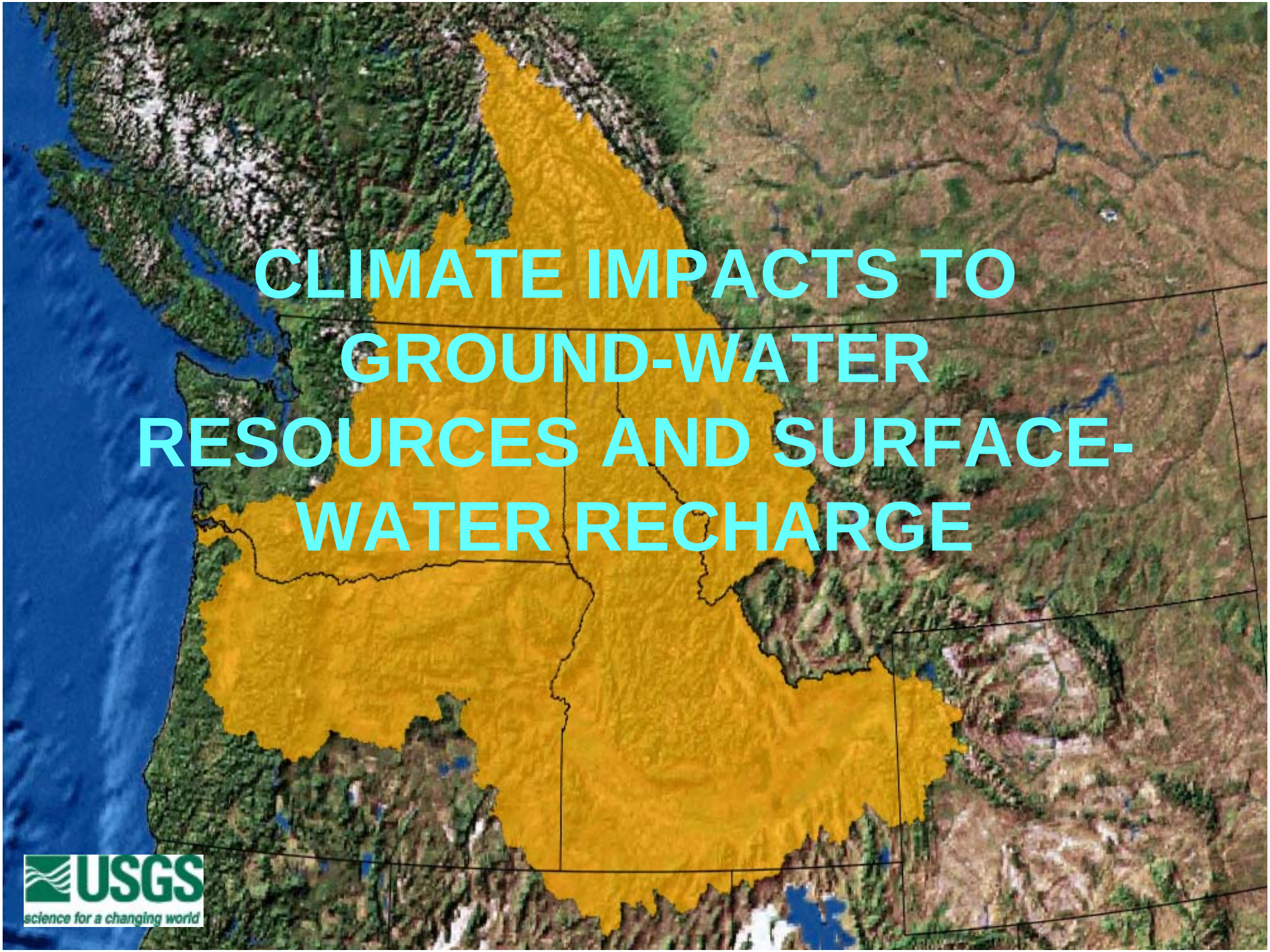

# CLIMATE IMPACTS TO GROUND-WATER RESOURCES AND SURFACE-WATER RECHARGE

USGS
science for a changing world

WHY RECHARGE AND GROUND WATER

GROUND WATER AND RECHARGE

ESTIMATING RECHARGE

CURRENT CLIMATE AND HUMAN IMPACT

PUMPAGE FOR HISTORICAL DRY CLIMATE REGIMES

SENSITIVITY OF GROUND-WATER SYSTEMS TO CLIMATE CHANGE

IMPORTANT UNKNOWNS FOR ASSESSING GROUND-WATER IMPACTS

USGS
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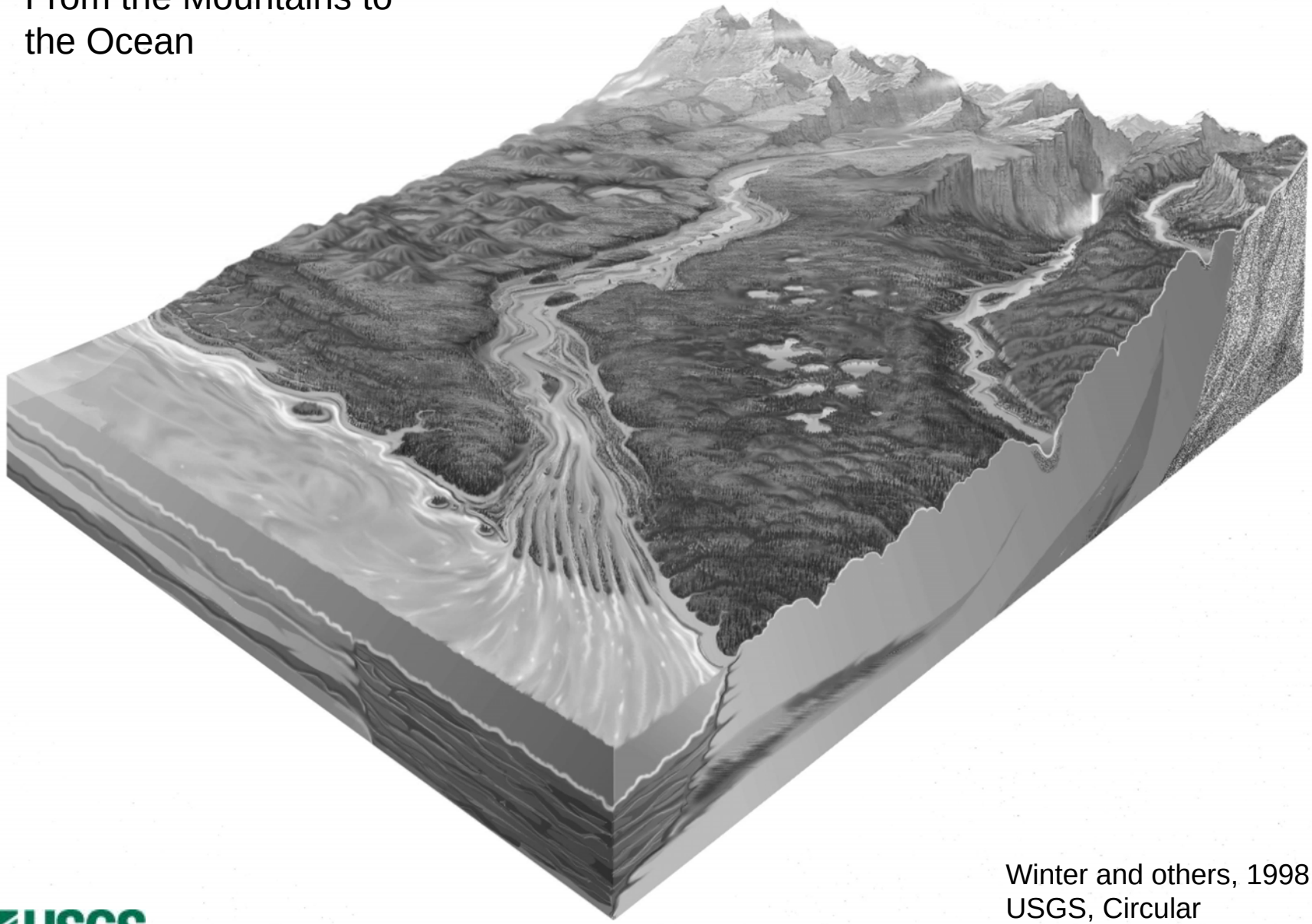
# WHY RECHARGE AND GROUND WATER?

USGS
science for a changing world

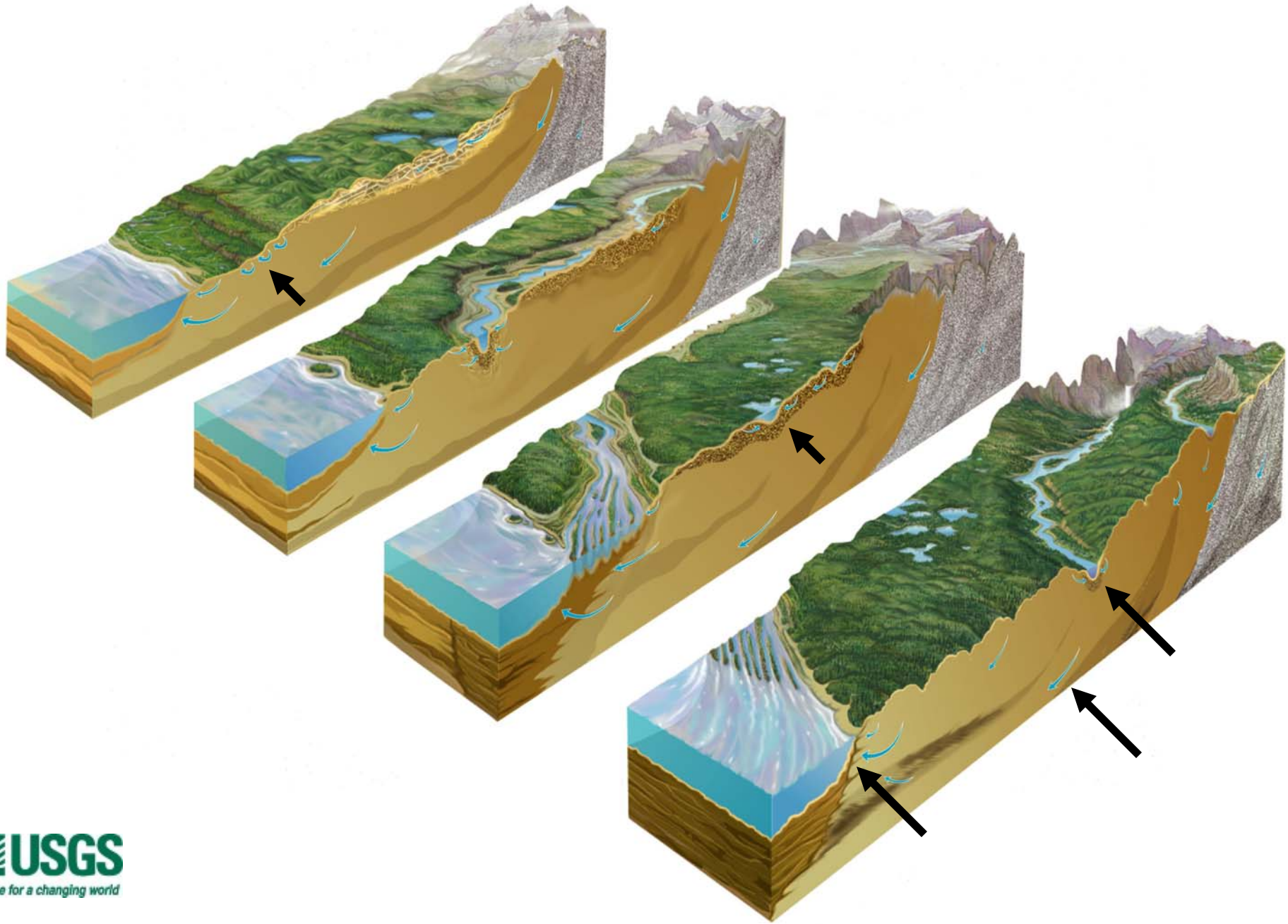
# From the Mountains to the Ocean



Winter and others, 1998, USGS, Circular

USGS
science for a changing world

Winter and others, 1998,
USGS, Circular



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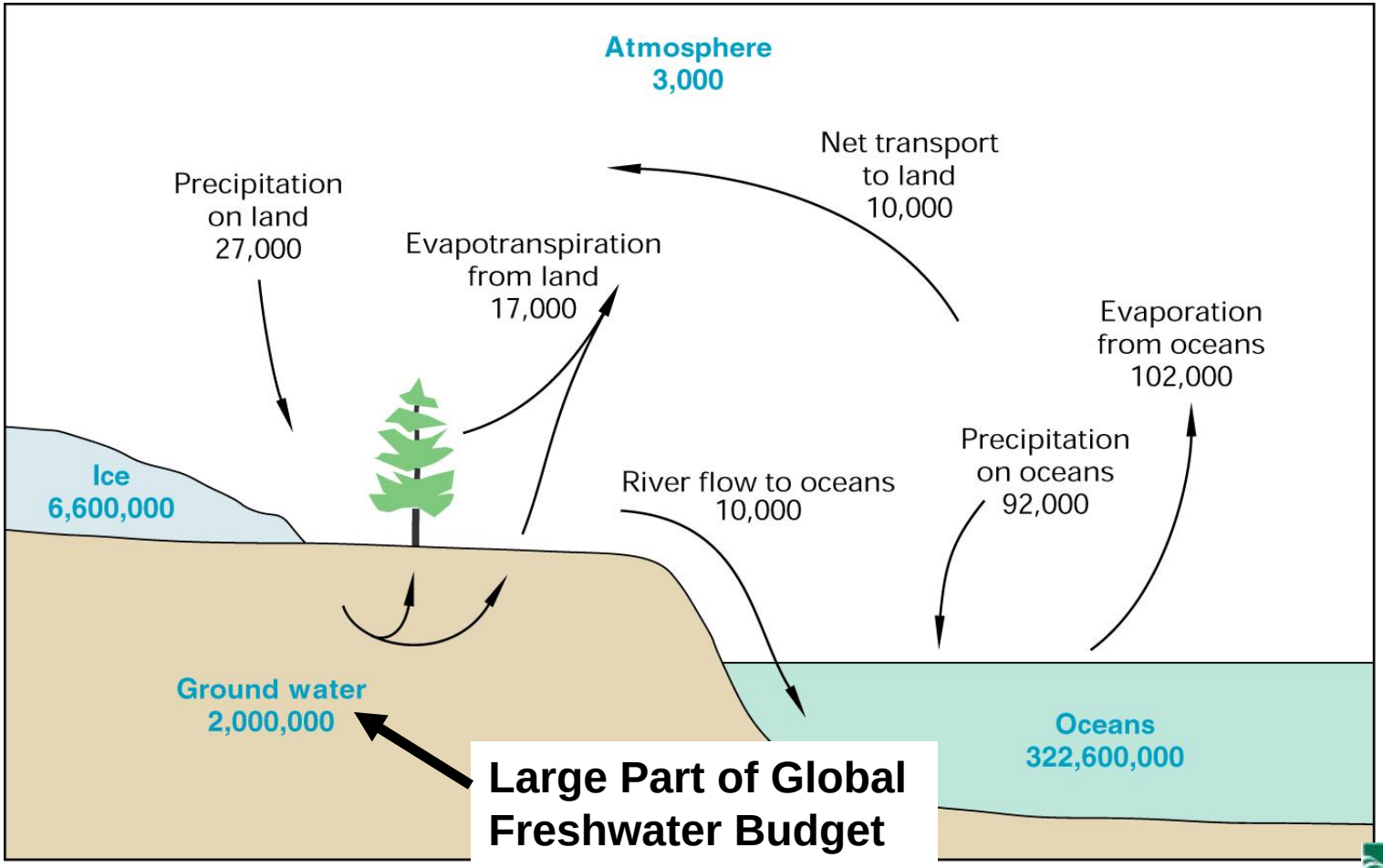
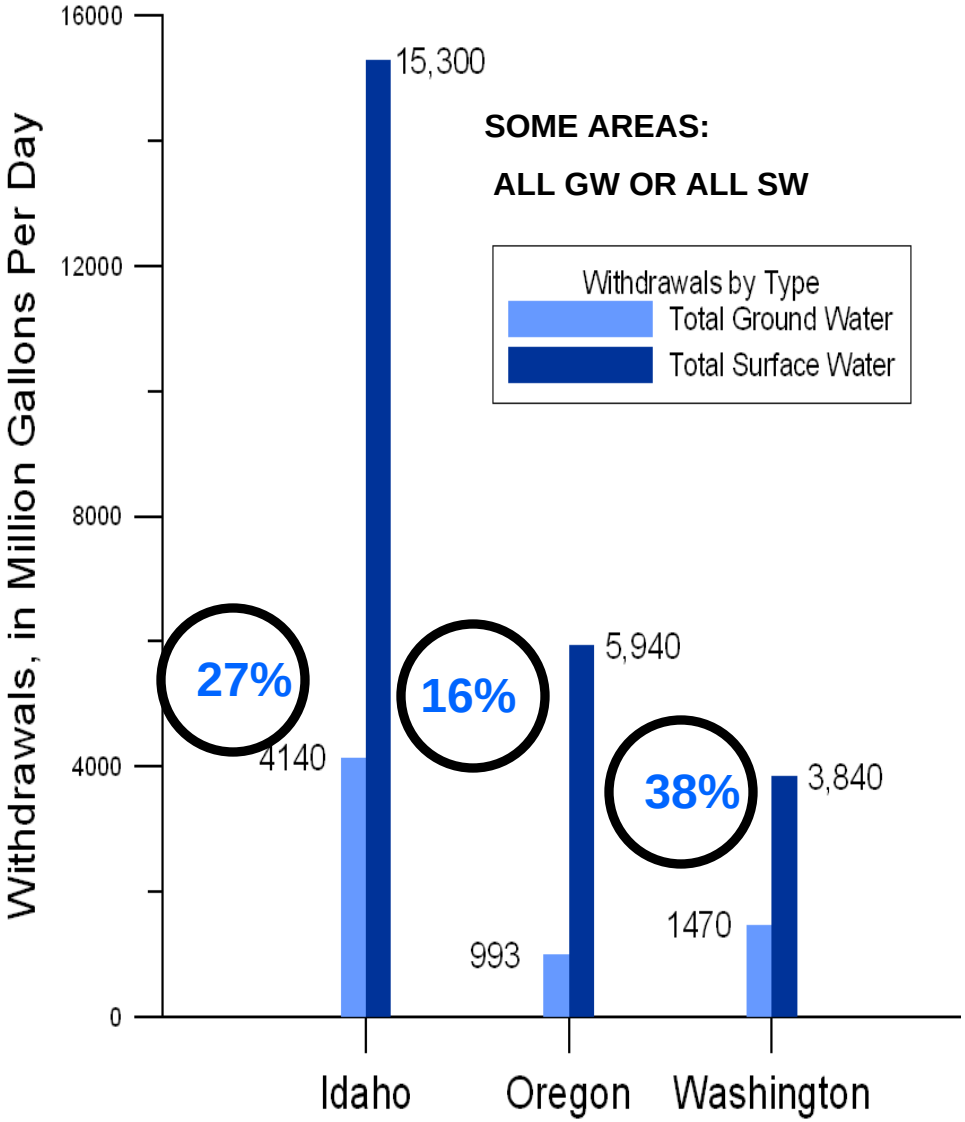
# MORE THAN 1.5 BILLION PEOPLE DRINK GROUND WATER, INCLUDING 50% OF THE POPULATION in the U.S.



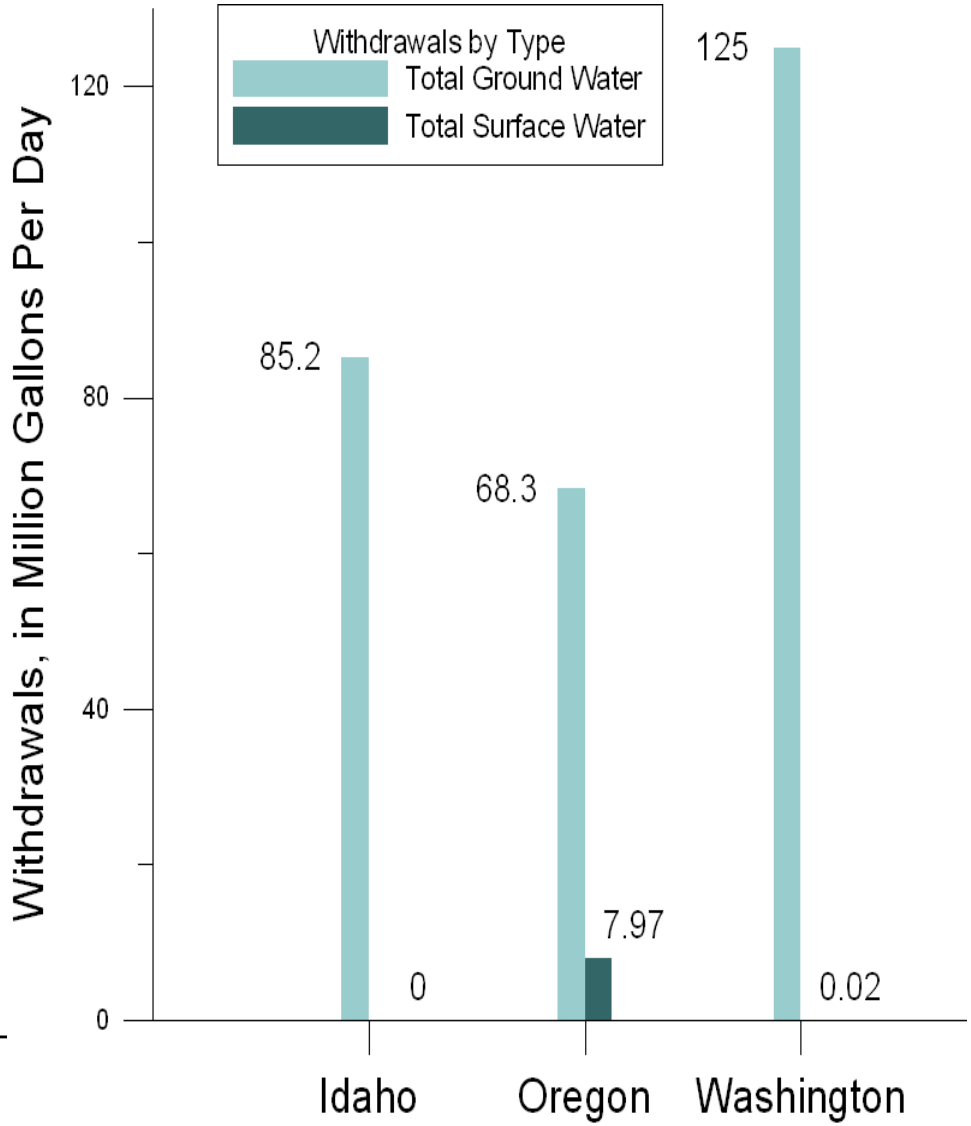

Pools are in cubic miles
Fluxes are in cubic miles per year

USGS
science for a changing world

# 2000 WITHDRAWALS ID, OR, WA (USGS, 2004, CIRCULAR)




ALL USES




DOMESTIC

GROUND WATER SUPPLIES ARE THREATENED THROUGHOUT THE WORLD, INCLUDING THE U.S.

