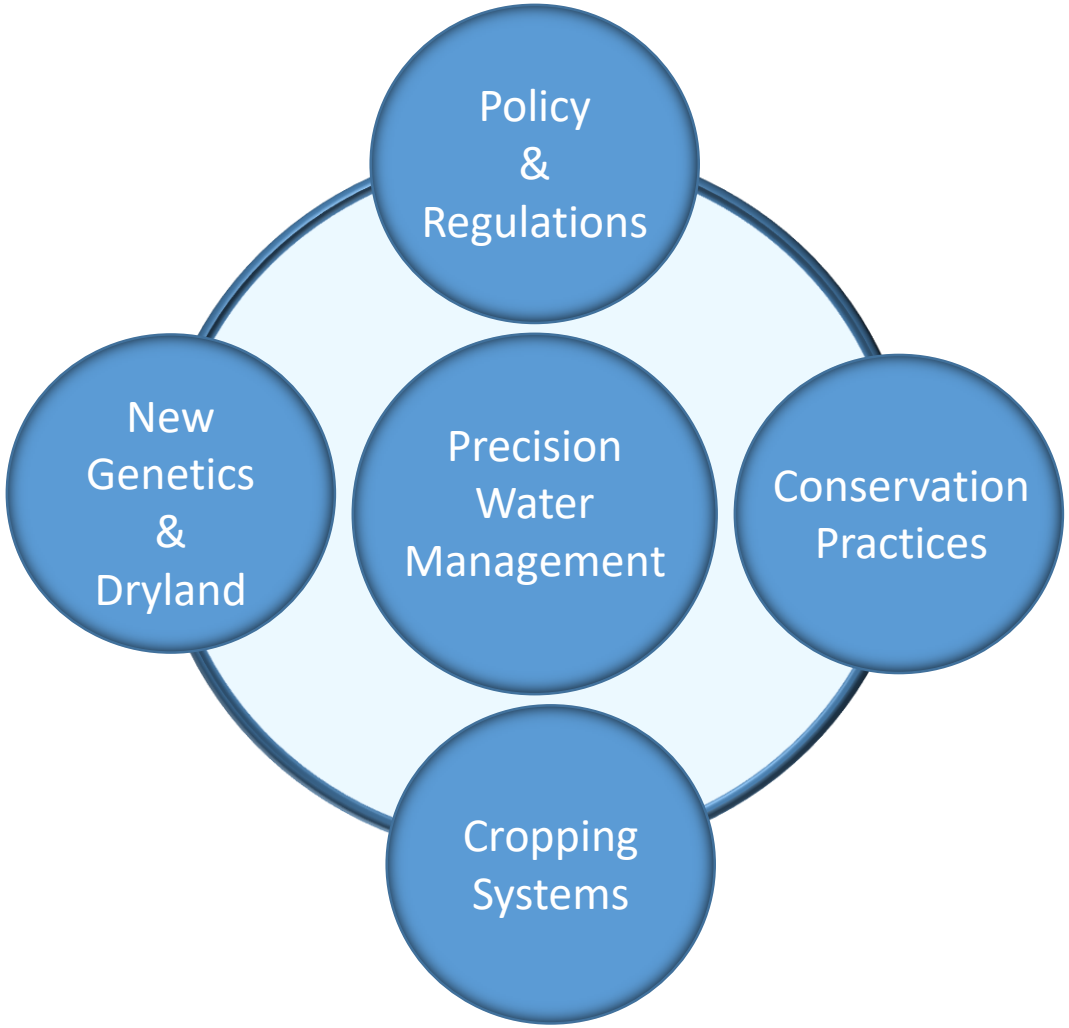
- ~1M people

Multi-prong approach to Water management in the Western Great Plains.

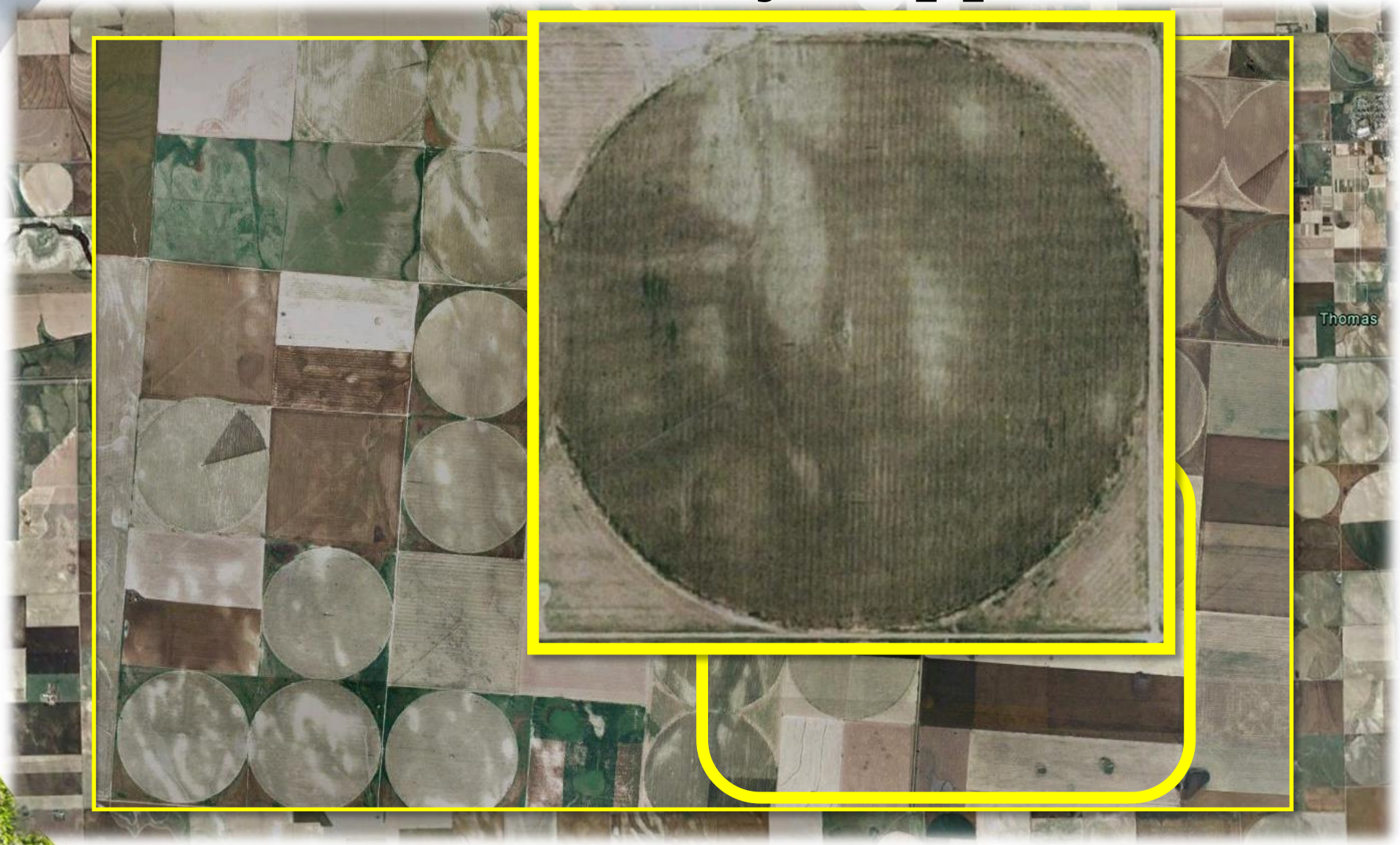


Five R's of Precision Water Management

- Use of Right Input - Water
- At the Right Time
- In the Right Amount
- At the Right Place
- In the Right Manner

managing spatial and temporal variability
in plant available water in farm-fields

Variability happens!!



