IM3

INTEGRATED MULTISECTOR MULTISCALE MODELING

Exploring the consistency of water scarcity vulnerabilities across scales: Do our inferences converge?

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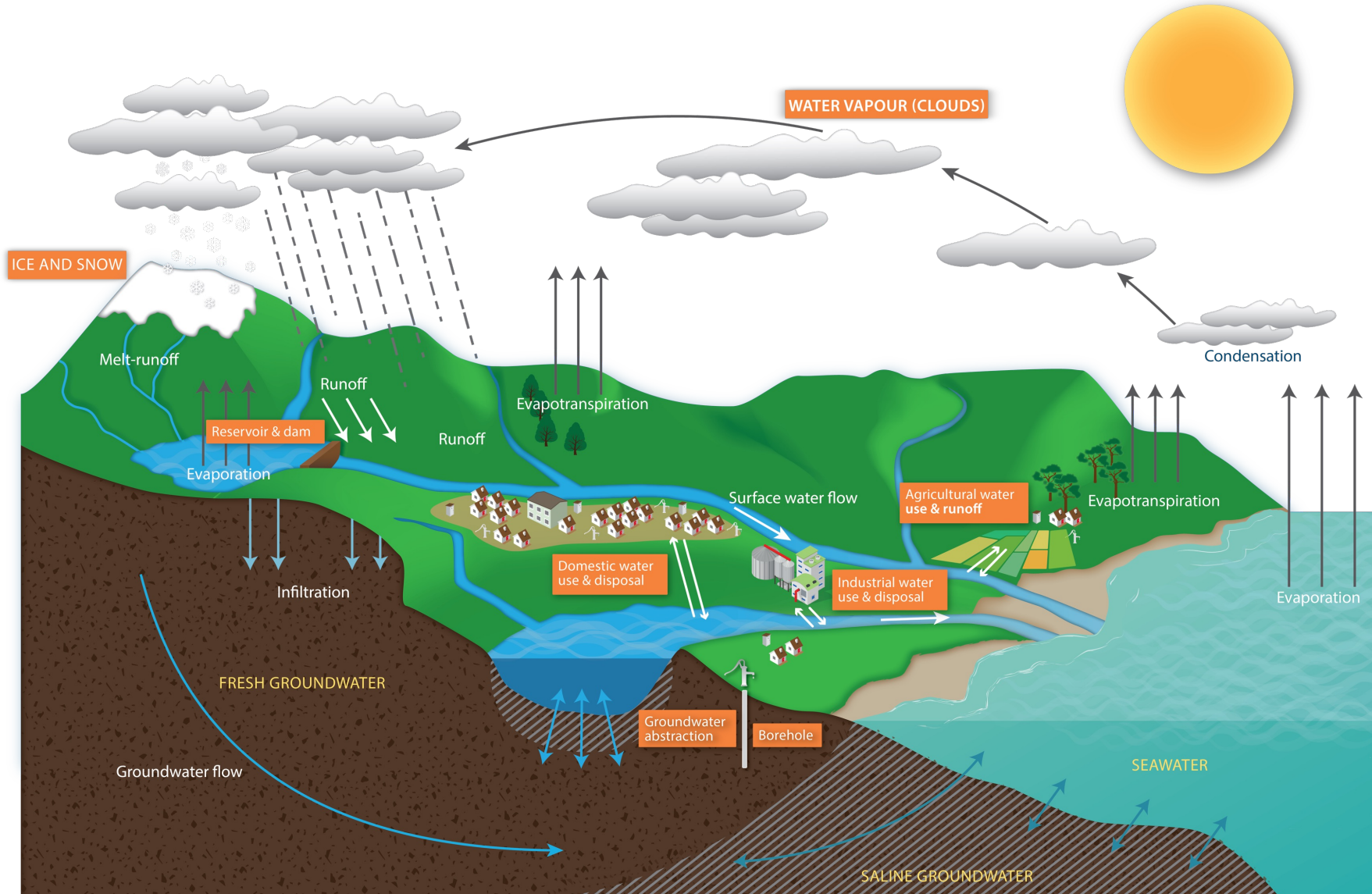
IM3

Simulation **modeling** is a **principal tool** for analyzing the behavior of water resources systems, evaluating future conditions, and assessing alternative management policies



Adapted from: The Water Module - Student Resource, School of Geography and the Environment, University of Oxford 2018 (https://upgro.files.wordpress.com/2018/03/water-module-student-resource-web.pdf)

Modeling typically in two communities

Modeling typically in two communities

Focusing on locally-relevant water system elements

Local scale

Modeling typically in two communities

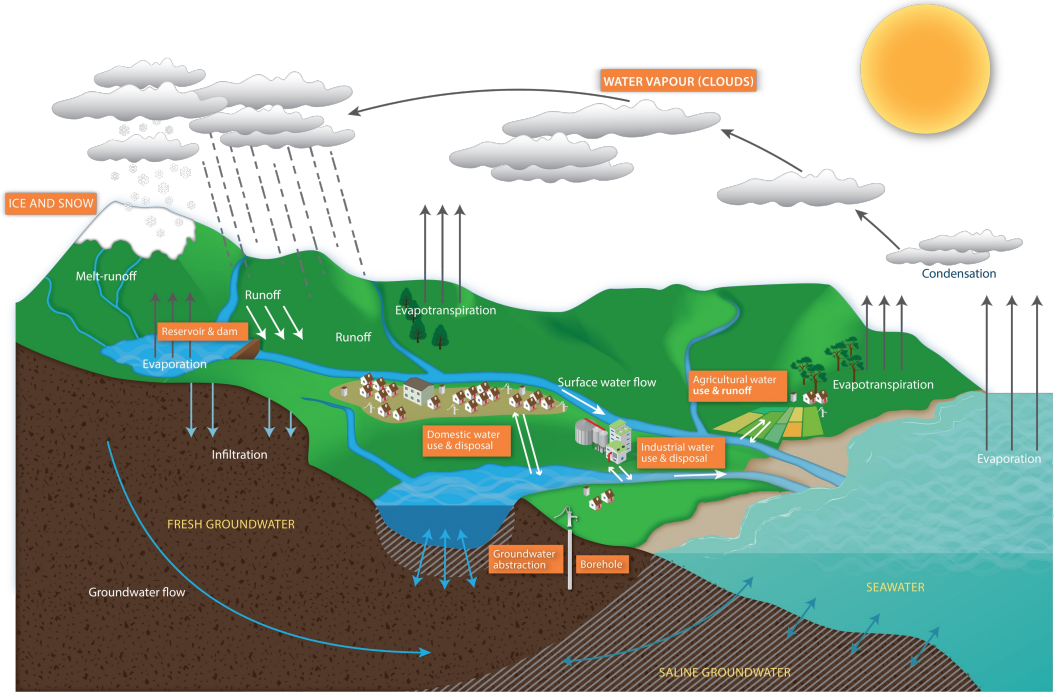
Focusing on locally-relevant water system elements

Local scale

Focusing on consistency with larger scale processes

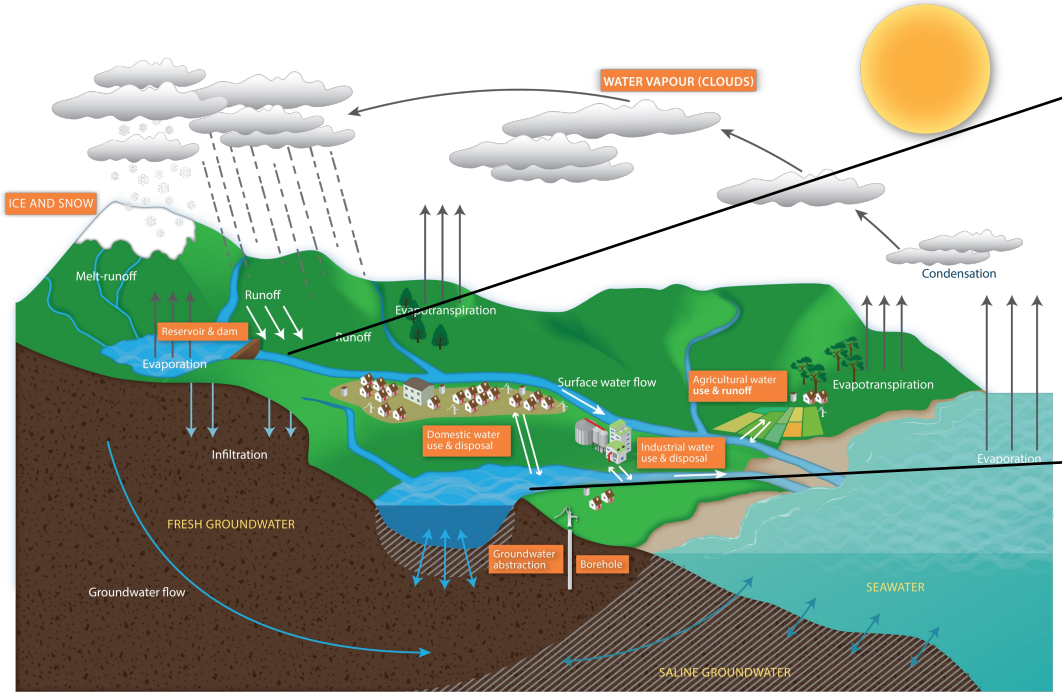
Large scale

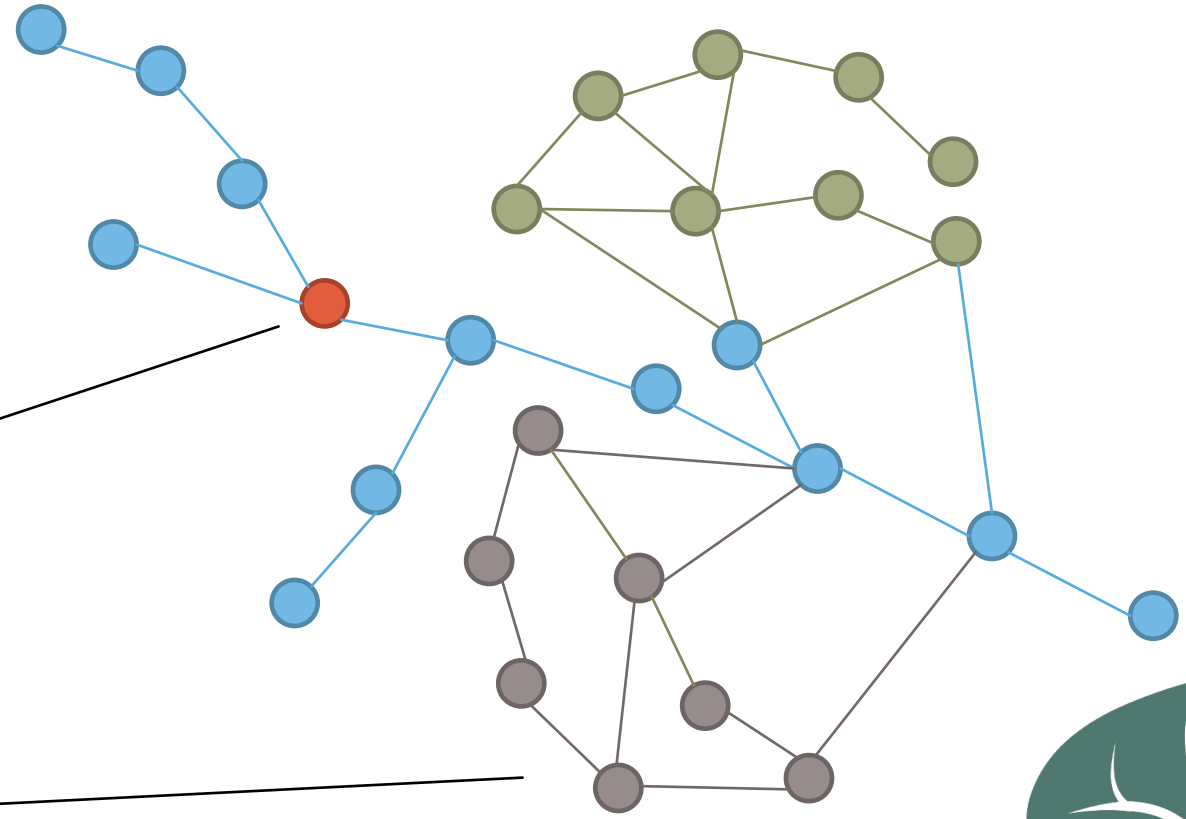
Water resources systems' models



Local scale

Water resources systems' models

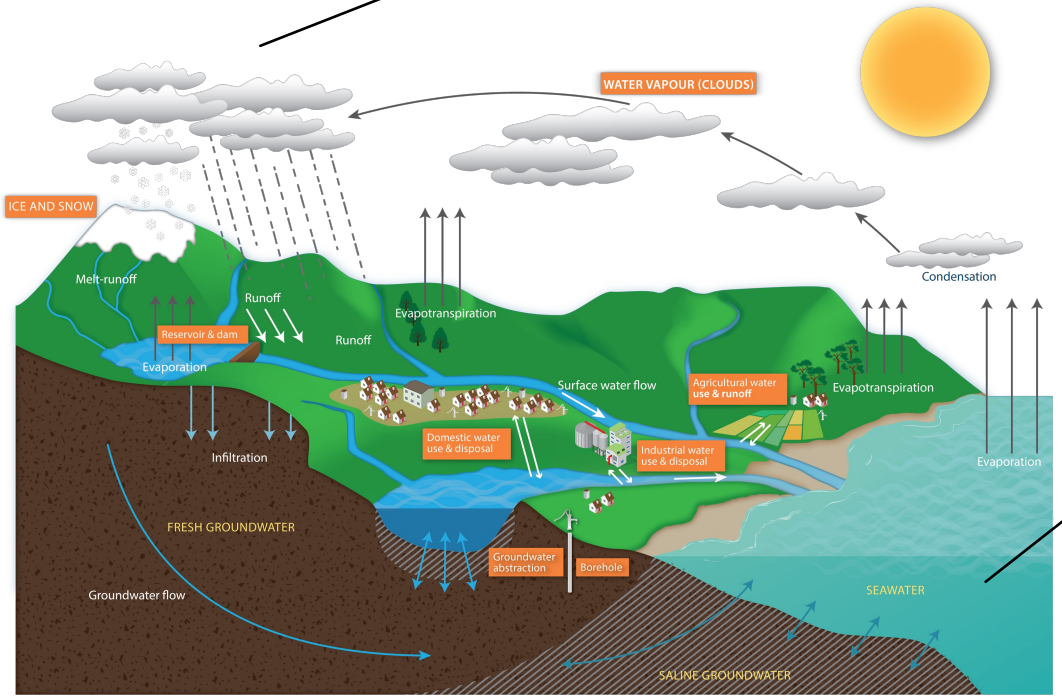


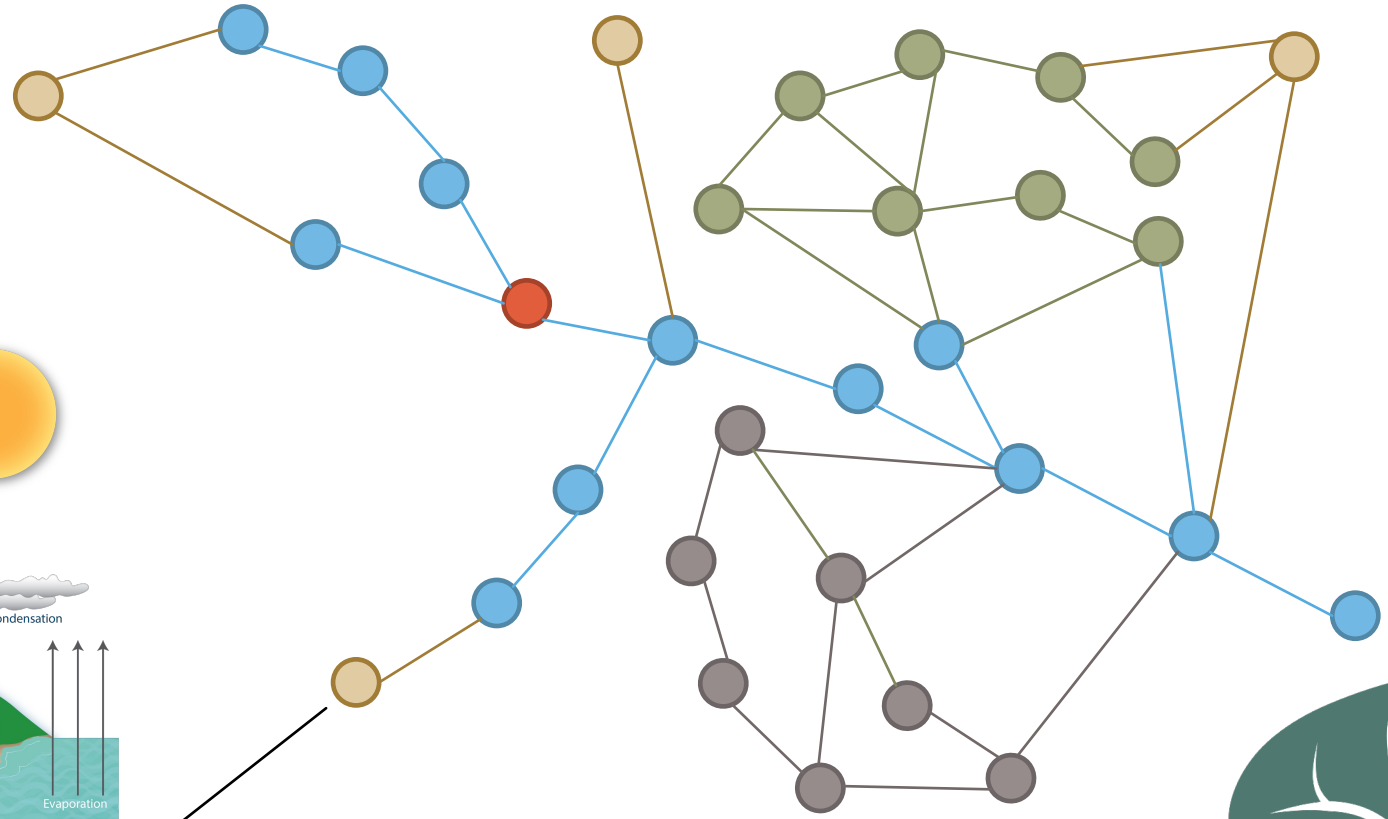


Represent water system components as elements with connections between them

Local scale

Water resources systems' models



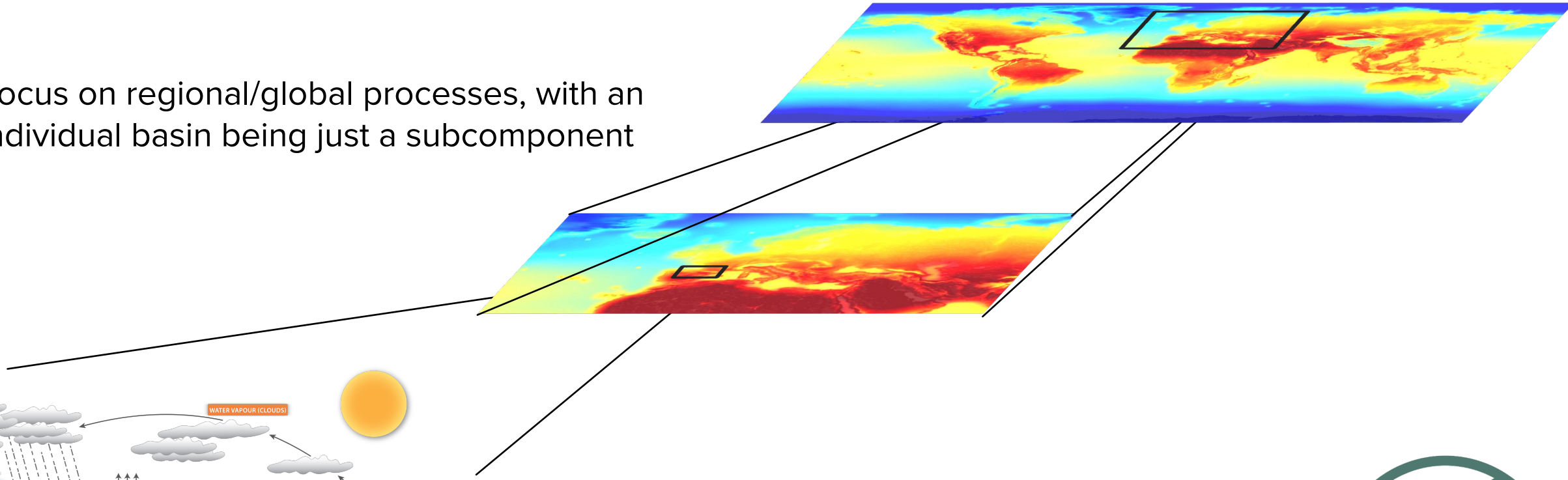


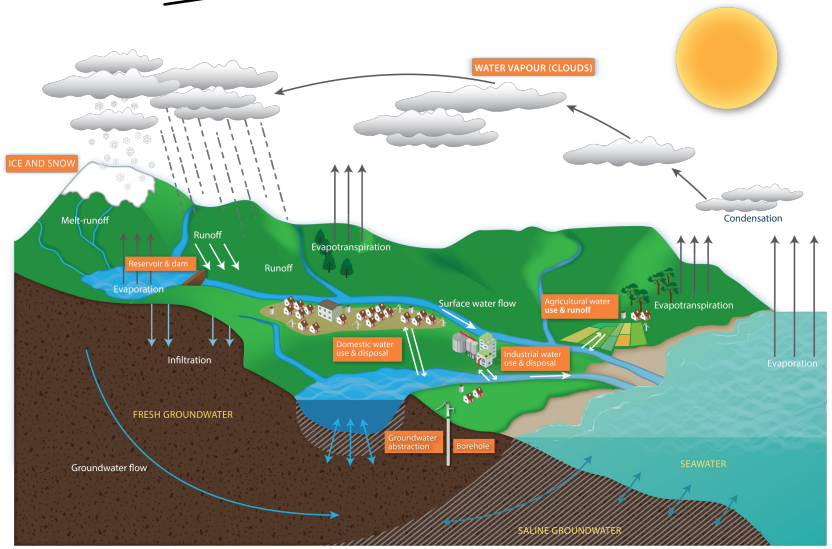
Broader scale components (e.g., precipitation, temperature) are treated external inputs to model components

Local scale

Large scale hydrologic models

Focus on regional/global processes, with an individual basin being just a subcomponent

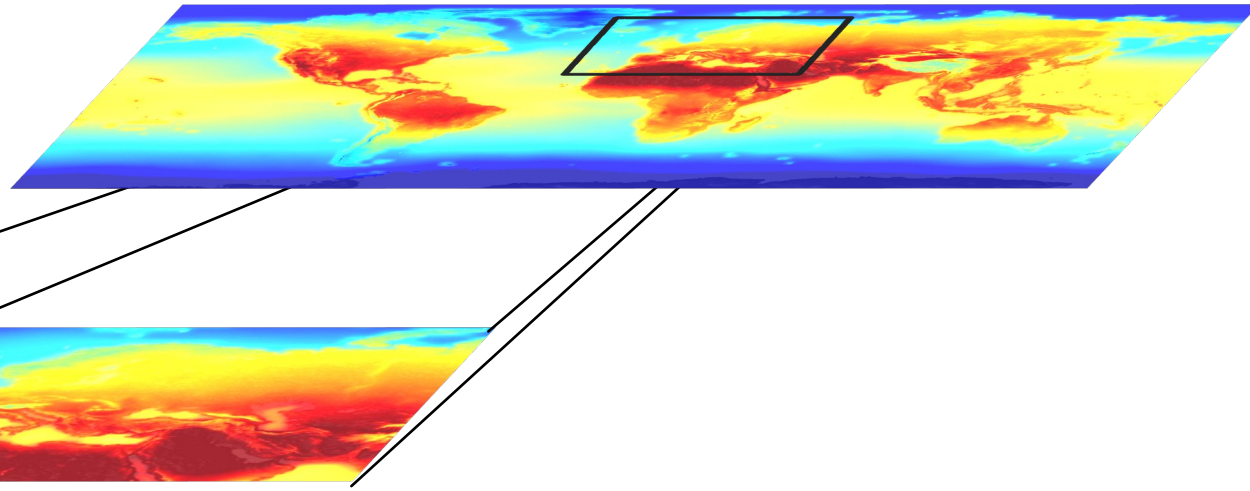


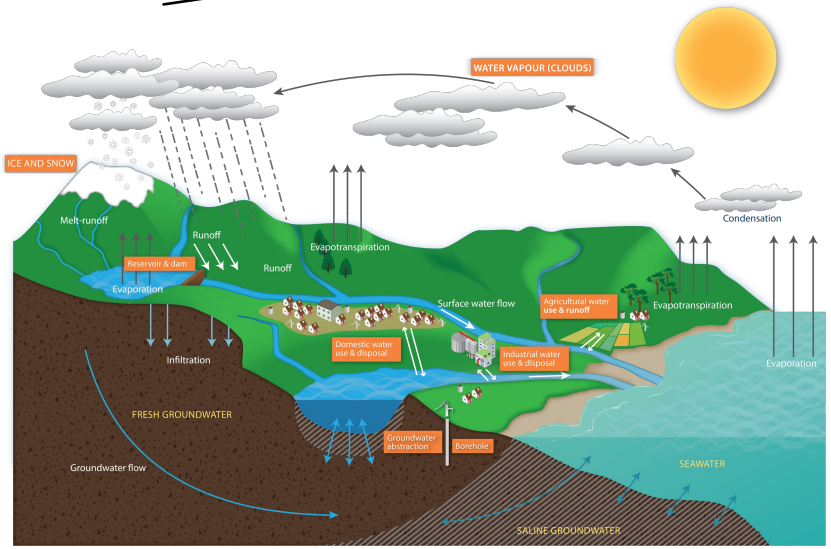


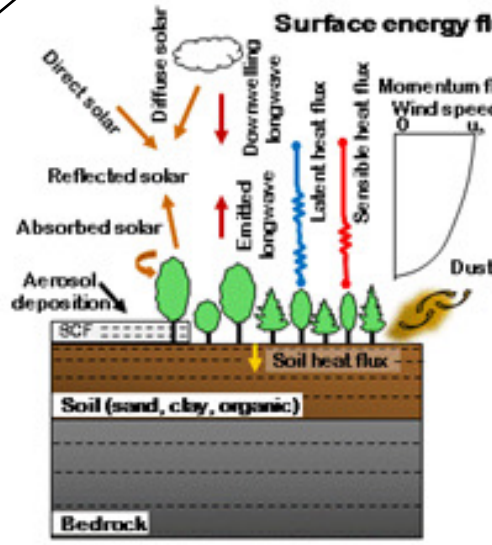
Large scale

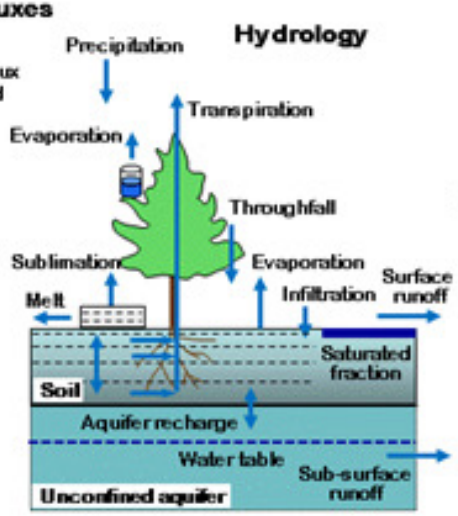
Large scale hydrologic models

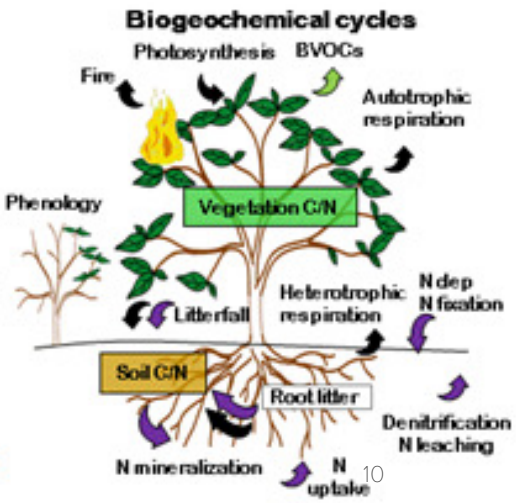
Enable consistency and interoperability with larger-scale processes: energy and water fluxes, biogeochemical cycles, atmospheric fluxes







