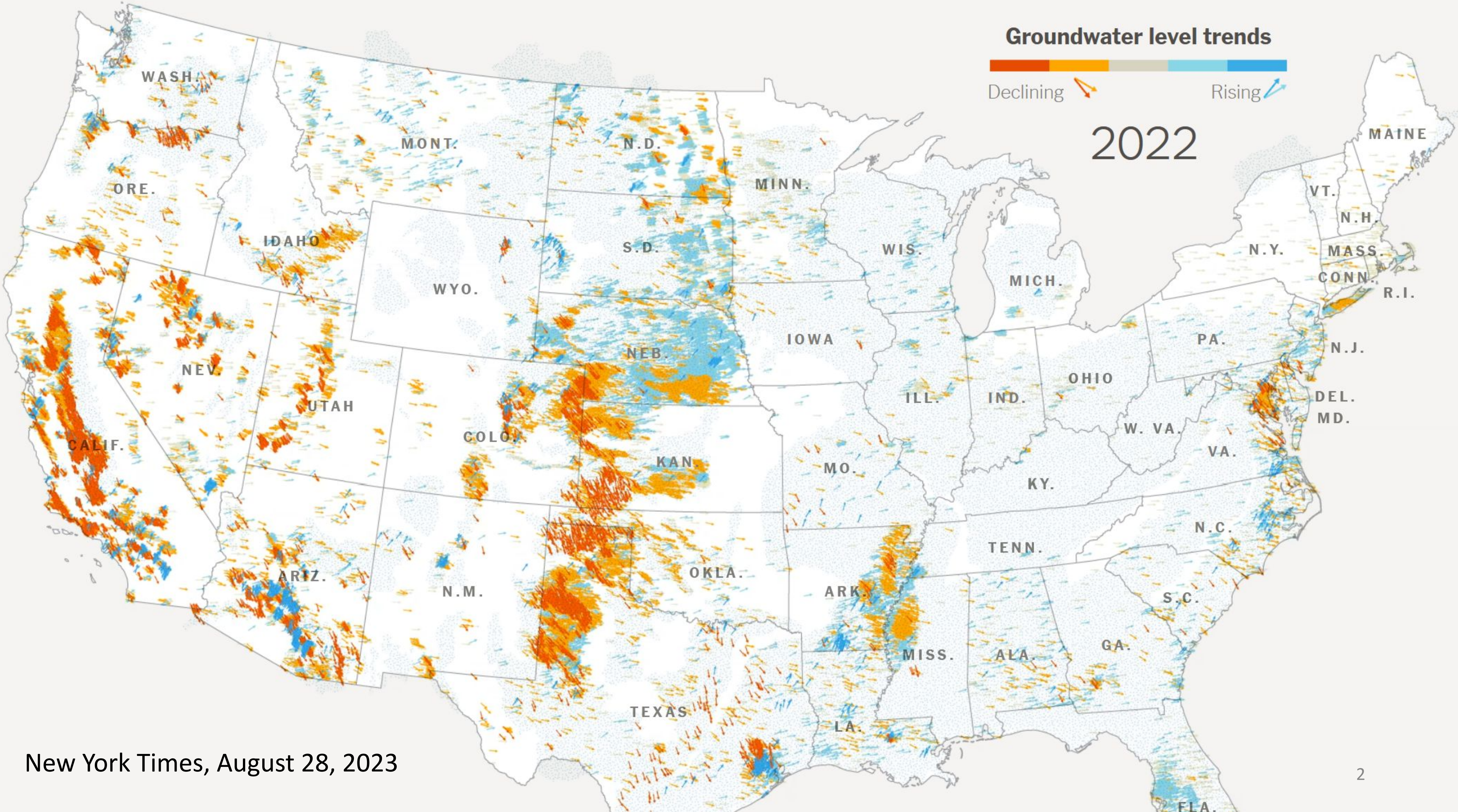
Advancing Sustainable Groundwater Management With a Hydro-Economic System Model: Investigations in the Harney Basin, Oregon

William Jaeger, Department of Applied Economics, Oregon State University

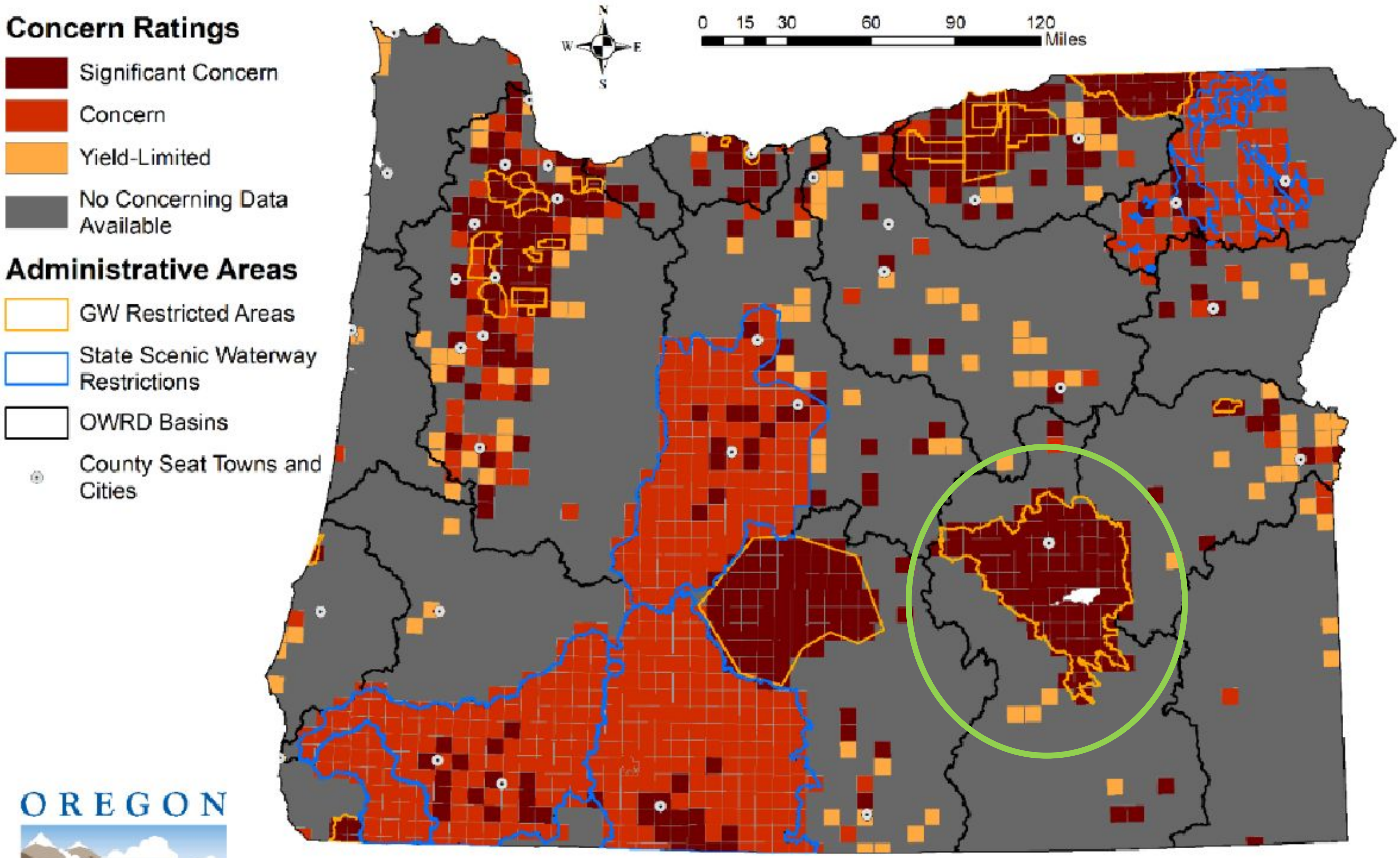
59th Pacific Northwest Regional Economic Conference
Bellingham, WA
May 21, 2025

Co-authors: John Antle, Dept. of Applied Economics, OSU (emeritus), Steve Gingerich, Research hydrologist, USGS, Portland, OR, Dan Bigelow, Dept. of Applied Economics, OSU

Published in *Water Resources Research* 60.11 (2024)

