Separating salinity increases due to saltwater intrusion from that due to evaporation by a dual-isotope model: a case study in the Shark River Slough

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Li Zhang, Evelyn Gaiser, Leo Sternberg*

Greater Everglades Priority Ecosystem program.

USGS
science for a changing world

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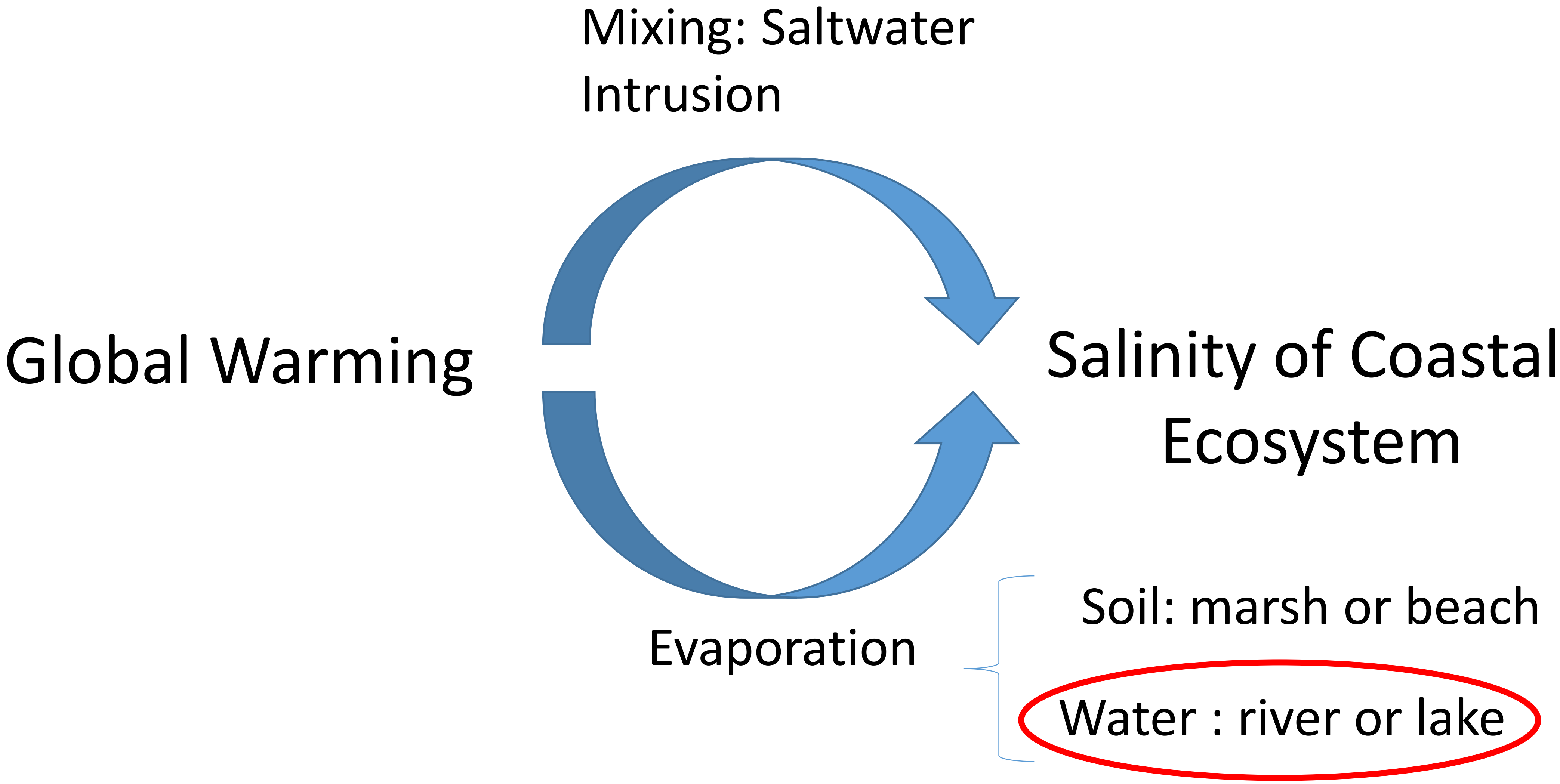
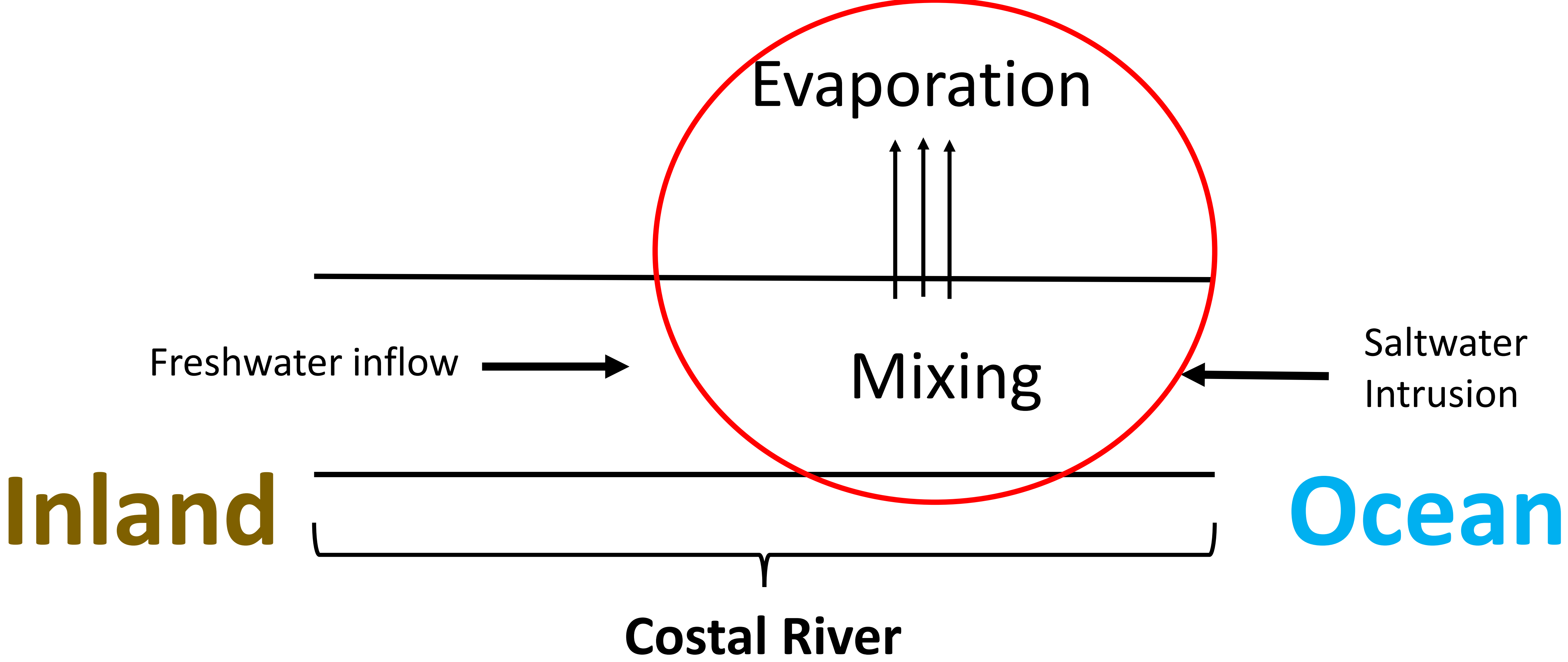
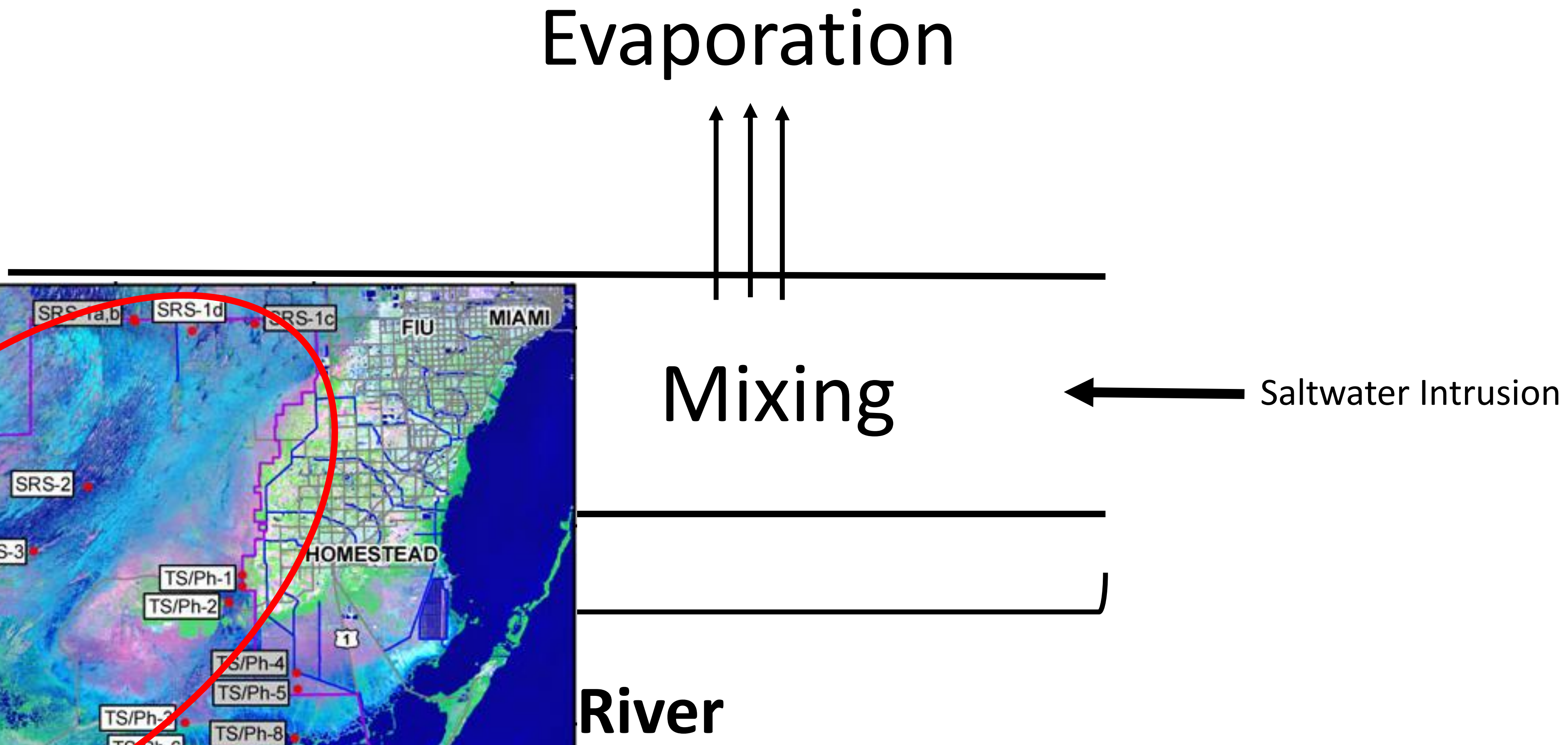
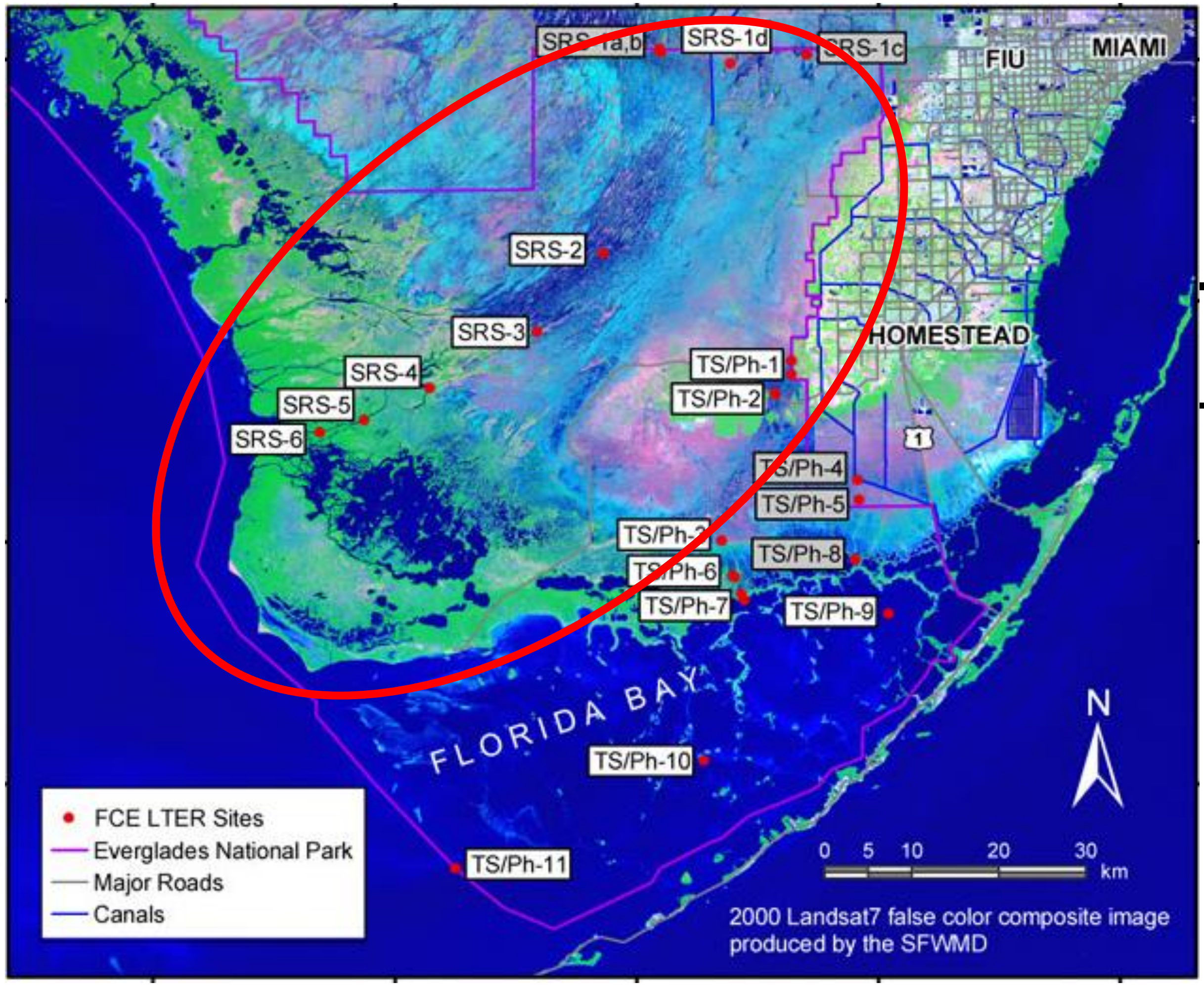
OF MIAMI


