Climate Change:
What We Know and Don't Know, and Implications for Water Resources and Source Water Protection

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Western States Source Water & Ground Water Protection Forum
Asilomar, CA

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Outline

- Overview of climate change
  - What we’ve seen so far
  - What we know (and don’t know) about climate changes for the coming decades
- Climate change implications for water resources and water users
- Implications for source water protection

Sequence of Key Climate Change Questions

1. What changes in climate are expected?
   – Wetter or dryer? How much warmer? By when?

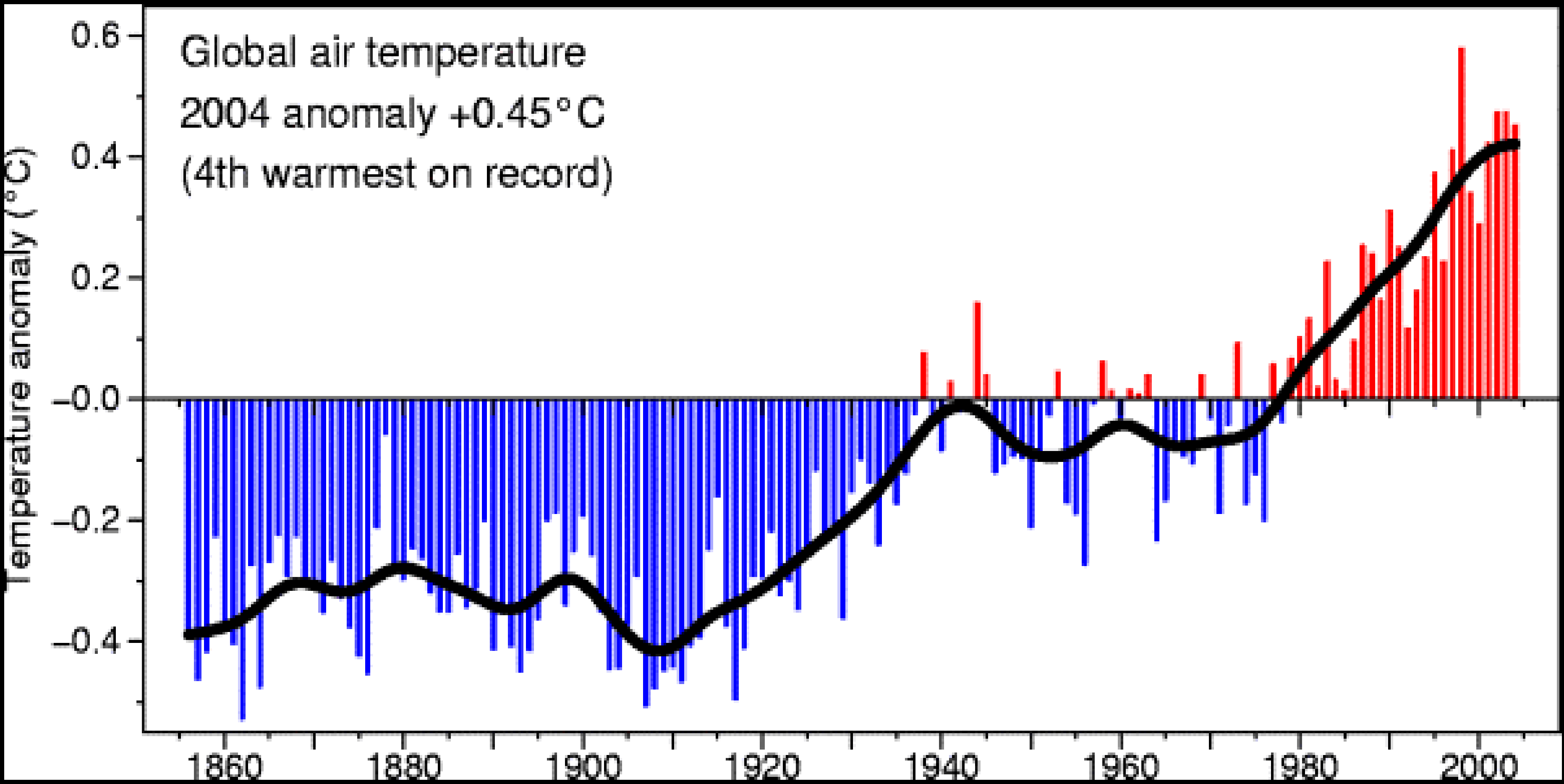
2. How will these changes impact the environment in which water users (e.g., utilities, fish) operate?
   – Steamflows and snowpack? Watershed conditions? Water quality? User/ utility customer demands?

3. How vulnerable are water users to these changes in their operating environment?
   – Which risks apply? Which risks are most critical?

4. What can and should water users do to manage their high risk vulnerabilities?
   – How to avoid, postpone, or adapt to critical risks?

The Climate is Warming

And, This Has Been Conclusively Linked to Human Activities by the IPCC



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Source: IPCC, 2007

The Climate is Warming:
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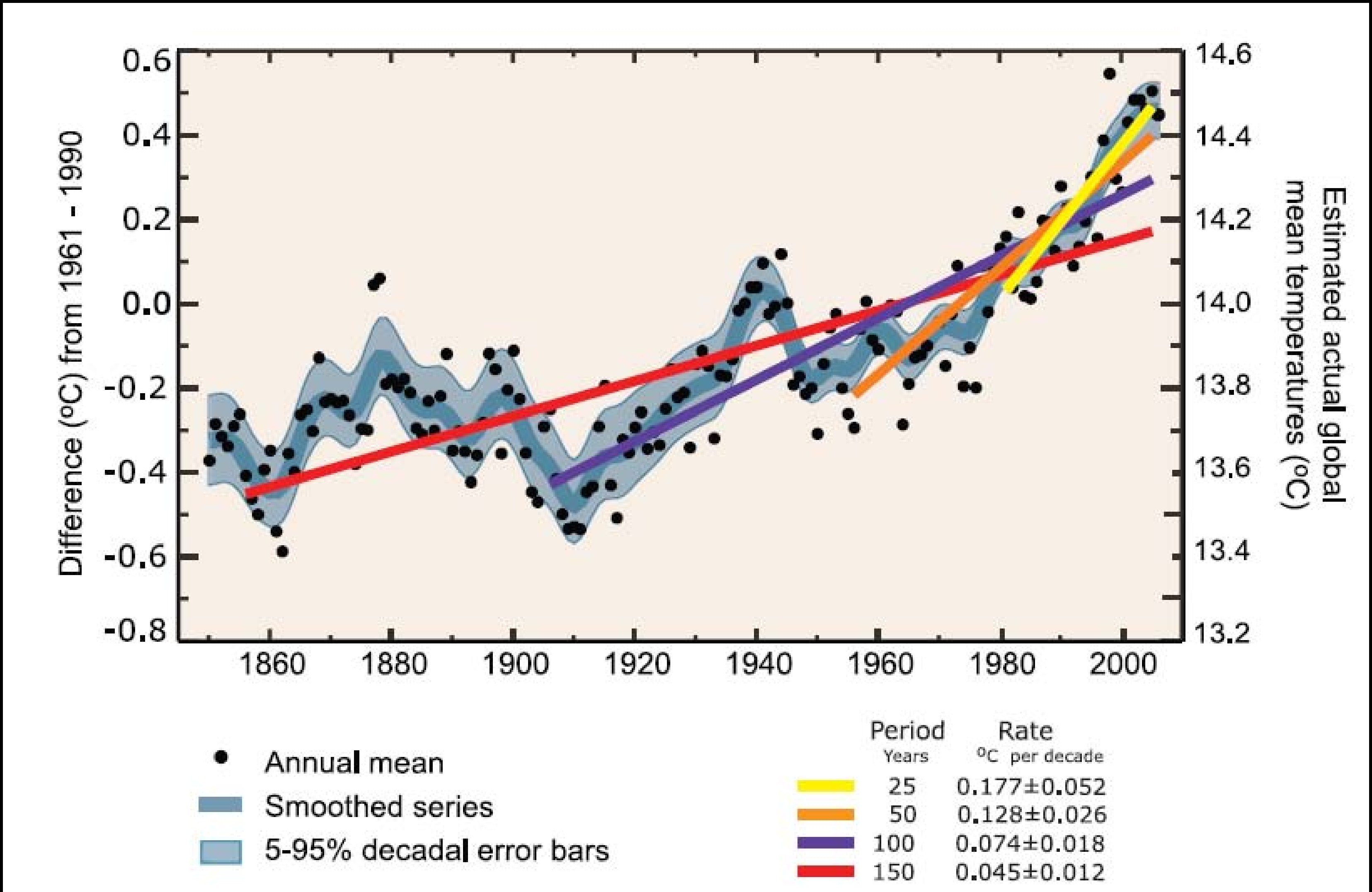

Source: IPCC, 2007

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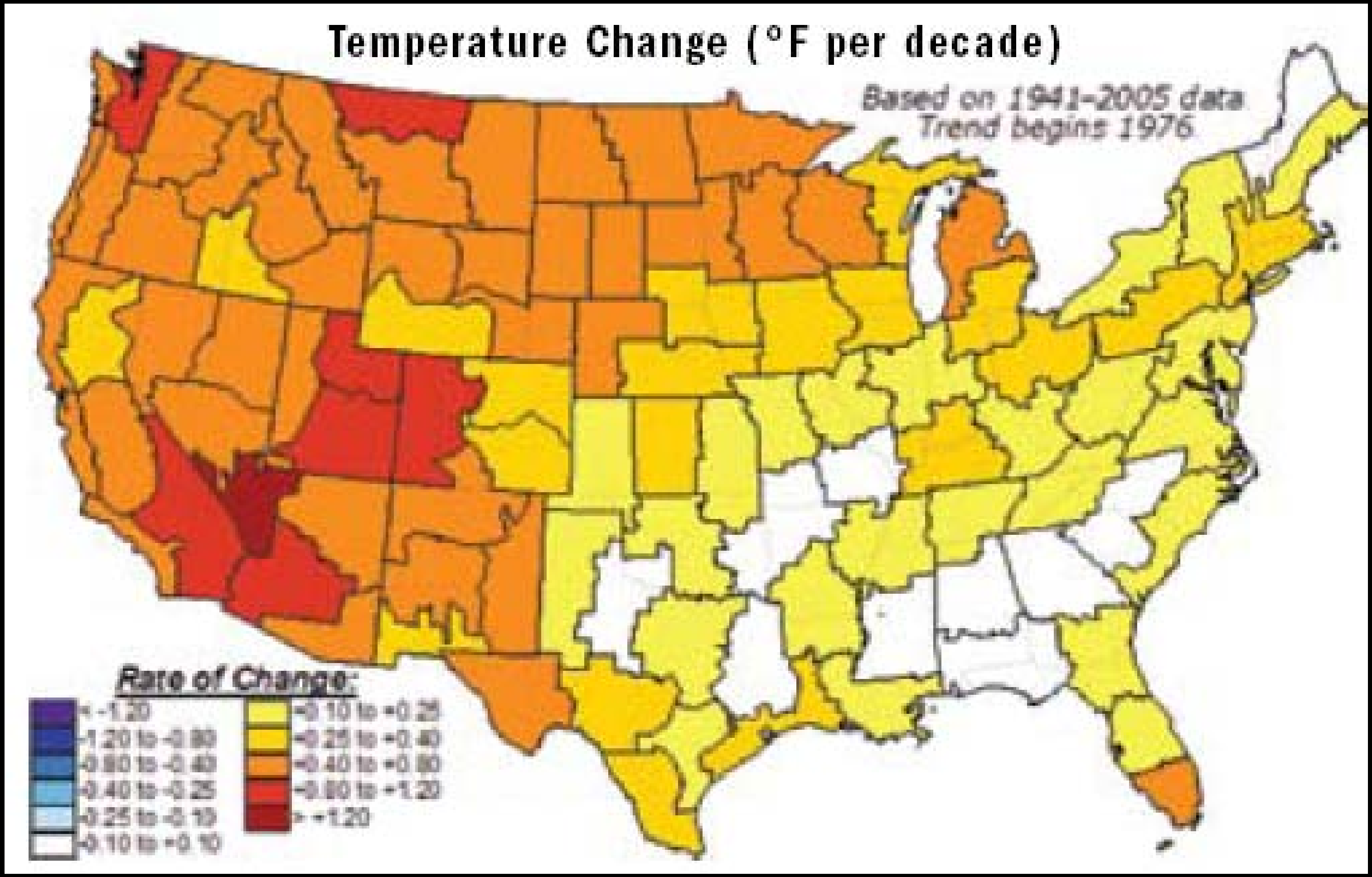
Temperatures Rose in most of the U.S. During the 20th Century



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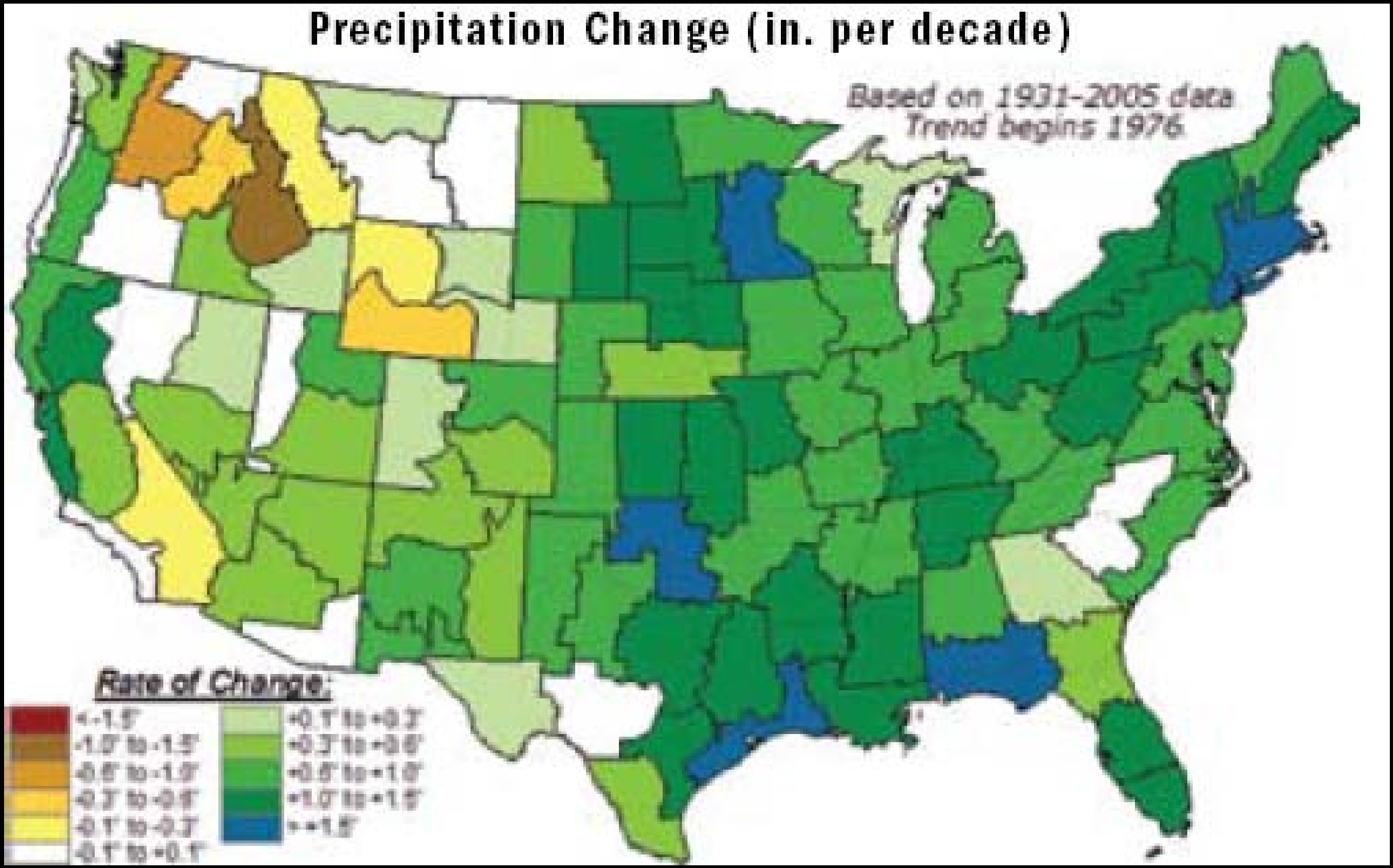
Source: NOAA Climate Prediction Center, 2007