***GROUNDWATER: A THREATENED RESOURCE***, UN ENVIRONMENT PROGRAMME, 1996

# Ground-Water Discharge is Basic to Ecological Function

- Provides preferred thermal structure and thus habitat for fish at different life-cycle stages
- Provides nutrients to the aquatic ecosystem
- Provides unique ecotone at interface where ground water interacts with surface water

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# Depending on ‘Where’ in a Ground-Water Flow System:

## Ground-Water Discharge (Recharge) and Water Levels Preserve Seasonal to Decadal Climate Signatures

# Ground Water and Recharge

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WATER IN GROUND-WATER FLOW SYSTEMS IS DERIVED FROM ‘RECHARGE’

# GROUND-WATER RECHARGE

SPATIALLY DISTRIBUTED RECHARGE

MOUNTAIN FRONT (SW) RECHARGE

FLOODPLAIN RECHARGE (ONCE UPON A TIME)

# SPATIALLY DISTRIBUTED RECHARGE

- POTENTIAL AMOUNT ENTERING A GROUND-WATER SYSTEM
- WATER LEAVING BOTTOM OF ROOT ZONE OR FOR BARREN SOILS, WATER LEAVING THE BOTTOM OF THE SOIL ZONE
- DECREASES WITH INCREASING ARIDITY
- IMPORTANT FOR TERRESTRIAL AND AQUATIC ECOSYSTEM

# MOUNTAIN FRONT RECHARGE

- OCCURS ON MANY STREAMS
- INCREASING IMPORTANCE WITH INCREASING ARIDITY
- IMPORTANT FOR GW AVAILABILITY
- IMPORTANT FOR AQUATIC ECOSYSTEM

# ESTIMATING RECHARGE

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# APPLICATION OF HYDROLOGIC MODELS

**Precipitation-Runoff Modeling System**
**(PRMS)**

**Deep Percolation Model**
**(DPM)**

**(Both in the USGS Modular Modeling System)**

**USGS MODFLOW (UNSAT, FARMPROCESS)**

**GSFLOW = PRMS+MODFLOW**

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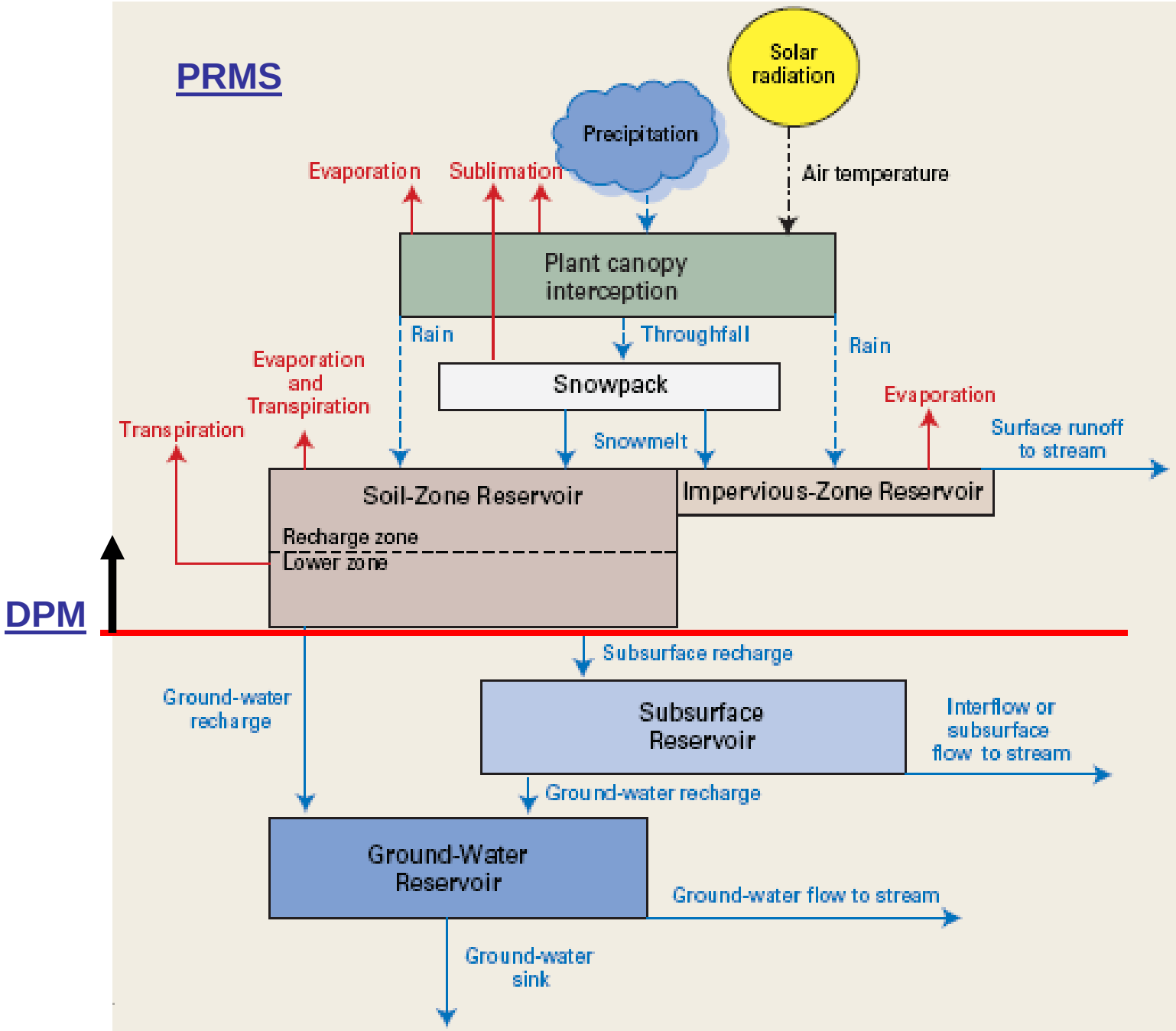
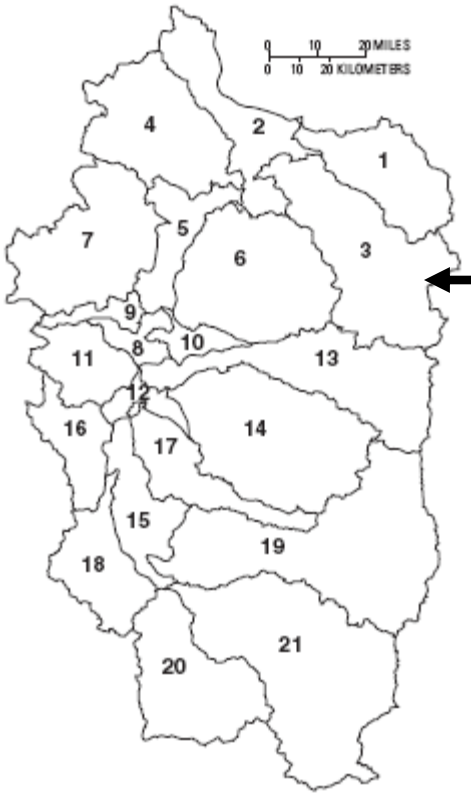
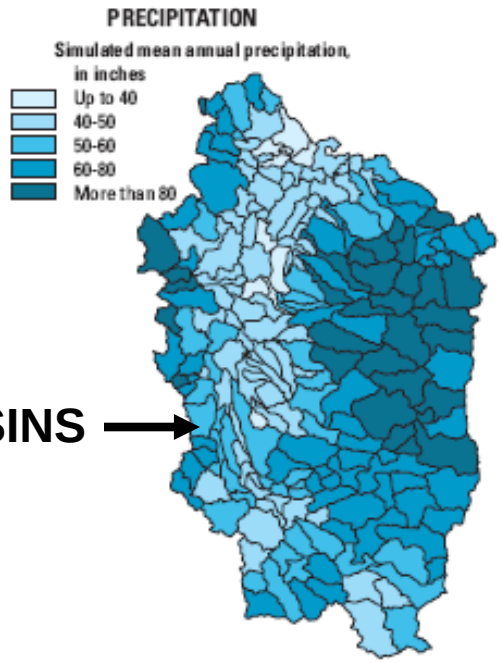
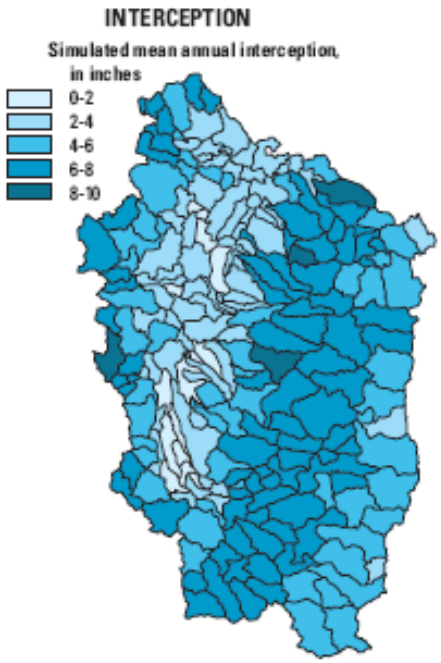

PRMS
Solar radiation
Precipitation
Air temperature
Evaporation
Sublimation
Plant canopy interception
Rain
Throughfall
Rain
Evaporation and Transpiration
Snowpack
Evaporation
Transpiration
Snowmelt
Surface runoff to stream
Soil-Zone Reservoir
Impervious-Zone Reservoir
Recharge zone
Lower zone
DPM
Subsurface recharge
Ground-water recharge
Subsurface Reservoir
Interflow or subsurface flow to stream
Ground-water recharge
Ground-Water Reservoir
Ground-water flow to stream
Ground-water sink

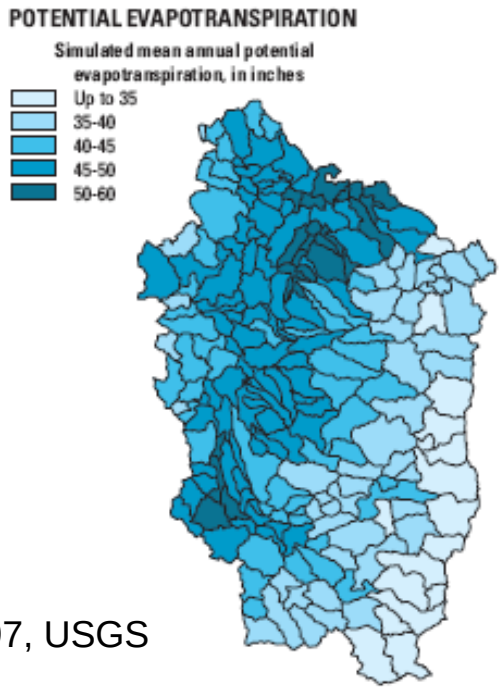


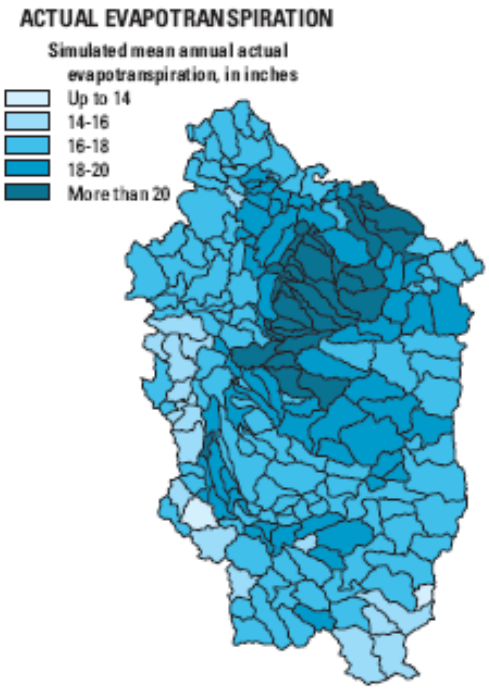

**BASINS**

**SUBBASINS**

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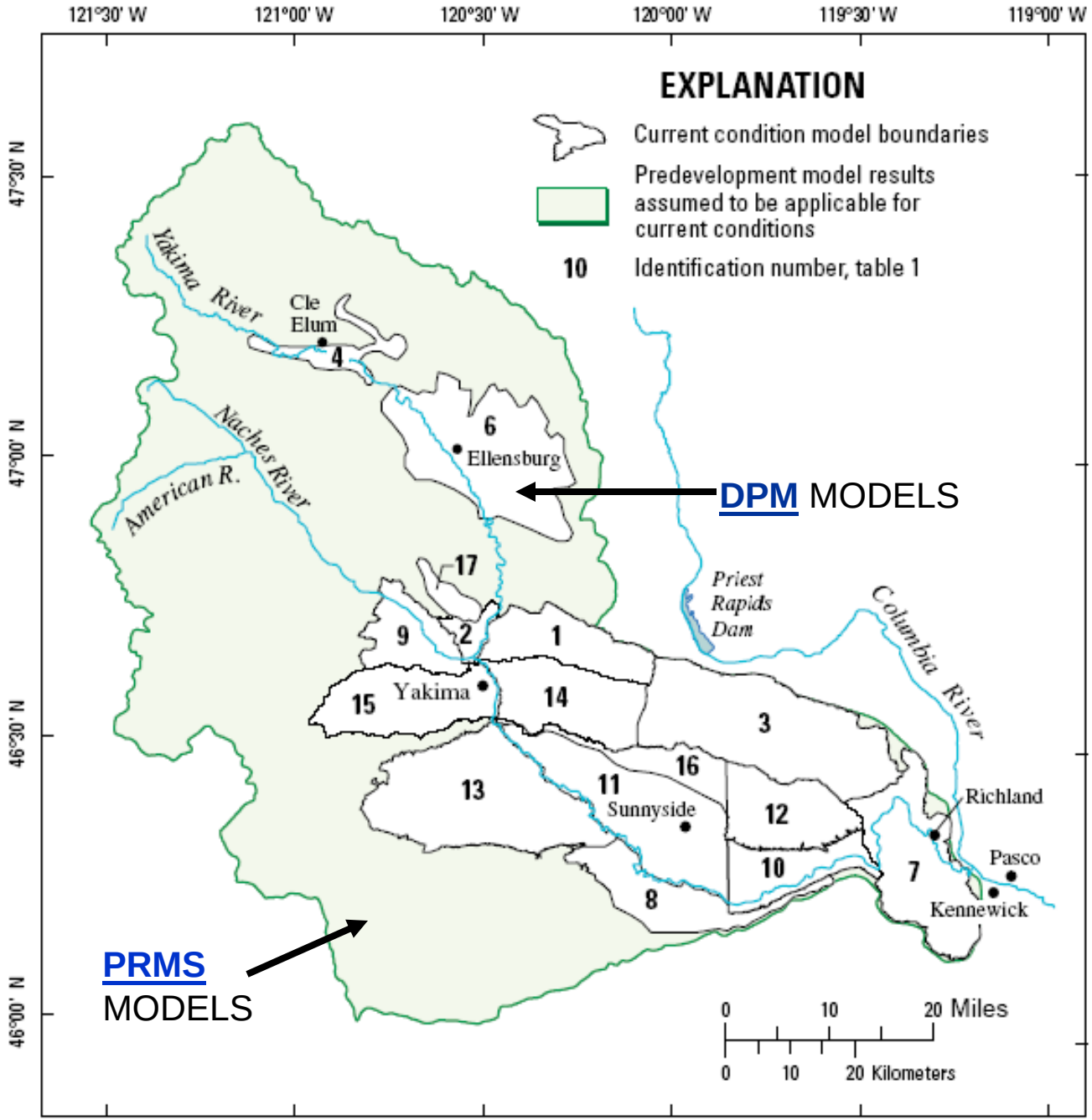
Laenen and Risley, 1997, USGS

**Areas modeled for estimating current condition recharge for input to a regional ground-water model**

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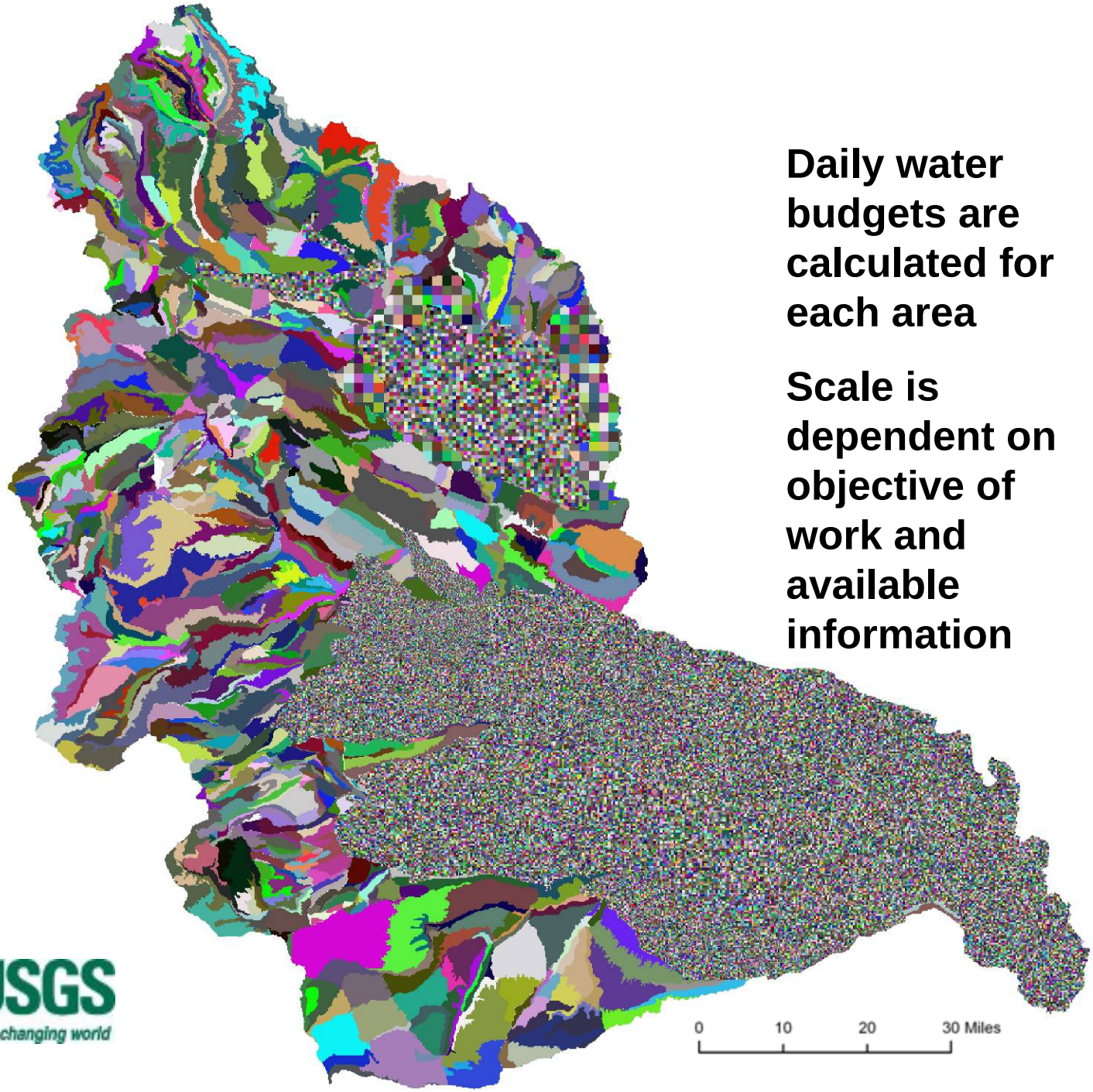


**Daily water budgets are calculated for each area**

**Scale is dependent on objective of work and available information**

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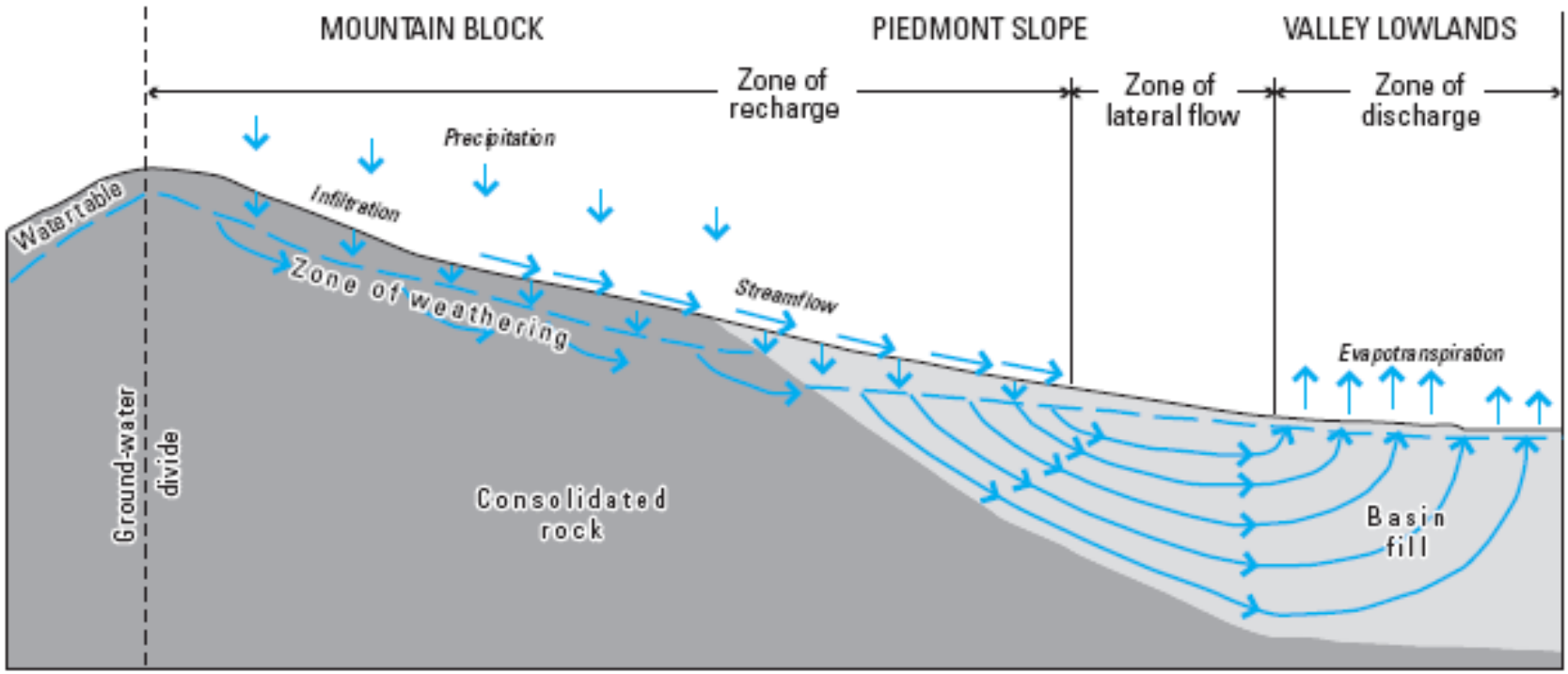
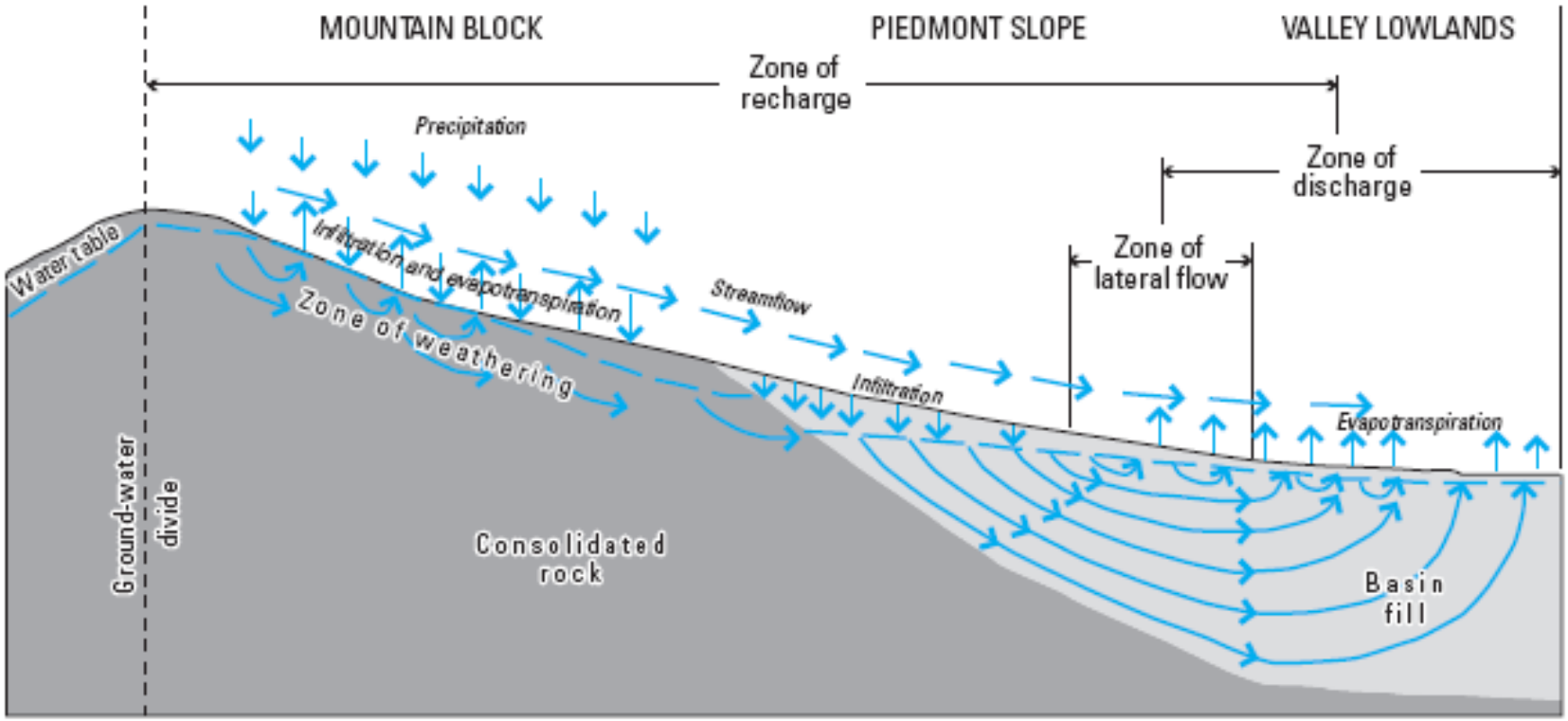
# RECHARGE AND GROUND WATER SYSTEMS ARE A FUNCTION OF THE GEOLOGY