Mixing: Saltwater Intrusion
Global Warming
Salinity of Coastal Ecosystem
Evaporation
Soil: marsh or beach
Water : river or lake

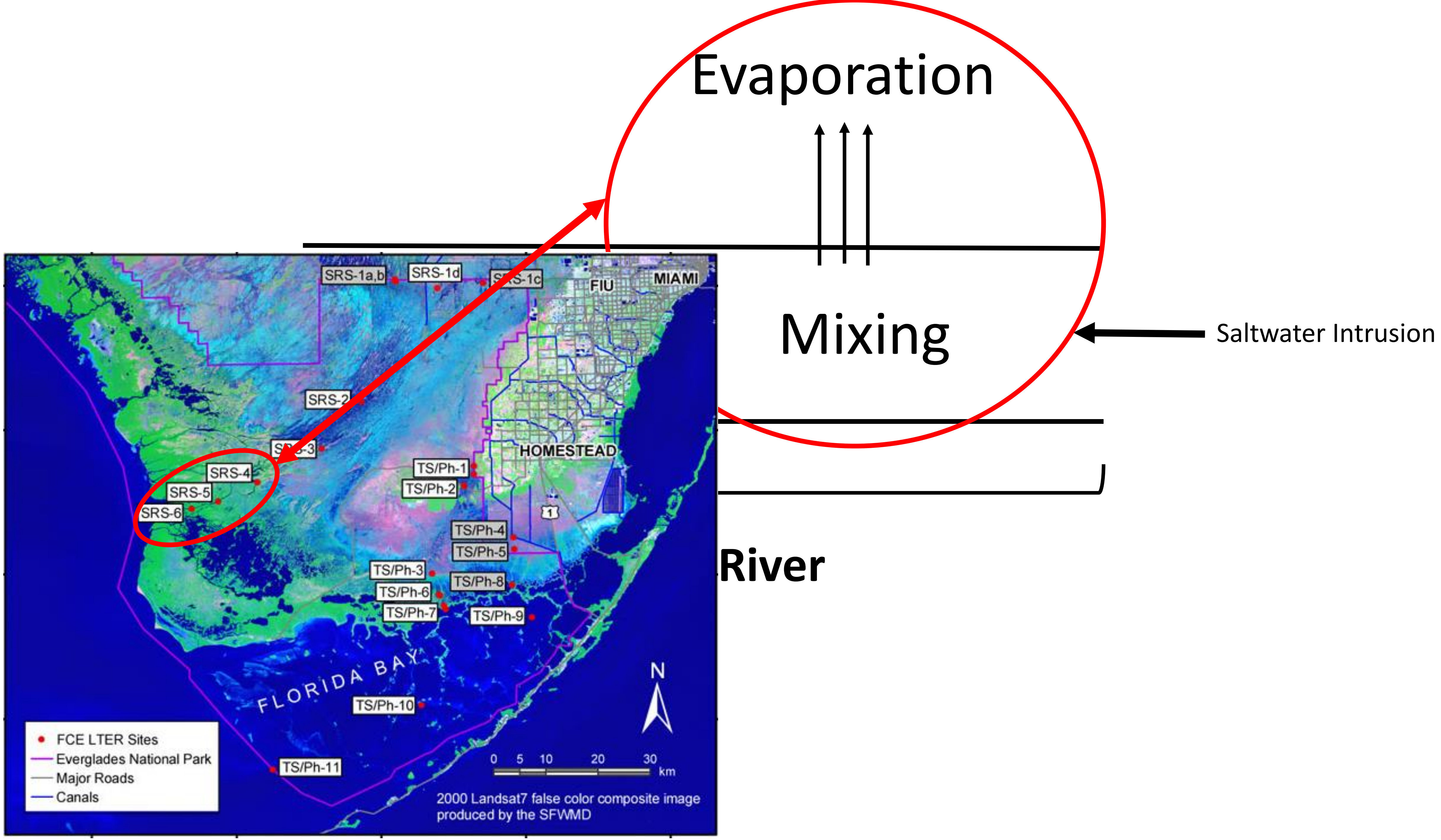

Evaporation
Mixing
Freshwater inflow
Saltwater
Intrusion
Inland
Ocean
Costal River