At the **regional** scale

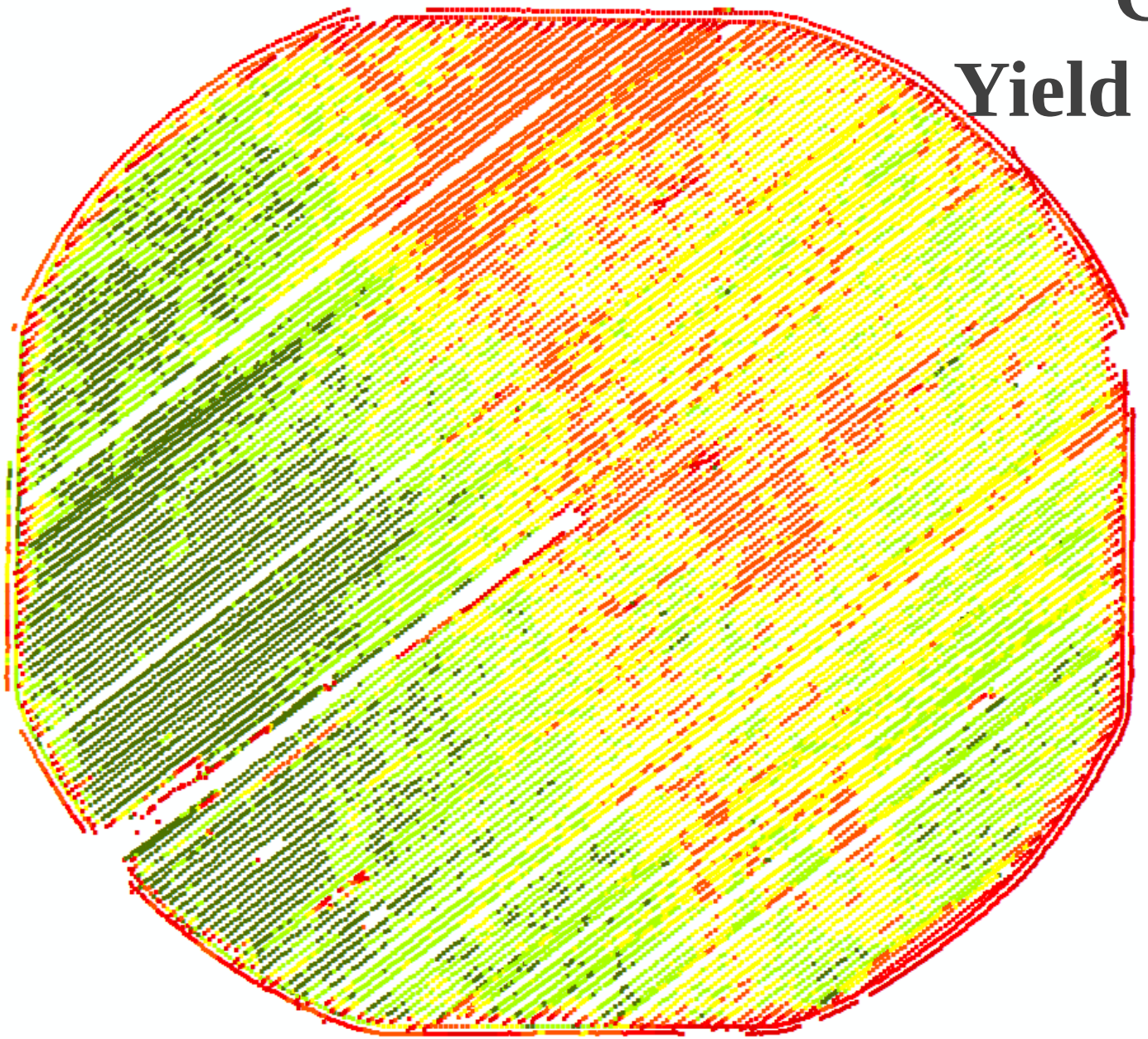
At the **farm** scale

At the **field** scale

Spatial variations in soil o… translate into variations in c…

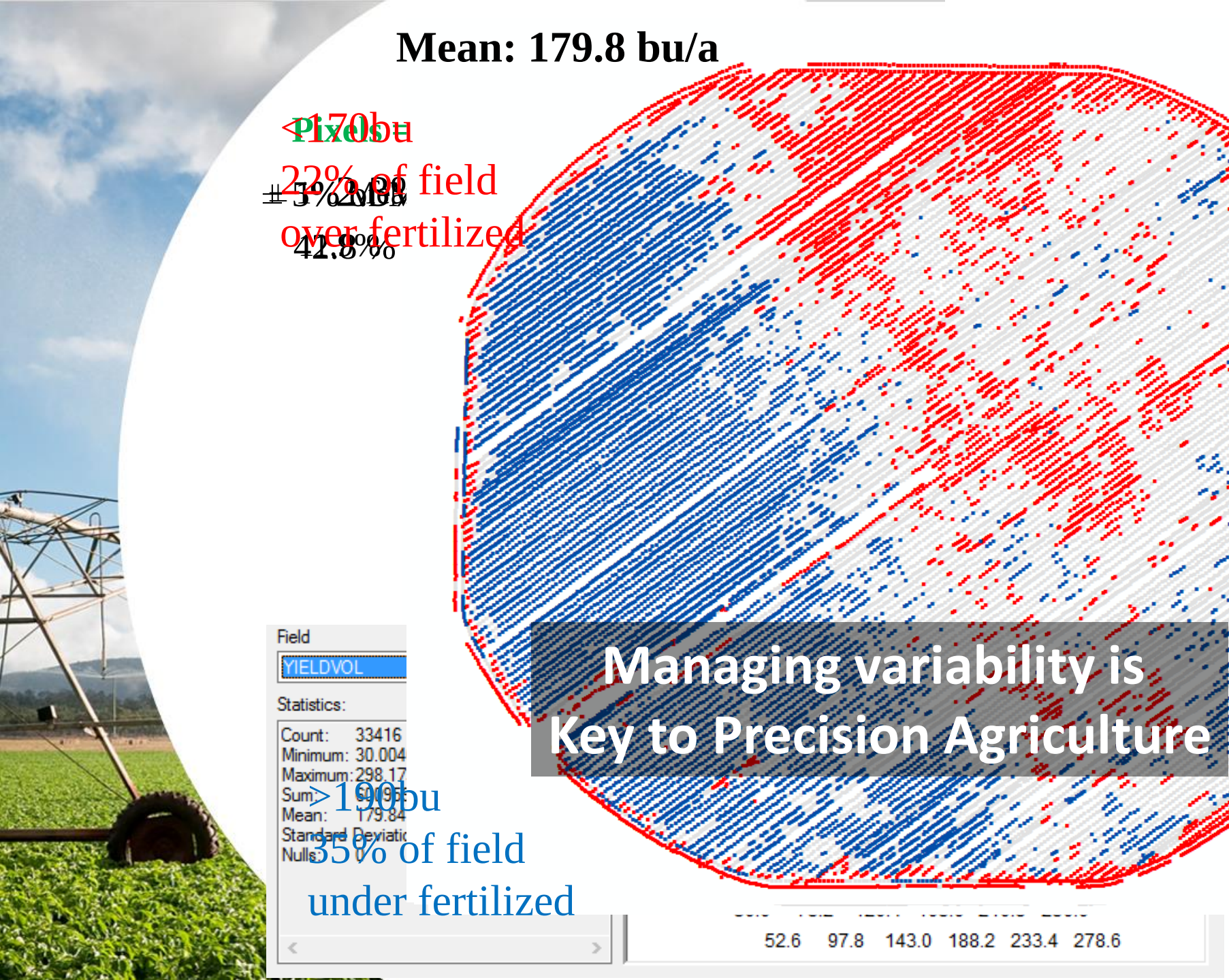

172
164
151
112
146
212

Corn Yield Map



Corn Yield Map

Mean: 179.8 bu/a



<170bu
22% of field
over fertilized

>190bu
35% of field
under fertilized

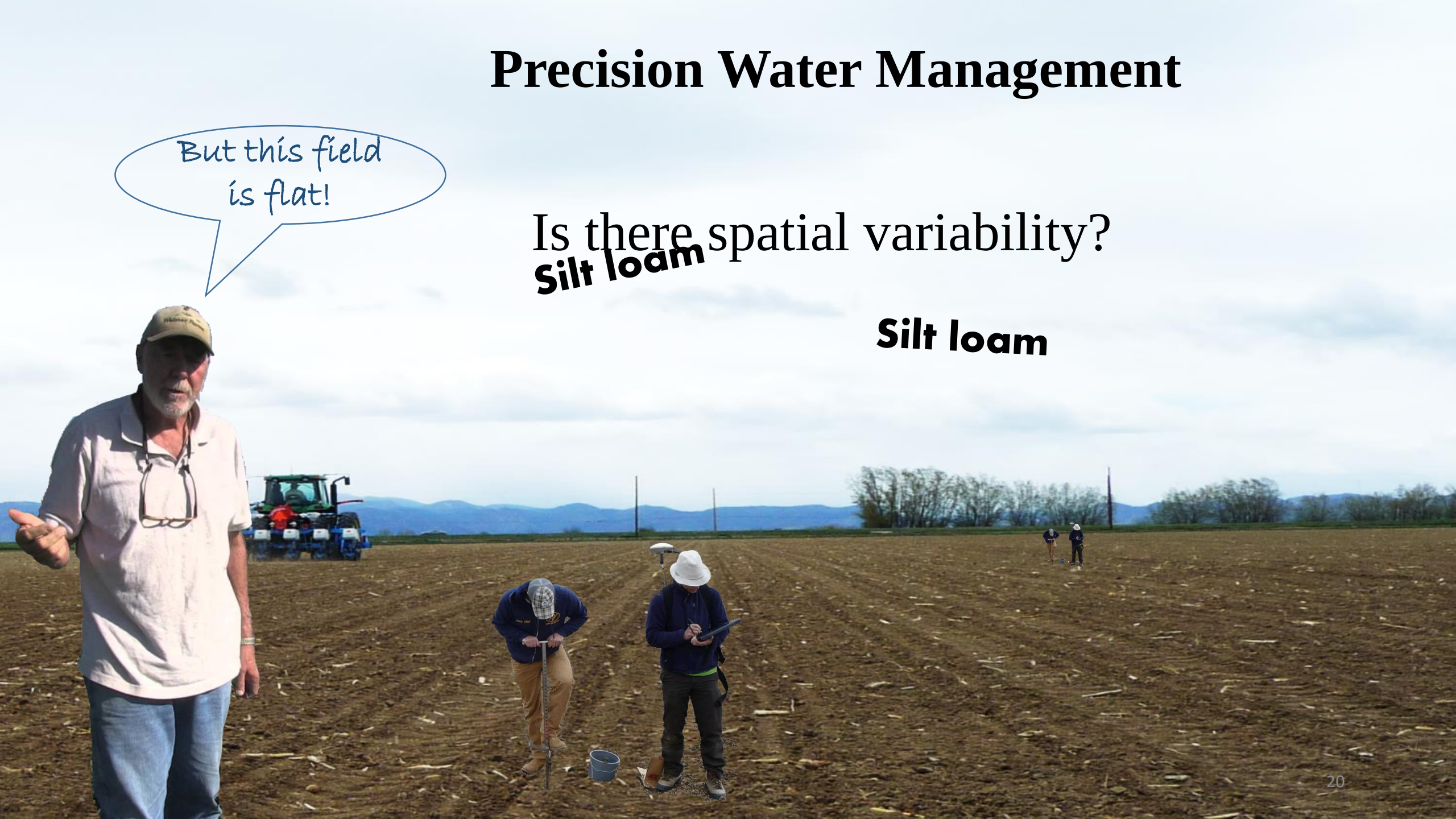
Managing variability is Key to Precision Agriculture

Current Water Management

One depth of water applied throughout the pivot


No variability?

