University of Massachusetts Amherst

HYDROGEOLOGY

Impacts of freshwater and brine extraction in salars

Simulations of Salar de Atacama and Salar del Hombre Muerto

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global transition to green energy

- surge in demand for lithium

Lithium extraction, particularly from continental brines, is expanding rapidly, akin to historical oil rushes.

sustainability concerns

These brine deposits are often located in environmentally sensitive and water-scarce regions

Salar de Atacama (SdA)

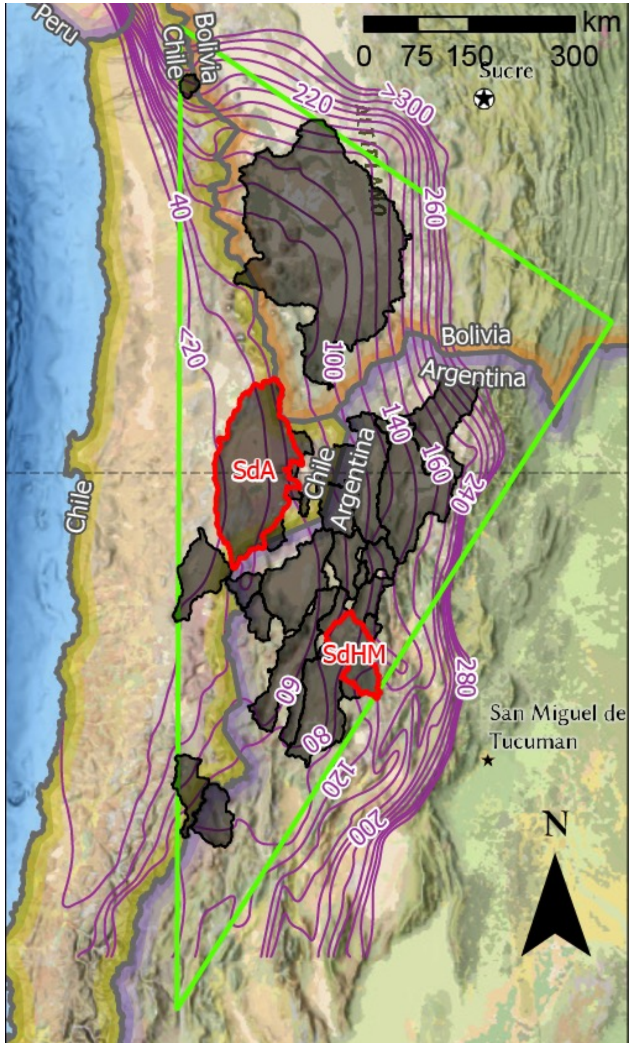
Mature halite salar
Hyper arid environment

Salar del Hombre Muerto (SdHM)

Complex geological setting with two distinct sub-basins:

- **East:** immature clastic salar
- **West:** mature halite salar

Arid environment



LITHIUM MINING

SdA

Traditional evaporative techniques

Evaporative ponds to obtain lithium

SdHM

Direct Lithium Extraction (DLE)