Precipitation Increased in Much of the US During the 20th Century



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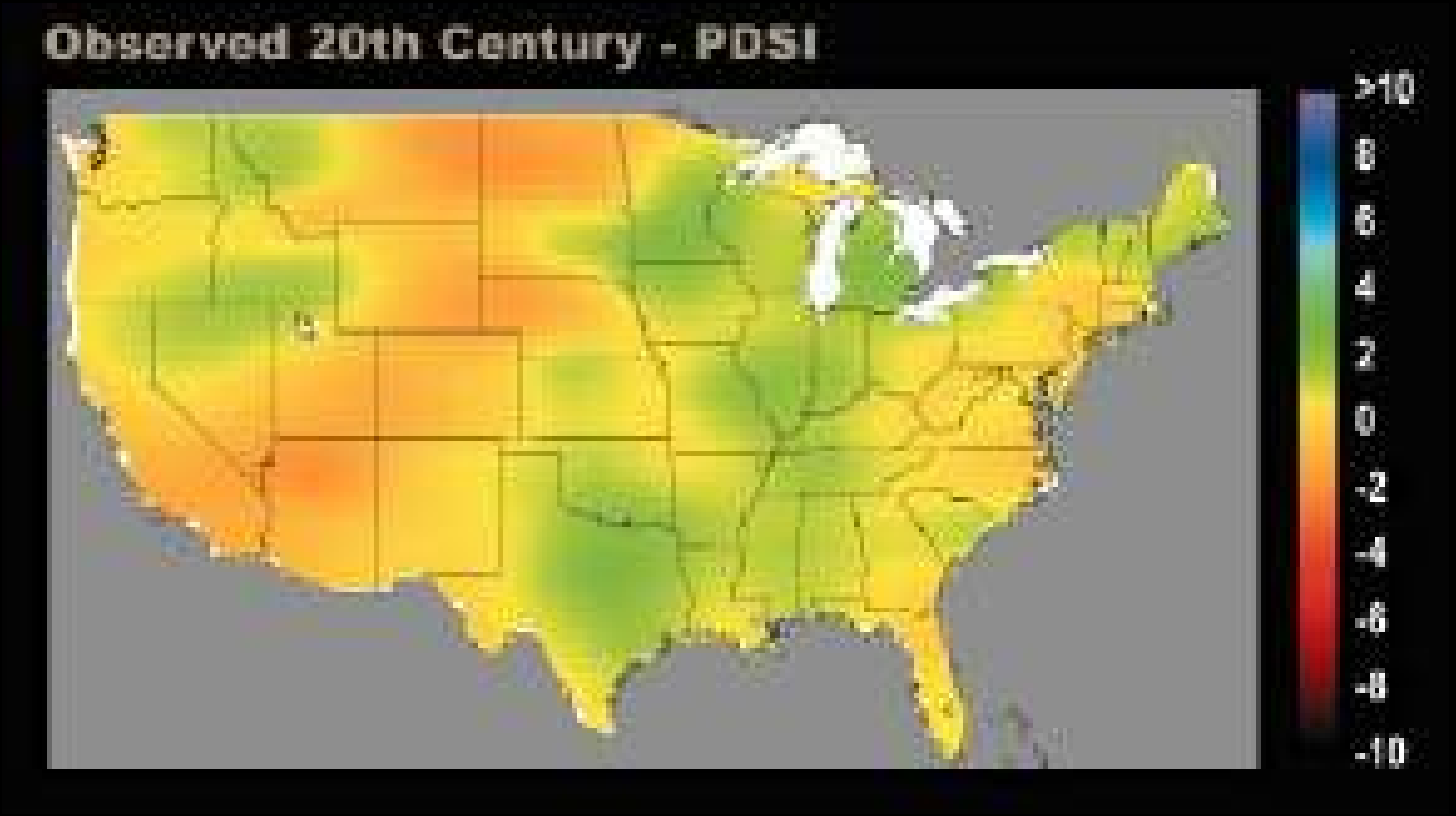
Source: NOAA Climate Prediction Center, 2007

Yet…. Many Areas Became Drier



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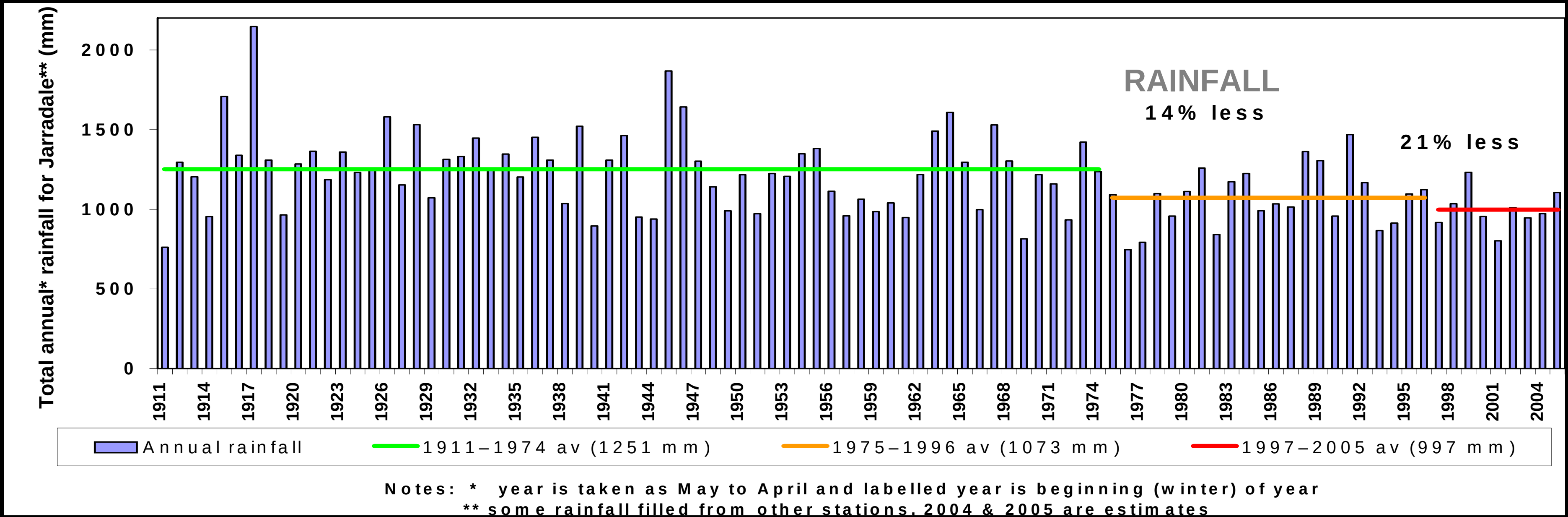
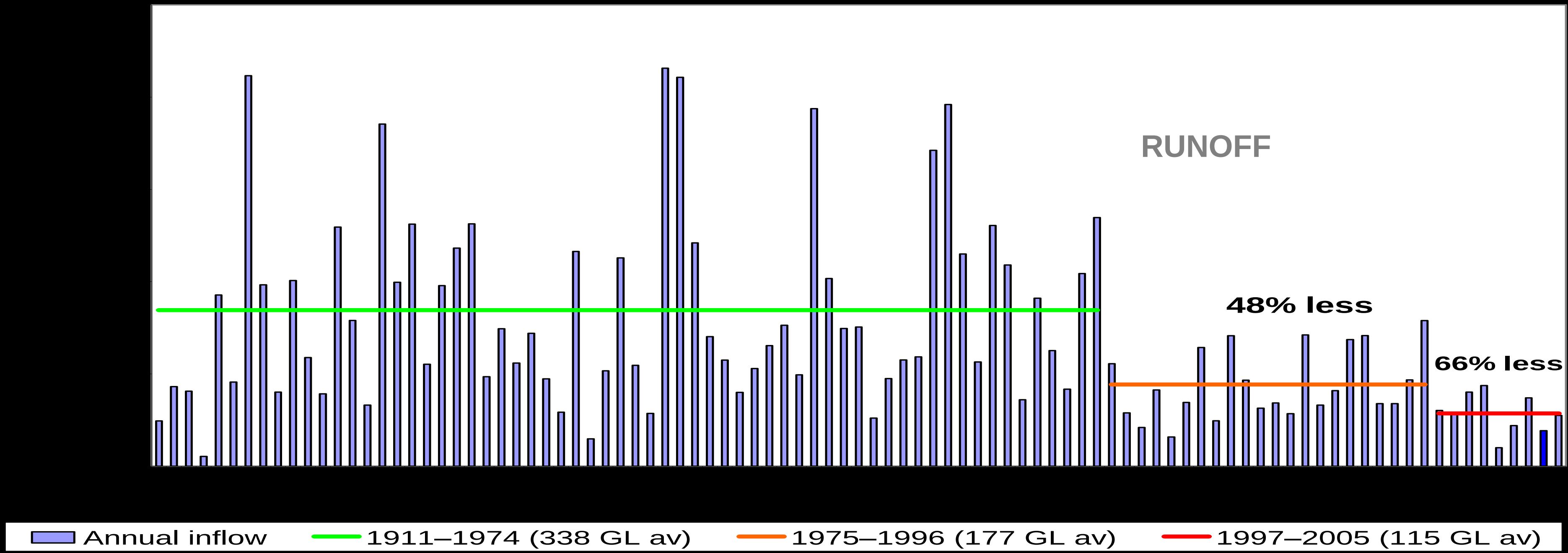
Source: U.S. National Assessment, 2000

Perth's Watersheds – Rainfall and Runoff





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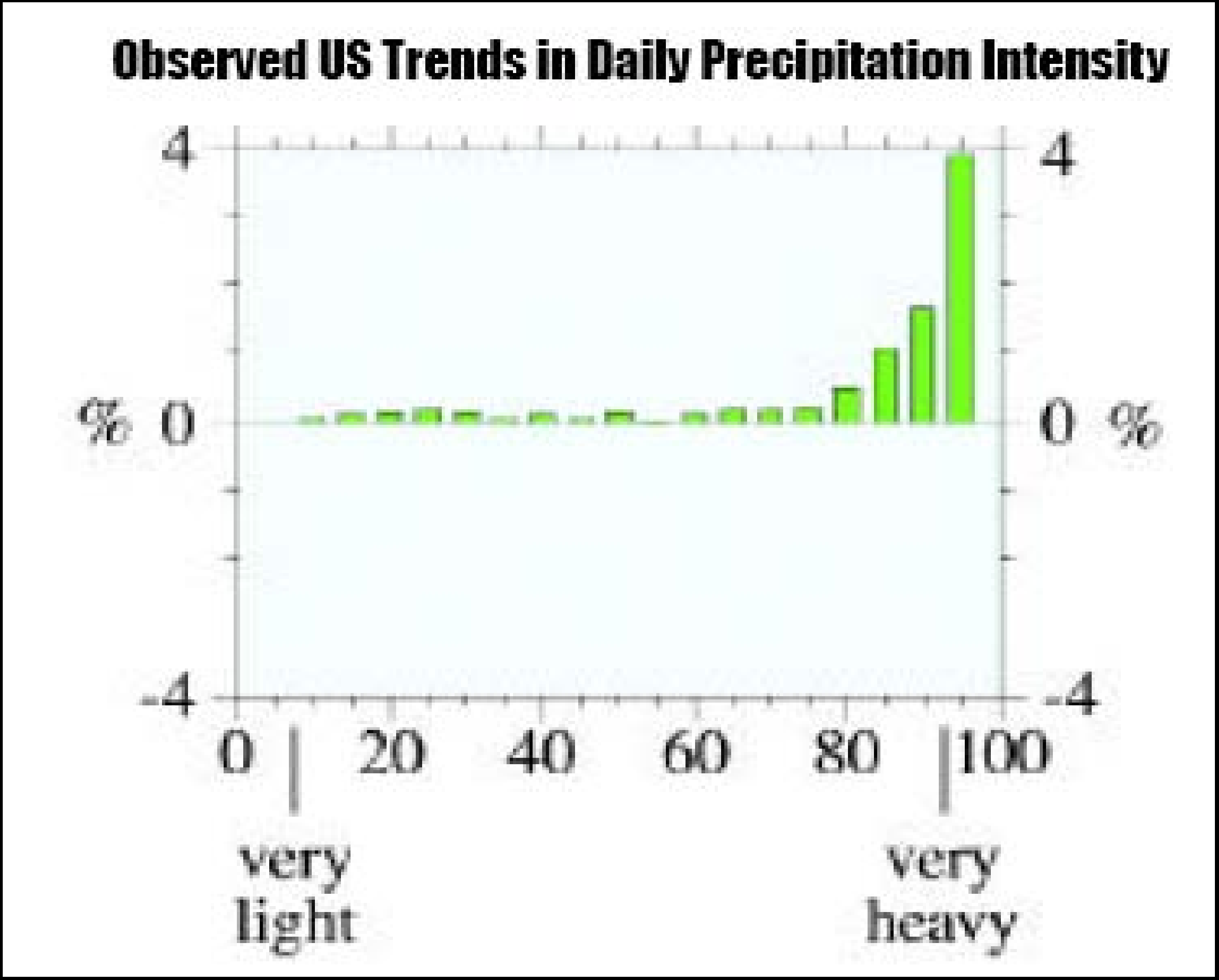
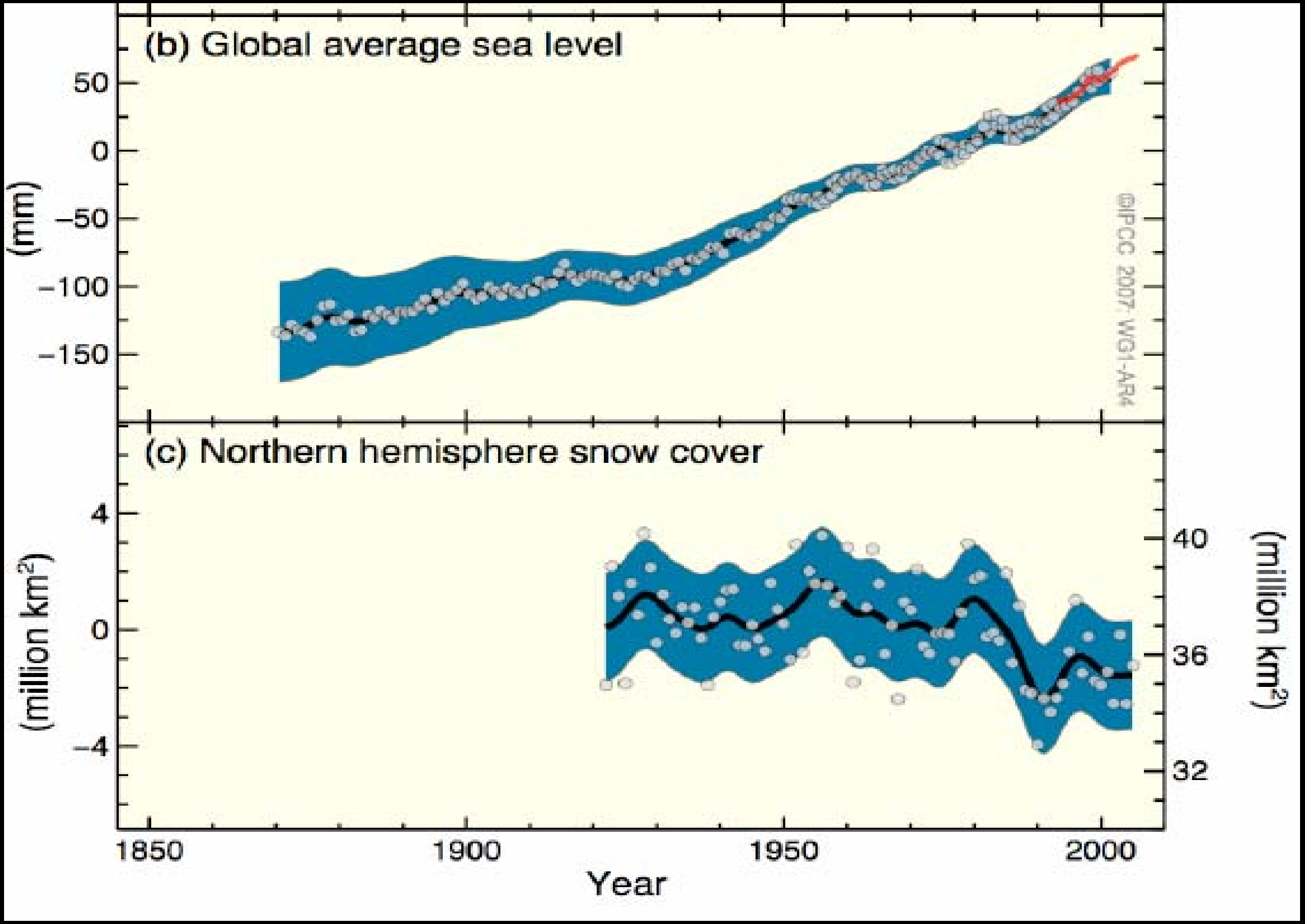
Extreme Precipitation Increased in the 20th Century



Source: U.S. National Assessment, 2000

Sea Levels are Rising
Snowpacks are Shrinking



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Source: IPCC, 2007

What Is Known About How *Future* Climate Will Change and Likely Impacts on Water Resources?