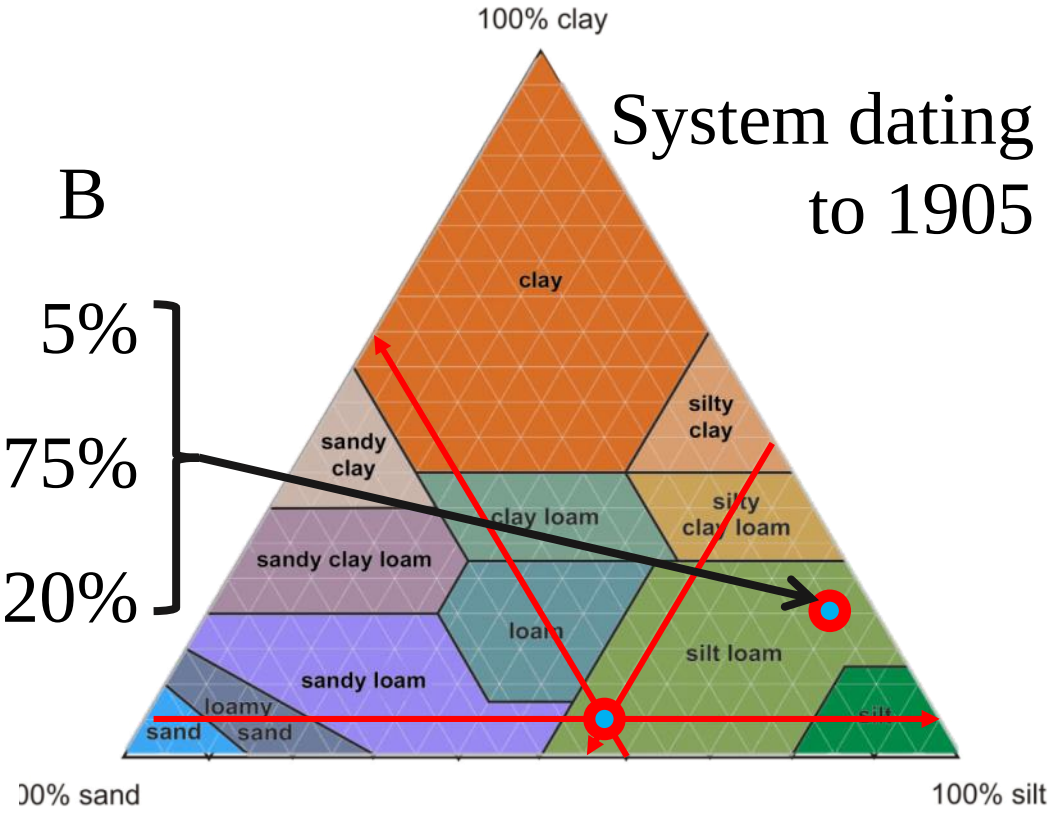
Precision Water Management

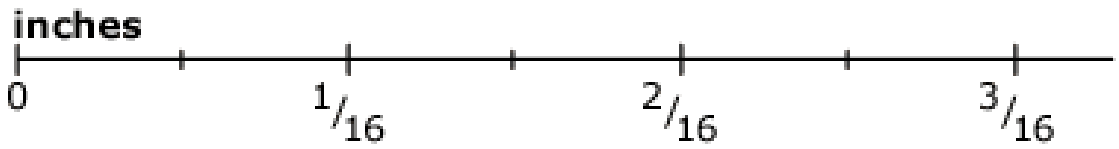


Sample	A	B
Sand:	39%	5%
Silt:	55%	75%
Clay:	6%	20%

Silt loam

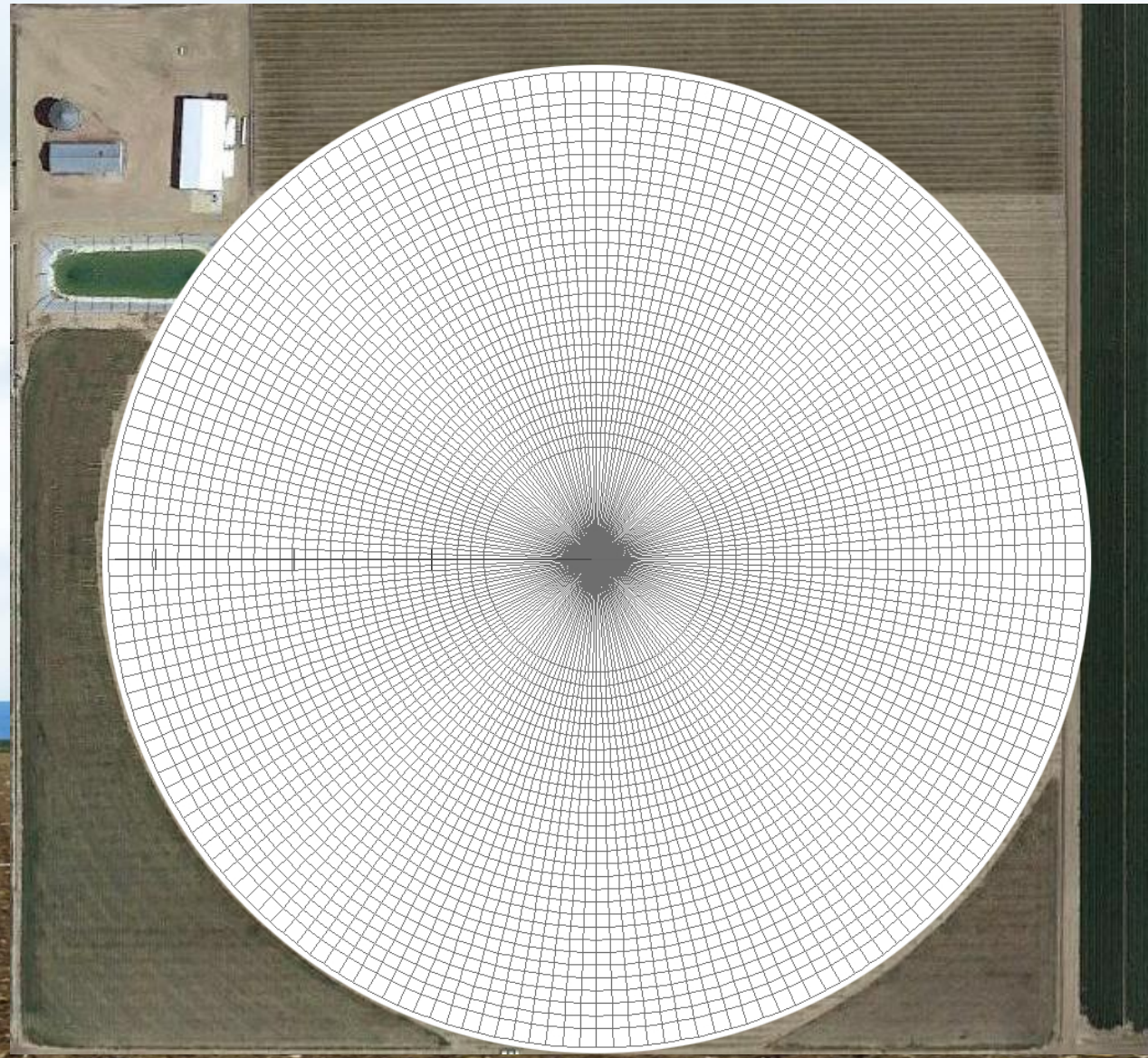
System dating to 1905





This field is not only flat, it is one soil type, and one soil texture class!