Lithium is filtered from brine, which is reinjected to the system

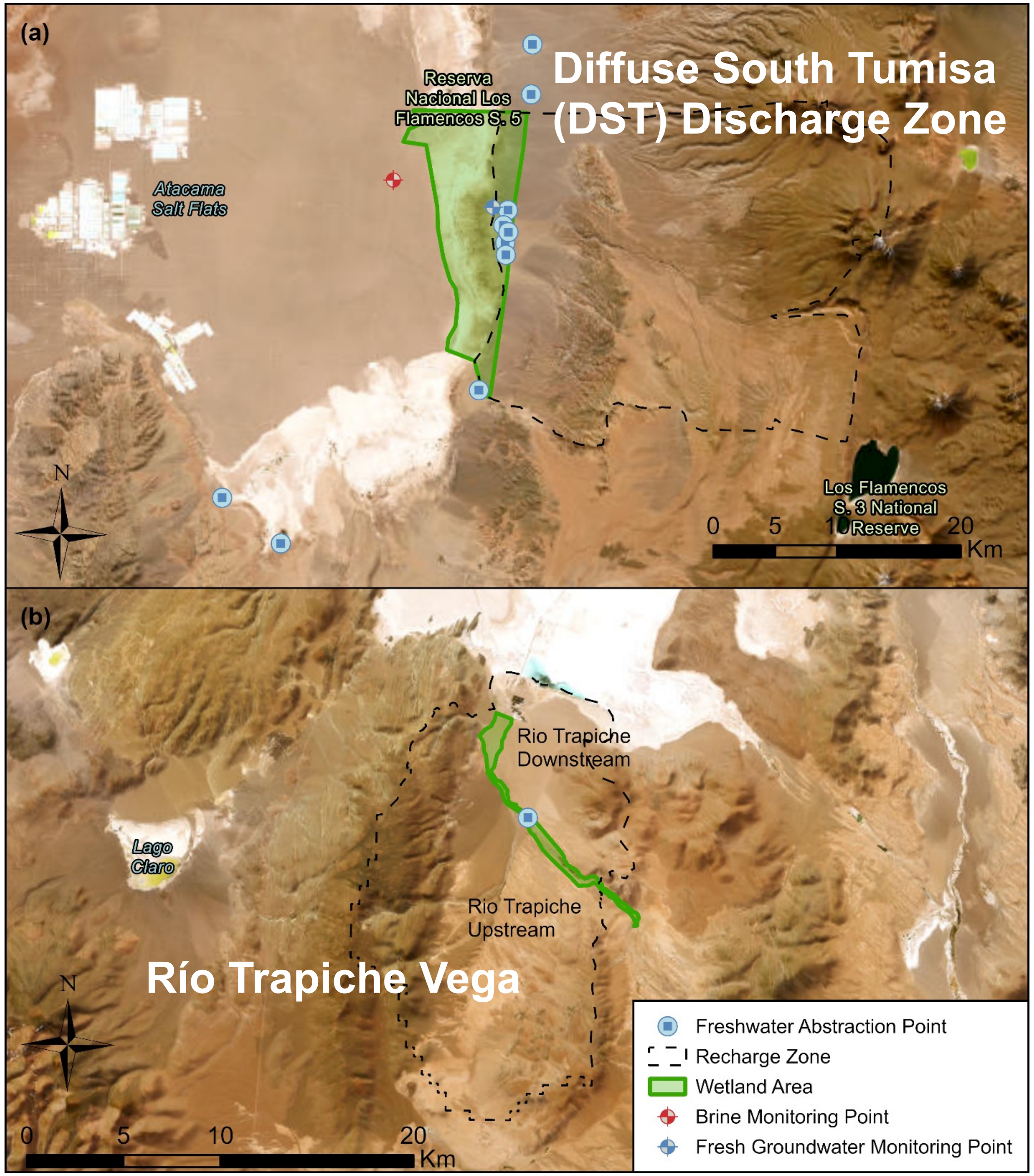
Wetlands

Diffuse South Tumisa (DST) Discharge Zone (SdA):

wetlands adjacent to the salar nucleus, which exhibits with **brine drawdowns** from 40 years of lithium mining by evaporative techniques and relatively **little freshwater abstraction**.

Río Trapiche Vega (SdHM – West) :

riparian wetland along the banks of Rio Trapiche, from which a nearby lithium mine using DLE technology has been abstracting fresh water for over 25 years: **no brine drawdowns** and **relatively high freshwater abstraction**



— How do different methods of lithium extraction from continental brines, specifically **brine abstraction versus freshwater use**, impact the hydrogeologic system, particularly **groundwater discharge** to ecologically **sensitive wetlands**?

Goal

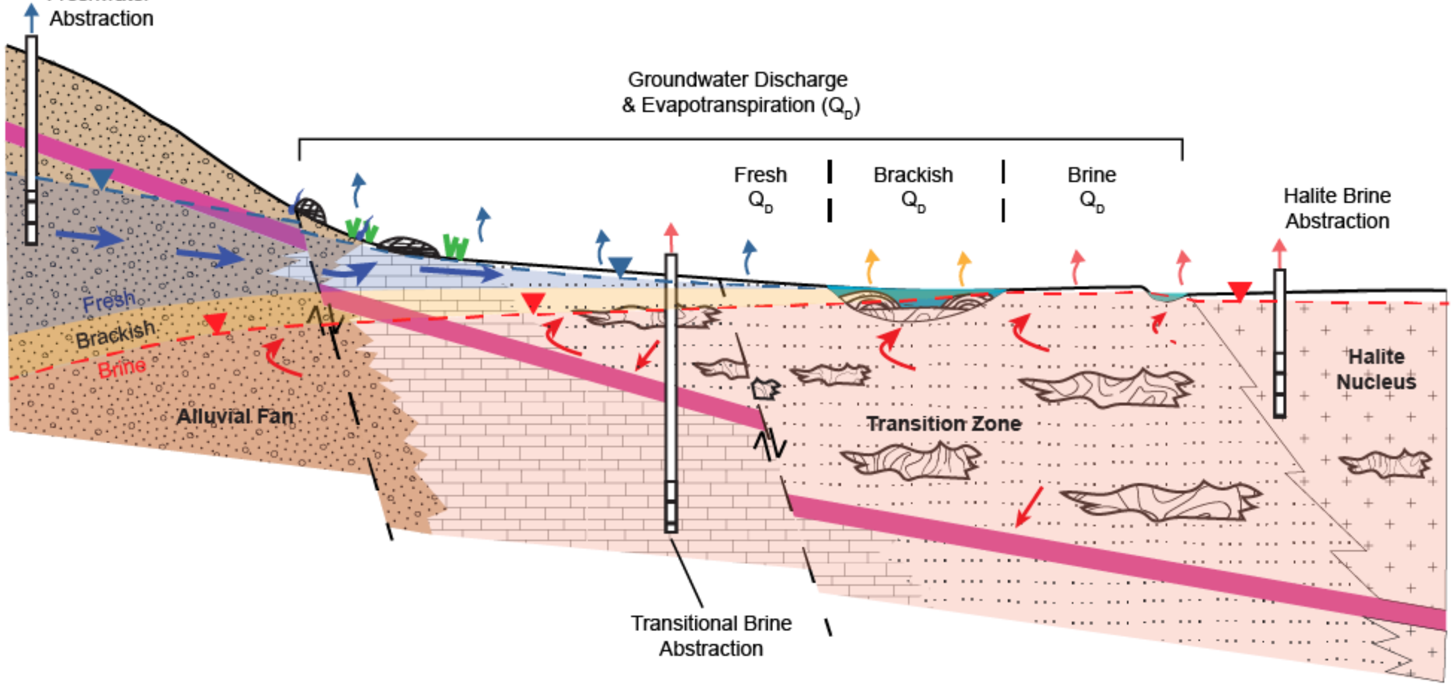
Conducting a parametric study using these 2D models to evaluate how **variations in groundwater and brine abstraction rates** impact the hydrogeologic system, particularly **with respect to groundwater discharge to ecologically sensitive wetlands**.