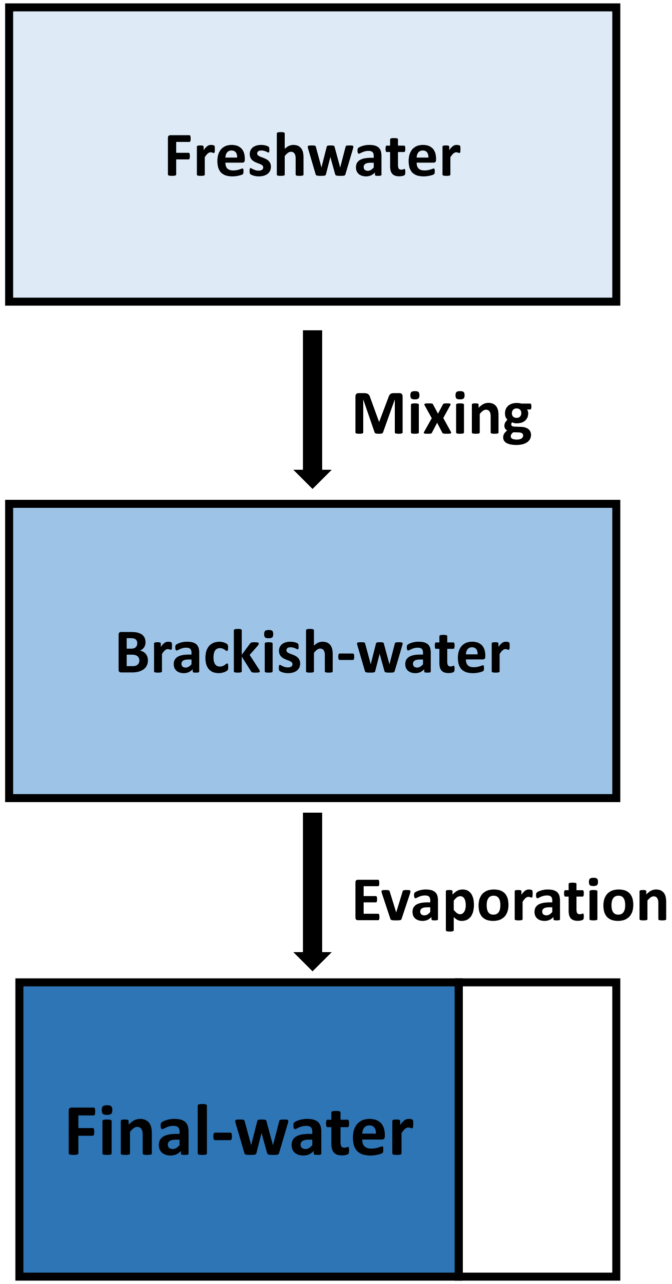


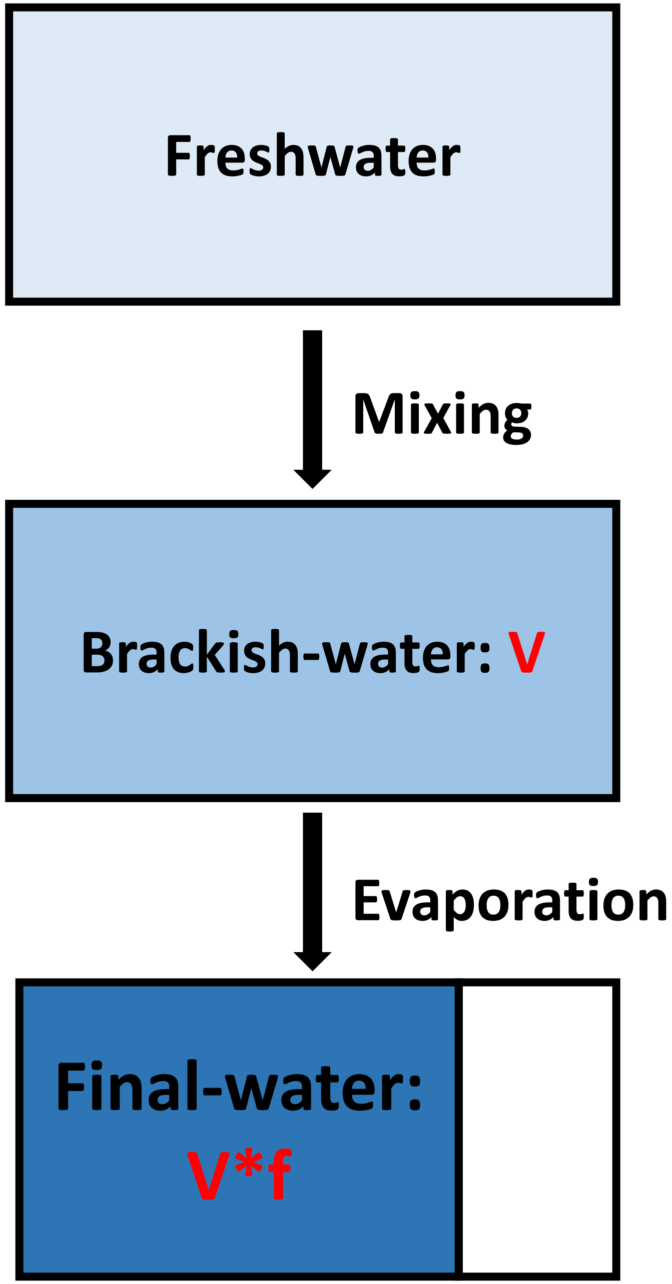


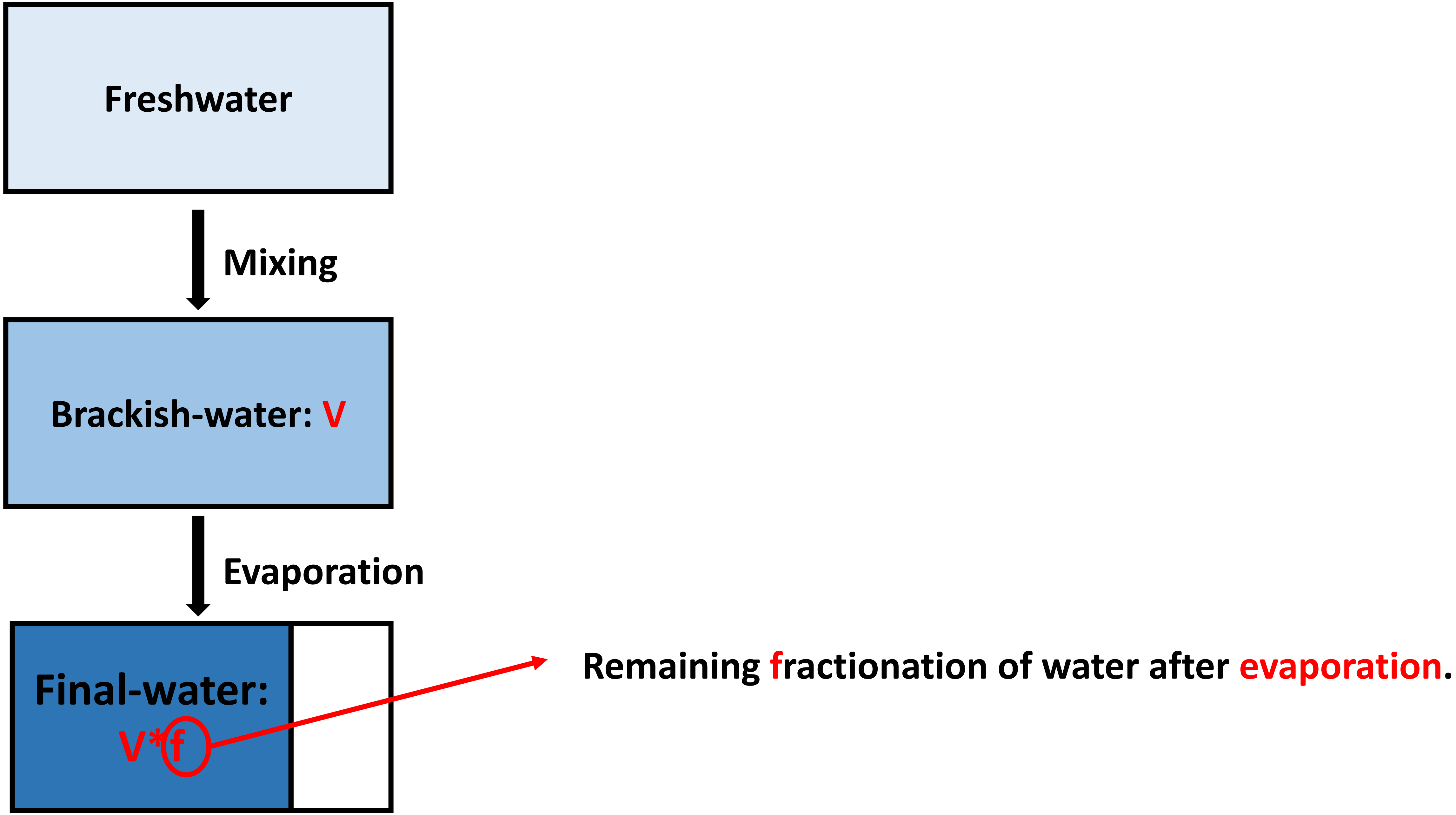
Shark River Slough

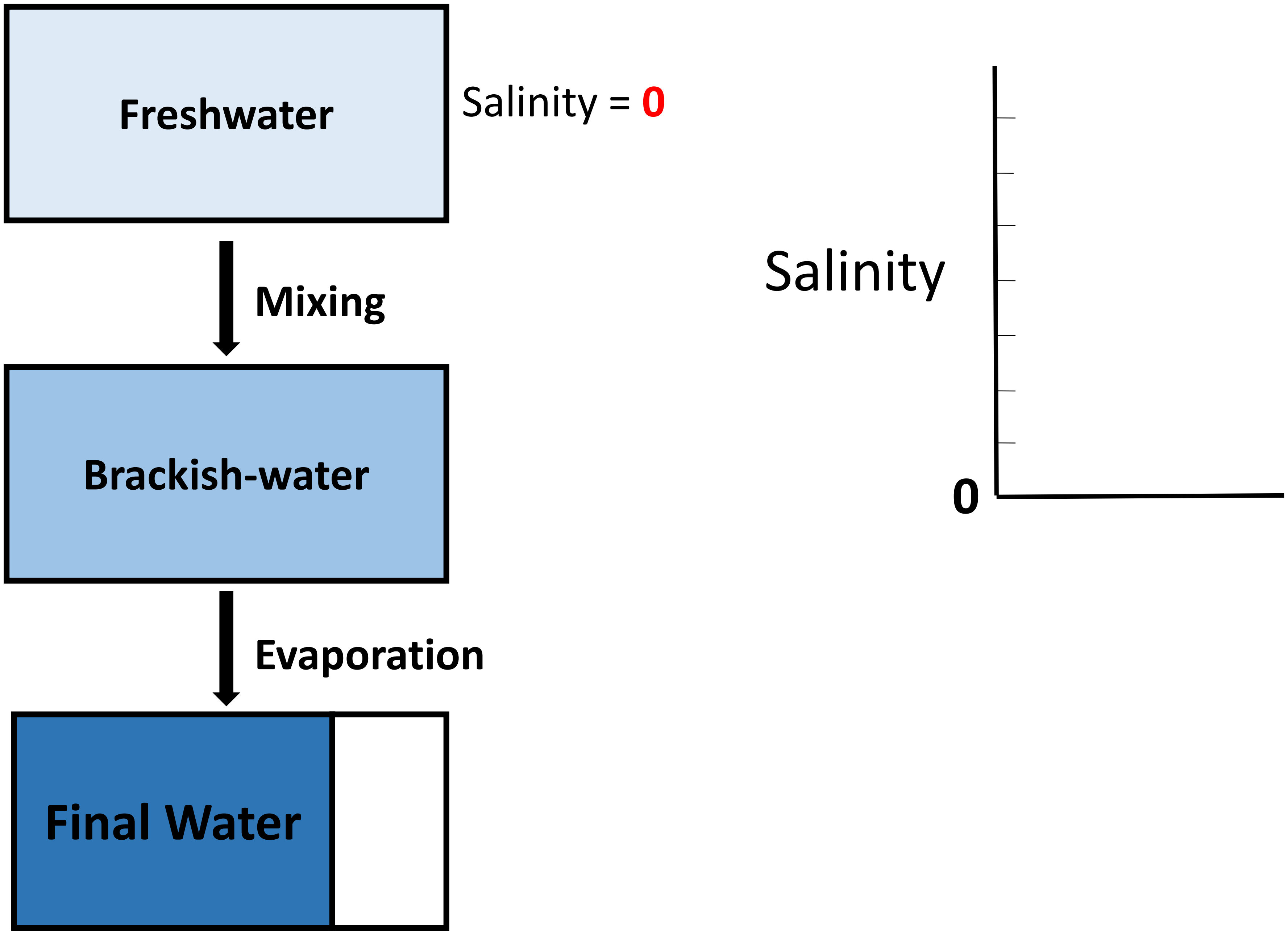
river of grass

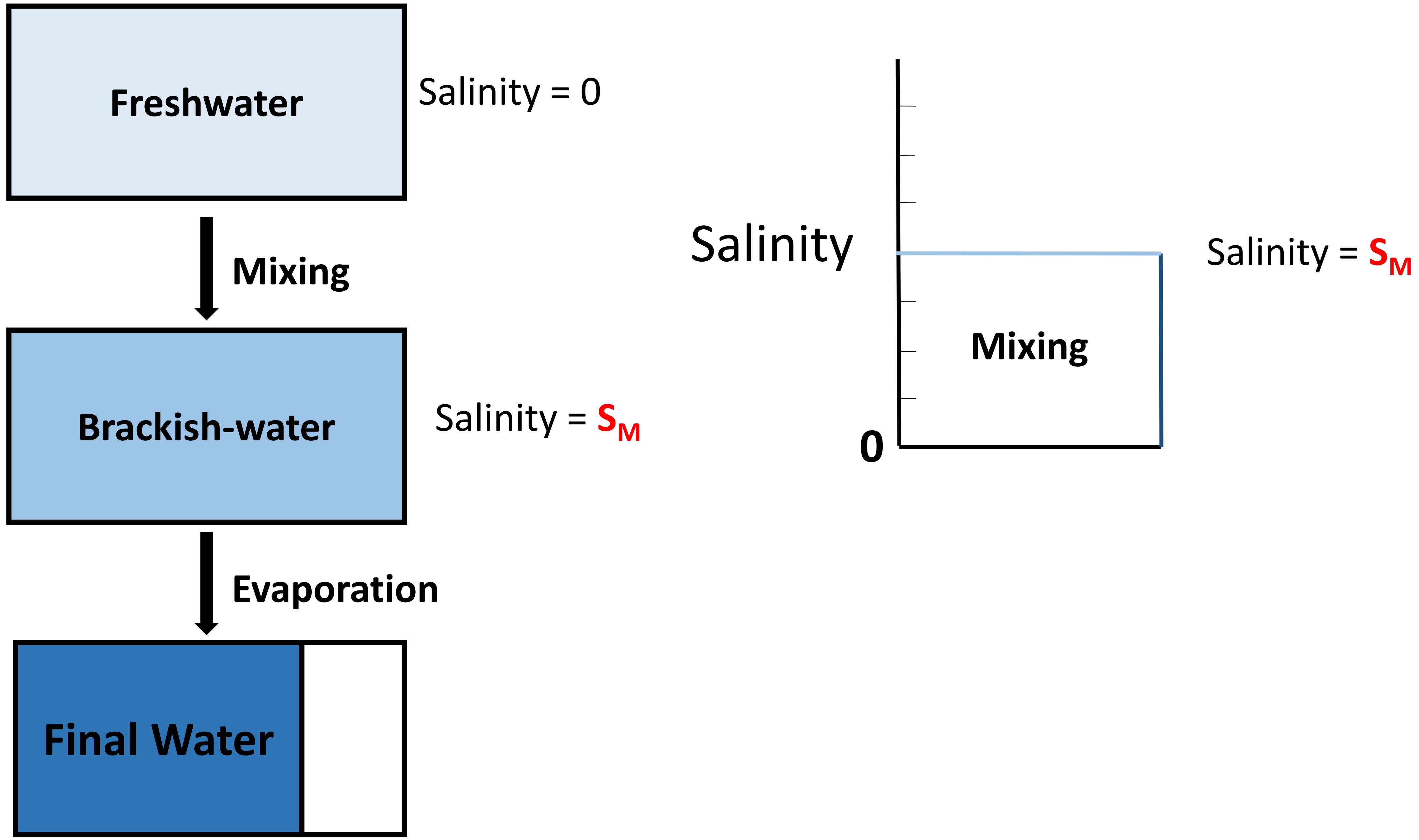

Evaporation
Mixing
Saltwater Intrusion
River
SRS-1a,b
SRS-1d
SRS-1c
FIU
MIAMI
SRS-2
SRS-3
SRS-4
SRS-5
SRS-6
HOMESTEAD
TS/Ph-1
TS/Ph-2
TS/Ph-4
TS/Ph-5
TS/Ph-3
TS/Ph-8
TS/Ph-6
TS/Ph-7
TS/Ph-9
FLORIDA BAY
TS/Ph-10
TS/Ph-11
N
FCE LTER Sites
Everglades National Park
Major Roads
Canals
0 5 10 20 30 km
2000 Landsat7 false color composite image produced by the SFWMD