Silt loam

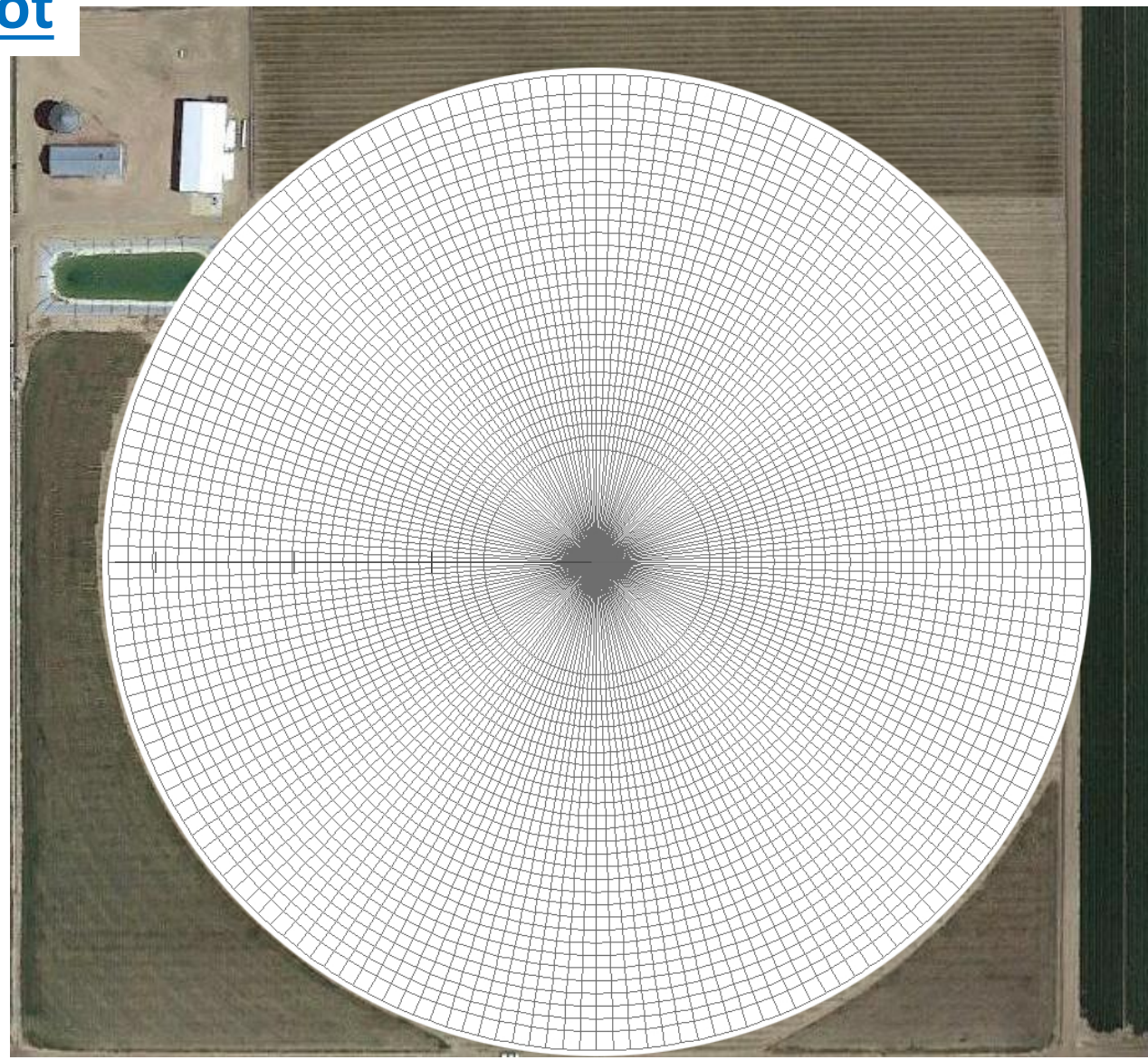


Variable Rate Irrigation Pivot

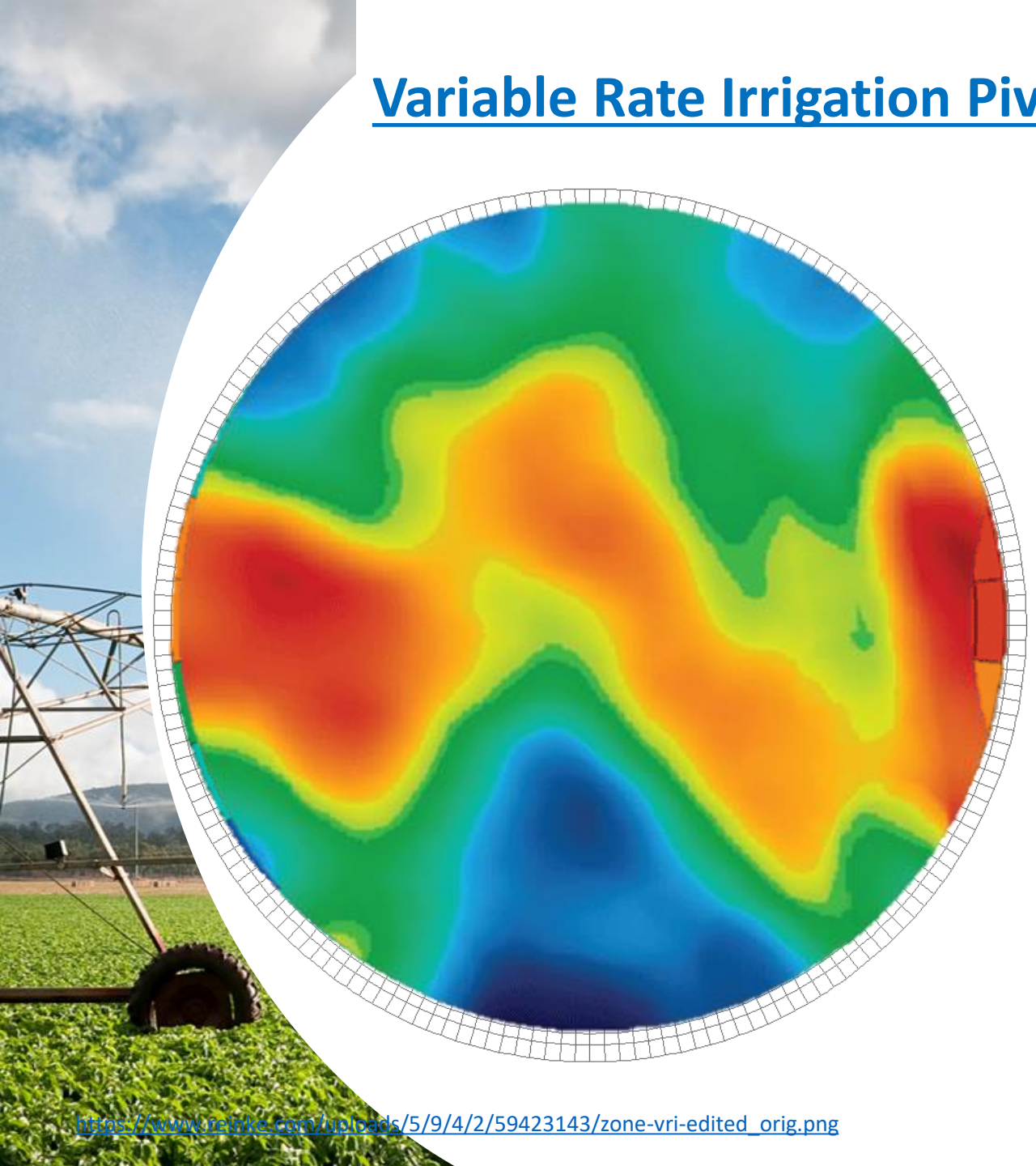
- Water can be varied
  - at every nozzle level
  - for every 2° of pivot movement

Silt loam

- $\frac{360^o}{2^o}$ = 180° x 30nozzles
- = 5400 water management zones
- Technology is ahead of science



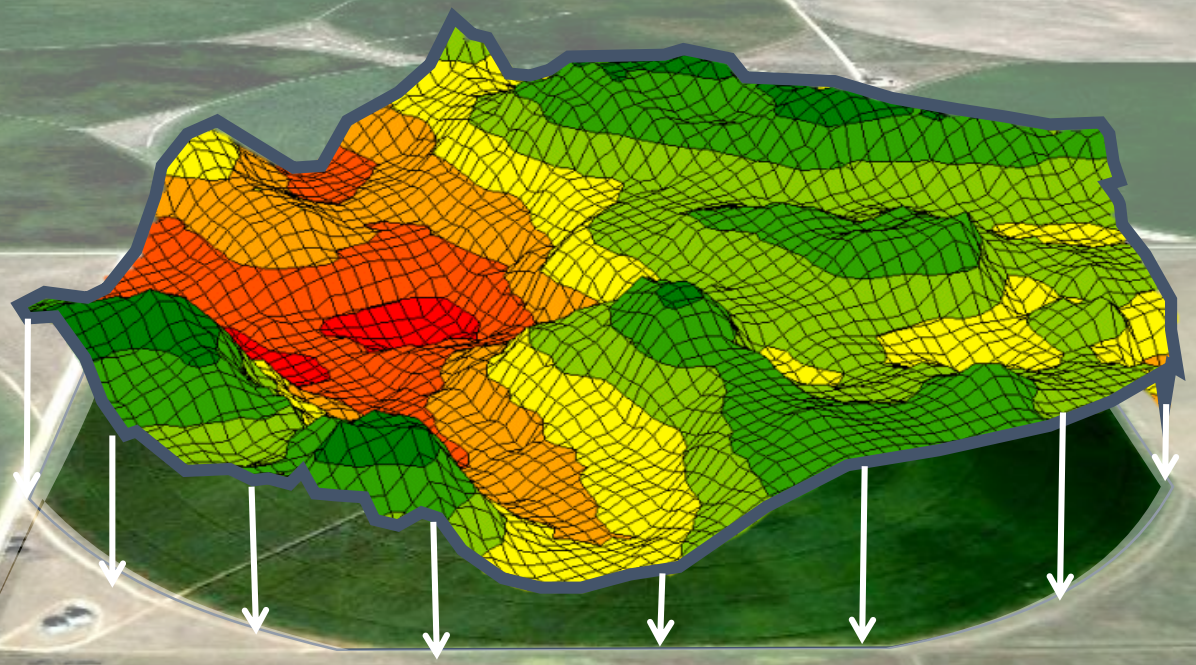
Variable Rate Irrigation Pivot



- Does it even make sense to apply different rate of water in each zone / pixel?
- How do we figure out how much water to be applied in each zones / pixel?
- How many zones are ideal for my field?
- Do these zones change?
- How much?
- How often?
- What about other parameters?