Conceptual framework

Brine–freshwater mixing

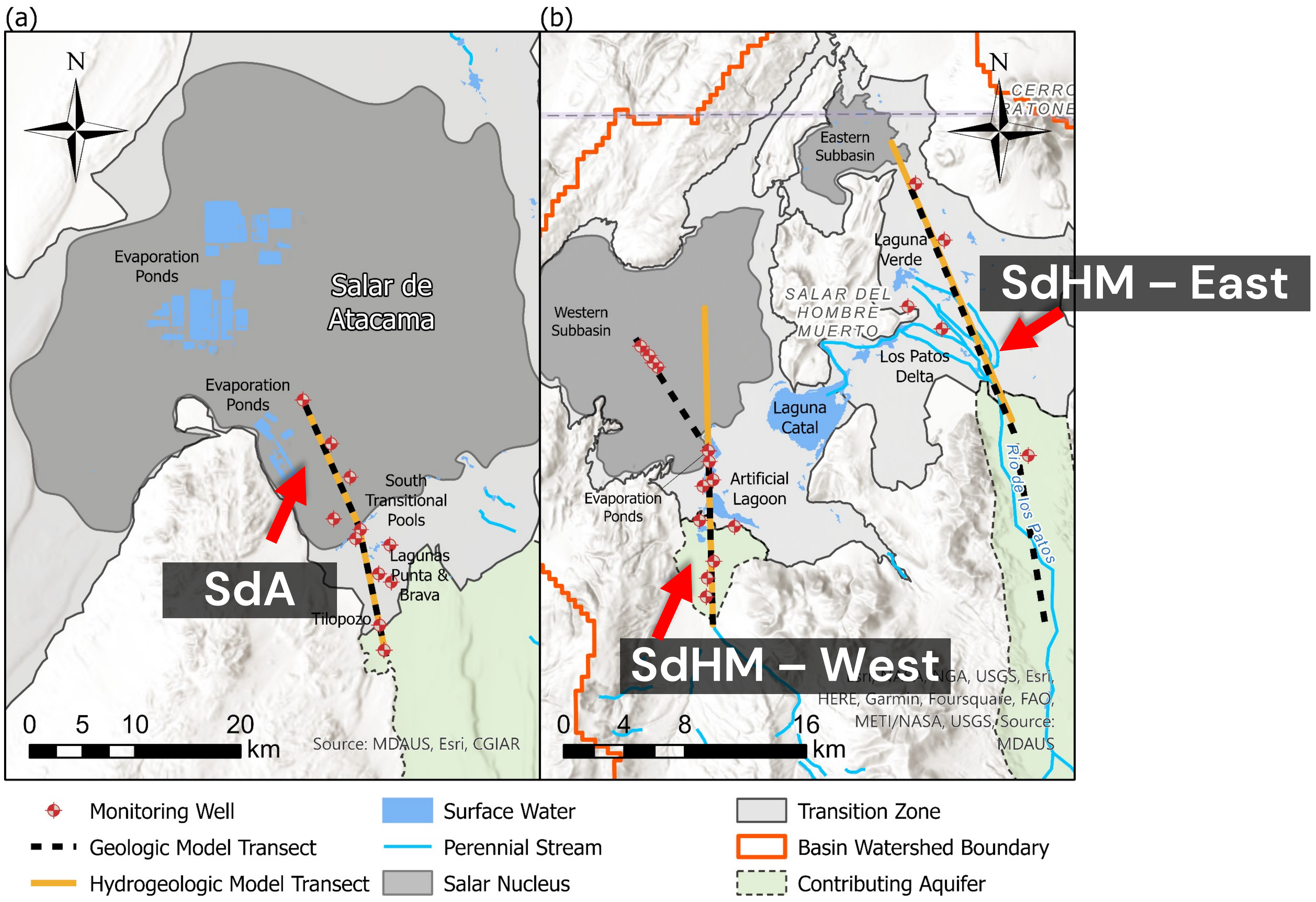
Significant influence of geologic heterogeneity on localized hydraulics and the resulting flow patterns

Munk et al. (2021)