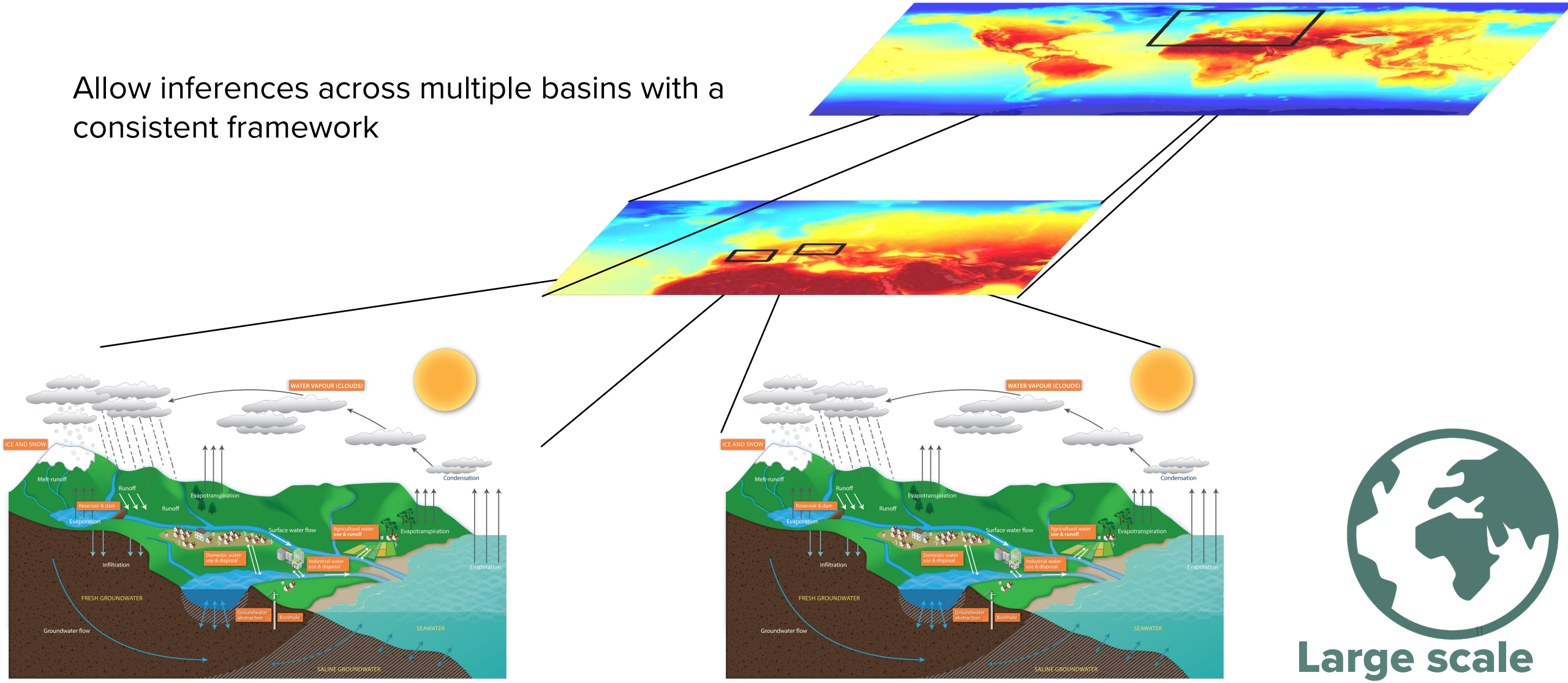




Source: https://www.cesm.ucar.edu/models/clm/

Large scale hydrologic models

Allow inferences across multiple basins with a consistent framework



Large scale

Modeling typically in two communities

\+ Can inform local decision making
Detailed and high resolution

– Large data requirements
Limited transferability to other locations/scales

Local scale

Modeling typically in two communities

Local scale

\+ Can inform local decision making
Detailed and high resolution

− Large data requirements
Limited transferability to other locations/scales

Large scale

\+ Directly linked to regional processes that shape local systems
Interoperable with non-hydrologic large-scale models

− Simplistic representation of human processes
Coarse at small scales

Modeling convergence

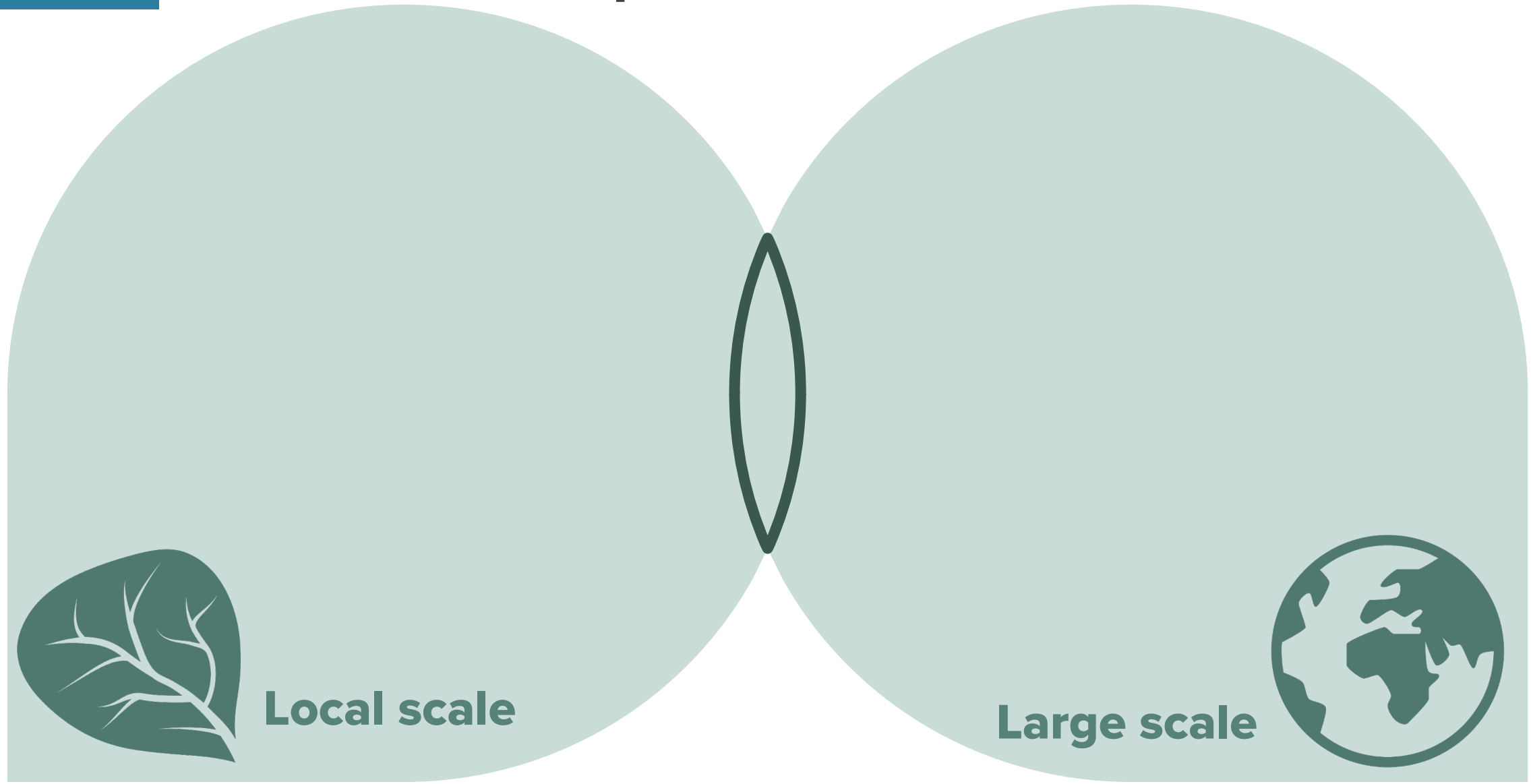
Efforts to internalize more larger-scale hydrologic and climatologic processes

Efforts to incorporate more institutional and infrastructure processes

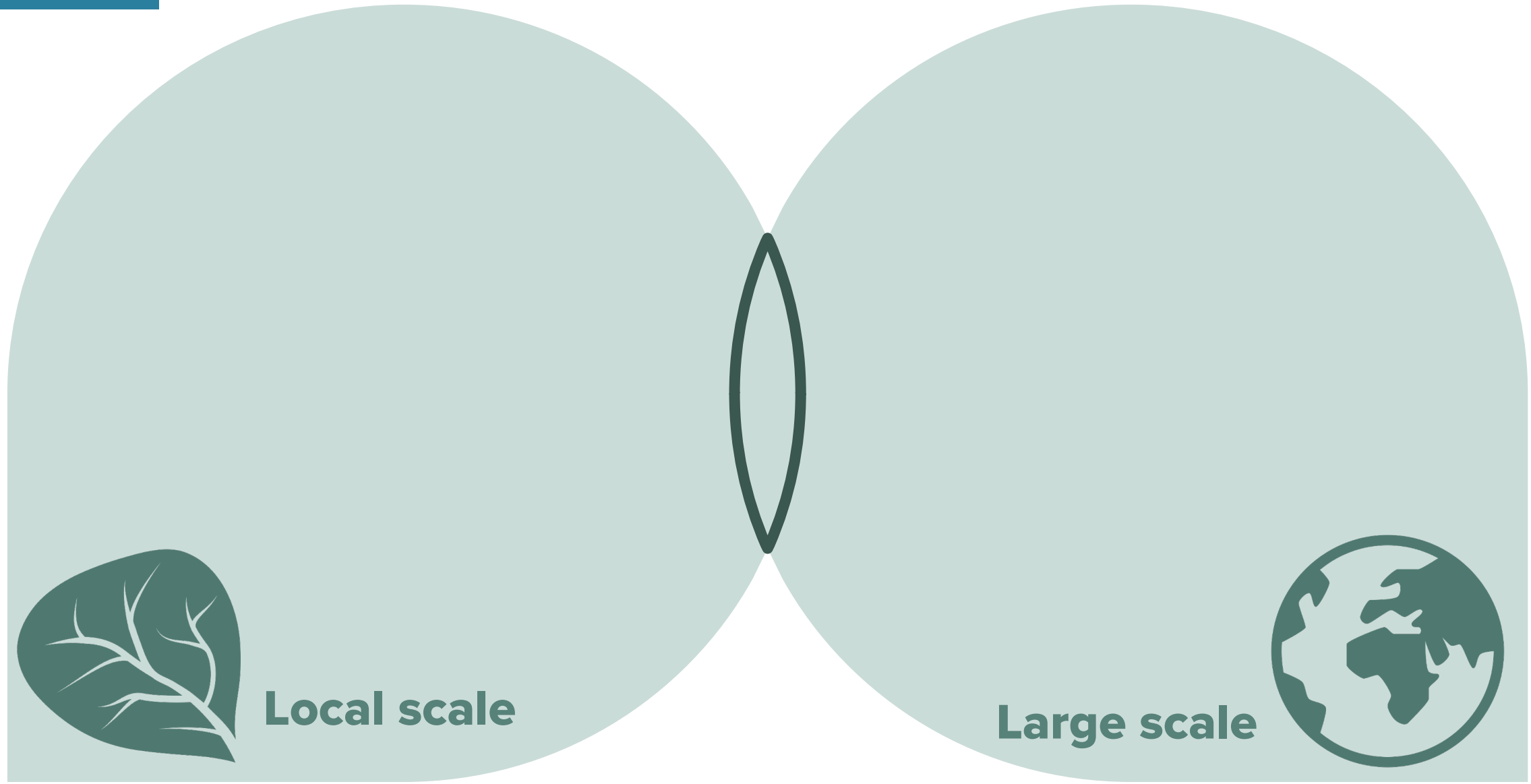
Local scale

Large scale

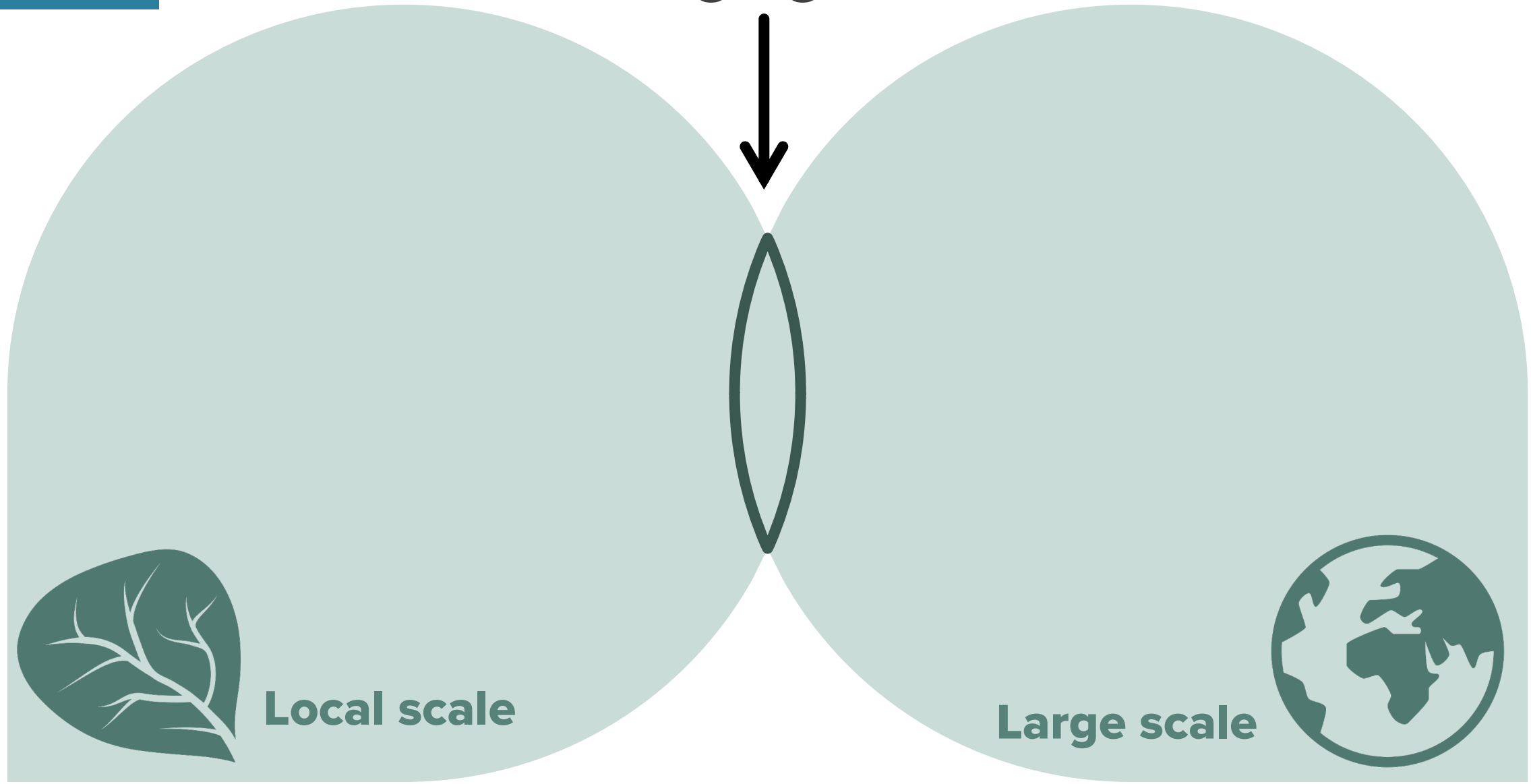
Focusing on this convergence, we want to address three questions:



IM3



If our modeling is converging, are our inferences converging too?



If our modeling is converging, are our inferences converging too?

A lot of our current and future stressors are shaped by processes in larger scales. What can we learn about modeling them better?

Local scale

Large scale

If our modeling is converging, are our inferences converging too?

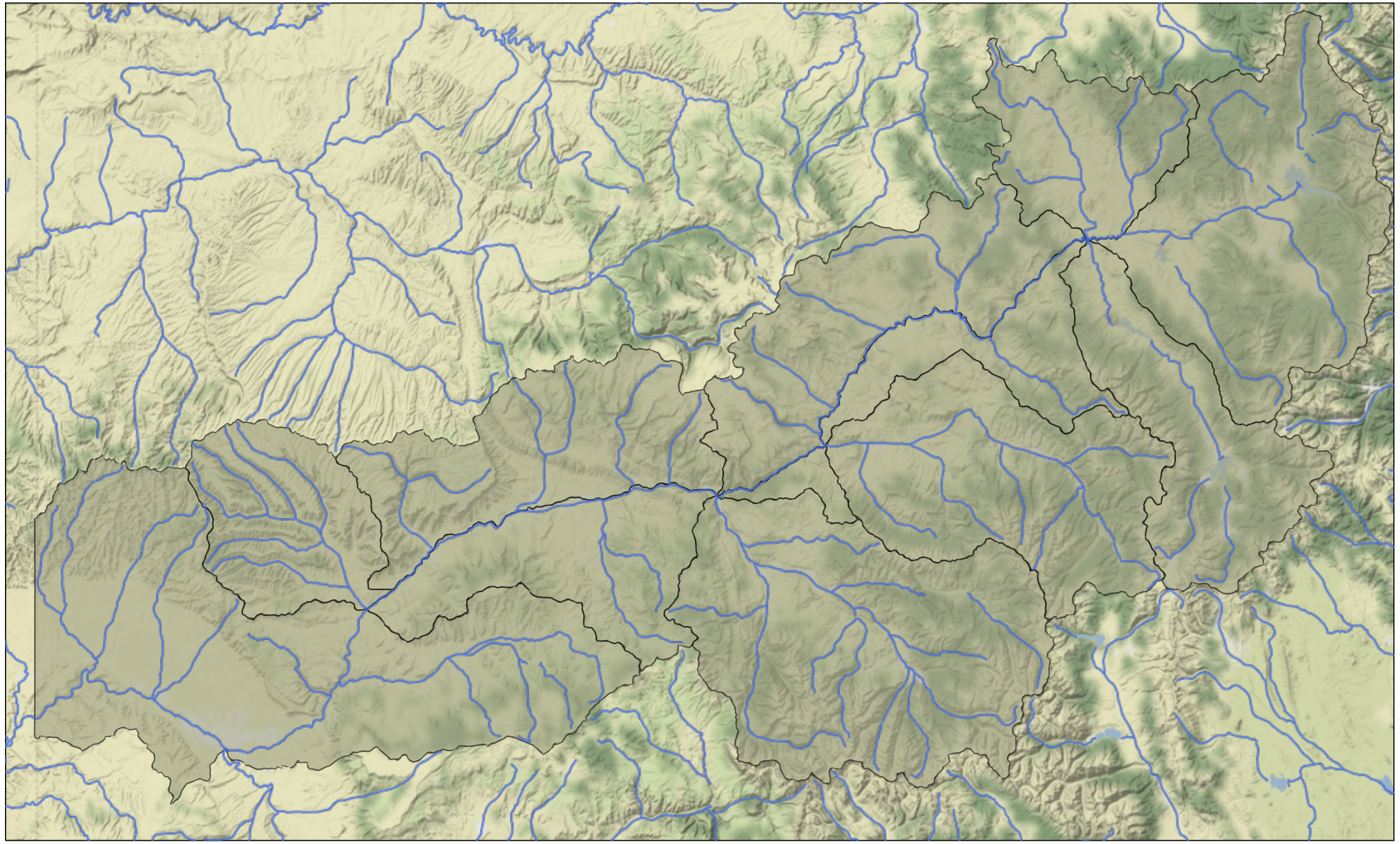
A lot of our current and future stressors are shaped by processes in larger scales. What can we learn about modeling them better?

Local scale

Many large-scale processes are shaped by humans. How can local-scale systems modeling better inform large-scale models?

Large scale

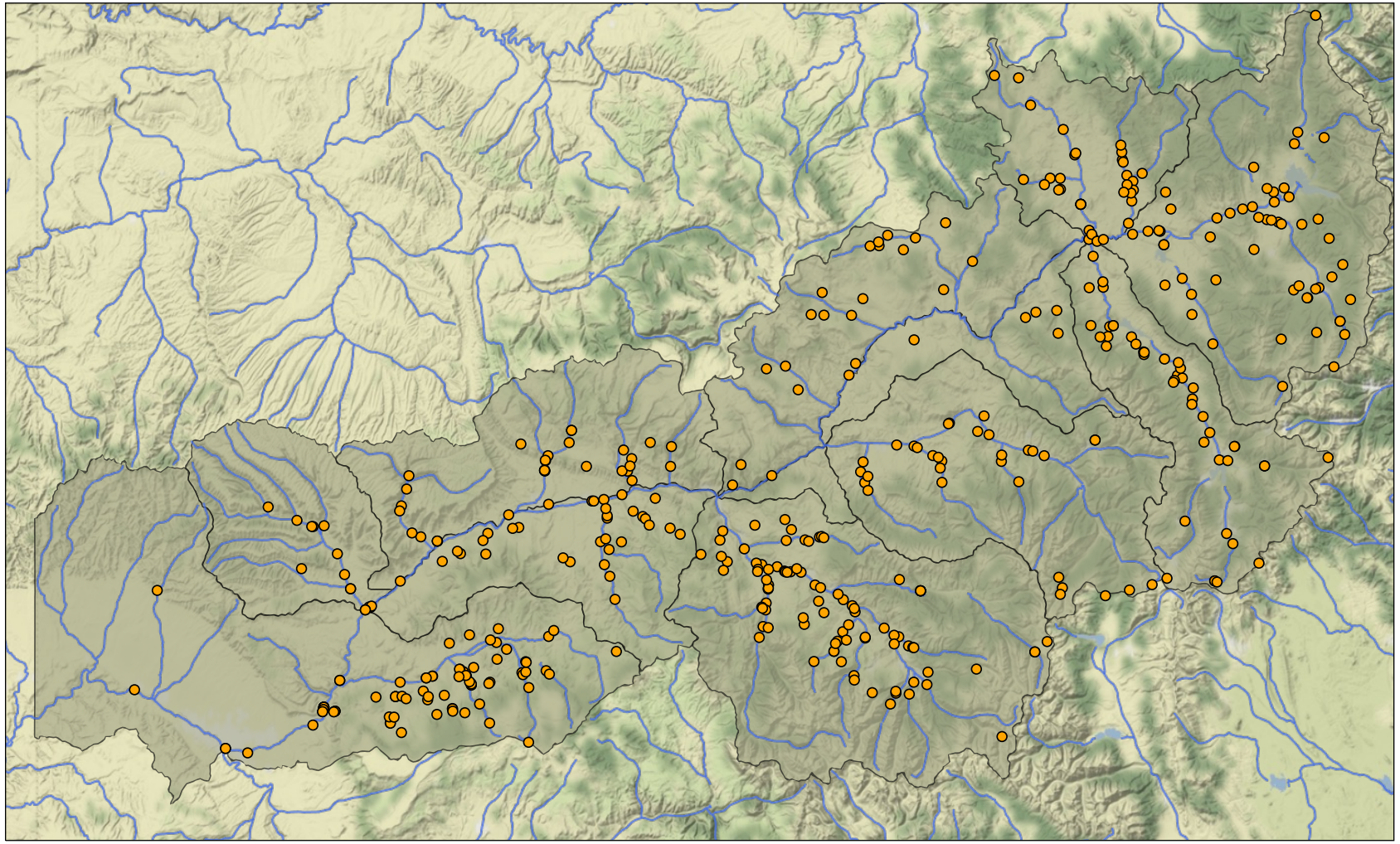
Upper Colorado River Basin (northwest Colorado)