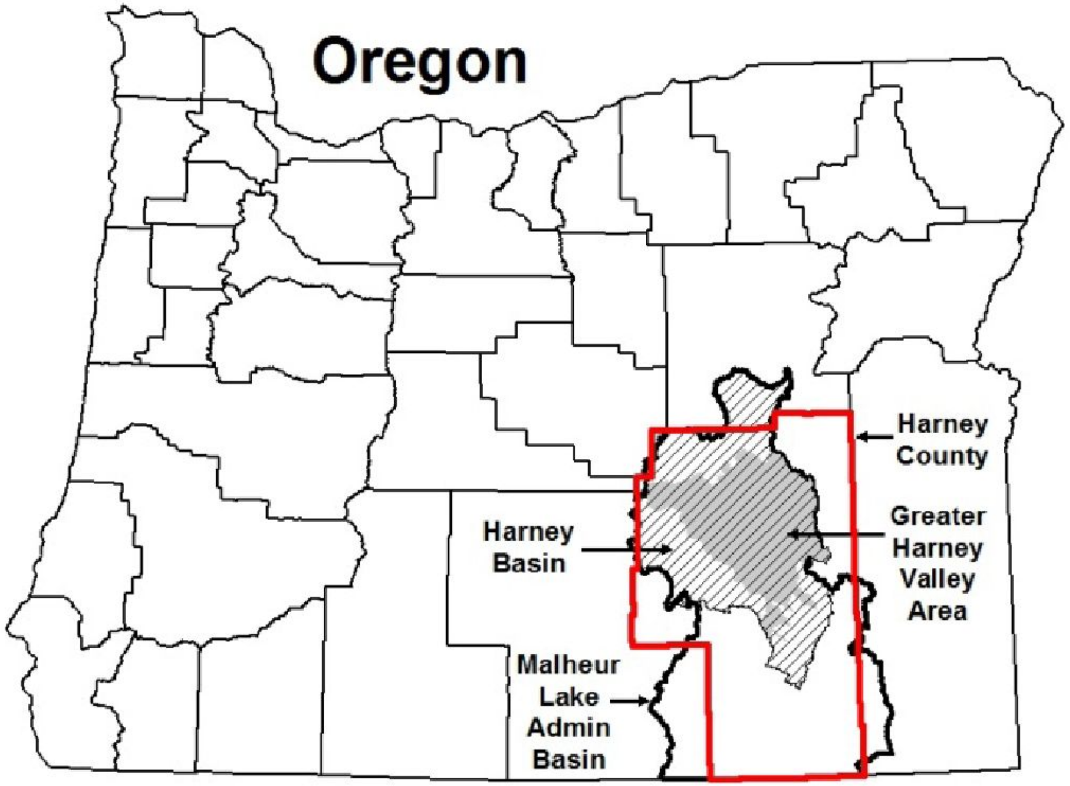


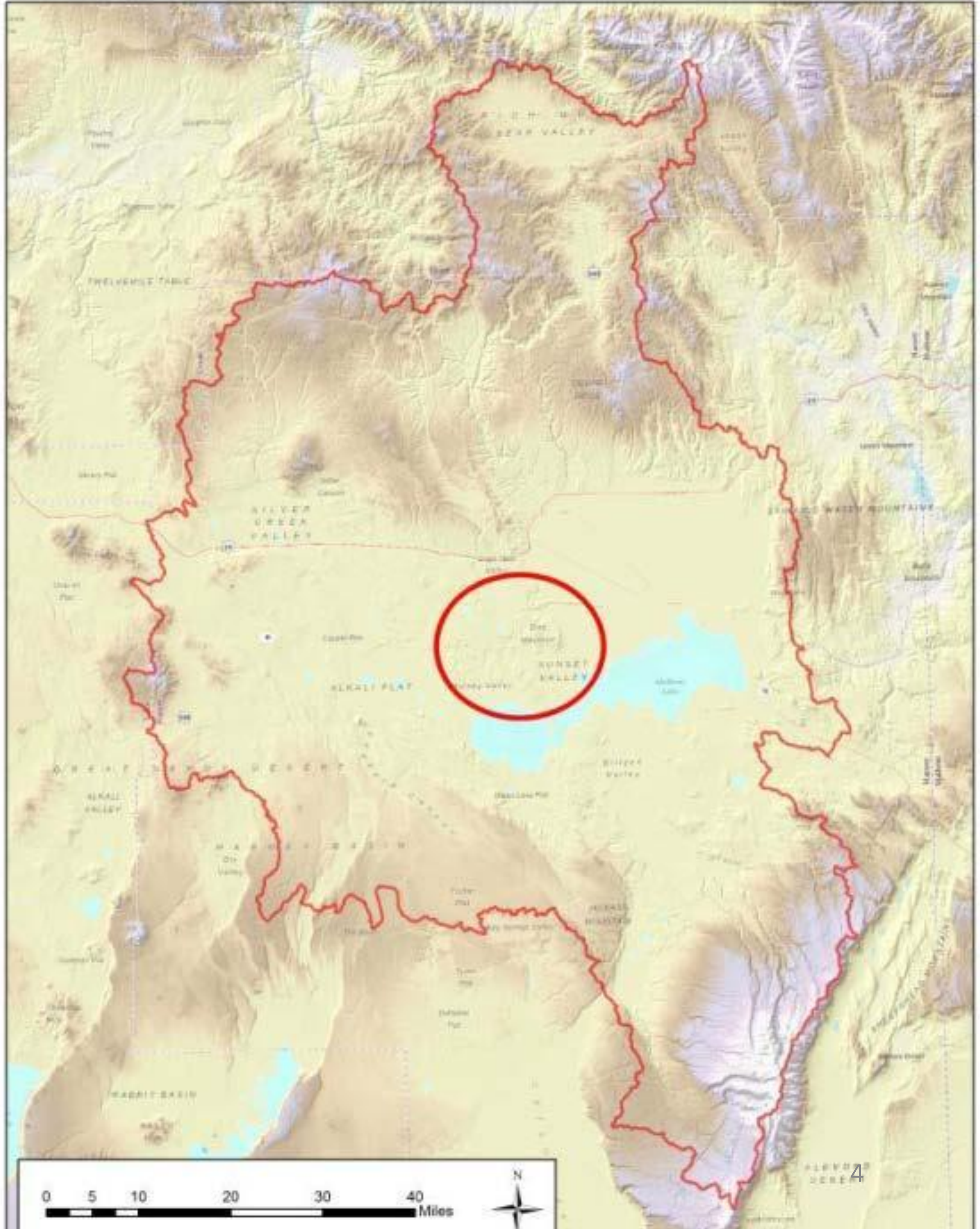
New York Times, August 28, 2023

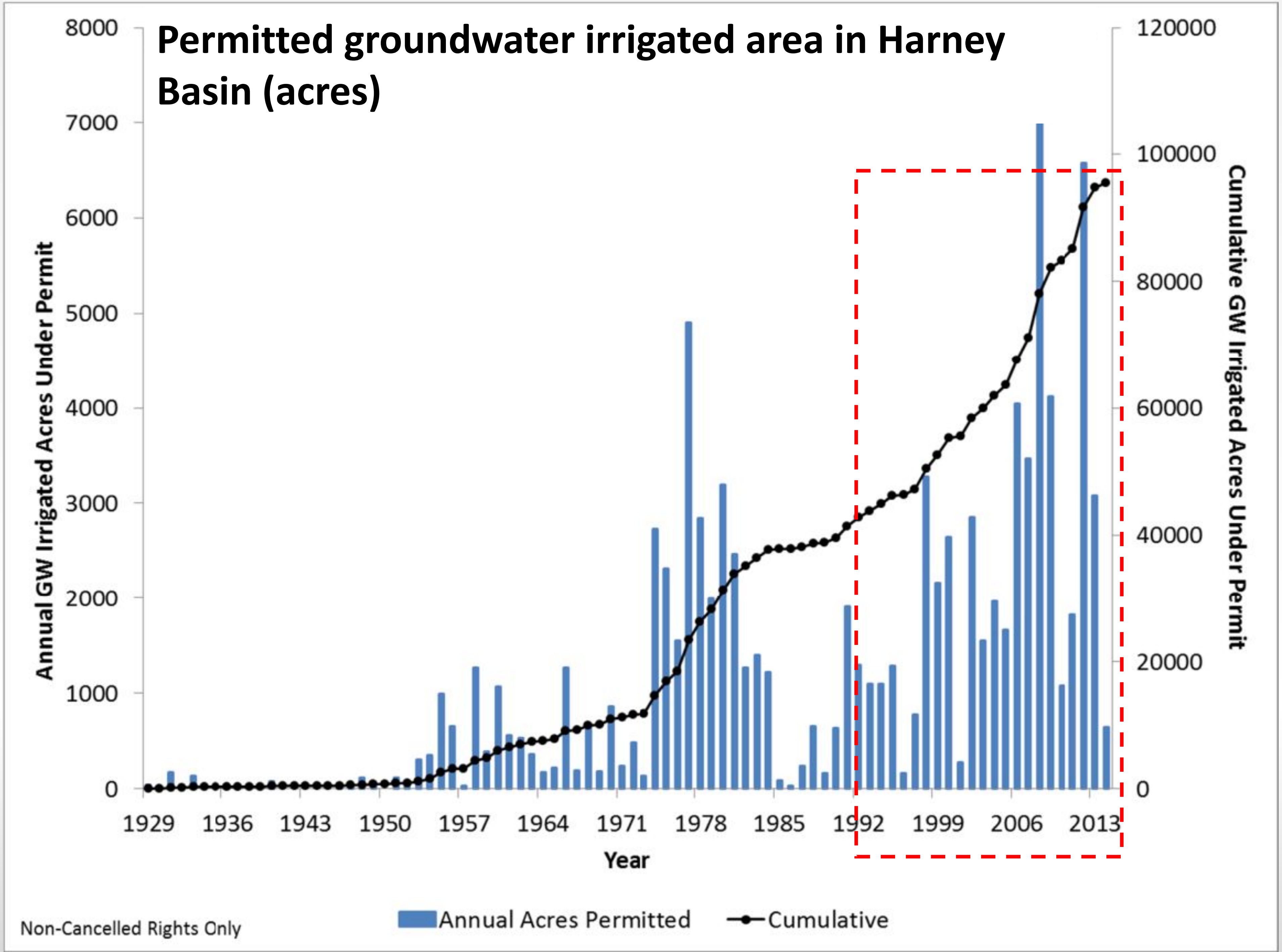


OREGON
WATER RESOURCES DEPARTMENT

The concern ratings shown on this map reflect the sustainability and restrictions associated with expanded consumptive use of groundwater in a given area. They are not a substitute for a review of a groundwater application to determine availability of water for a specific use. Users of this information should consult the primary report and data to ascertain the usability of the information. This map may not be suitable for legal, engineering, or surveying purposes.
OWRD Groundwater Section, 4/20/2021. Projection: Oregon Lambert NAD 83 (EPSG #2992).

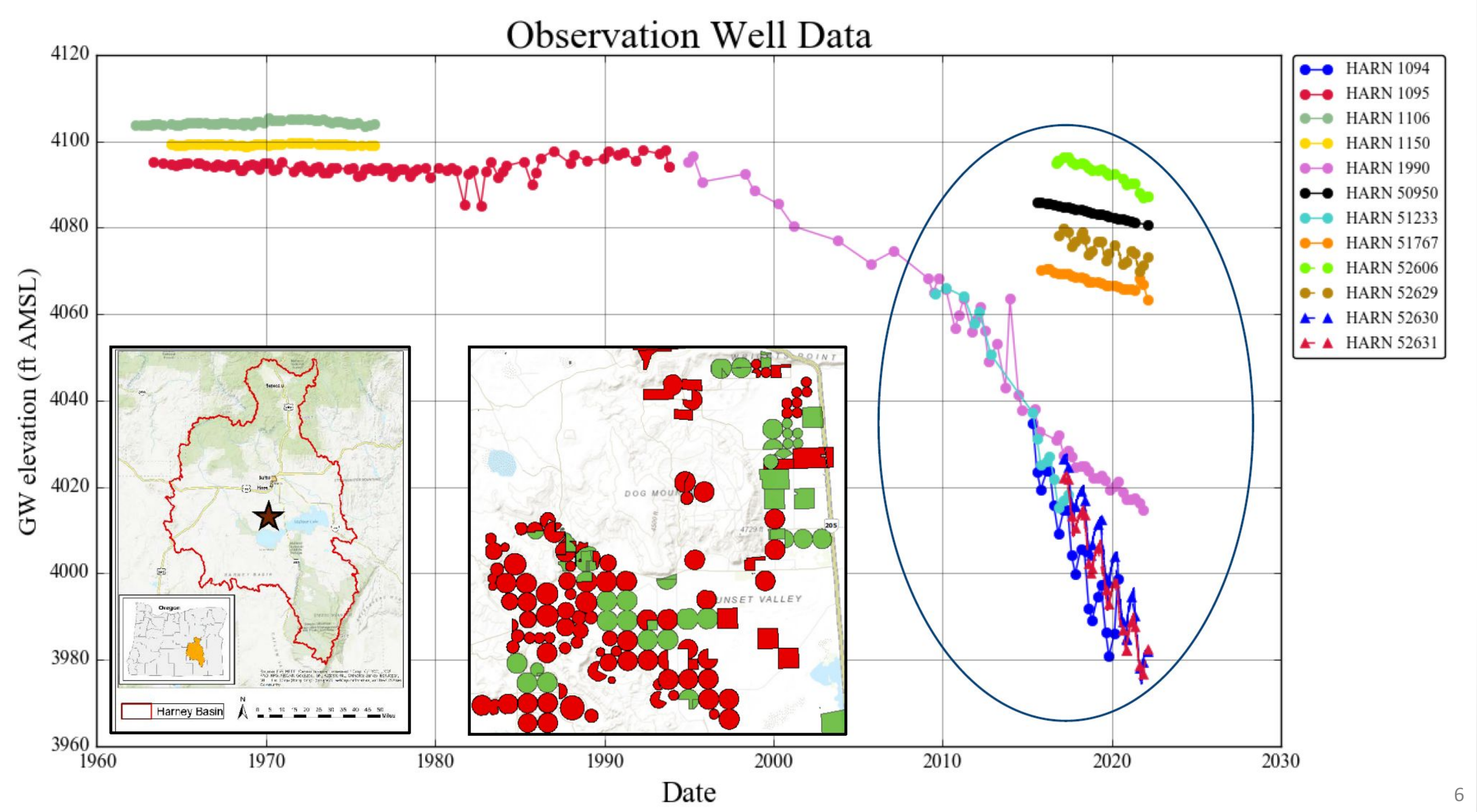

Oregon
Harney County
Harney Basin
Greater Harney Valley Area
Malheur Lake Admin Basin


0 5 10 20 30 40
Miles
N



Permitted groundwater irrigated area in Harney Basin (acres)
Annual GW Irrigated Acres Under Permit
Cumulative GW Irrigated Acres Under Permit
0
1000
2000
3000
4000
5000
6000
7000
8000
20000
40000
60000
80000
100000
120000
1929
1936
1943
1950
1957
1964
1971
1978
1985
1992
1999
2006
2013
Year
Annual Acres Permitted
Cumulative
Non-Cancelled Rights Only

A system in transition from abundance to scarcity



Project goals and approach

1. One goal: to reduce uncertainty. A hydro-model can narrow divergent views and foster shared understanding of the nature of the problem and feasible solutions.

2. Approach: A systems perspective recognizing the Harney Basin as a complex, adaptive human-natural system.

3. Hypothesis: that a systems approach can be useful and important.

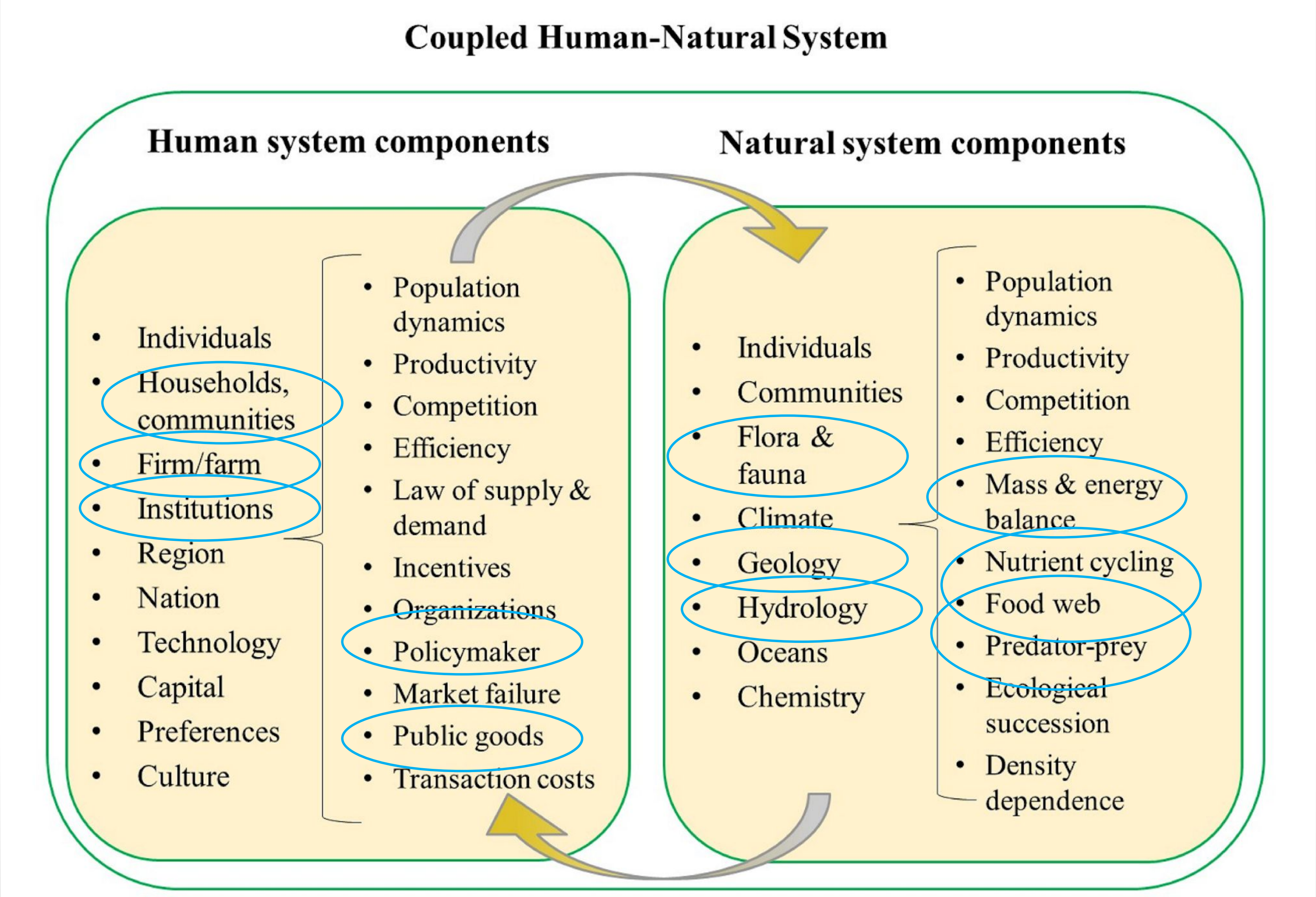
4. Hypothesis: that there will be surprises in what the model reveals, including surprises for stakeholders, policymakers, and also us (the researchers).

"Complex, adaptive social-ecological systems"

"Systems linking people and nature, known as social-ecological systems, are increasingly understood as complex adaptive systems. Essential features of these systems – such as nonlinear feedbacks, strategic interactions, individual and spatial heterogeneity, and varying time scales – pose substantial challenges for modeling."