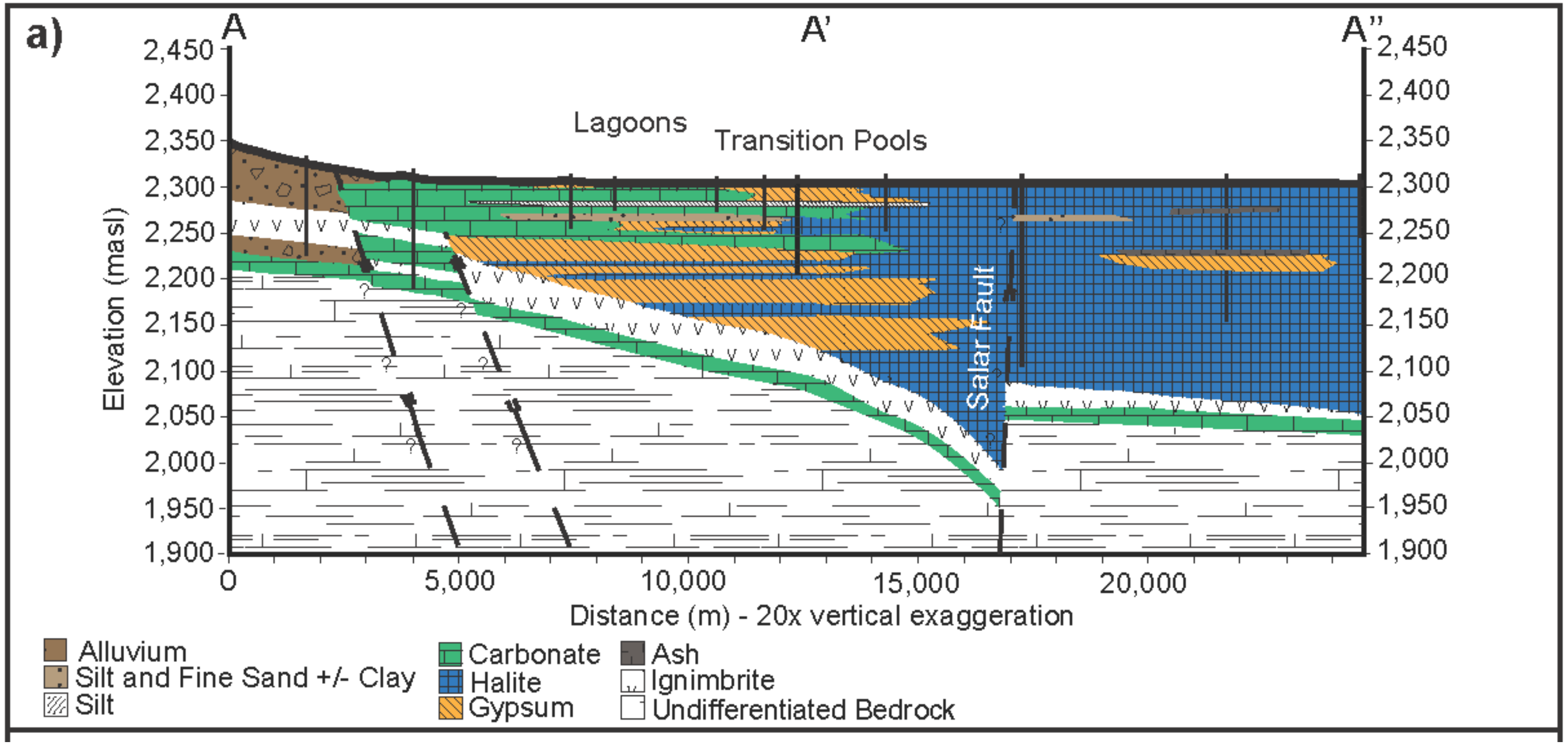
➔ **endmembers**

Cross sections



Endmembers

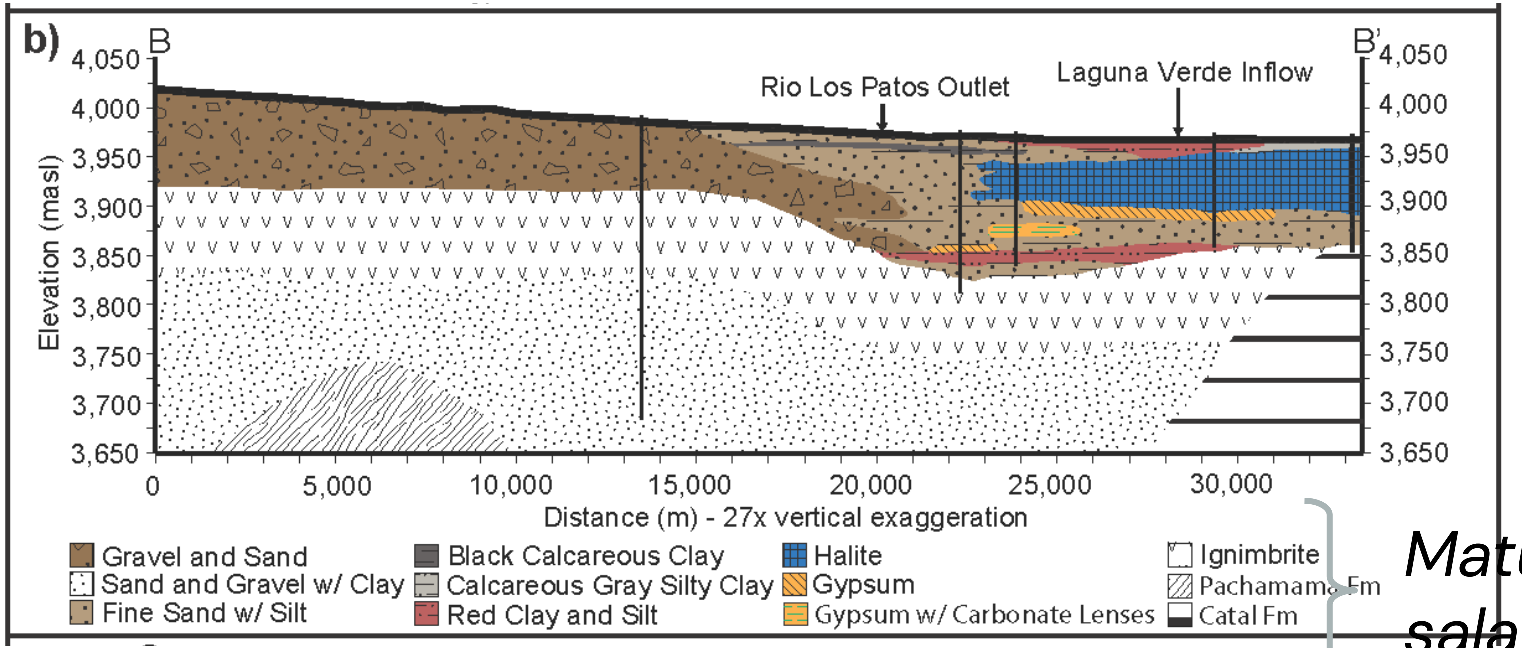
SdA



Carbonate → Gypsum → Halite } *Mature salar*

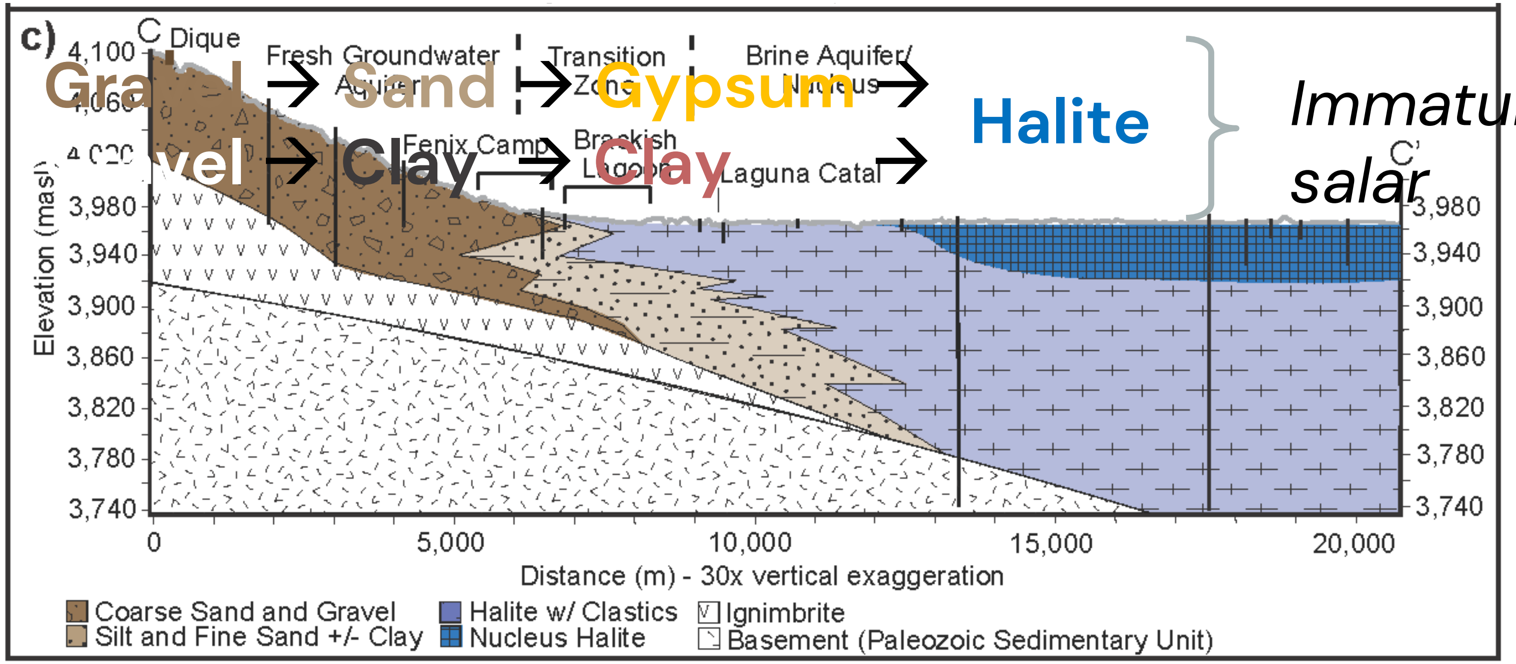
Endmembers

SdHM – East



Mature salar