Water resources system model of the basin

StateMod

https://cdss.colorado.gov/



Local scale

Water resources system model of the basin

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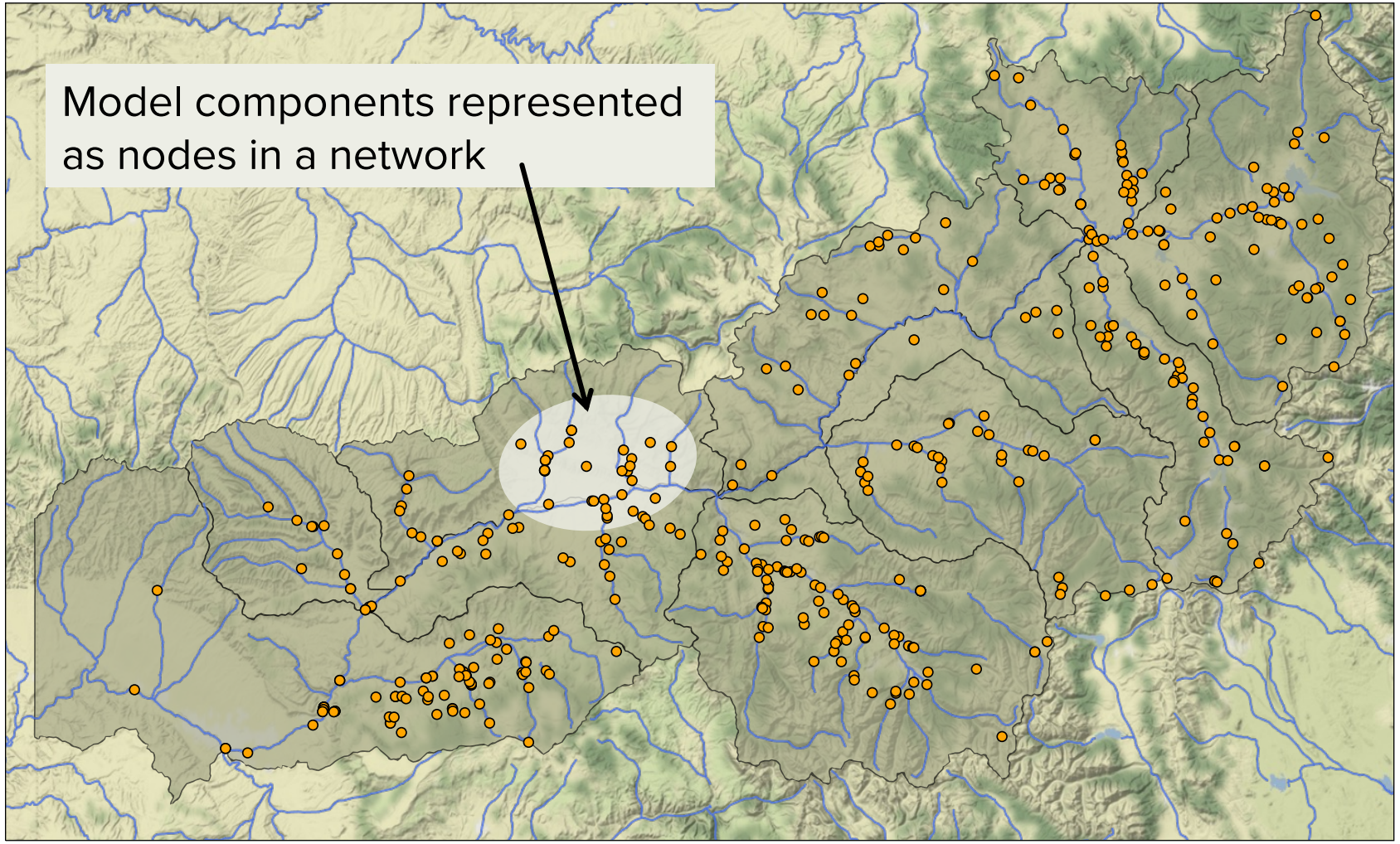

Local scale

Water resources system model of the basin

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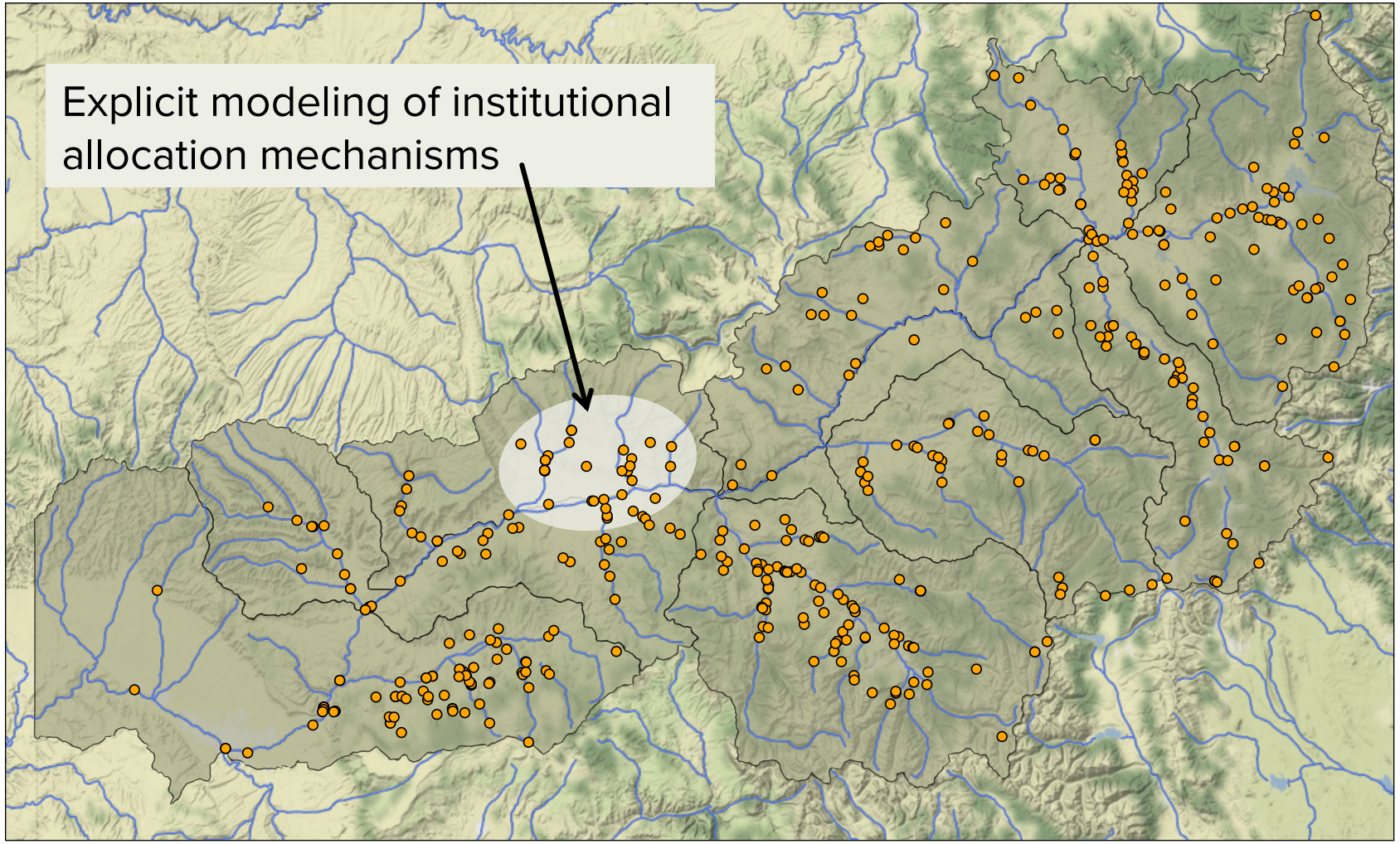

Local scale

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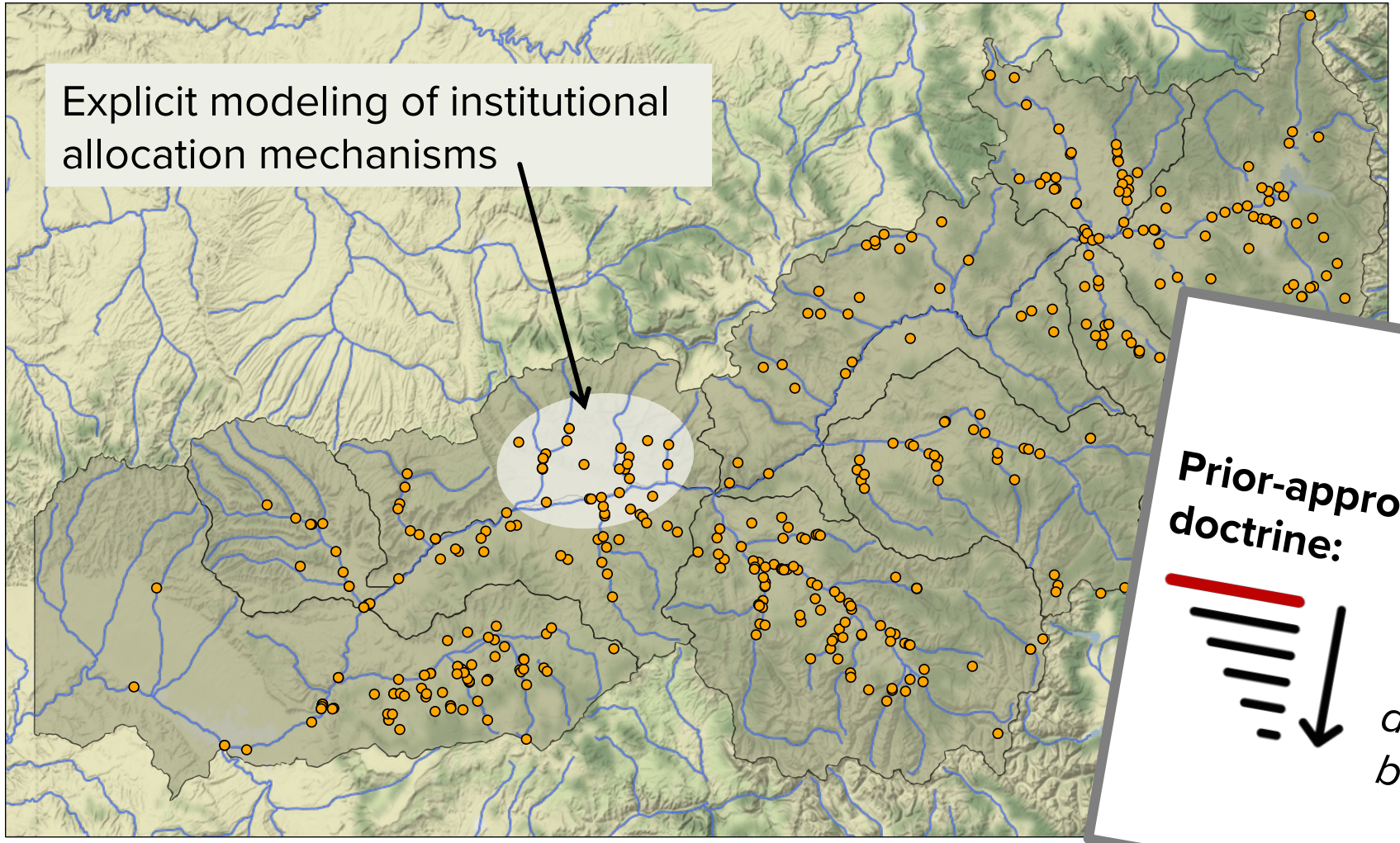
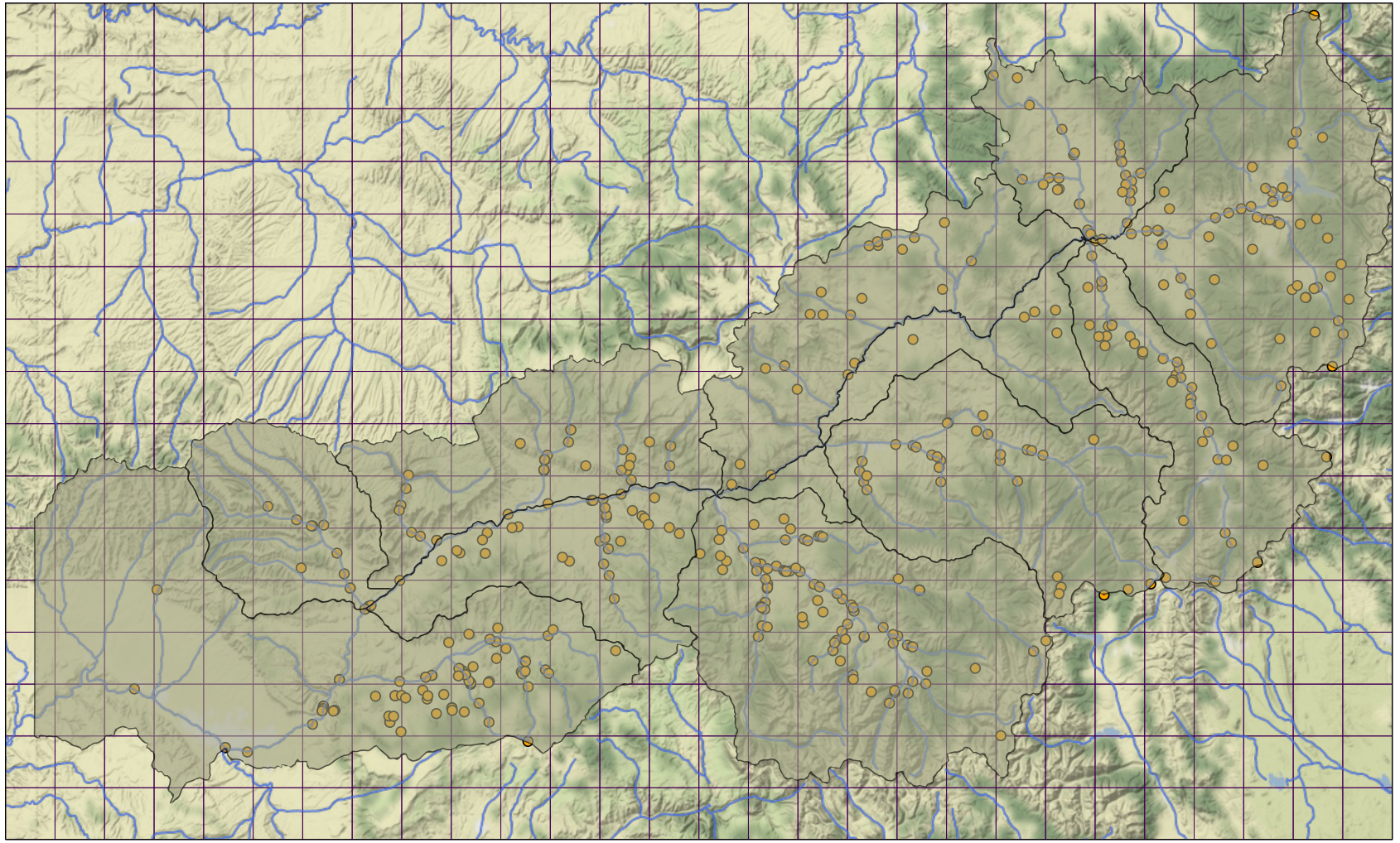


Prior-appropriation doctrine:

*Senior users get **all** water demands met before others*

Local scale

Large-scale hydrologic model (basin extent)

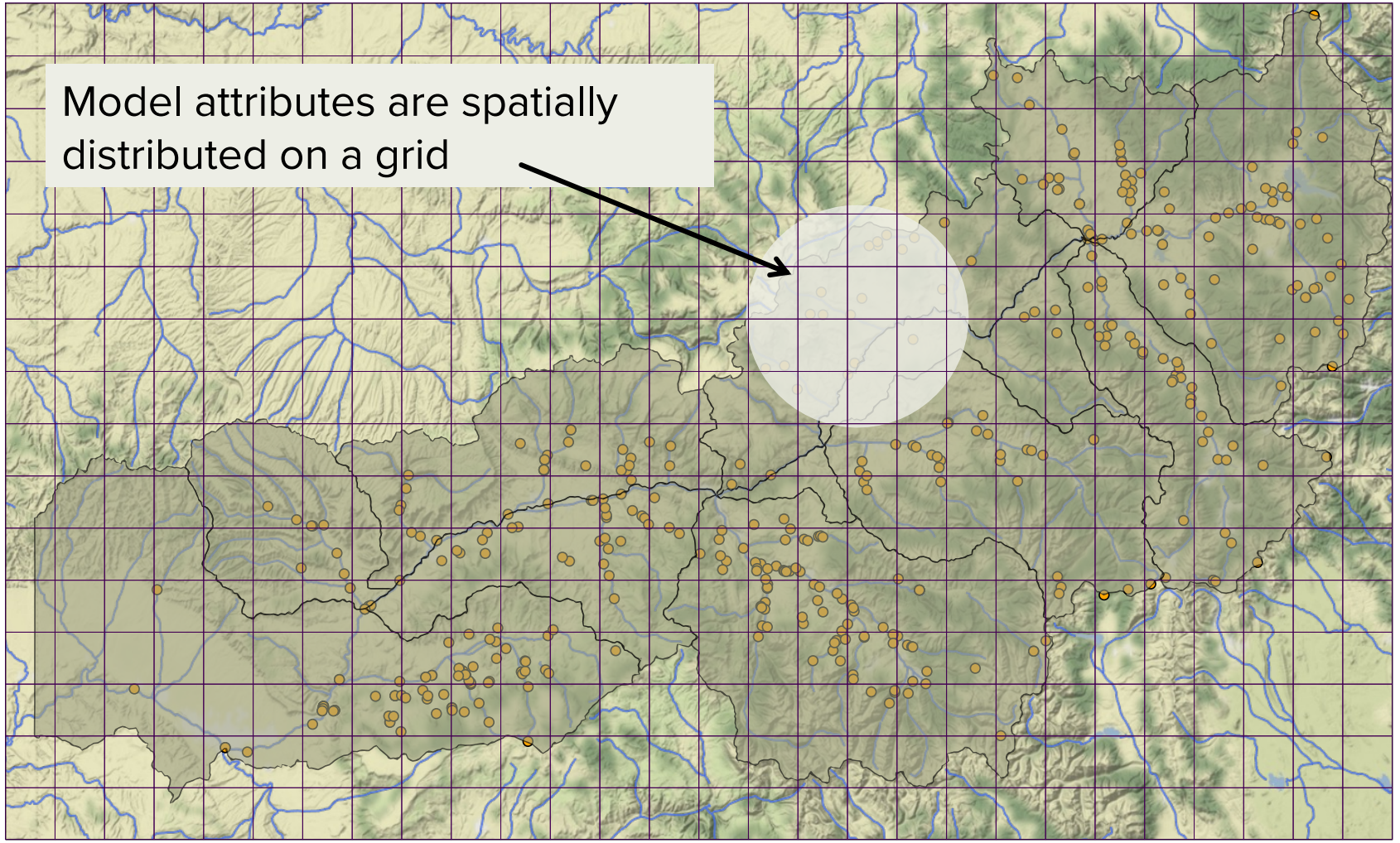


MOSART-WM

https://im3.pnnl.gov/model?model=MOSART-WM

Large scale

Large-scale hydrologic model (basin extent)



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Large scale

Representation of reservoirs

StateMod

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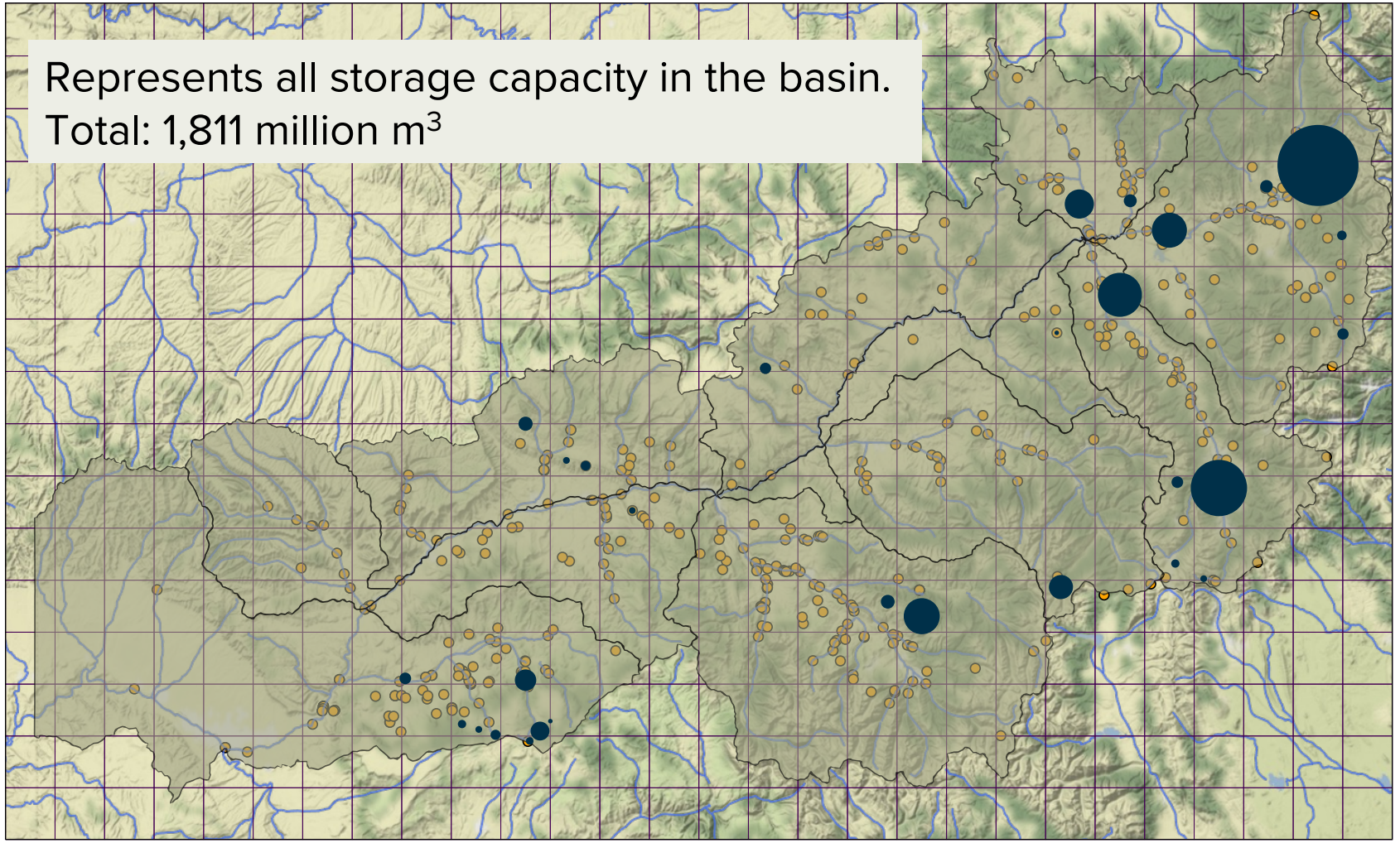

Local scale

Representation of reservoirs

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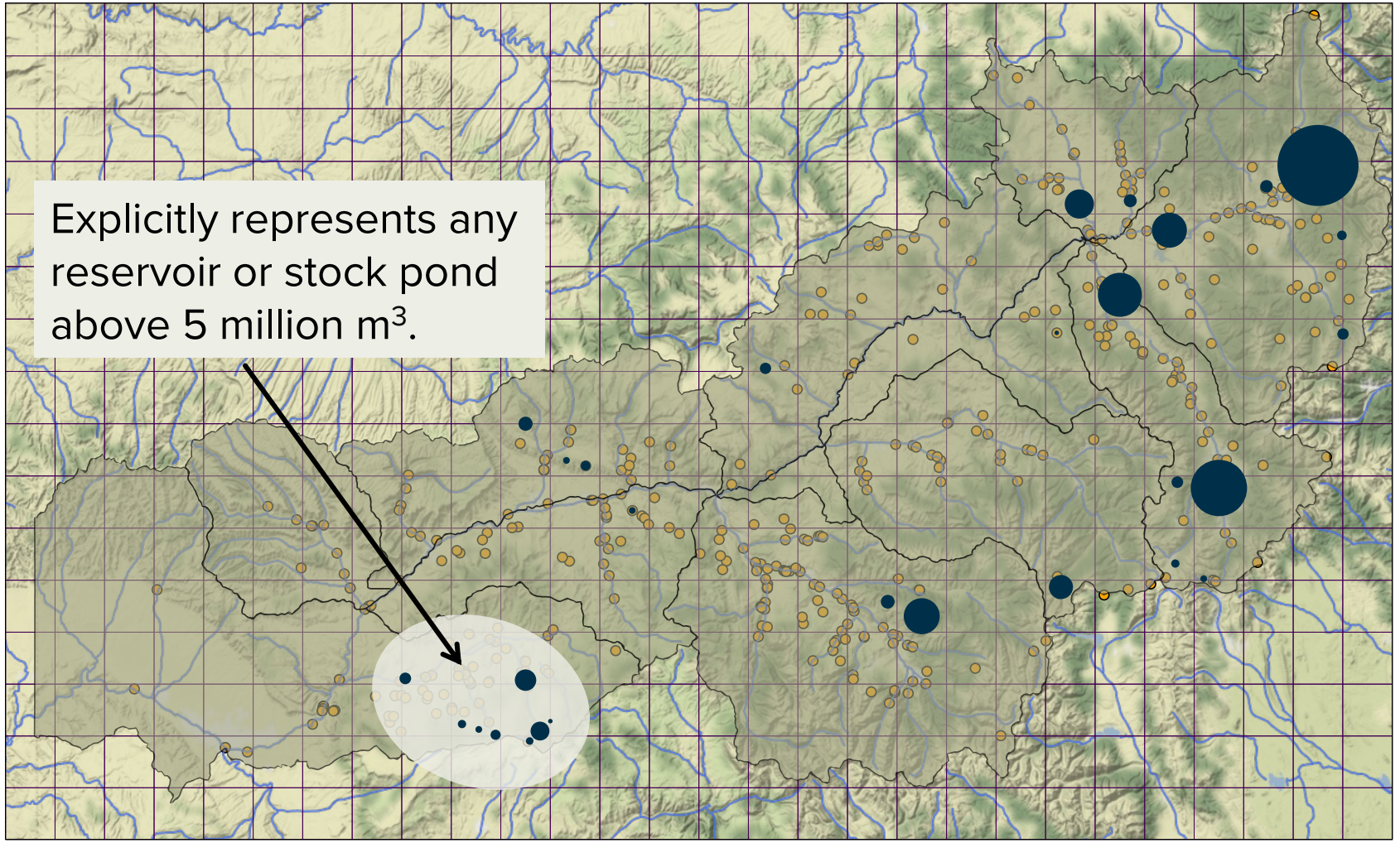