Expected Future Climate Changes

- Higher temperatures
  - Larger increases in summer than winter
- Likely changes in *seasonal* precipitation
  - *Annual average* regional precipitation: +/-?
  - Summers likely to see less rainfall
  - More dry days between rainfall events
- More intense precipitation events
- Potential for more extreme droughts
- Stresses on watershed & recharge areas
- Sea level rise

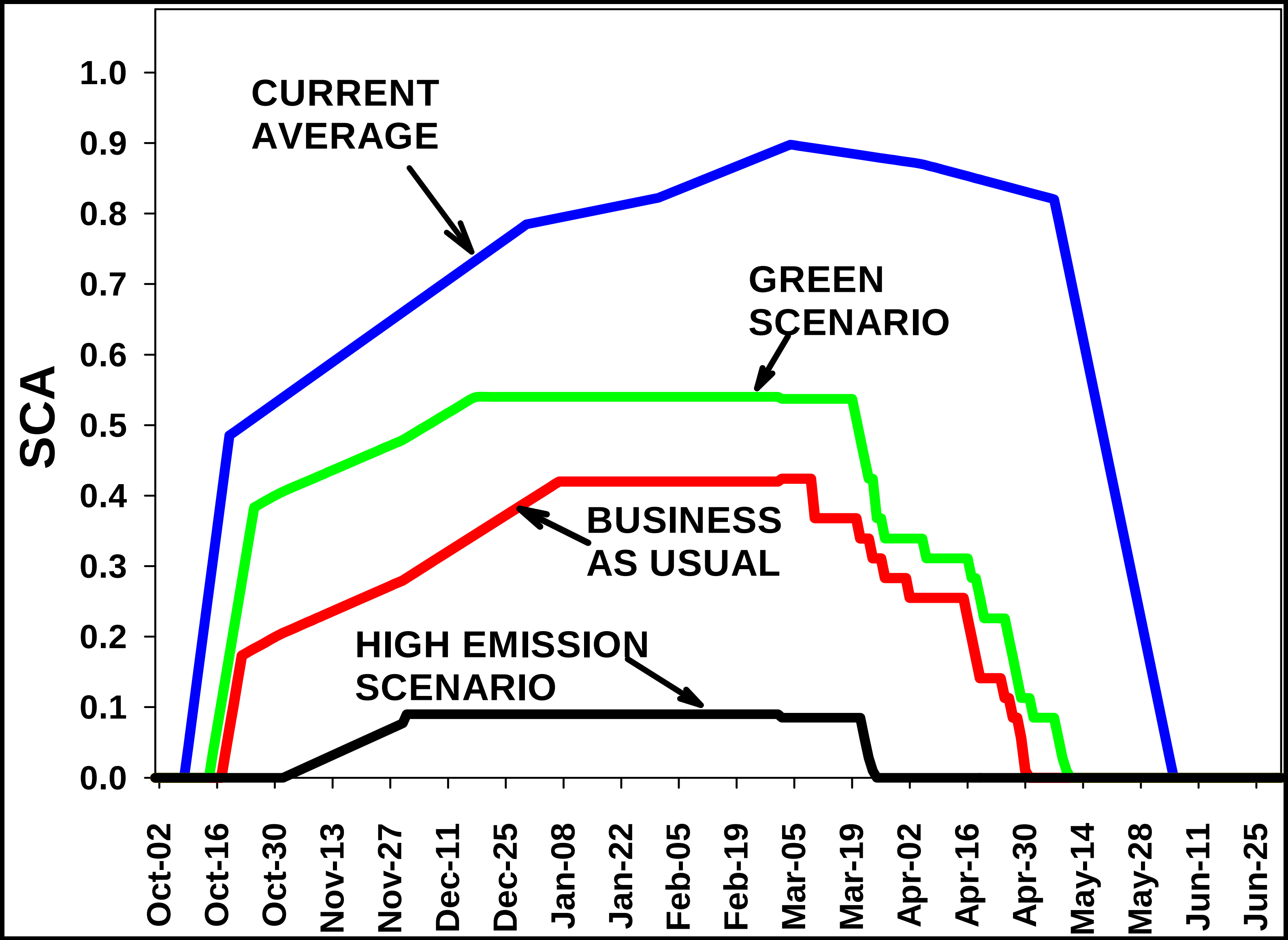
Likely Impacts on Water Utilities

- Implications from Source to Tap
  - Watershed changes
  - Treatment challenges
  - Distribution impacts
  - User demands
- Impacts include risks to:
  - Water quantity
  - Water *quality*
  - Facilities & supporting infrastructure

Impacts on *Quantity* of Water

- Less supply/storage from snow melt
  - Higher % of precipitation as rain, and runoff
  - Earlier melt and peak flows
- Loss of reservoir storage
  - More evaporation and sedimentation
  - Dam operating constraints => More releases:
    - Flood control concerns in Spring
    - Hydropower demands increase in Summer/Fall
    - Instream flow needs increase in Summer/Fall
- More drought in many locations
  - Severity, duration, and frequency
- Water quantity changes impact water *quality*

Snowpack Will Be Smaller (Park City UT, 2075)



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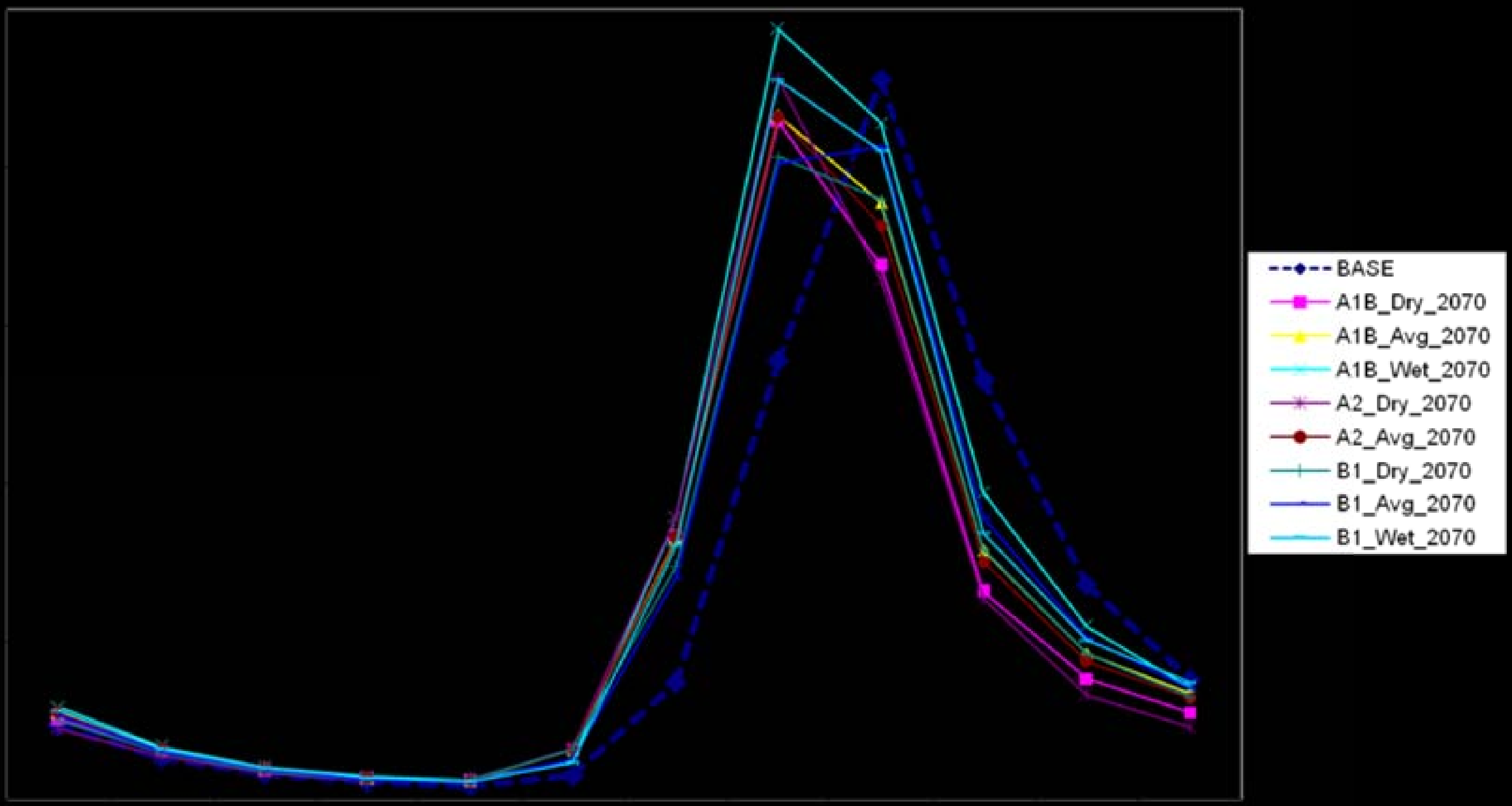
Peak Runoff and Flows Will Come Earlier (Hydrograph for Boulder Creek 2070)



Impacts on Water *Quality*

- Watershed changes
  - Wildfires, more intense rainfall, higher temps...
  - Imply higher turbidity, eutrophication, salinity

- Changes in key water quality parameters
  - Temperature, pH, alkalinity, bromides, etc.
  - Possible DBP & disinfectant residual challenges

- Sewer overflows, stormwater, CAFO threats

- More likely power outages & other disruptions
  - Treatment, storage, & distribution reliability impacts

Watershed Vegetation = Valuable Natural Asset

- A study of 27 water utilities found a 20% decrease in treatment & chemical costs for every 10% increase in forested cover (Ernst et al., 2004)
- Important ecologic, recreation, and other values as well

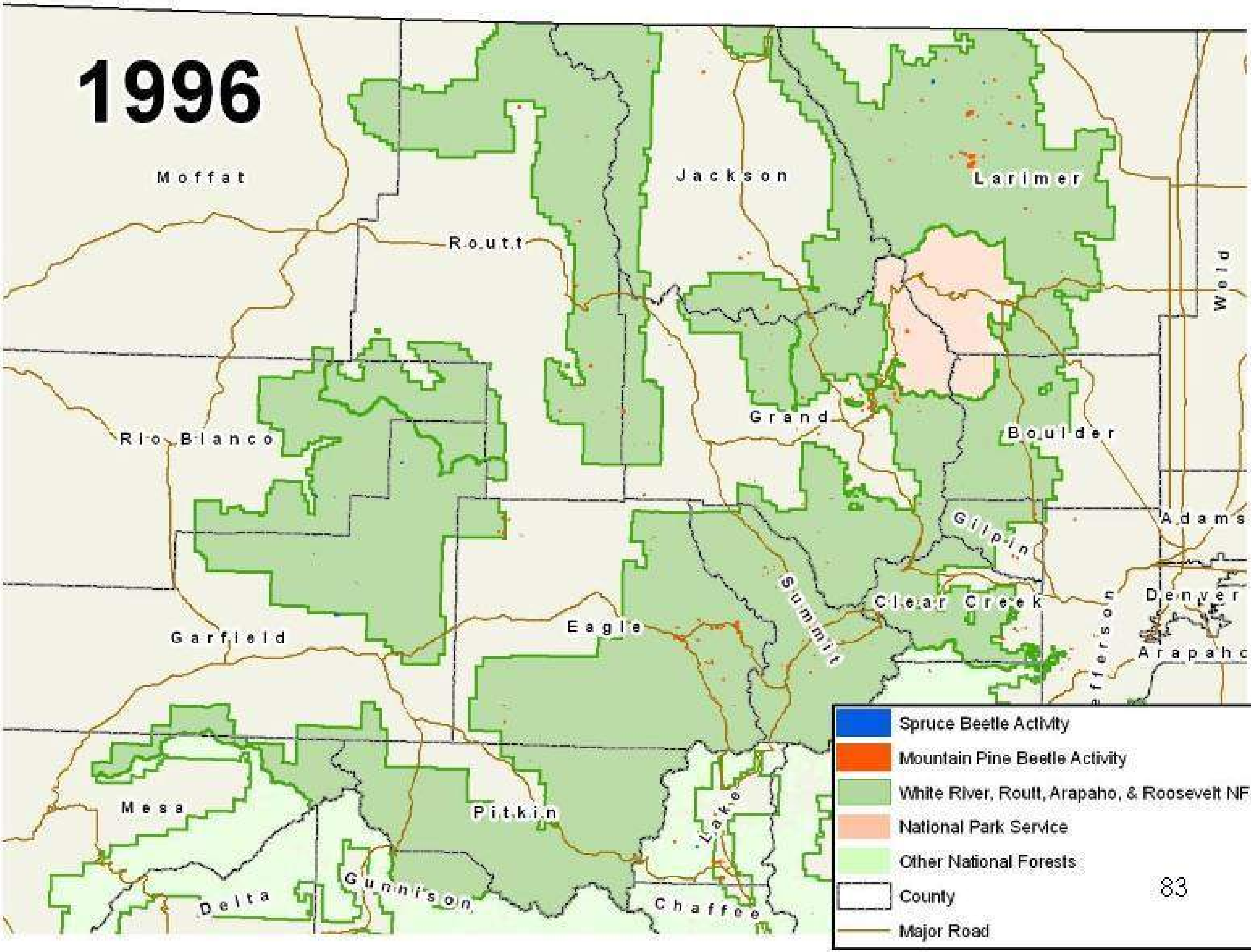
Events Causing Catastrophic Vegetation Changes in Watersheds