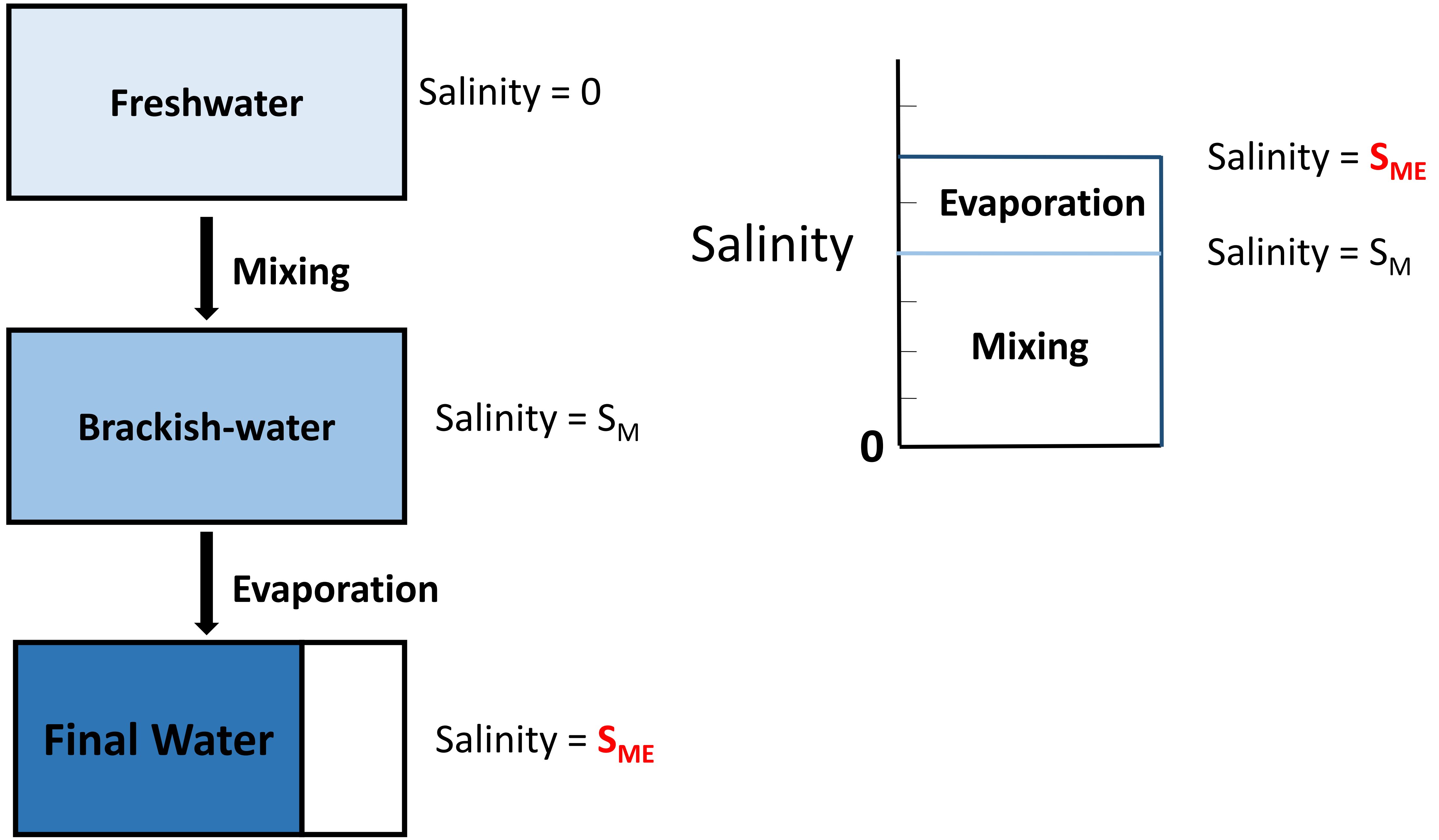

Freshwater
Mixing
Brackish-water
Evaporation
Final-water

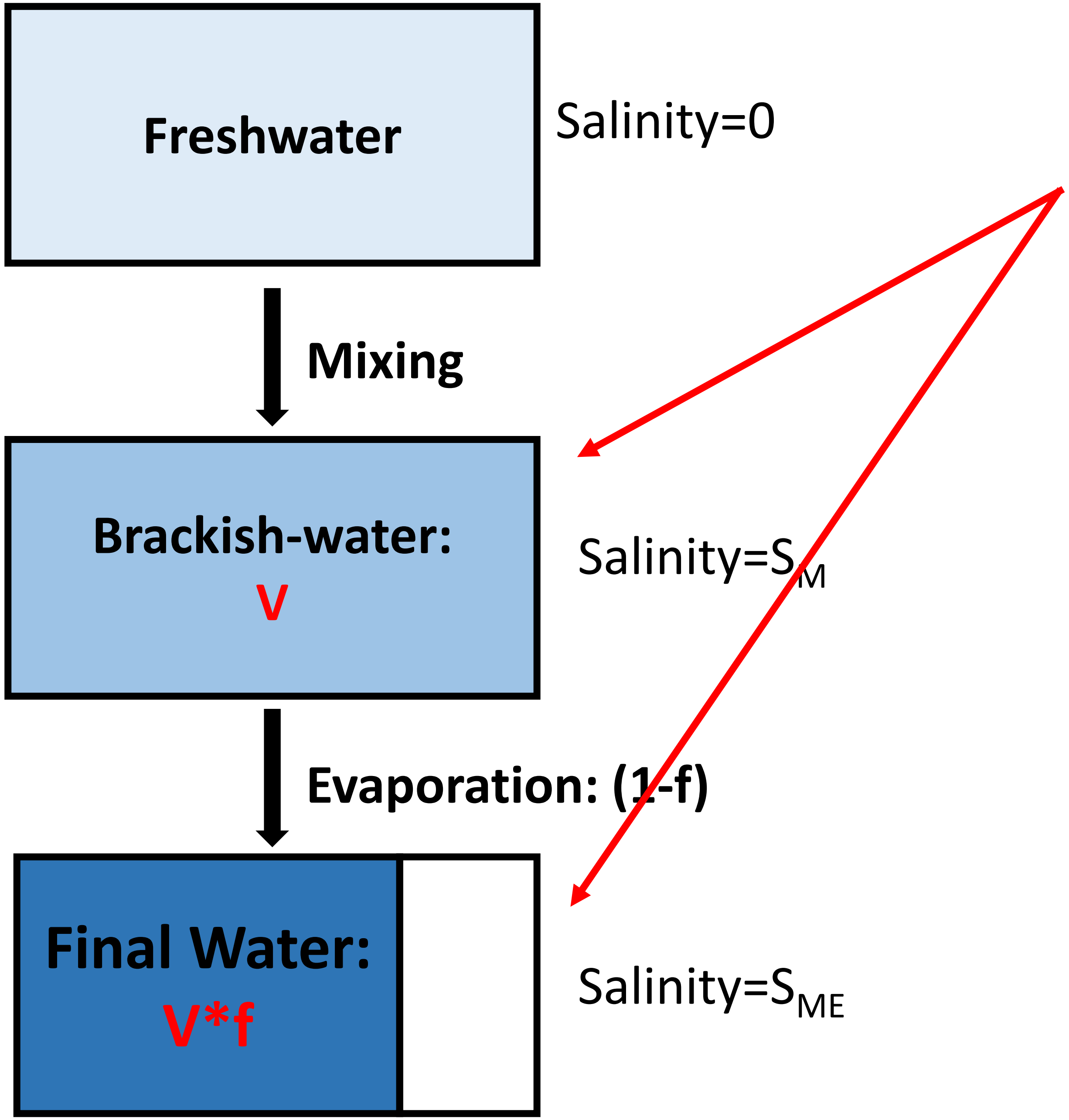

Freshwater
Mixing
Brackish-water: V
Evaporation
Final-water:
V*f


Freshwater
Mixing
Brackish-water: V
Evaporation
Final-water:
V*f
Remaining fractionation of water after evaporation.


Freshwater
Salinity = 0
Mixing
Brackish-water
Evaporation
Final Water
Salinity
0

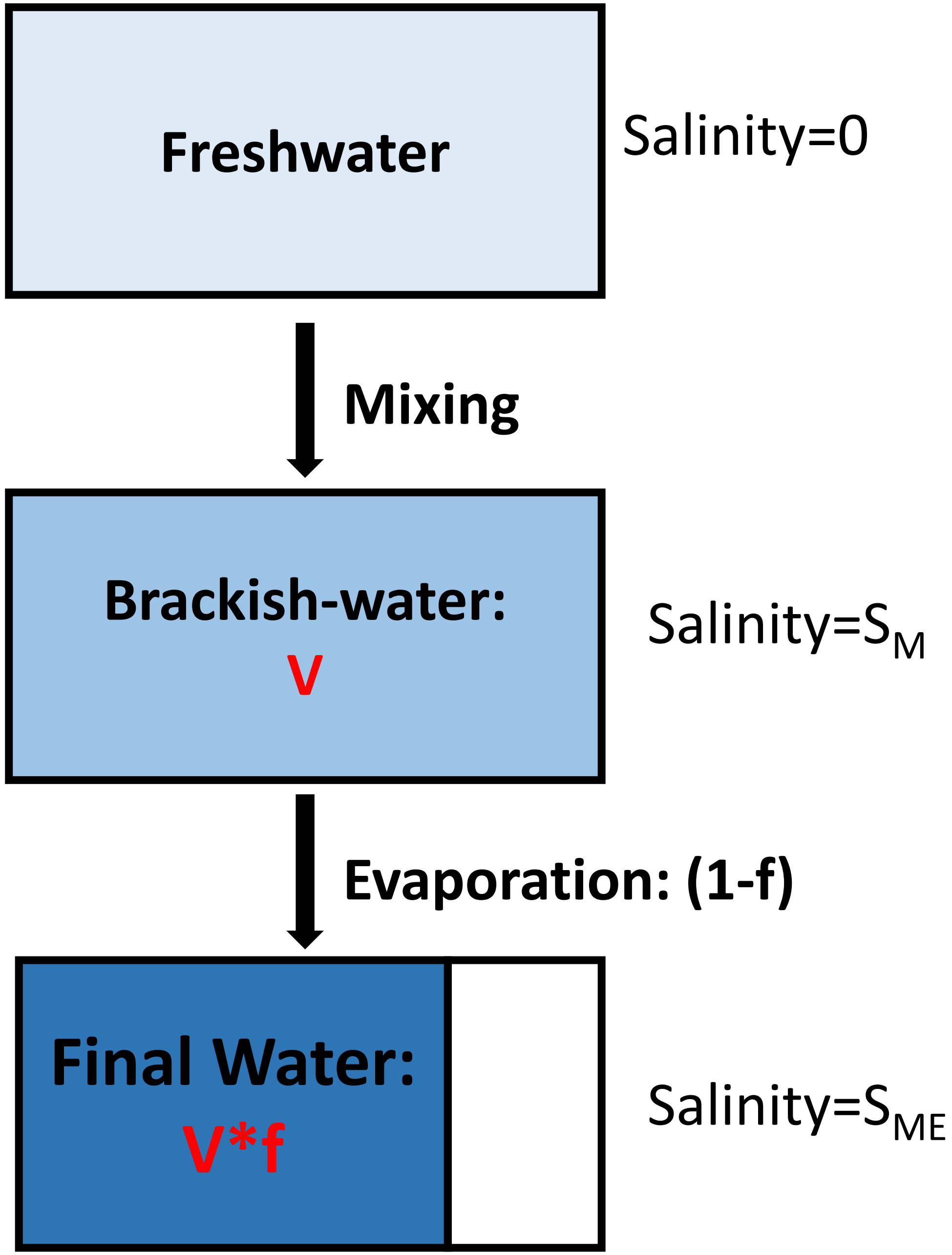

Freshwater
Salinity = 0
Mixing
Brackish-water
Salinity = S_M
Evaporation
Final Water
Salinity
Salinity = S_M
Mixing
0


Freshwater
Salinity = 0
Mixing
Brackish-water
Salinity = S_M
Evaporation
Final Water
Salinity = S_{ME}
Salinity
Salinity = S_{ME}
Evaporation
Salinity = S_M
Mixing
0



Salt Mass Balance:

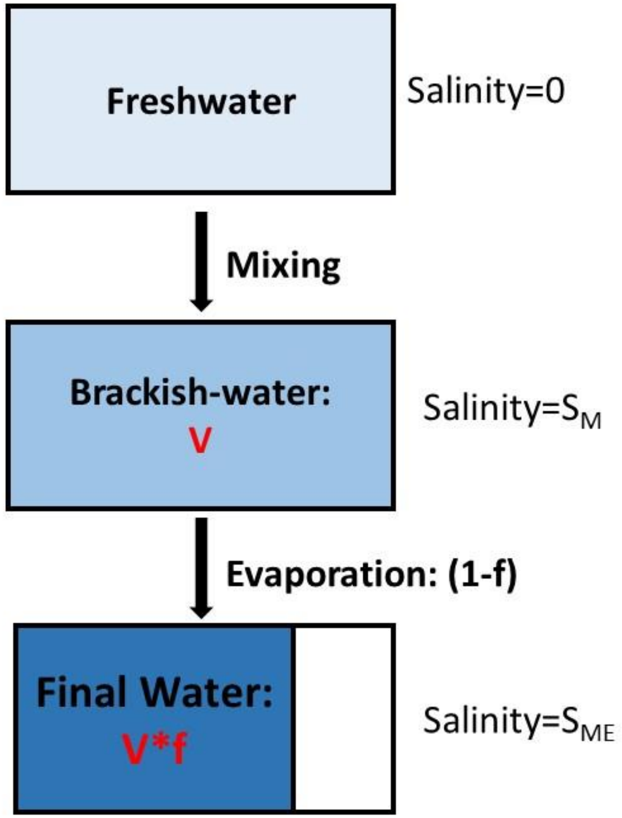
$$V * S_M = V * f * S_{ME}$$



Salt Mass Balance:

$$V * S_M = V * f * S_{ME}$$

$$S_M = f * S_{ME}$$

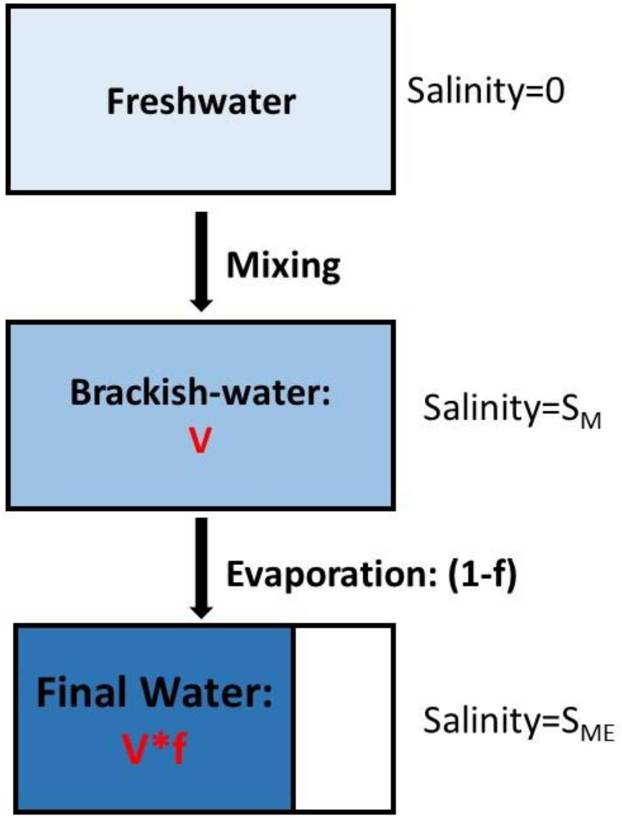


Salt Mass Balance:

$$V * S_M = V * f * S_{ME}$$

$$\Downarrow$$

$$S_M = f * S_{ME}$$



Salt Mass Balance:

$$V * S_M = V * f * S_{ME}$$

⬇

$$S_M = f * S_{ME}$$

Salinity increase from Evaporation:

$$= \frac{S_{ME} - S_M}{S_{ME}}$$

$$= \frac{S_{ME} - f \times S_{ME}}{S_{ME}}$$

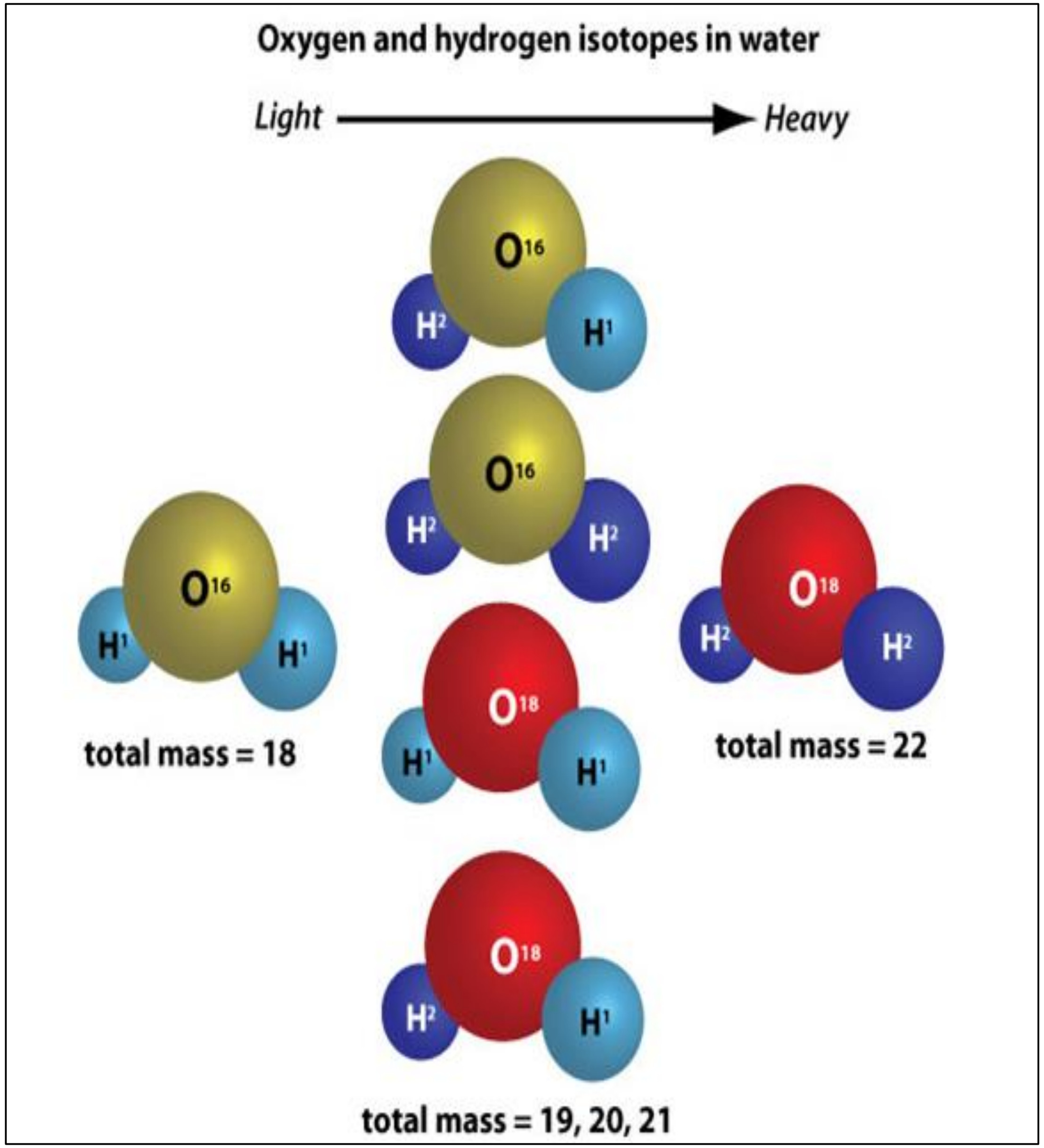
$$= 1 - f$$

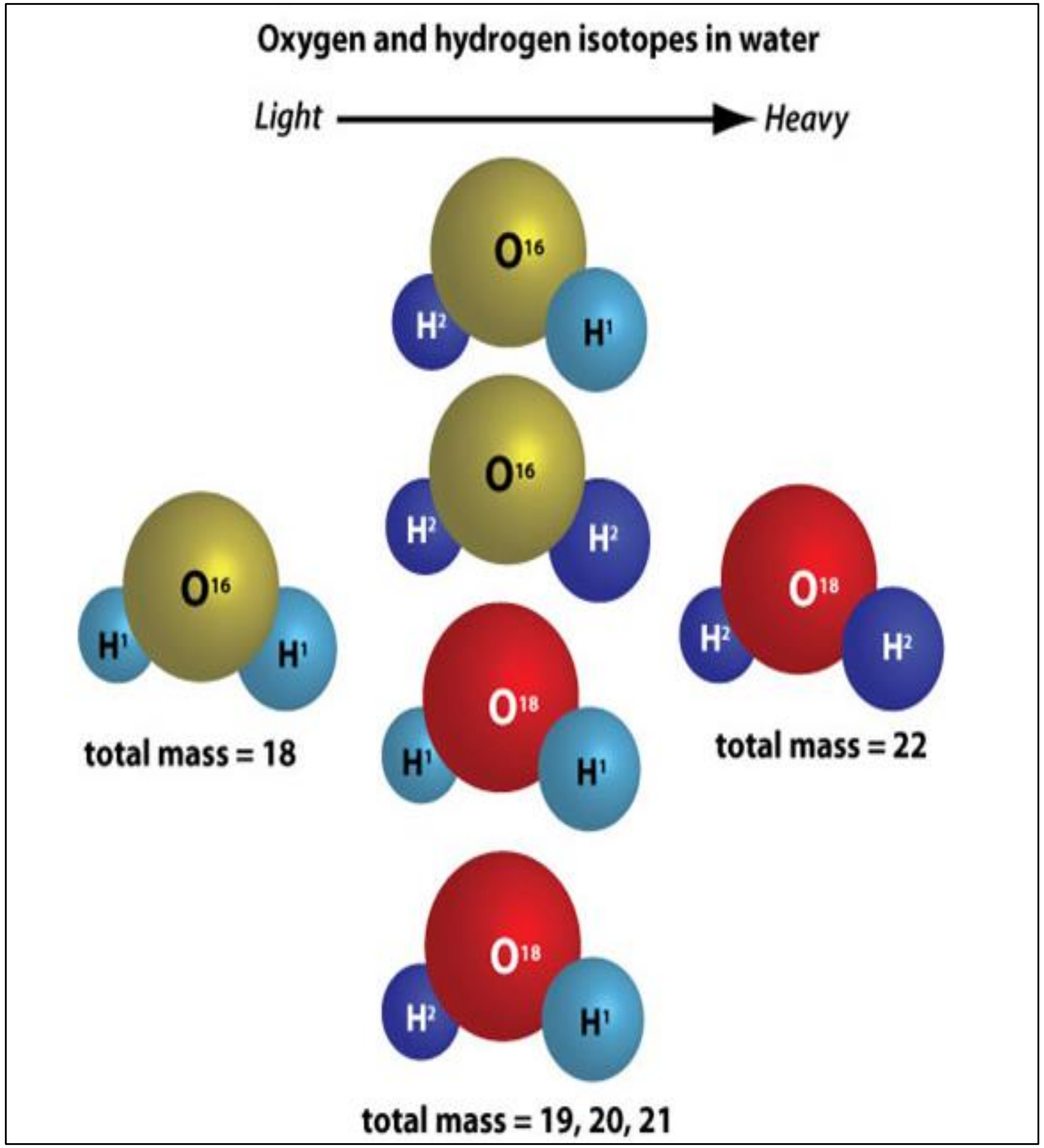
Salinity increase from Mixing:

$$= 1 - (1 - f)$$

$$= f$$

f can be quantified by a duel-isotope based method


Oxygen and hydrogen isotopes in water
Light
Heavy
O16
H1
H1
total mass = 18
O16
H2
H1
O16
H2
H2
O18
H1
H1
O18
H2
H1
total mass = 19, 20, 21
O18
H2
H2
total mass = 22



Water → Vapor

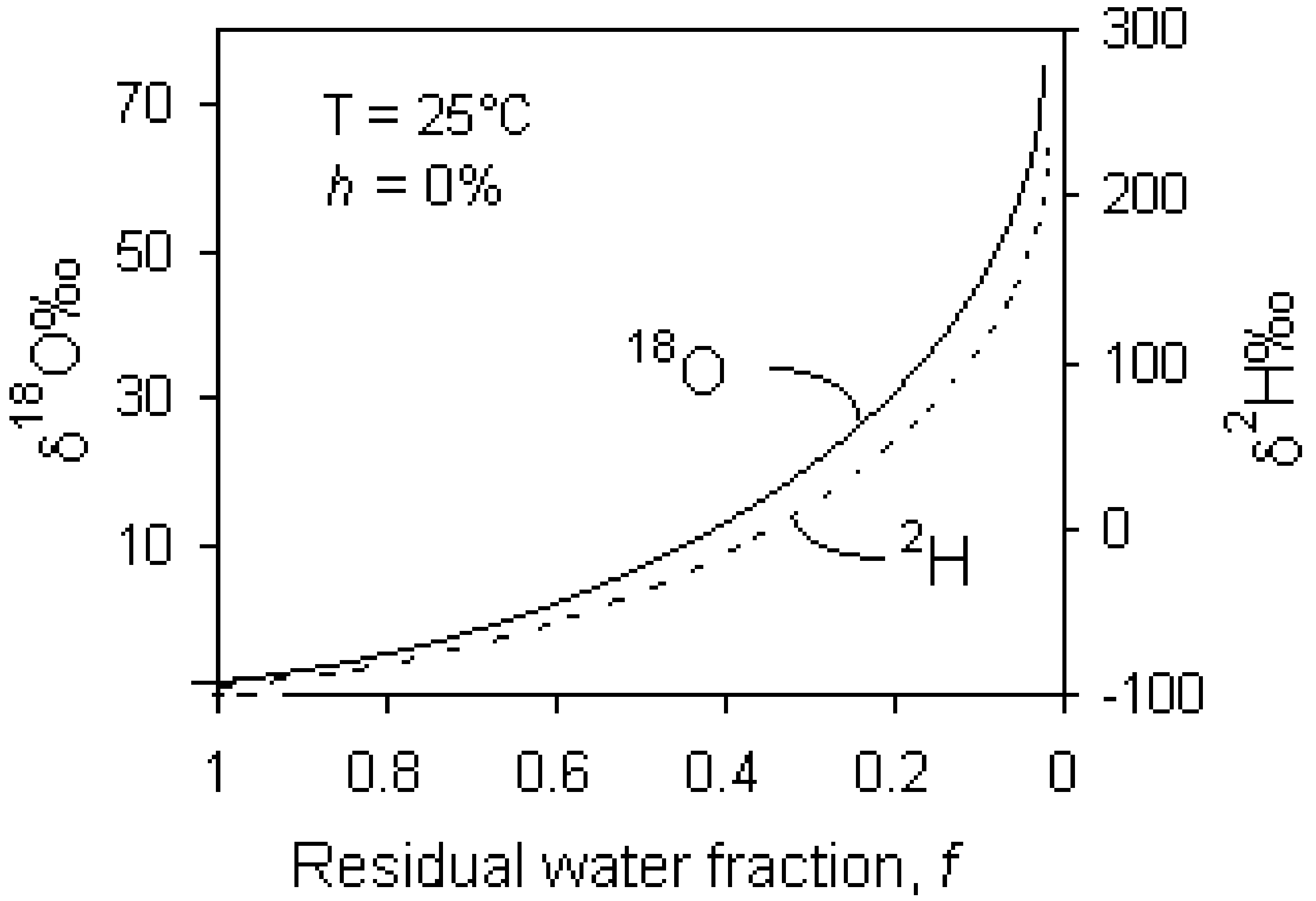
⬇

More **lighter** isotopes evaporate to vapor
More **heavier** isotopes left in the **remaining water**