SdHM – West



Immature salar

Modeling framework

theoretical models

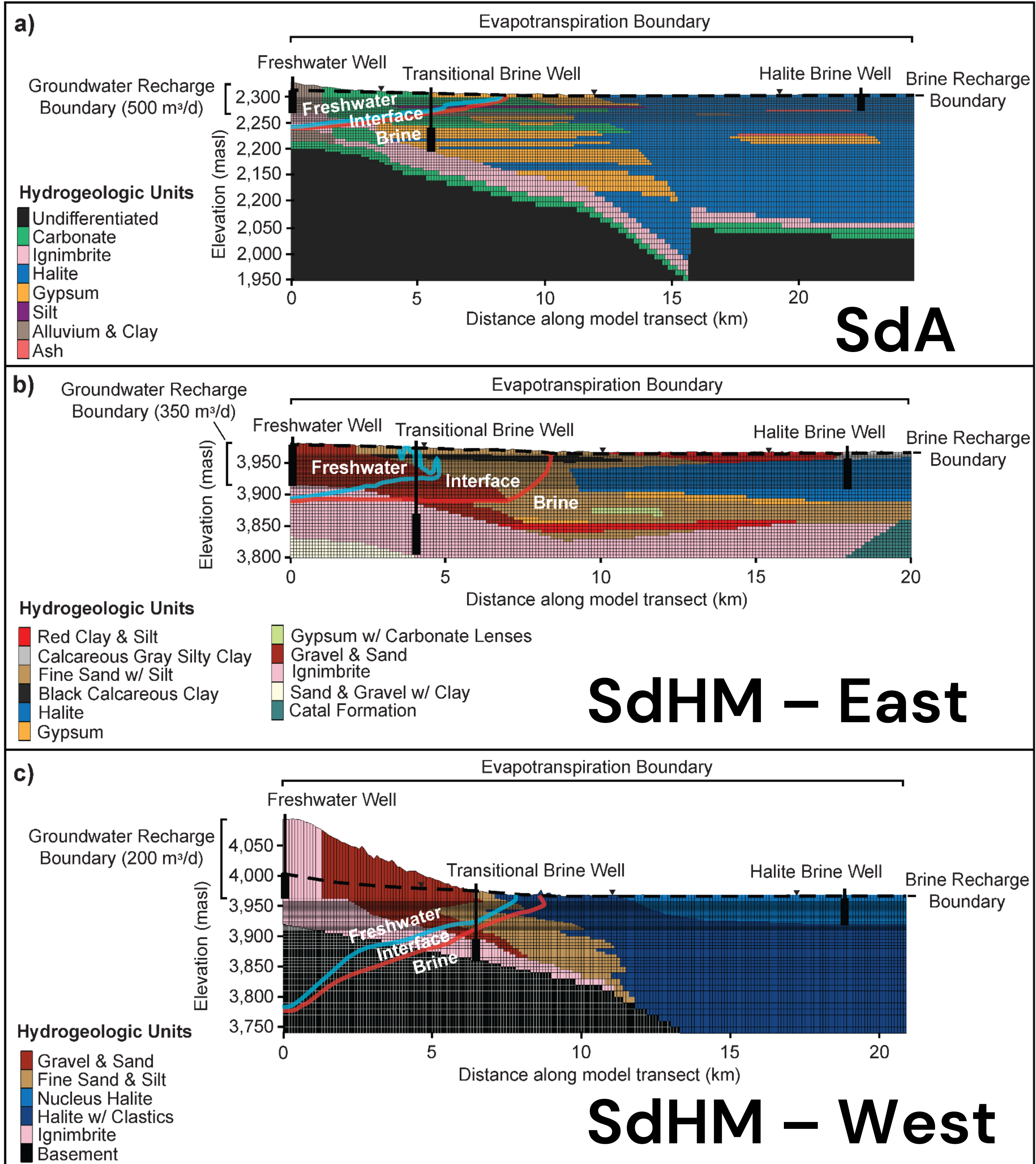
2D finite-difference	MODFLOW
Parametric	Systematically **changing key parameters** to *understand their impact* on the system's behavior
Variable-density flow	SEAWAT