Local scale

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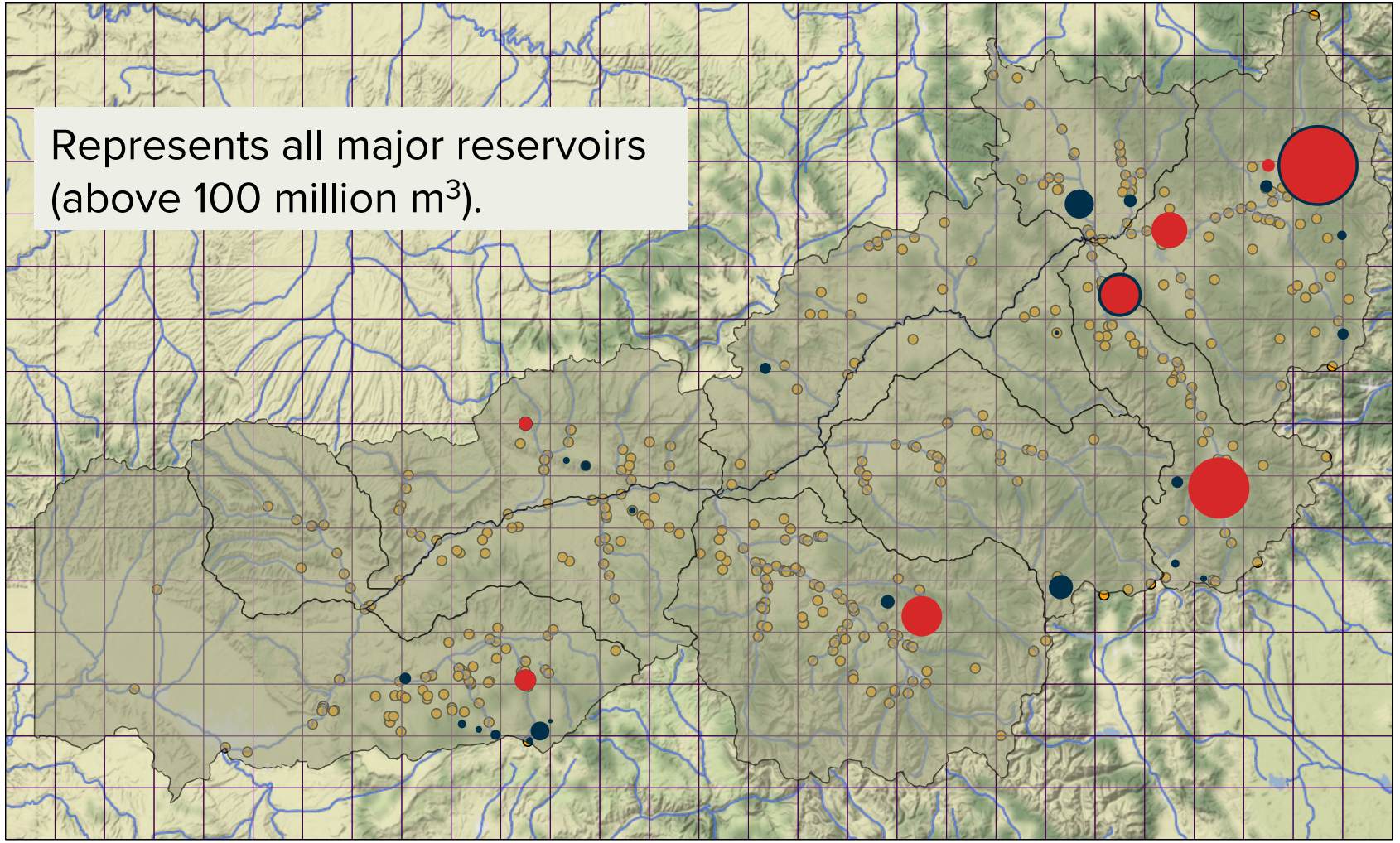

MOSART-WM

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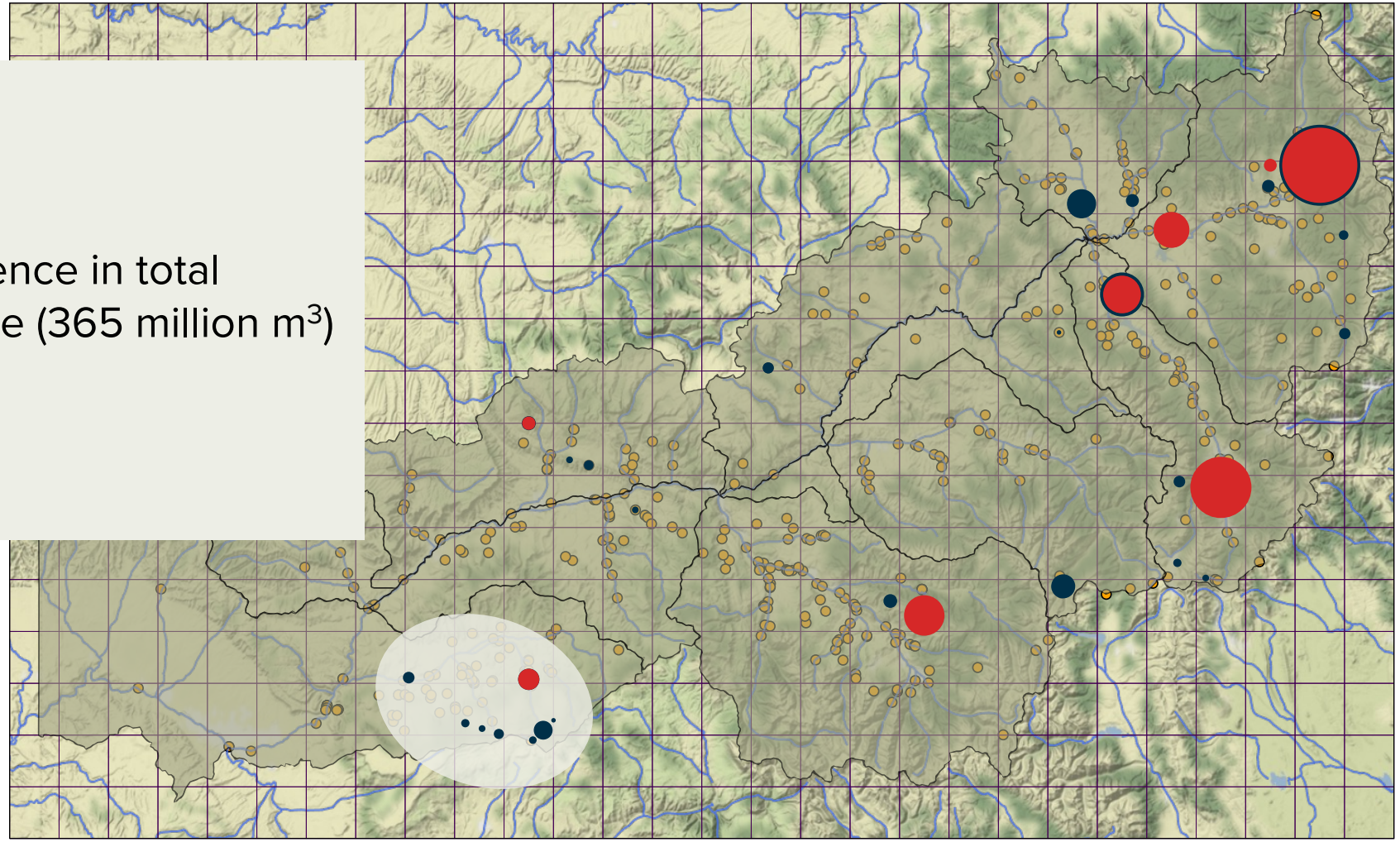
Large scale

Difference in total storage

Difference in total storage (365 million m^3)

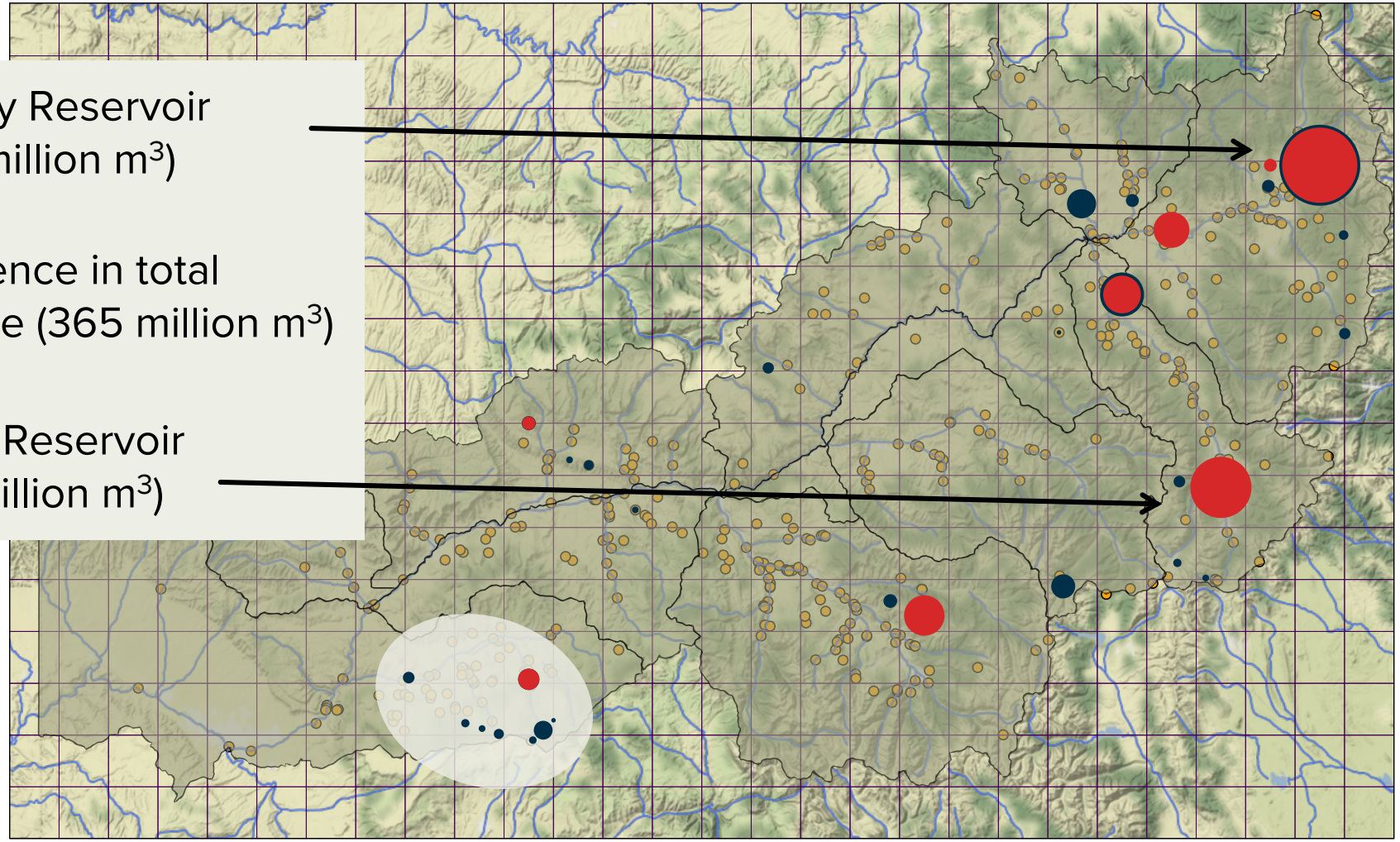


Difference in total storage

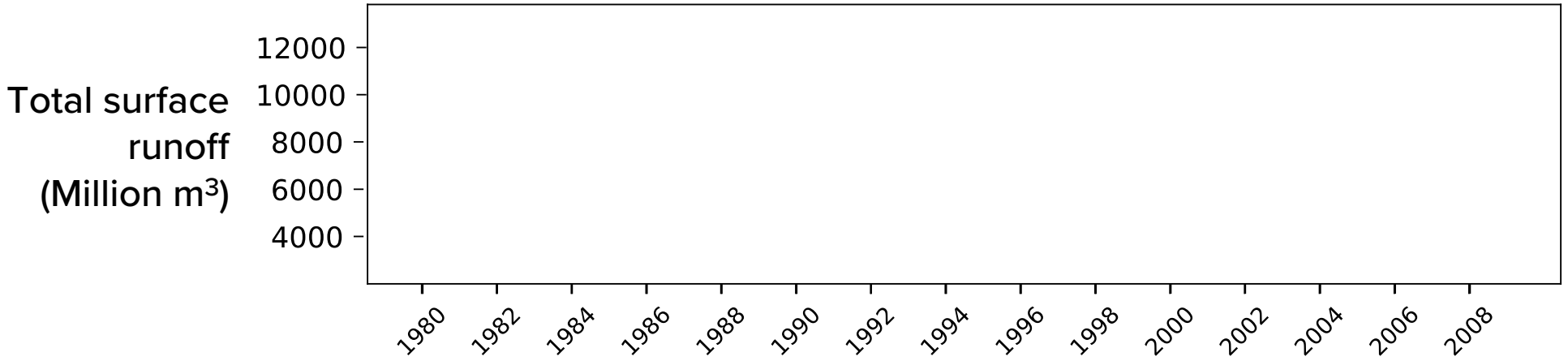
Granby Reservoir
(666 million m^3)

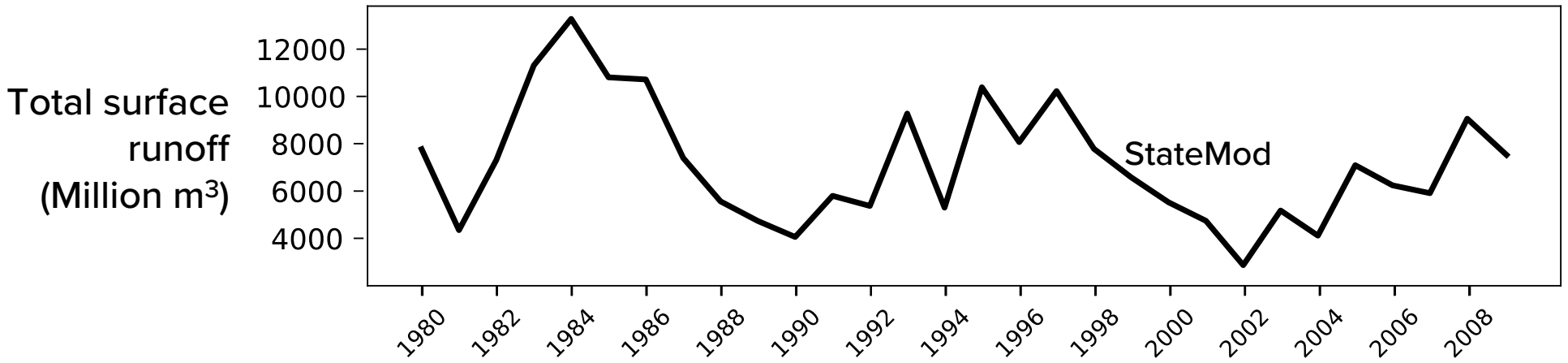
Difference in total
storage (365 million m^3)

Dillon Reservoir
(317 million m^3)



Is our modeling indeed converging?


Total surface runoff (Million m³)
12000
10000
8000
6000
4000
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008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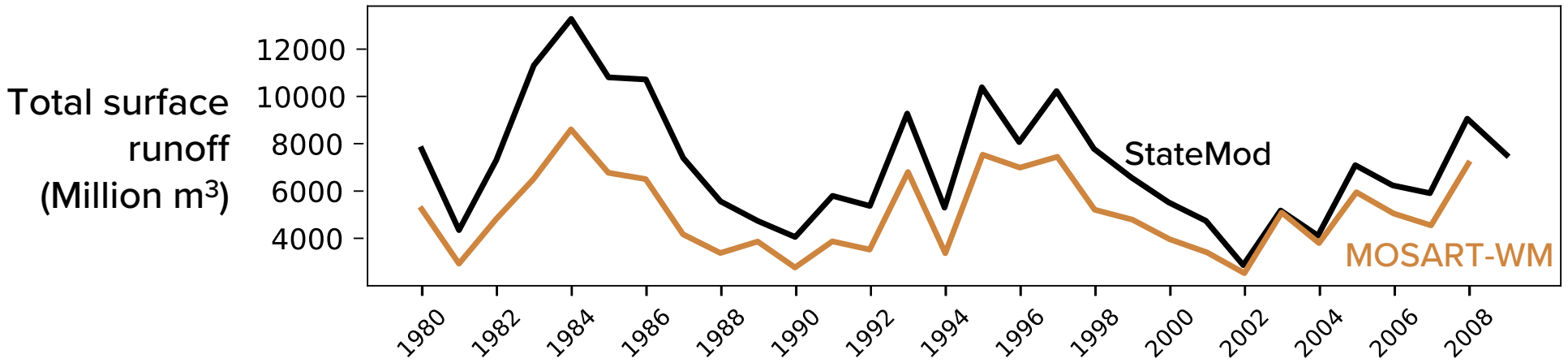
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StateMod
MOSART-WM
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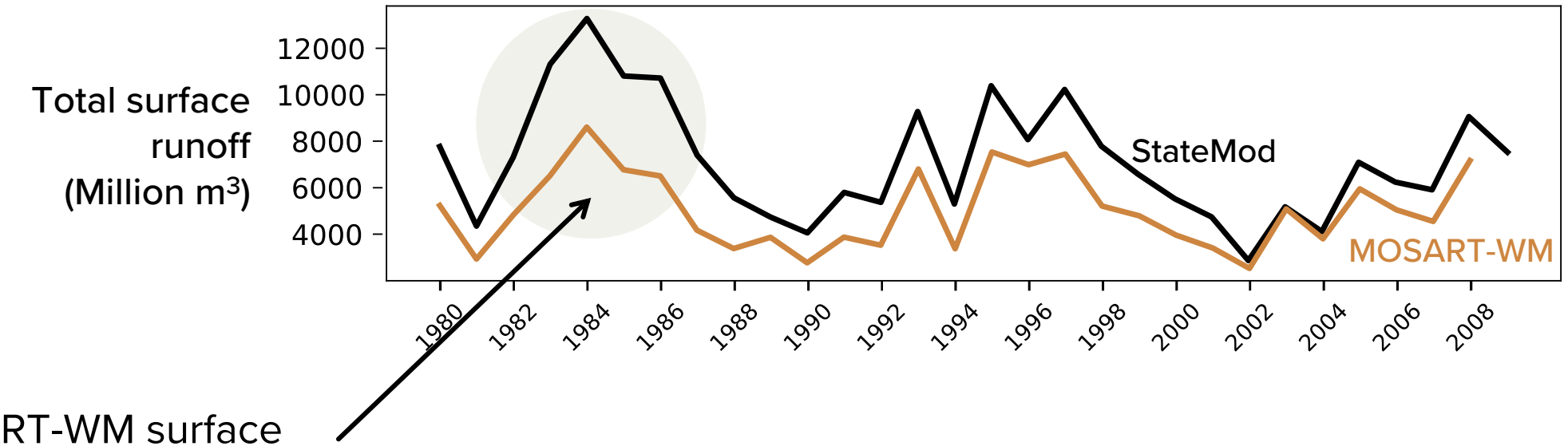
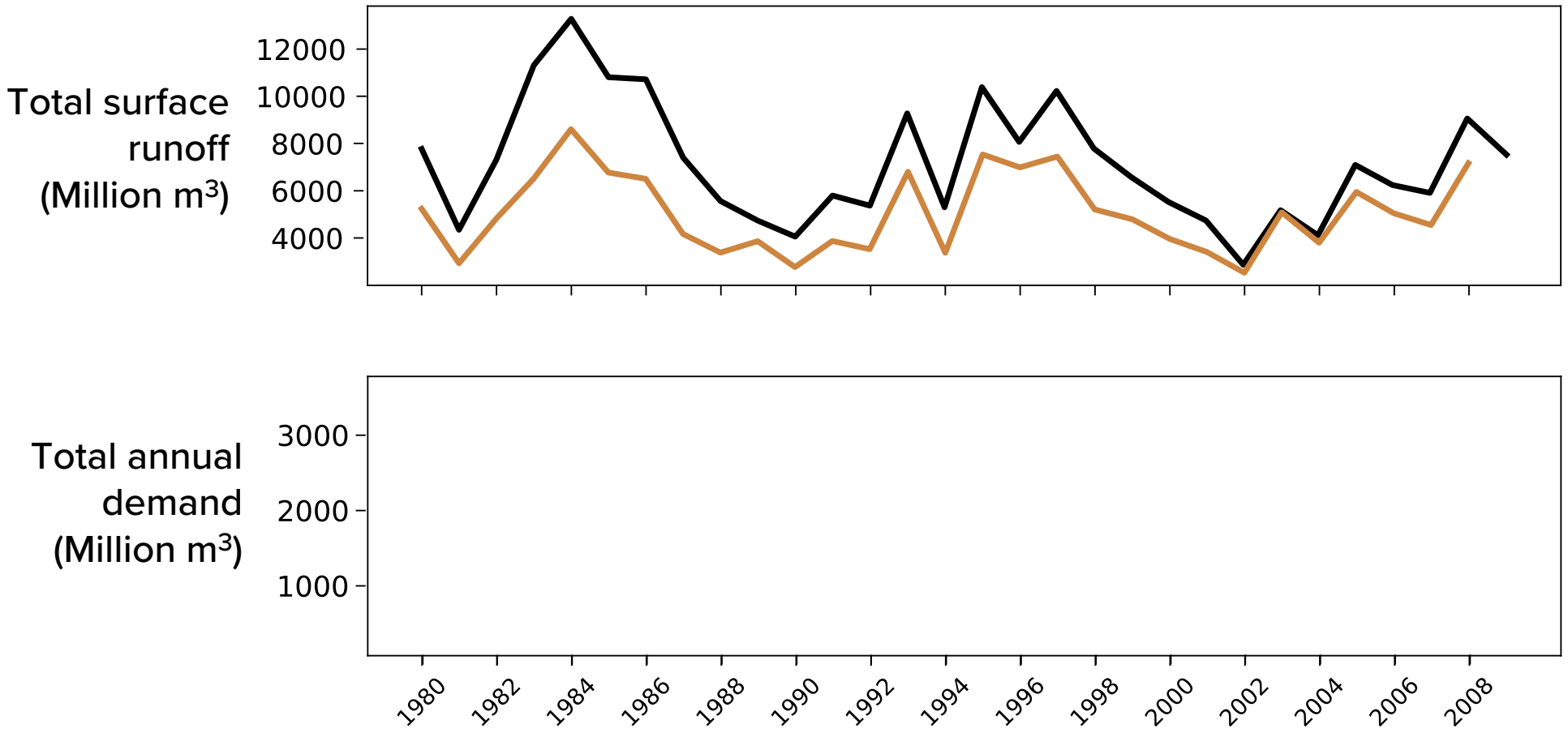


The MOSART-WM surface runoff input appears to underestimate total surface runoff in this basin, especially during wetter periods.


Total surface runoff (Million m³)
12000
10000
8000
6000
4000
Total annual demand (Million m³)
3000
2000
1000
1980
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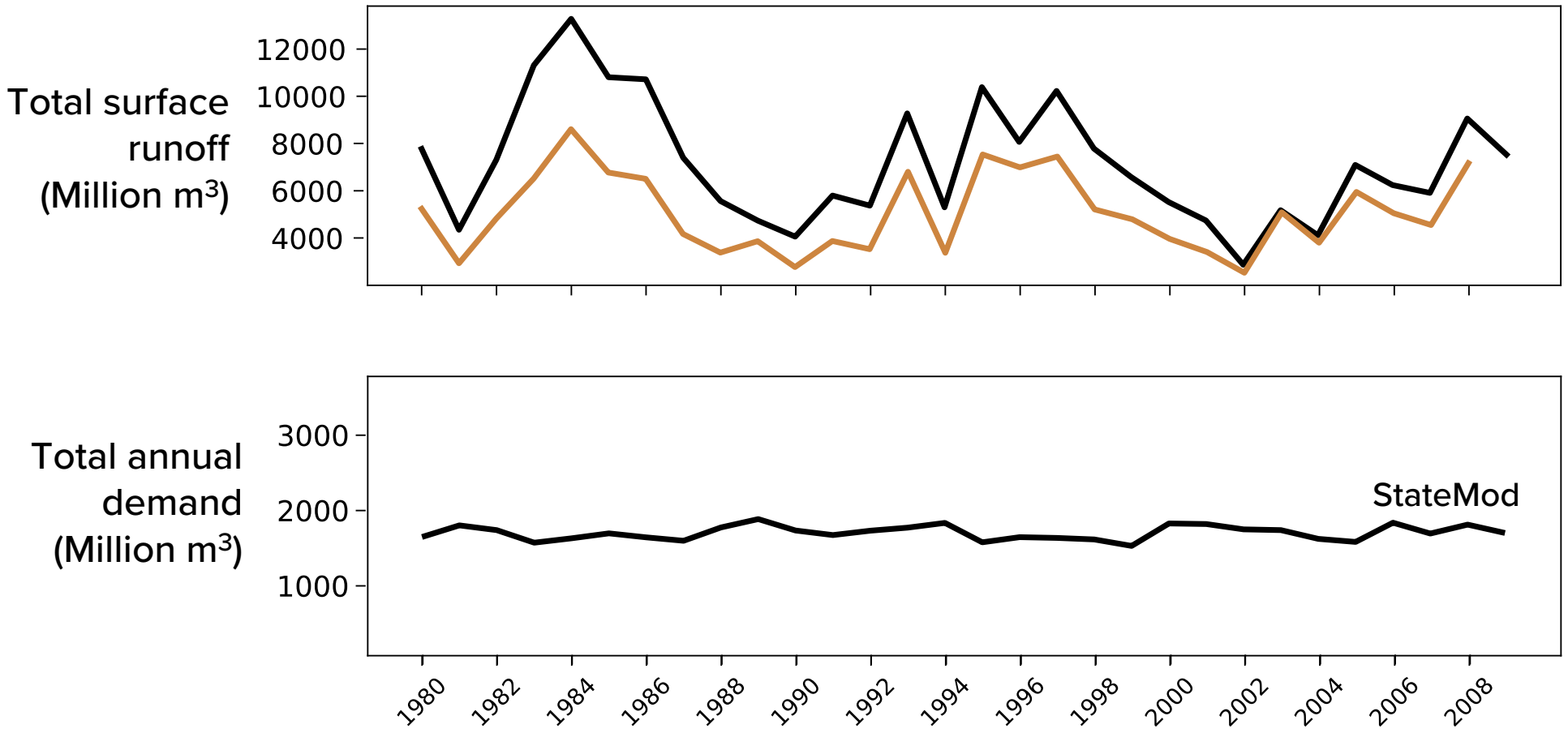
2002
2004
2006
2008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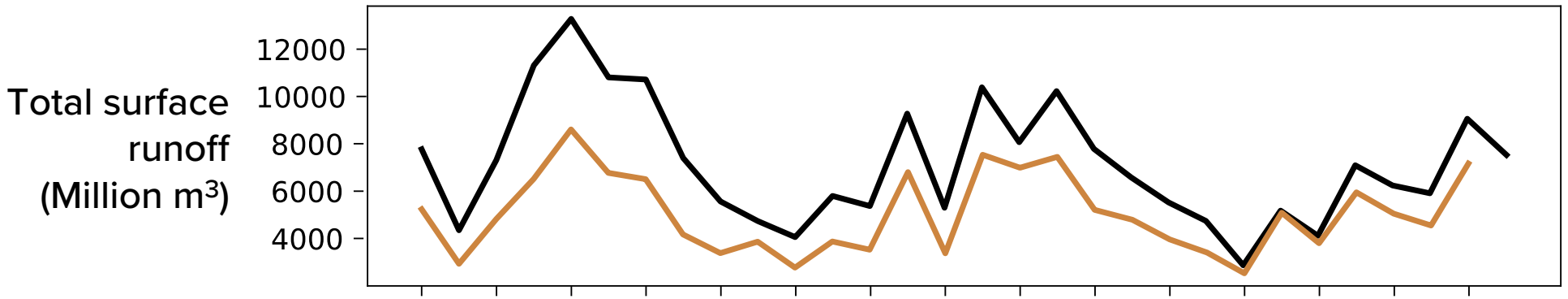
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12000
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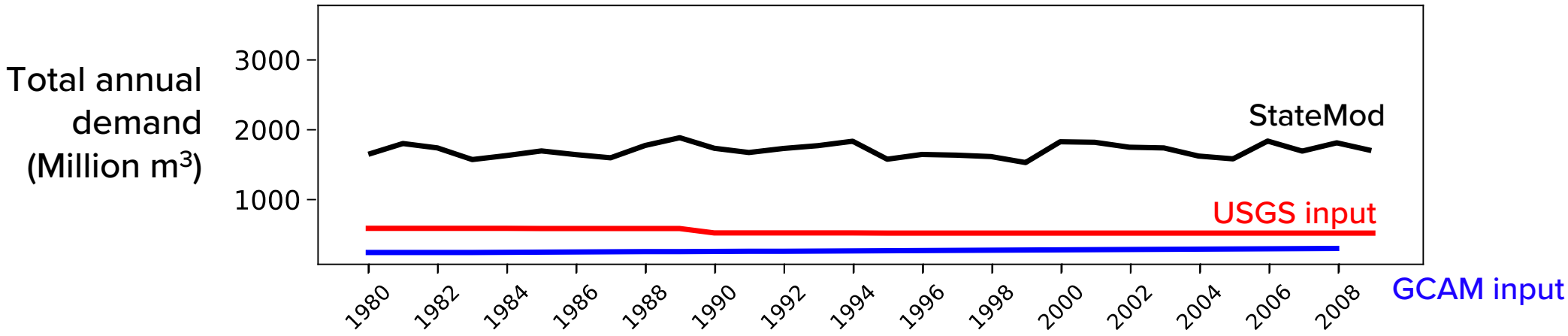
4000