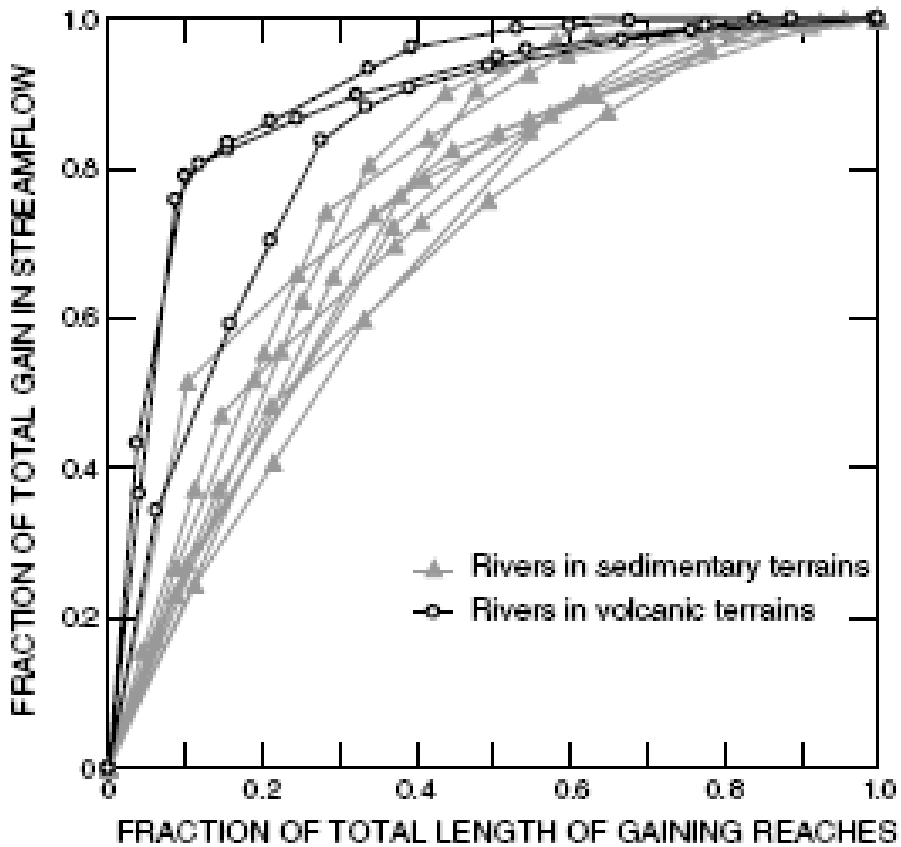



Stonestrom and others, 2008, USGS PP 1703




Stonestrom and others, 2008, USGS PP 1703

# EXAMPLE OF IMPORTANCE OF HYDROGEOLOGIC UNITS




Konrad, 2006, JH

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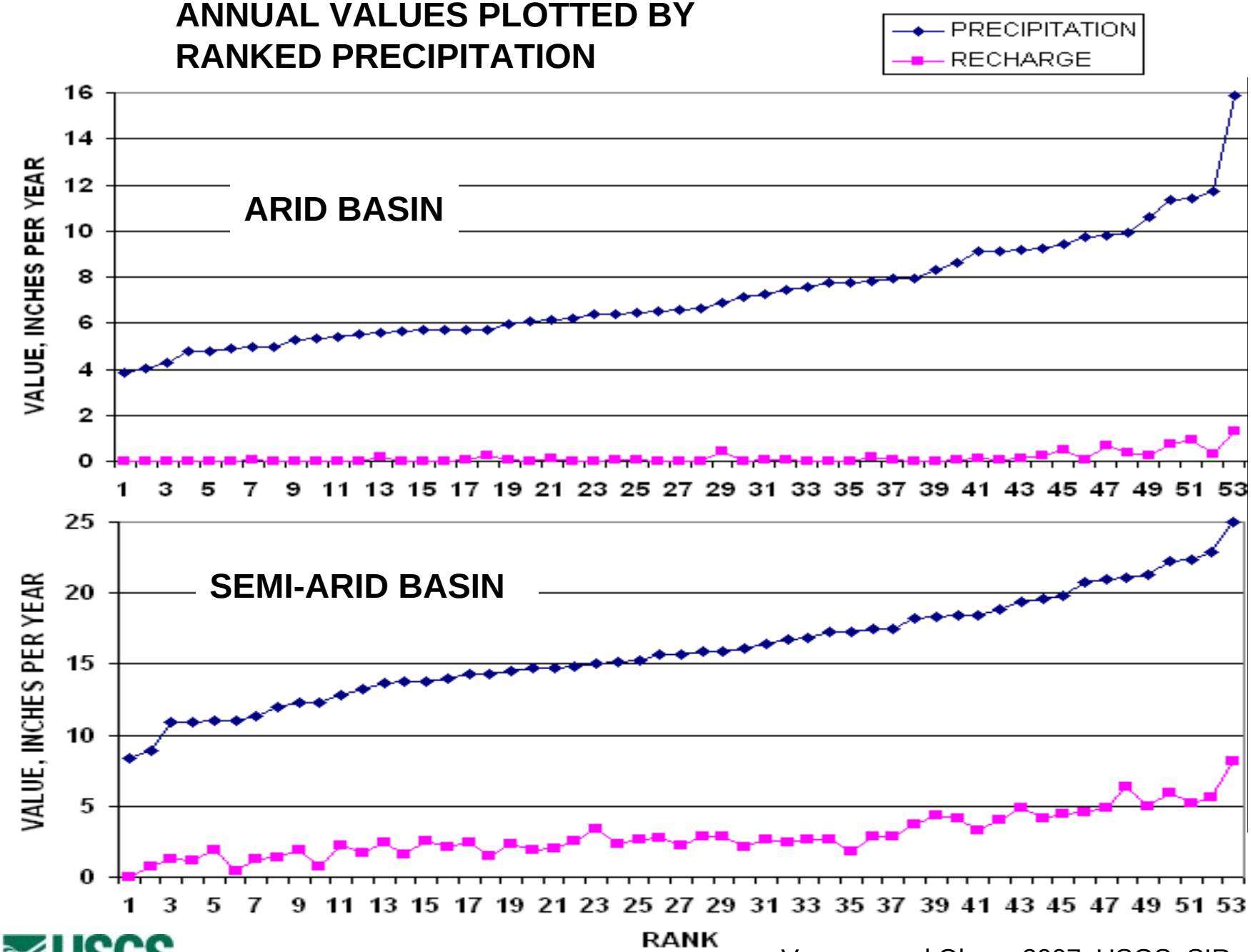
# RECHARGE RESULTS FROM NON-LINEAR HYDROLOGIC PROCESS

# ANNUAL VALUES PLOTTED BY RANKED PRECIPITATION




Vaccaro and Olsen, 2007, USGS, SIR

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# WHAT ABOUT CURRENT CLIMATE AND HUMAN IMPACT?

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# AN EXAMPLE FOR THE COLUMBIA PLATEAU AQUIFER SYSTEM

# USGS REANALYSIS: GW AVAILABILITY IN THE U.S.

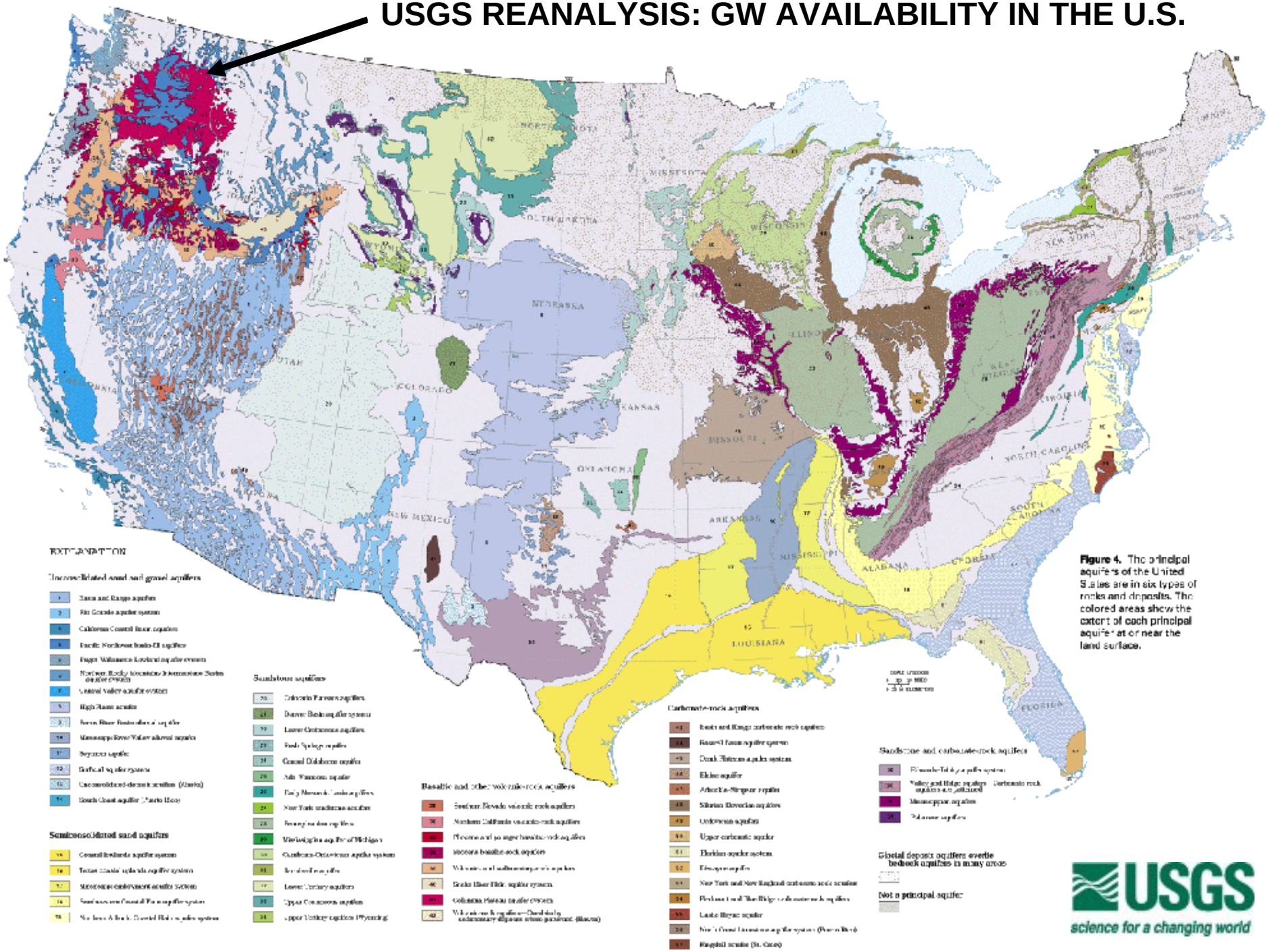
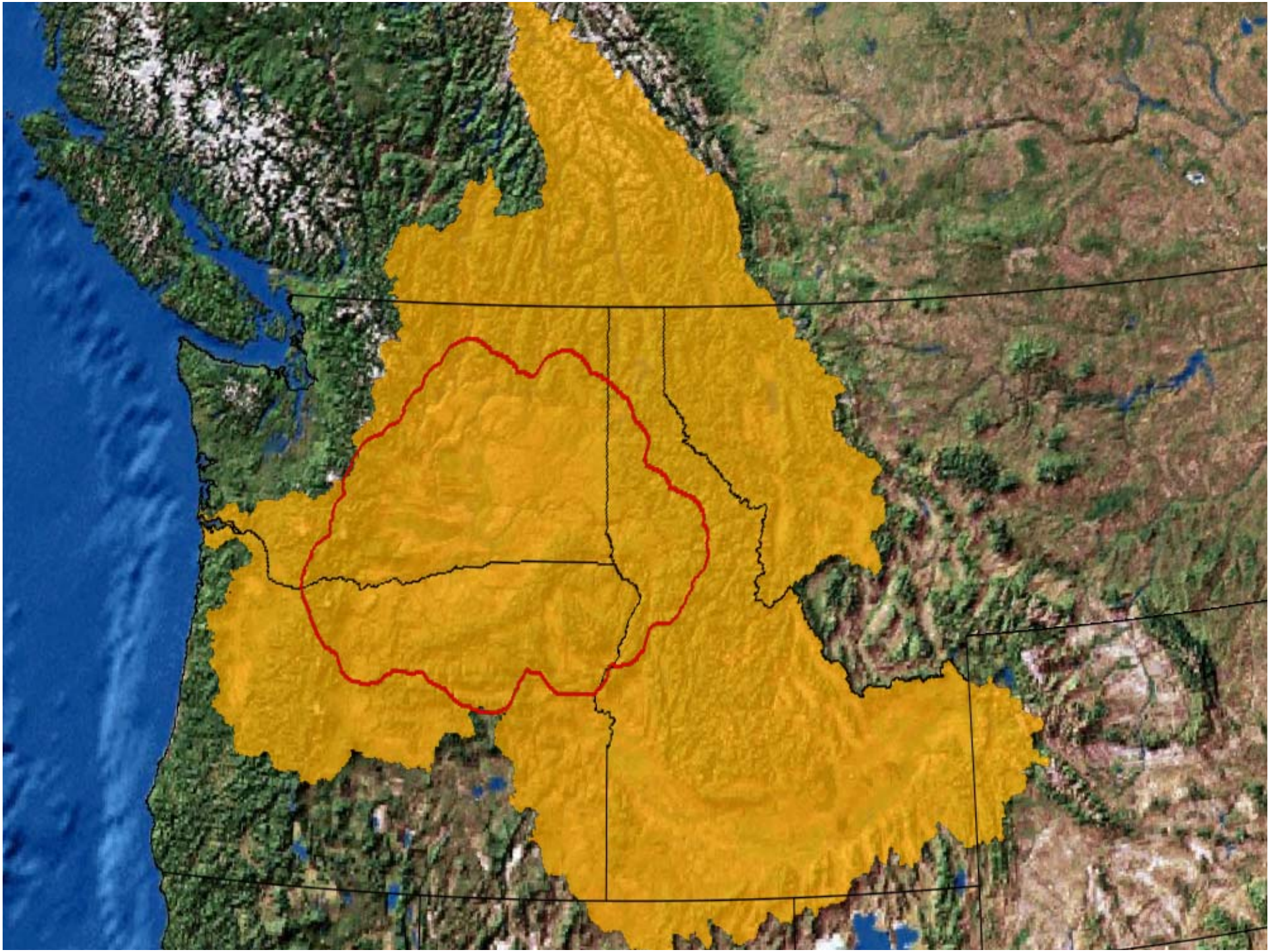
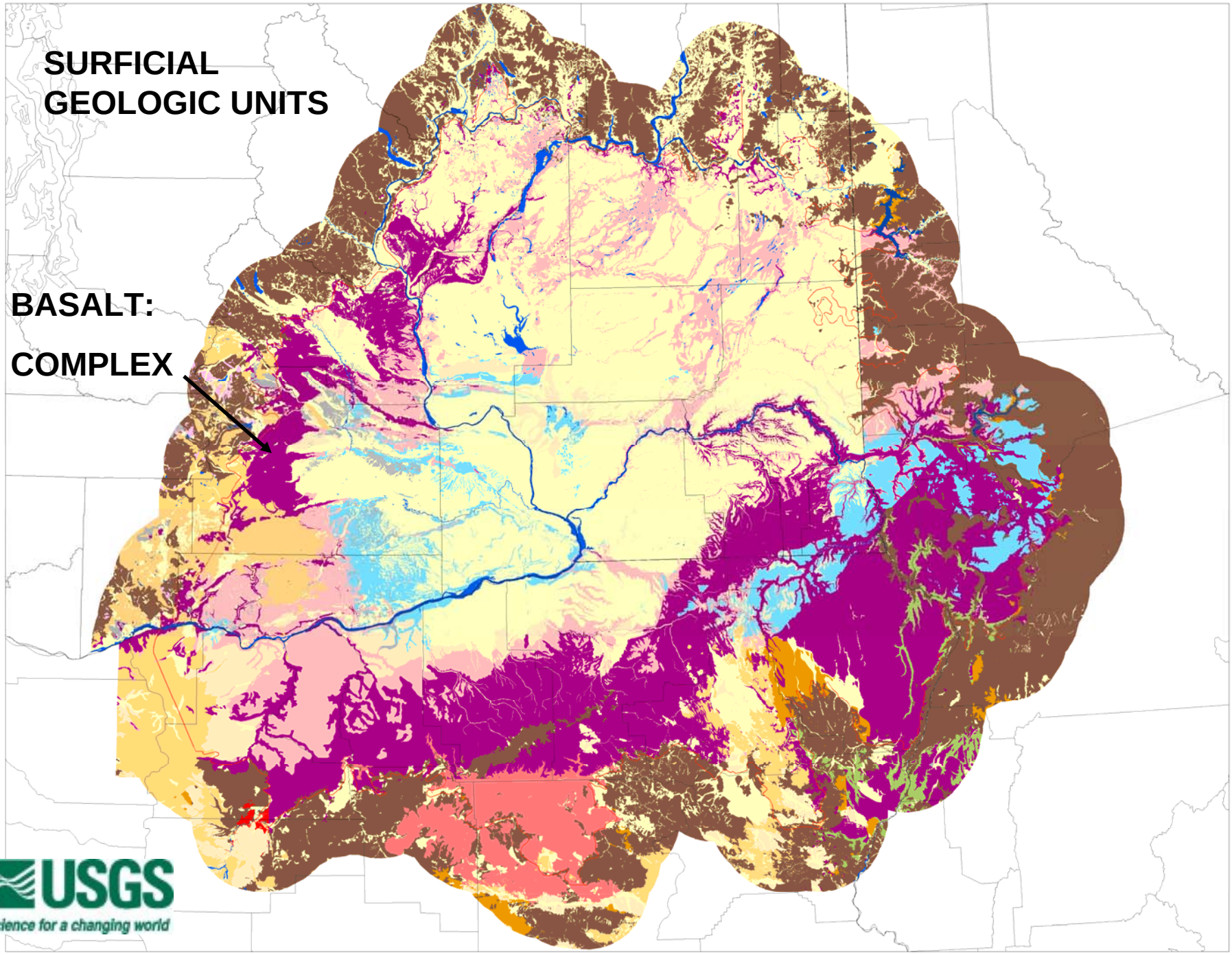


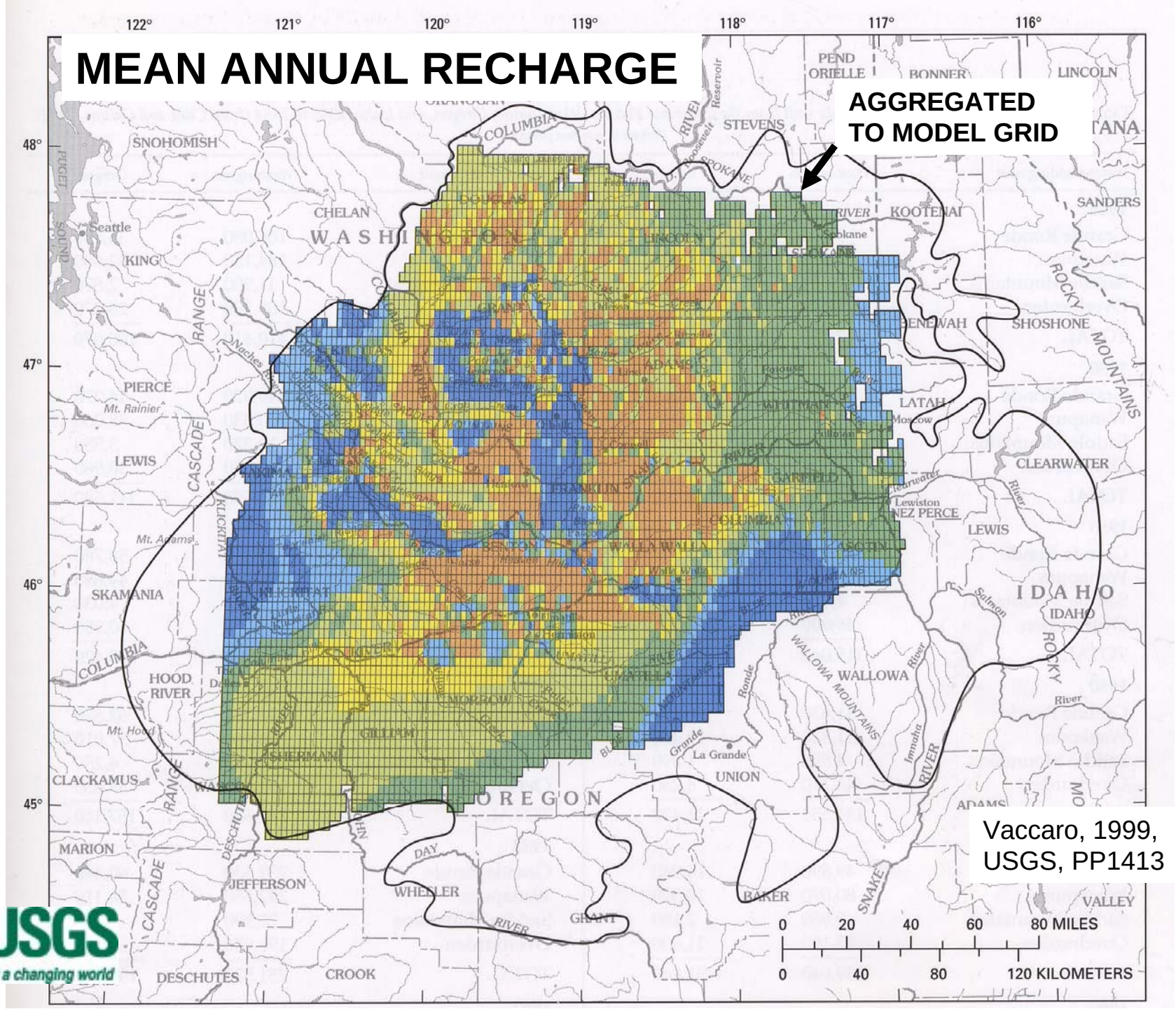

**Figure 4.** The principal aquifers of the United States are in six types of rocks and deposits. The colored areas show the extent of each principal aquifer at or near the land surface.

USGS
science for a changing world



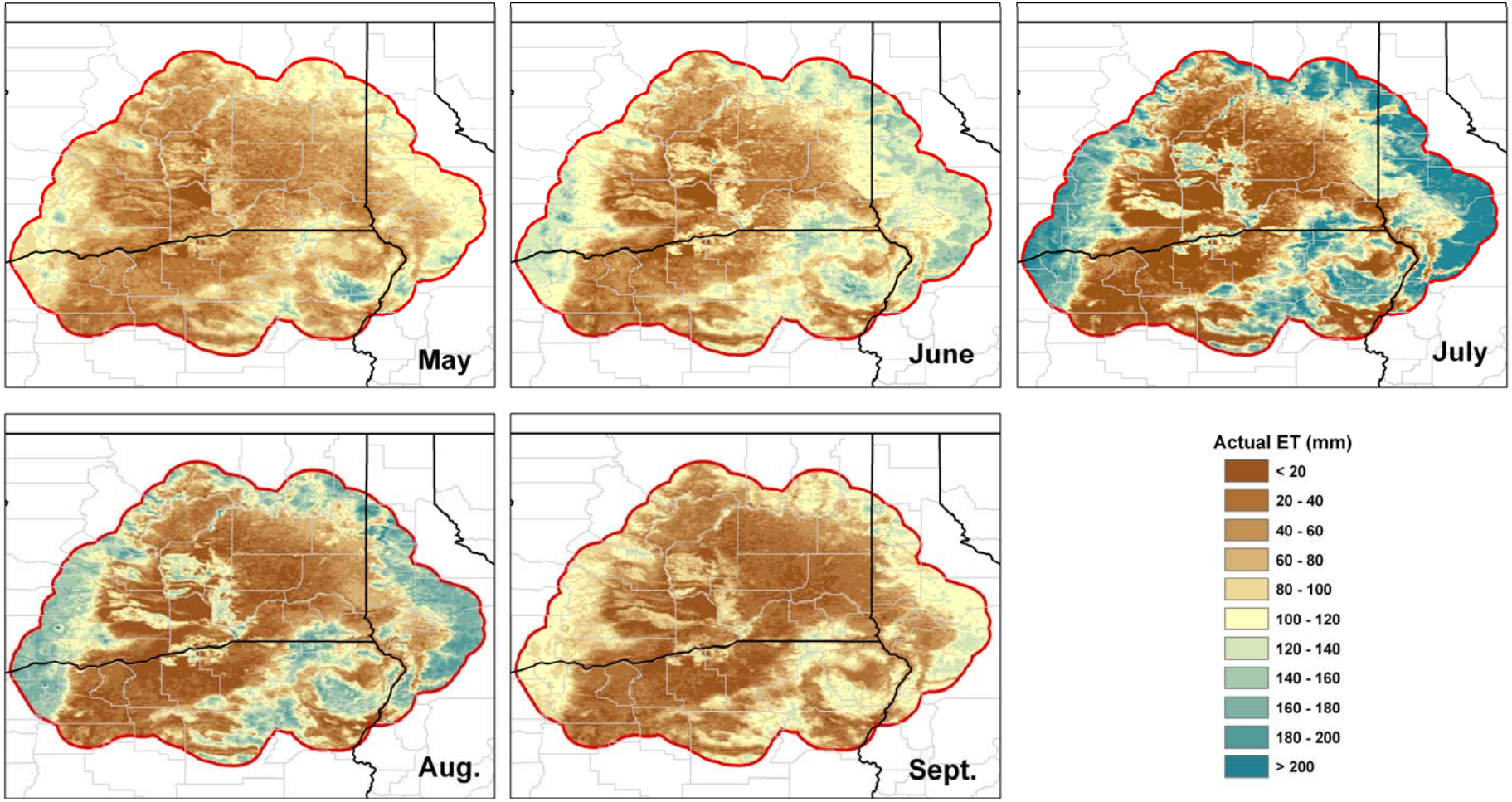

SURFICIAL
GEOLOGIC UNITS
BASALT:
COMPLEX
USGS
science for a changing world

# MEAN ANNUAL RECHARGE




Vaccaro, 1999,
USGS, PP1413

USGS
science for a changing world




States
Counties
Columbia Plateau Buffer

USGS
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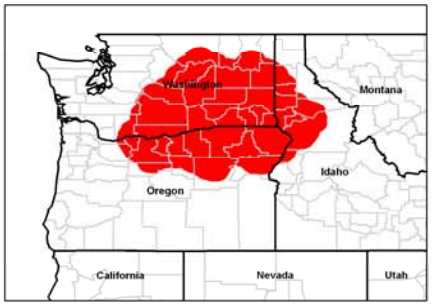
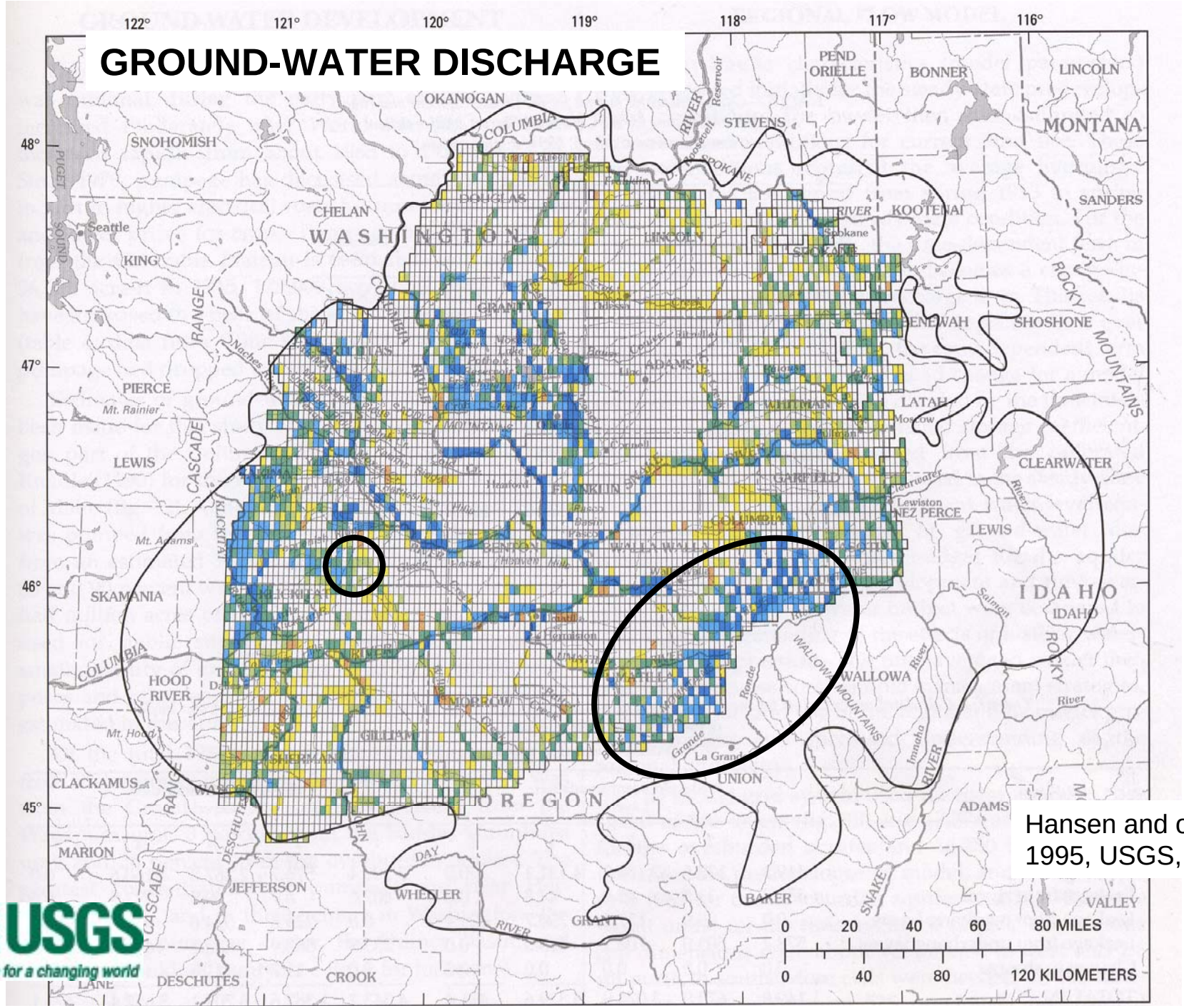
## Columbia Plateau Monthly Actual ET (ETa)
## May - September 2006