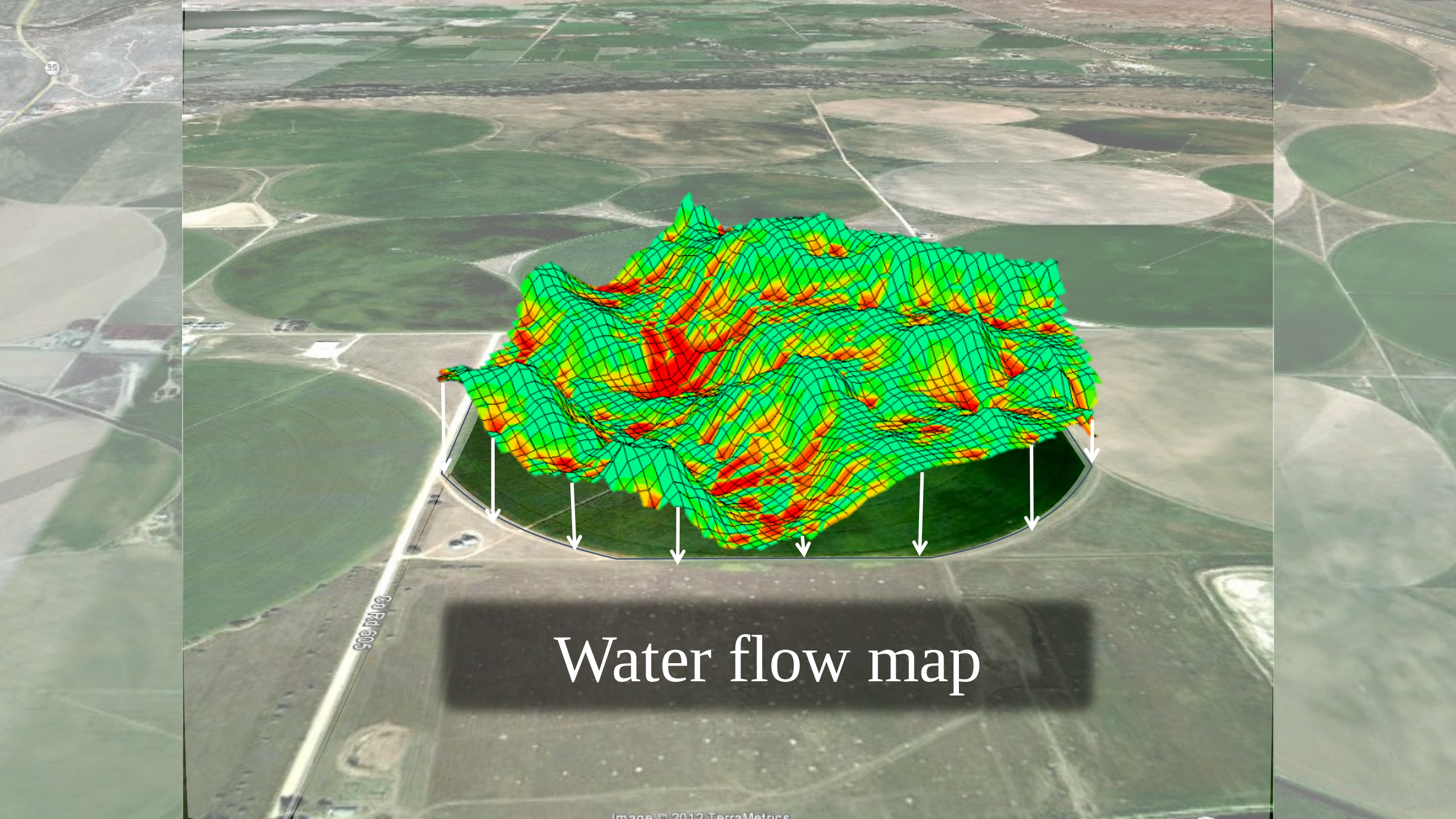
https://www.reinke.com/uploads/5/9/4/2/59423143/zone-vri-edited_orig.png

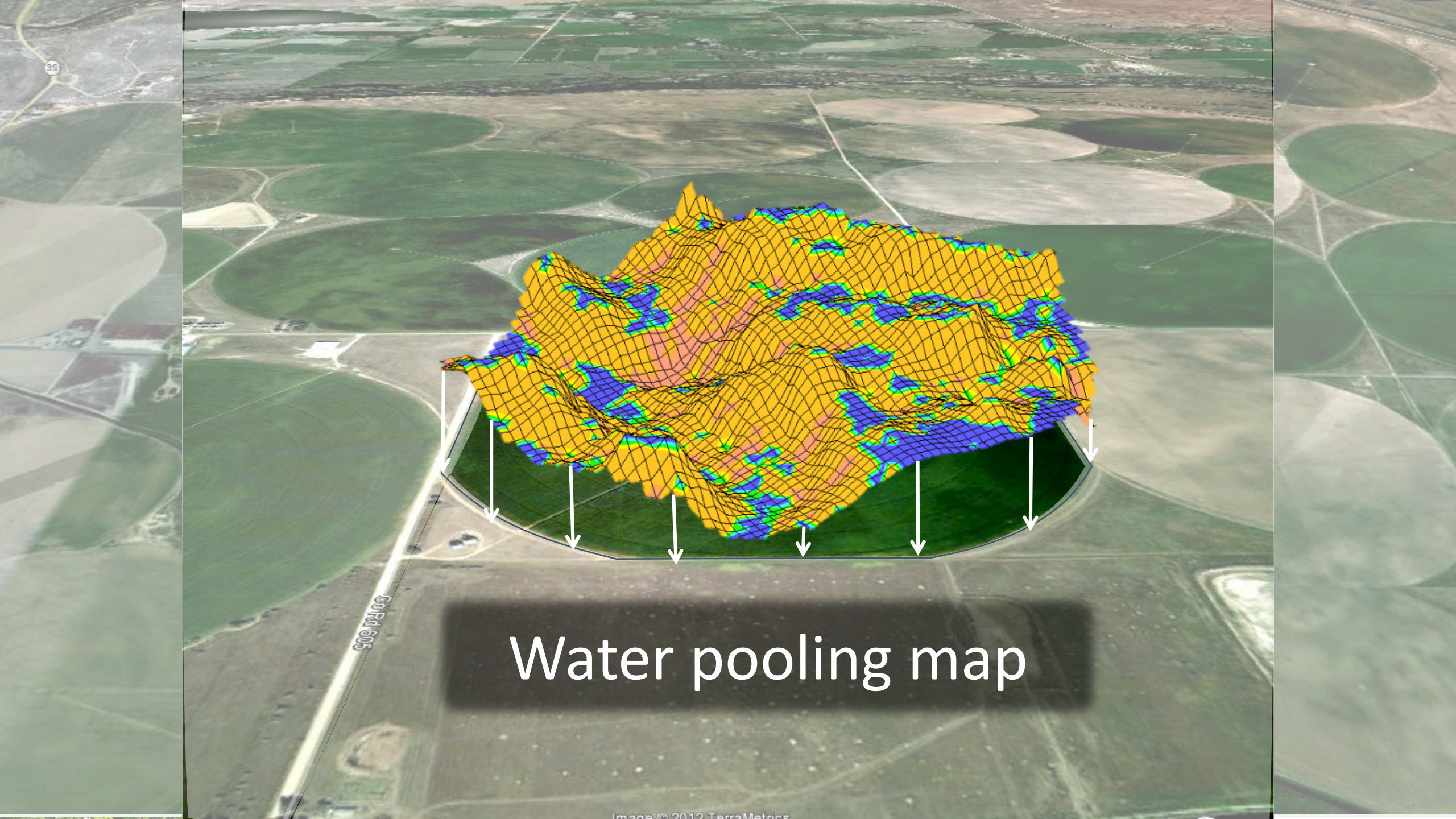
Field topography



Elevation map

Grain yields are correlated with topography


Water flow map


Water pooling map

Variable rate irrigation Pivot

- Can this approach save me any power?
- Can this approach save me any water?
- Can this approach maintain my production?
- Can this approach increase my production?
- Can this approach make me more money?