Sudden Impacts

- Wildfire
- Storms
- Invasive plants
- Insect outbreaks

Gradual Impacts

- Urbanization
- Agriculture
- Drought
- Timber harvesting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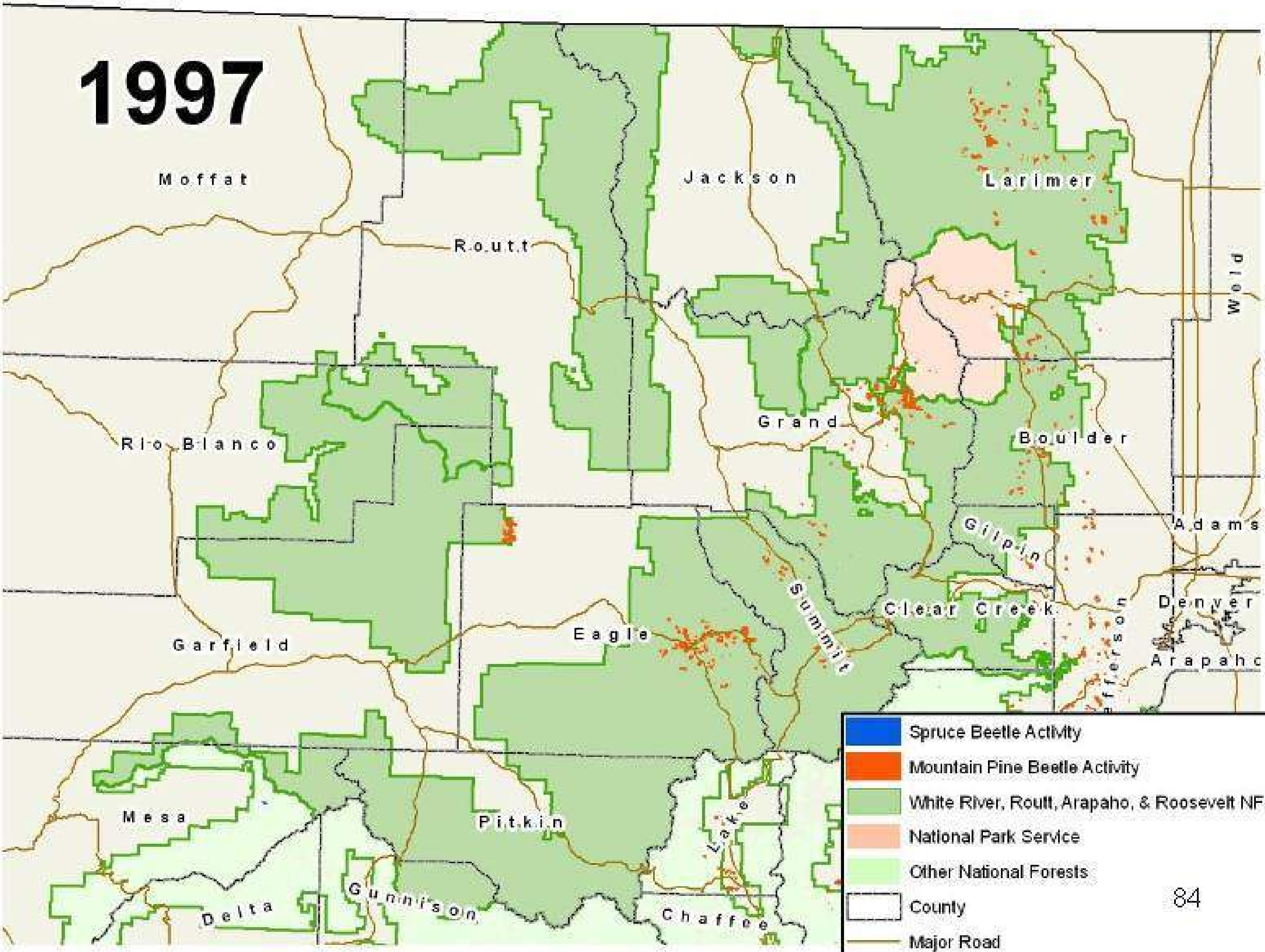
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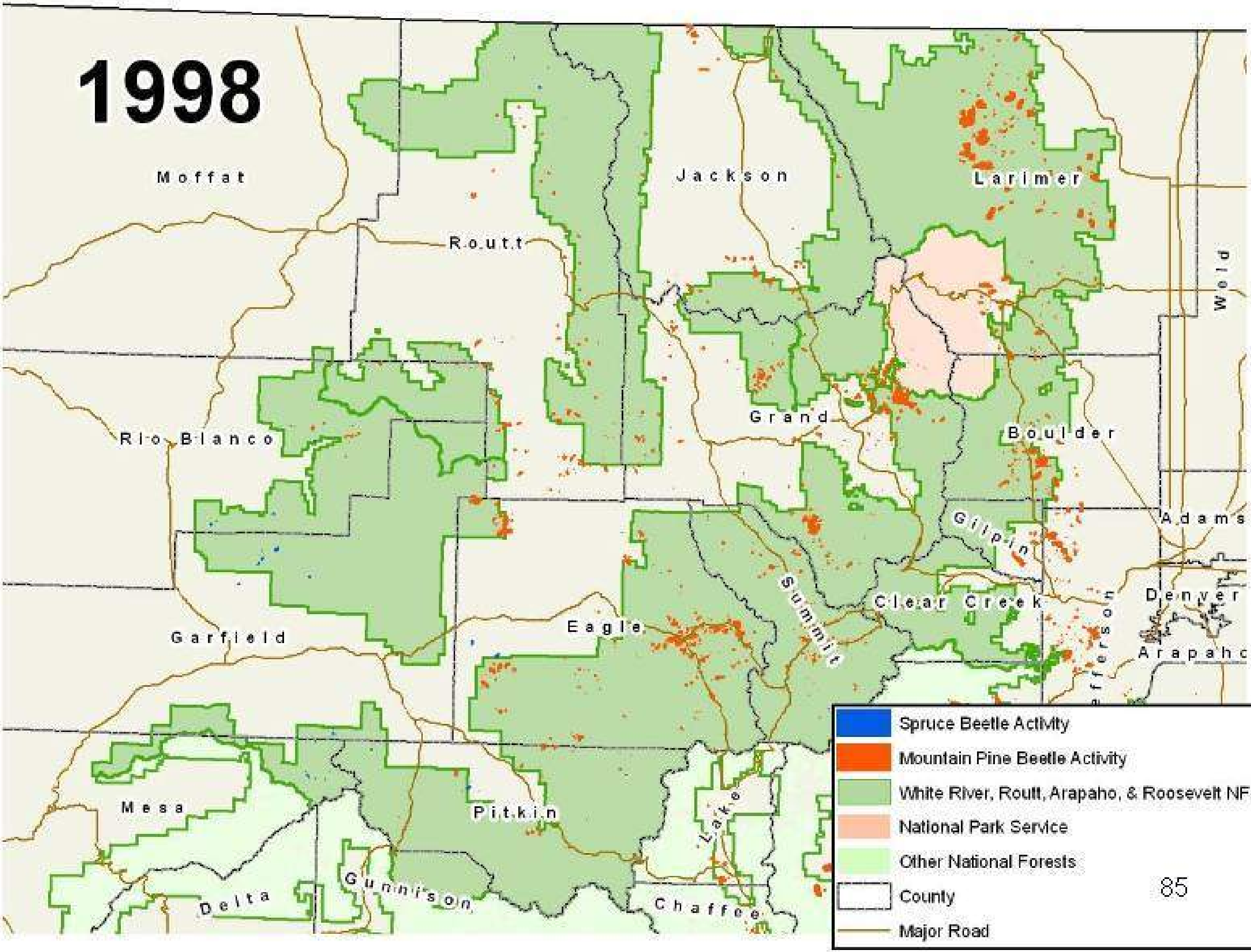
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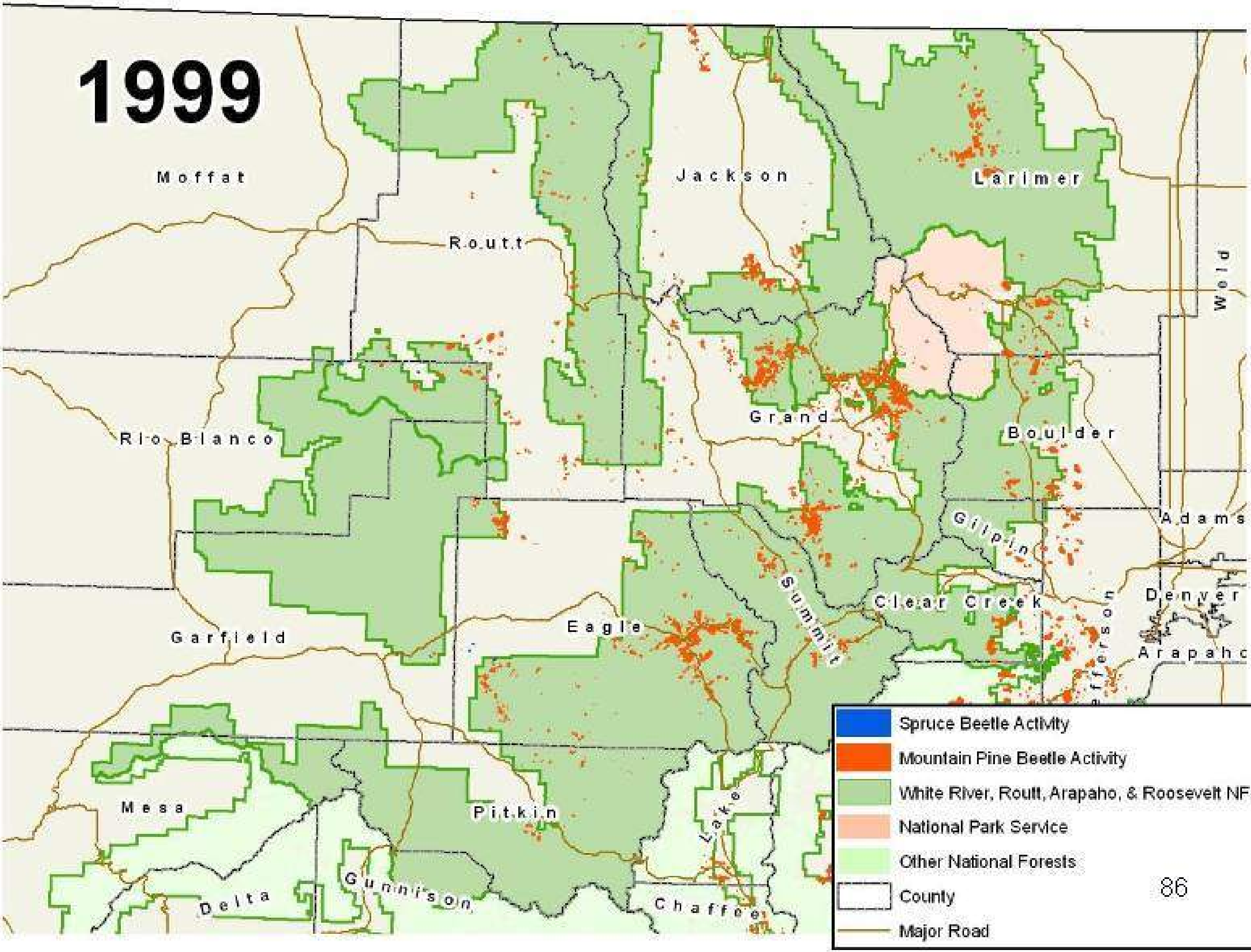
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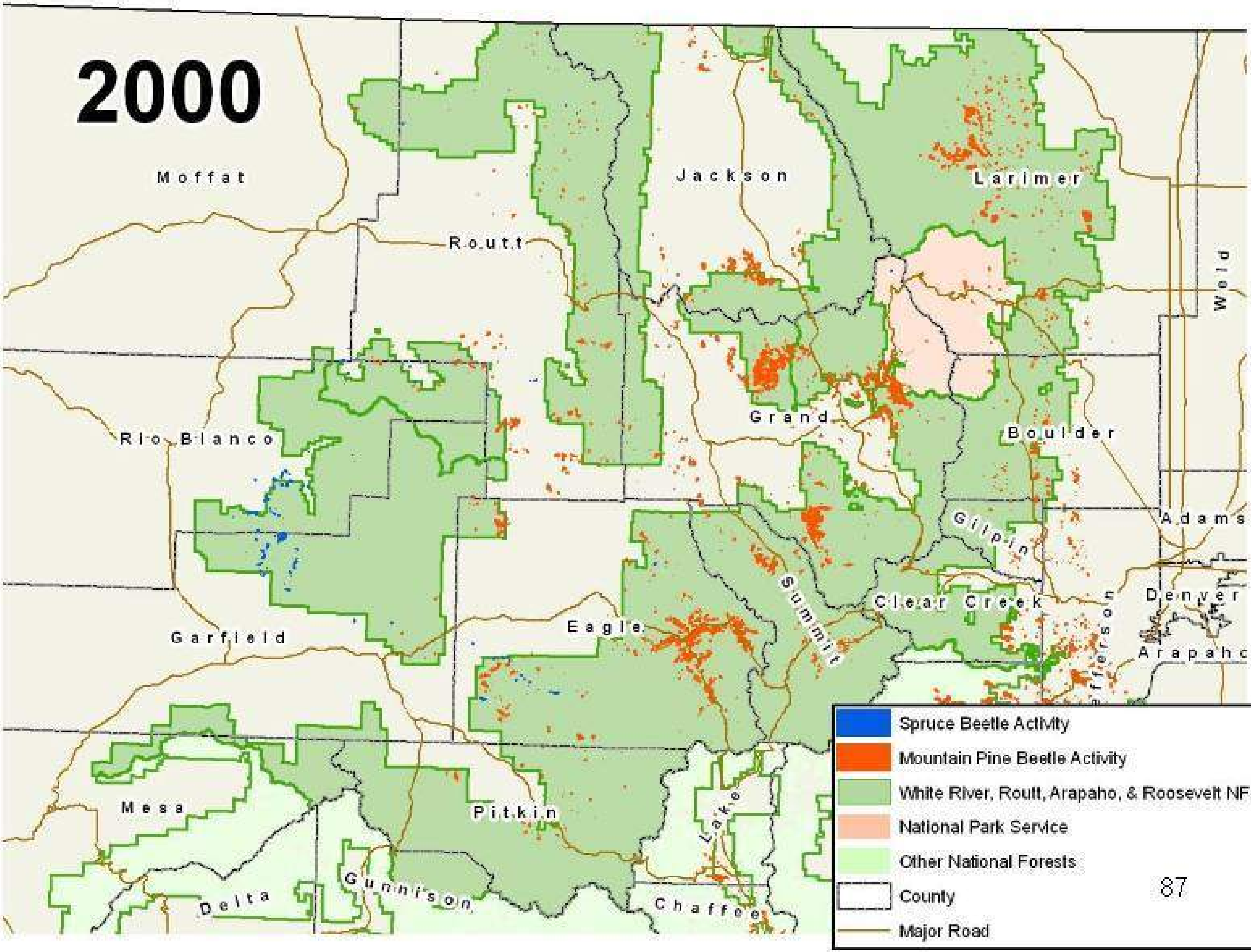