⬇

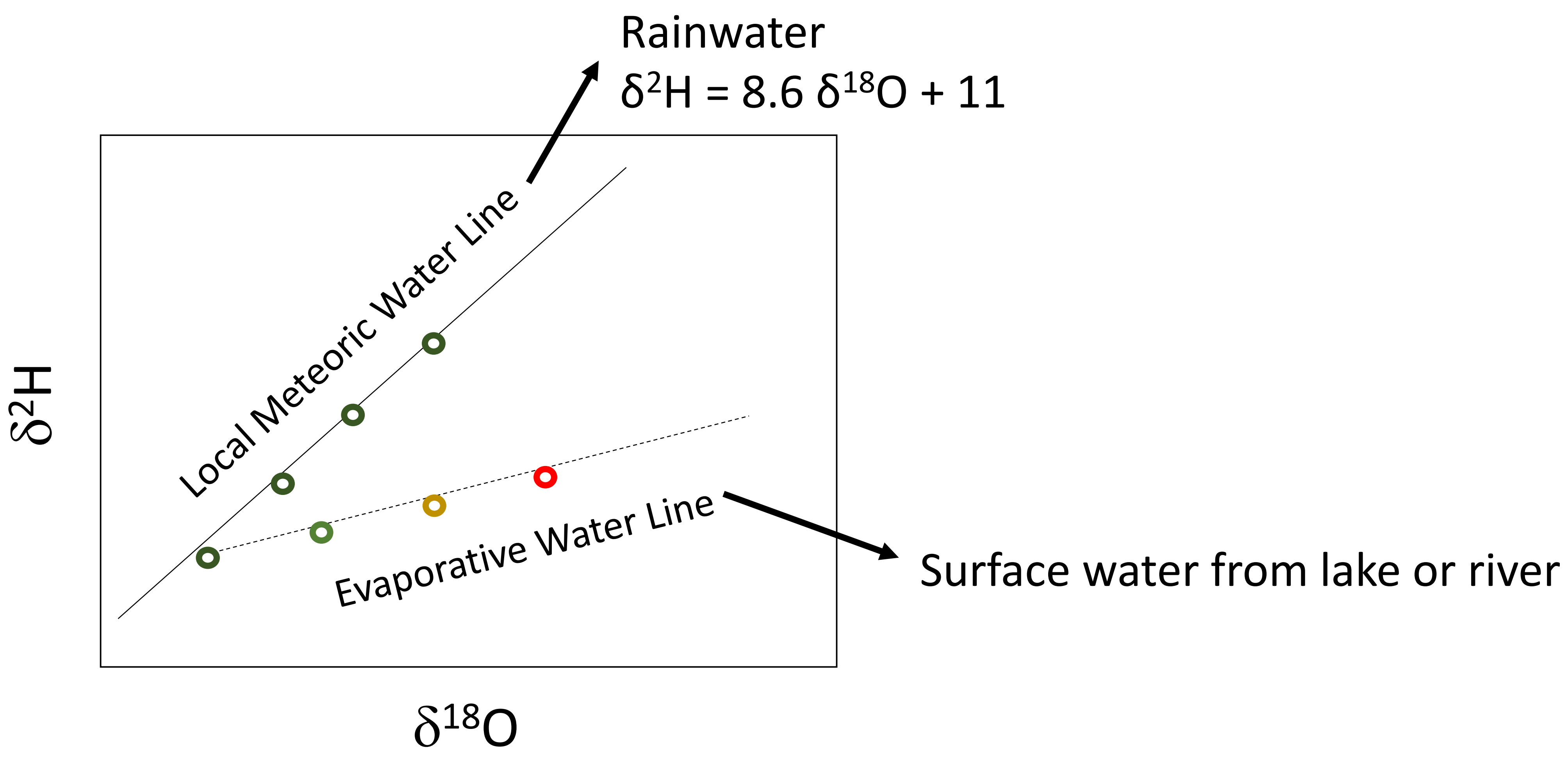
$\delta^{18}O$ or δD of **remaining water** will increase

Rayleigh Distillation: changes of δ¹⁸O and δD of remaining water during evaporation

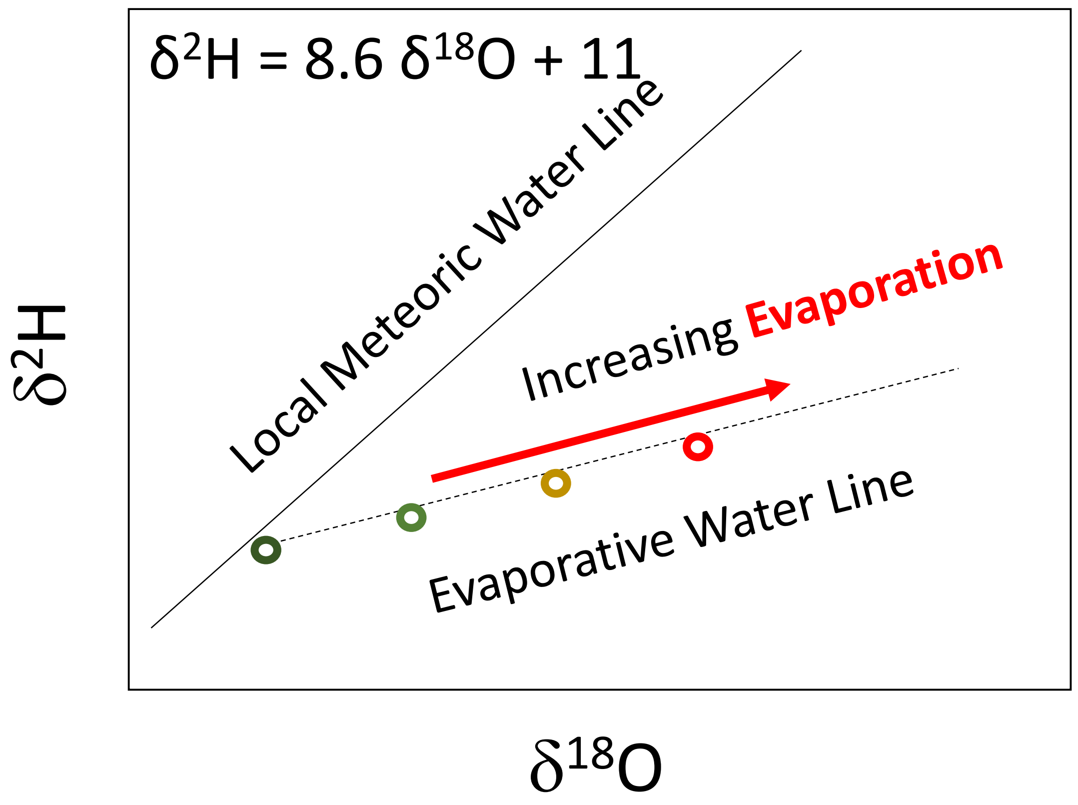


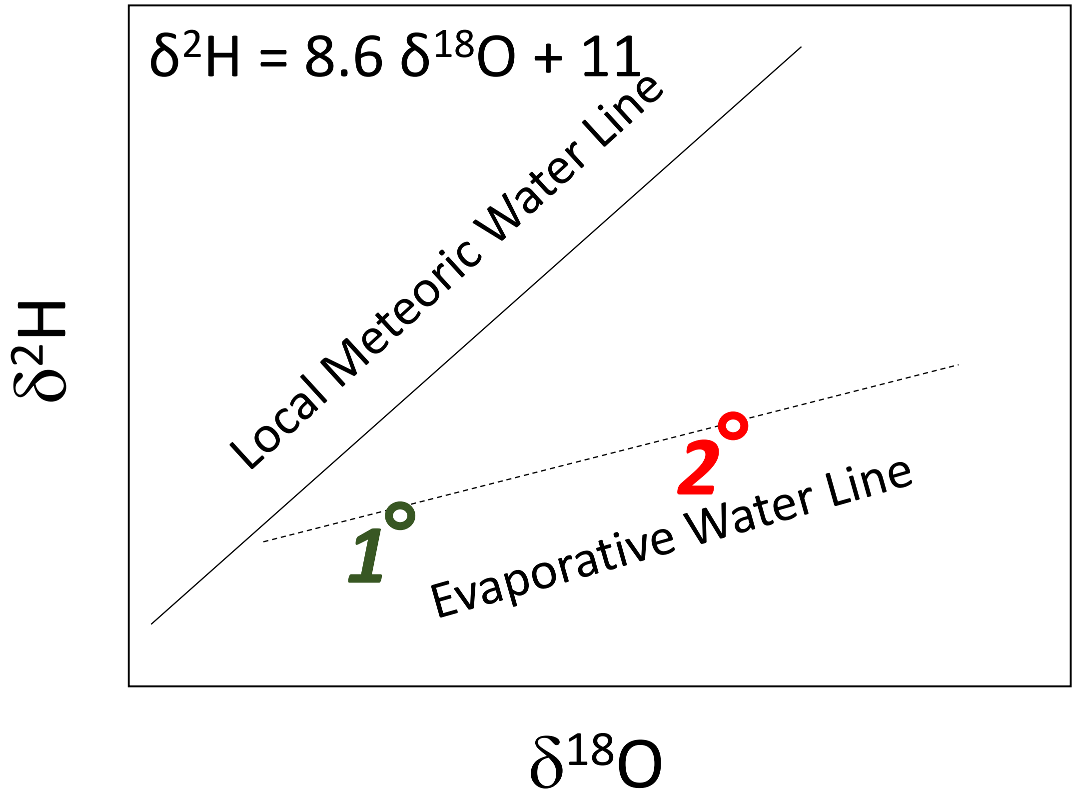
$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

ε is enrichment factor



Rainwater
$\delta^2H = 8.6\ \delta^{18}O + 11$
Local Meteoric Water Line
Evaporative Water Line
Surface water from lake or river
δ^2H
$\delta^{18}O$

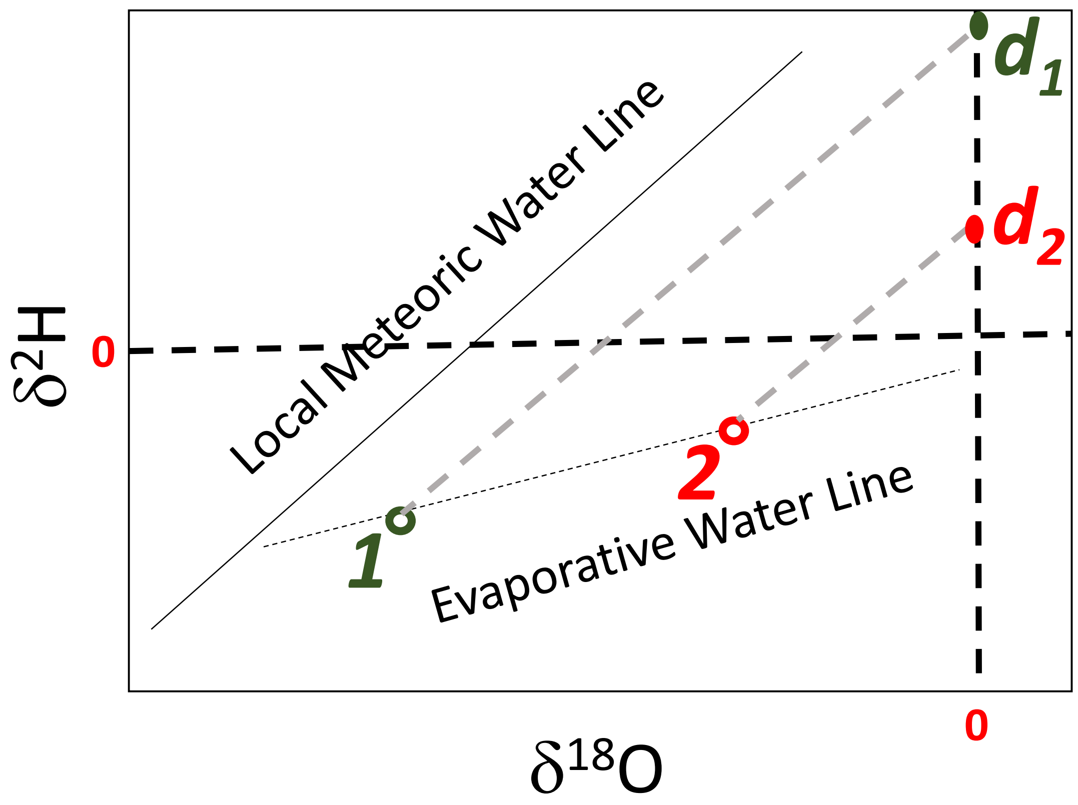

δ2H = 8.6 δ18O + 11
Local Meteoric Water Line
Increasing Evaporation
Evaporative Water Line
δ2H
δ18O



deuterium excess (d) = $\delta D - 8.6\ \delta^{18}O$

In south Florida, the average d of rainwater is 11.