Boundary conditions

Rech
- High – elev : freshwater
- Low – elev : brine

EVT Evapoconcentration

WEL Brine extraction



Multiple scenarios simulations

Simulation Number	Abstraction Type	Total Abstraction (% of Recharge)
0	None (baseline)	0
1	Fresh Groundwater	10
2	Fresh Groundwater	20
3	Fresh Groundwater	30
4	Fresh Groundwater	40
5	Halite Brine	10
6	Halite Brine	20
7	Halite Brine	30
8	Halite Brine	40
9	Transitional Brine	10
10	Transitional Brine	20
11	Transitional Brine	30
12	Transitional Brine	40

Abstractions as % of fresh recharge

12 simulations:

baseline scenario with no abstraction

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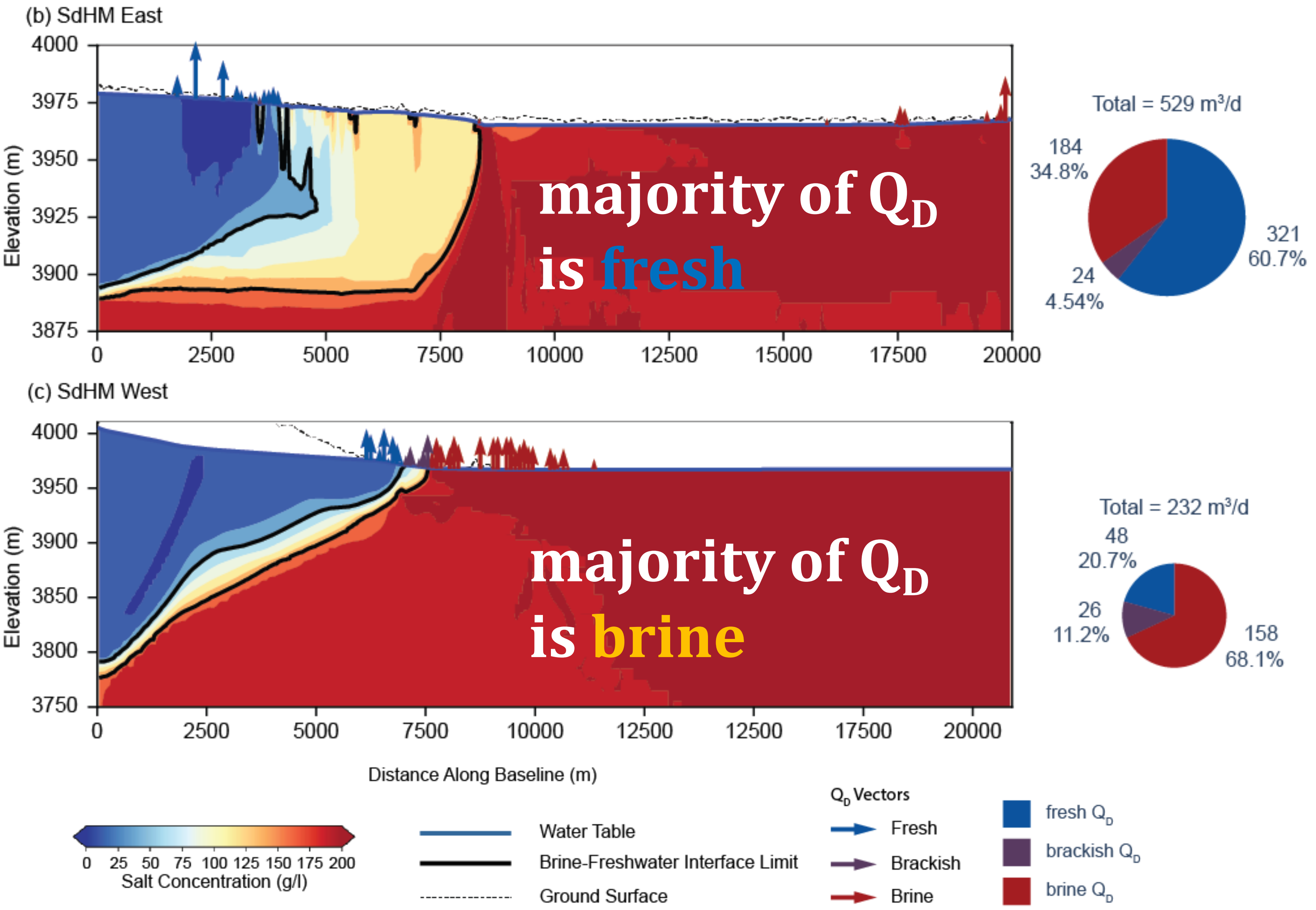
3 types of abstraction at varying rates (11 scenarios)

Changes in:

1) hydraulic **head**, QD,
2) **salinity** over a period of 200 years per abstraction scenario