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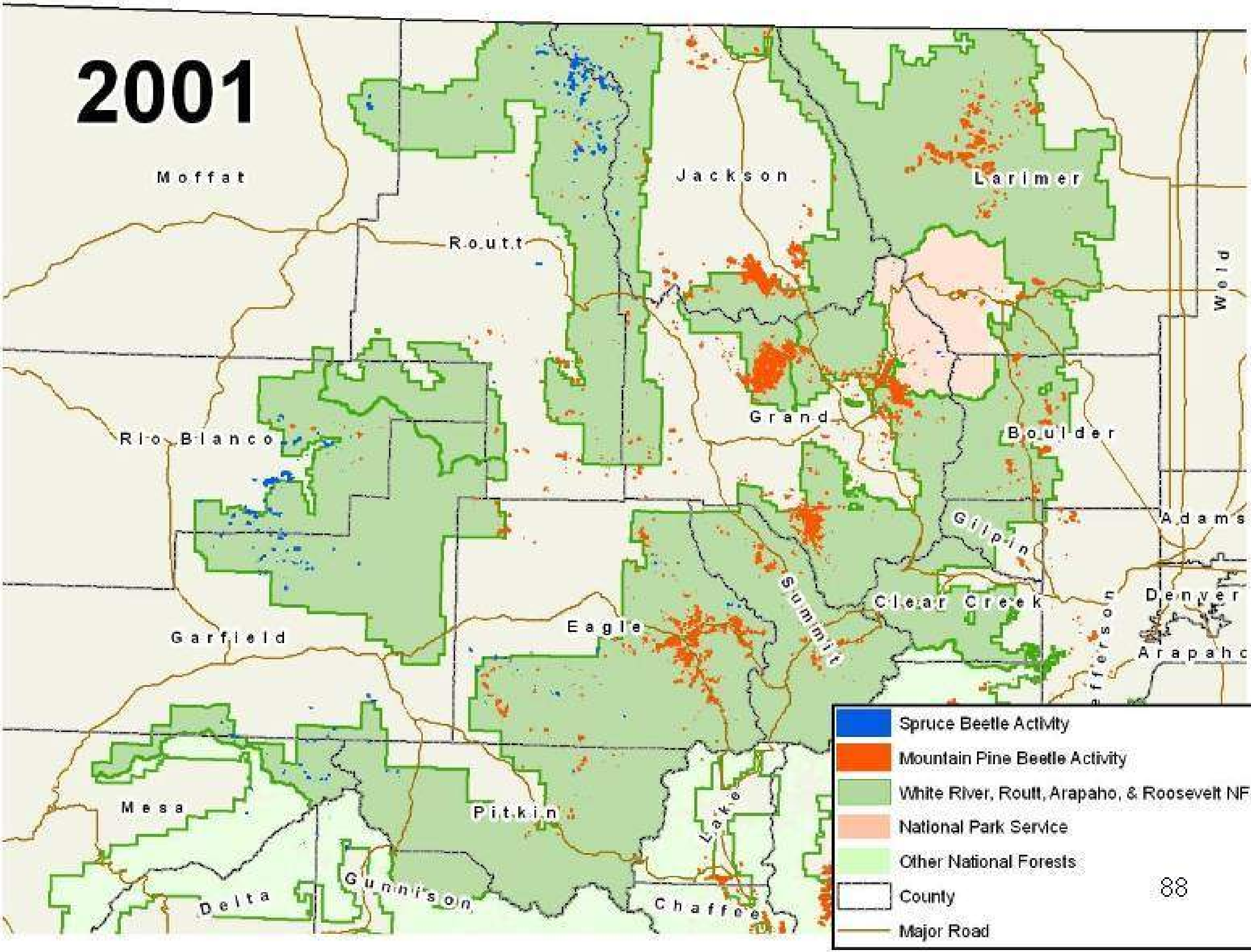
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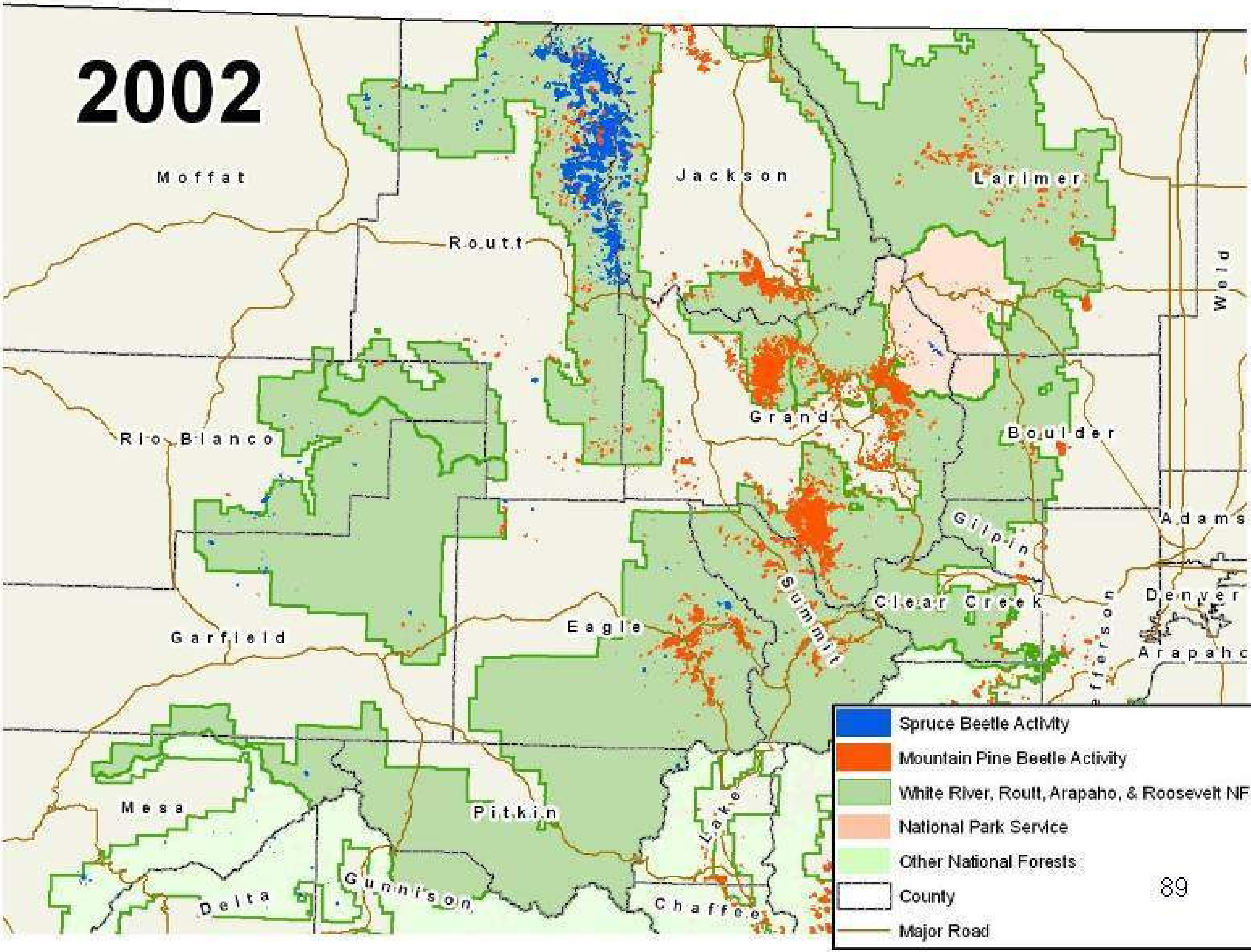
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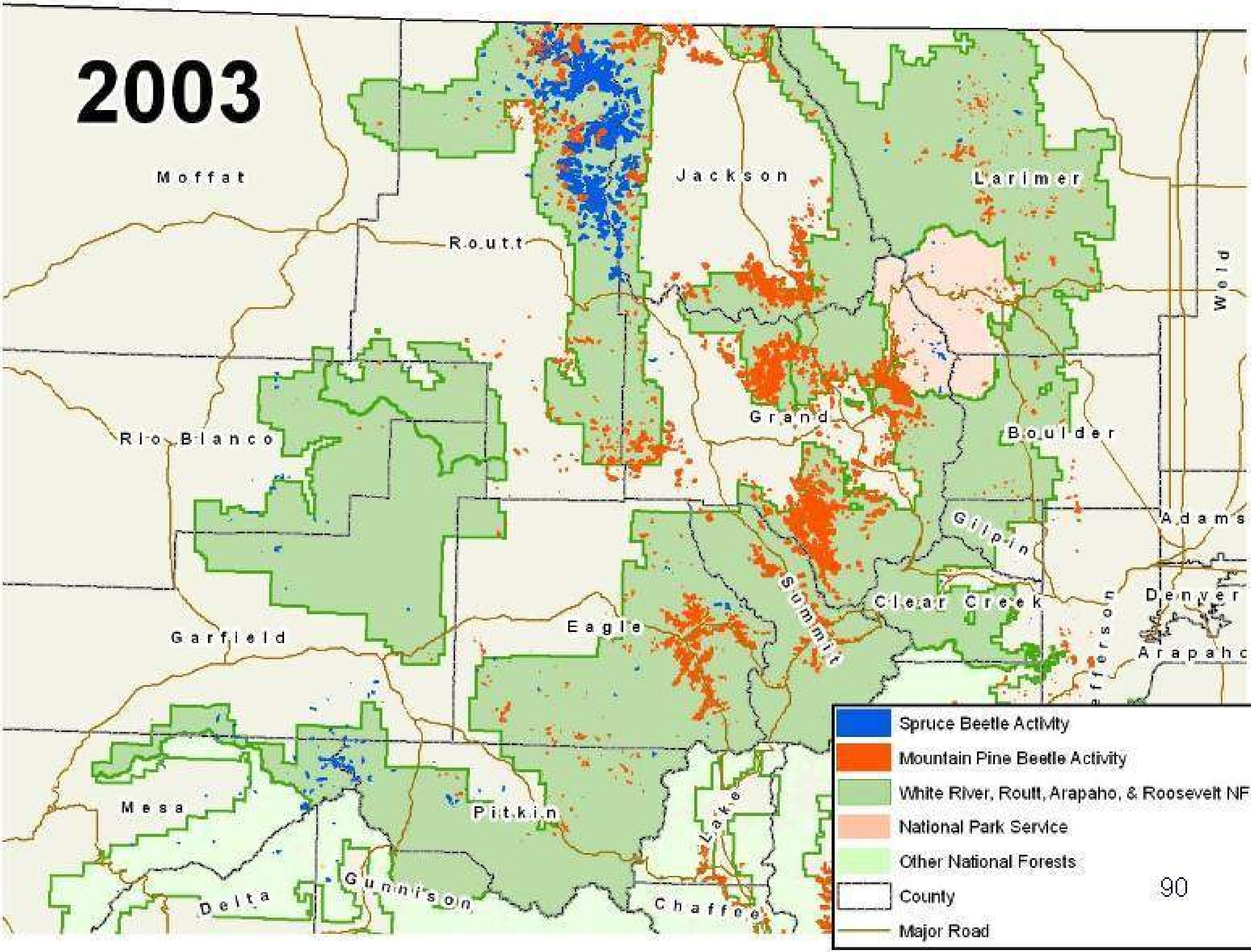
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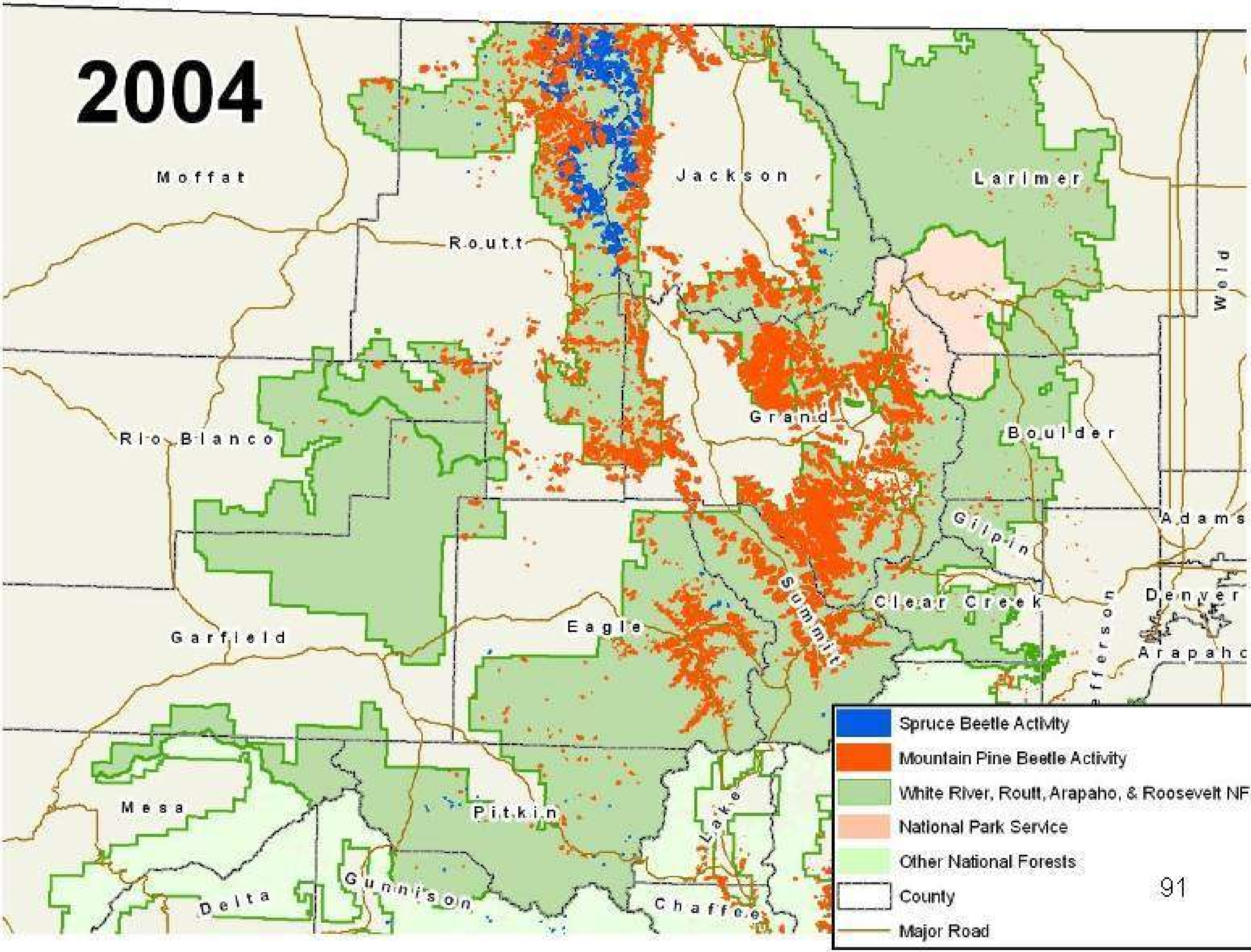
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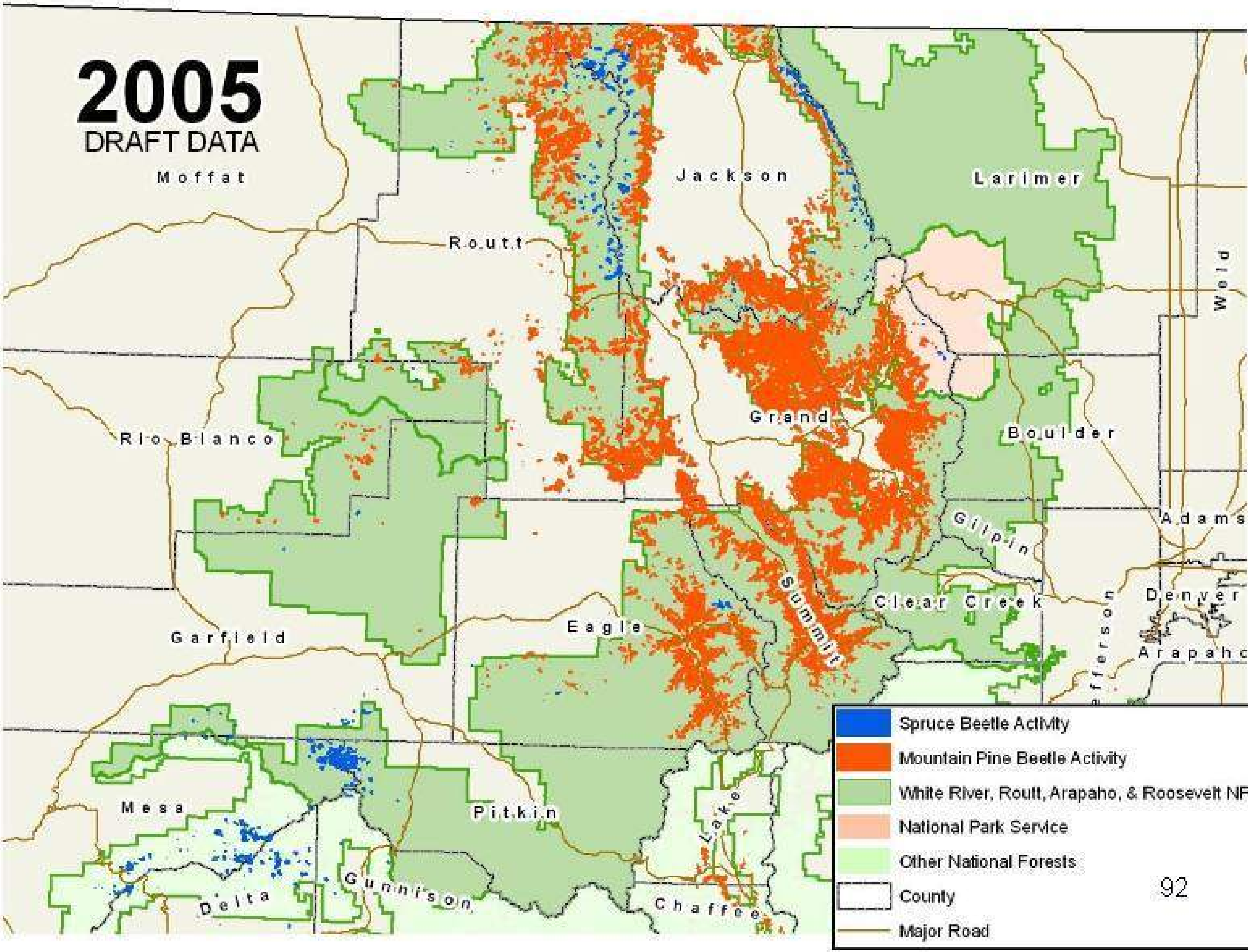
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Watershed Vulnerability