**FOR IRRIGATED AGRICULTURE: FAMINE EARLY WARNING SYSTEMS NETWORK, UN**



# GROUND-WATER DISCHARGE




Hansen and others, 1995, USGS, WRIR

USGS
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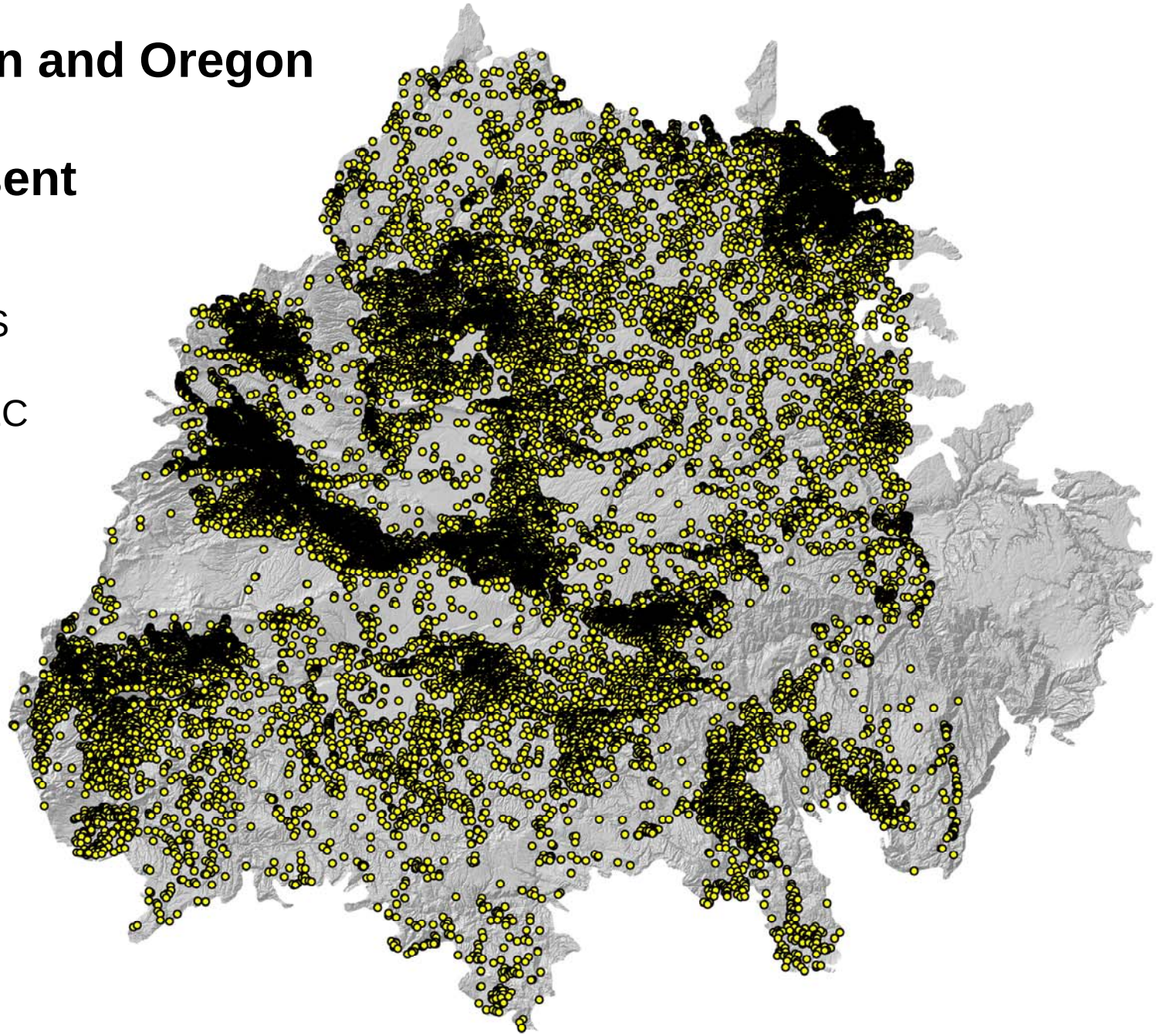
# Washington and Oregon wells
# 1880 - Present

PUMPAGE IS MORE THAN 1,050 $FT^3$/SEC



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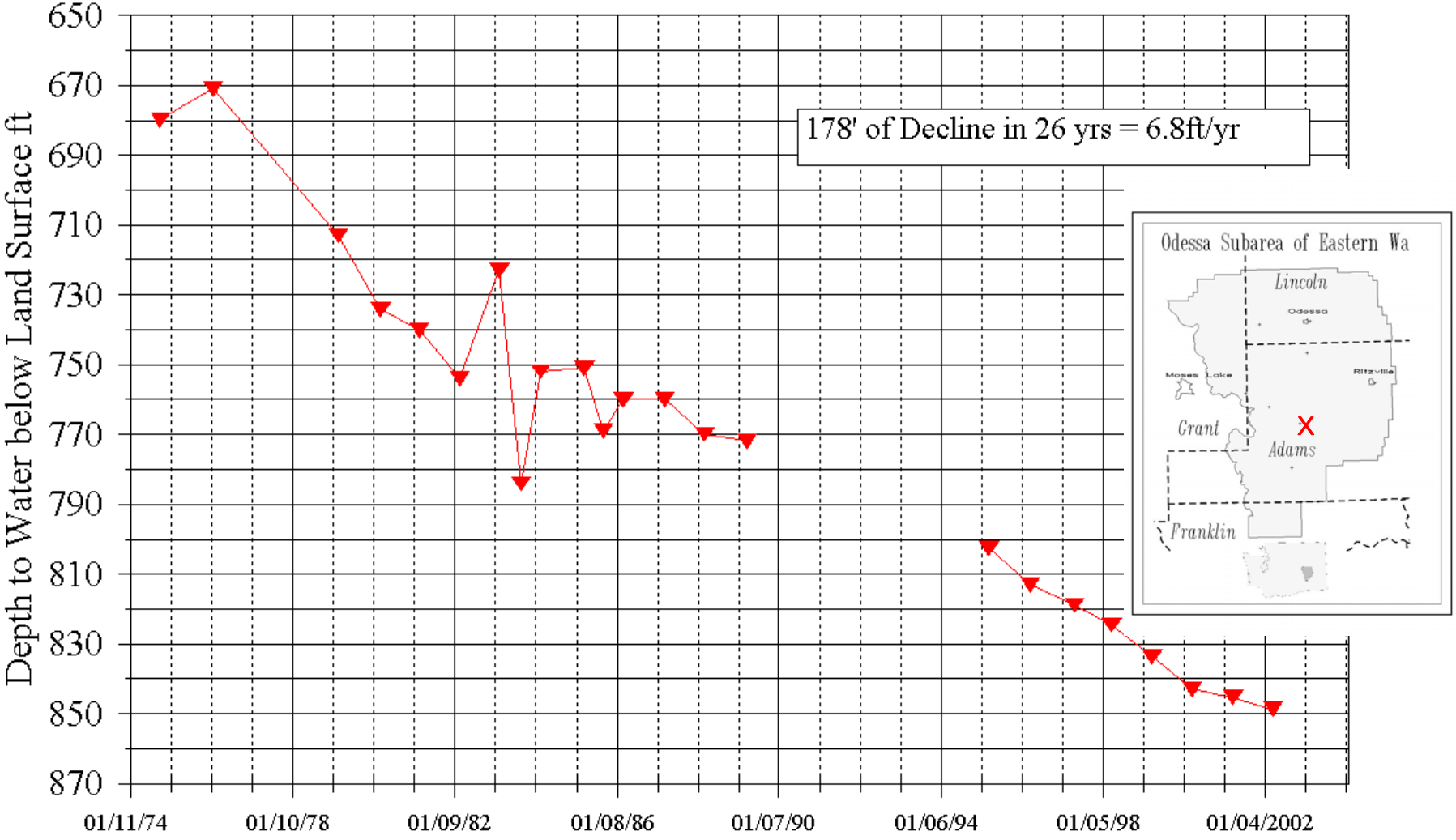
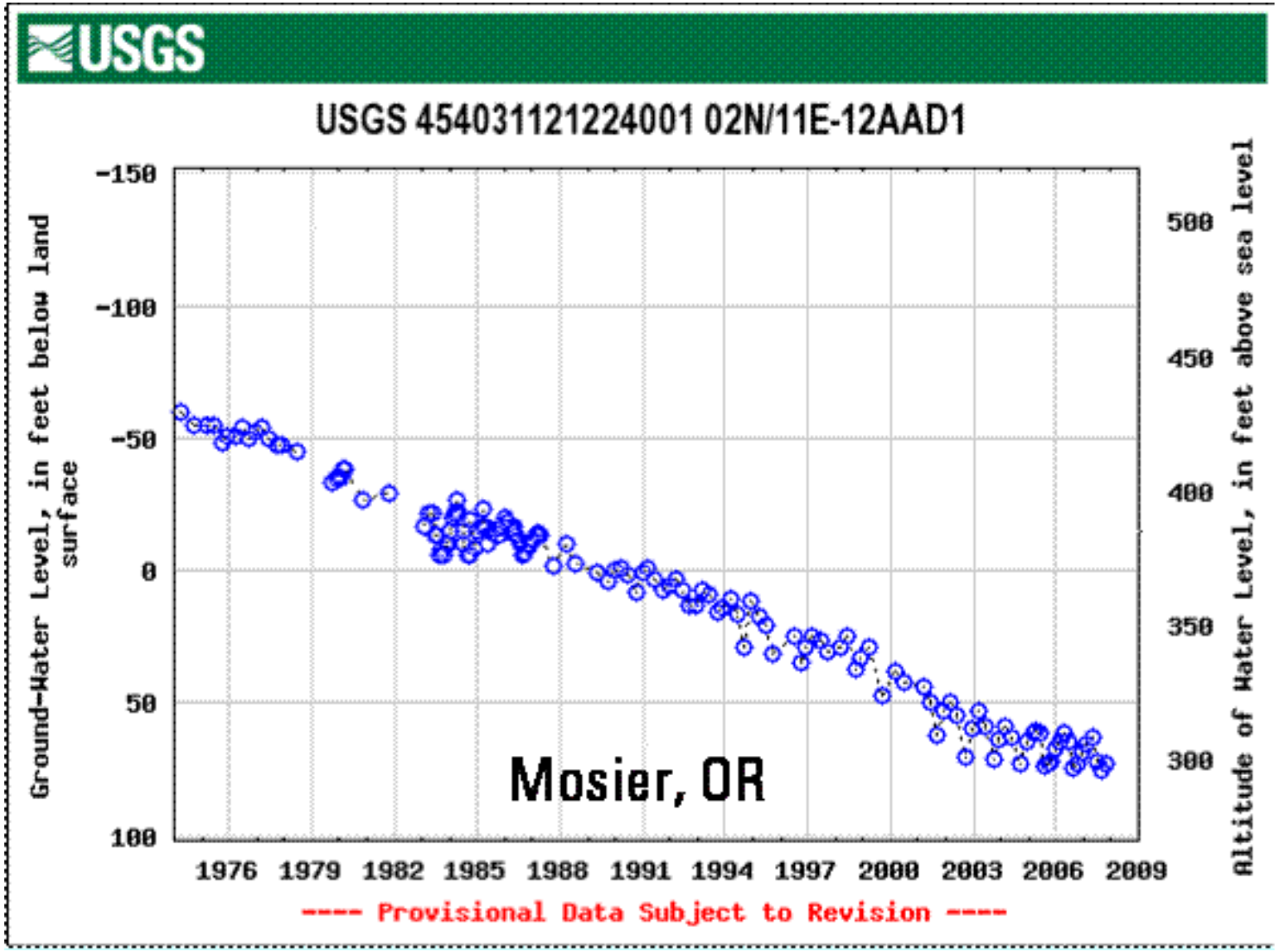
# Water Level Measurements

## 17N/33E-06E01

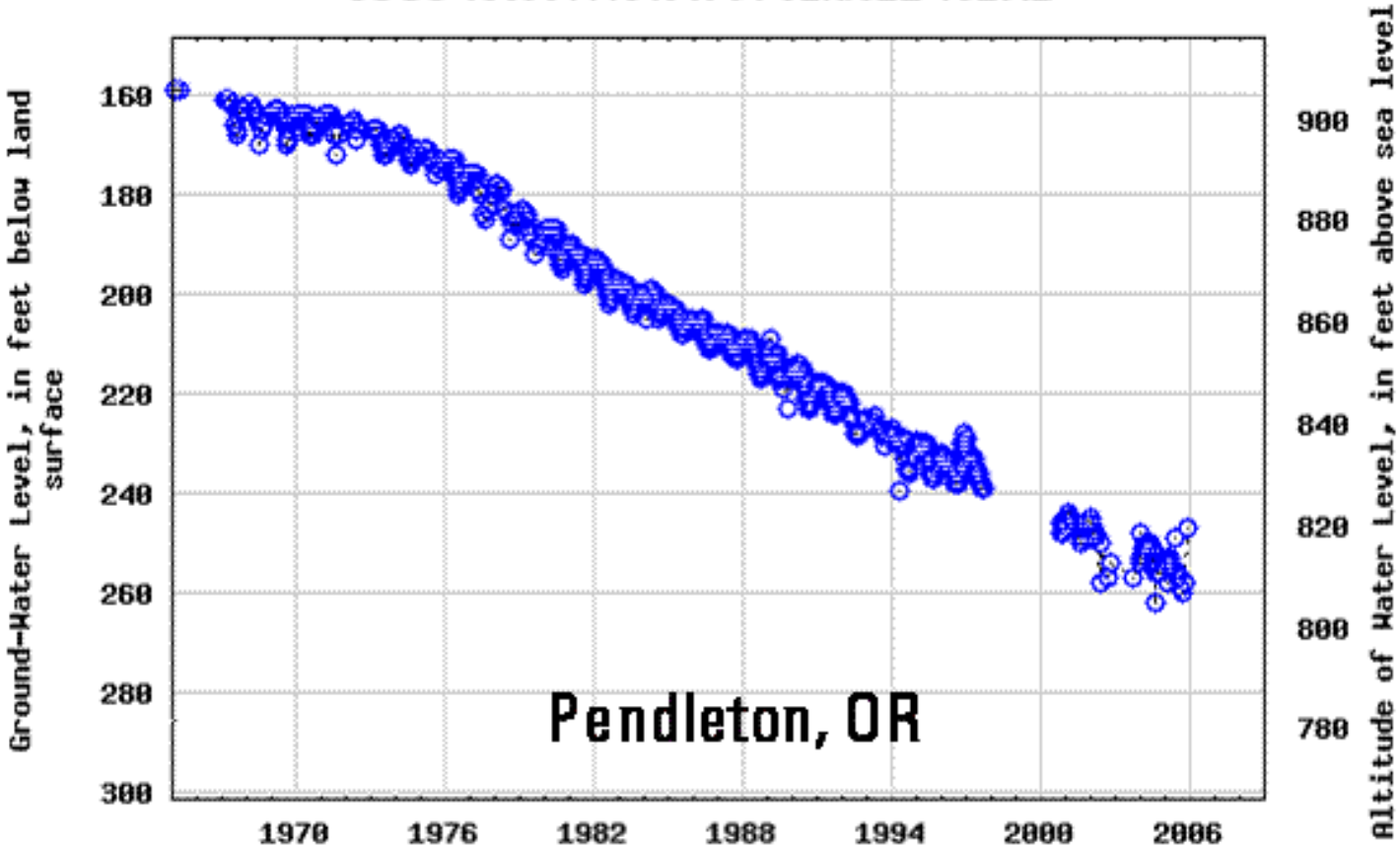



**DECLINE + PUMPING LEVEL = $$$$$$**

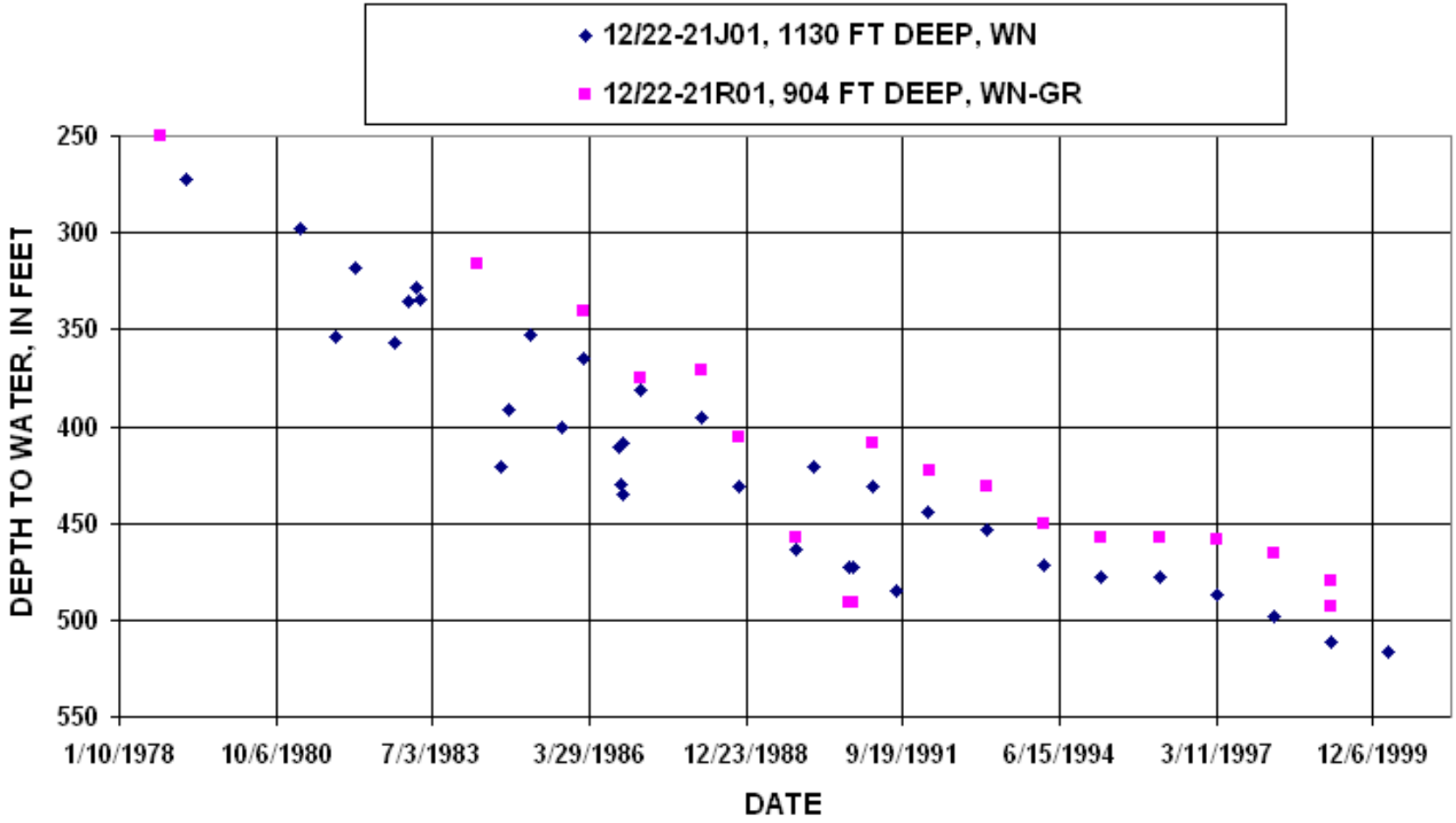

USGS
USGS 454031121224001 02N/11E-12AAD1
Ground-Water Level, in feet below land surface
-150
-100
-50
0
50
100
Altitude of Water Level, in feet above sea level
500
450
400
350
300
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
Mosier, OR
---- Provisional Data Subject to Revision ----