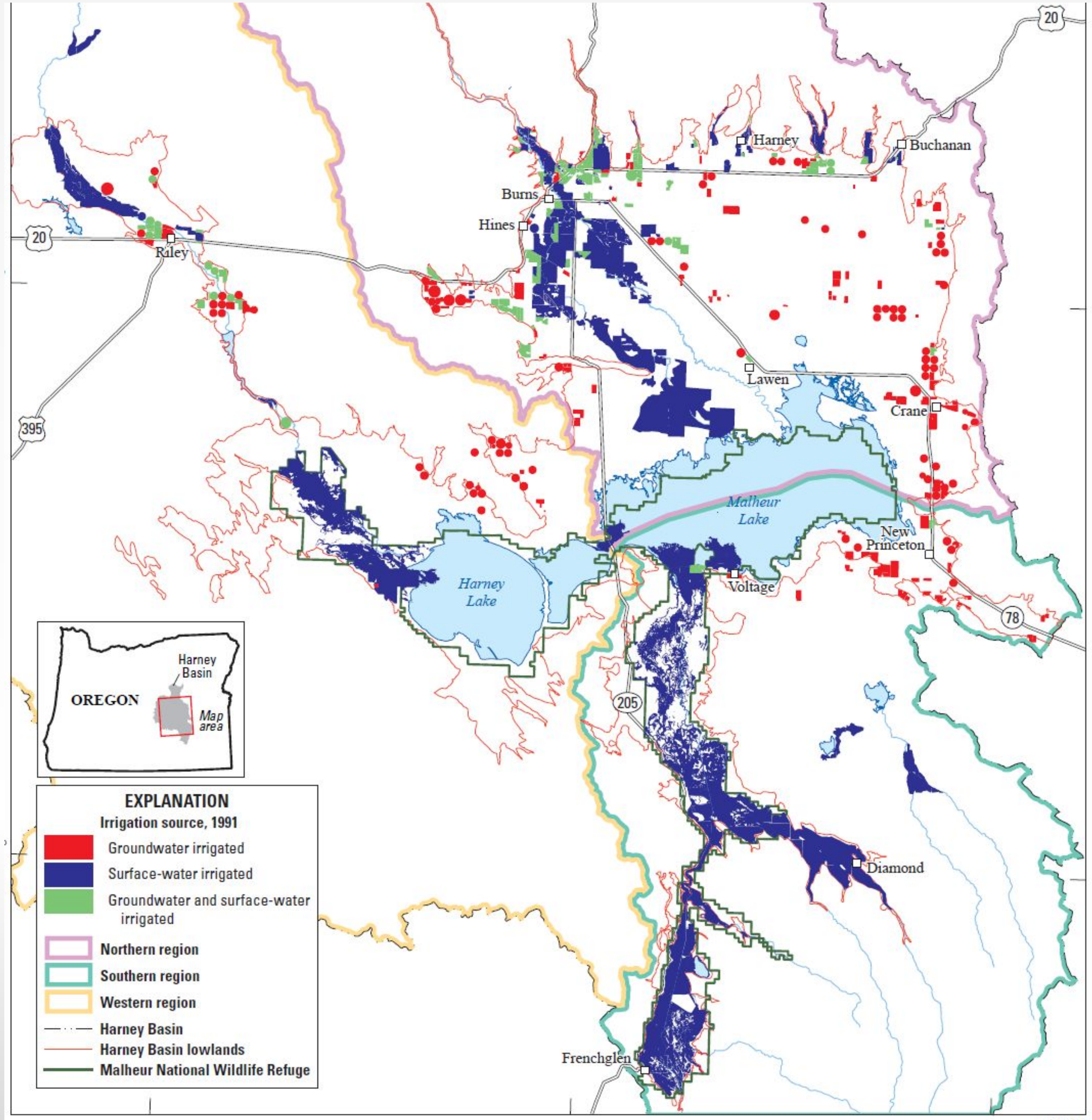
… However, ignoring these characteristics can distort our picture of how these systems work, causing policies to be less effective or even counterproductive."

- Levin S, Xepapadeas T, Crépin AS, Norberg J, De Zeeuw A, Folke C, Hughes T, Arrow K, Barrett S, Daily G, Ehrlich P., et al., Social-ecological systems as complex adaptive systems: modeling and policy implications. Environment and development economics. 2013 Apr;18(2):111-32.



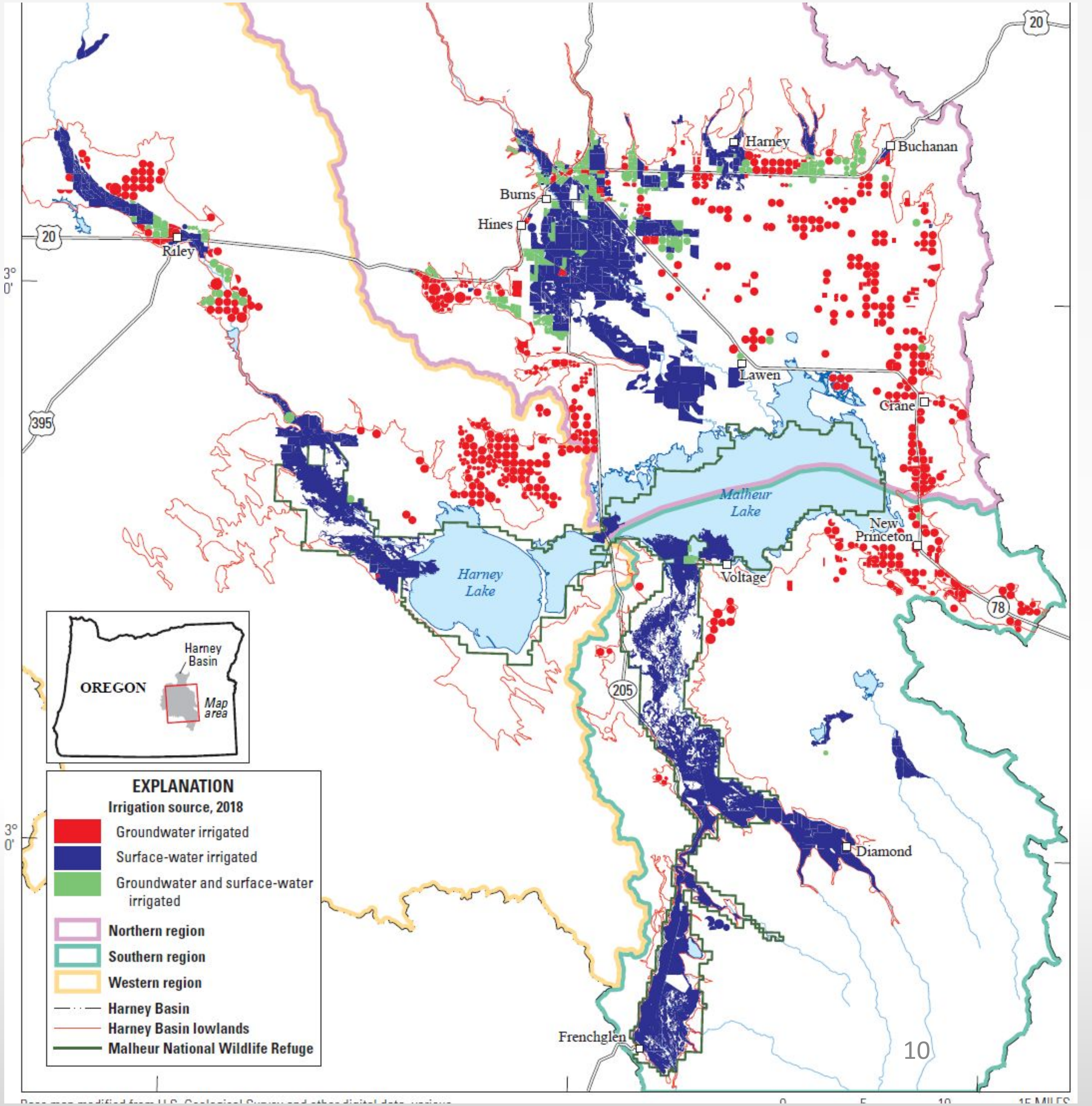
Source: Jaeger WK, Irwin EG, Fenichel EP, Levin S, Herziger A. Meeting the challenges to economists of pursuing interdisciplinary research on human–natural systems. Review of Environmental Economics and Policy. 2023 Jan 1;17(1):43-63.

1991



Harney
Buchanan
Burns
Hines
Riley
Lawen
Crane
Malheur Lake
Harney Lake
New Princeton
Voltage
Diamond
Frenchglen
20
395
205
78
OREGON
Harney Basin
Map area
EXPLANATION
Irrigation source, 1991
Groundwater irrigated
Surface-water irrigated
Groundwater and surface-water irrigated
Northern region
Southern region
Western region
Harney Basin
Harney Basin lowlands
Malheur National Wildlife Refuge

2018



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Northern region
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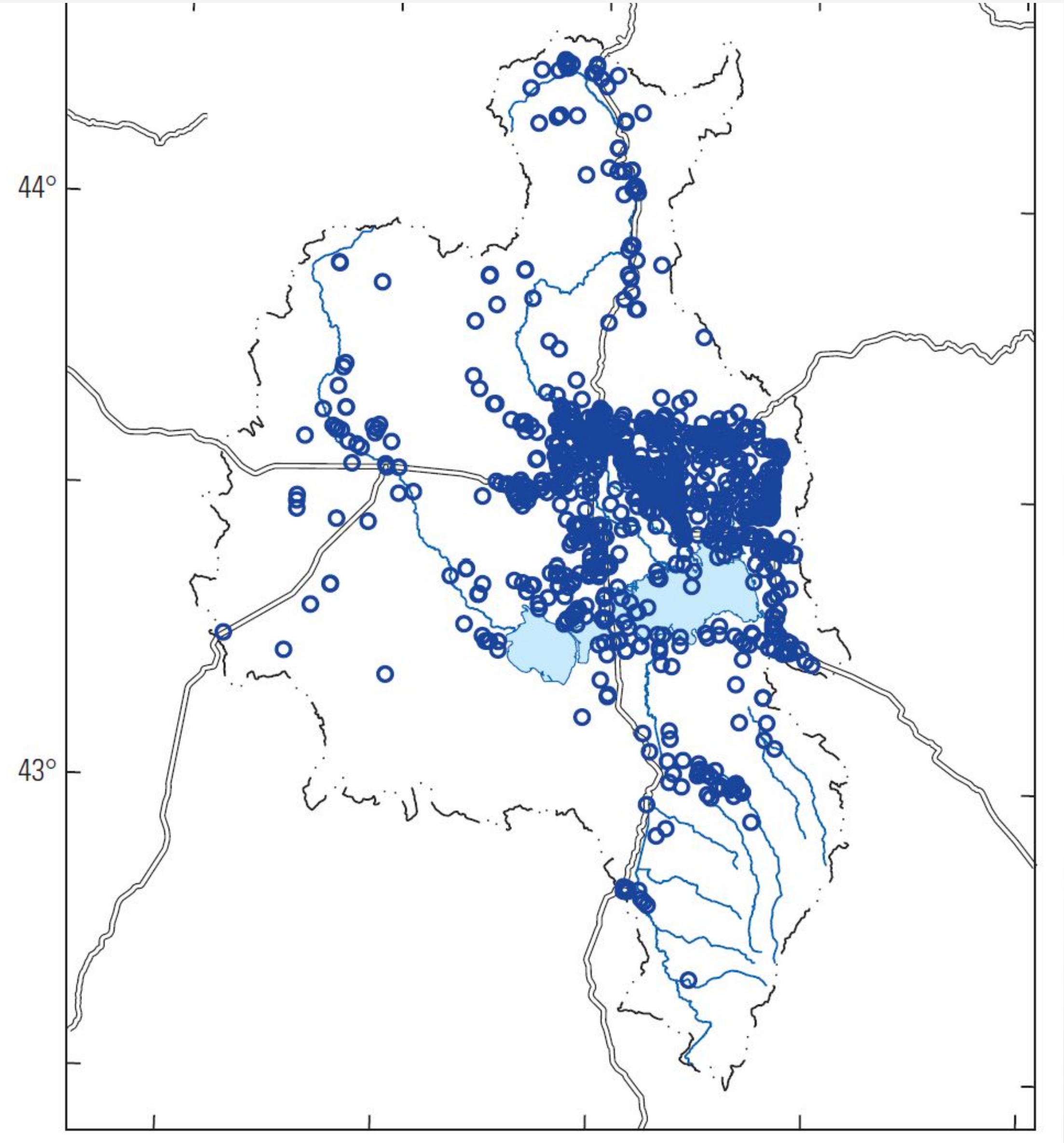
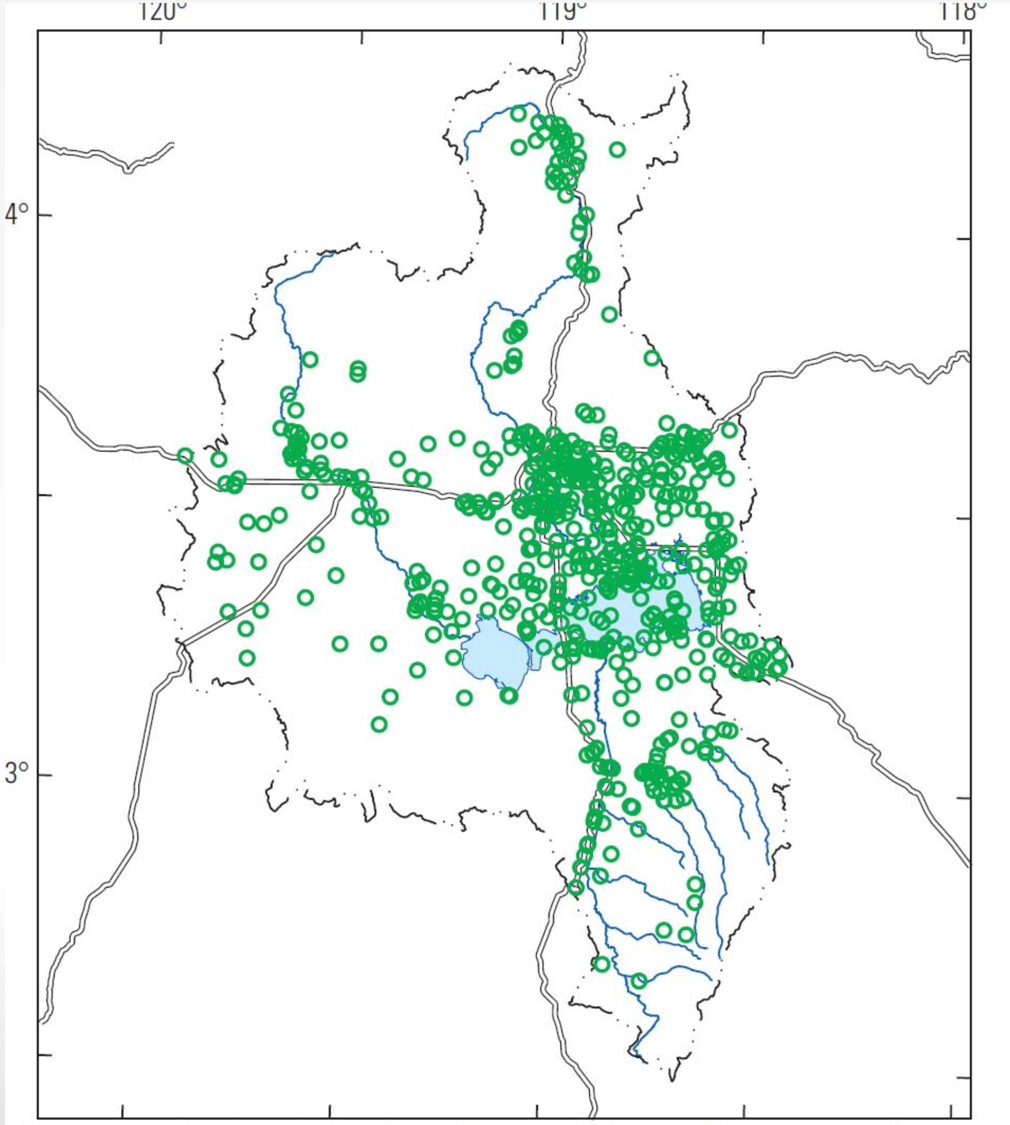
Harney Basin
Harney Basin lowlands
Malheur National Wildlife Refuge