Example: Denver Water watershed…

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Near Denver's Cheesman Reservoir just after 2002 Hayman Fire.

Significant Erosion and In-Channel Sedimentation Following Storm over Burned Watershed

Strontia Springs Reservoir after 1996 Buffalo Creek Fire

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Additional Source Water Quality Vulnerabilities

- Algae
- Fecal coliform
- Turbidity
- Nonpoint source loads
- Sewer overflows
- pH
- Water temperature
- Reduced dilutions

Climate Change May Lead to Increased Blue-Green Algal Blooms

Increased rainfall, nutrient loading, and temperature effects:

- Oxygen depletion
- Taste & odor issues
- Color problems
- Fish kills
- DBPs

Fecal Coliform Bacteria

- Waterfowl migrations will change with climate; increase threat to SWTR compliance
- Increased stormwater runoff from CAFOs
- More frequent and/or severe sewer overflows

Increase in Turbidity Events

Other Implications for Water Quality

- Increased fire can result in more pollutant loadings
- Increased acidification of surface waters due to higher atmospheric CO_2

Instream Flow and Ecosystem Vulnerabilities

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Implications for Water Quality and Aquatic Life

- Increased eutrophication potential due to drier summers and droughts
- Changes in nutrient and other pollutant loadings from more intense storms
  - Resulting hypoxia produces “dead zones” devoid of aquatic life

Implications for Water Quality and Aquatic Life (cont.)

- Change in water temperature
  - Fish will need to migrate (or be transplanted) to more northern or higher altitude water bodies
- Changes in seasonality of streamflow and minimum flows
  - Increased winter flows and decreased summer flows
  - Lower summer flows exacerbate summer instream temperature issues

Implications of Increased Storm Intensity

- Flooding of drinking water treatment plants
- Flooding of sewage conveyance and treatment facilities
- More infiltration potential
- More power interruptions

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Implications of Sea Level Rise for Coastal Water Supplies

- Saline intrusion where water river intakes are located
- Saline intrusion into coastal aquifers
- Increased need to desalinate water
- Inundation of coastal and low-lying facilities

Boston: The Future 100-Year Flood under the Higher-Emissions Scenario

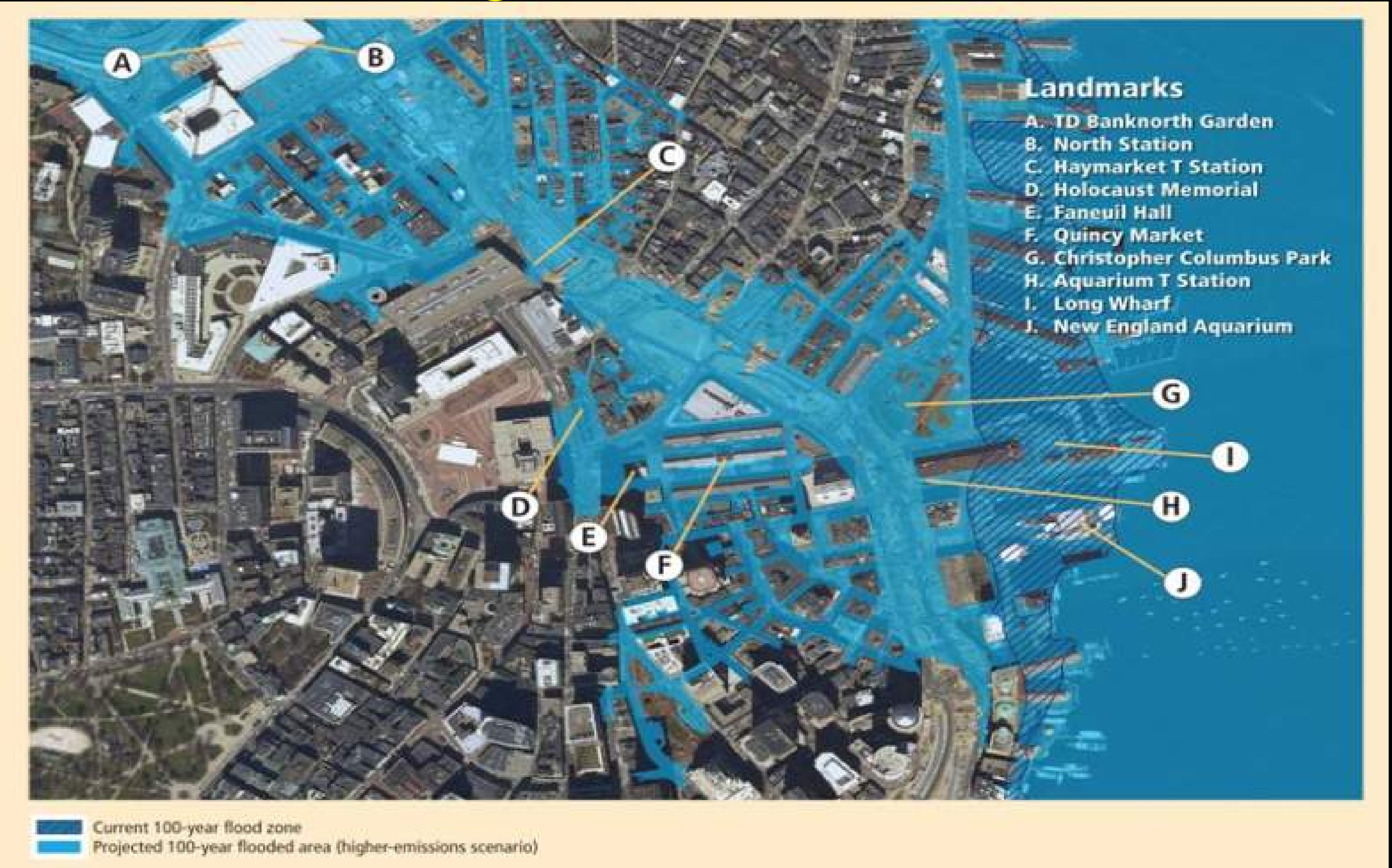
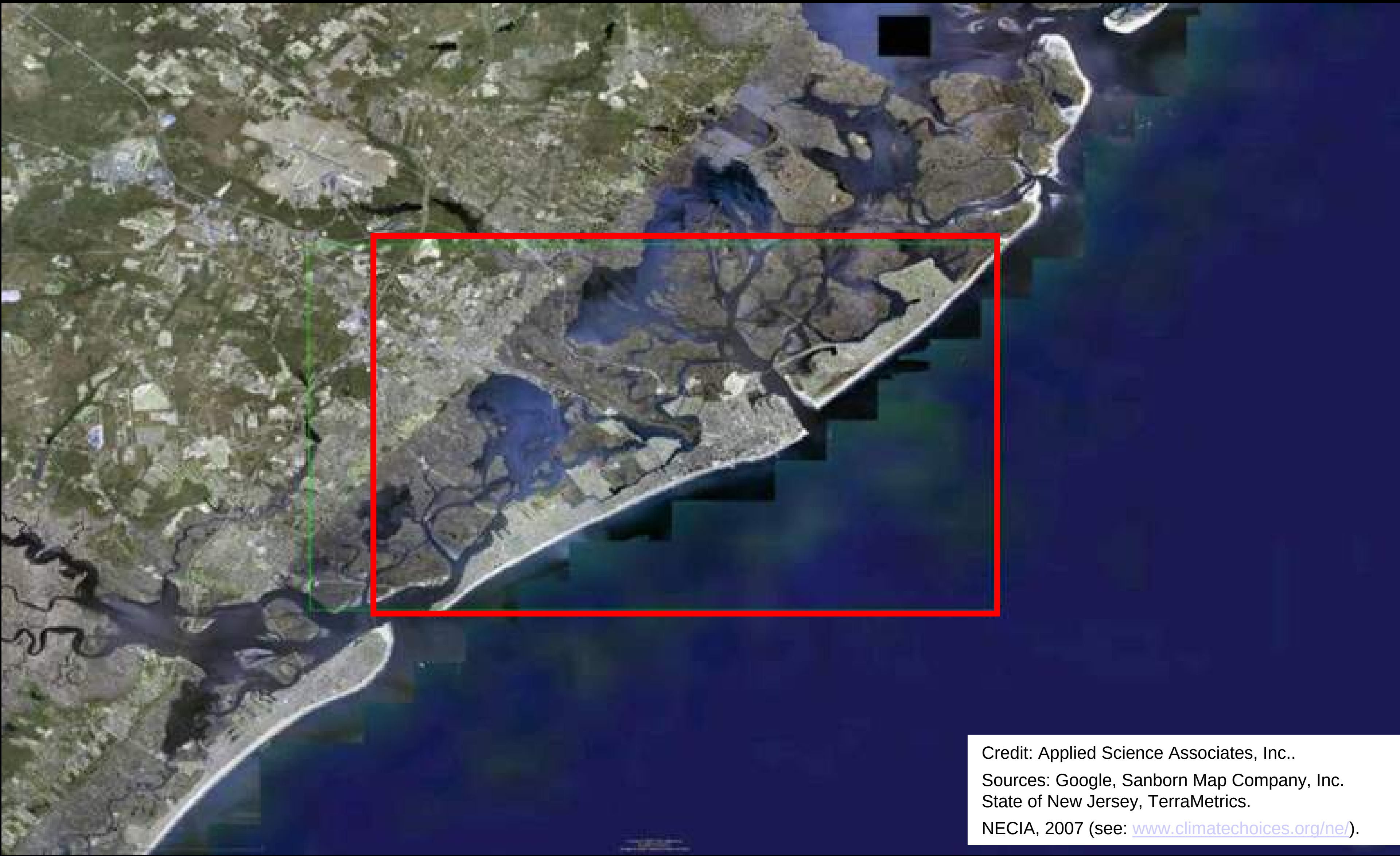


Table of Future Recurrence Intervals

Station	Scenario	100-yr Storm Surge Elevation at MHHW (feet NAVD)				Recurrence Interval of 2005 100-yr Anomaly (years)	
		2005	2030	2050	2100	2050	2100
Boston	B1 (mid-range)	9.7	10.2	10.7	11.8	3	<<2
•	A1FI (mid-range)	9.7	10.2	10.7	12.3	2	<<2
Woods Hole	B1 (mid-range)	10.0	10.2	10.5	11.1	51	21
	A1FI (mid-range)	10.0	10.2	10.5	11.6	46	9
New London	B1 (mid-range)	7.4	7.6	7.8	8.3	61	32
	A1FI (mid-range)	7.4	7.6	7.8	8.9	56	17
New York City	B1 (mid-range)	9.0	9.3	9.5	10.2	50	22
	A1FI (mid-range)	9.0	9.3	9.6	10.7	46	11
	Rahmstorf (mid-range)	9.0	9.5	10.1	12.5	24	<2
Atlantic City	B1 (mid-range)	7.7	8.7	9.5	11.6	4	<<2
	A1FI (mid-range)	7.7	8.7	9.6	12.1	4	<<2

Atlantic City: Today's 100-Year Flood Could Become a 2-Year Flood by 2100

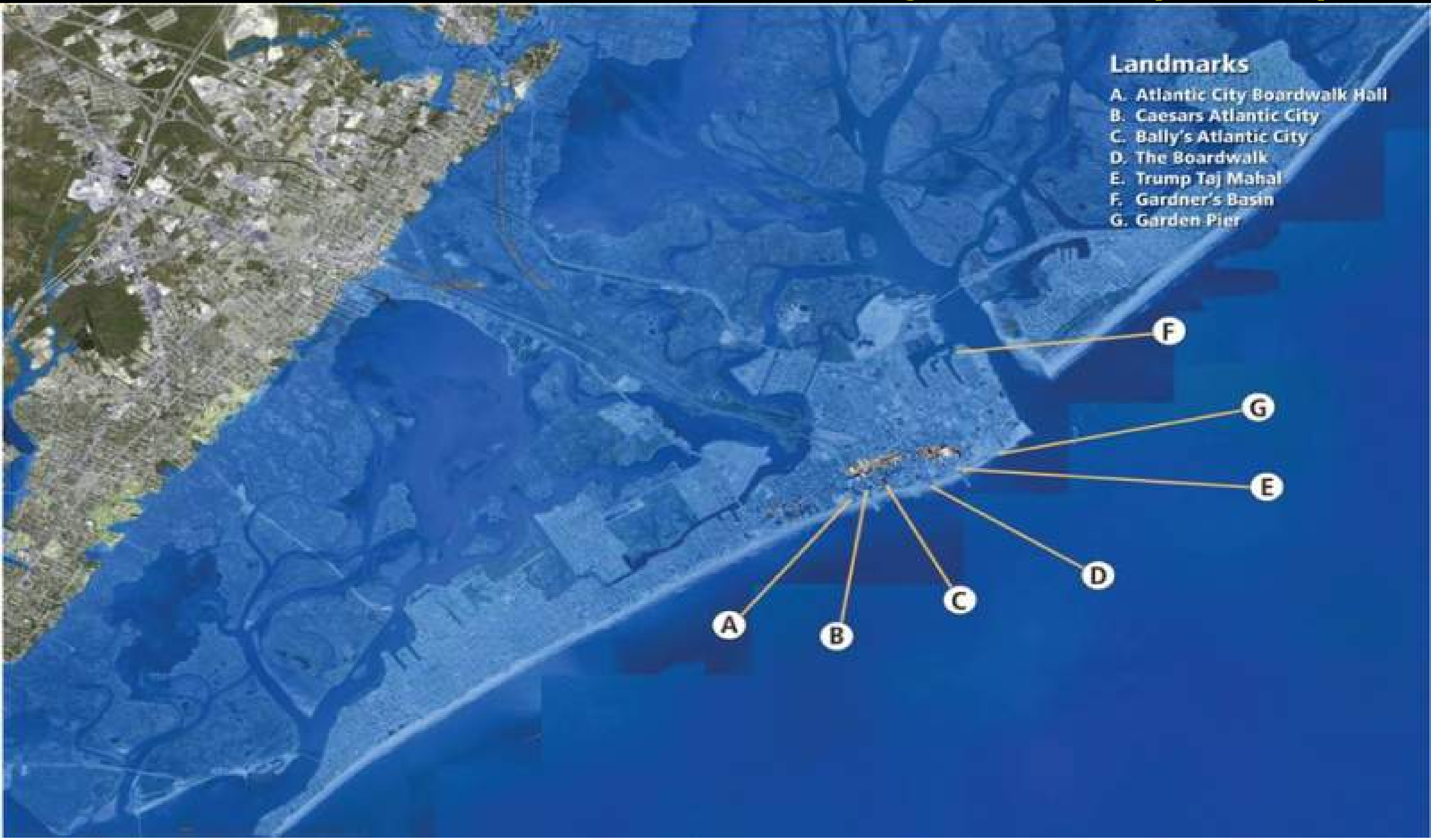


Credit: Applied Science Associates, Inc..