USGS

USGS 453934118491701 02N/32E-16BAB

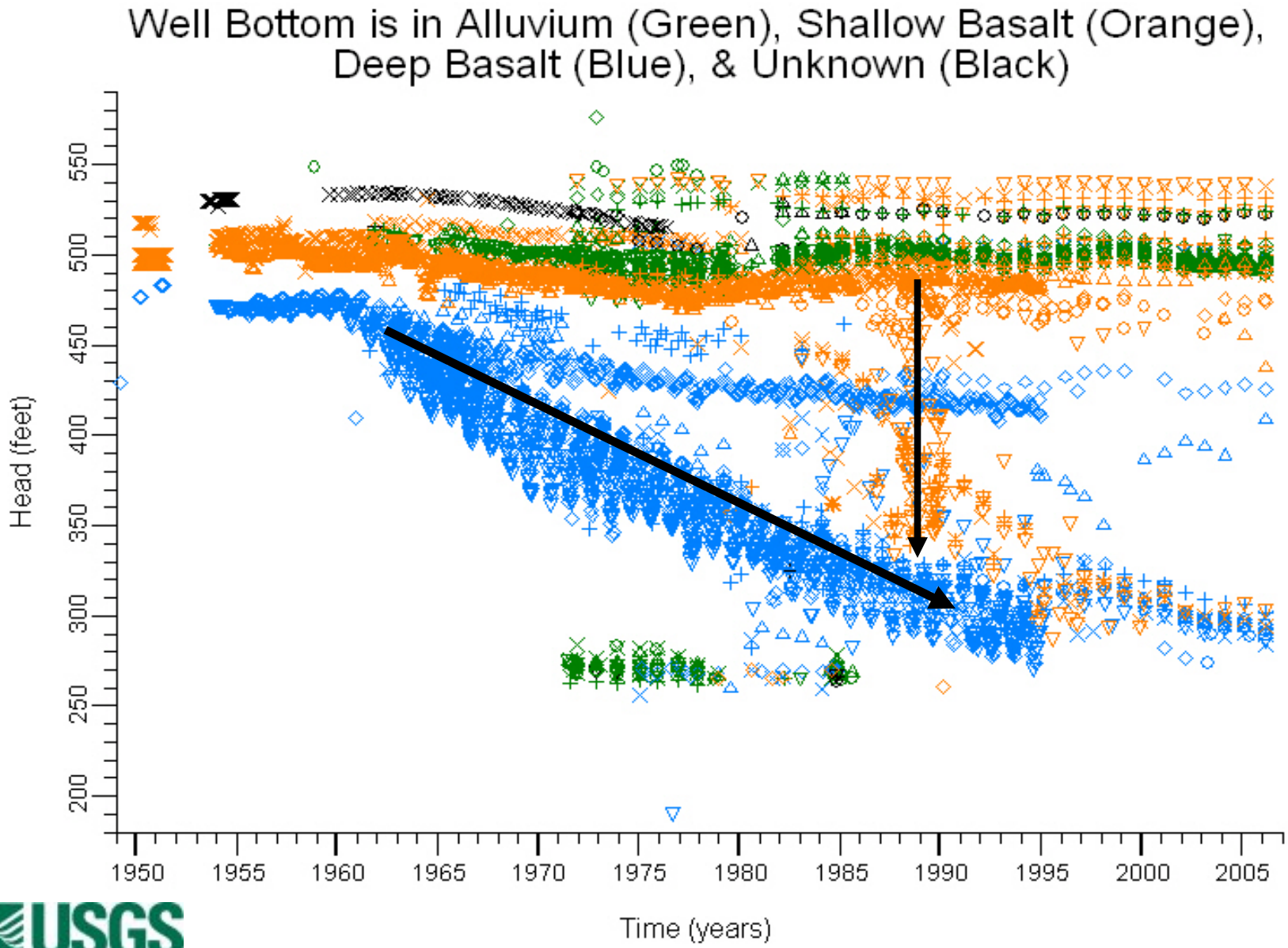



---- Provisional Data Subject to Revision ----




- **11 FEET/YEAR DECLINE**

# Ordance Critical GW Area-Umatilla Basin

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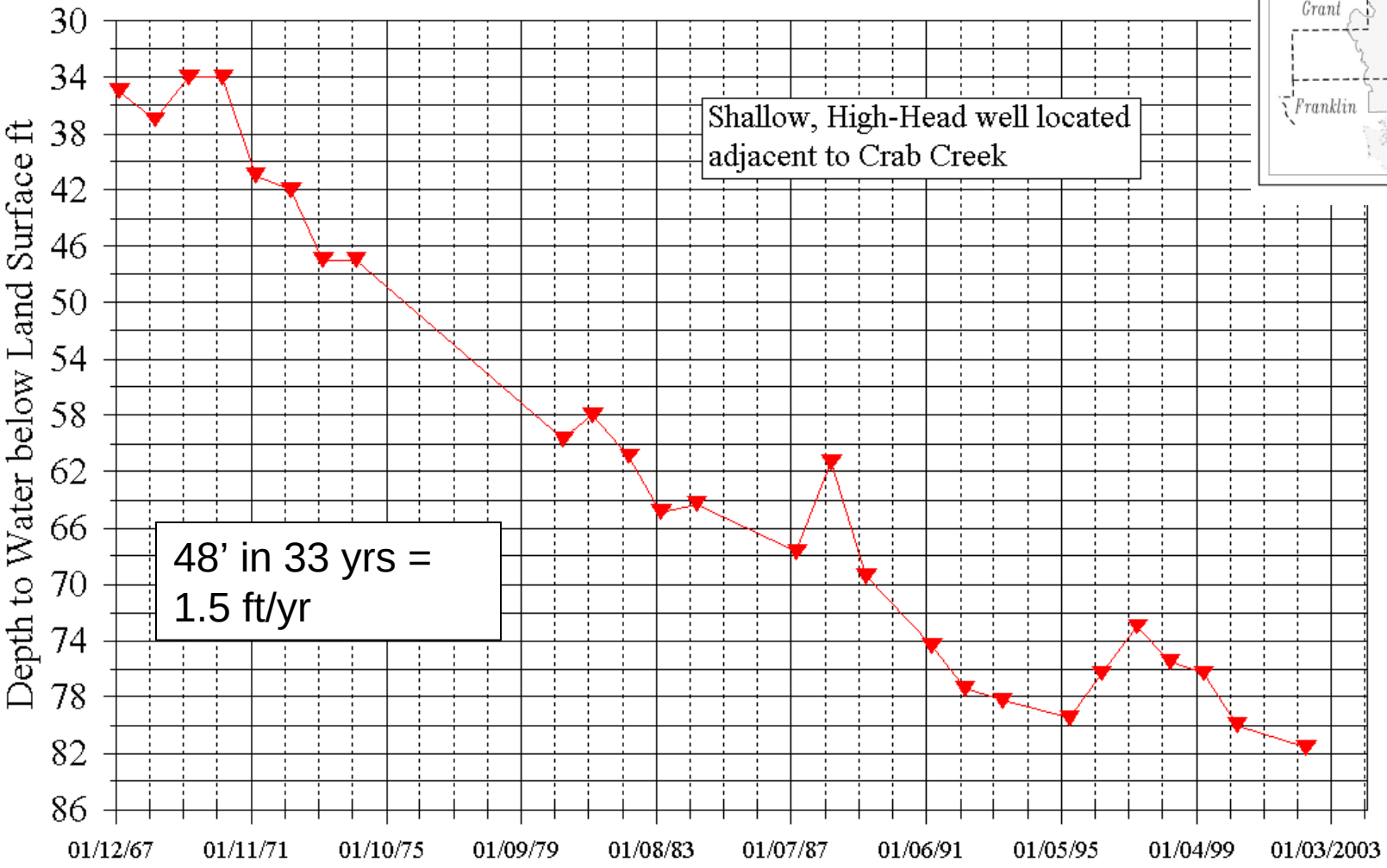
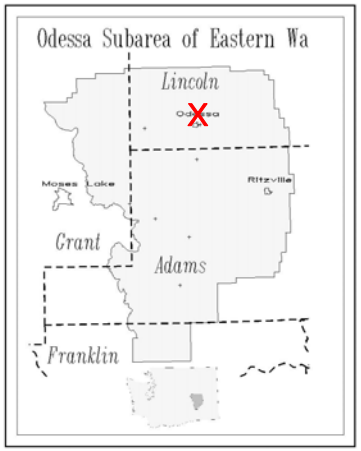
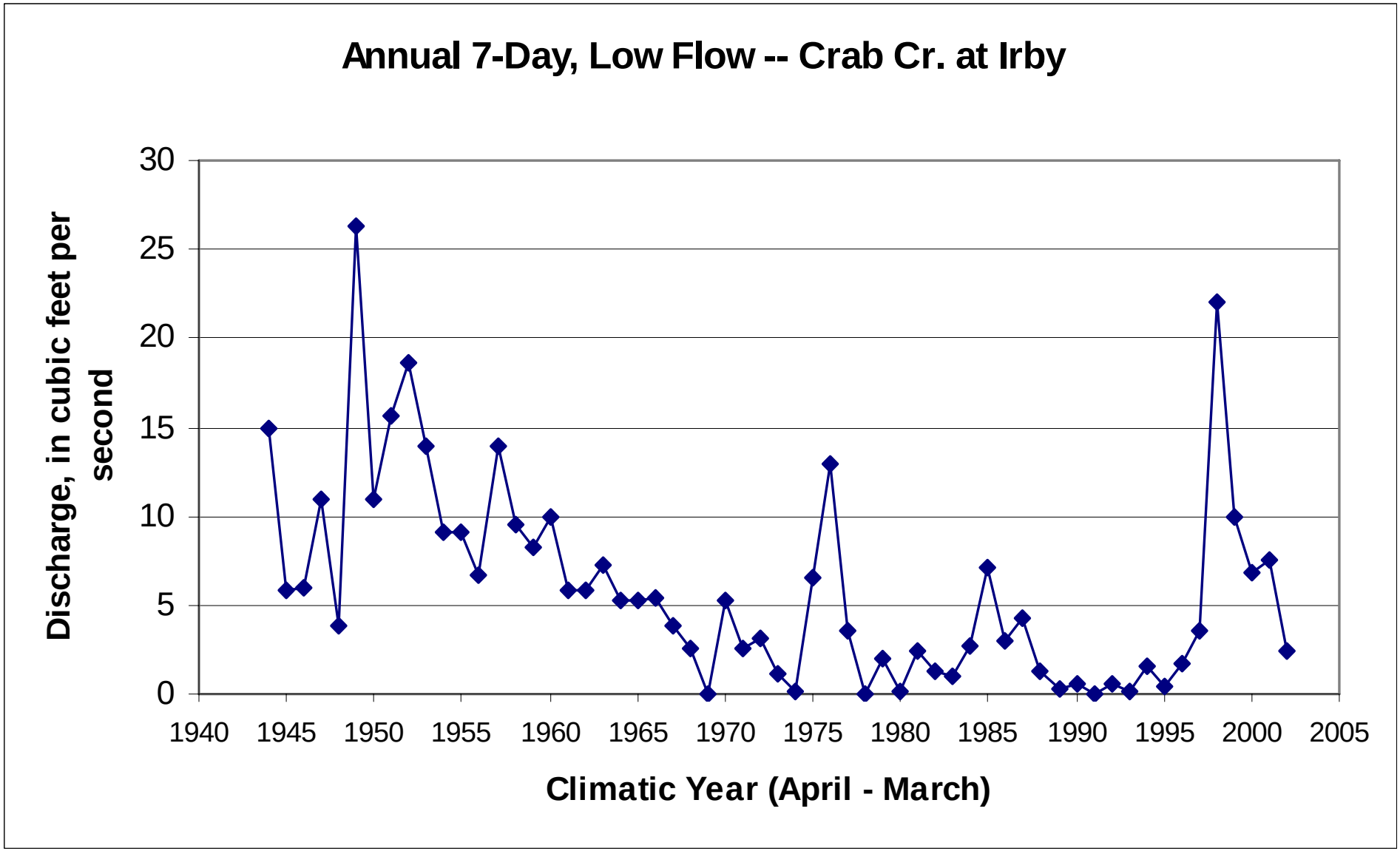
# Water Level Measurements

## 21N/33E-04Q01






Data from USGS, NWIS

# WHAT CURRENTLY HAPPENS UNDER DRY CLIMATE REGIMES

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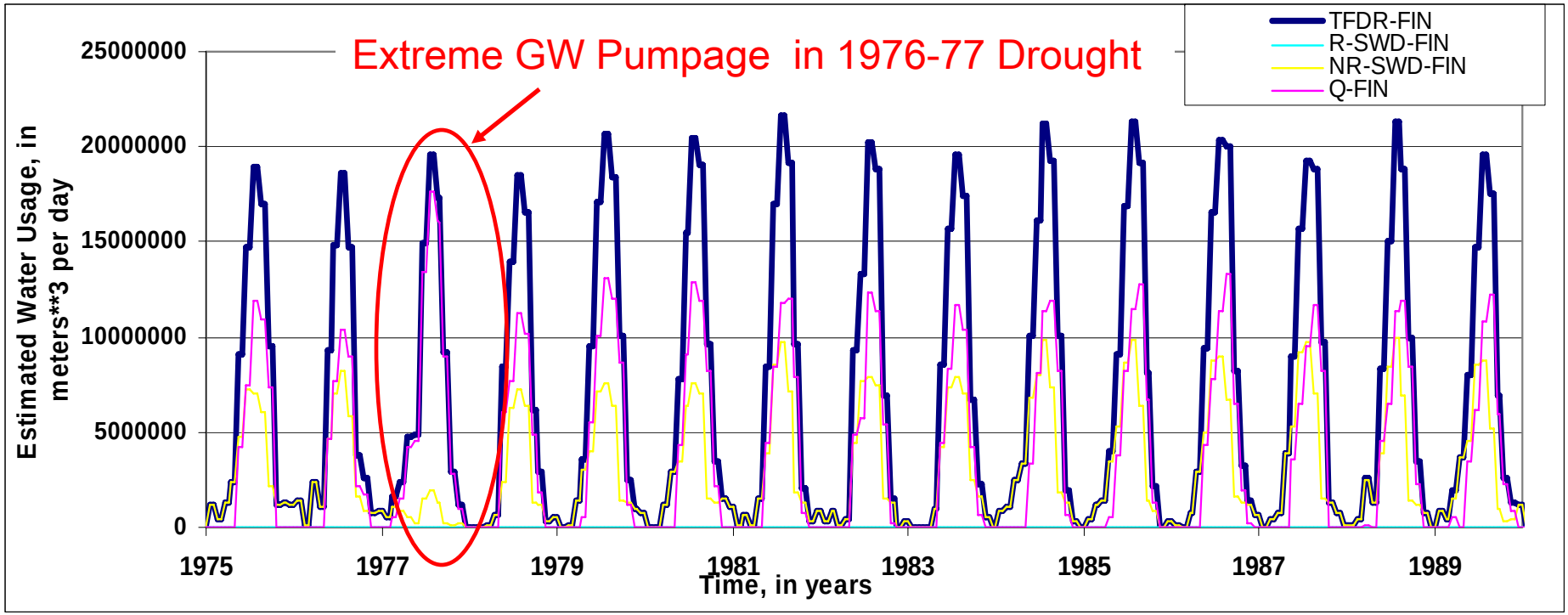
## *Change in Dominant Water Source with Climate*




**Central Valley, California**
**Declining Water Levels**
**Land subsidence**

HANSEN AND SCHMID, 2008

USGS
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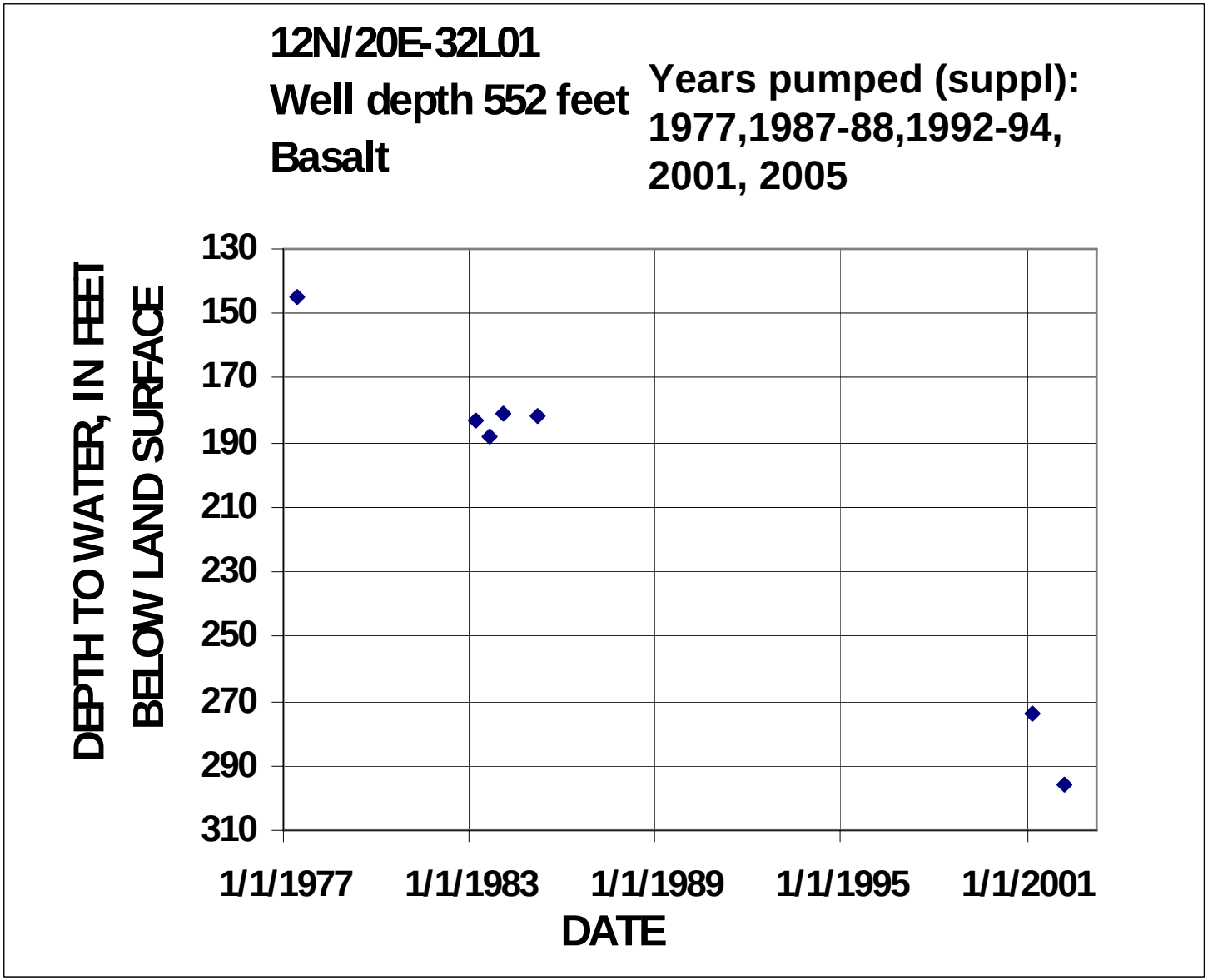
## *IRRIGATION WELL: STANDBY/RESERVE RIGHT, PUMPS DROUGHT YEARS*

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MANY BELIEVE GROUND WATER WILL SUPPLEMENT SURFACE-WATER SUPPLIES IN A WARMING WORLD BECAUSE GW IS ‘BUFFERED’ AGAINST CHANGING CLIMATE

# SENSITIVITY OF RECHARGE AND GROUND WATER TO CLIMATE CHANGE

SOME EXAMPLES

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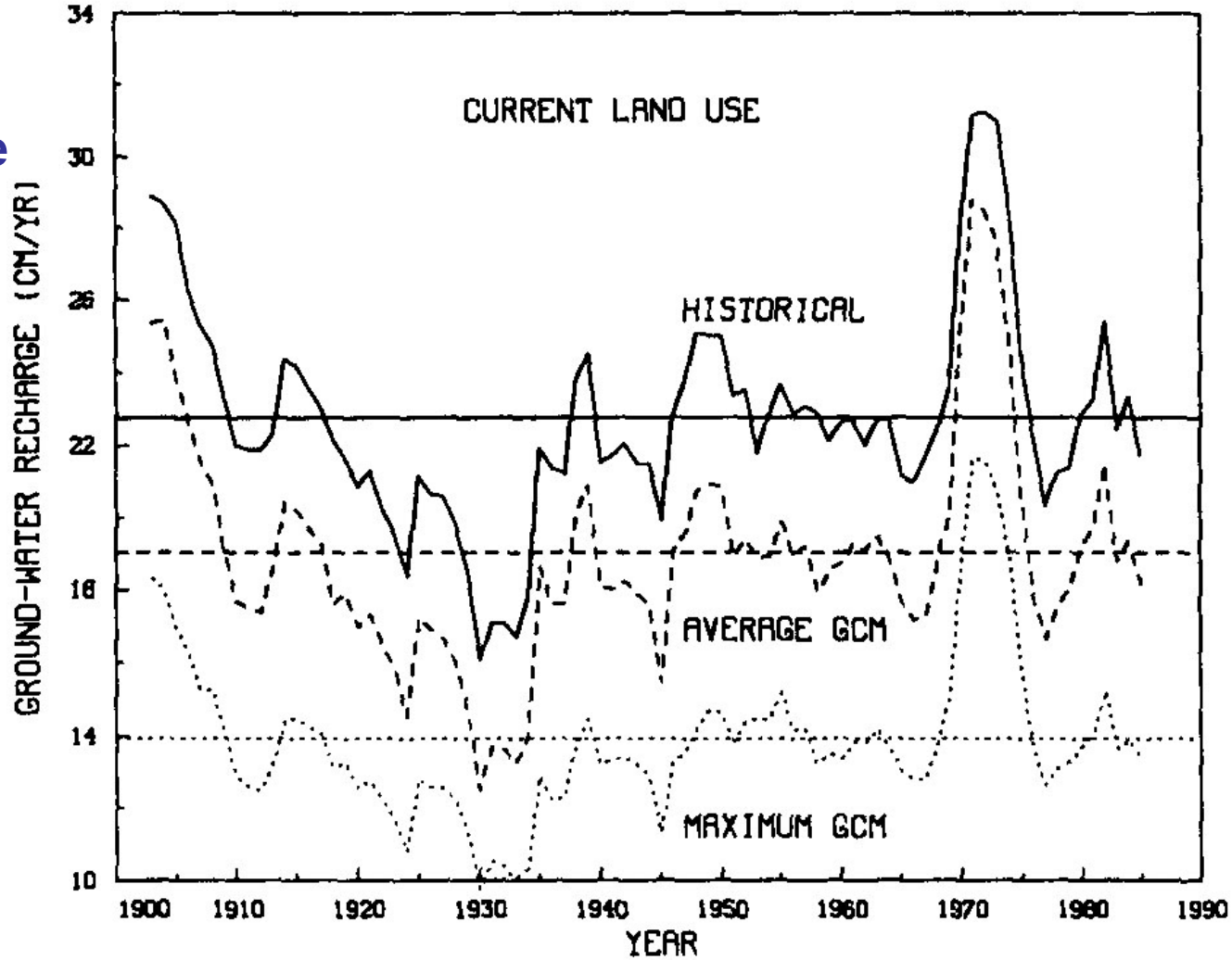
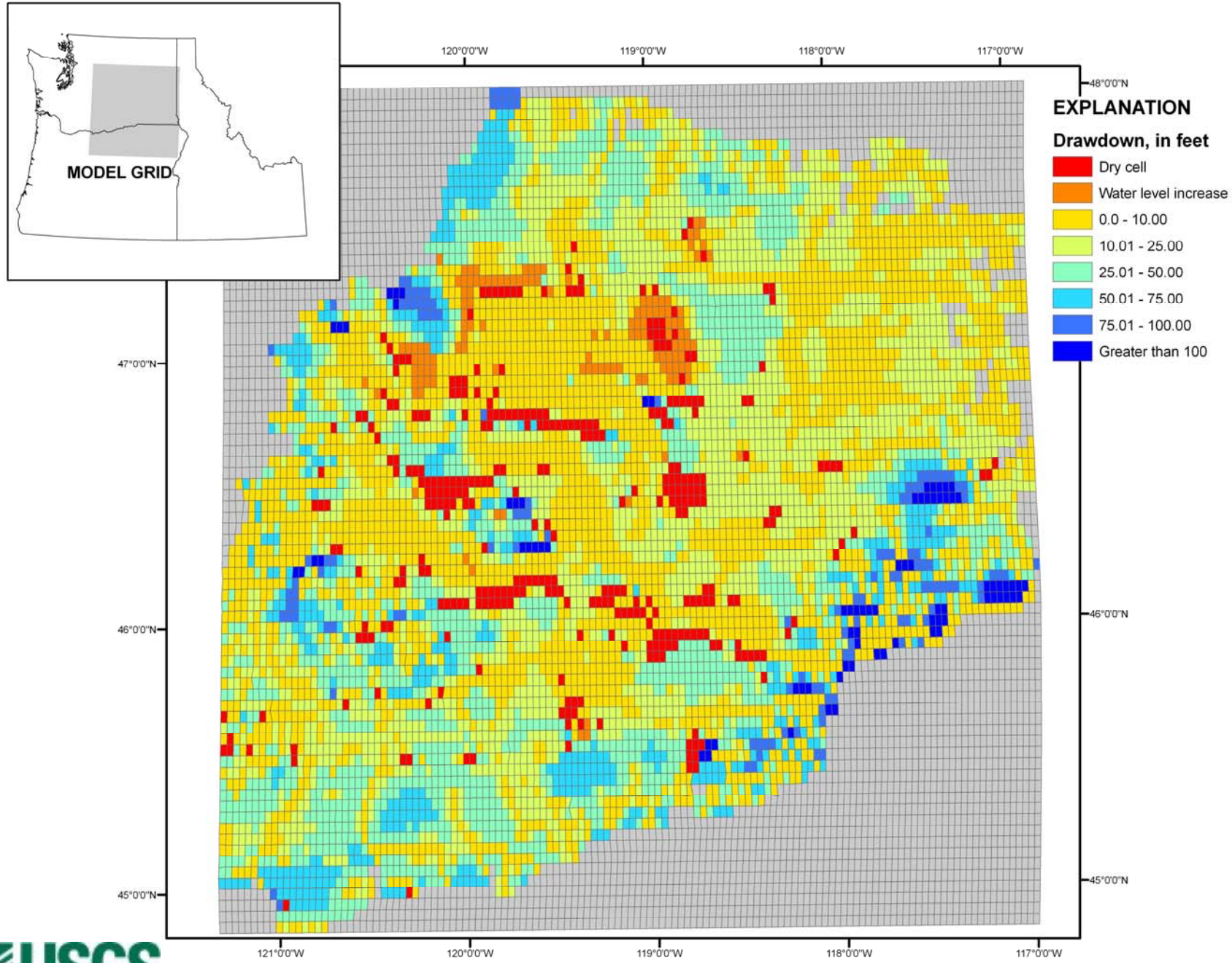
**93 ft$^3$/s reduction in mean recharge**

**ASSUMES IRRIGATION STARTS APRIL 1**




FIVE-YEAR MOVING AVERAGES OF GROUND-WATER RECHARGE

Vaccaro, 1992, JGR

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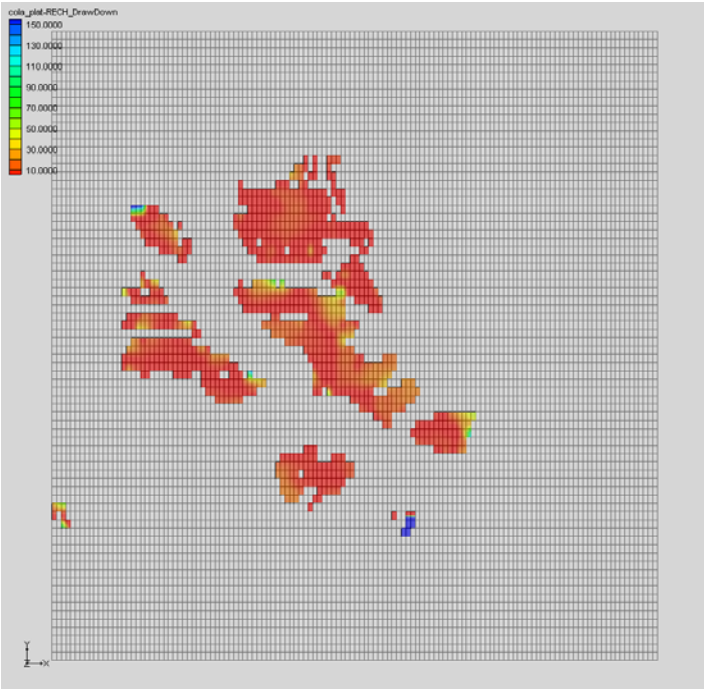
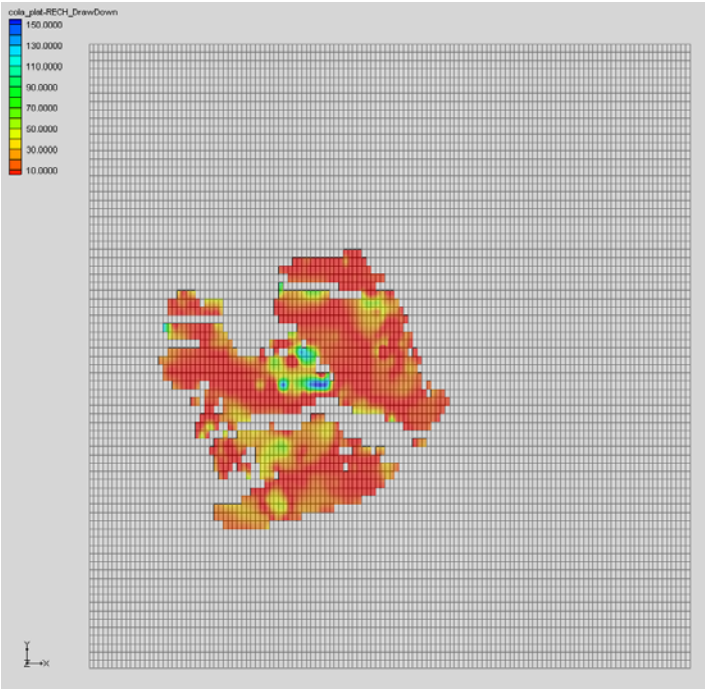
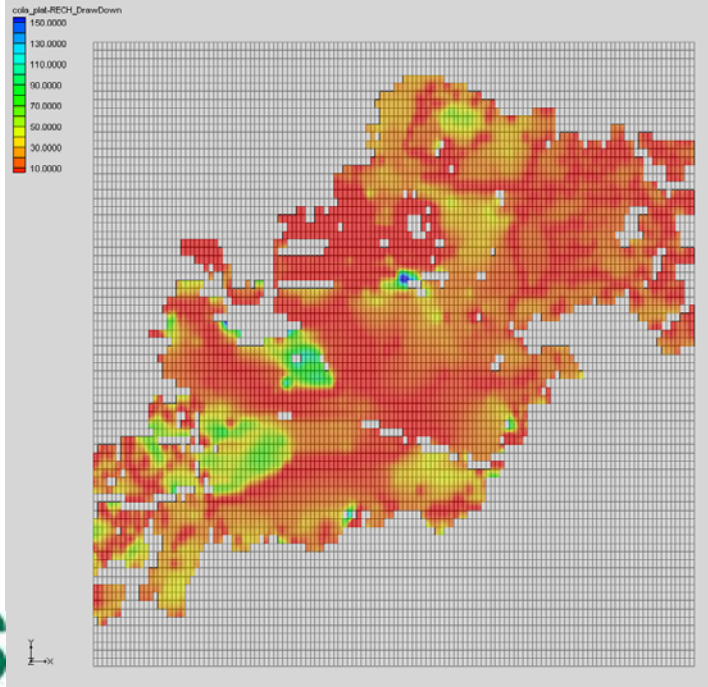
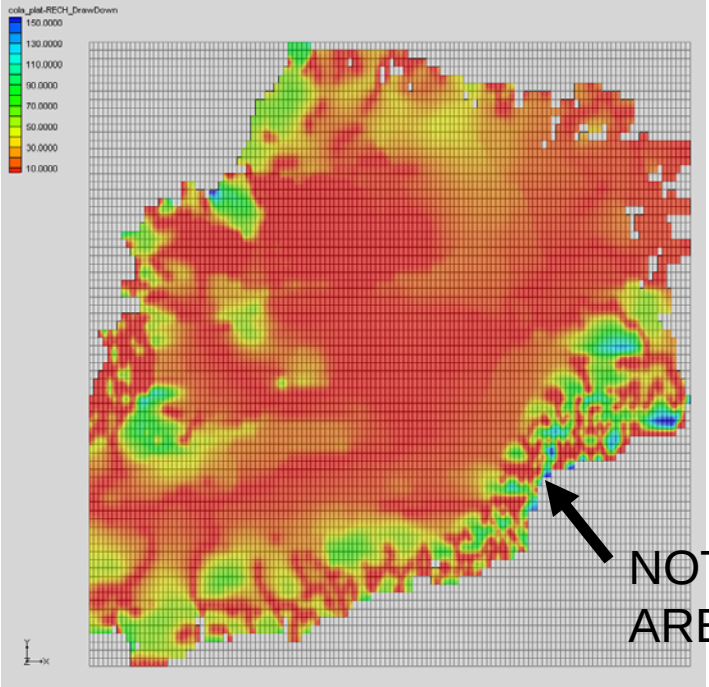
# DRAWDOWN IN WATER LEVELS, 15% DECREASE IN RECHARGE