Total annual demand (Million m³)
3000
2000
1000
StateMod
USGS input
GCAM input
1980
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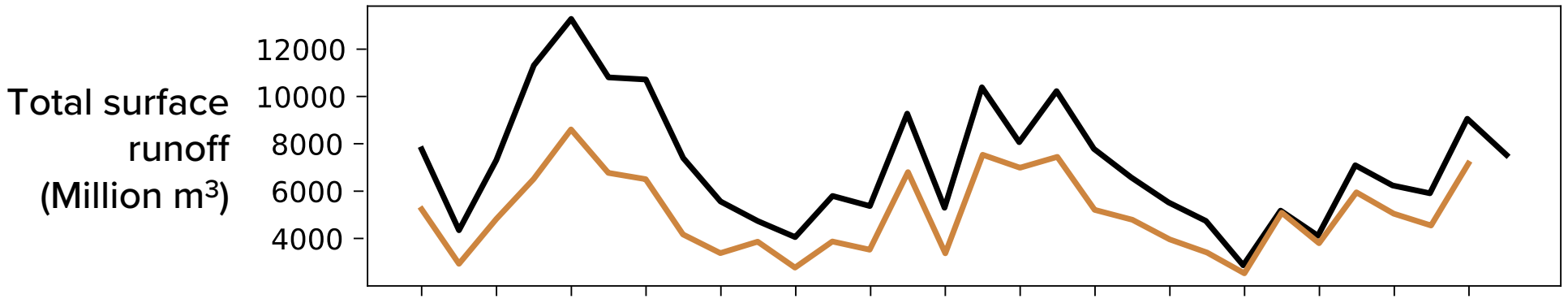
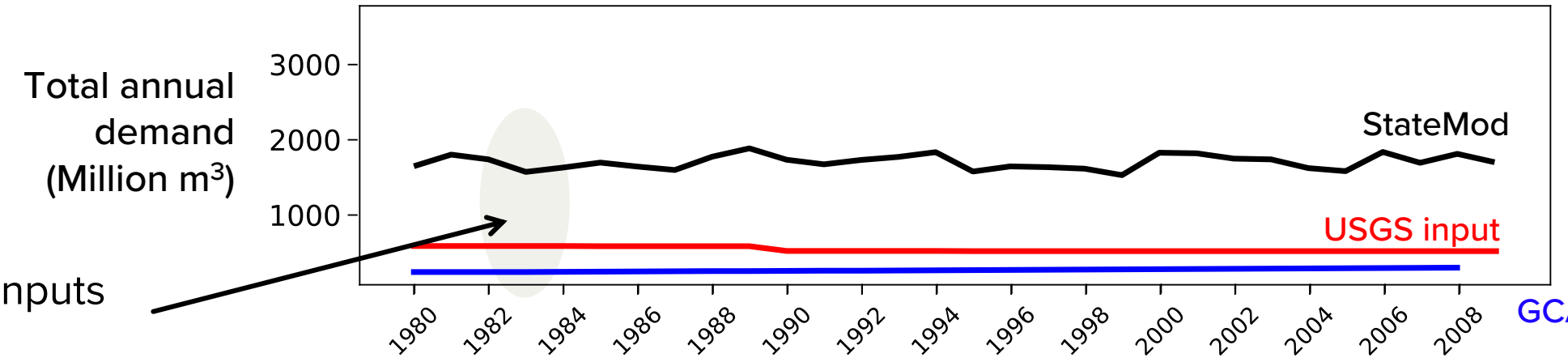
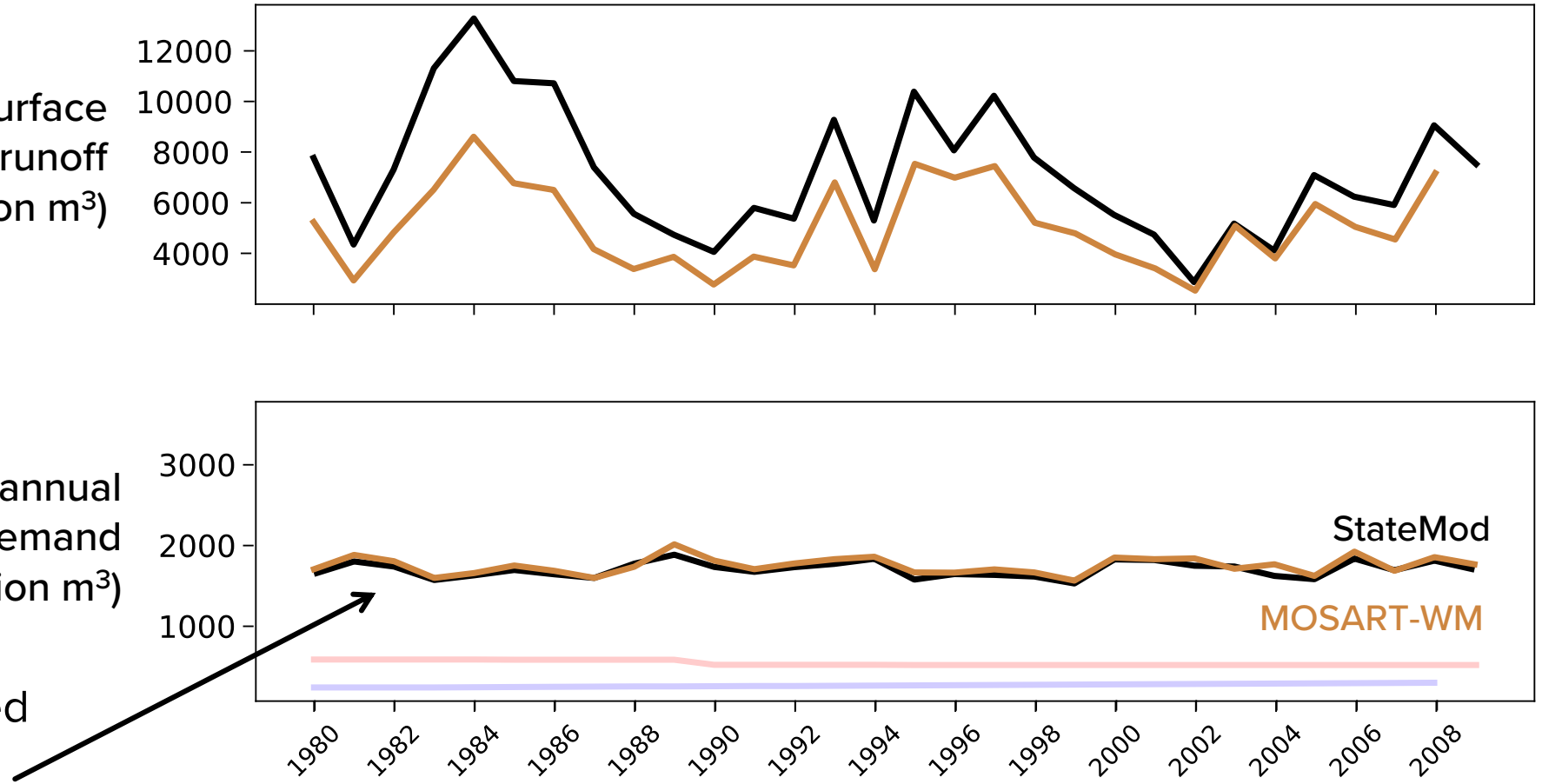




MOSART-WM inputs underestimate demands



Experiment conducted with adjusted MOSART-WM water demands

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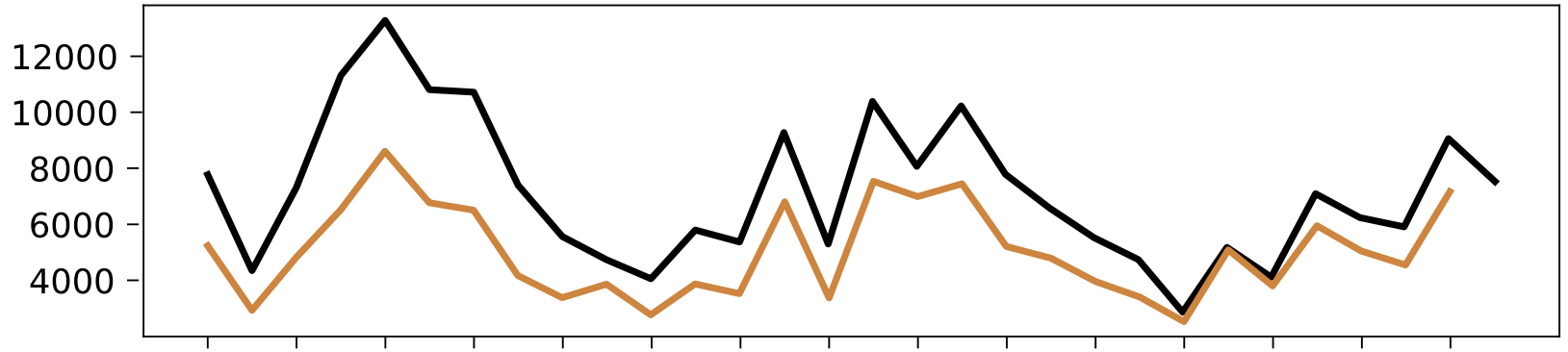
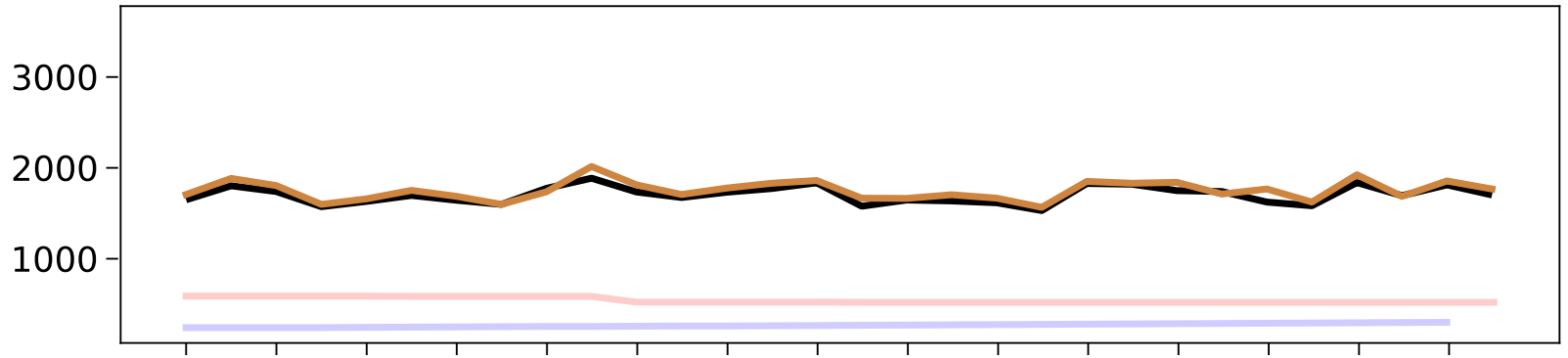
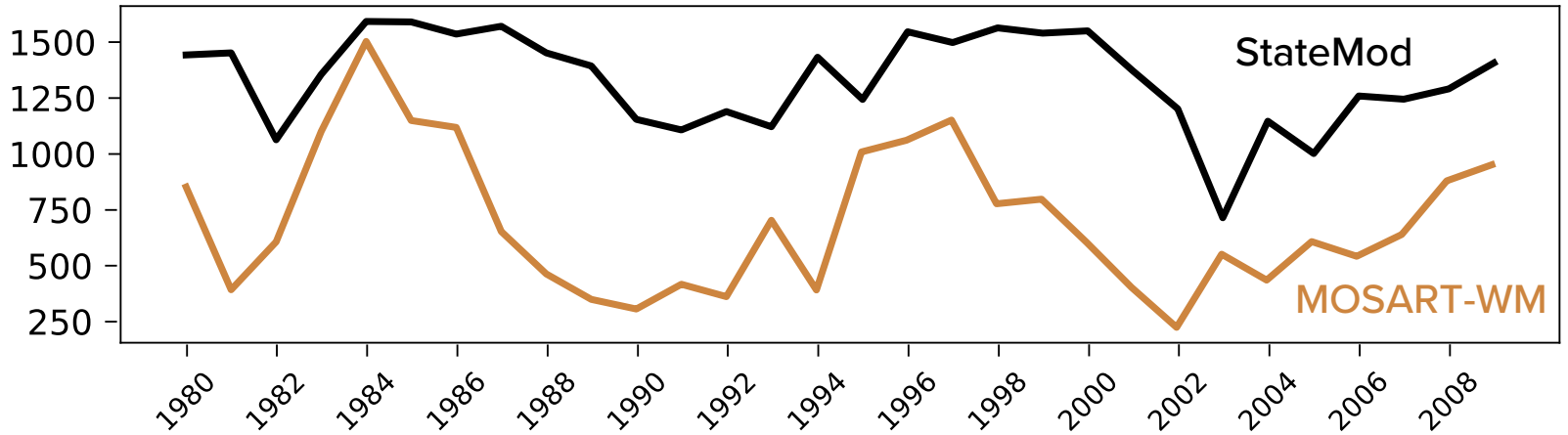
Total surface runoff (Million m³)



Total annual demand (Million m³)



End-of-year total storage (Million m³)



IM3

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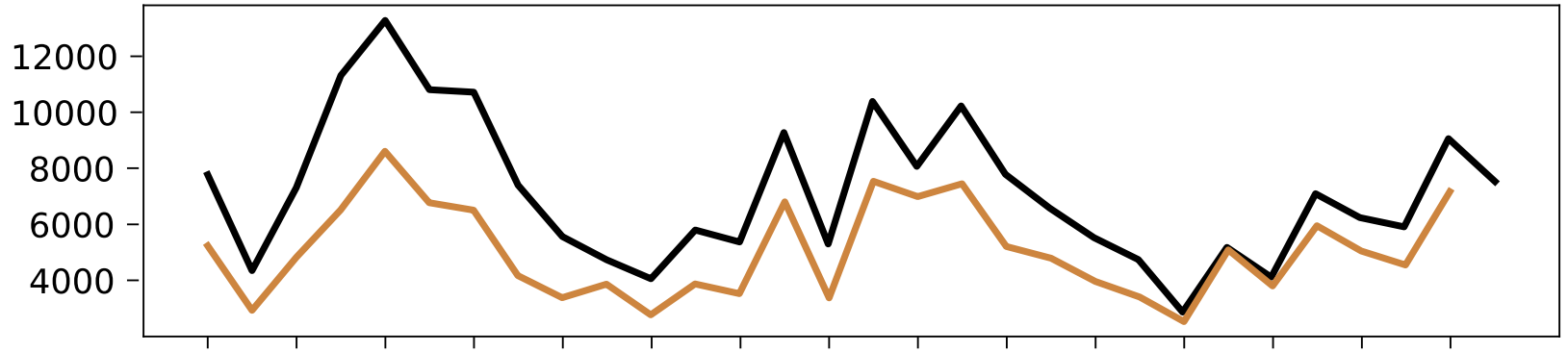
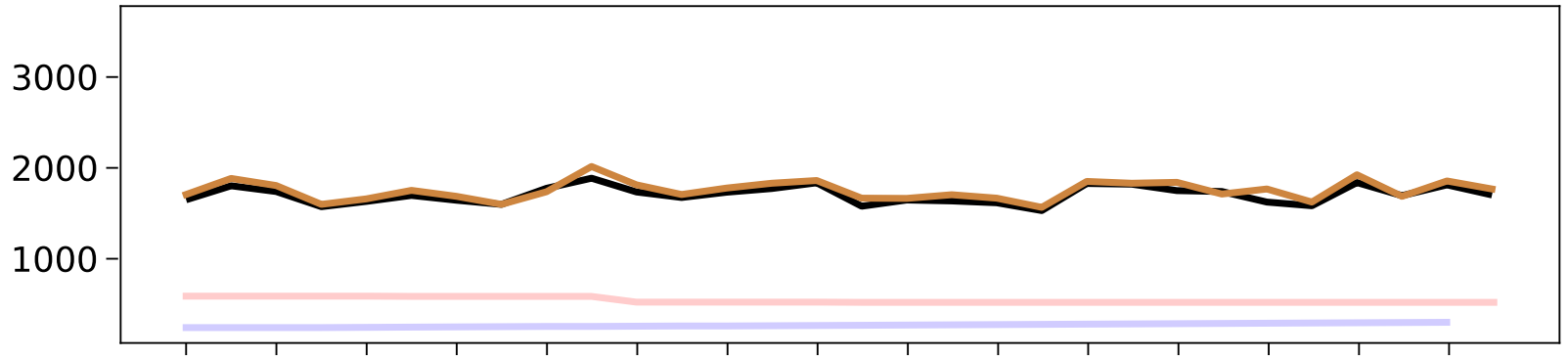
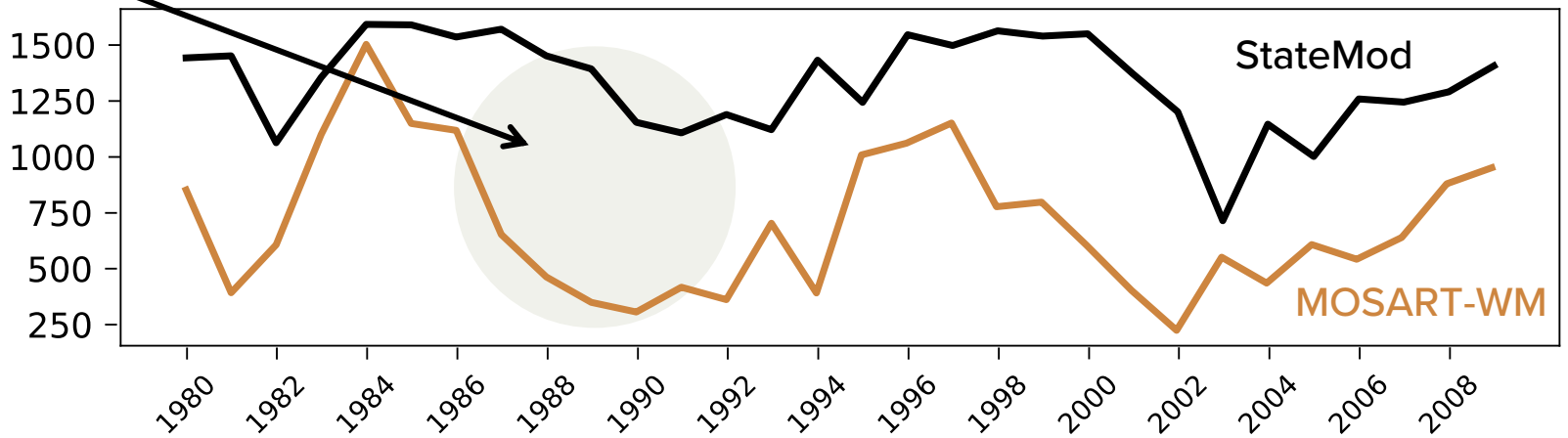


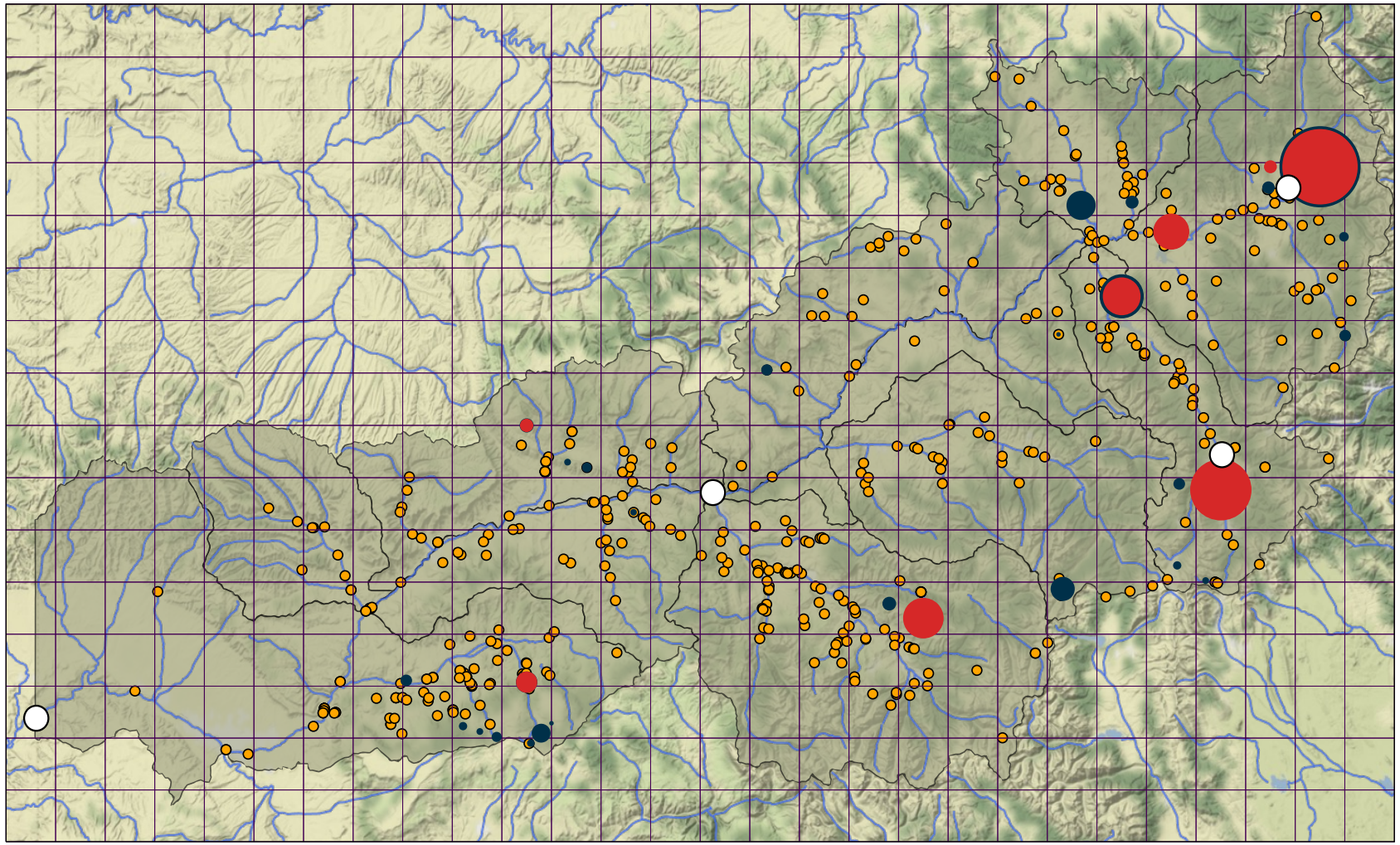


MOSART-WM represents a smaller storage capacity in this basin, used at lower levels

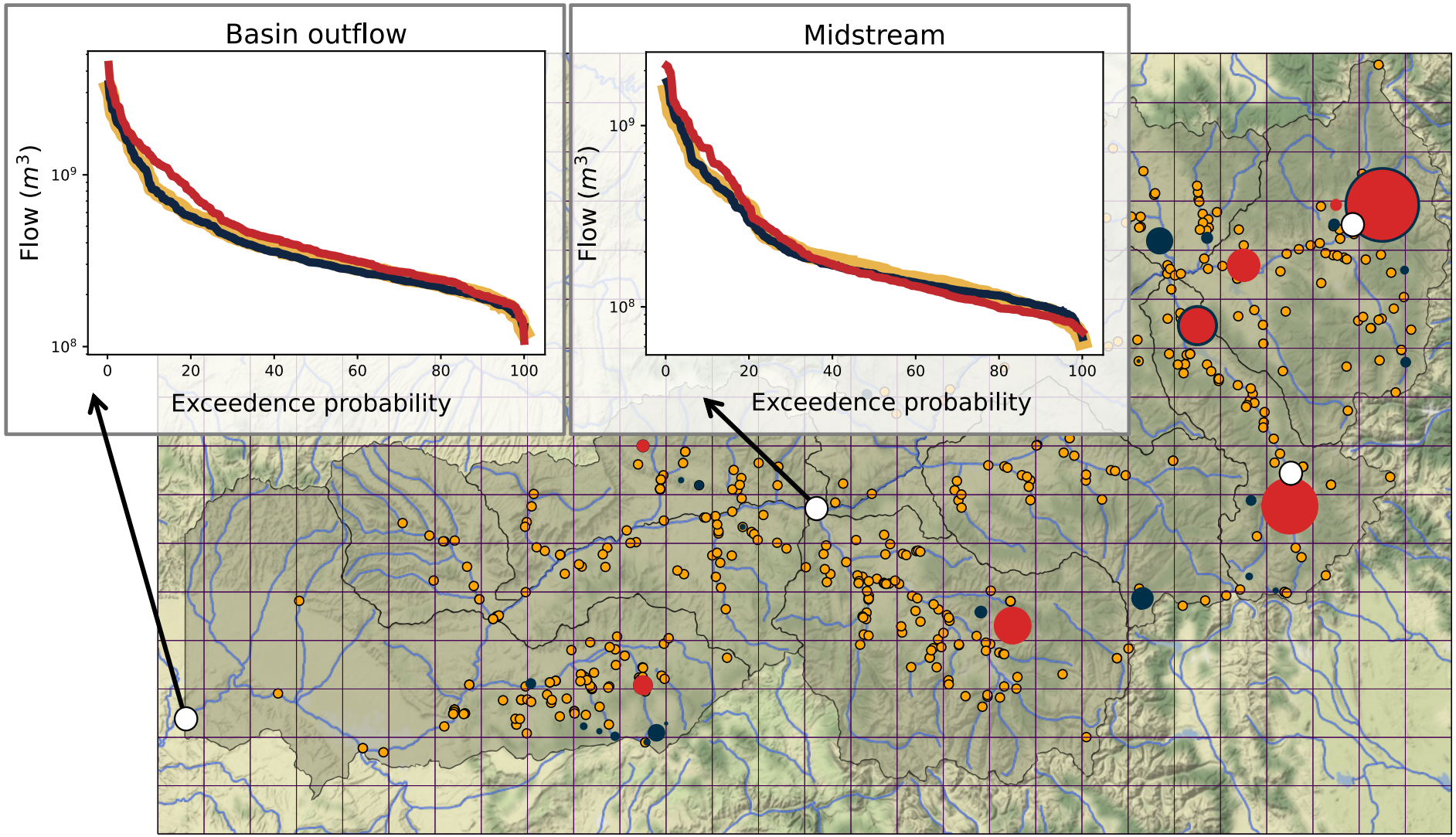
End-of-year total storage (Million m³)