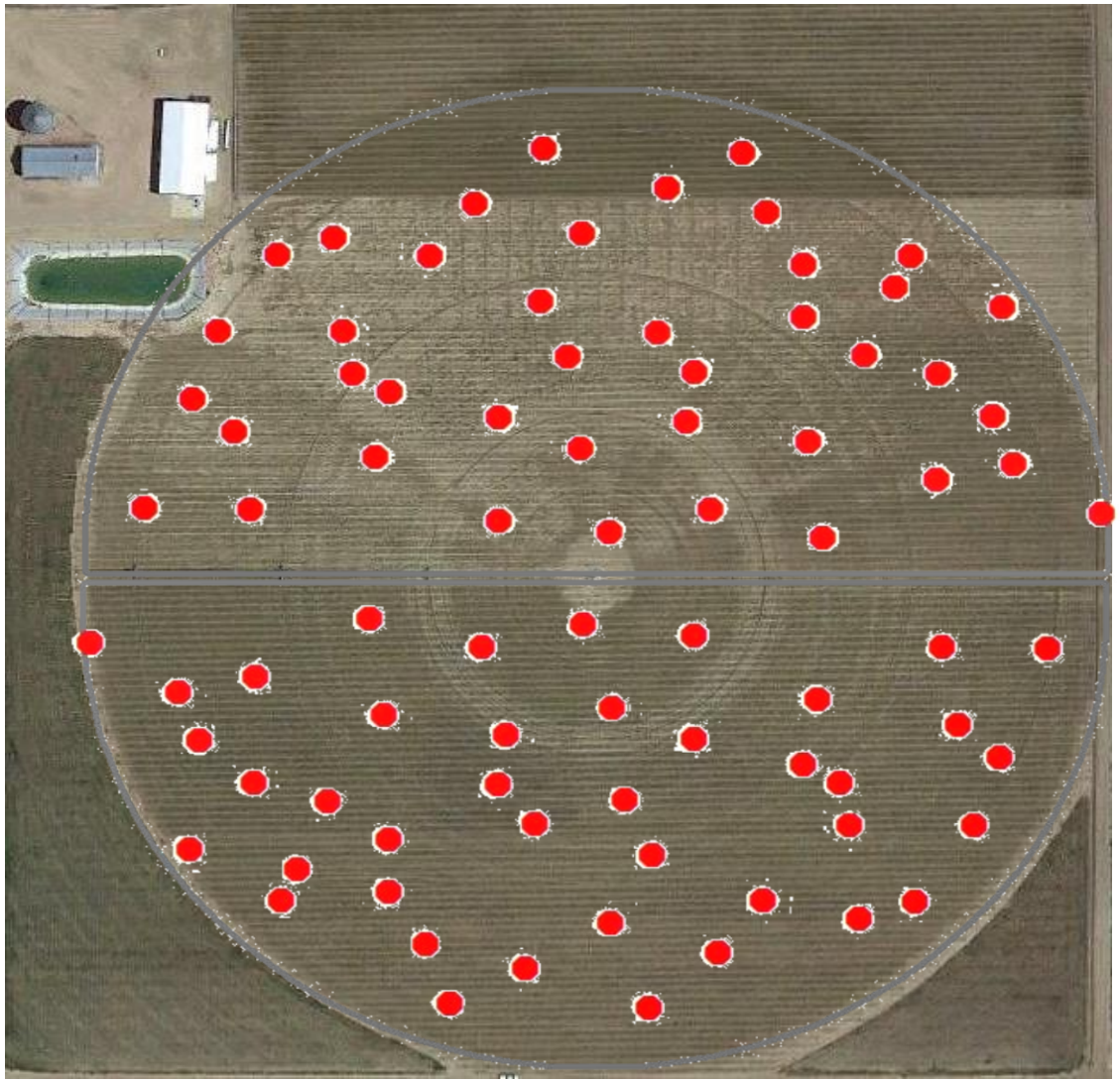
More questions than answers

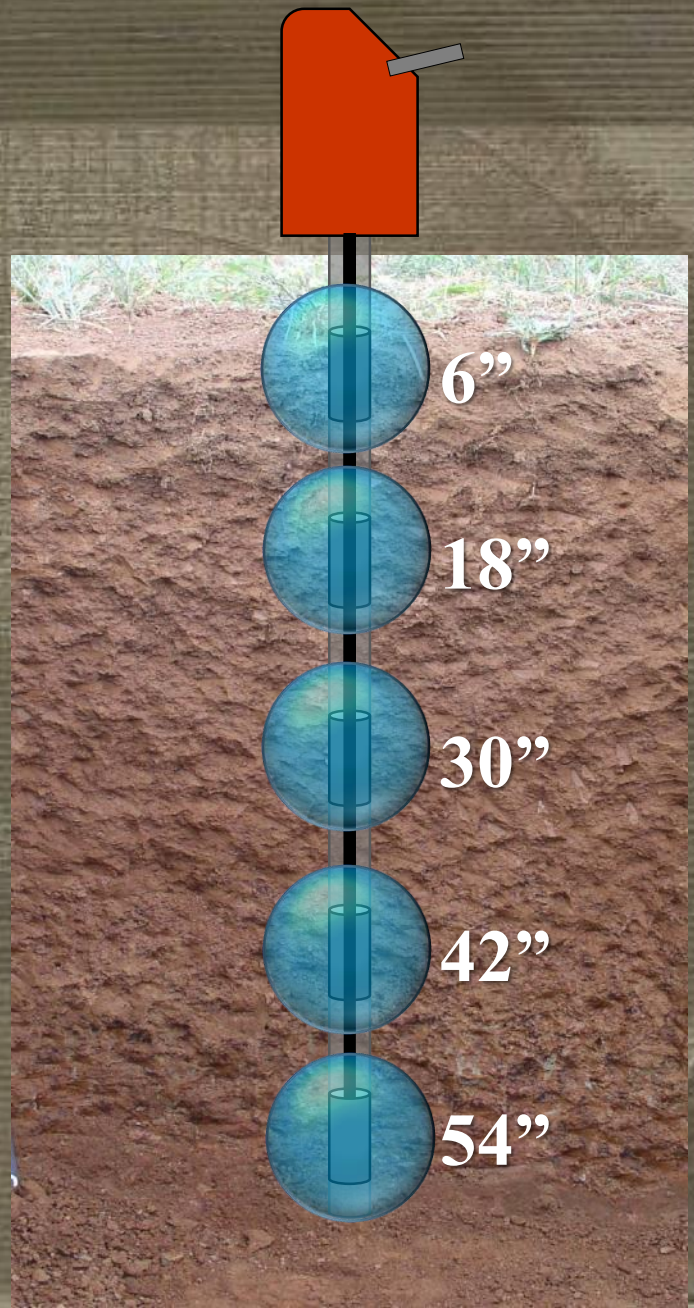
Question. How do we figure out how much water to be applied in each zones / pixel?

Answer. We need to know how much moisture is in soil everywhere in the field

Ques much water to be applied in each zones / pixel?

Answ moisture is in soil everywhere in the field

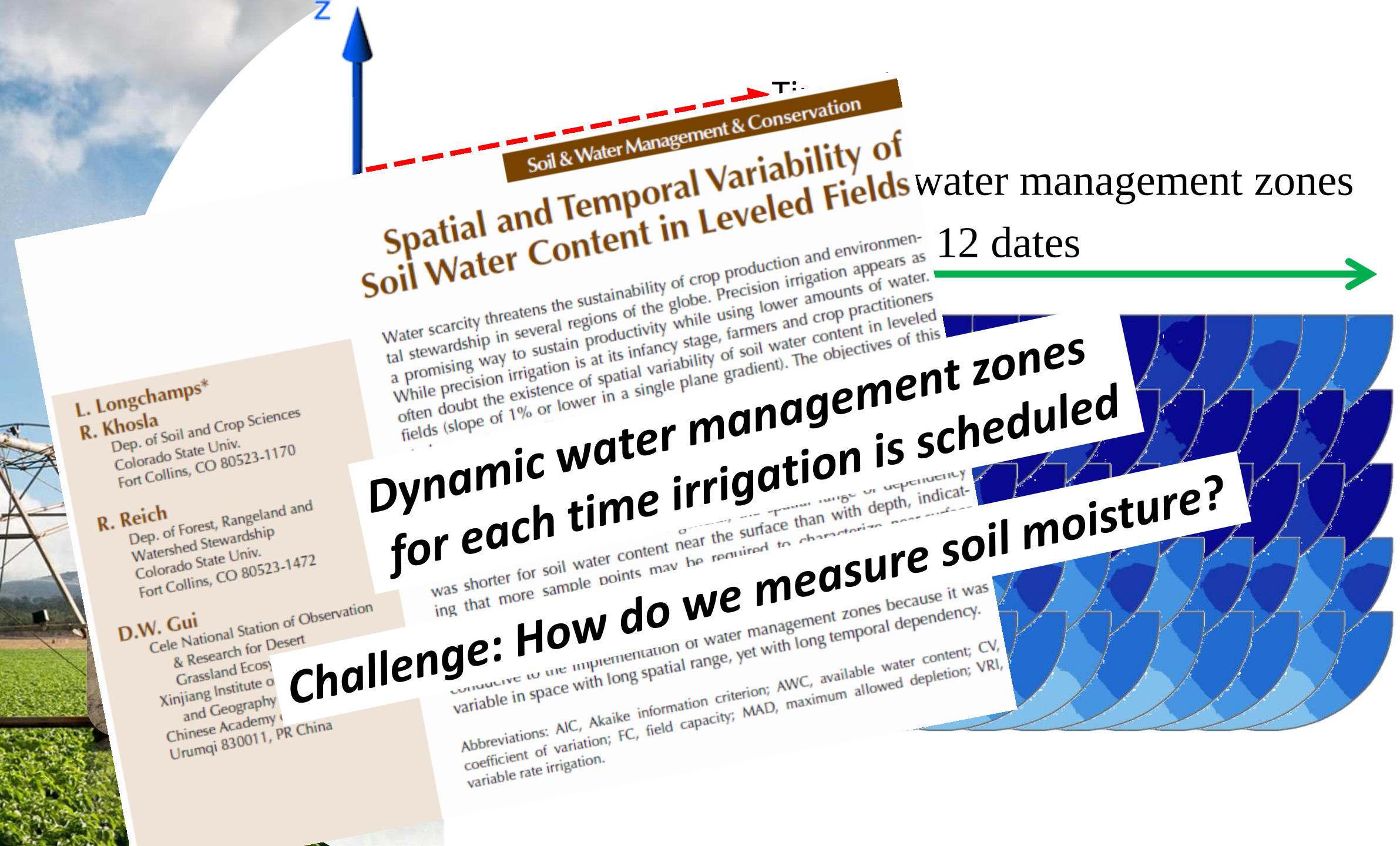



6”
18”
30”
42”
54”

Moisture distribution at 42” depth

Probe readings
- 0.00 – 2.25
- 2.26 – 2.50
- 2.51 – 3.00 (in/ft)
- 3.01 – 3.50
- 3.51 – 4.00
- 4.01 – 4.51

June July Aug. Sept.


Z
Soil & Water Management & Conservation
Spatial and Temporal Variability of Soil Water Content in Leveled Fields
Water scarcity threatens the sustainability of crop production and environmental stewardship in several regions of the globe. Precision irrigation appears as a promising way to sustain productivity while using lower amounts of water. While precision irrigation is at its infancy stage, farmers and crop practitioners often doubt the existence of spatial variability of soil water content in leveled fields (slope of 1% or lower in a single plane gradient). The objectives of this
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was shorter for soil water content near the surface than with depth, indicating that more sample points may be required to
variable in space with long spatial range, yet with long temporal dependency.
Abbreviations: AIC, Akaike information criterion; AWC, available water content; CV, coefficient of variation; FC, field capacity; MAD, maximum allowed depletion; VRI, variable rate irrigation.
water management zones
12 dates
Dynamic water management zones for each time irrigation is scheduled
Challenge: How do we measure soil moisture?