USGS
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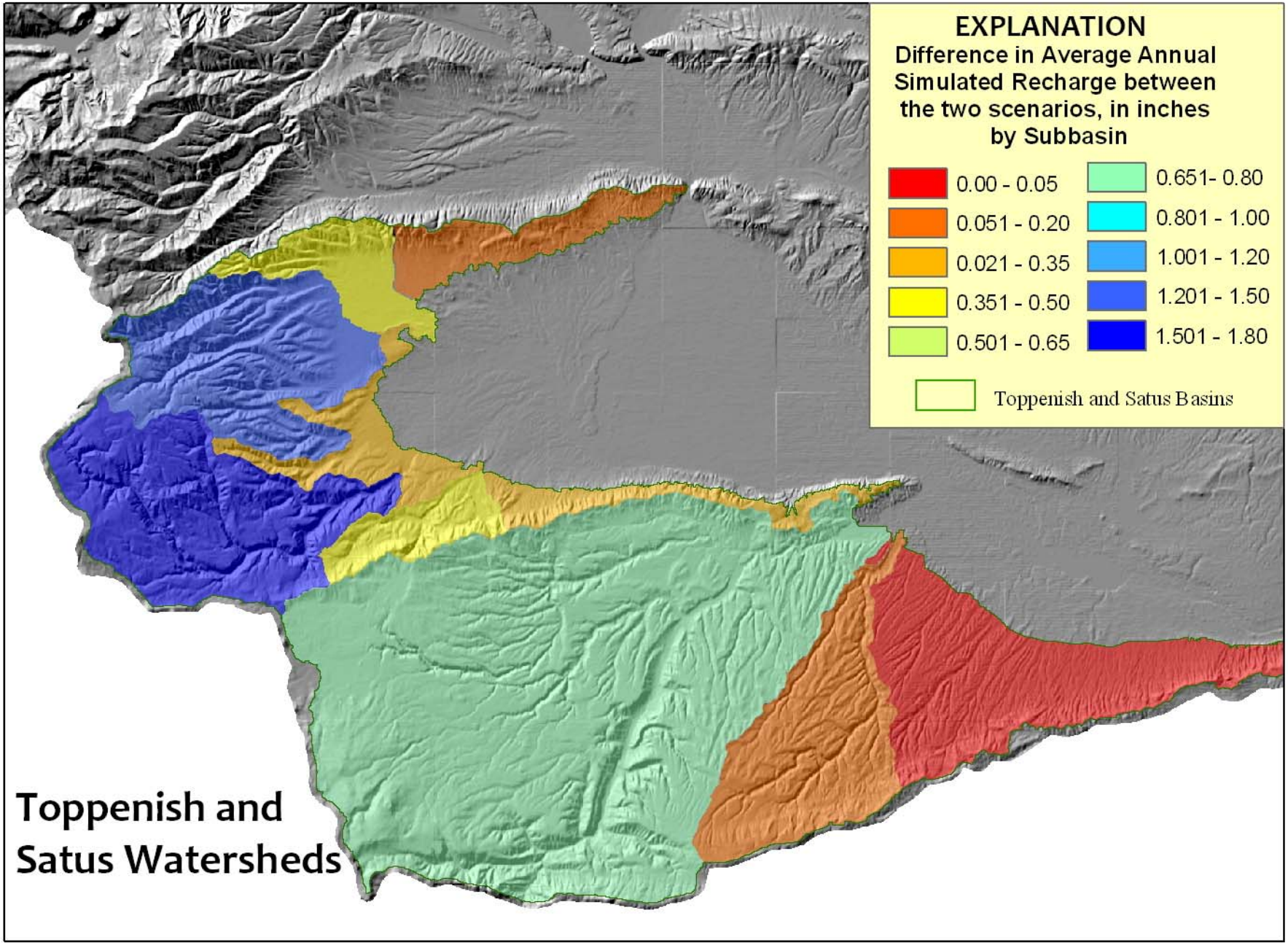
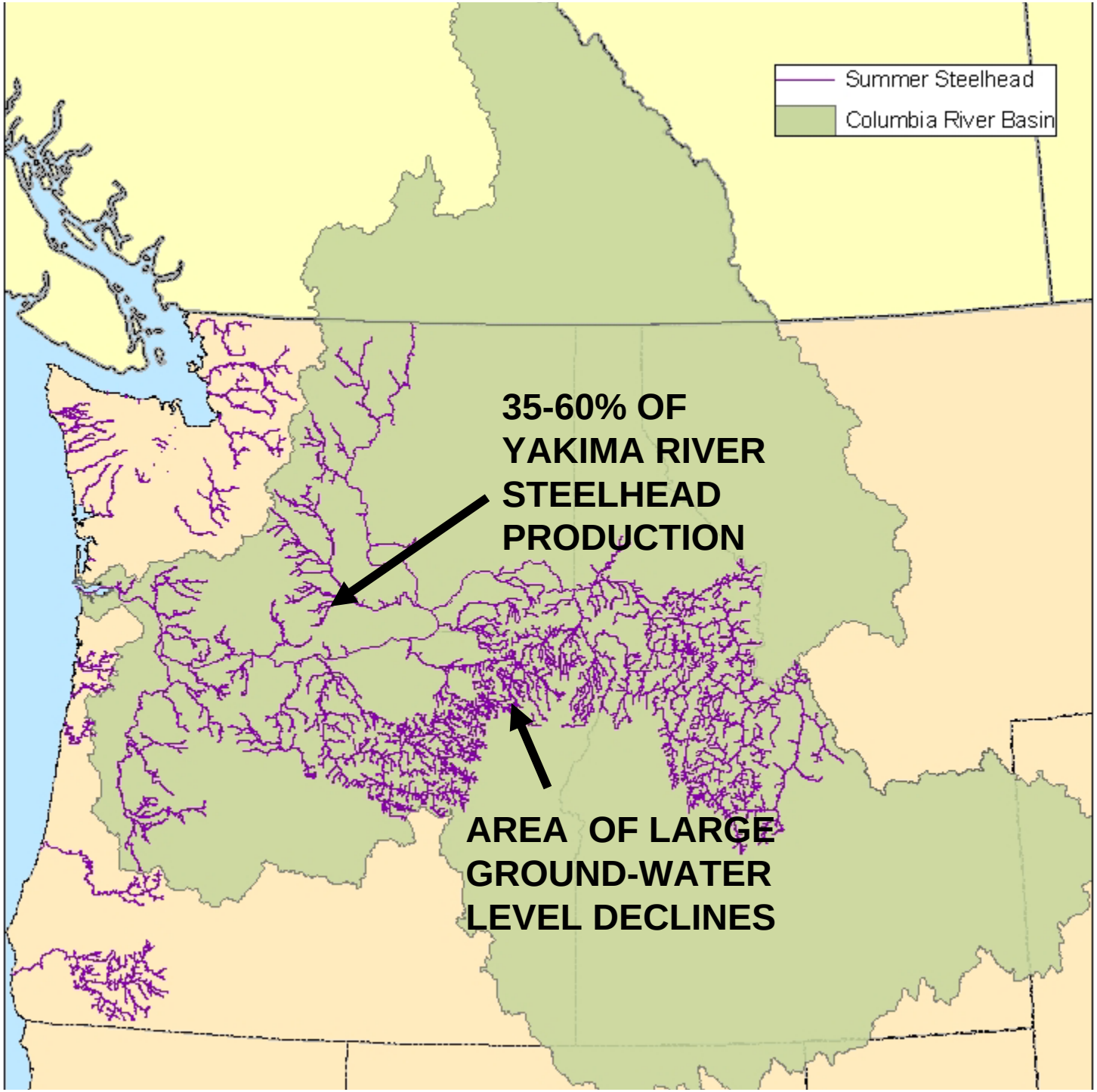
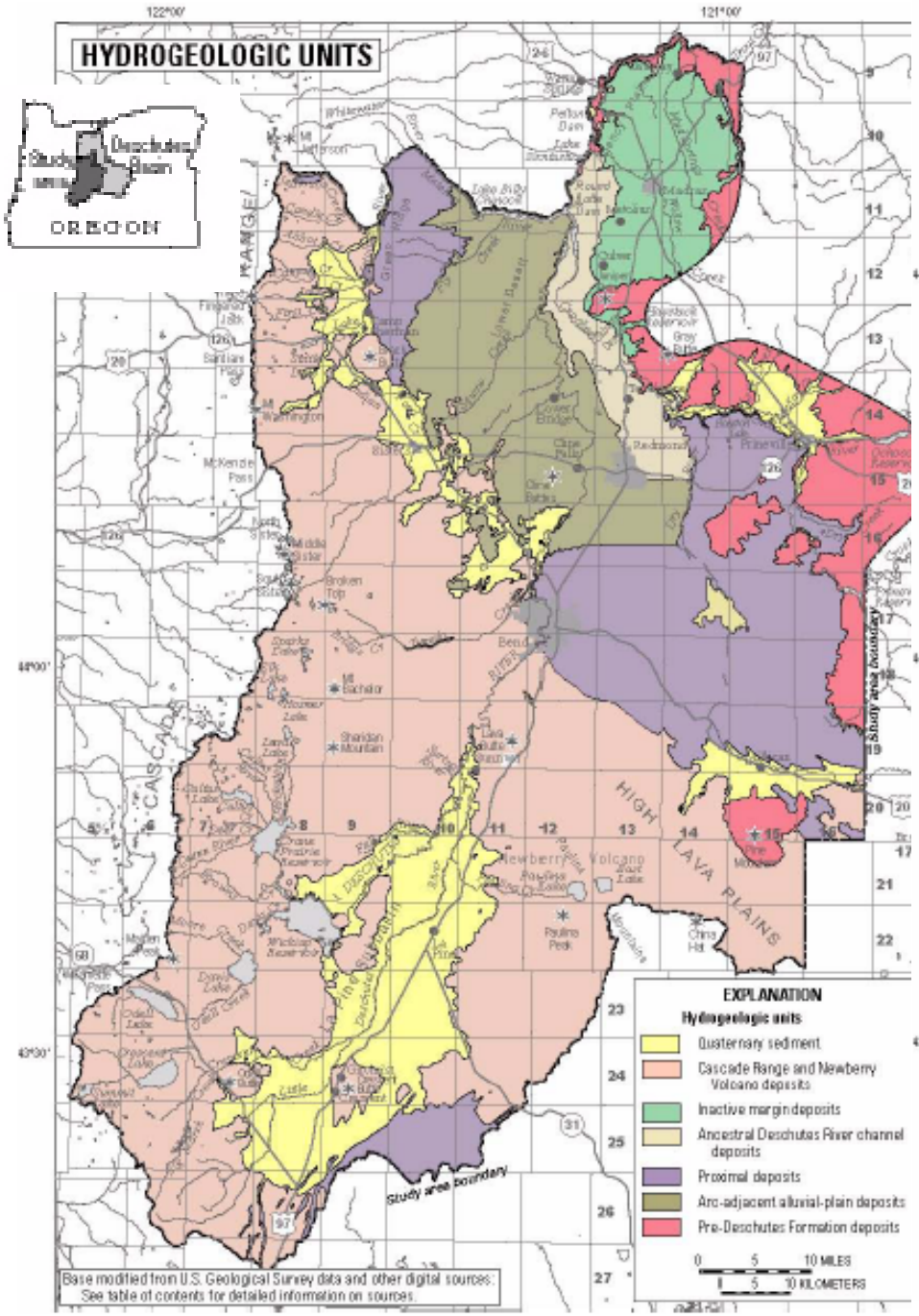
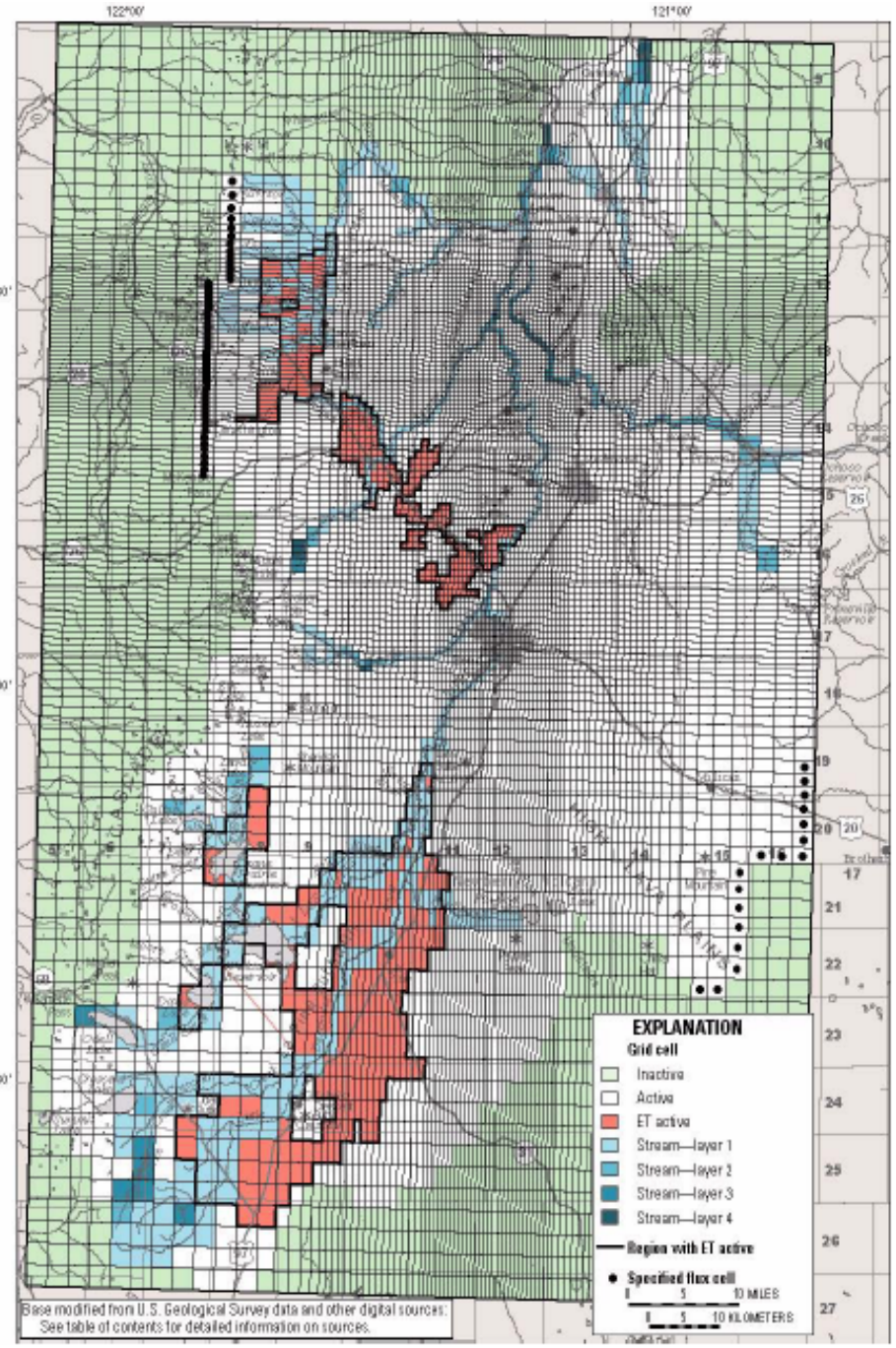



SENSITIVITY OF 3 °C INCREASE ON RECHARGE, YAKIMA RIVER BASIN


Summer Steelhead
Columbia River Basin
35-60% OF
YAKIMA RIVER
STEELHEAD
PRODUCTION
AREA OF LARGE
GROUND-WATER
LEVEL DECLINES

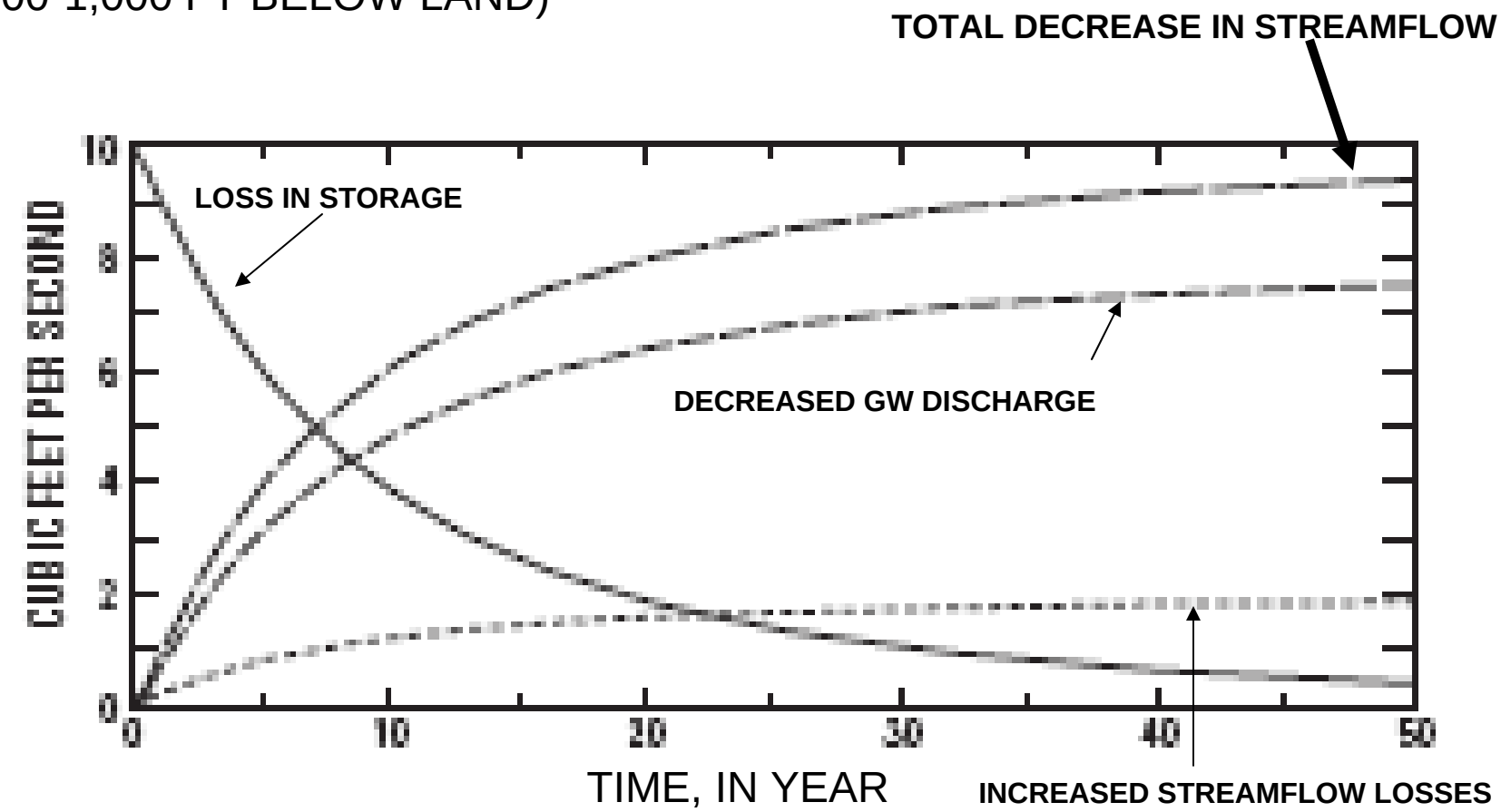



Gannett and Lite, 2004, USGS, SIR

LAYER 7, 300 FT

(700-1,000 FT BELOW LAND)

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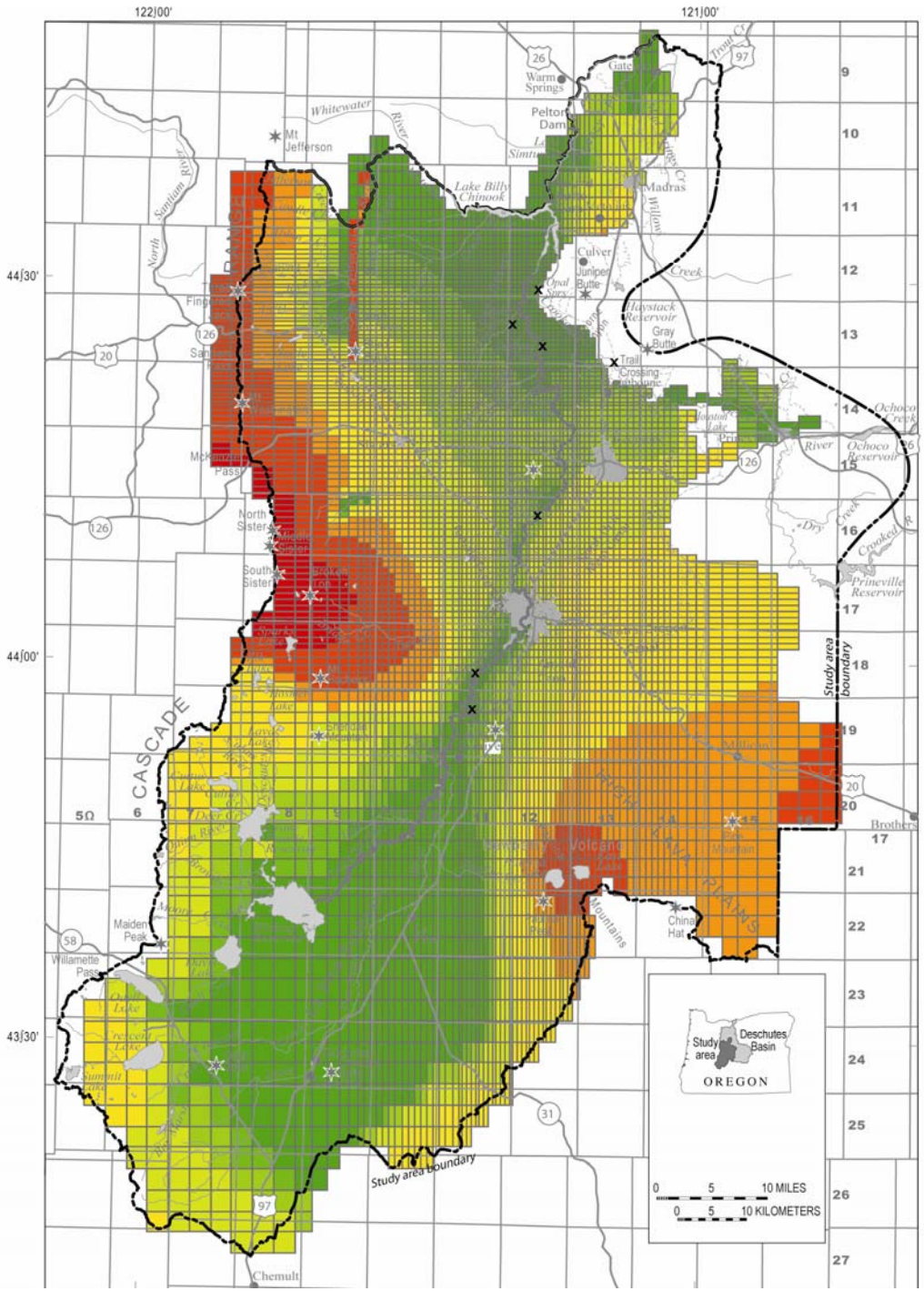