Streamflow compared with USGS observations



Streamflow compared with USGS observations



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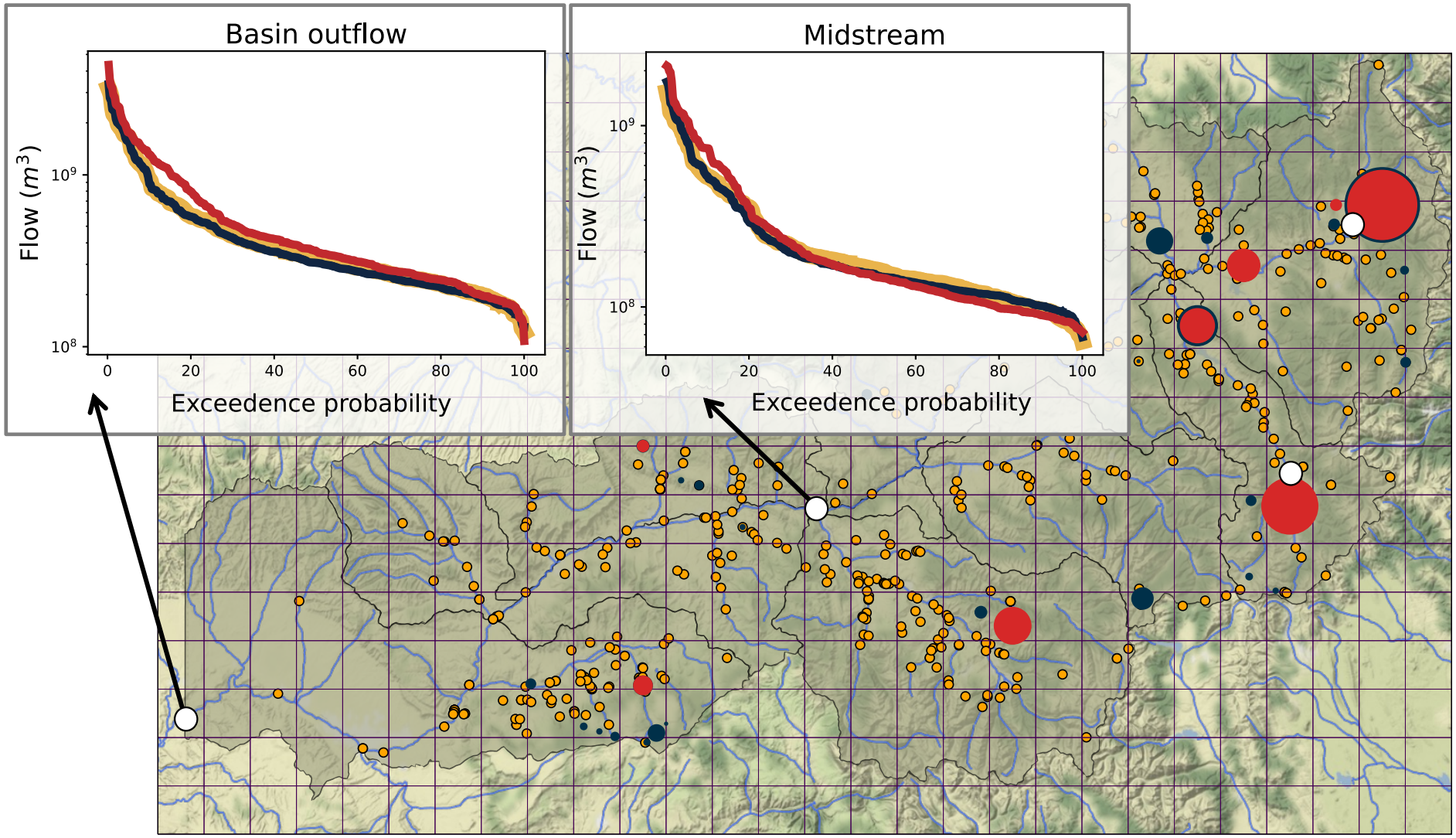
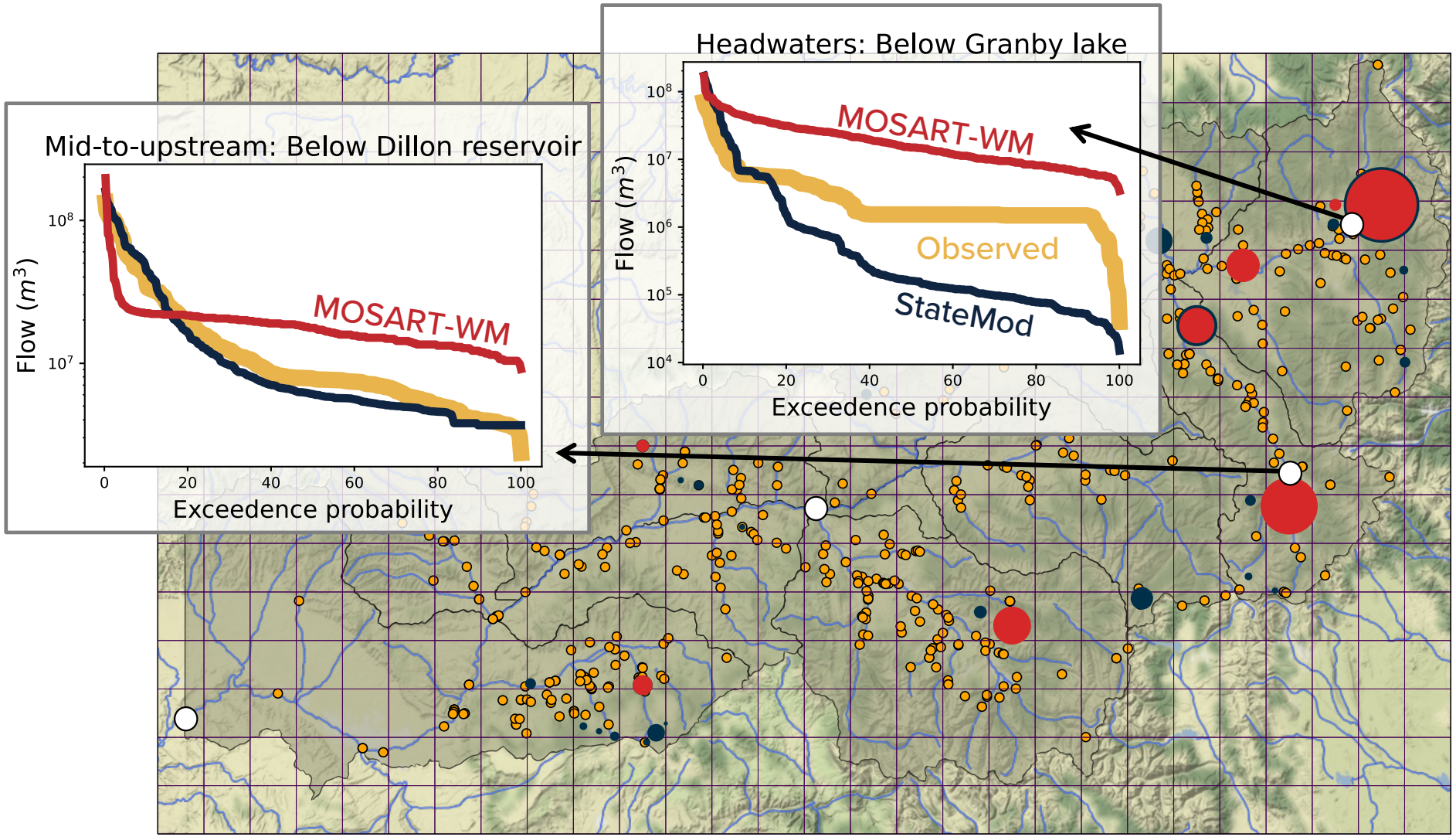


Both models perform very well in representing observed flow

Streamflow compared with USGS observations



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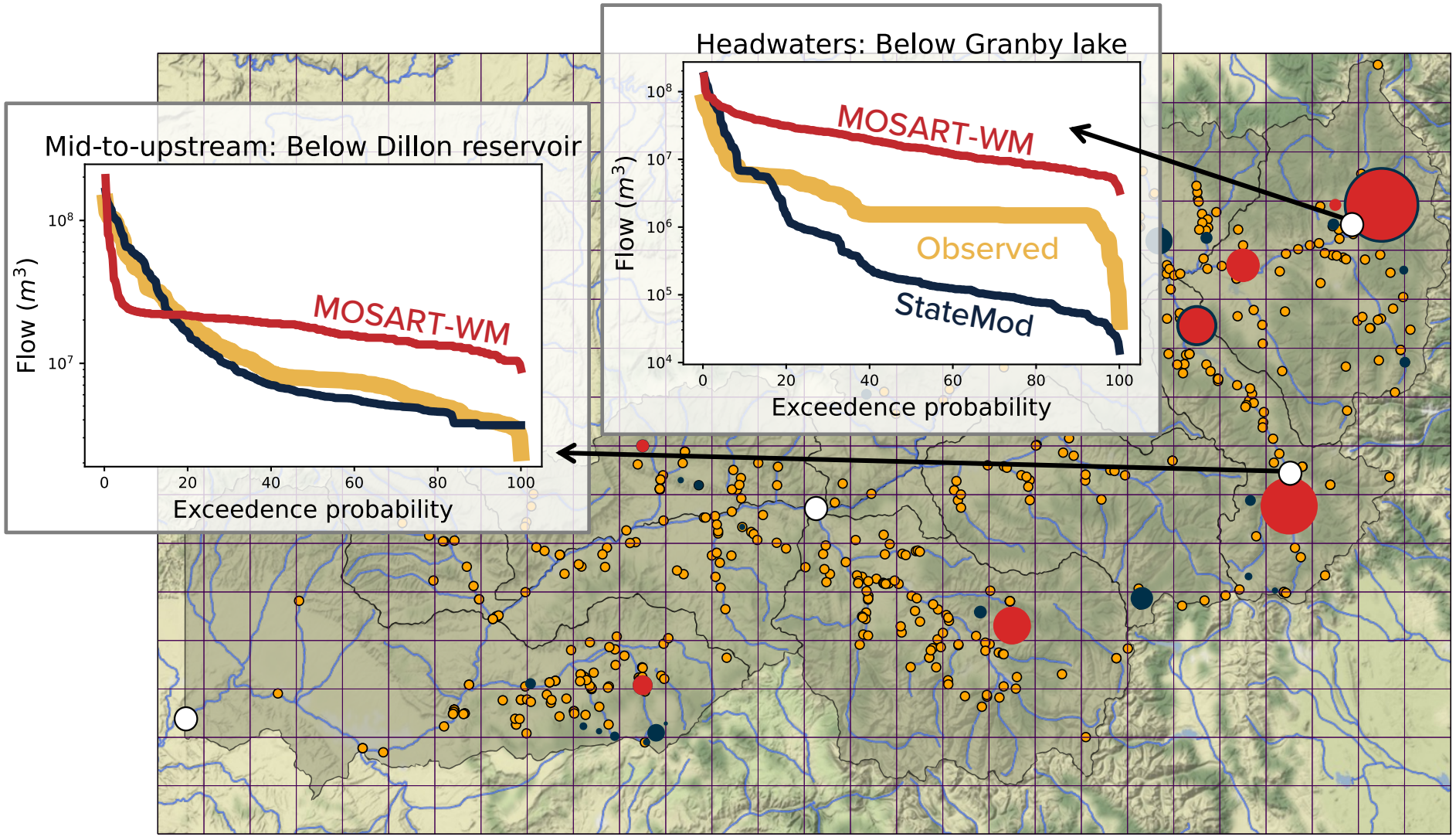
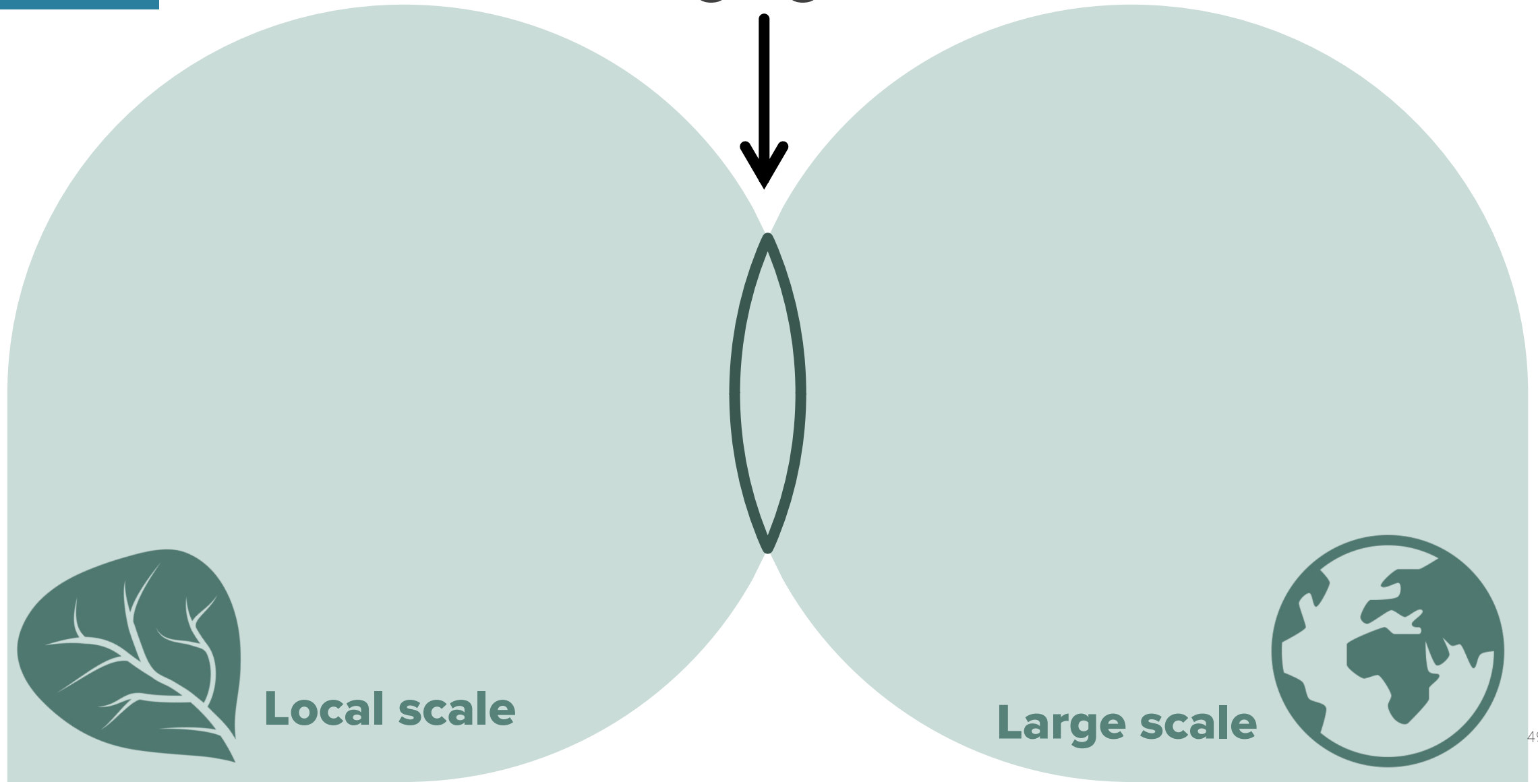


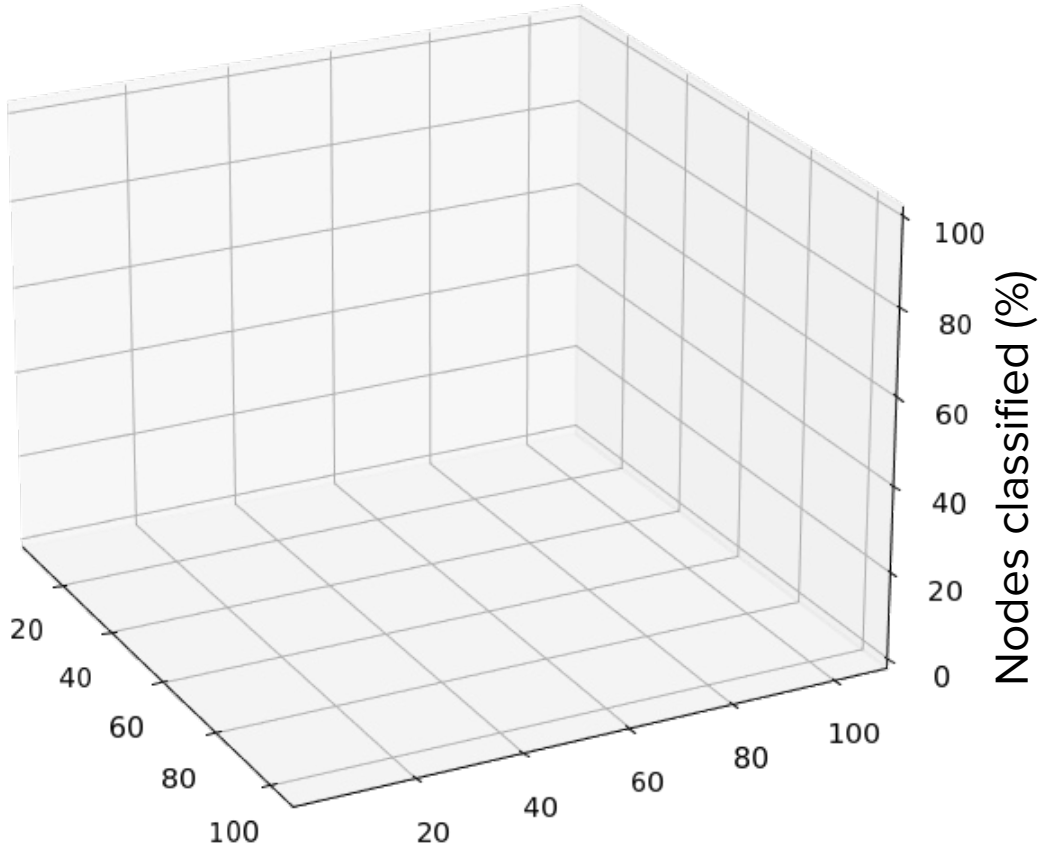
Going upstream, MOSART-WM begins to struggle, with both models diverging substantially in the headwaters

If our modeling is converging, are our inferences converging too?



How about water scarcity inferences?

How many users are vulnerable to water scarcity?



StateMod

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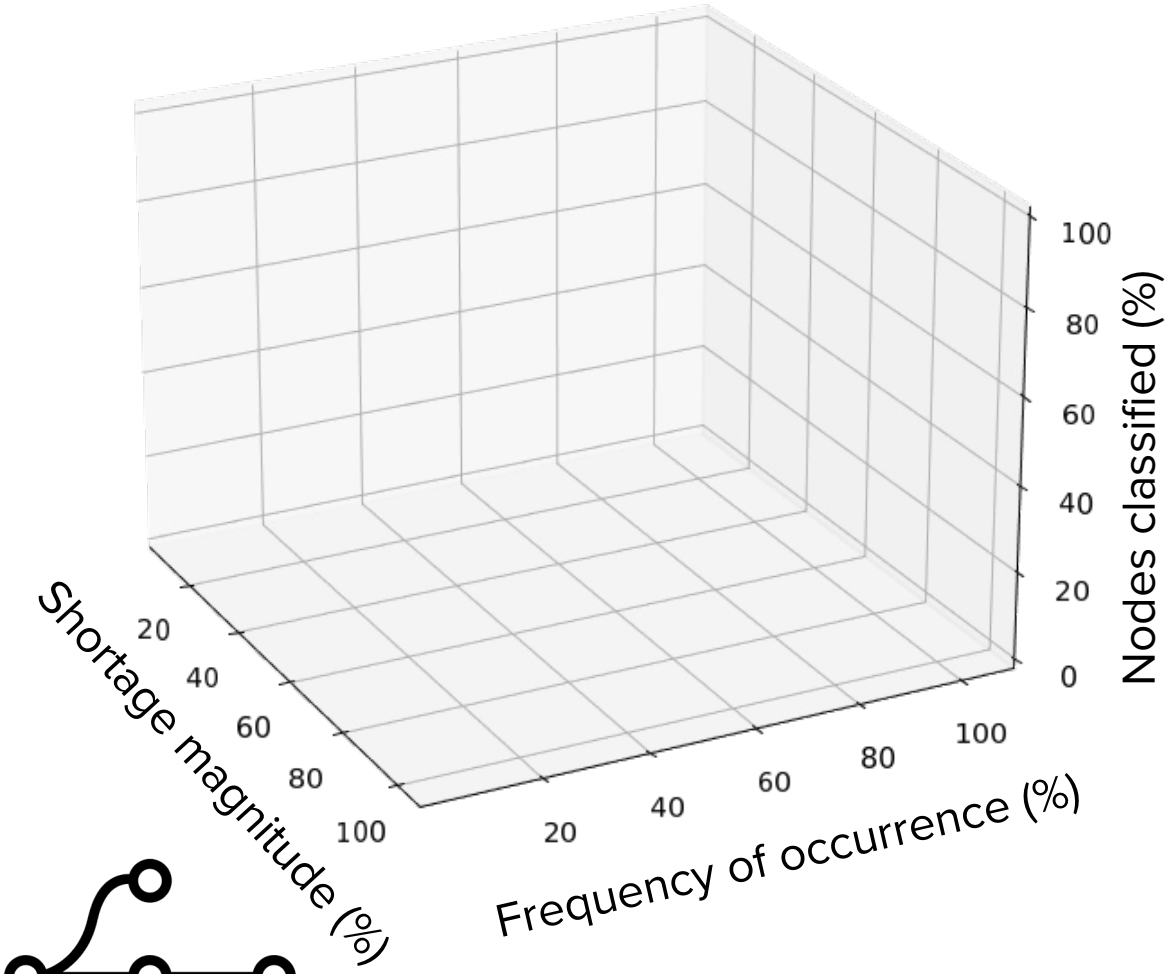

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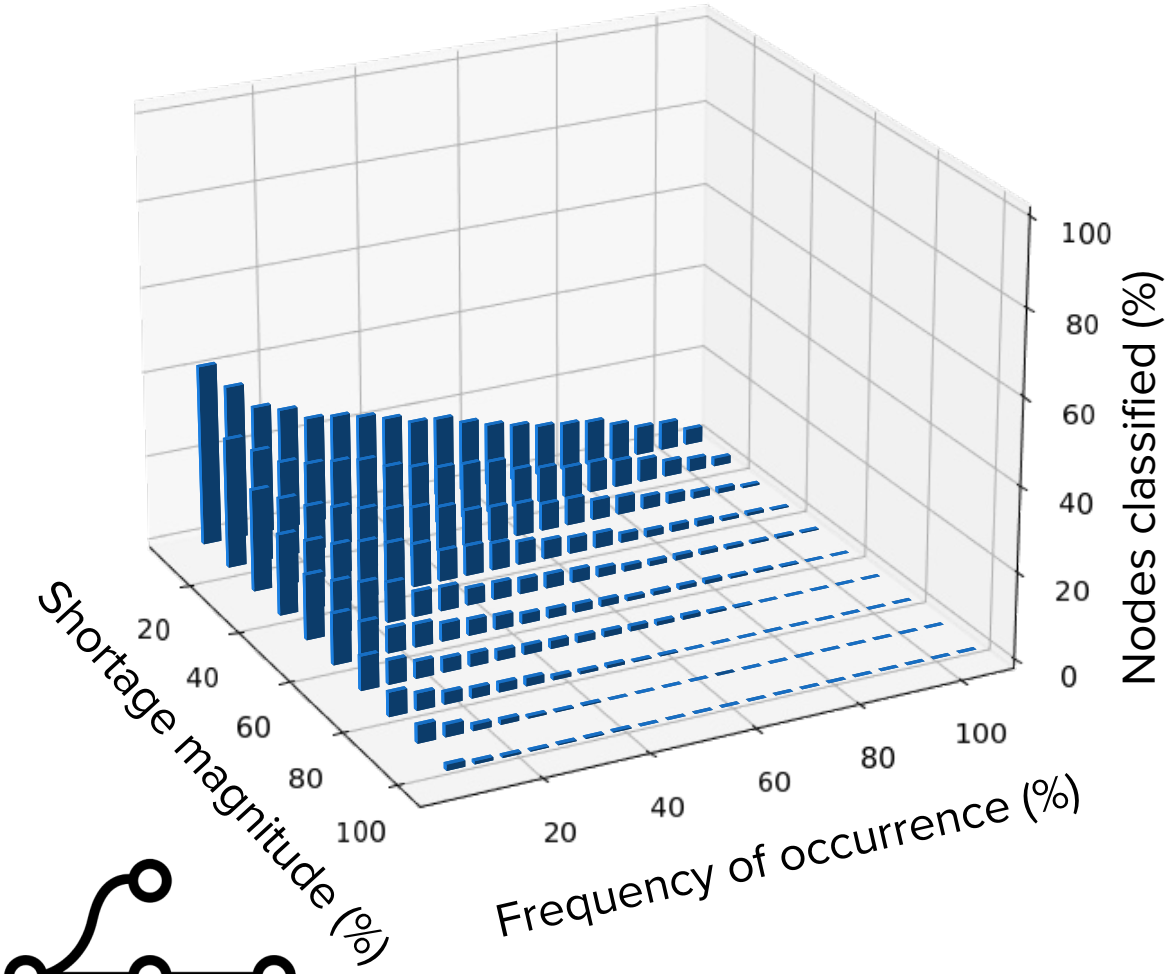