Precision Agriculture using Networks of Degradable Analytical Sensors (PANDAS)

1. SUMMARY

In the propose work, we will develop, fabricate and test a **network of additively fabricated, biodegradable sensor nodes** with costs of **<$1/unit** capable of accurately and continuously monitoring soil and crop conditions, function an entire season, be easily distributed by planters with no need for ongoing maintenance, and be read remotely. This will enable a **>100× increase in information density** over current solutions for precision farming of row and other crops. This technology would enable characterization of spatially and temporally variable soil and crop properties to precisely synchronize inputs (water, fertilizer, etc.) to crop needs; thereby **enhancing input use efficiency, grain yields, and farm profitability while mitigating environmental losses, and decreasing energy use, for food, feed and fuel crops**. The proposed approach uses large-area print manufacturing techniques and biodegradable materials to produce complete stand-alone sensor nodes that can be widely dispersed over large areas at high concentrations with minimal effort. During operation these sensors will accurately report on various

In Future

unding from federal agency is allowing us to develop cheap (<$1) biodegradable soil moisture sensors

NASA SPINOFF

NASA TECHNOLOGY TRANSFER PROGRAM

Sensors Enable Plants to Text Message Farmers

Energy and Environment

NASA Technology

Long-term human spaceflight means long-term menu planning. Since every pound of cargo comes with a steep price tag, NASA has long researched technologies and techniques to allow astronauts to grow their own food, both on the journey and in some cases at their destination. Sustainable food technologies designed for space have resulted in spinoffs that improve the nutrition, safety, and durability of food on Earth.

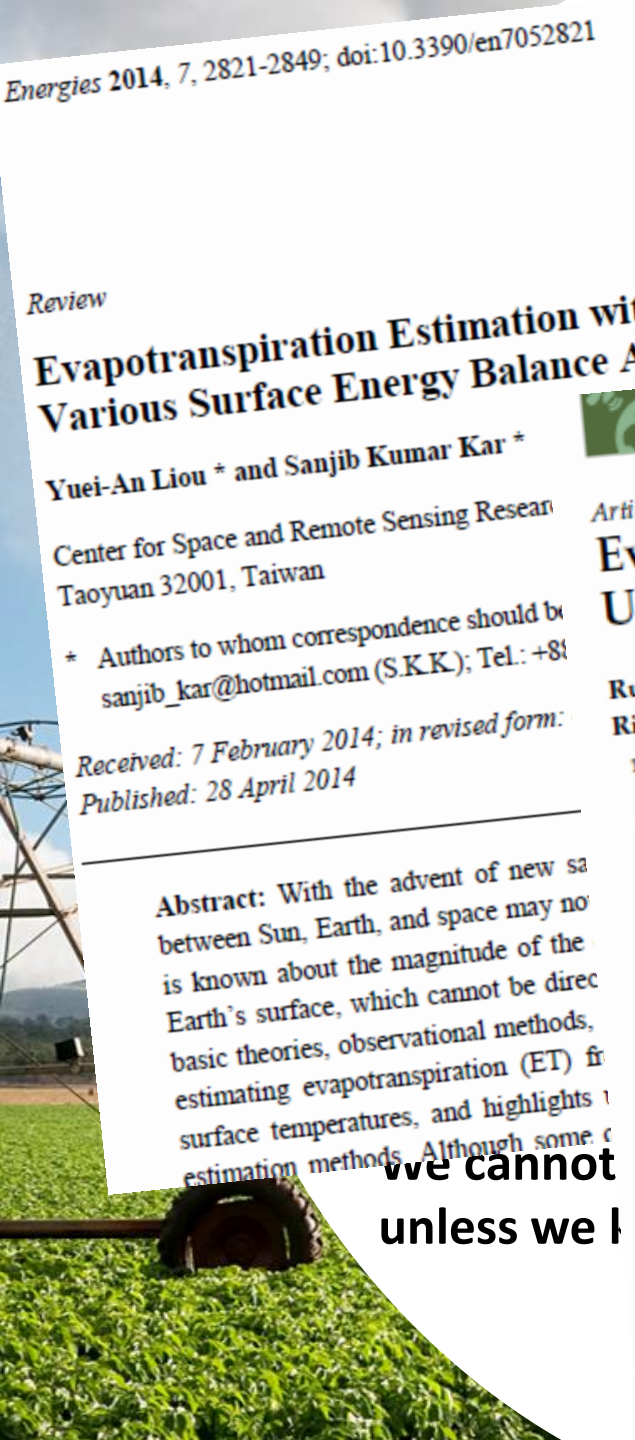
There are of course tradeoffs involved in making astronauts part-time farmers. Any time spent tending plants is time that can't be spent elsewhere: collecting data, exploring, performing routine maintenance, or sleeping. And as scarce as time is for astronauts, resources are even more limited. It is highly practical, therefore, to ensure that farming in space is as automated and precise as possible.

Technology Transfer

In the early 2000s, a NASA cooperative agreement for developing hardware for biological experiments in space was made available to Hans Seelig, at the time a PhD student at the University of Colorado Boulder and an employee of BioServe Space Technologies, a nonprofit, NASA-sponsored research partnership center located at the university and at the time connected to the Space Product Development Office at Marshall Space Flight Center. As part of his research, Seelig studied the relationship between plant leaf rigidity and its water content, and whether such data could be directly measured using sensors. "No device was available that could measure leaf thickness continually, so I built a prototype sensor that measured thickness by way of electrical pulses," he says.

Seelig hypothesized that sensor-based watering could eliminate a significant amount of guesswork in farming and free up time and resources that could be applied elsewhere. "Astronauts are not supposed to spend their days weeding, watering, and the like, so we wanted to

By measuring electrical pulses, AgriHouse's sensors can determine several characteristics important to plant health. The sensors can remain attached through wind and rain while leaving the plant unharmed.



we cannot
unless we k

Energies **2014**, 7, 2821-2849; doi:10.3390/en7052821

OPEN ACCESS
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www.mdpi.com/journal/energies

Review

Evapotranspiration Estimation with Remote Sensing and Various Surface Energy Balance Algorithms—A Review

Yuei-An Liou * and Sanjib Kumar Kar *

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Received: 7 February 2014; in revised form:
Published: 28 April 2014

Abstract: With the advent of new sa
between Sun, Earth, and space may no
is known about the magnitude of the
Earth's surface, which cannot be direc
basic theories, observational methods,
estimating evapotranspiration (ET) fr
surface temperatures, and highlights
estimation methods. Although some

remote sensing

Article

Evapotranspiration Estimate over an Almond Orchard Using Landsat Satellite Observations

Ruyan He [1,2], Yufang Jin [2,*], Maziar M. Kandelous [3], Daniele Zaccaria [2], Blake L. Sanden [4], Richard L. Snyder [2], Jinbao Jiang [1] and Jan W. Hopmans [2]

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Academic Editors: George P. Petropoulos and Pr
Received: 7 March 2017; Accepted: 1 May 2017; 1

Abstract: California growers face challeng
use the least amount of water while optim
(ET), a dominant component of crop con
irrigation management based on in-field spat
performance of a remote sensing-based app
with Internalized Calibration (METRIC), in n
by Landsat satellite observations. Reference
grass (ET_o) was used for the internal calib
period, instead of alfalfa based reference eva
ET estimates during Landsat overpass

MDPI

Research Article

Estimation of Crop Evapotranspiration Using Satellite Remote Sensing-Based Vegetation Index

Arturo Reyes-González [1,2], Jeppe Kjaersgaard [3], Todd Trooien [1], Christopher Hay [4] and Laurent Ahiablame [1]

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[2] *Instituto Nacional de Investigaciones Agrícolas, Forestales y Pecuarias (INIFAP), Blvd. Prof. José Santos Valdez, No. 1200 Pte, Col. Centro, Matamoros, COAH, Mexico*
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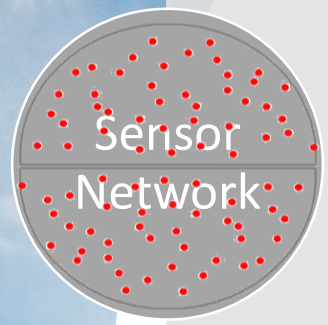
Academic Editor: Jan Friesen

Calibration Study



Data

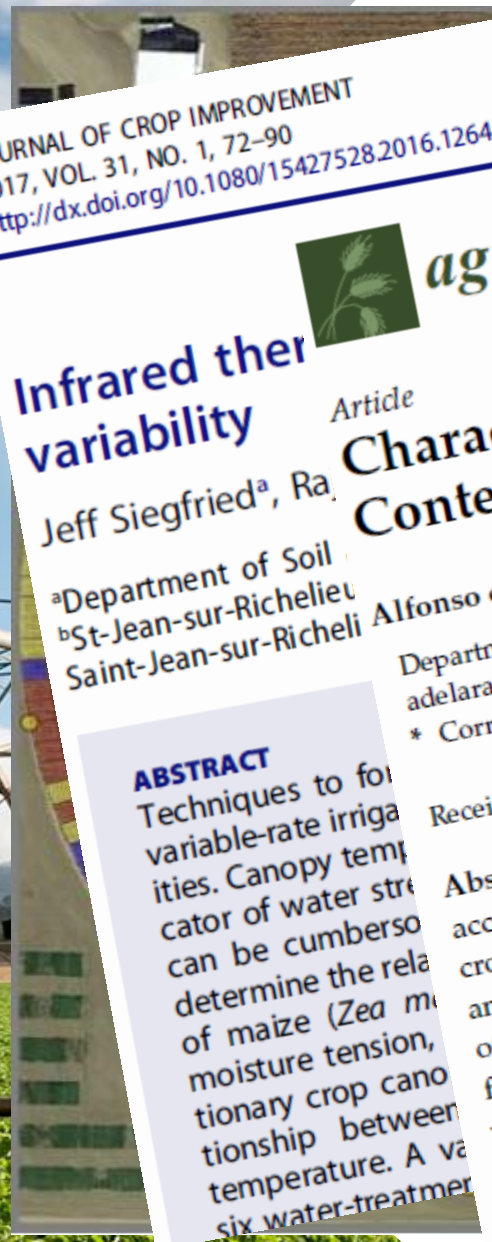
- With ability to override

ML = Machine Learning
AI = Artificial Intelligence

Objective 2

Approach

Validation St



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2017, VOL. 31, NO. 1, 72–90
http://dx.doi.org/10.1080/15427528.2016.1264532