Rural residential wells (~1,100)



Livestock wells (~600)



Base map modified from U.S. Geological Survey and other digital data, various scales.
Projection: UTM Zone 11 North. North American Datum of 1983

Groundwater decline contours in past 2 decades. Declines concentrated in "cones of depression" e.g., A, B, & C.

- A: 2.5 meters/year
- B: 1.5 meters/year
- C: 0.6 meters/year

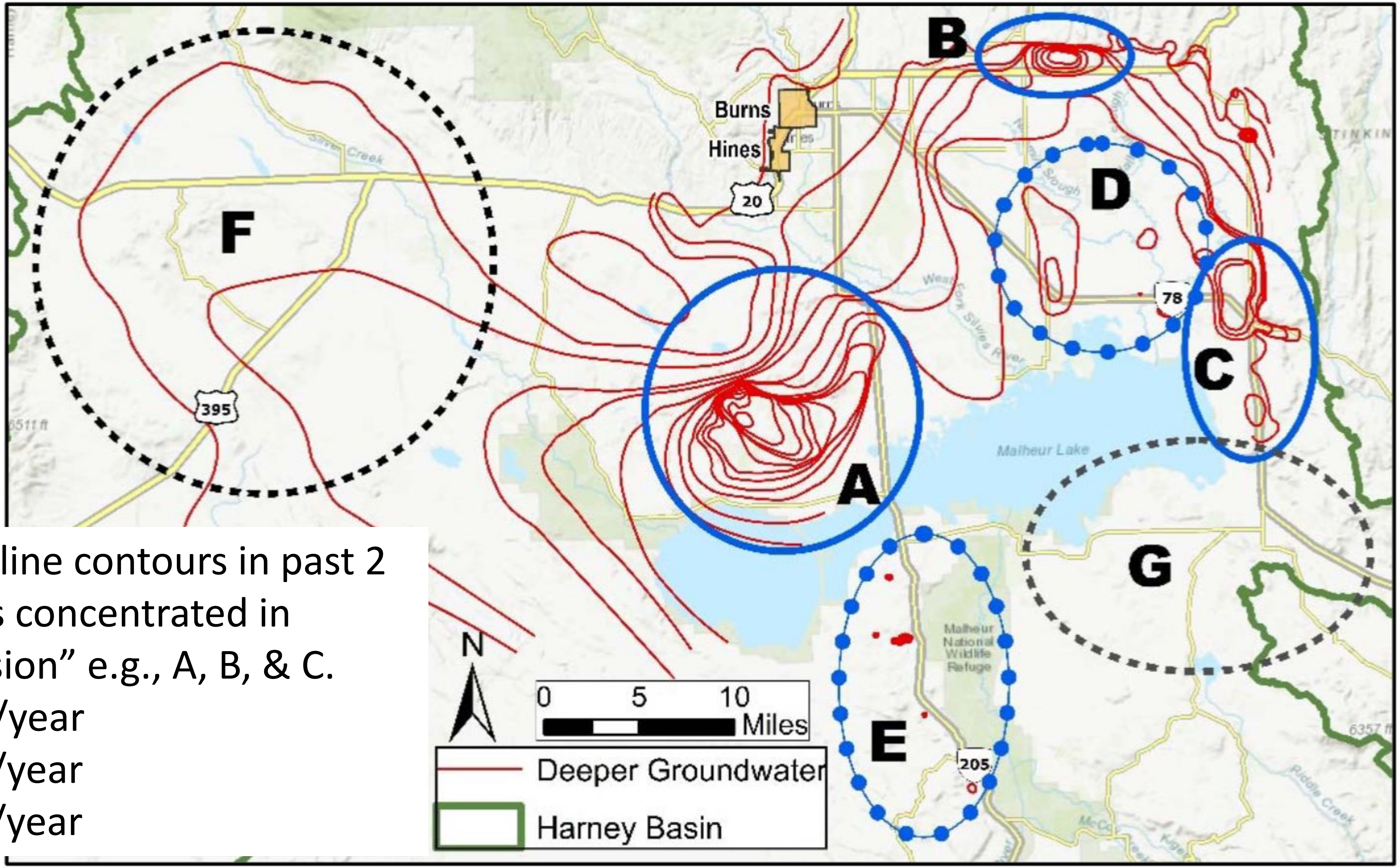
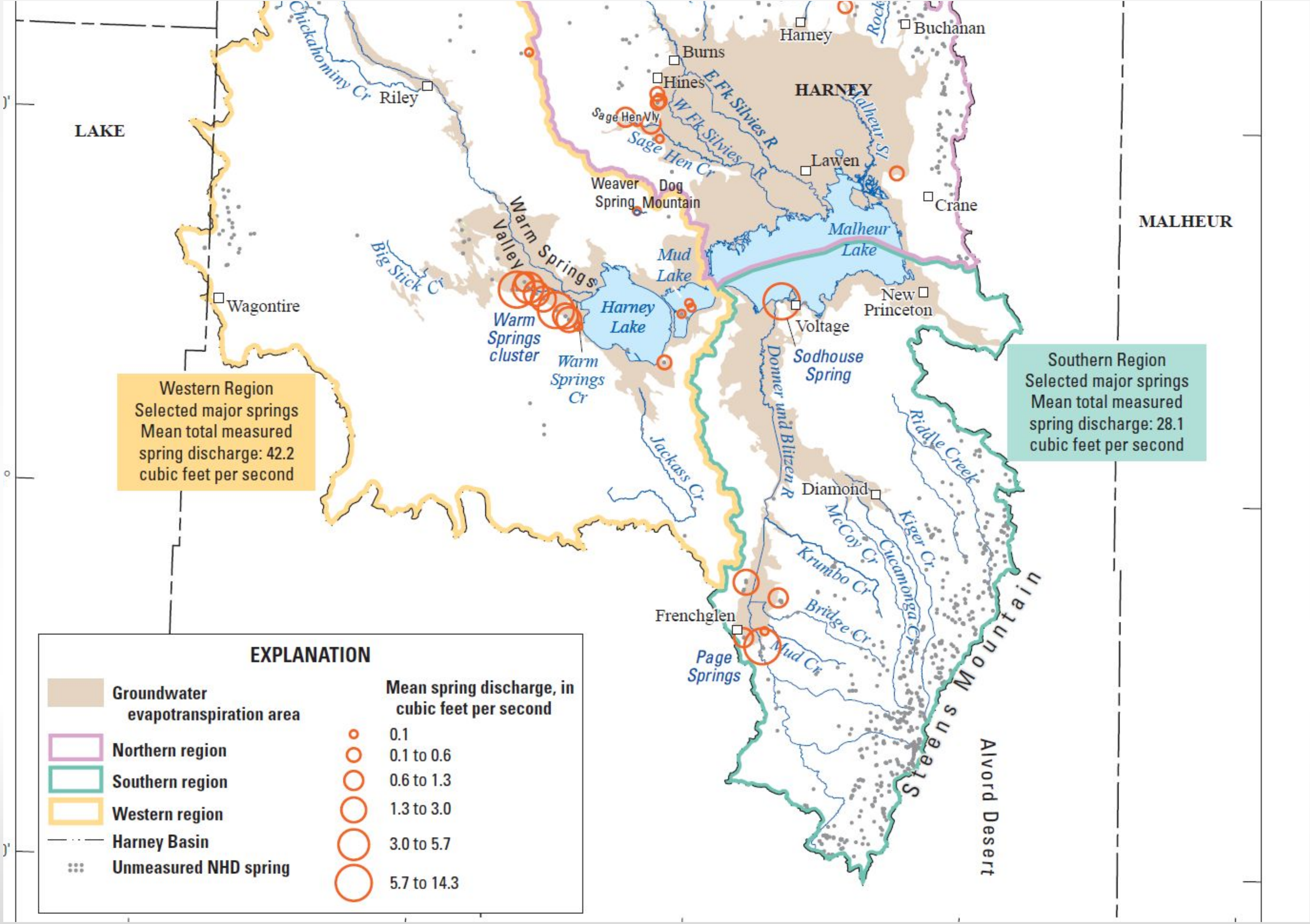


Figure 3. Harney Basin lowland groundwater-level decline areas



LAKE
MALHEUR
HARNEY
Burns
Hines
Harney
Buchanan
Riley
Lawen
Crane
Wagontire
New Princeton
Voltage
Diamond
Frenchglen
Chickahominy Cr
E Fk Silvies R
W Fk Silvies R
Sage Hen Vly
Sage Hen Cr
Malheur Sl
Weaver Spring
Dog Mountain
Warm Springs Valley
Big Stick Cr
Mud Lake
Harney Lake
Malheur Lake
Warm Springs cluster
Warm Springs Cr
Sodhouse Spring
Donner und Blitzen R
Jackass Cr
Riddle Creek
McCoy Cr
Kiger Cr
Krumbo Cr
Cucamonga Cr
Bridge Cr
Mud Cr
Page Springs
Steens Mountain
Alvord Desert
Western Region
Selected major springs
Mean total measured
spring discharge: 42.2
cubic feet per second
Southern Region
Selected major springs
Mean total measured
spring discharge: 28.1
cubic feet per second
EXPLANATION
Groundwater evapotranspiration area
Northern region
Southern region
Western region
Harney Basin
Unmeasured NHD spring
Mean spring discharge, in cubic feet per second
0.1
0.1 to 0.6
0.6 to 1.3
1.3 to 3.0
3.0 to 5.7
5.7 to 14.3

A groundwater system in transition from abundance to scarcity

2015 – Oregon Water Resources Department (OWRD) raised concerns about groundwater pumping exceeding annual recharge

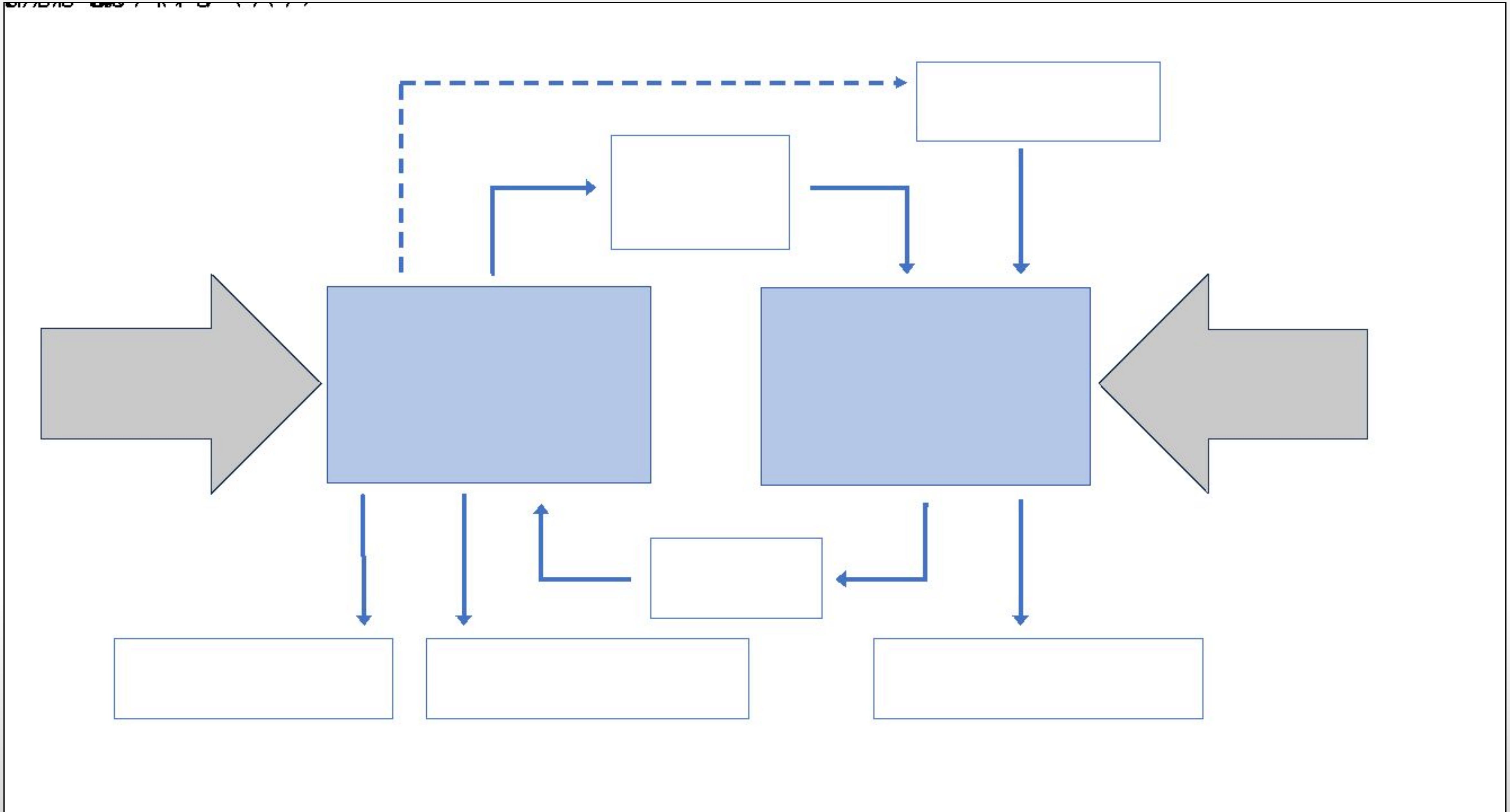
2016 – Basin designated an “area of concern”