Sources: Google, Sanborn Map Company, Inc. State of New Jersey, TerraMetrics.

NECIA, 2007 (see: www.climatechoices.org/ne/).

Atlantic City: Today's 100-Year Flood Could Become a 2-Year Flood by 2100 (cont.)

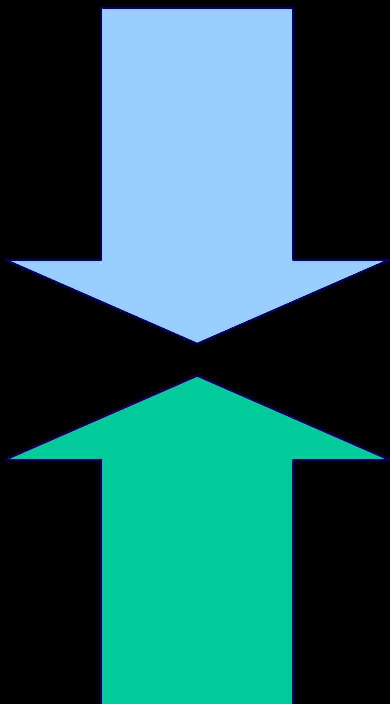


Credit:: Applied Science Associates, Inc.. Sources: Google, Sanborn Map Company, Inc. State of New Jersey, TerraMetrics

How Agencies Can Manage These Risks

- Assess vulnerability
  - Identify critical thresholds
  - Use climate change scenarios
- Assess adaptation strategies
  - Adopt adaptive management
  - Promote flexibility
  - Explore phased response options
  - Test their systems
  - Look for “no regrets” options

Two Approaches to Assessing Climate Change Risks



- The scenario approach
  - Applies a “top down” perspective
- The threshold approach
  - Based primarily on a “bottom up” perspective
  - But also draws on top down scenarios

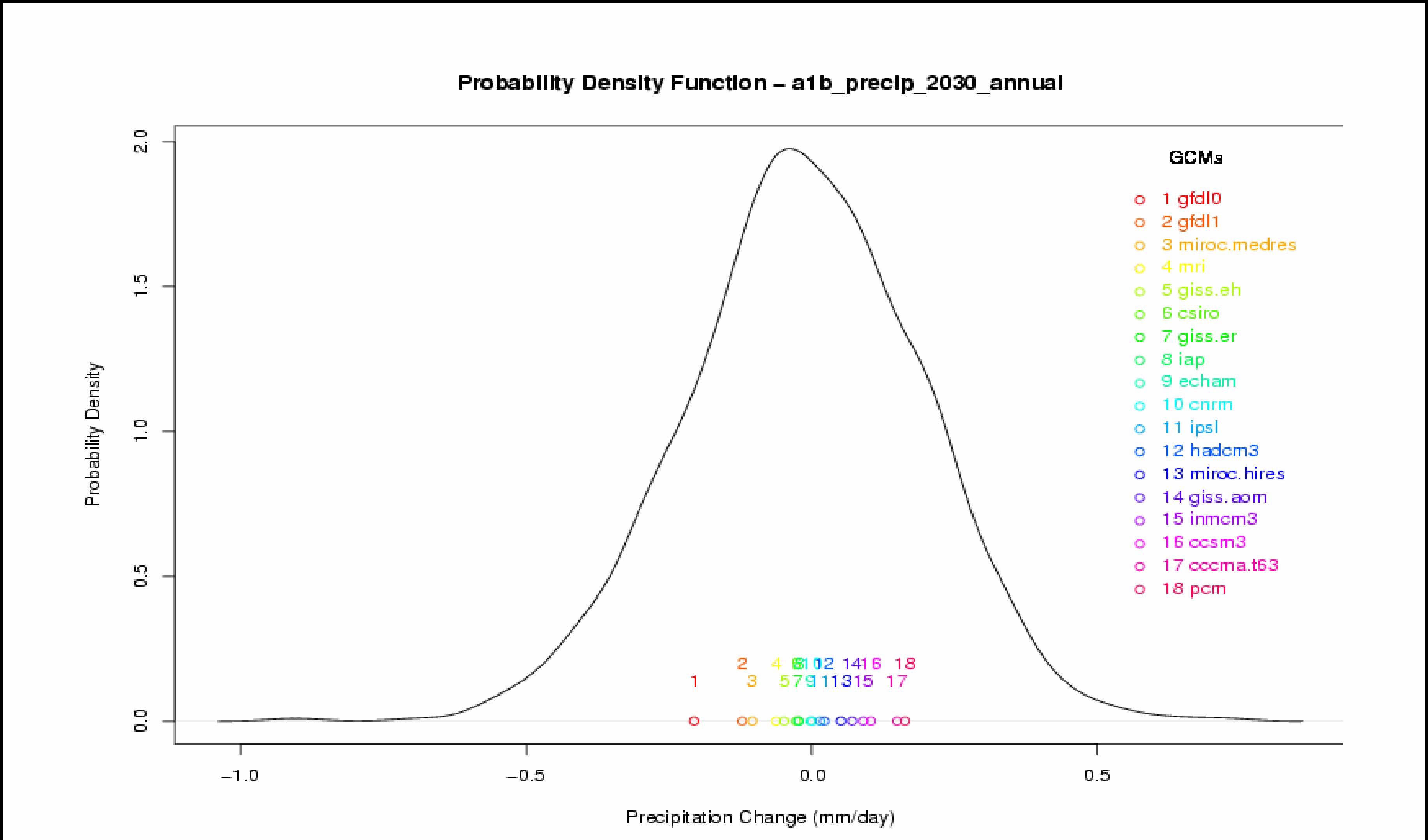
Scenario Approach

- Select scenarios to reflect a wide yet plausible range of changes in future climate
  - Examine many global models (GCMs) to see what changes they project at a regional scale
  - Projections of temperature & precipitation vary across climate models, and across emission scenarios
- Note seasonal & other shorter term outcomes, rather than focusing on annual means
- Examine potential impacts when these climate outputs are used as inputs to your planning

Issues with Climate Scenario-Based Top-Down Approach

- What GCM model to use?
- What emissions scenario to use?
- How are results downscaled?
  - Geographic scale
  - Level of resolution
- Accuracy of predicted impacts????
- How do models mesh with watershed managers’ and utilities’ own set of models and tools?

Boulder Study:
Using "Wet," "Middle," and "Dry" Scenarios



Threshold Approach

- Step 1: Identify critical threshold(s)
  - Start with <u>your agency's planning models</u>
  - Determine how much of a climate impact would cause large problem for your agency
    - ID tipping points (thresholds)
    - E.g., what decreases in streamflow cause a major supply challenge

Threshold Approach (cont.)

- Step 2: Assess the likelihood that the threshold will occur
  - Examine climate change projections from numerous global models
  - Determine if threshold change likely to occur within your planning horizon
  - e.g., 70% of climate models suggest this outcome would occur by 2030

Summary of Model Results for Boulder

Emission Scenario	Model Type	Year	1-in-20 year criterion met?	1-in-100 year criterion met?	1-in-1000 year criterion met?	% of years with reduced deliveries		# of "events" (1 or more consecutive years with reduced deliveries)		maximum event length, years		maximum delivery reduction (AF)		average of delivery reductions, (AF)	
						Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
Drought Plan (300 years)			yes	yes	yes	3%		6		4		6552		3313	
BASE CASE			yes	yes	yes	2%	3%	3	5	4.8	7	2526	5334	1247	1604
B1	Wet	2030	yes	yes	yes	0%	0%	0	2	0.5	2	524	1573	1159	1573
B1	Mid	2030	yes	yes	yes	4%	5%	5	8	6.6	11	2848	5334	1369	1899
B1	Dry	2030	no	yes	yes	5%	7%	7	11	6.3	10	4138	9377	1419	1800
A1B	Wet	2030	yes	yes	yes	0%	0%	0	2	0.3	1	295	1573	719	982
A1B	Mid	2030	yes	yes	yes	4%	5%	5	7	5.8	7	3120	5334	1371	1724
A1B	Dry	2030	no	yes	yes	7%	11%	10	16	7.1	10	3953	5838	1448	1864
A1B	Dry3	2030	no	no	no	23%	27%	27	36	11.3	14	10120	12130	1847	2232
A2	Mid	2030	yes	yes	yes	3%	5%	5	6	5.2	6	2736	5334	1286	1656
A2	Dry	2030	no	yes	yes	13%	18%	16	22	8.5	11	4426	5838	1484	1716
B1	Wet	2070	yes	yes	yes	0%	0%	0	2	0.5	2	426	1573	893	1234
B1	Mid	2070	yes	yes	yes	2%	3%	3	6	4.2	6	2533	5334	1217	1713
B1	Dry	2070	yes	yes	yes	3%	5%	4	6	4.8	6	3098	5838	1414	2044
A1B	Wet	2070	yes	yes	yes	0%	0%	0	2	0.3	1	295	1573	719	982
A1B	Mid	2070	yes	yes	yes	2%	3%	3	6	3.7	6	2531	5652	1106	1818
A1B	Dry	2070	no	yes	no	14%	16%	18	26	8.9	13	9657	11398	1857	2253
A1B	Dry3	2070	no	yes	yes	4%	6%	6	10	5.5	7	3829	5838	1481	1755
A2	Mid	2070	no	yes	yes	5%	6%	7	10	5.8	7	5933	9036	1431	2078
A2	Dry	2070	no	no	no	21%	26%	23	29	12.8	17	10475	12332	2153	2467

Source: AMEC-Hydrosphere

Prevention and Response Strategies for Source Water Protection

Management of Forest Lands: forest diversity promotes forest health and limits effects of catastrophic events

http://www.mass.gov/dcr/waterSupply/watershed/quablmp.htm

Straw Dams

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Upstream Debris Trap

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Conceptual Model

How do watershed vegetation changes affect drinking water supply?

Harmful Event:
Wildfire

↓

Changes to Vegetation:
Loss of vegetative cover

↓

Effects on Watershed Characteristics or Processes:
Erosion

↓

Effects on Source Water Quality and Quantity:
Increased sedimentation of reservoir

↓

Effects on Drinking Water:

Need for increased treatment

How can prevention and response mitigate the effects of harmful vegetation changes?

Prevention

Example: reduce fuel load

Response

Example: build sediment traps

Source: Strange, E., D. Lane, and C.N. Herrick. 2008. *Catastrophic Vegetation Change: How Water Utilities can Understand, Prevent, and Respond to Events in Their Watershed* (Awwarf Project 4009). Denver, Colo.: AwwaRF.

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Green Infrastructure and Stormwater Management: The Philadelphia Story

- Green urban management options (e.g., low impact development) may appear costly
  - E.g., Green approach to CSO control may cost same (or more) than the traditional “grey” options
  - Regulator acceptance of green approach is uncertain
- However, intuition suggests considerable beneficial values of going green
  - But what are the benefits?
  - How large are they?
  - Do they justify any added expense or potential regulatory pushback?

Green CSO Approach

Activities

Add:

- Watershed restoration
- Stormwater regulations
- Bioretention features
- Tree planting
- Urban greenspace, parks
- Green roofs

Subtract:

- Excavation/disruption
- Concrete
- Pump and treat

Benefits of Green CSO Approach

Activities

Add:

- Watershed restoration
- Stormwater regulations
- Bioretention features
- Tree planting
- Urban greenspace, parks
- Green roofs

Subtract:

- Excavation/disruption
- Concrete
- Pump and treat

Benefit Categories

- Water quality
- Aquatic/riparian ecosystem
- Recreation
- Aesthetics
- Energy savings
- Air quality
- Public health
- Carbon footprint
- Traffic flow
- Green collar jobs

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Benefits of Watershed Activities

Activities	Benefit Categories
Add:	
Watershed restoration	Water quality
Stormwater regulations	Aquatic/riparian ecosystem
Bioretention features	Recreation
Tree planting	Aesthetics
Urban greenspace, parks	Energy savings
Green roofs	Air quality
Subtract:	Public health
Excavation/disruption	Carbon footprint
Concrete	Traffic flow
Pump and treat	Green collar jobs

Benefits of Vegetation Activities

Activities	Benefit Categories
Add:	
Watershed restoration	Water quality
Stormwater regulations	Aquatic/riparian ecosystem
Bioretention features	Recreation
Tree planting	Aesthetics
Urban greenspace, parks	Energy savings
Green roofs	Air quality
Subtract:	Public health
Excavation/disruption	Carbon footprint
Concrete	Traffic flow
Pump and treat	Green collar jobs

Benefits from Avoided Grey Impacts

Activities

Add:

- Watershed restoration
- Stormwater regulations
- Bioretention features
- Tree planting
- Urban greenspace, parks
- Green roofs

Subtract:

- Excavation/disruption
- Concrete
- Pump and treat

Benefit Categories

- Water quality
- Aquatic/riparian ecosystem
- Recreation
- Aesthetics
- Energy savings
- Air quality
- Public health
- Carbon footprint
- Traffic flow
- Green collar jobs