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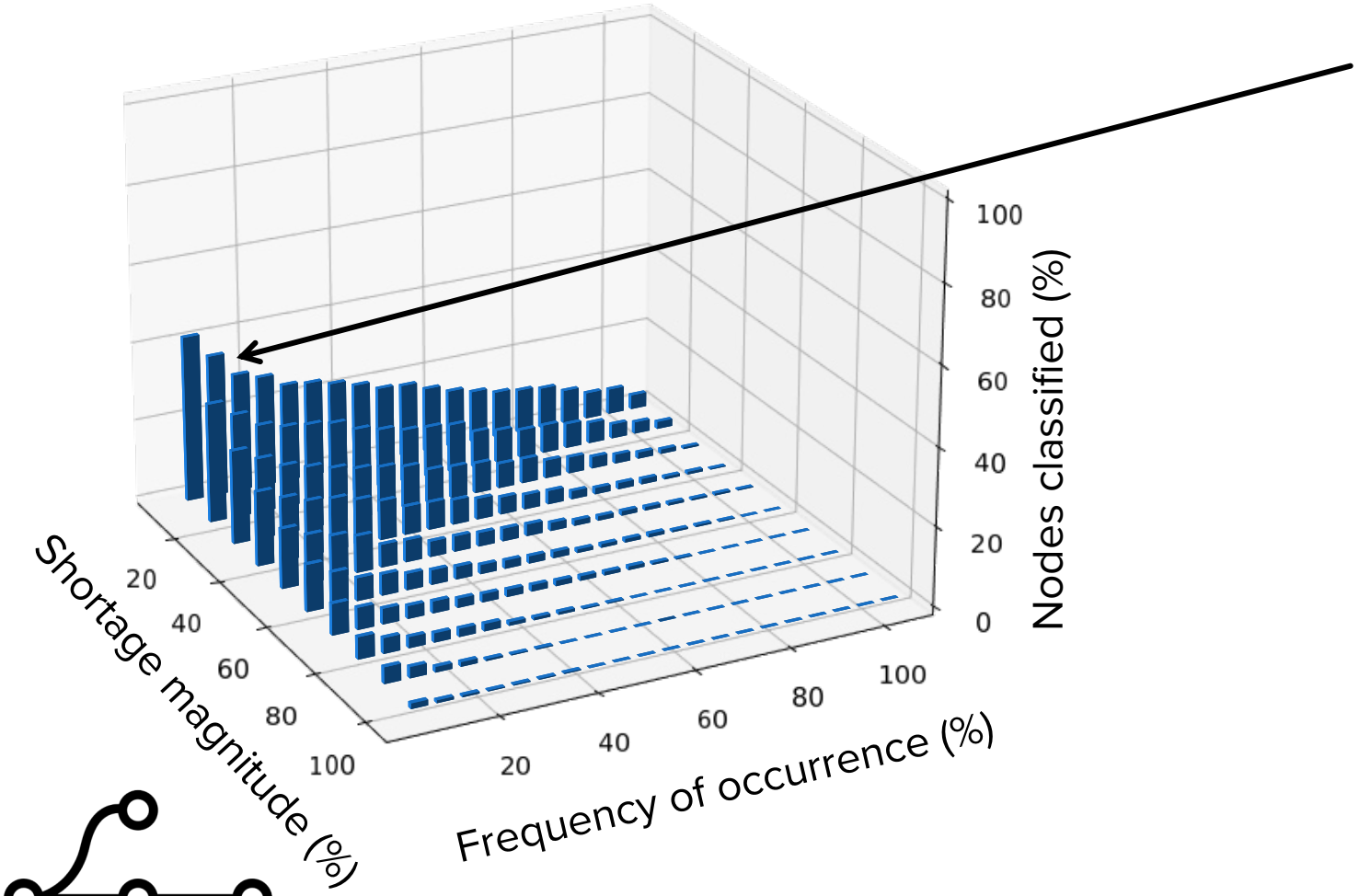

Vulnerability criterion:
"if they experience a water shortage of 10% of their demand 5% of the time"

StateMod

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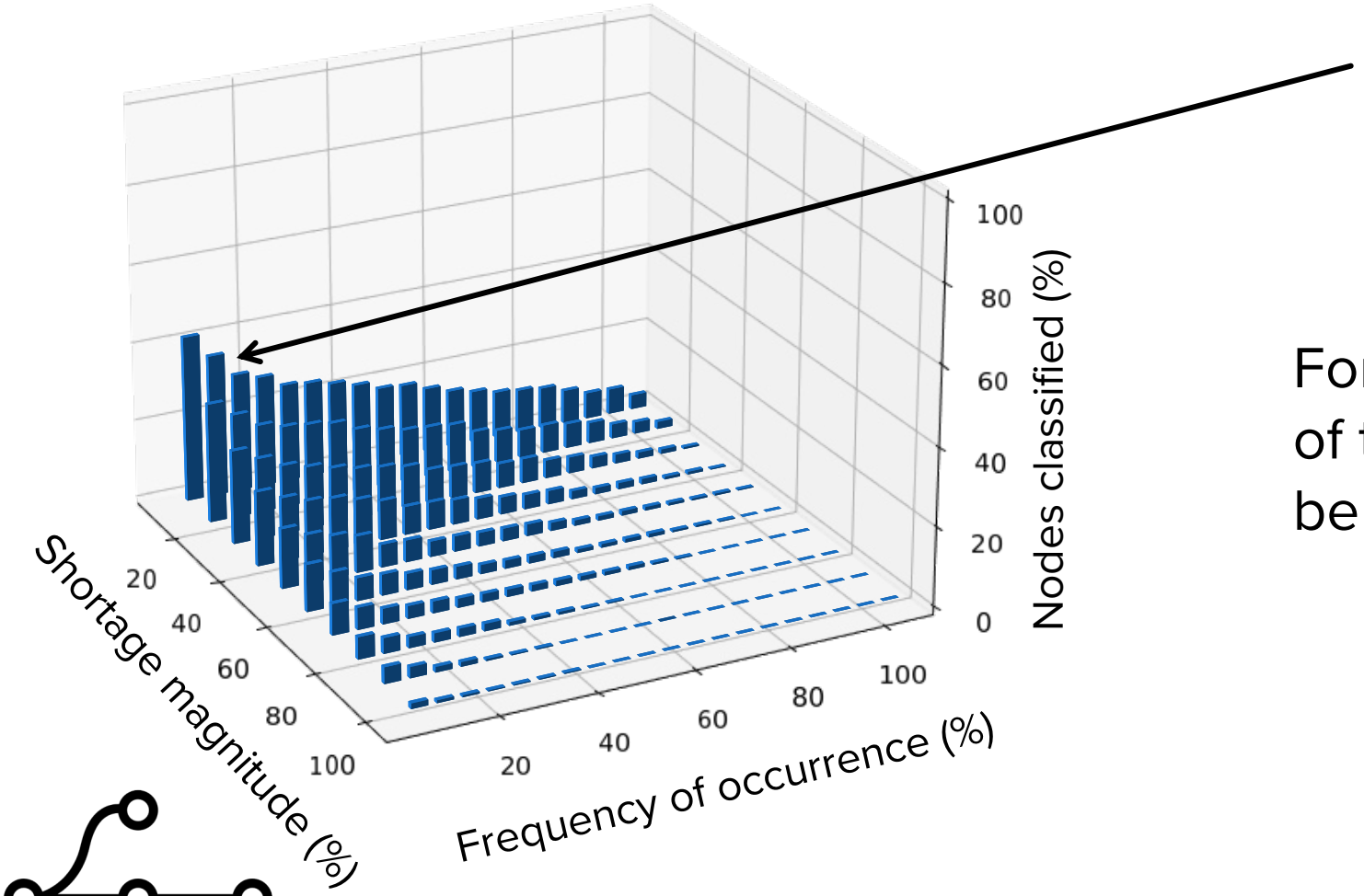

Vulnerability criterion:
"if they experience a water shortage of 10% of their demand 5% of the time"

For any given metric, **up to 40%** of the basin's water users could be classified as vulnerable.

StateMod

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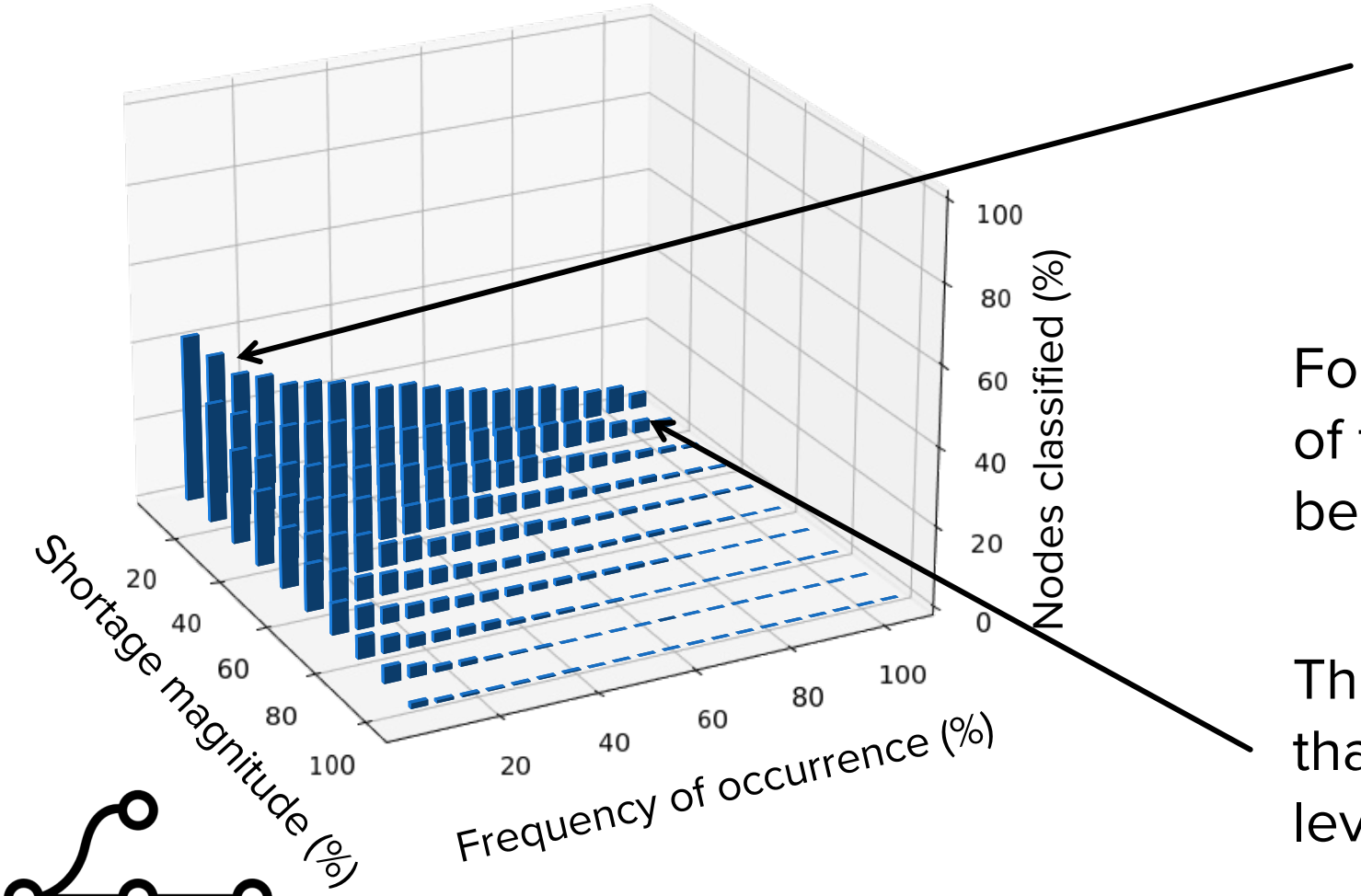


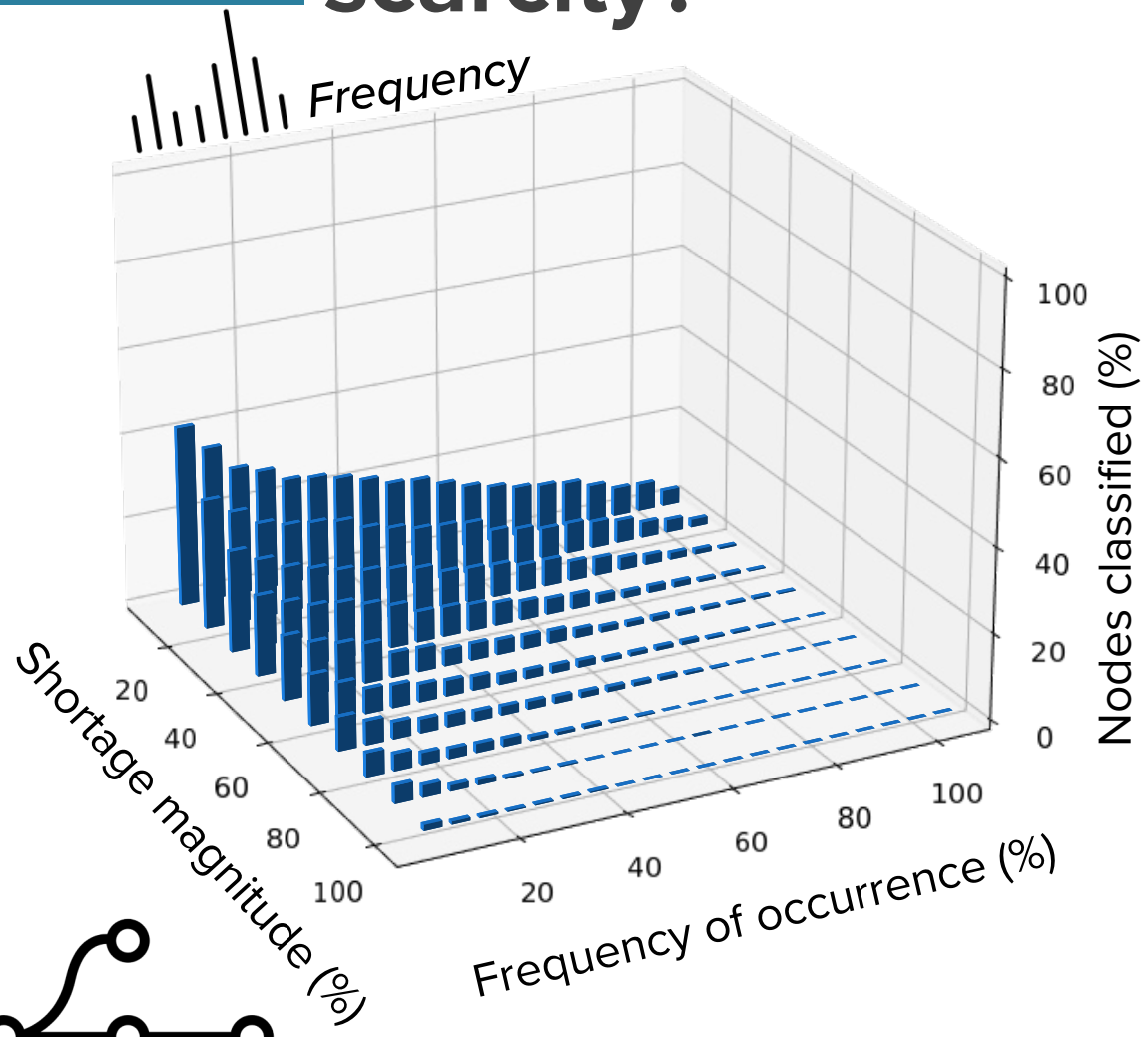
Vulnerability criterion:
"if they experience a water shortage of 10% of their demand 5% of the time"

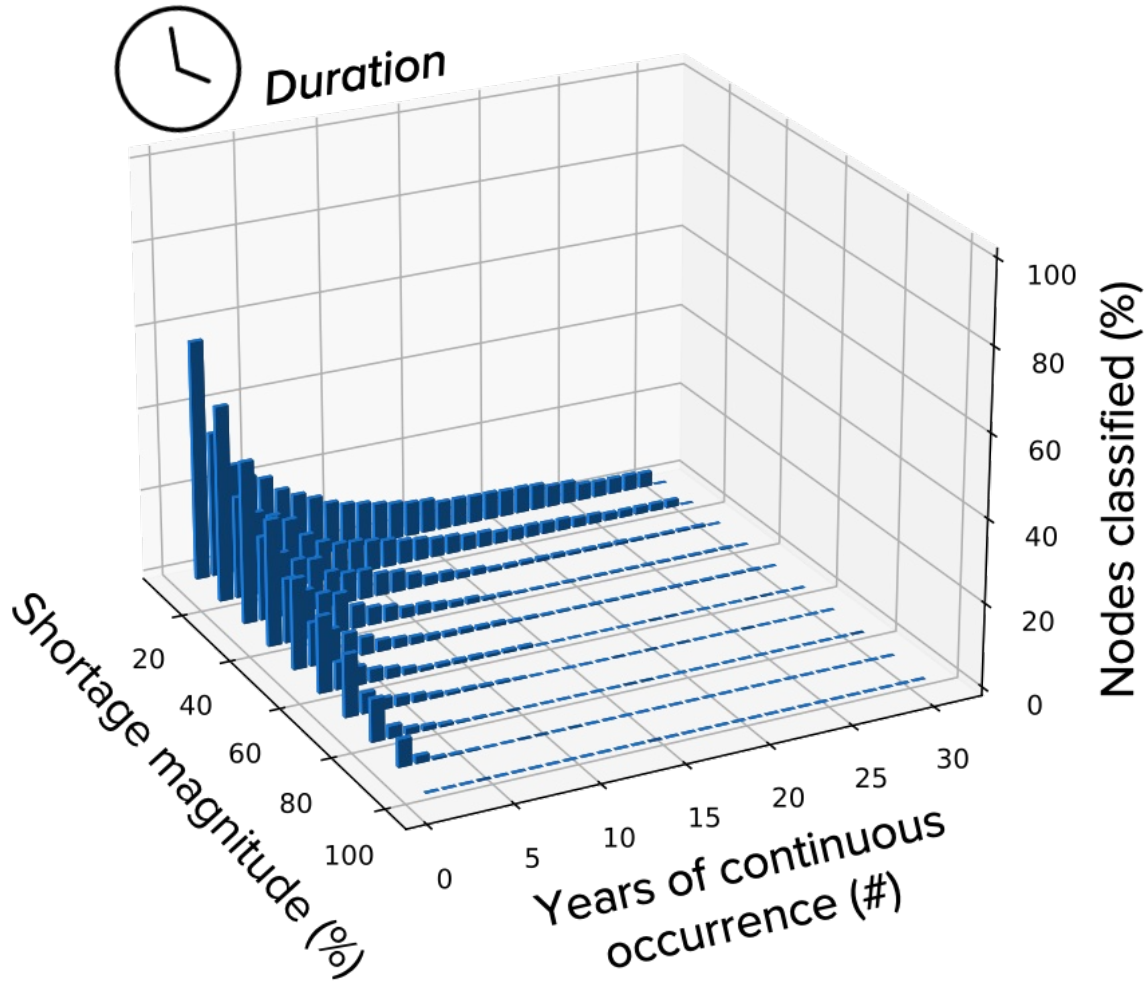
For any given metric, **up to 40%** of the basin's water users could be classified as vulnerable.

There is a small number of users that always experience *some* level of shortage.

StateMod

How many users are vulnerable to water scarcity?





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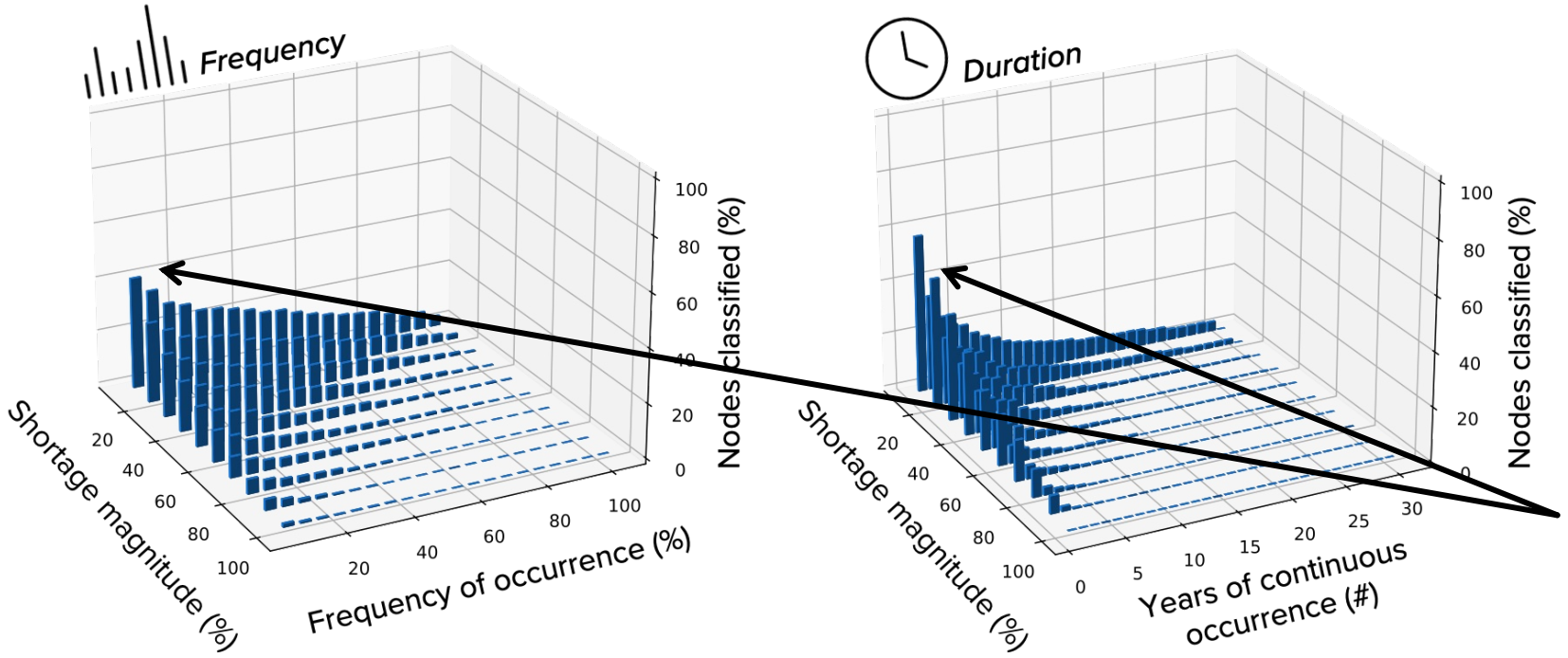
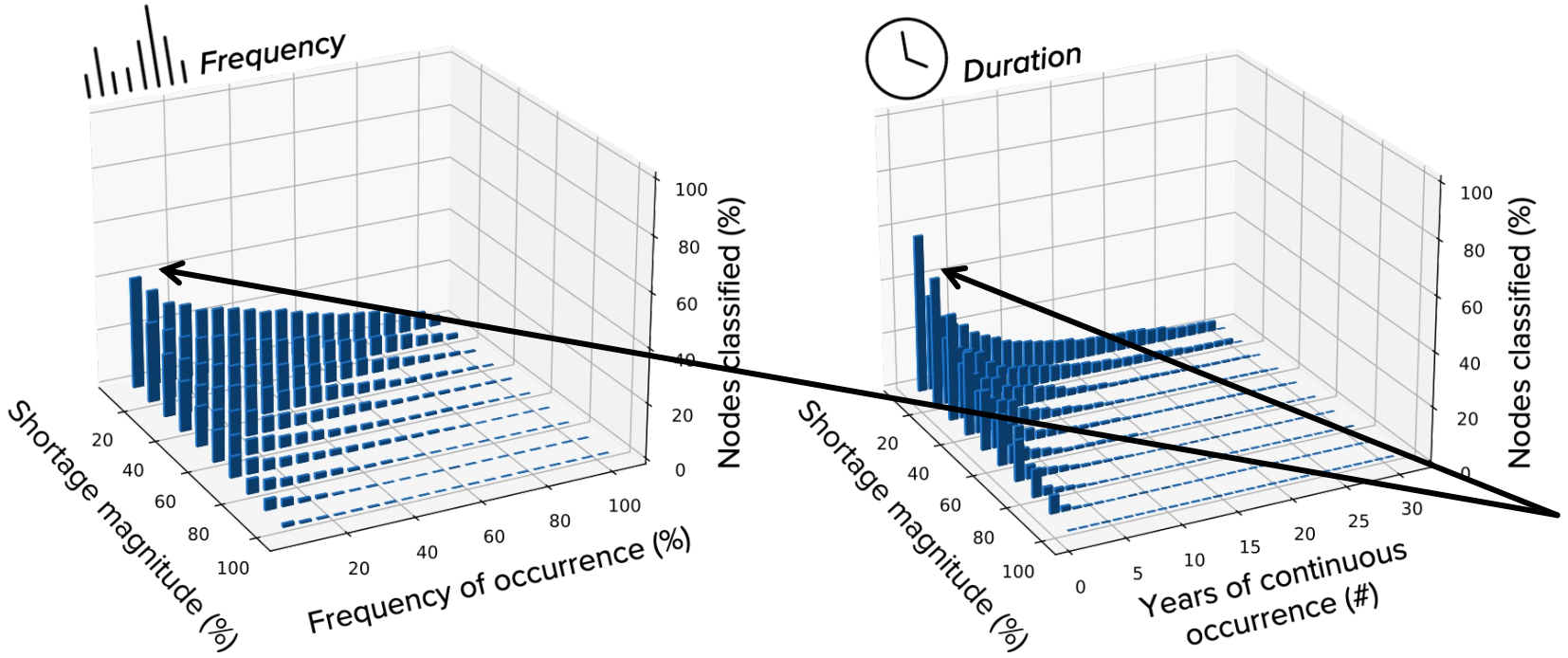


Even with the strictest metrics considered, approximately **half of the basin** would **not** be identified as vulnerable to water scarcity.

StateMod

How many users are vulnerable to water scarcity?