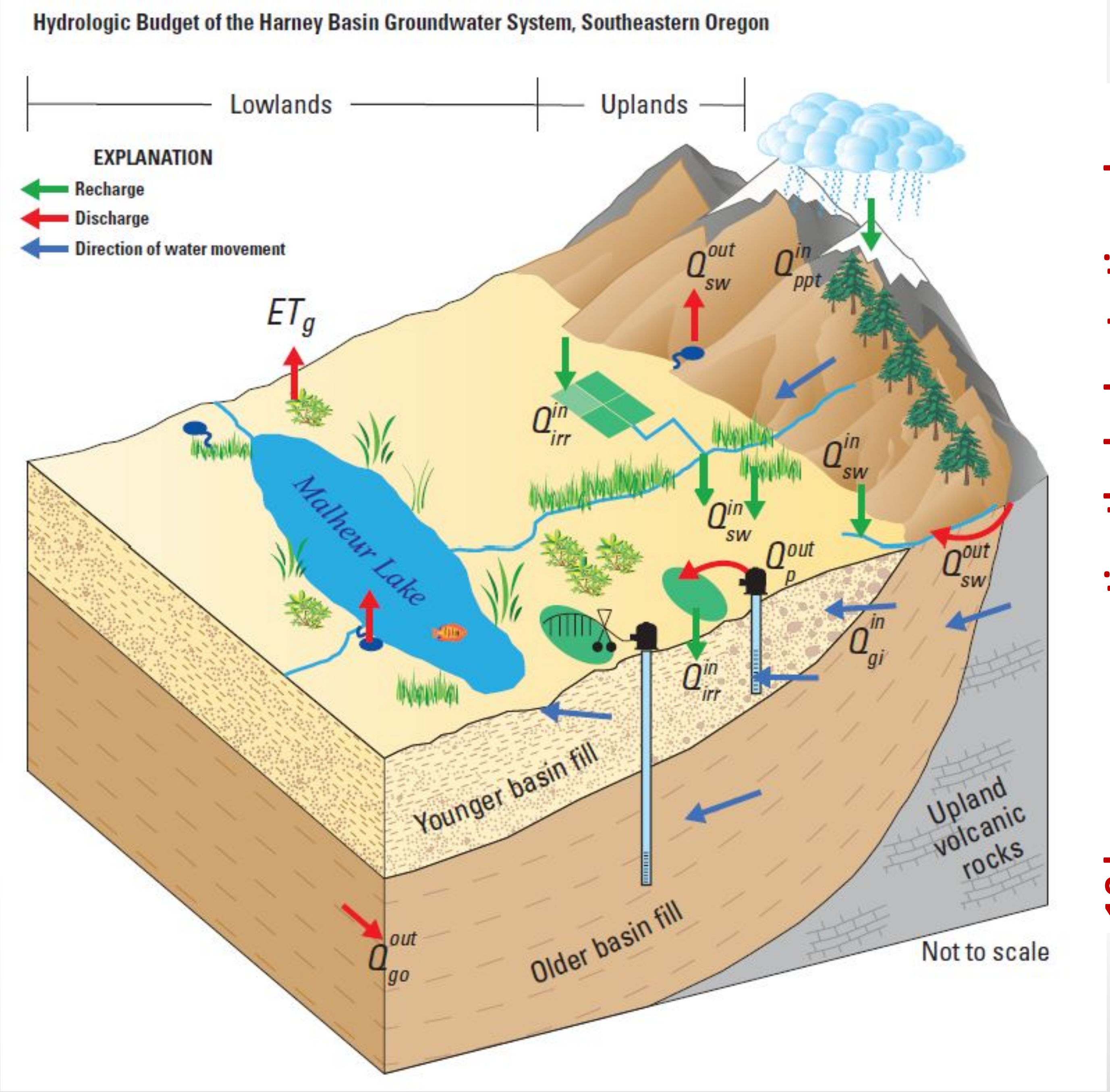
2017 – Groundwater studies initiated by USGS and OWRD

2017-21 - Community efforts initiated to find common ground through Community-based Water Planning Collaborative

2020-23 – Groundwater hydrology model completed; hydro-economic model study initiated

Harney Basin groundwater hydrology and economic model (HEM)

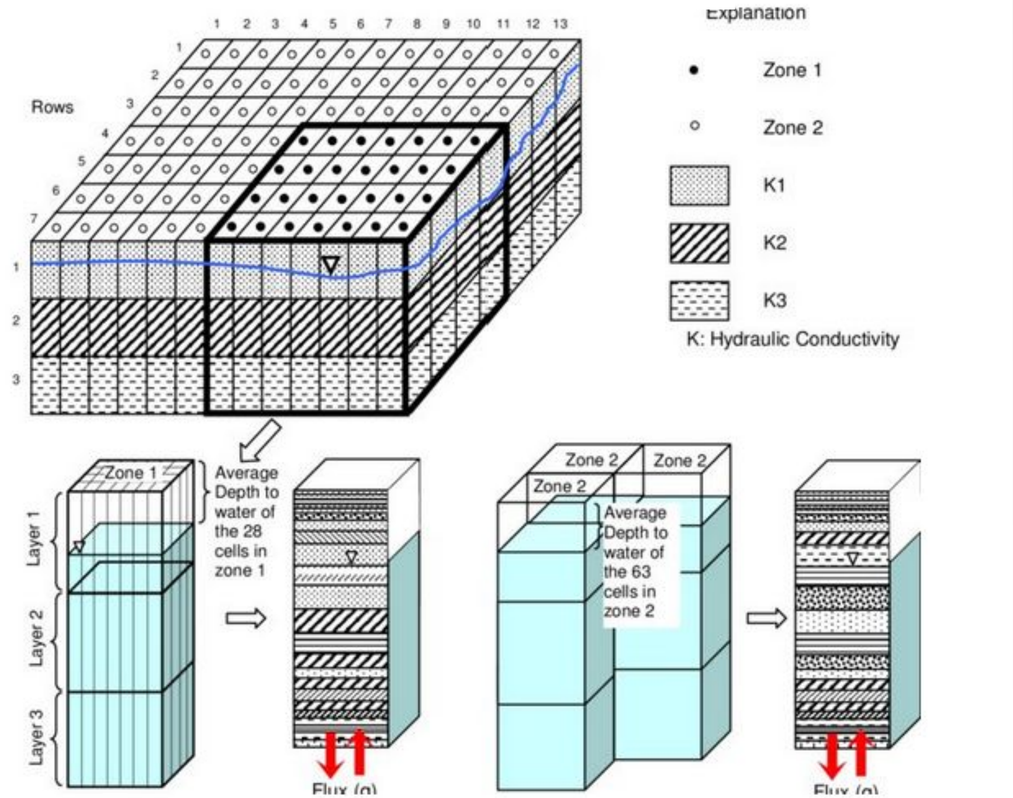




MODFLOW Model

10 layers representing the hydrostratigraphy

A uniform spatial grid



See Gingerich, Stephen B., et al. *Groundwater resources of the Harney Basin, southeastern Oregon*. No. 2021-5103. US Geological Survey, 2022.

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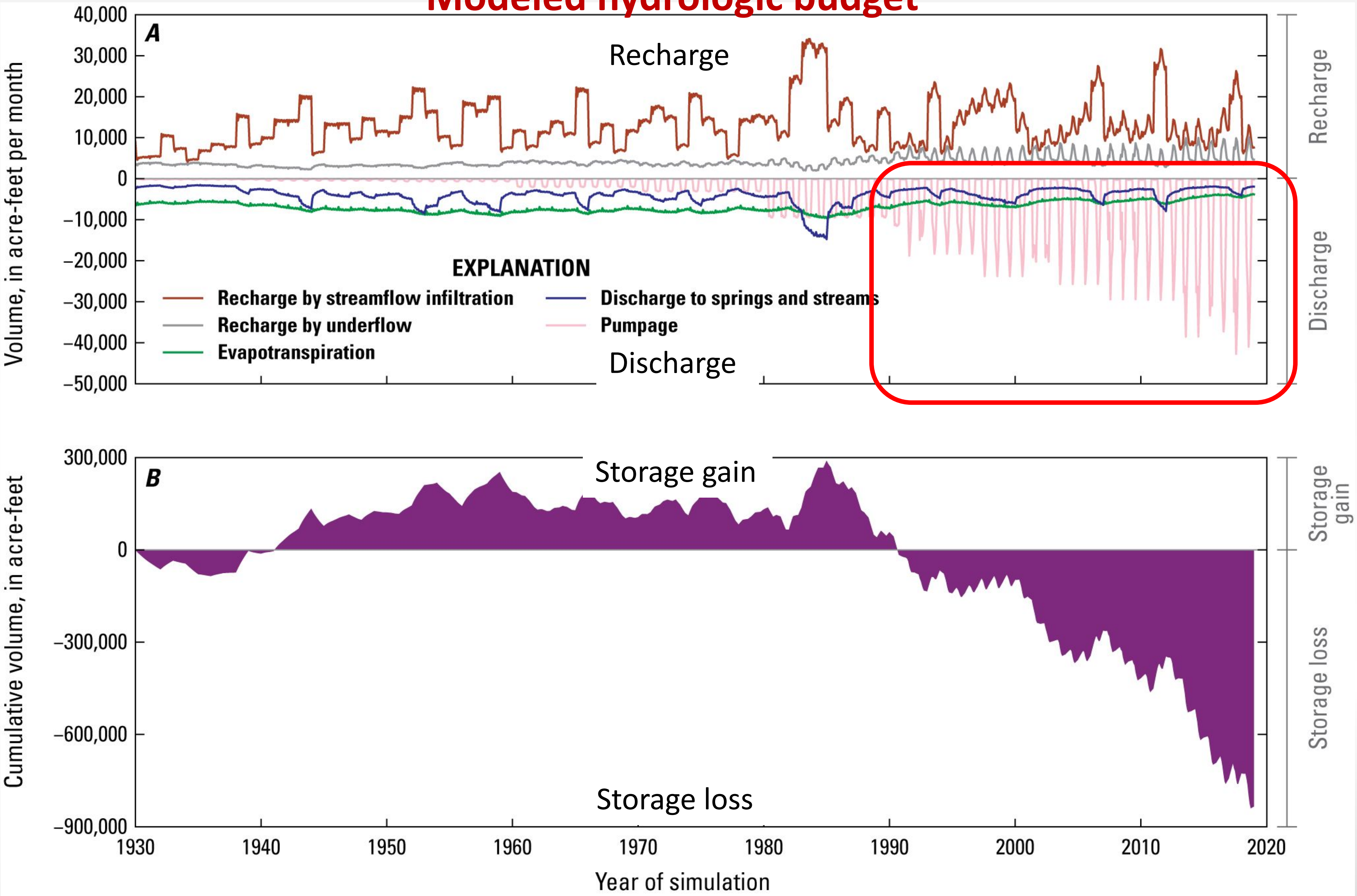
Modeled hydrologic budget



Agricultural production model

- Field-level decisions made to maximize profits (choice of irrigation technology, plant/don’t plant); relatively few choices.
- A key challenge: lack of site-specific data on yields and costs, so…
- Implemented a novel approach using available site-specific data on land values, and other secondary data on costs of production (ag census, enterprise budgets) to infer site-specific expected profit (hedonic land value method)

Hedonic model to estimate site-specific farm profit and yield

- Estimate farm profit using a hedonic model fitted to modeled fields

$$(Price/acre)_i = \beta_0 + \beta_1 X + \tau_t 1\{sale\ year_i = t\ \} + \alpha_{d(i)} + \epsilon_i$$

<u>Estimation details</u>

- Pooled cross-section of 1,605 irrigated farmland transactions in eastern Oregon spanning 2000-2017
- τ_t = year dummies
- $\alpha_{d(i)}$ = OWRD district dummies
- X includes fraction of irrigable area in irrigated land capability classes 1/2, 3, 4, and 5/6 and growing-season temperature and precipitation
- Regressions weighted by irrigable acreage

Farm profit drives irrigation decisions

Estimates reveal intuitive relationship between soil class and land price

Use estimates to fit prices for 1,040 fields in simulation model

Convert to annual profit using 5% discount rate

Mean profit = $289/ac (s.d. = $44/ac)