***d* of surface water will decrease with evaporation.**



deuterium excess (d) = $\delta D - 8.6\,\delta^{18}O$

In south Florida, the average d of rainwater is 11.

***d* of surface water will decrease with evaporation.**

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 δ^{18}O

d$_{rain}$=11

d$_{sample}$ will decrease with **evaporation**.

deuterium excess (*d*$_i$) = δD_i - 8.6 $\delta^{18}O_i$

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 $\delta^{18}O$

d$_{rain}$=11

***d**$_{sample}$* will decrease with **evaporation**.

deuterium excess (*d*$_i$) = δD_i - 8.6 $\delta^{18}O_i$

$$= (\delta_0 D + \varepsilon_D \cdot \ln f) - 8.6(\delta_0 O + \varepsilon_O \cdot \ln f)$$

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 $\delta^{18}O$
d_{rain}=11
d_{sample} will decrease with **evaporation**.

deuterium excess (d_i) = δD_i - 8.6 $\delta^{18}O_i$
$$= (\delta_0 D + \varepsilon_D \cdot \ln f) - 8.6(\delta_0 O + \varepsilon_O \cdot \ln f)$$

$$f_i = e^{[(d_i - \underline{\delta_0 D + 8.6\delta_0^{18} O})/(8.6\varepsilon_O - \varepsilon_D)]}$$

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 $\delta^{18}O$
d_{rain}=11
d_{sample} will decrease with **evaporation**.

deuterium excess (d_i) = δD_i - 8.6 $\delta^{18}O_i$

$$=(\delta_0 D + \varepsilon_D \cdot \ln f) - 8.6(\delta_0 O + \varepsilon_O \cdot \ln f)$$

$$f_i = e^{[(d_i - \delta_0 D + 8.6\delta_0^{18} O)/(8.6\varepsilon_O - \varepsilon_D)]}$$
$$= e^{[(d_i - d_{rain})/(8.6\varepsilon_O - \varepsilon_D)]}$$

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 δ^{18}O
d$_{rain}$=11
d$_{sample}$ will decrease with **evaporation**.

deuterium excess (*d*$_i$) = δD_i - 8.6 $\delta^{18}O_i$

$$=(\delta_0 D + \varepsilon_D \cdot \ln f) - 8.6(\delta_0 O + \varepsilon_O \cdot \ln f)$$

⬇

$$f_i = e^{[(d_i - \delta_0 D + 8.6\delta_0^{18}O)/(8.6\varepsilon_O - \varepsilon_D)]}$$
$$= e^{[(d_i - d_{rain})/(8.6\varepsilon_O - \varepsilon_D)]}$$
$$= e^{[(d_i - 11)/(8.6\varepsilon_O - \varepsilon_D)]}$$

$$\delta_f O = \delta_0 O + \varepsilon_O \cdot \ln f$$
$$\delta_f D = \delta_0 D + \varepsilon_D \cdot \ln f$$

deuterium excess (*d*) = δD - 8.6 $\delta^{18}O$
d$_{rain}$=11
***d**$_{sample}$* will decrease with **evaporation**.

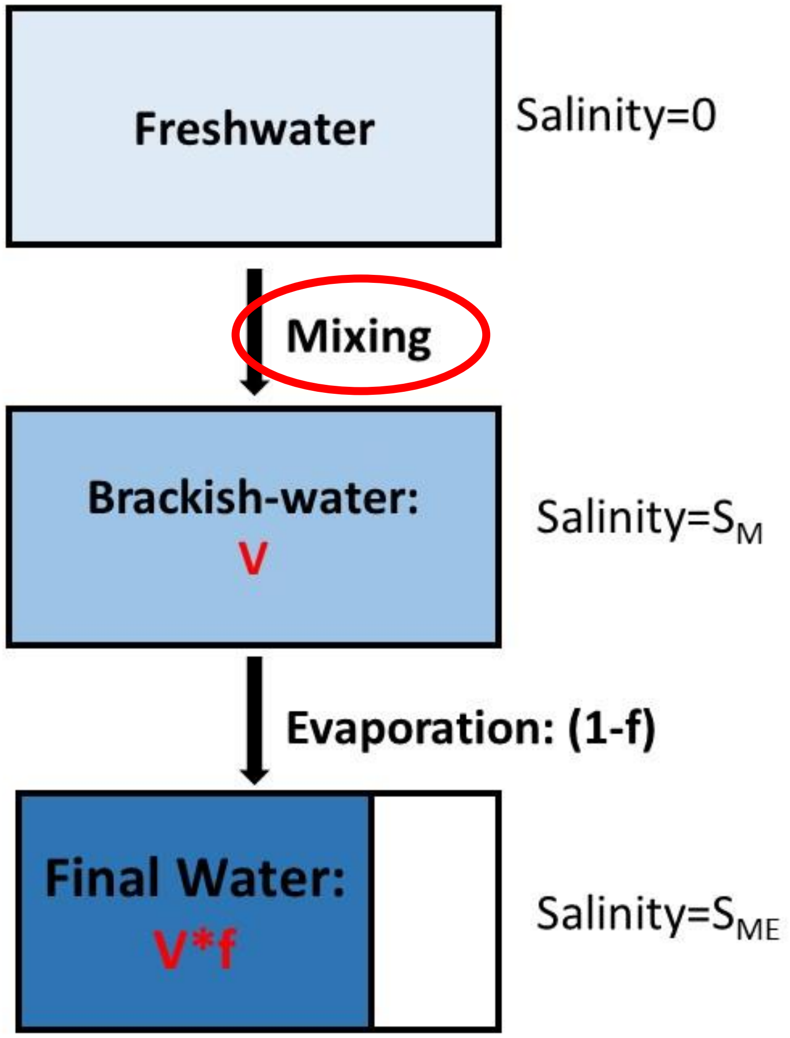
deuterium excess (*d$_i$*) = $\delta D_i - 8.6\, \delta^{18}O_i$

$$= (\delta_0 D + \Delta D \cdot \ln f) - 8.6(\delta_0 O + \Delta O \cdot \ln f)$$

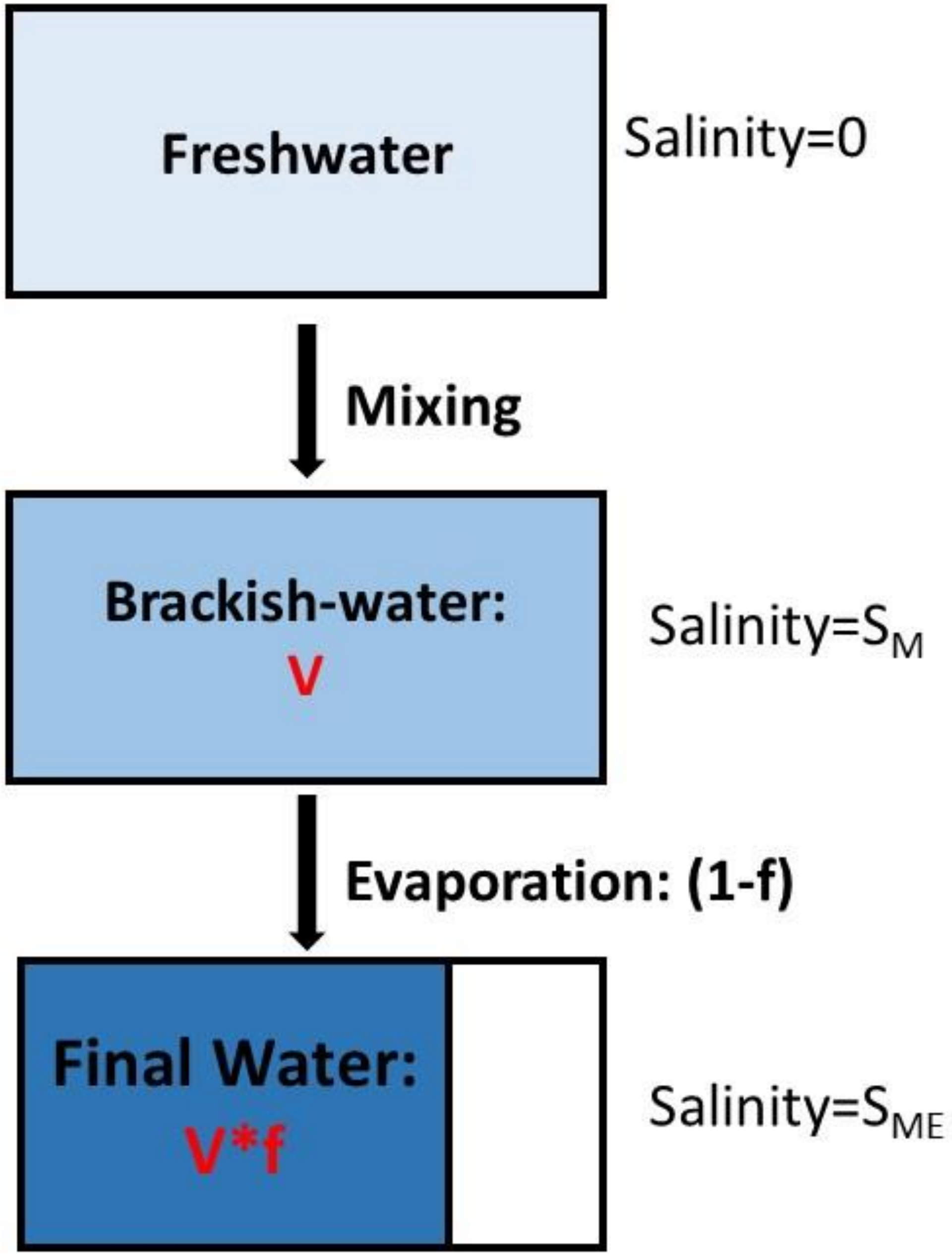
⬇

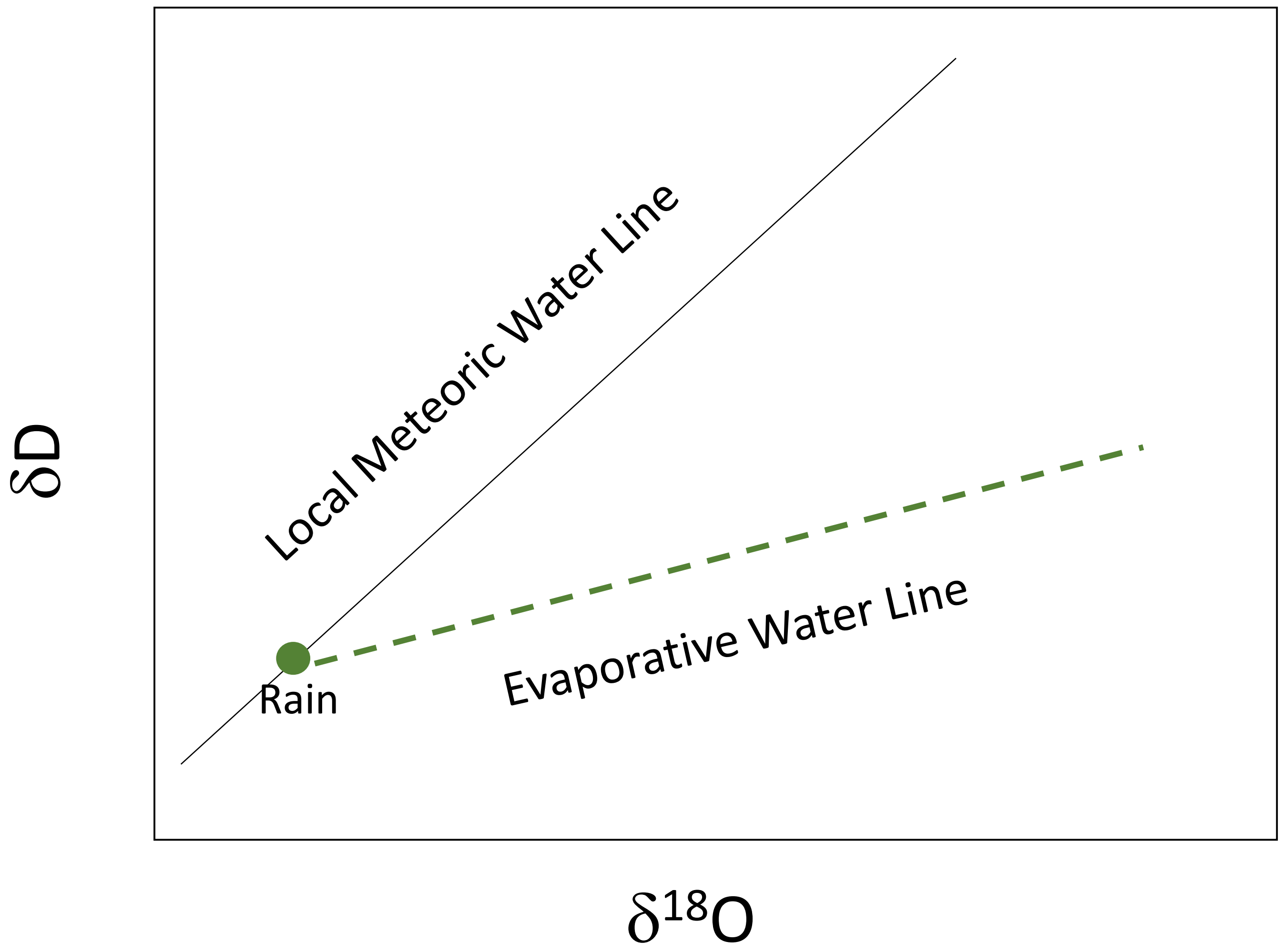
$$f_i = e^{[(d_i - \delta_0 D + 8.6\delta_0^{18}O)/(8.6\varepsilon_O - \varepsilon_D)]}$$
$$= e^{[(d_i - d_{rain})/(8.6\varepsilon_O - \varepsilon_D)]}$$
$$= e^{[(d_i - 11)/(8.6\varepsilon_O - \varepsilon_D)]}$$