Simulated drop in hydraulic head in the upper Deschutes River Basin resulting from a 15 percent reduction in ground-water recharge

Change in Head, in feet

- 0 - 11
- 12 - 17
- 18 - 28
- 29 - 51
- 52 - 97
- 98 - 188
- 189 - 370
- 371 - 735

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FRACTION OF PUMPAGE CAPTURED FROM STREAMS AFTER 10-YRS

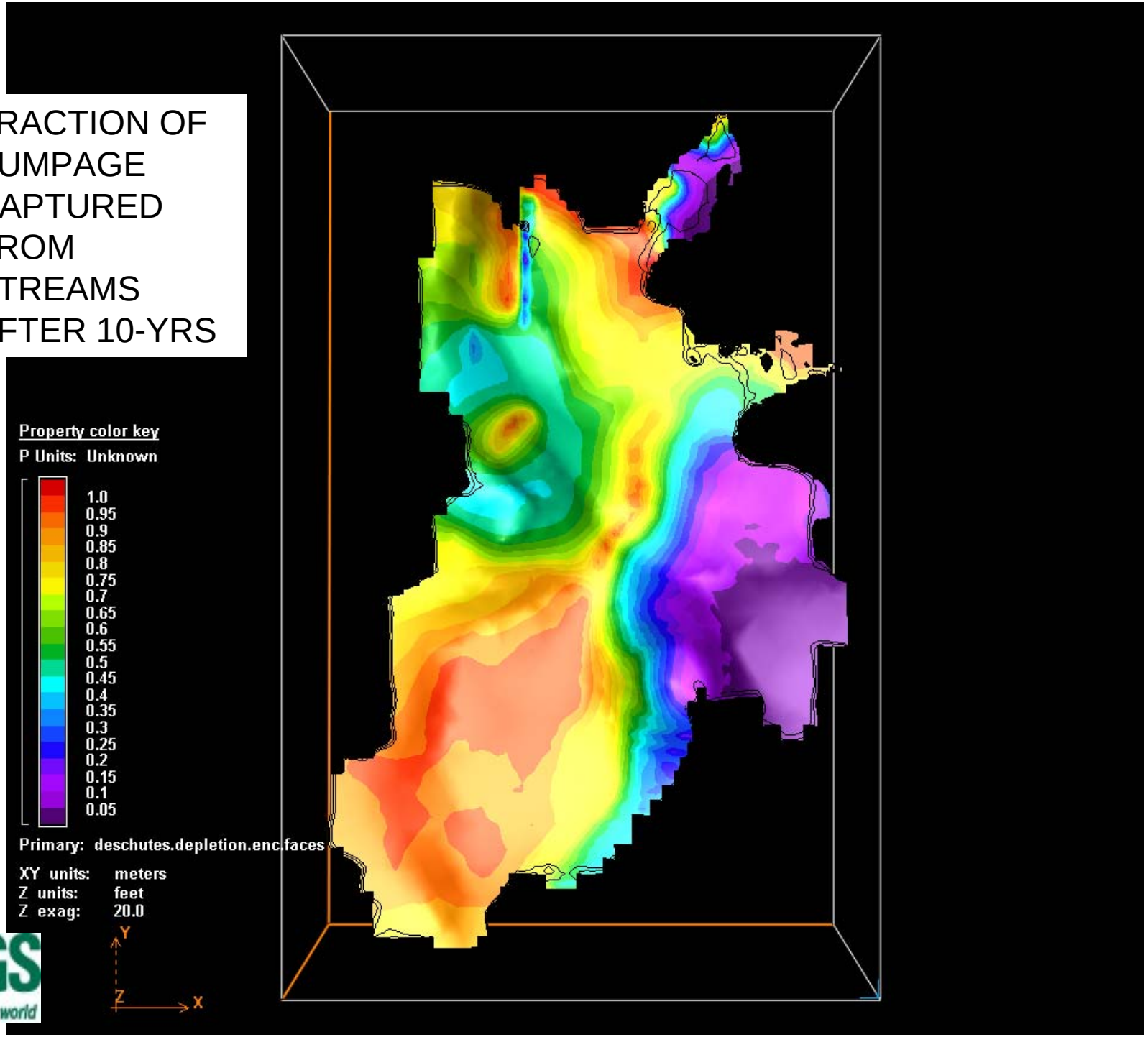


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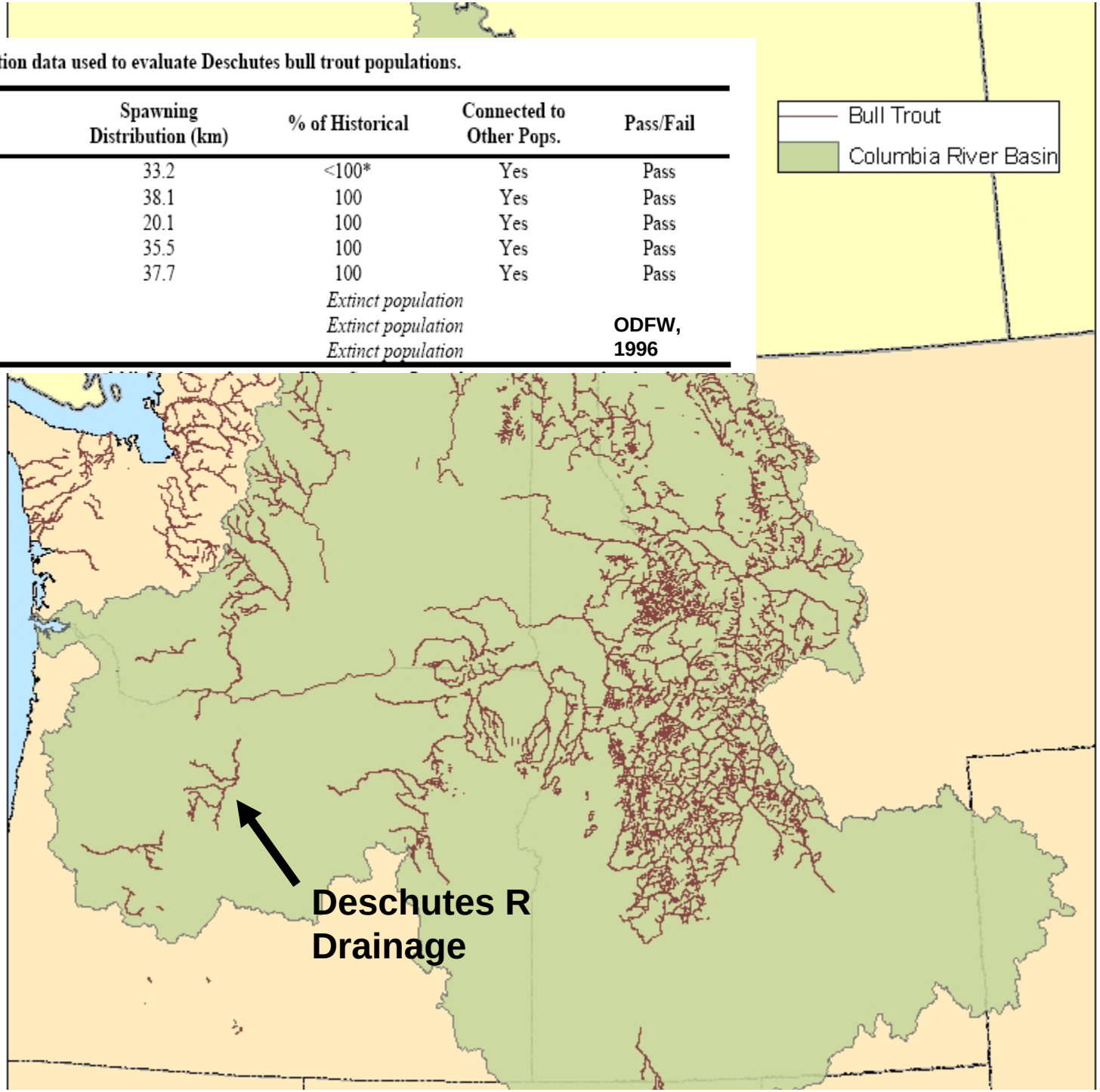
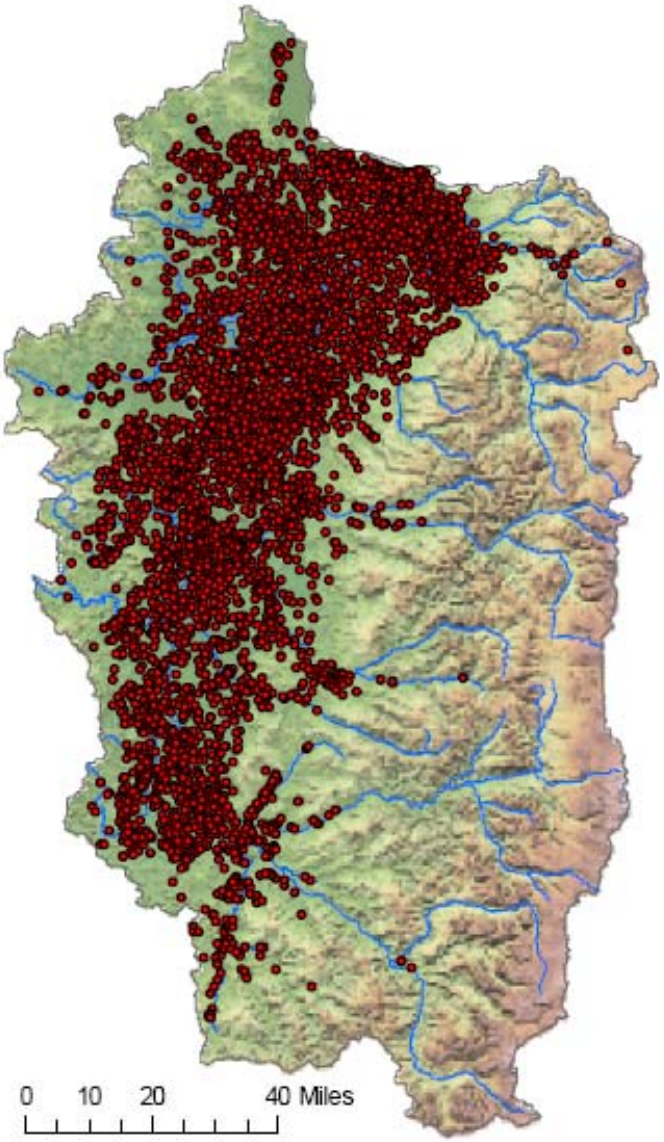
Table 2. Distribution data used to evaluate Deschutes bull trout populations.

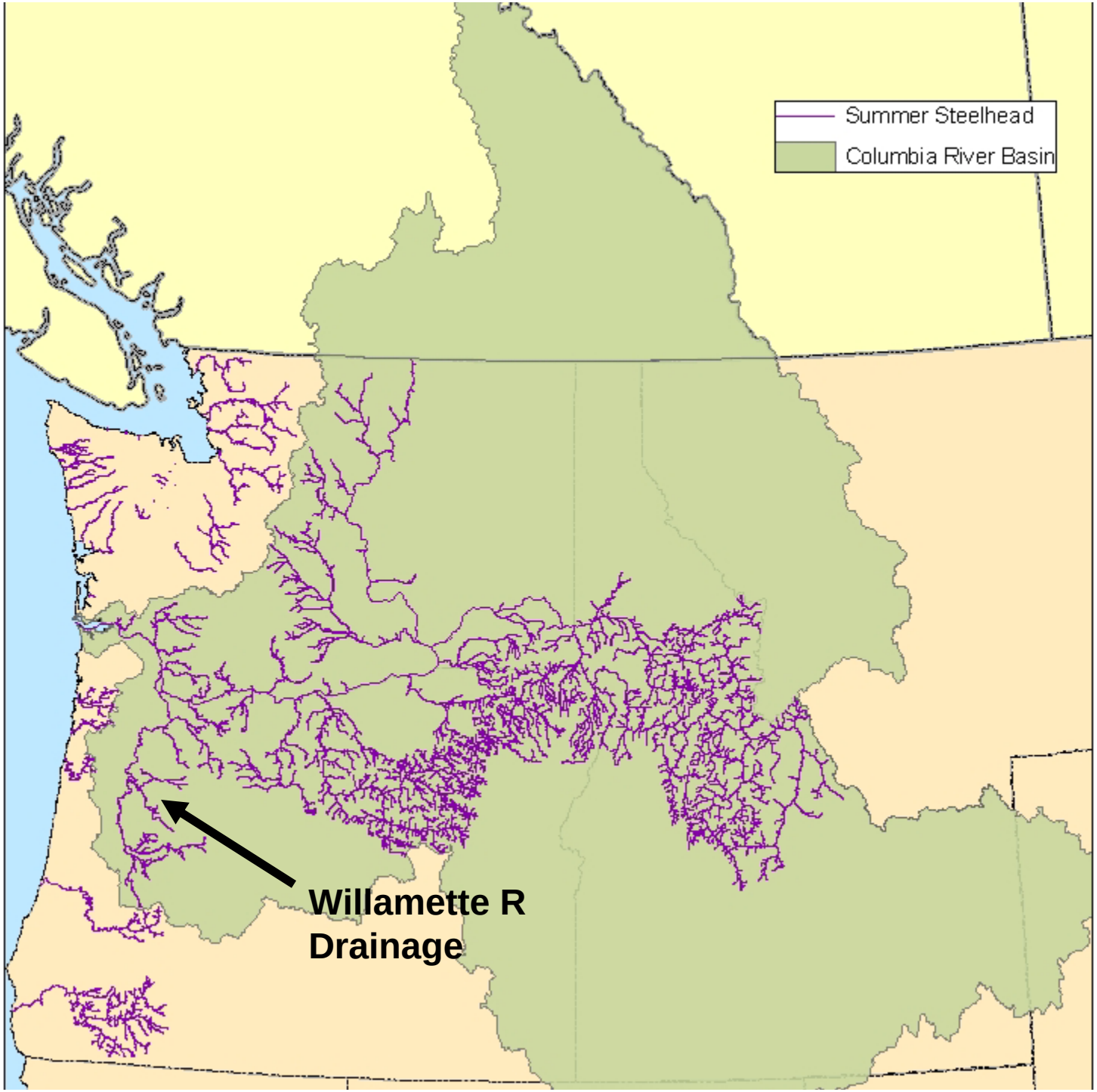
| Population | Spawning Distribution (km) | % of Historical | Connected to Other Pops. | Pass/Fail |
|---|---|---|---|---|
| Warm Springs | 33.2 | <100* | Yes | Pass |
| Shitike | 38.1 | 100 | Yes | Pass |
| Whitewater | 20.1 | 100 | Yes | Pass |
| Jefferson Complex | 35.5 | 100 | Yes | Pass |
| Jack Complex | 37.7 | 100 | Yes | Pass |
| Suttle Lake | | *Extinct population* | | |
| Upper Deschutes | | *Extinct population* | | |
| Crescent Lake | | *Extinct population* | | |

**ODFW, 1996**

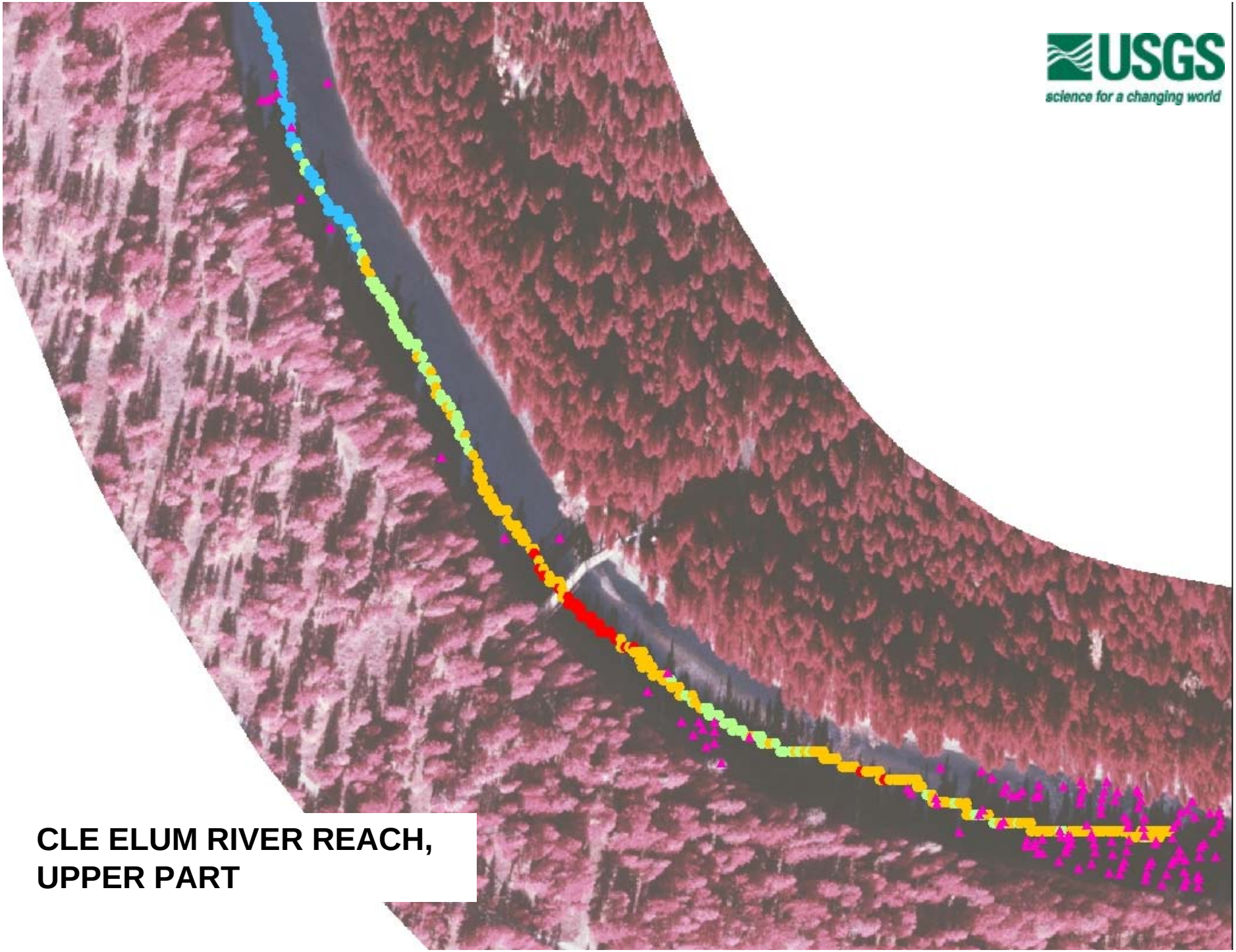


**Wells in the Willamette Valley**



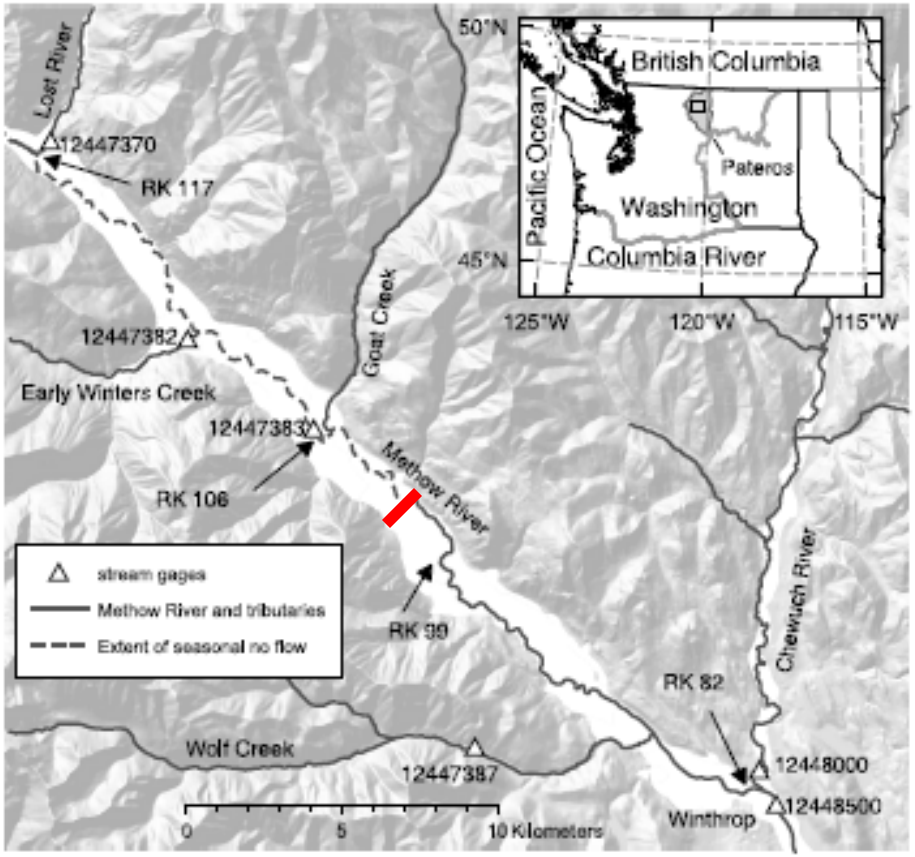

Summer Steelhead
Columbia River Basin
Willamette R
Drainage

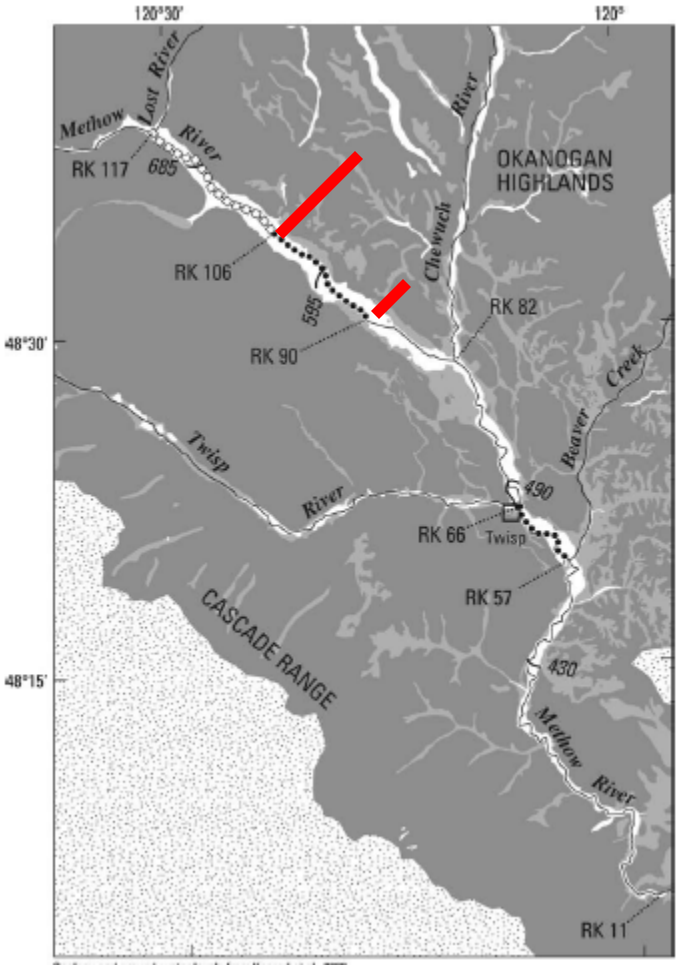
# A MORE LOCAL LOOK AT GROUND-WATER DISCHARGE AND CLIMATE IMPACTS



**CLE ELUM RIVER REACH, UPPER PART**

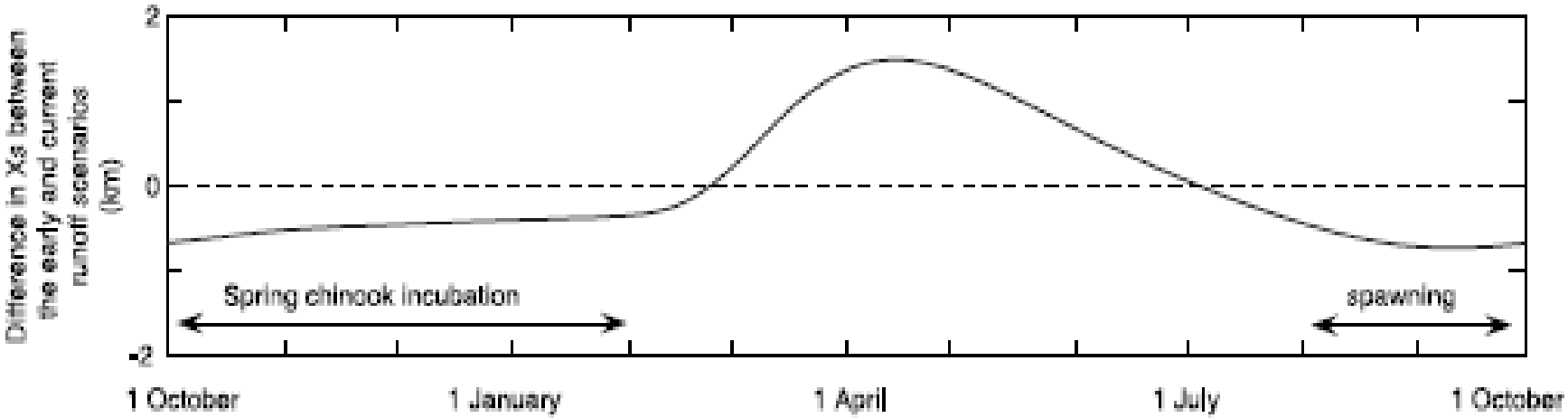
# Methow River, North Cascades, Washington




Konrad, 2006, WRR

DIFFERENCE IN UPSTREAM EXTENT OF GAINING REACH BETWEEN CURRENT AND EARLIER RUNOFF SCENARIOS




Konrad, 2006, WRR

# SOME ENVIRONMENTAL ASPECTS OF DECREASED GW DISCHARGE

(QUANTITY AND SPATIAL DISTRIBUTION)