Implies average yield of 3.02 ton/ac (2017 Census of Ag -> 3.01 ton/ac)

Variable	Coef. (SE)
POU IRR LCC 1 and 2 %	51.38
	(11.58)***
POU IRR LCC 3 %	51.05
	(8.18)***
POU IRR LCC 4 %	44.22
	(9.96)***
POU IRR LCC 5 and 6 %	35.83
	(9.87)***
Temperature	460.28
	(113.75)***
Precipitation	19.75
	(12.52)

Production decisions: irrigation technology choice

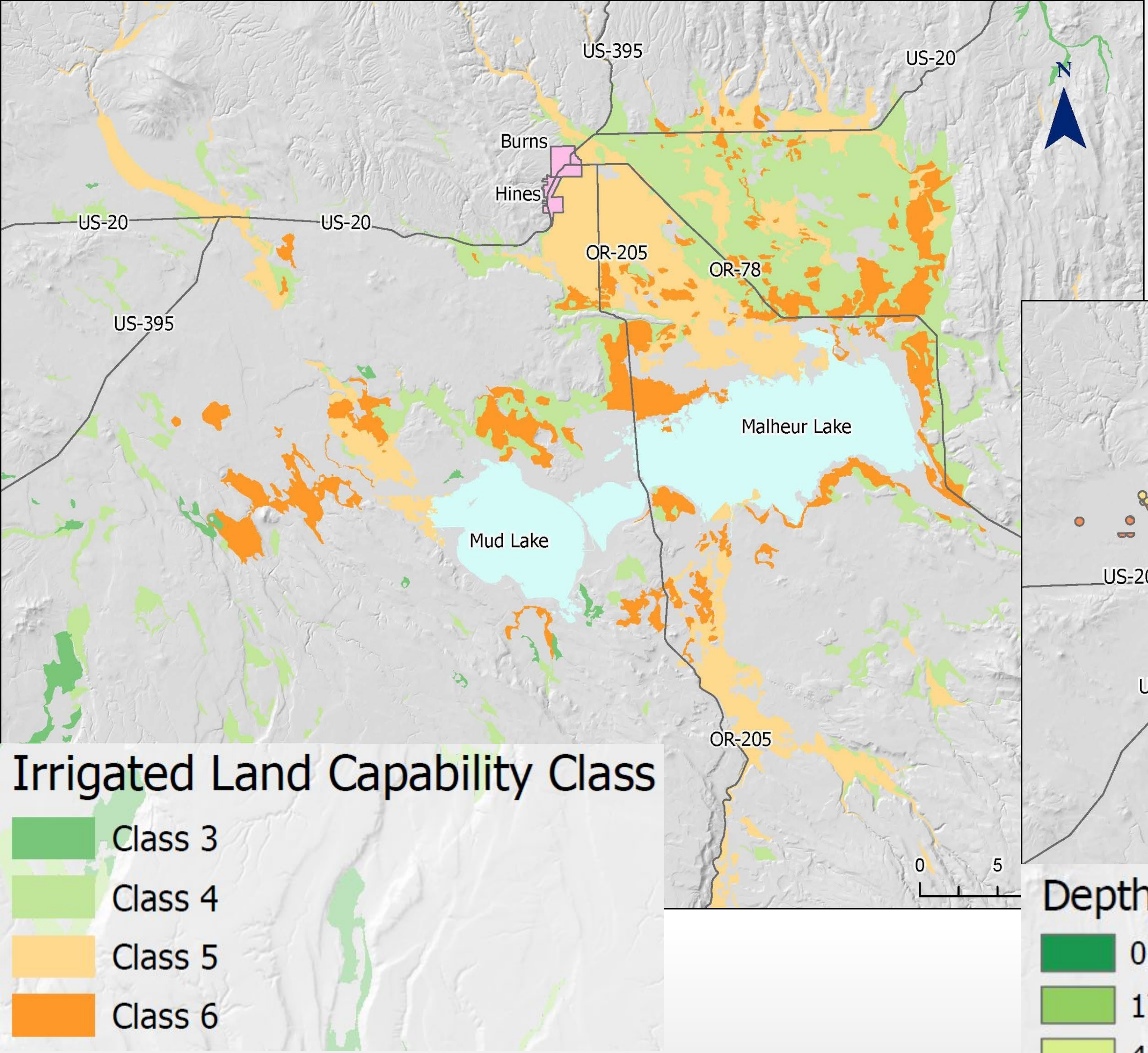
1) Estimated land value $\hat{L}_i$ implies $\bar{\pi}_i(\bar{k}) = r\hat{L}_i$ and $\bar{Y}_i = \dfrac{\bar{\pi}_i + \bar{C}_i(\bar{k})}{\bar{p}}$

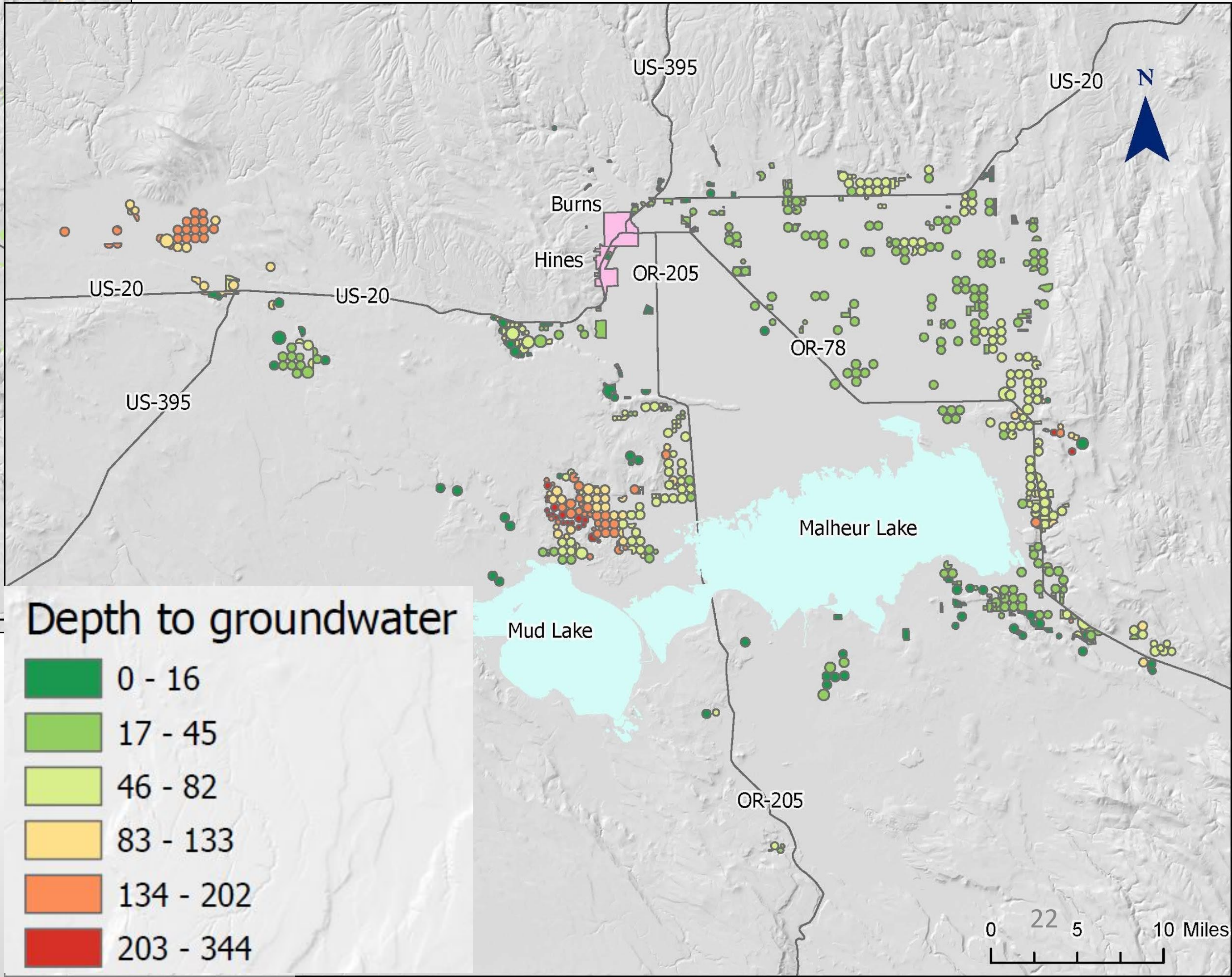
2) For a given field *i* with area A_i, profit $\pi_{it}(k)$ with irrigation technology *k* is

$$\pi_{it}(k) = p\bar{Y}_i A_i - \left[C_{it}^{e}(k) + C_{it}^{o}(k) + C^{x} + C^{f}\right] A_i$$

p = hay price, $\bar{Y}_i$ = expected yield, A_i= acres, $C_{it}^{e}(k)$= irrigation equipment cost, $C_{it}^{o}(k)$ = irrigation operating cost, C^{x}= non-irrigation input cost, C^{f}= non-irrigation fixed cost

3) Crop and technology choice: choose combination with highest expected profit


US-395
US-20
Burns
Hines
US-20
US-20
OR-205
OR-78
US-395
Malheur Lake
Mud Lake
OR-205
N
0
5
Irrigated Land Capability Class
Class 3
Class 4
Class 5
Class 6


US-395
US-20
N
Burns
Hines
OR-205
US-20
US-20
OR-78
US-395
Malheur Lake
Mud Lake
OR-205
Depth to groundwater
0 - 16
17 - 45
46 - 82
83 - 133
134 - 202
203 - 344
0
5
10 Miles

Declining groundwater levels raise pumping costs and limit well yield

1. Pumping cost parameters include:
    - Total dynamic head (function of lift, pressure, head loss)
    - Evapotranspiration, pumping rate, energy efficiency,
    - Hours of pumping, price of energy

2. Maximum well yield (acre-feet/month) declines with declining “water column” (distance from the water level to well bottom)

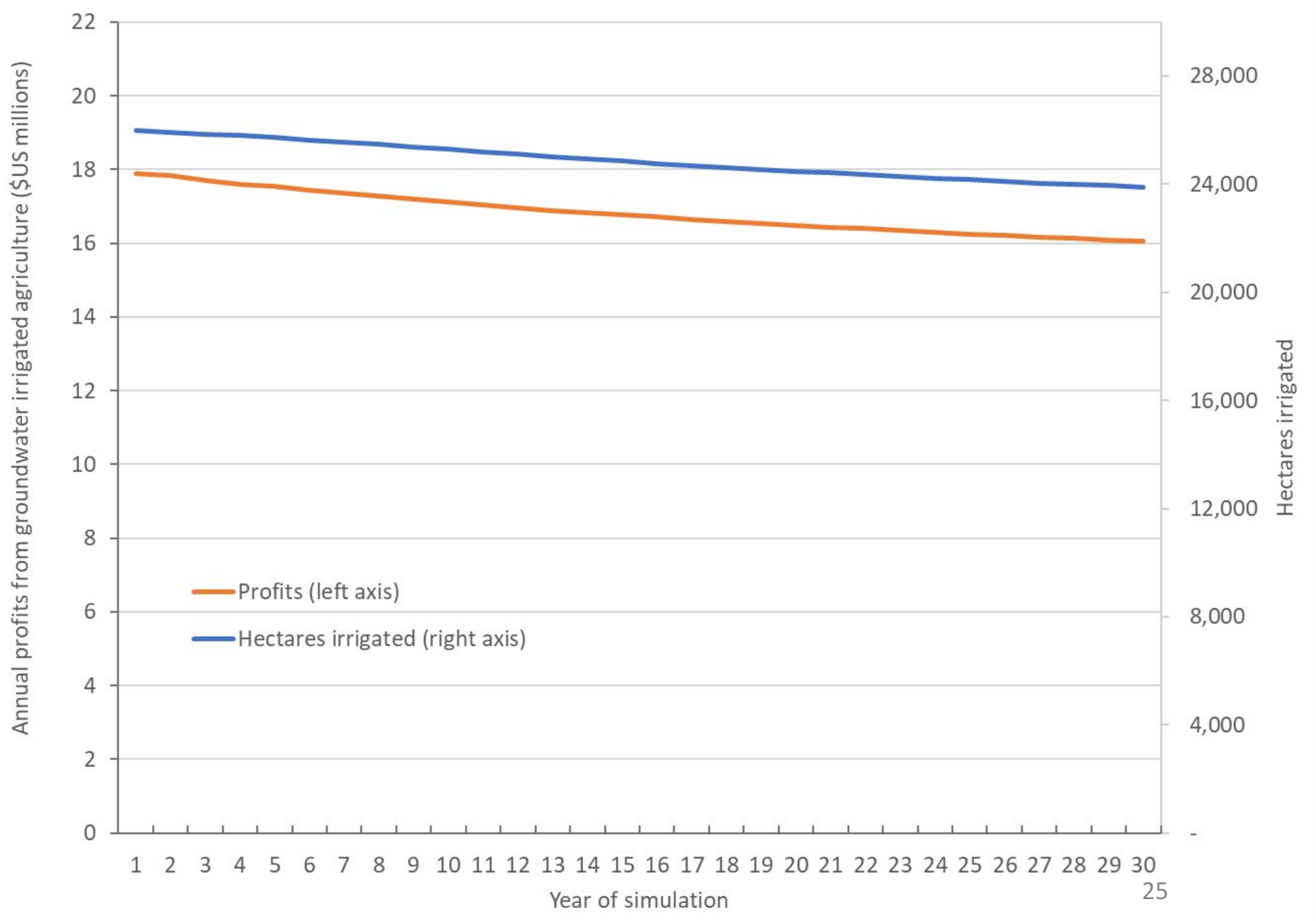
Model was used to simulate 15 future scenarios

Some were based on collaborative community efforts to identify several preferred/desired solutions. Examples:

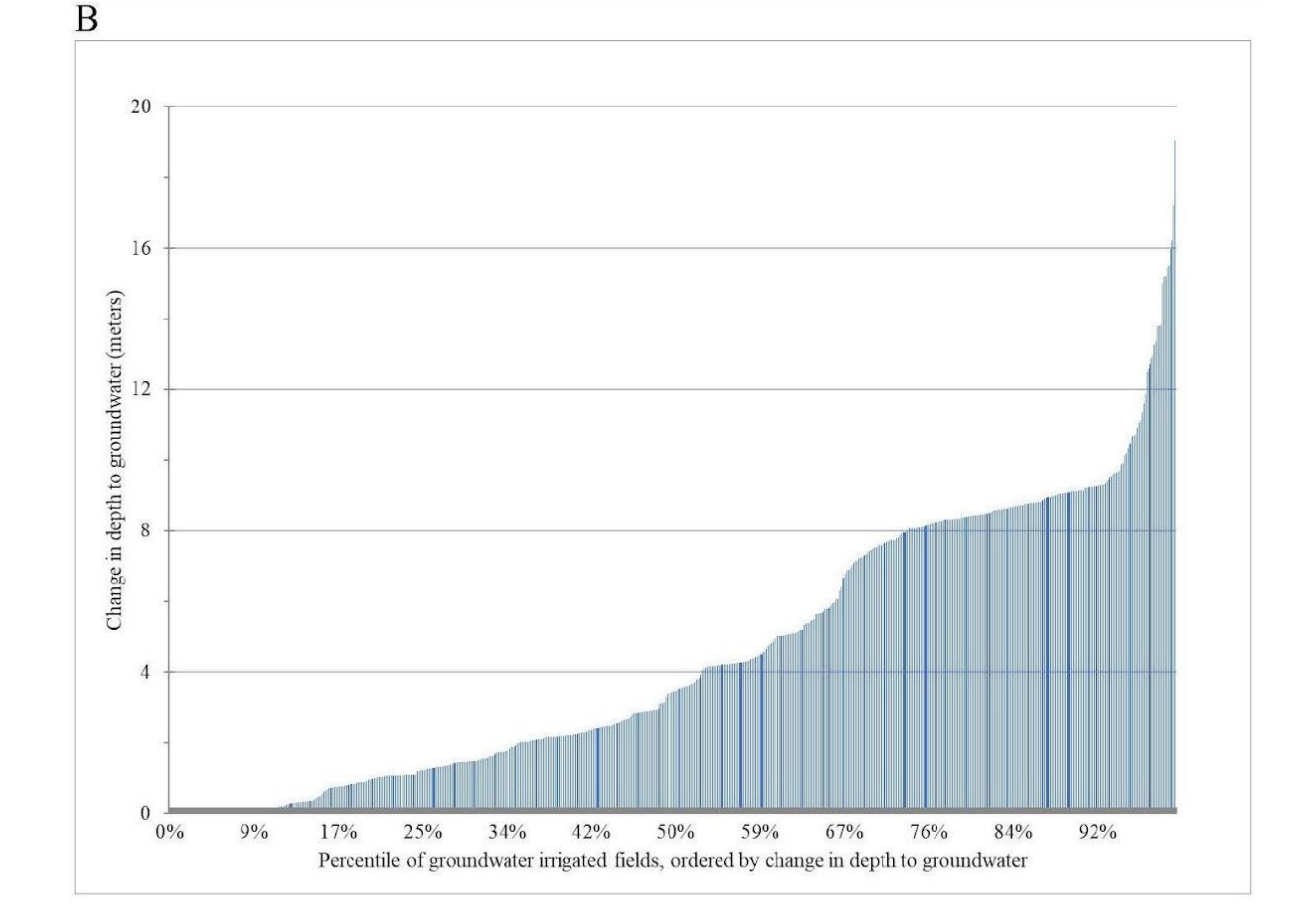
1. Adoption of water-efficient irrigation technologies (e.g., low-elevation sprinkler application, LESA)
   Removing some fields from production by paying farmers not to irrigate them (i.e., CREP program funded)
   Pumping restrictions only in areas where groundwater depletion is greatest (in “cones of depression”)

Scenario #1 – Baseline

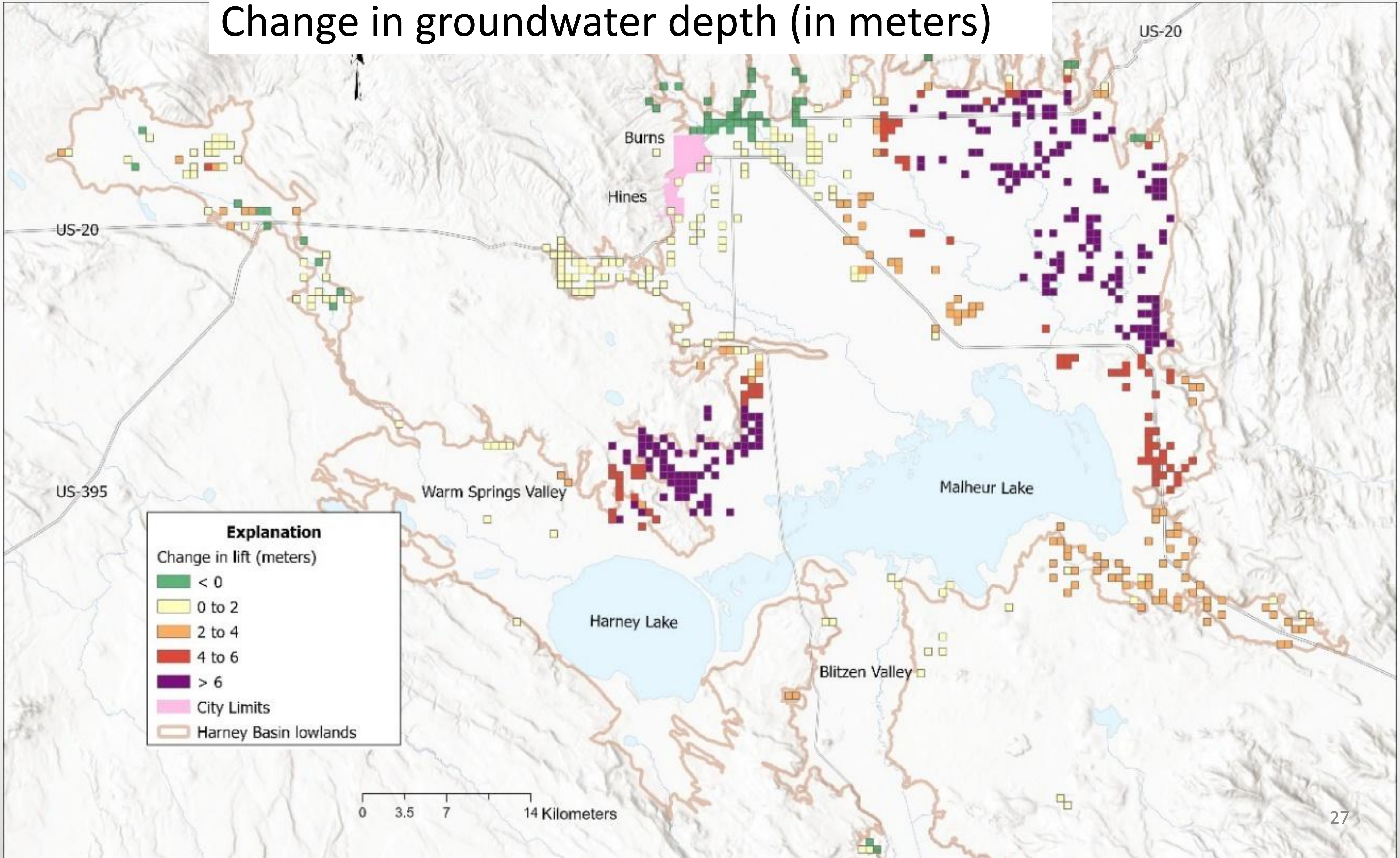
Maintains current or recent relations: prices, incentives, and policies



The decline in groundwater levels over the 30-year scenario varies considerably by field.



Change in groundwater depth (in meters)



Scenario 2 - Water Conservation Technology

- Assumes the adoption of more efficient irrigation technologies across all fields during all years of the simulation
  The reduction in water pumped over the 30 years with scenario 2 compared to scenario 1 is 5%

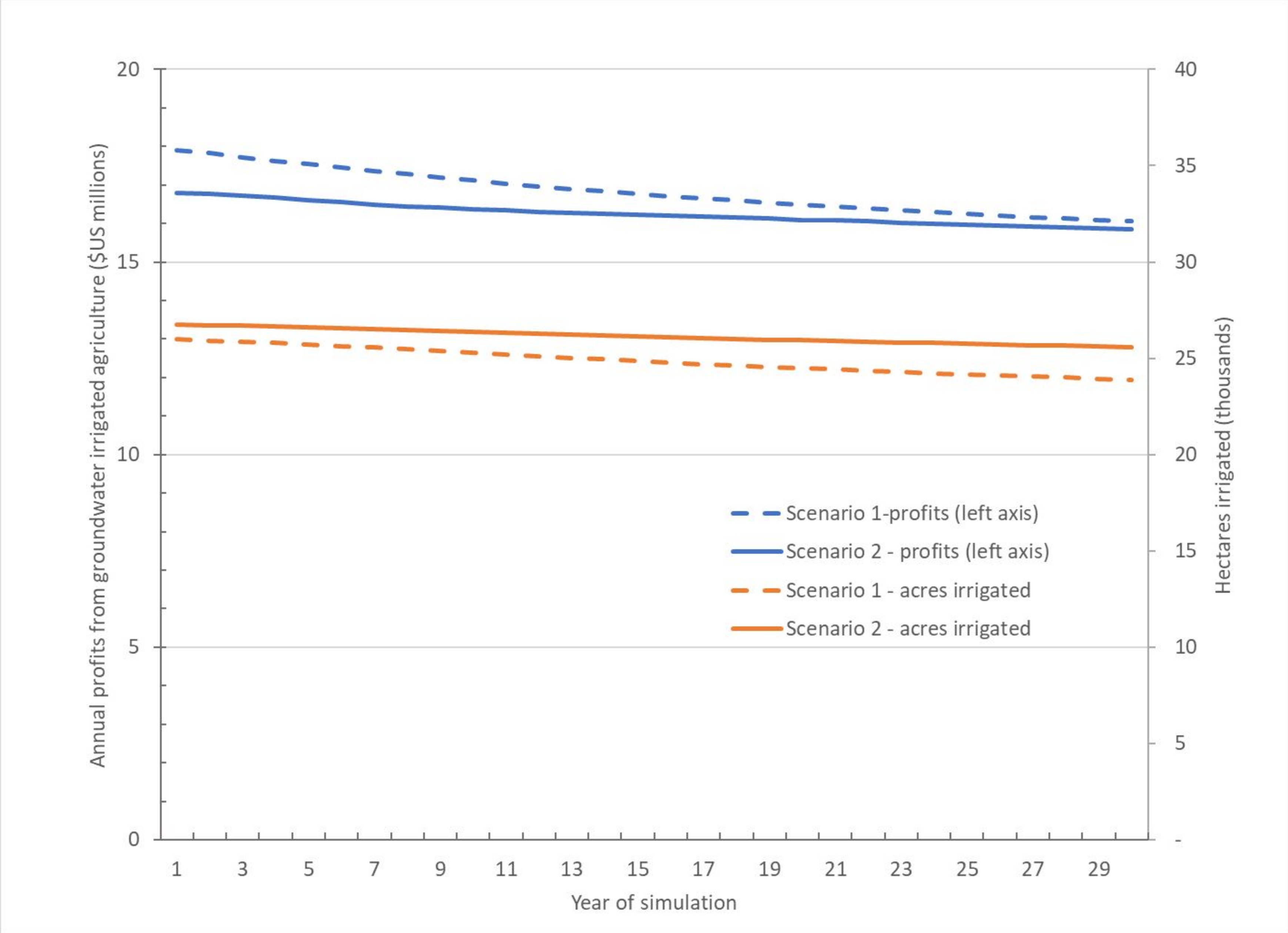


Table 1. Scenario descriptions and present value of farm profits over 30 years for each scenario ($2022 M)

Scenario	Description	Present value of farm profits
Scenario 1	Baseline or 'business as usual.'	306.0
Scenario 2	Water conserving technology required (LESA and LEPA allowed).	293.9
Scenario 3a	Land idling #1- on fields with lowest profit per unit of water, pumping reduced 80% by year 3.	205.4
Scenario 3b	Land idling #2 – fields with lowest profit per unit of water reduce pumping to zero by year 3.	176.8
Scenario 3c	Land idling #3 – on fields with lowest profit per unit of water pumping reduced 50% by year 3.	247.5
Scenario 4a	Incentive-based #1 – pumping cost raised to $1/kwh by year 3.	179.6
Scenario 4b	Incentive-based #2 – cost of pumping raised to $0.80/kwh by year 3.	213.1
Scenario 4c	Incentive-based #3 – cost of pumping raised to $1.20/kwh by year 3.	133.7

Figure 7. Cumulative number of dry (non-irrigation) wells (panel A)