Results

Flow dynamics

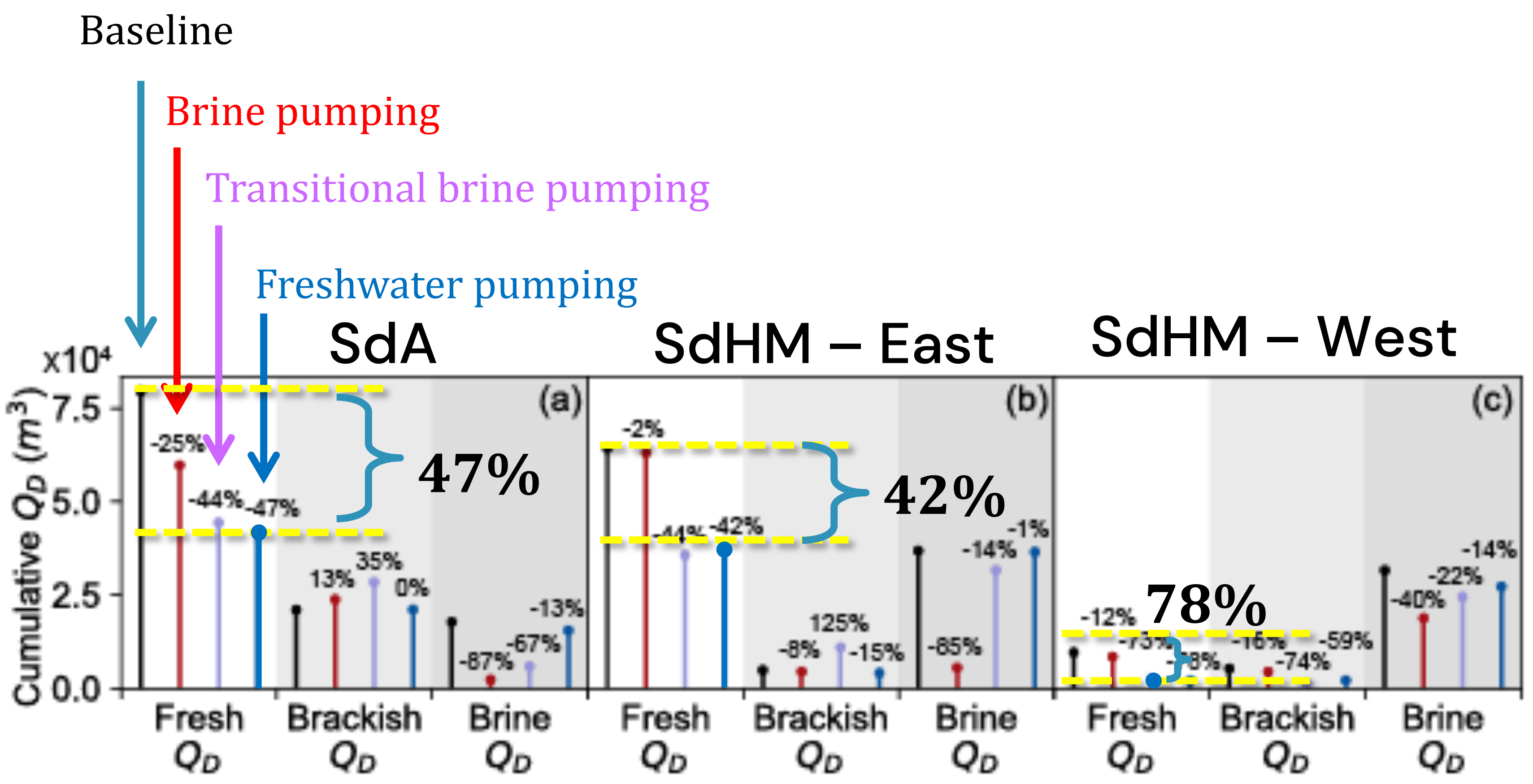


– Baseline

SdHM

Results

Groundwater discharge



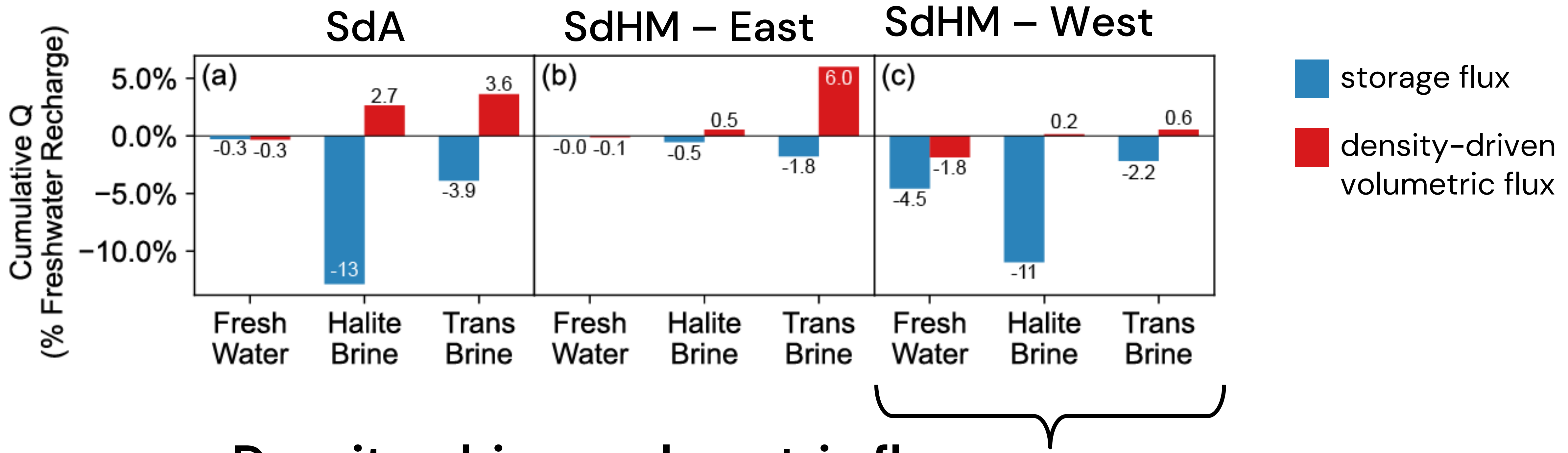
Change with respect to the Baseline

– Freshwater abstraction has greater environmental impact than brine abstraction

- Fresh Water: fresh groundwater abstraction scenario
- Halite Brine indicates the halite brine abstraction scenario
- Trans Brine indicates the transitional brine abstraction scenario