**IMPACTS ON:**

**SPAWNING AREAS**

**REFUGIA DURING SALMONID MIGRATION (DECREASED CONNECTIONS)**

**REARING AREAS (LESS)**

**SLOW VELOCITY--SHALLOW WATER AREAS (MORE DEWATERING)**

**CREATION OF MIGRATORY BARRIERS**

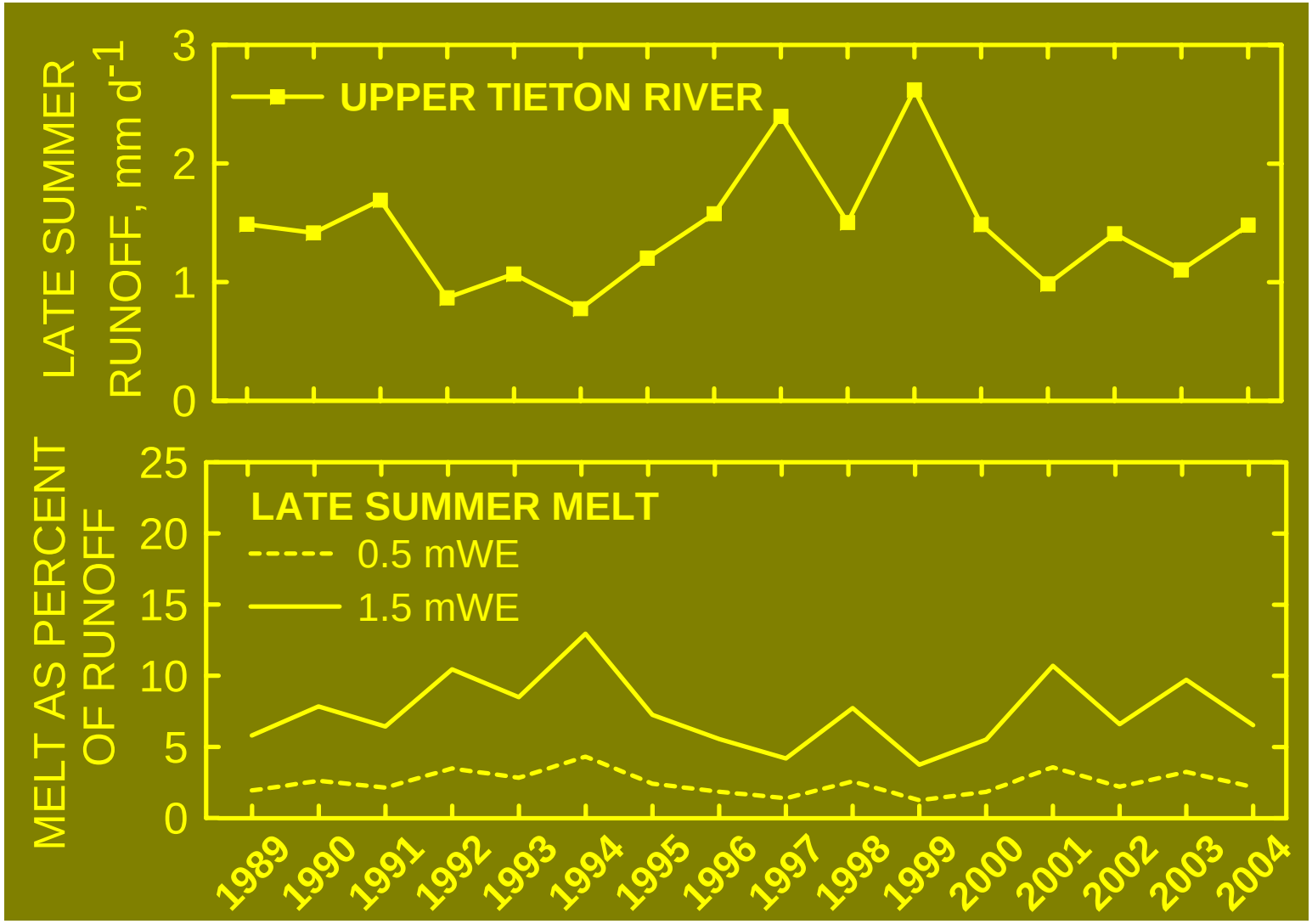
**RECRUITMENT OF BLACK COTTONWOODS**

**LOSS OF RIPARIAN HABITAT**

# EXAMPLE: ENVIRONMENTAL ASPECT

TIETON RIVER HAS THE HEALTHIEST BULL TROUT STOCK IN THE YAKIMA RIVER BASIN

# GLACIER MELT CONTRIBUTION TO LATE SUMMER RUNOFF

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# GLACIER THICKNESS CHANGE, 1970-2004

**10 MILLION CUBIC METERS OF WATER LOST FROM THE GOAT ROCKS GLACIERS**

(Bidlake, 2007)

SNOWMELT IS A MAJOR COMPONENT OF SPATIALLY DISTRIBUTED GROUND-WATER RECHARGE -- 30-70% OF MELT

PROVIDES COLD WATER FOR LATER DISCHARGE TO STREAMS AND PREVENTS WINTER ICING

DECREASING SNOWPACK

EARLIER RUNOFF

INCREASING ELEVATION OF SNOW TRANSITION ZONE

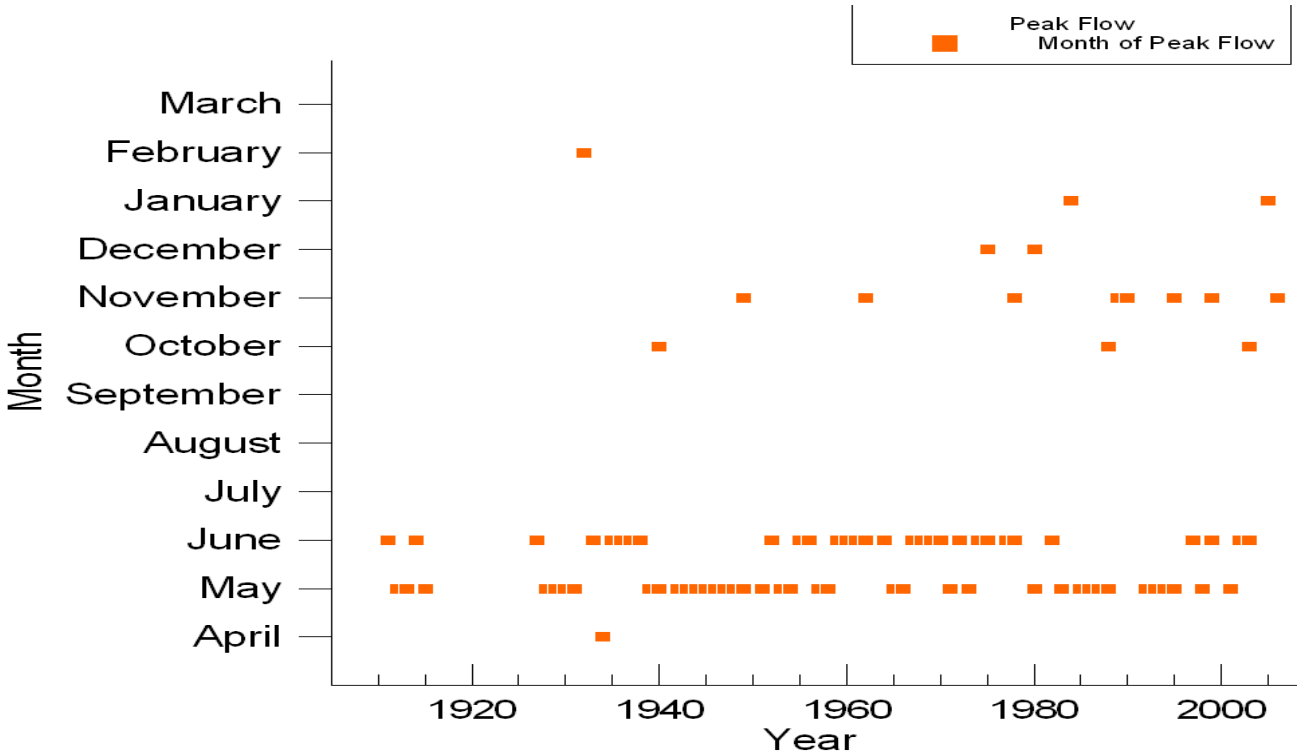
INCREASED ET

↓

DECREASED RECHARGE

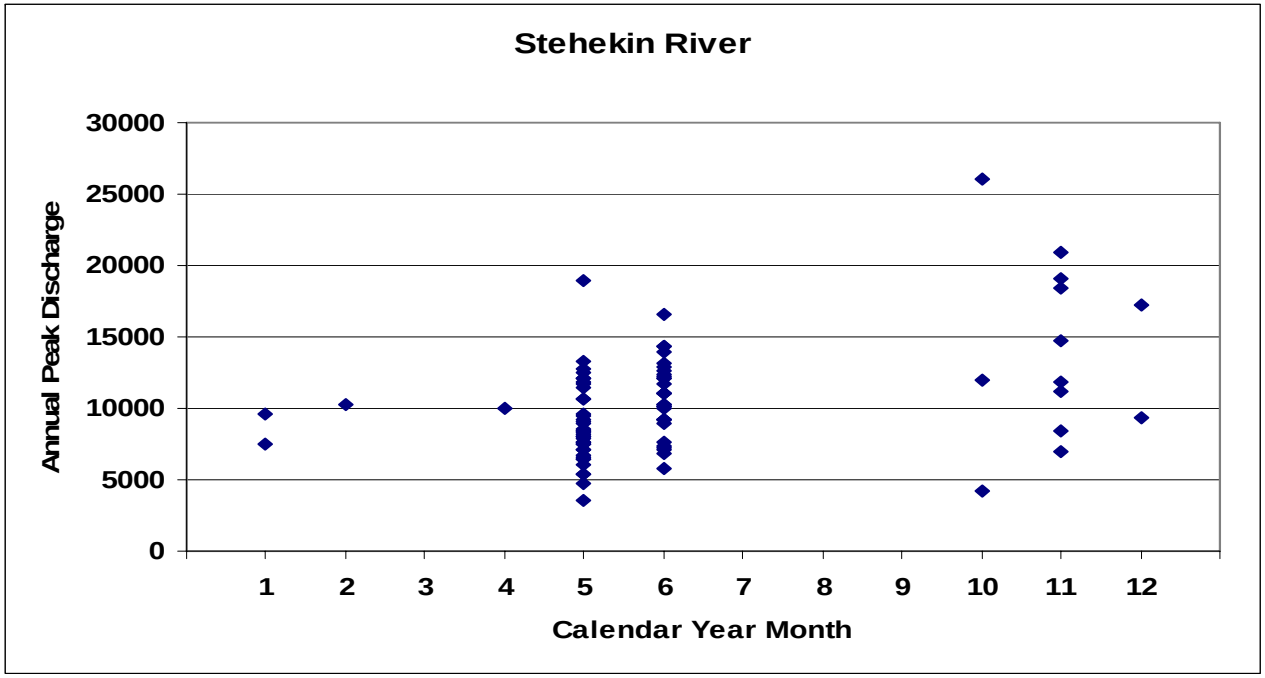
WARMER RECHARGE

DECREASED GROUND-WATER DISCHARGE




INCREASE IN RAIN-ON SNOW EVENTS, STEHEKIN R, NORTH CASCADES NATIONAL PARK

**(Data from USGS, NWIS)**



INCREASED POPULATION
INCREASED NEED FOR IRRIGATION GW
(FEW BASINS HAVE ALLOCATABLE SW)

INCREASED PUMPAGE

↓

DECLINING WATER LEVELS

DECREASED GW DISCHARGE

# UNKNOWN BUT IMPORTANT QUESTIONS FOR ASSESSING CLIMATE IMPACTS ON GROUND WATER

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**POPULATION** – WHEN/WHERE: POPULATION GROWTH/MOVEMENT

RIVER VALLEYS, RURAL, LARGE CITIES??

**PRECIPITATION -** QUANTITY AND TIMING (DAILY IMPORTANT)

**LAND-COVER** – SPATIAL DISTRIBUTION WITH TIME f(precipitation)

**IRRIGATION METHODS** – RILL, DRIP, SURGE, WHEEL LINE, SPRINKLER

**CROPS** – TYPES, EXPANDING ACREAGE? DECREASING ACREAGE?

**TEMPERATURE LAPSE RATES** – DIMINISHING?

**OIL SUPPLIES** – INTRICATELY RELATED TO WATER, POPULATION MOVEMENT,

and AGRICULTURE

**CLIMATIC REGIME** – OREGON LAVA PLATEAU-SNAKE RIVER BASIN

**WATER POLICY/RIGHTS** – WILL POLICY OR LAWS CHANGE**?**

# WATER RIGHTS???

## IRRIGATION: APRIL 1

(EACH INDIVIDUAL RIGHT)

**LEGAL**—BOTH SW AND GW WATER CODES

**INSTITUTIONAL**—OVERLAPPING MANDATES/POLICY

**SOCIAL**—DRINKING WATER/ENVIRONMENT vs

AGRICULTURAL INTERESTS vs TRIBAL

INTERESTS (TRIBAL TRUST, WINTER

DOCTRINE, TREATY RIGHTS)

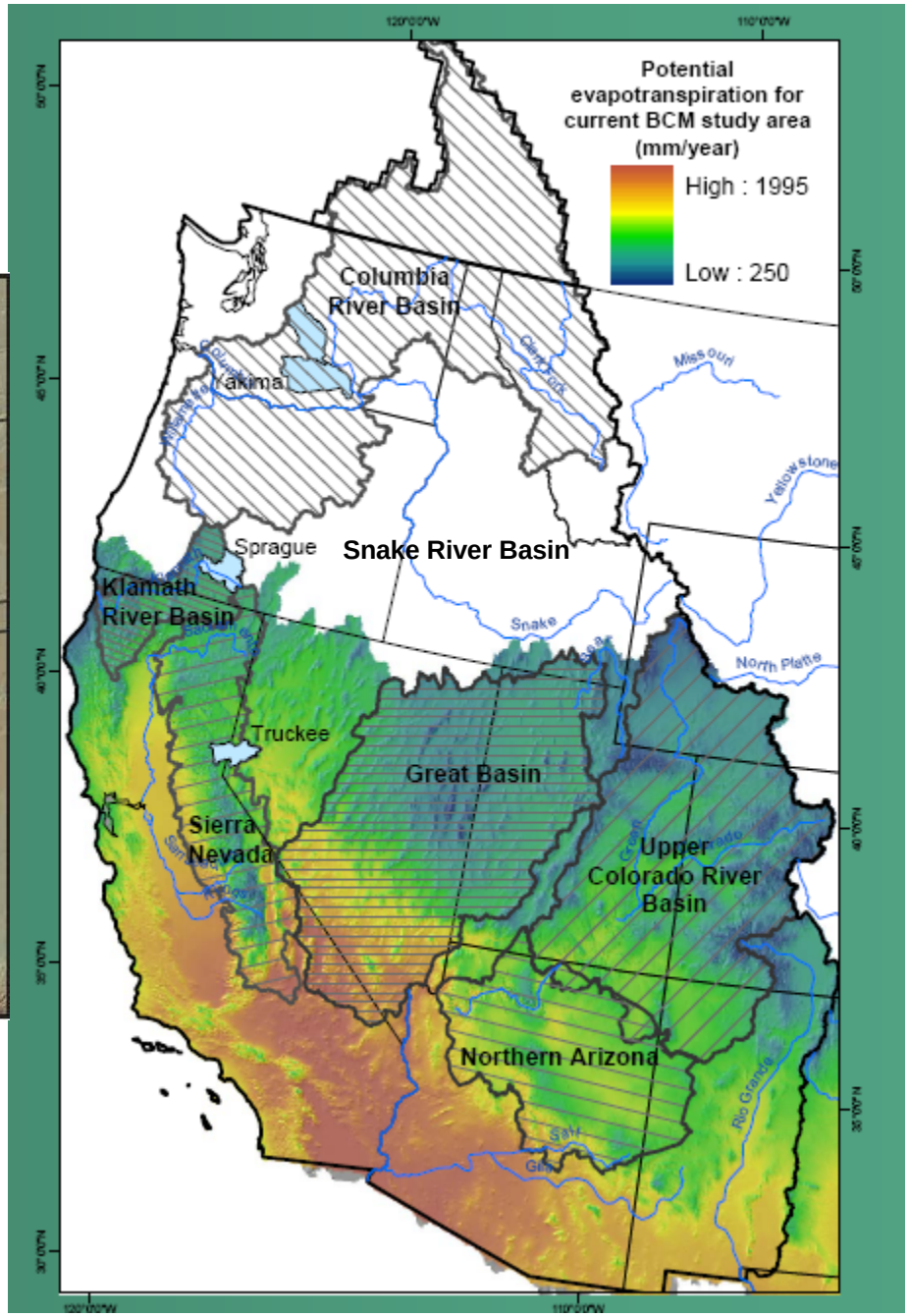
DRINKING WATER vs ENVIRONMENT

**ECONOMIC**—NONUSE VALUE, COST OF WATER

Nonuse Values: values individuals hold for a resource even if they will never actually use it--Reclamation, 2008 (e.g., threatened and endangered species)

# END WITH A THOUGHT

# SOUTHWEST STUDY AREA: GROUND-WATER RECHARGE

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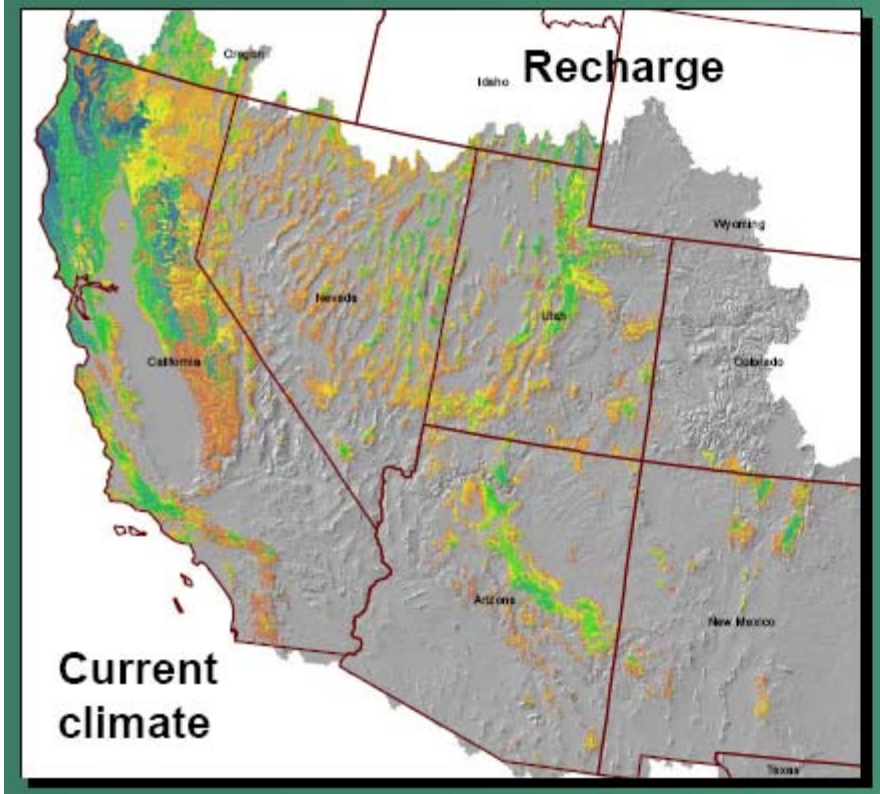
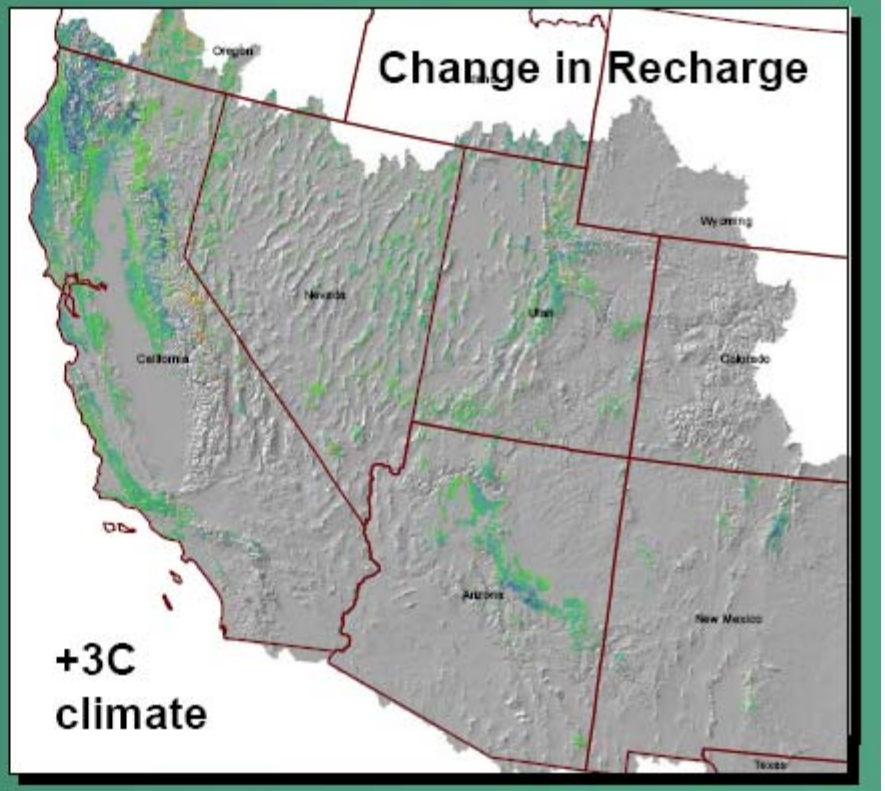
# Change in Recharge




(mm/yr)

- < 0.01
- 0.1 - 1
- 1 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 75
- 75 - 100
- 100 - 200
- 200 - 300
- 300 - 500
- 500 - 750
- 750 - 1,200
- > 1,200

(mm/yr)

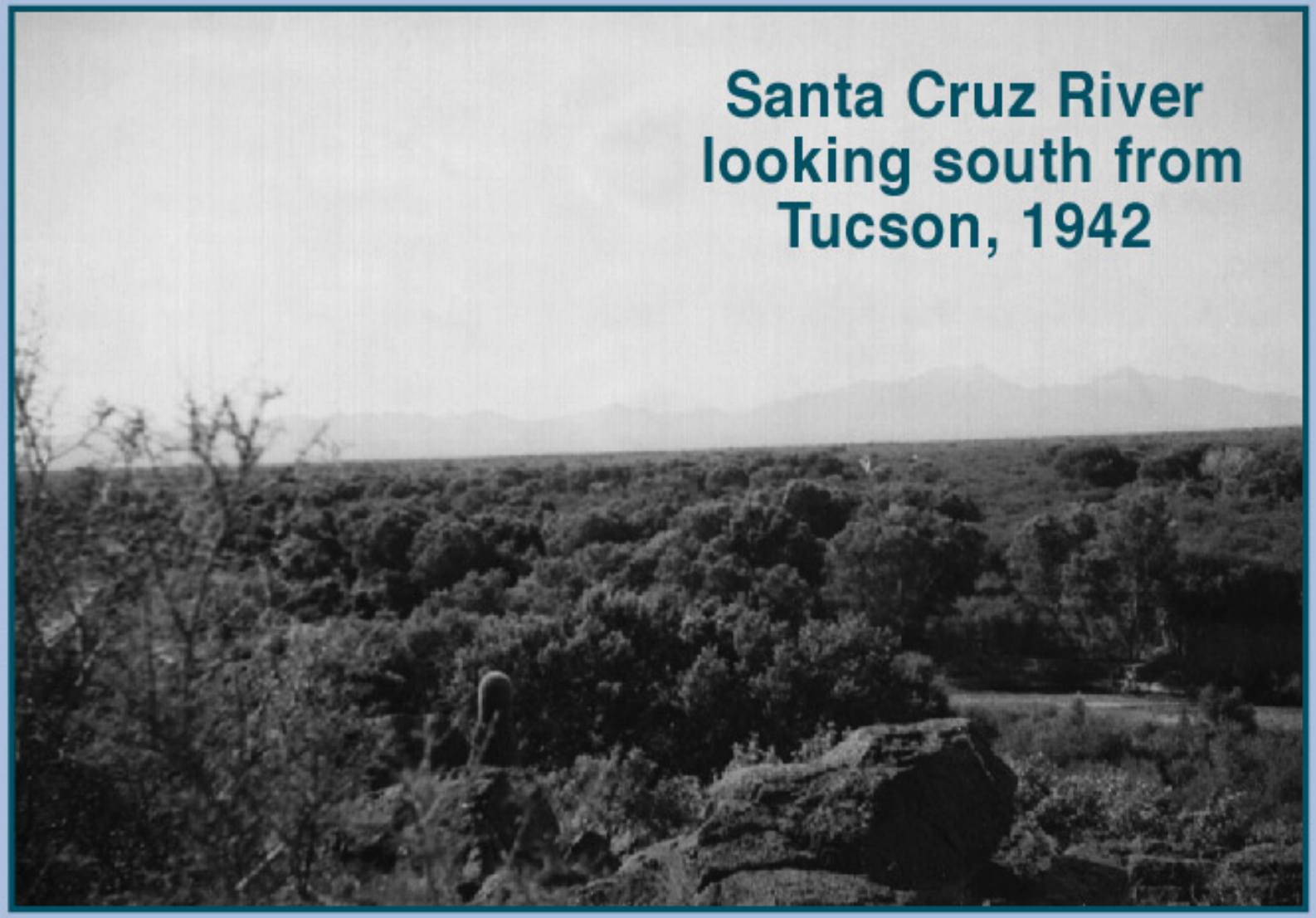
- 320 - 100
- 100 - 25
- 25 - 10
- 10 - -10
- -10 - -25
- -25 - -50
- -50 - -100
- -100 - -150
- -150 - -520

# The Future Is Drying Up

Simon Norfolk/NB Pictures, for The New York Times

JON GERTNER, New York Times, 2008

# PROJECTED NORTHWARD MIGRATION OF POPULATION


Santa Cruz River
looking south from
Tucson, 1942

Santa Cruz River
looking south from
Tucson, 1989
IS THIS ALSO OUR FUTURE