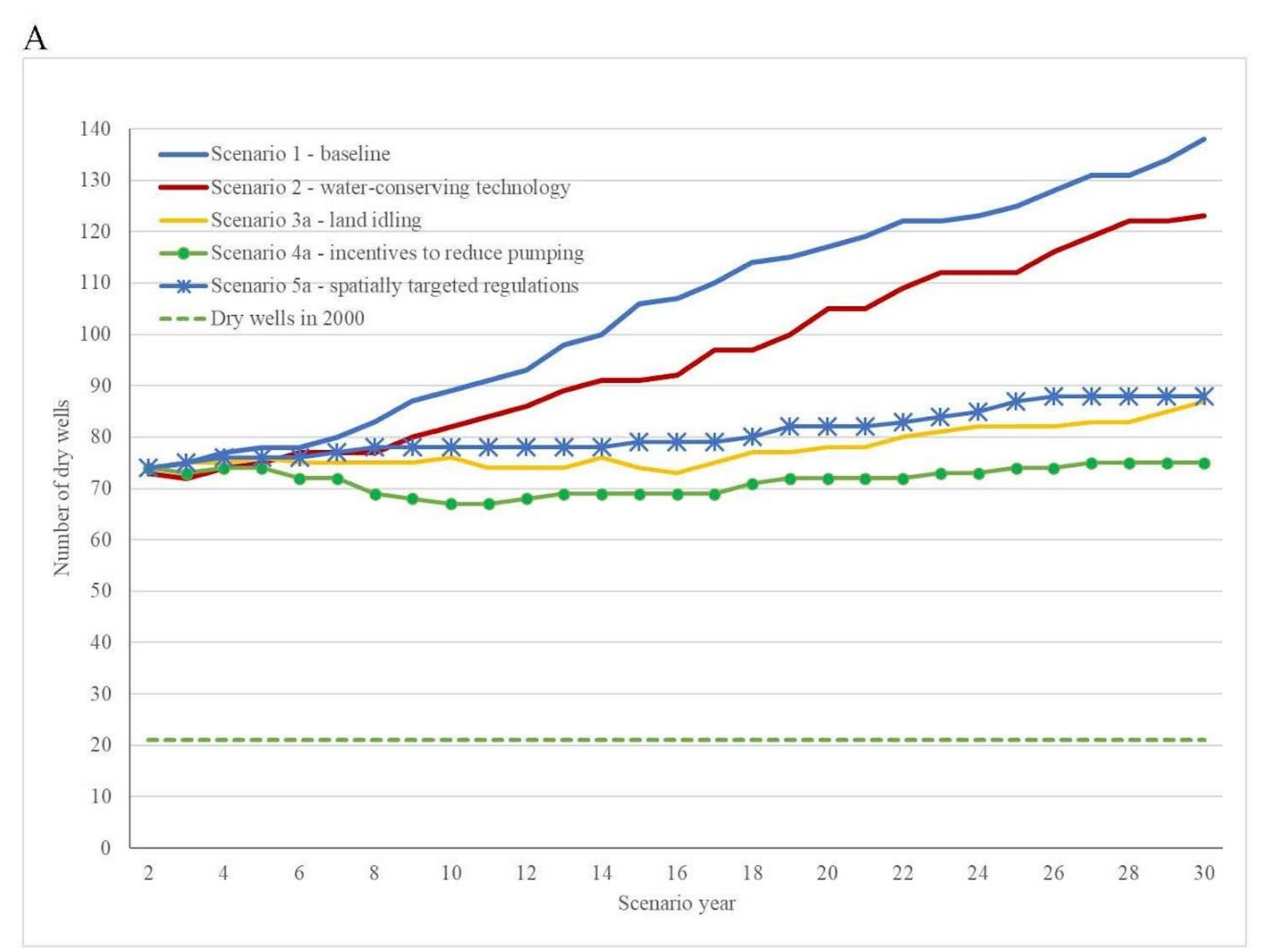
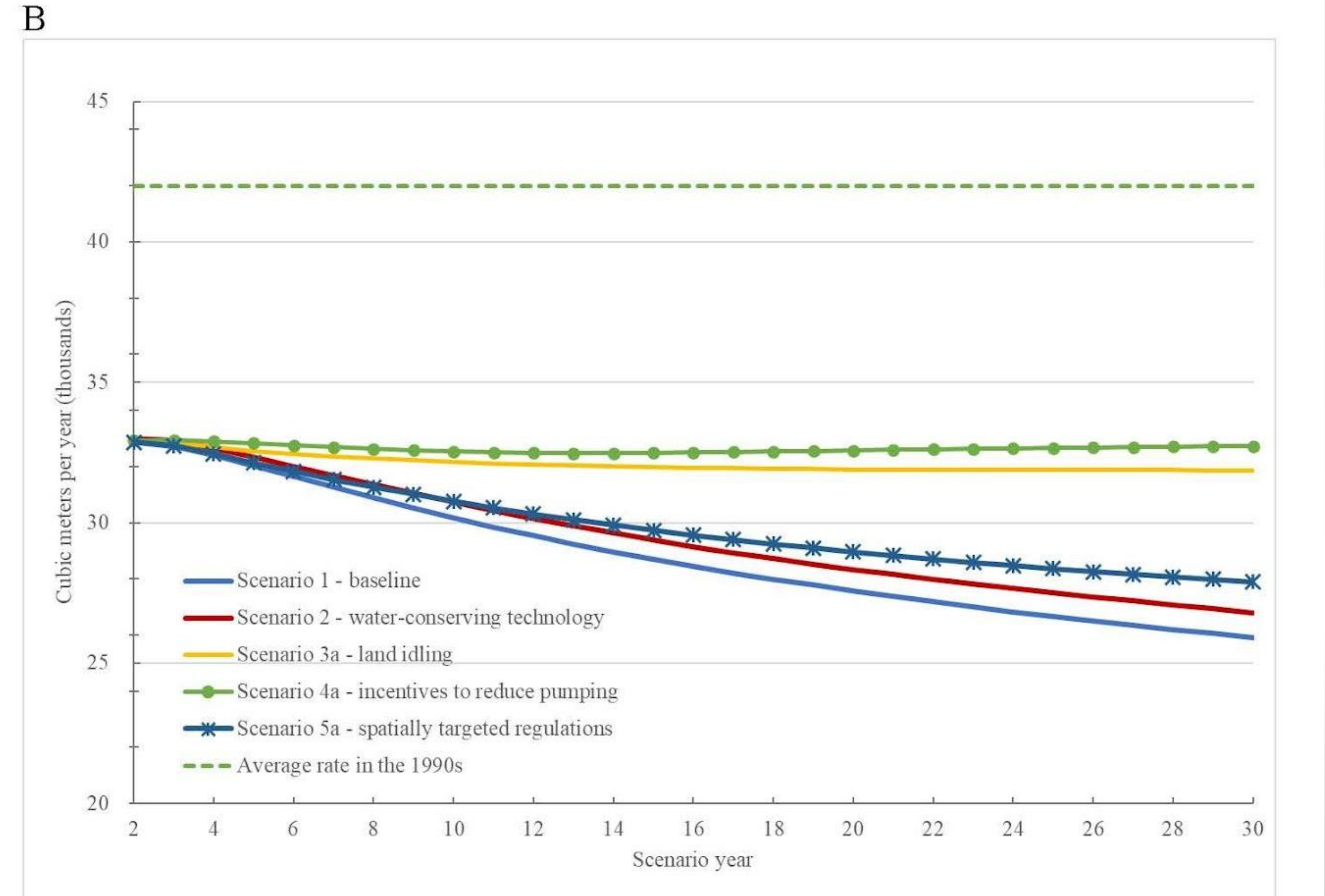
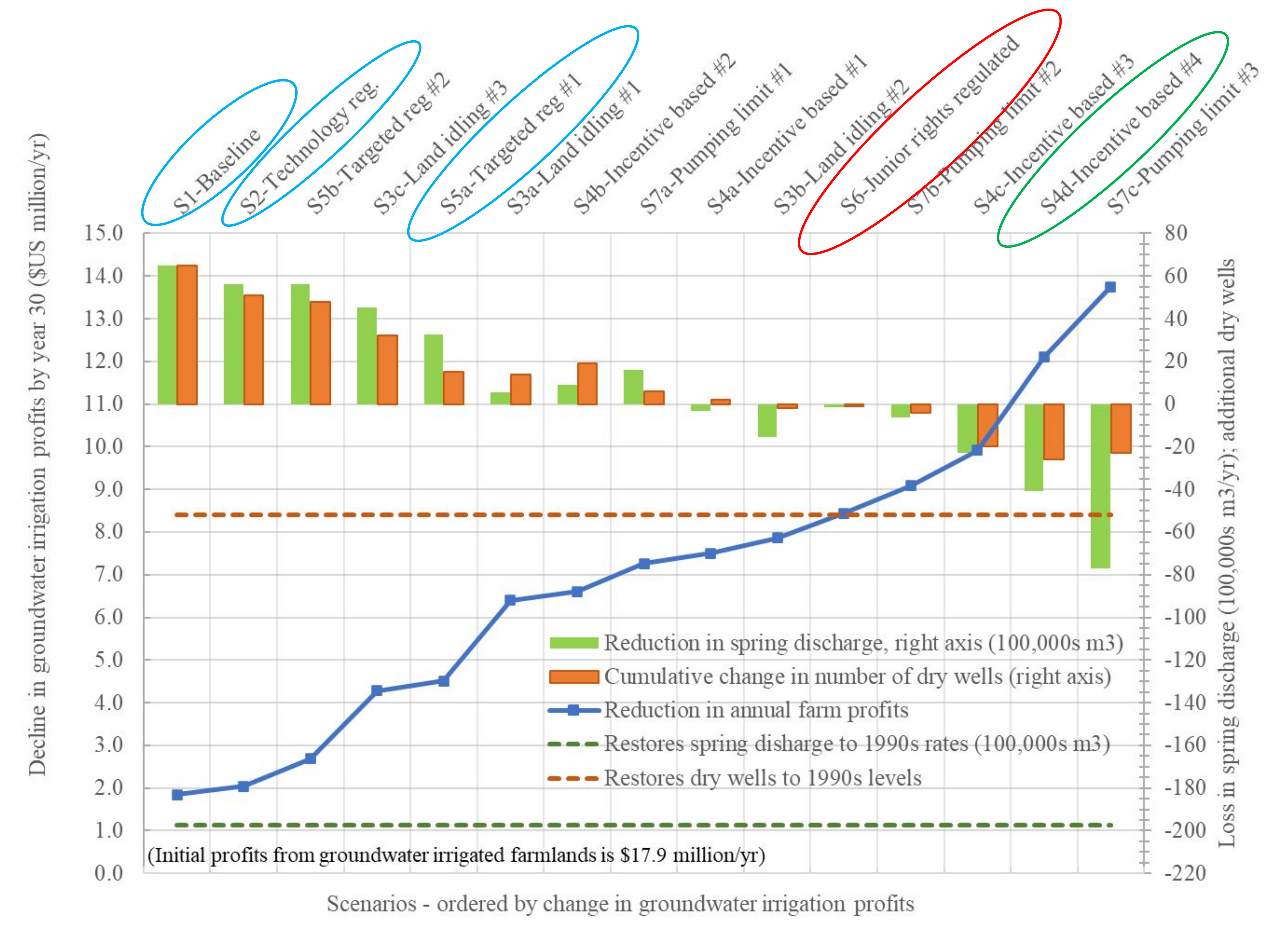


Figure 7. Spring discharge and lowland flows (panel B) by scenario





S1-Baseline
S2-Technology reg.
S5b-Targeted reg #2
S3c-Land idling #3
S5a-Targeted reg #1
S3a-Land idling #1
S4b-Incentive based #2
S7a-Pumping limit #1
S4a-Incentive based #1
S3b-Land idling #2
S6-Junior rights regulated
S7b-Pumping limit #2
S4c-Incentive based #3
S4d-Incentive based #4
S7c-Pumping limit #3
Decline in groundwater irrigation profits by year 30 ($US million/yr)
Loss in spring discharge (100,000s m3/yr); additional dry wells
Reduction in spring discharge, right axis (100,000s m3)
Cumulative change in number of dry wells (right axis)
Reduction in annual farm profits
Restores spring disharge to 1990s rates (100,000s m3)
Restores dry wells to 1990s levels
(Initial profits from groundwater irrigated farmlands is $17.9 million/yr)
Scenarios - ordered by change in groundwater irrigation profits

Insights about groundwater and its use in the Harney Basin

1. Lowland areas of the basin (indeed all areas) are hydrologically connected, limiting the efficacy of regulations targeting only some portions of the basin.

2. Unsustainable rates of pumping were reached much sooner than previously understood (by more than 20 years).

3. Although current pumping rates gradually raise costs and reduce well yields, current pumping rates offer the highest aggregate economic returns to irrigators for the foreseeable future.

Insights about groundwater policies and management

1. Community views and expectations about the effectiveness of many options were overly optimistic.
2. Stabilizing the groundwater system will come at a high cost to current rates of groundwater irrigated farming.
3. [Repeated] Unsustainable rates of pumping were reached much sooner than previously understood (by more than 20 years).
4. Incentive-based policies showed small advantages over regulatory polices, based on the field-level heterogeneity reflected in the model.
5. A standard economics approach would have likely overlooked the linkages to and impacts on residential and livestock wells, and environmental flows.

Insights about institutional design for managing groundwater

1. The transition from abundant to scarce groundwater can occur long before it is recognized.
2. Adaptive management needs the capacity for timely responses, and the ability to correct for overallocation.
3. One recognized approach calls for: a) capping the total resource use, b) allocating rights to users, and c) defining rules to adjust the cap or reallocate in response to changing conditions (Holley et al., 2020).
4. Oregon’s water law and management rules fail on the third element.

How do rigid water law institutions make timely adaptivity impossible:

1) The prior appropriations water law, the seniority system, cannot work if a) you must prove interference from a well with junior water rights, and b) managers have no alternative way to limit permitted pumping rates.

2) Attempts to revoke or reduce junior groundwater rights have been stopped by legal challenges – citing a lack of due process or proof of interference.

3) Current situation in Harney: a sluggish, ongoing negotiation process with OWRD and (mainly) irrigators, converging on a plan to transition toward stable groundwater levels starting in 2030 and aiming to stabilize groundwater in 2060.

4) An analogy might be an ocean fishery where managers are only able to increase the permitted catch but never reduce it – except after 10 years of delays, and then a 30-year transition plan to stabilize fish stock.

What researchers learned

I. A traditional groundwater-and-irrigator model likely would have overlooked the externalities impacting residential and livestock wells, environmental flows and related recreation and tourism.

II. Standard economic analysis would likely have focused on irrigation and alternative policy options.

III. But the study drew our attention to this transition from abundance to scarcity, with lags in the hydrology, information, and especially in the institutional response.

IV. The model helped us recognize that the institutional dynamics (or lack thereof) was the most important insight from the research. The failure of the institutions to have a mechanism to be “adaptive” due to rigid water law institutions.


Thank you

References for Harney Groundwater Studies

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