Results

Storage and Density Effects



Abstraction types

– Density-driven volumetric flux can buffer impacts of brine abstraction

- Fresh Water: fresh groundwater abstraction scenario
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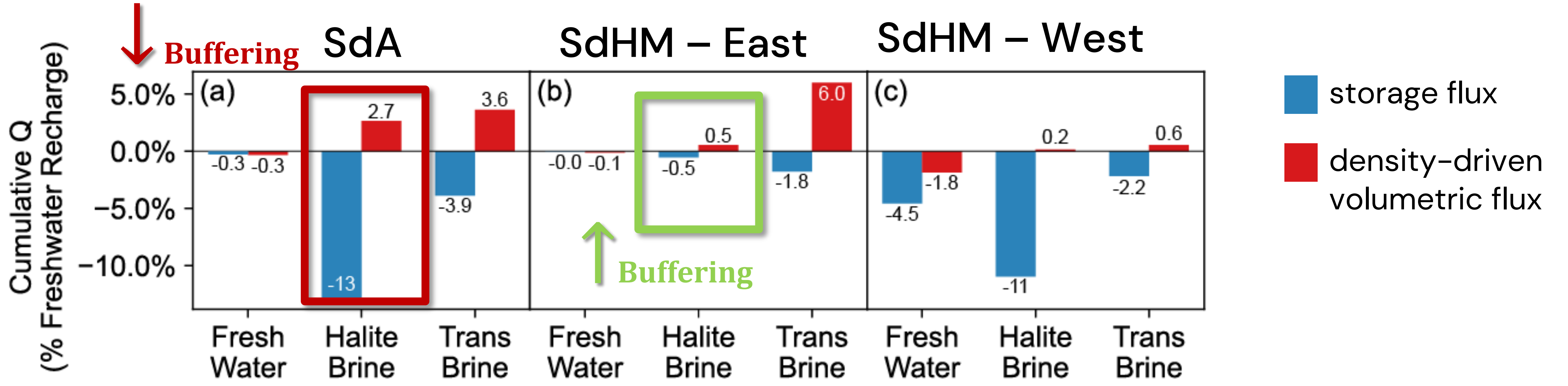
Results

Storage and Density Effects



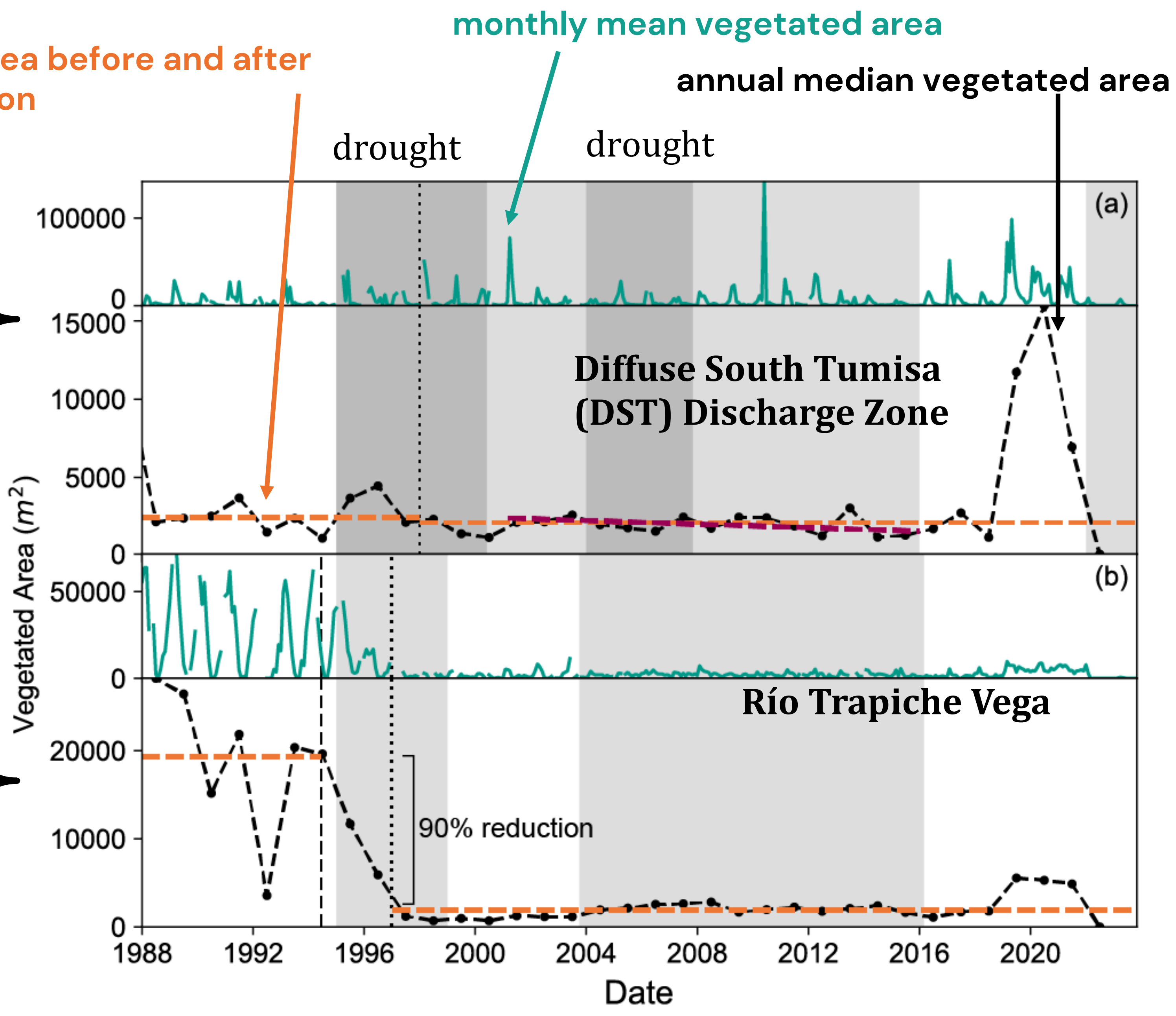
– Buffering capacity is more effective in large transition zone systems.

Normalized Difference Vegetation Index (NDVI): Landsat 5 – 8 and Sentinel images over 1988 – 2023

– Vegetated area responds more strongly to precipitation changes than brine levels

– Direct correlation between freshwater abstraction and adverse impacts on wetlands, with less influence from precipitation variability

median vegetated area before and after freshwater abstraction



Key take aways

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- **Abstraction Type** Matter
- **Freshwater** Abstraction Poses a **Greater Risk**
- **Buffering effect:** environmental impacts of **brine abstraction are mitigated** by density-driven increases in the volume of the remaining groundwater. This buffering effect **was not observed with freshwater abstraction**, which more directly reduces the water available to ecosystems.
- While **DLE** may reduce the negative impact of brine drawdown on wetlands, **it requires significantly more fresh water**, thus presenting a **trade-off**.