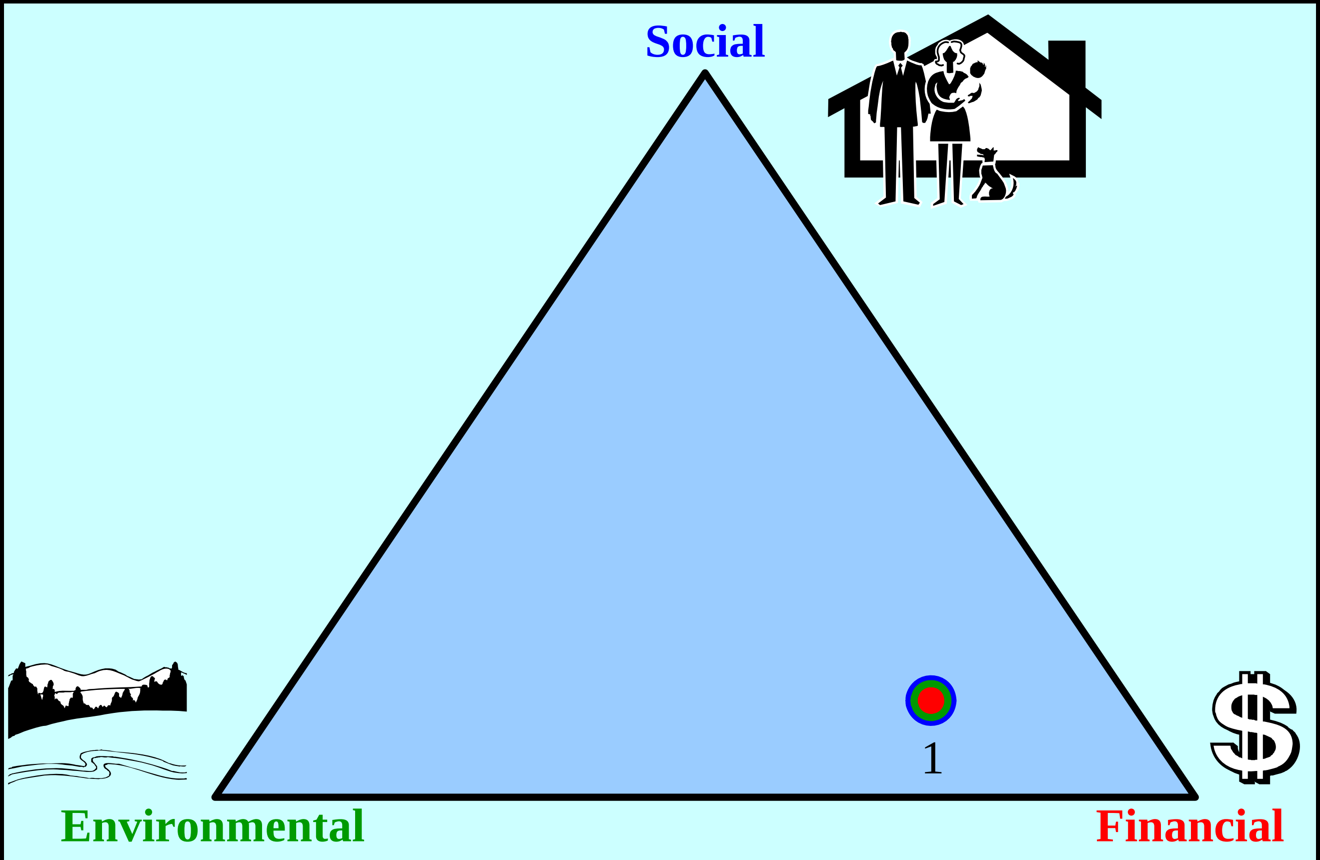
Preliminary Estimates of Present Value Benefits for Tookany-Tacony-Frankford Watershed

Benefit Categories	Green 50% (Alt 1a-2)	Grey 30 ft (Alt 2-4)
Increased Recreational Opportunities	\$ 41.8 million	
Reduction in Heat Stress Mortality	\$ 93.5 million	
Energy Savings/Usage	\$9.8 million	(\$1.3 million)
Air Quality Improvements from Trees	\$ 51.2 million	
Reduced (Increased) Costs of SO_2 and NO_x Emissions	\$14.5 million	(\$12.3 million)
Reduced (Increased) Costs of CO_2 emissions	\$4.4 million	(\$1.3 million)
Social Costs Avoided by Green Collar Jobs	\$27.8 million	
Improved Aesthetics/Property Value (50%)	\$41.5 million	
Disruption Costs from Construction and Maintenance	(\$1.2 million)	(\$1.9 million)
Aquatic and Terrestrial Ecosystems	+	(-)
Water Quality Enhancement	+	+
Total	**\$283+ million**	**(\$17+ million)**

Link to Triple Bottom Line (TBL)

- TBL can be a useful approach for trying to reflect broad array of all benefits (and costs)
- Three bottom lines:
  - ***Financial*** (i.e., cash flows, revenues, expenses)
  - ***Social*** (e.g., employment, equity, sustainability)
  - ***Environmental*** (e.g., water quality, carbon footprint)
- In essence, TBL = a comprehensive benefit-cost analysis
  - I.e., Identifying *all* benefits and costs; both internal and external

TBL Graphic: Choosing the Least Cost Option May Not Deliver Social and Environmental Values to the Community



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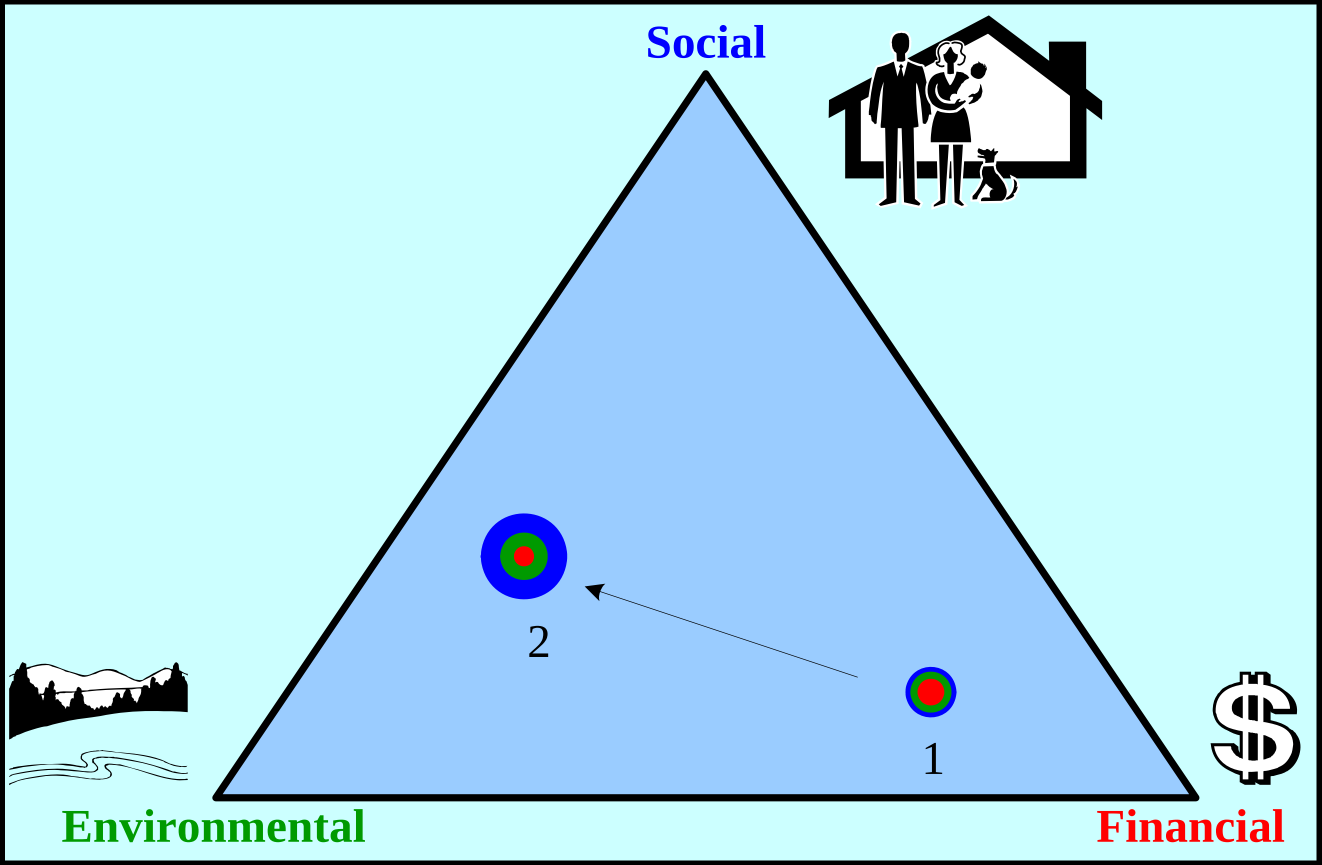
Options that Meet Broader Goals May Increase Financial Costs to a Utility, but Yield Larger Net Benefits to the Community

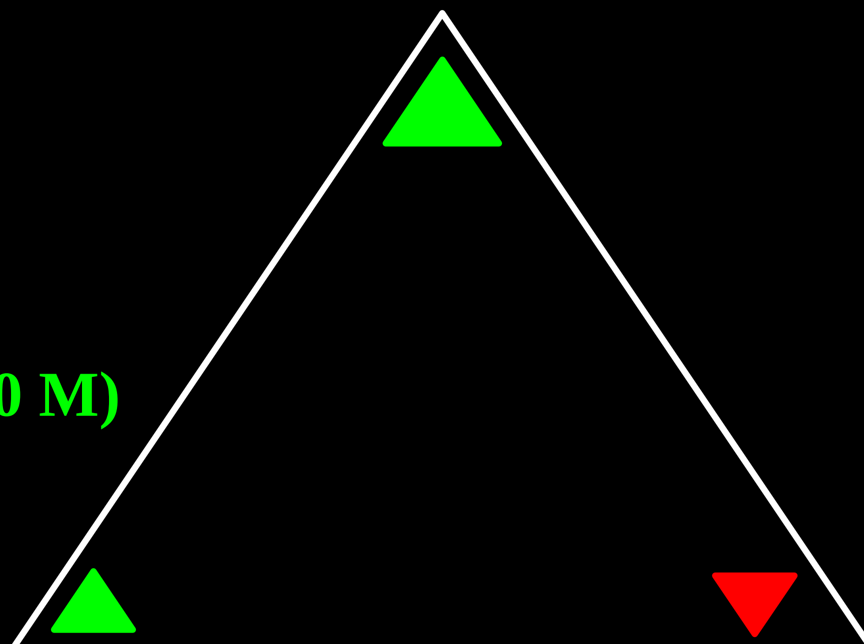


TBL Graphic for Green CSO Control

(Preliminary PV Estimates for Green 50% in TTF Watershed)

Social (> \$200 M)

- Recreation (\$42 M)
- Property values/aesthetics (\$42 M*)
- Green jobs (\$28 M)
- Public health (\$94 M)
- Energy cost savings (\$10 M)



Environmental (> \$70 M)

- Air quality (\$66 M)
- Water quality (+)
- Carbon footprint (\$4 M)
- Ecosystems (+)

Financial

- Cost of Green <u>may</u> exceed that of Grey CSO control

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Future Prospects for Public Water Supply with Climate Change

- Demands for water will be increasing
  - – More people
  - – Hotter, longer, and drier summers
- Less supply from traditional sources
  - – Less storage in snowpack and reservoirs
  - – Less infiltration, less runoff, more dryness
  - – More constraints on freshwater extractions
  - – Many areas probably facing more drought
  - – Saltwater intrusion

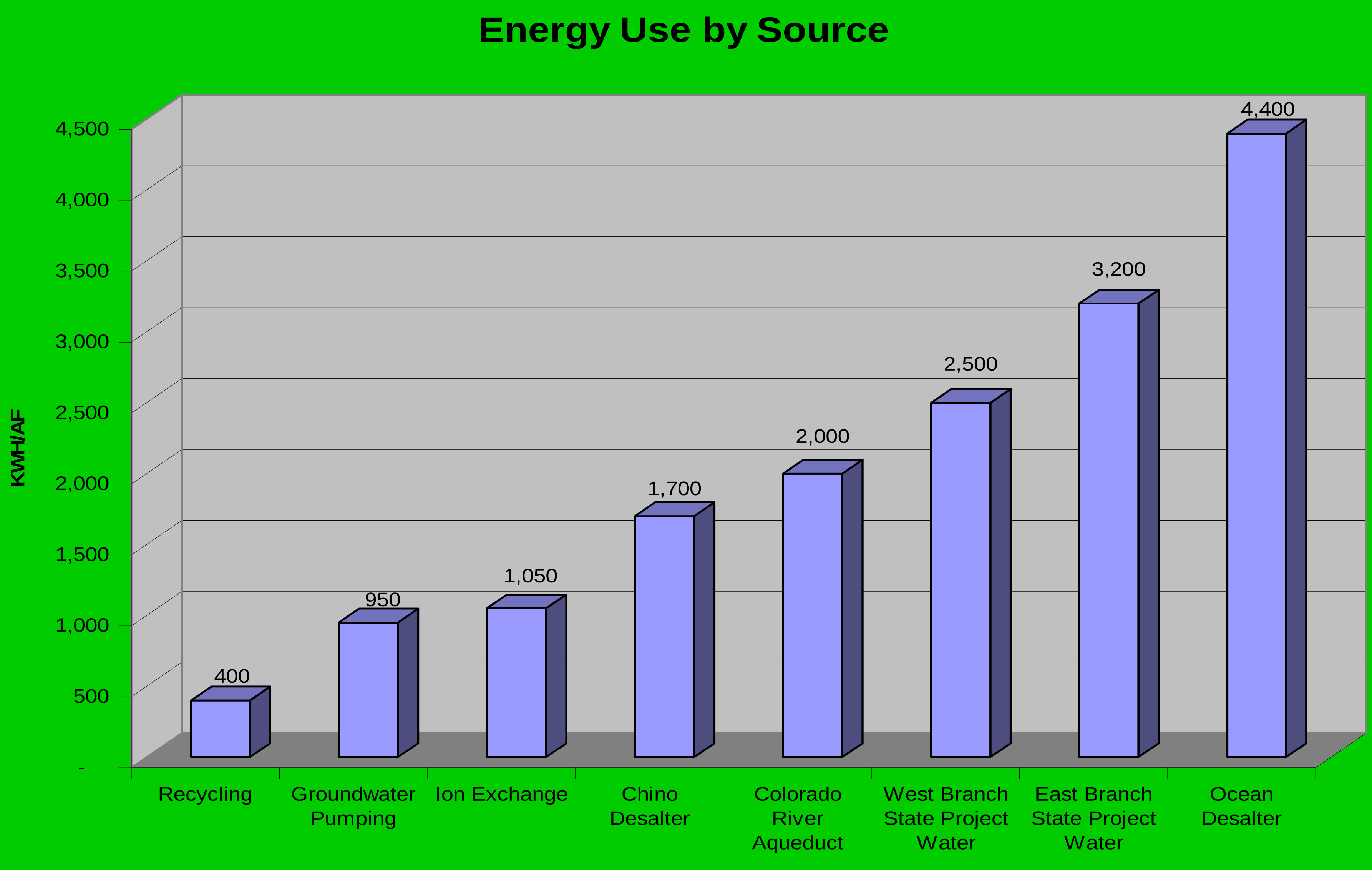
Future Prospects with Climate Change

- Lower water quality of traditional sources
  - Treatment needs and related energy needs increase
  - Desal & reuse increasingly cost-competitive, and increasingly necessary
- Increased benefit of drought resistant supplies
  - Desal and reuse yields not climate-linked
  - Reliability aspect becomes more attractive

Increasing Water Sector Reliance on Energy

- Energy use and reliance is likely to increase in water sector in years ahead
  - Energy intensive treatment processes for regulatory compliance (UV, membranes)
  - New sources of supply (desalination, water reclamation) are energy intensive
  - Pumping longer distances and from greater depths to meet growing demands
- Carbon footprint challenges
  - Also cost and reliability concerns

The Energy Intensity of Water Supplies: Example from the Inland Empire



Conclusions

- Climate change will create many water resource management challenges
  - Vulnerabilities exist from source to tap (and from drain to receiving waters)
  - Impacts on water quantity and <u>quality</u>
  - Infrastructure and operations at risk
- Opportunities exist to adapt (and mitigate)
- Changes to the suite of regulatory concerns
  - Source water quality and related DW treatment challenges (e.g., higher turbidity, more variability)
  - Desal and reuse likely to be more prevalent
  - Increased value of Green Infrastructure investments for stormwater management

Thank You!

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