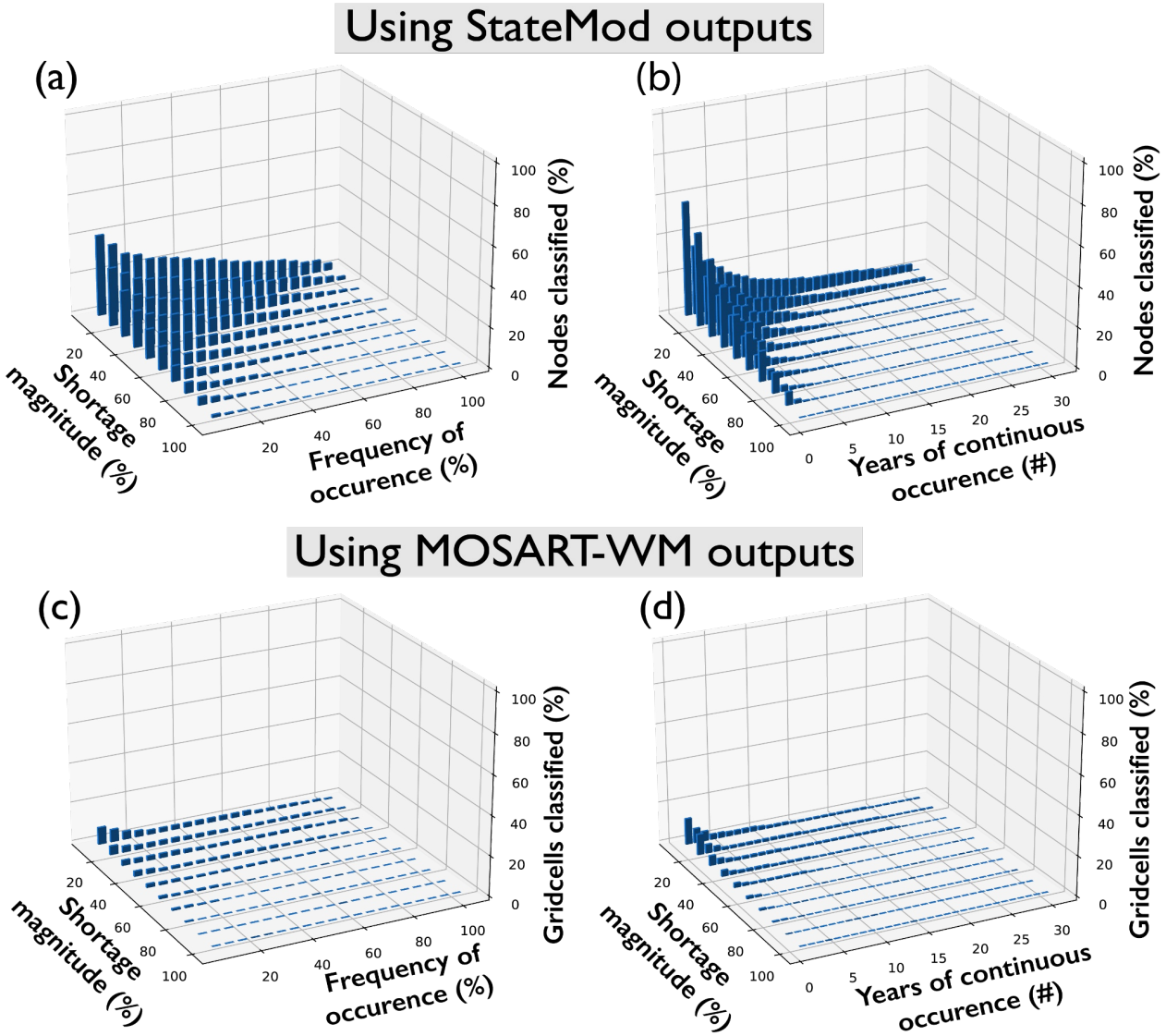


Even with the strictest metrics considered, approximately **half of the basin** would **not** be identified as vulnerable to water scarcity.

StateMod

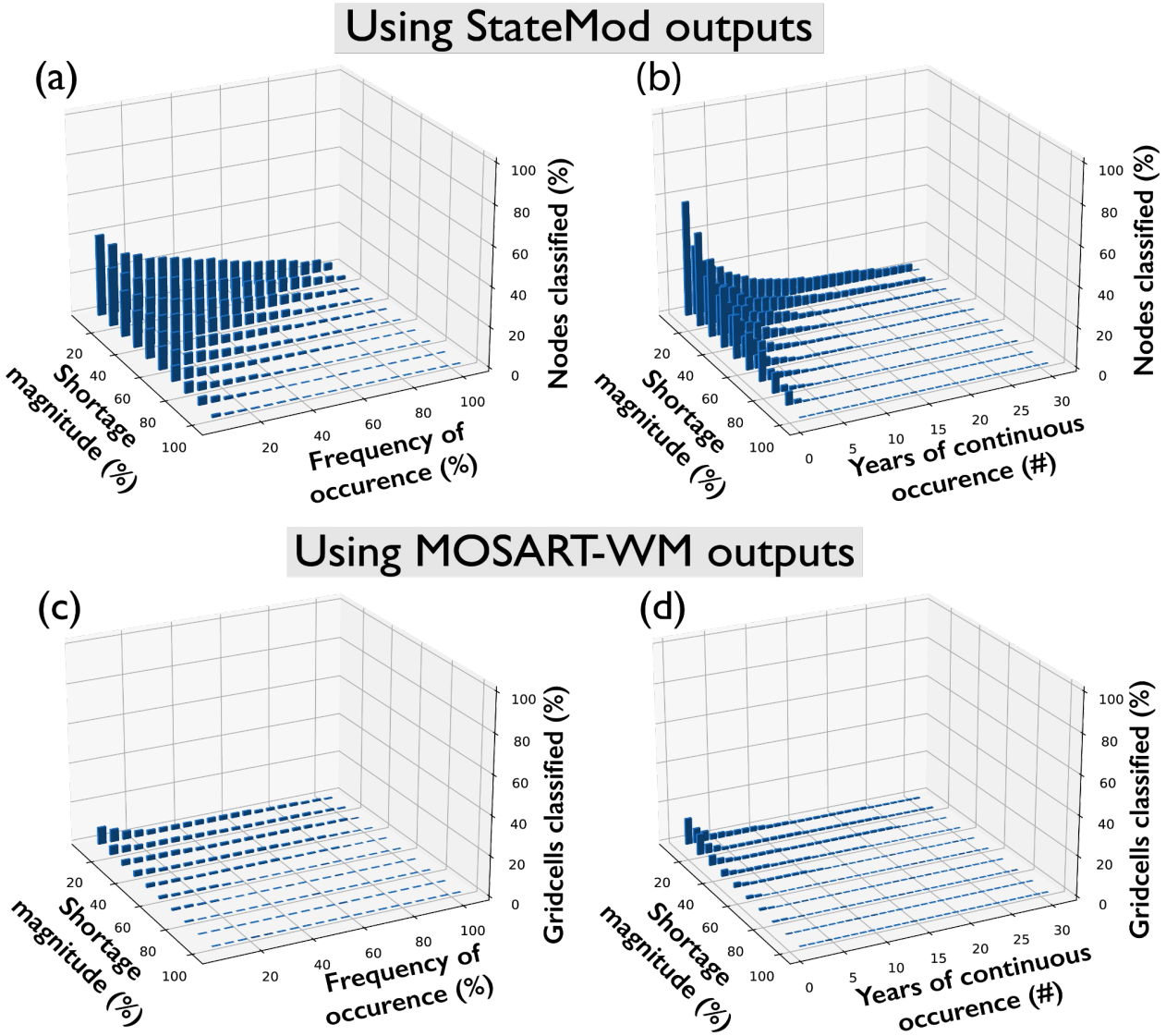
If one were to aggregate to a basin-wide metric the shortages that were experienced would be **dampened** by the ones that did not.

How many users are vulnerable to water scarcity?



Similar attenuation happening with MOSART-WM outputs

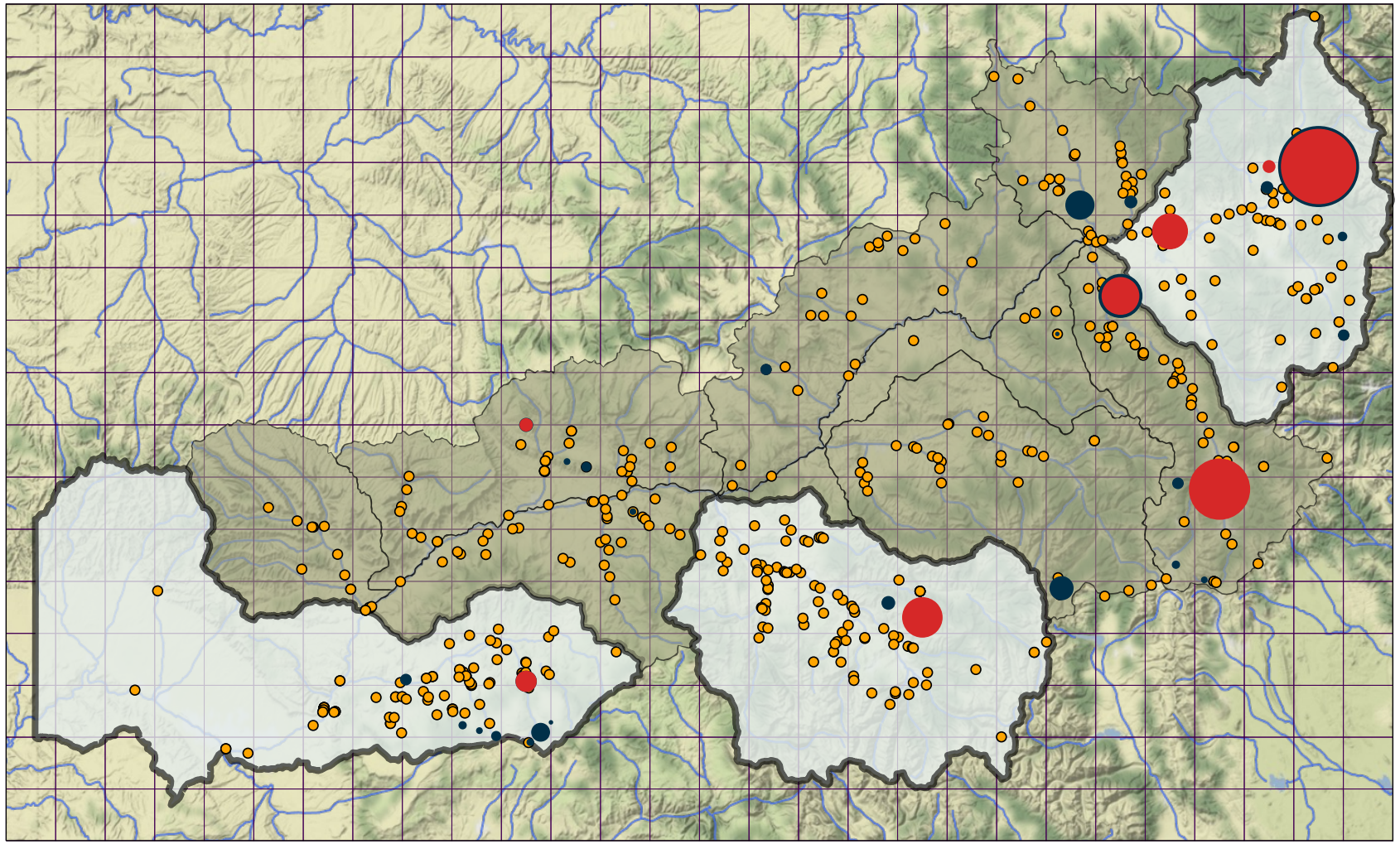
How many users are vulnerable to water scarcity?



Similar attenuation happening with MOSART-WM outputs

Even though average levels of allocation and shortage are approximated well, **sub-basin variance is not captured**

Spatial distribution of shortages



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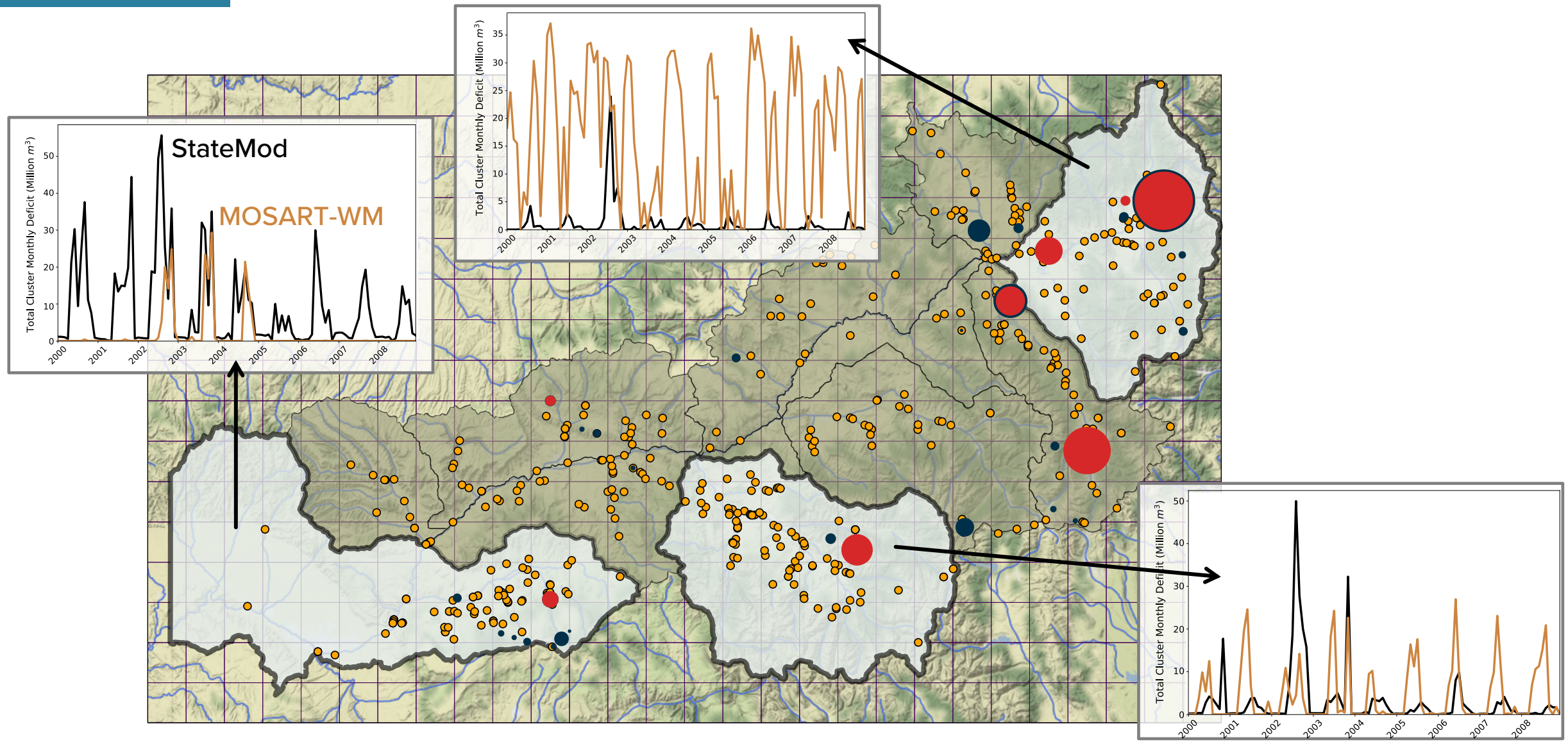
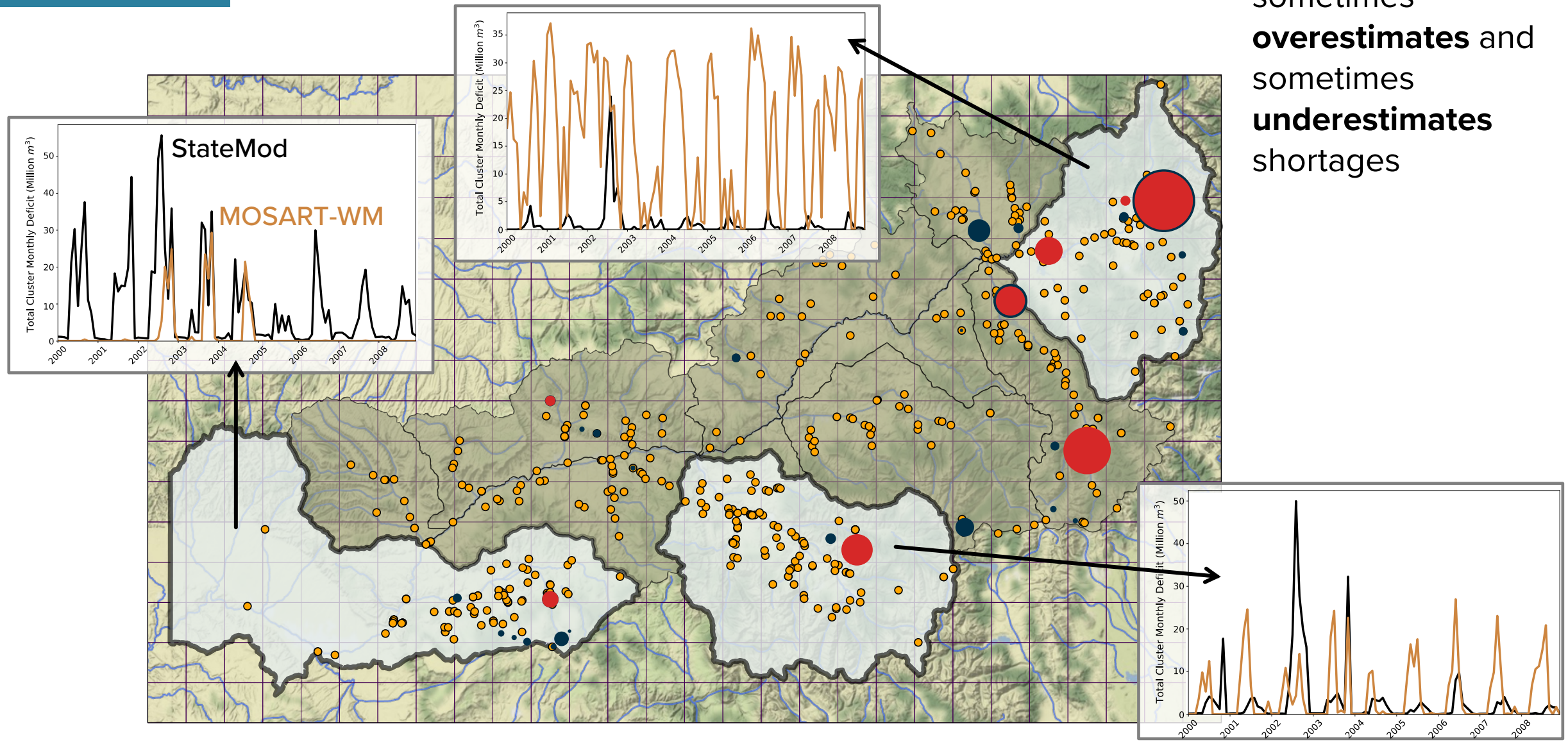


Spatial distribution of shortages

MOSART-WM sometimes **overestimates** and sometimes **underestimates** shortages



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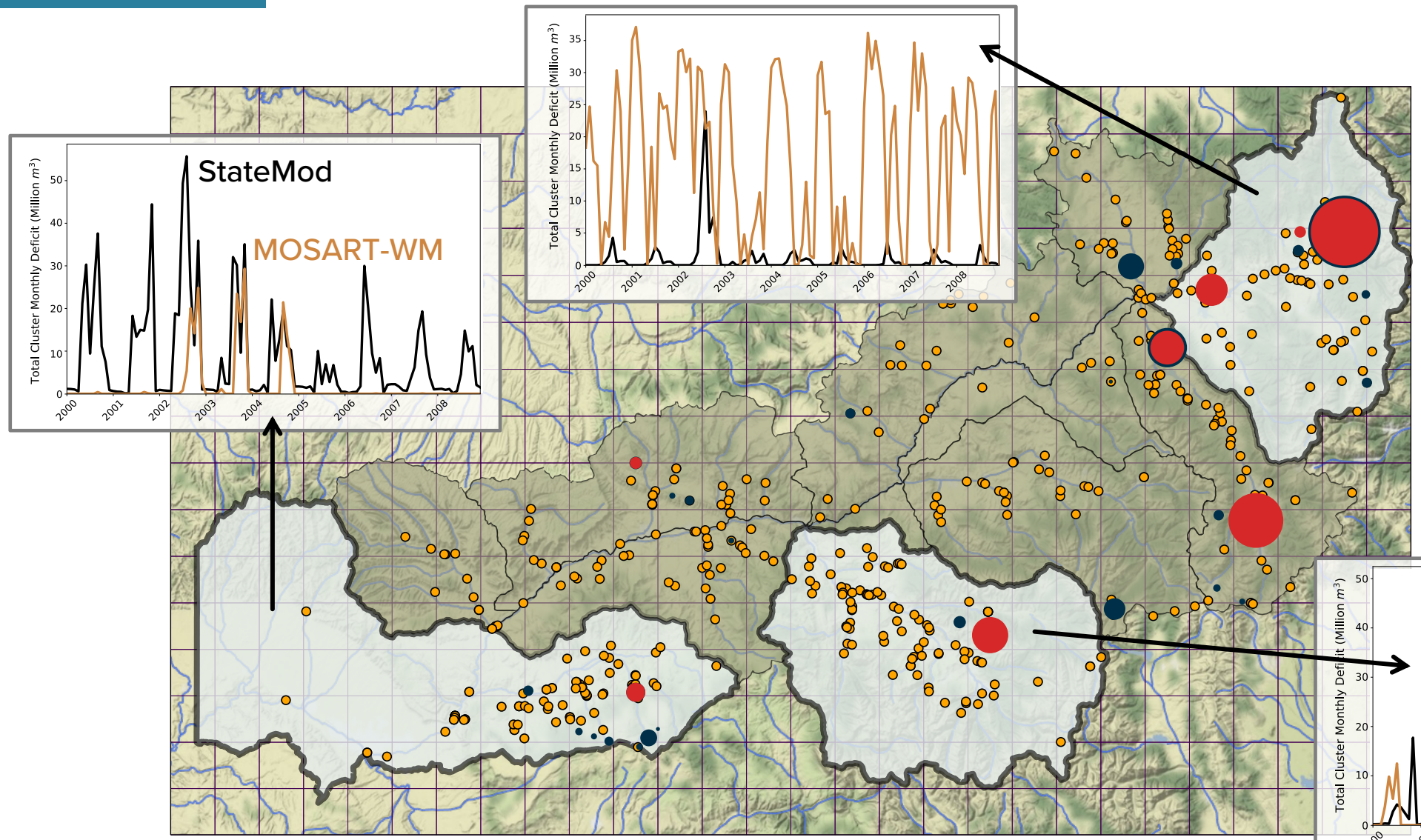
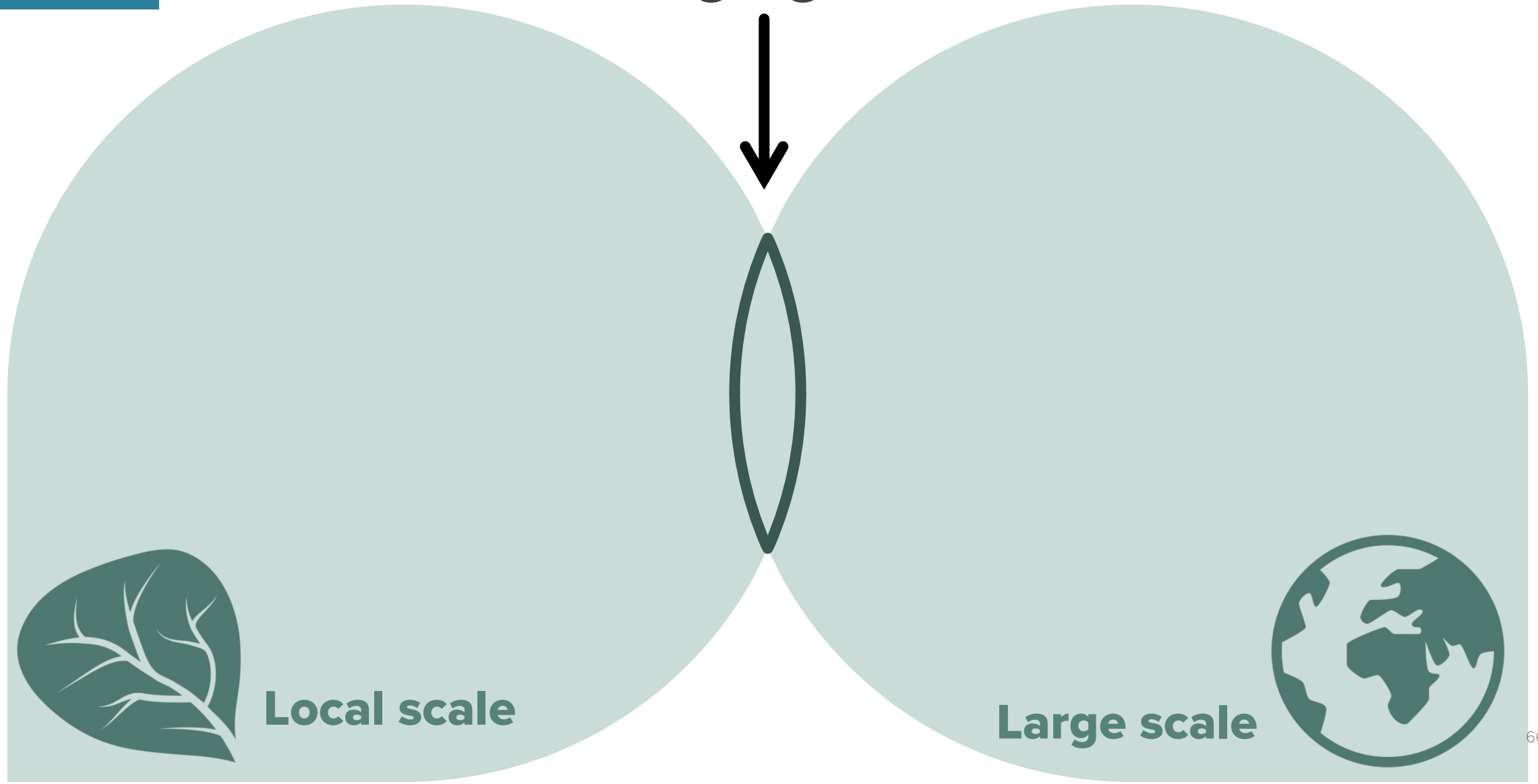


MOSART-WM sometimes **overestimates** and sometimes **underestimates** shortages

Attributed to the **allocative mechanisms** used to apportion reservoir water supply to dependent cells downstream

If our modeling is converging, are our inferences converging too?



If our modeling is converging, are our inferences converging too?

Yes! *But several* ***challenges*** *remain in bridging between scales: e.g.,* ***data availability****, semantic* ***differences in representation***

Local scale

Large scale

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What can we learn about modeling large-scale processes better?

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Large scale

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Large-scale models can capture **basin-scale dynamics** and could be used to **bridge** across interacting basins with **limited data** availability

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What can we learn about modeling large-scale processes better?

How can local-scale systems modeling better inform large-scale models?

*Information from data- and model-rich basins can be used to establish **human system relationships** for larger scales*

Local scale

Large scale

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Large-scale models can capture **basin-scale dynamics** and could be used to **bridge** across interacting basins with **limited data** availability

What can we learn about modeling large-scale processes better?

How can local-scale systems modeling better inform large-scale models?

Innovations are needed to better incorporate local water shortage mechanisms in large-scale models. ***MOSART-WM is currently the only model that attempts to do so.***

Local scale

Large scale

IM3

INTEGRATED MULTISECTOR MULTISCALE MODELING

Thank you!

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Pacific Northwest National Laboratory · Berkeley Lab · Oak Ridge National Laboratory · Sandia National Laboratories · Baylor University · Boston University · Cornell University · NC State University · The University of North Carolina at Chapel Hill · UC Davis · PennState