Taylor & Francis
Taylor & Francis Group

Infrared ther variability

Jeff Siegfried[a], Ra
[a]Department of Soil
[b]St-Jean-sur-Richelieu
Saint-Jean-sur-Richeli

ABSTRACT
Techniques to fo
variable-rate irriga
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can be cumberso
determine the rela
of maize (*Zea m*
moisture tension,
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MDPI

agronomy

Article

Characterizing Content for Pr

Alfonso de Lara, Raj Khos
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* Correspondence: raj.khosl

Received: 15 March 2018; Ac

Abstract: Among one of
accurate characterization
crop growing season. The
and has received little atte
of this study was to assess
field scale by the apparen
was compared against rep
showed that mean SWC w
a macro-scale, soil ECa cou
zones. Results also showe
Considering other soil pr
relationship between

MDPI

agronomy

Article

Soil Water Content and High-Resolution Imagery for Precision Irrigation: Maize Yield

Alfonso de Lara [1], Louis Lon
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doi:10.2489/jswc.74.1.33

Multispectral satellite imagery to quantify in-field soil moisture variability

Received: 31 January 2019; Acce

J. Siegfried, L. Longchamps, and R. Khosla

Abstract: Improvement in
increasing global water dema
defining the amount of wate
new concept in agriculture, a
maintaining or increasing gra
and accurate method to estim
have been successfully used t
to root water uptake. Crop y
in time and at different depth
of SWC and its r

Abstract: As pressure on available water resources increases, the need to exploit technology in order to produce more food with less water becomes crucial. The technological hardware requisite for precise water delivery methods, such as variable rate irrigation, is commercially available. Despite that, techniques to formulate a timely, accurate prescription for those systems are inadequate. Spectral vegetation indices are often used to gauge crop vigor and related parameters (e.g., leaf nitrogen [N] content). However, research heretofore rarely addresses the influence of soil moisture on the indices. The objectives of this study were to determine (1) if vegetation indices derived from multispectral satellite imagery could assist in quantifying soil moisture variability in irrigated maize (*Zea mays* L.) production, and (2) the period of time that a single image is representative of soil moisture. A variable rate irrigation pivot was used to form six water treatment zones. Each was equipped with tensiometers installed in the center of the plots at 20, 45, and 75 cm depths to individually monitor conditions in the treatment zones. Water was applied for each treatment as a percentage of the estimated (ET) requirement: 40%, 60%, 80%, 100%, 120%, and 140%. Data collected with the image pixels corresponding to its ground location. to assess whether vegetation indices are represen- from this study indicate that Red

Evans et al. (1996)
and formulating a prescr
water application as th
for researchers to addr
the aforementioned a
"identification and c
tributing factors and
influence a real-time
cult." Continually c
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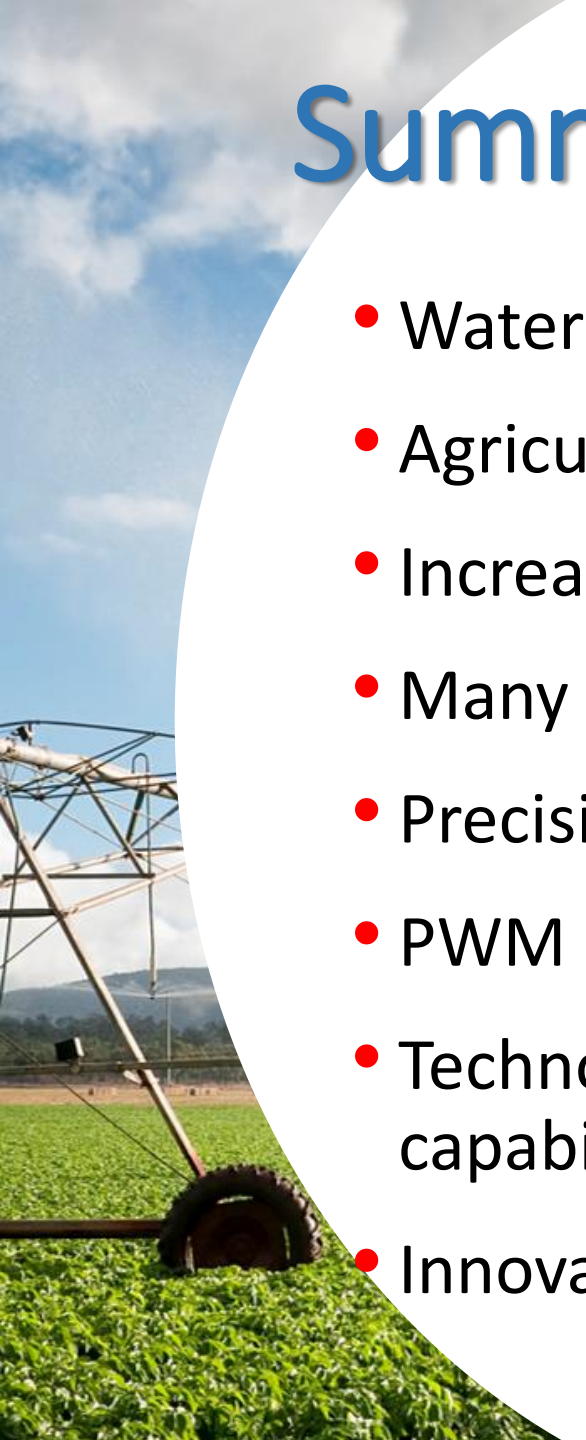
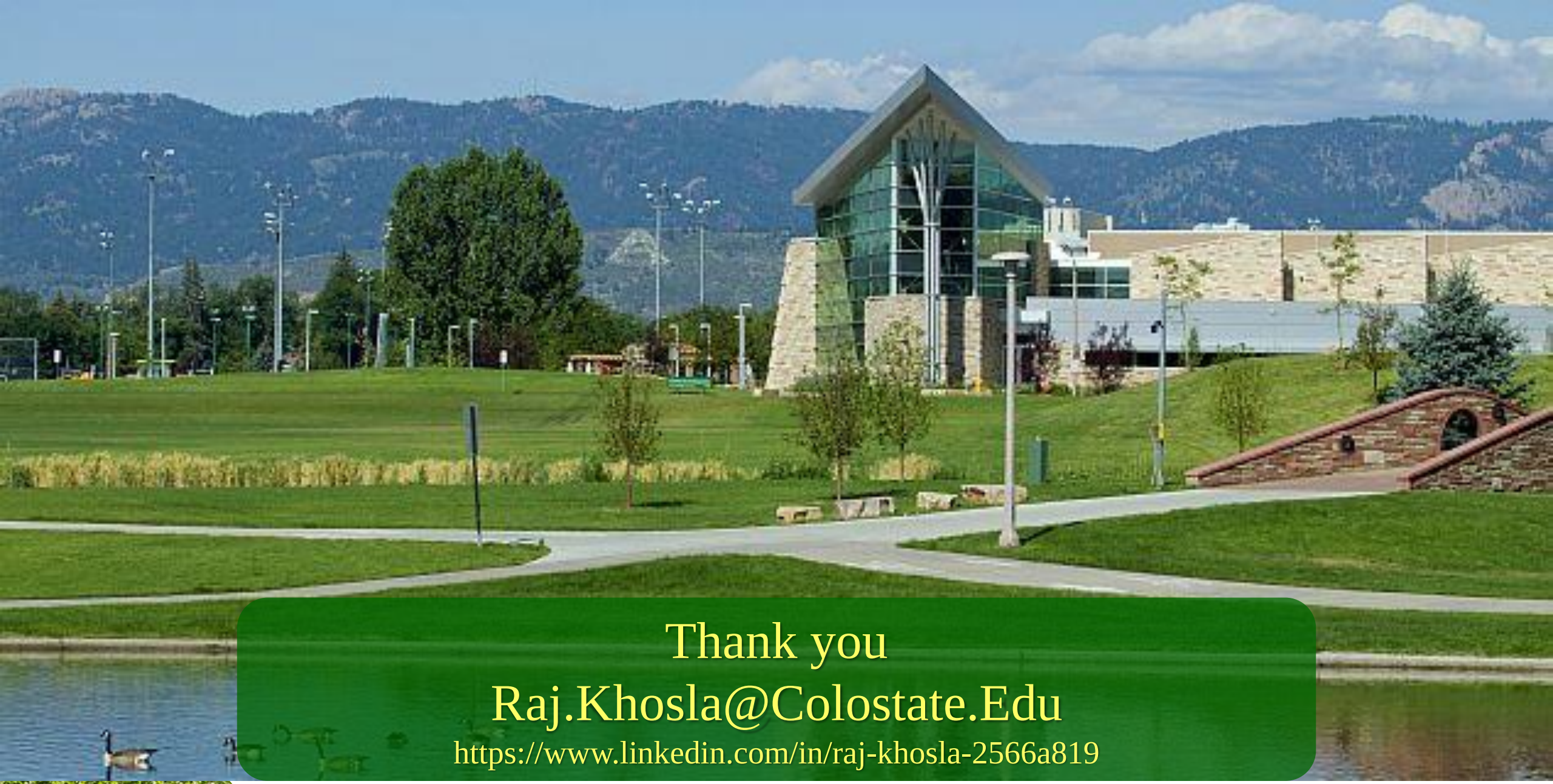


Summary

- Water in the west is precious
- Agriculture continues to be the major consumer of fresh water
- Increasing demand for water from municipalities
- Many solutions to address the water challenge
- Precision water management (PWM) is one among many solutions
- PWM is complex, we have the tools and technology
- Technology is ahead of science and that is currently limiting our capability to harness what it promises to deliver
- Innovative sensing and data analytics will help in bridging this gap



Thank you

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