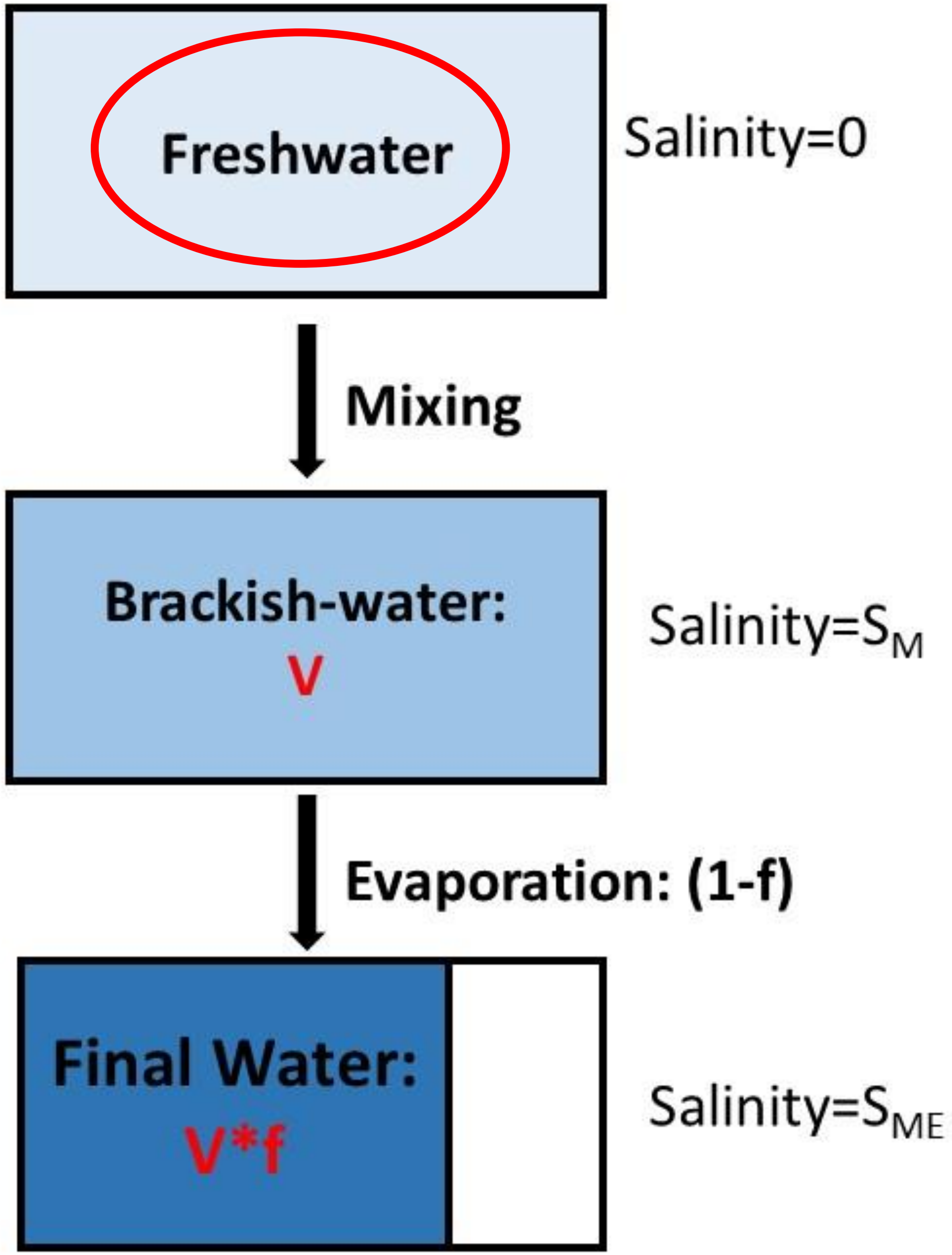
However, in addition to **evaporation**, **saltwater intrusion** also can affect δO and δD values.

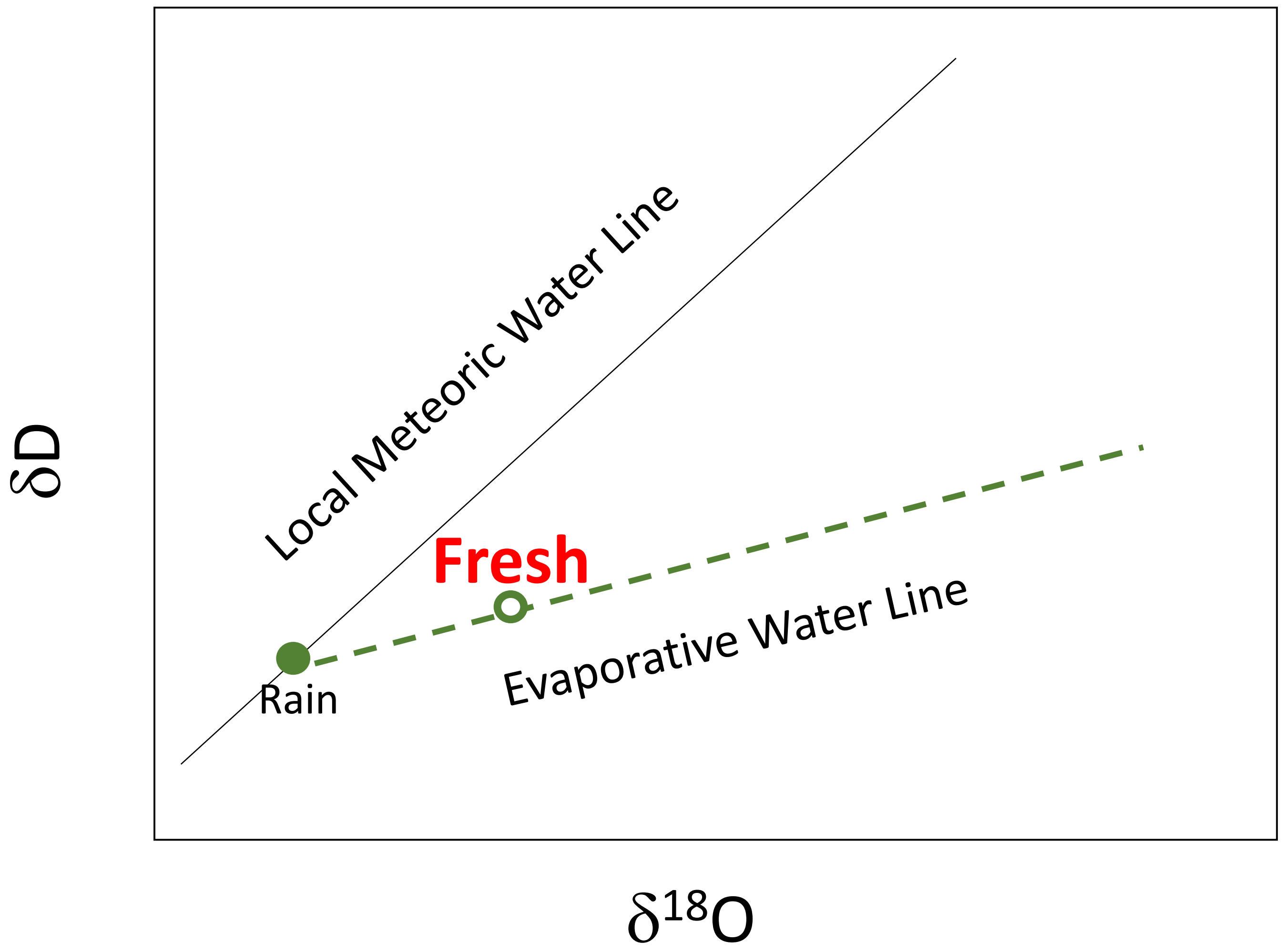


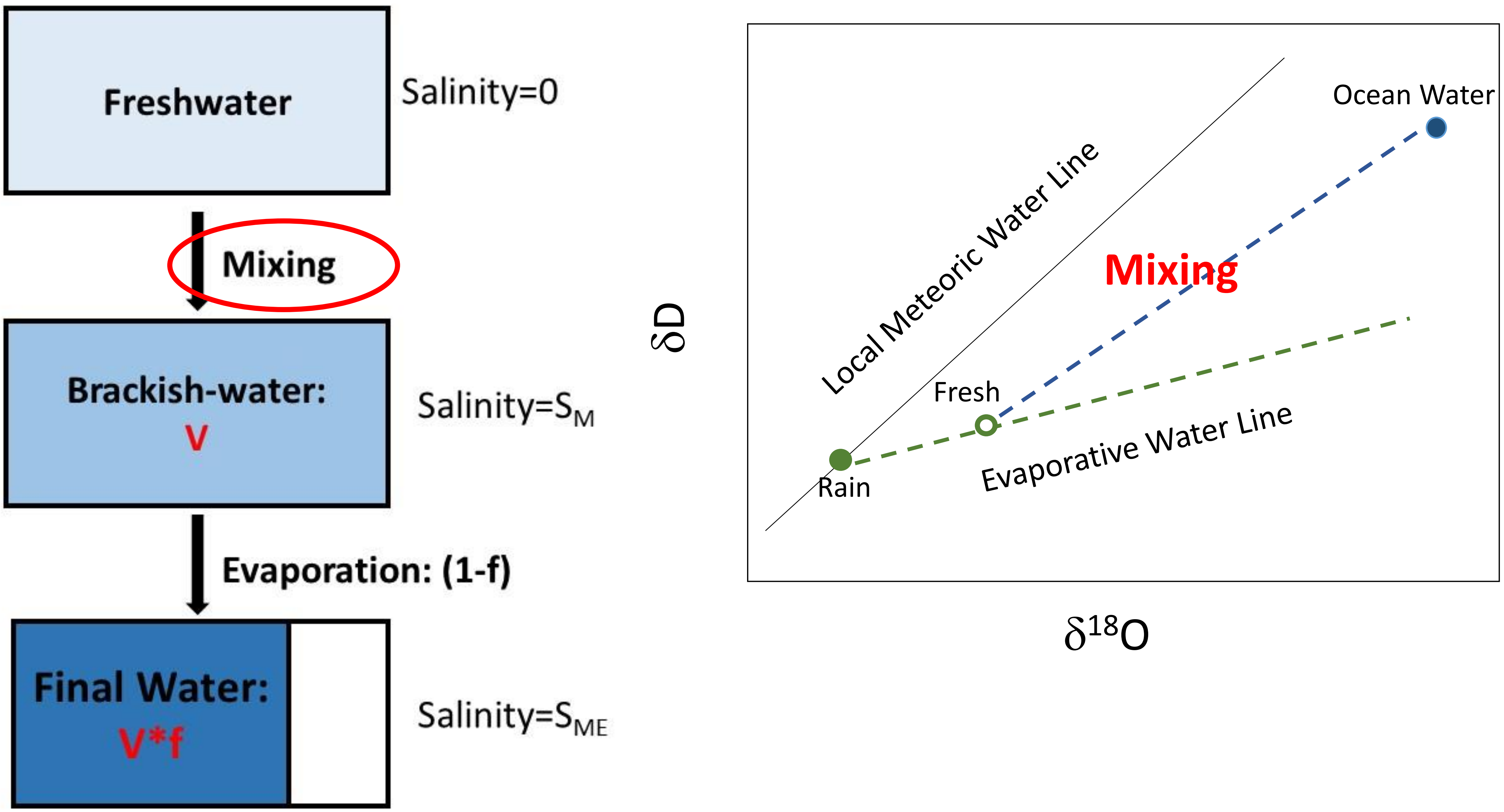
Stable isotope based model
of the mixing and evaporation processes: Visualization


Freshwater
Salinity=0
Mixing
Brackish-water:
V
Salinity=S_M
Evaporation: (1-f)
Final Water:
V*f
Salinity=S_ME

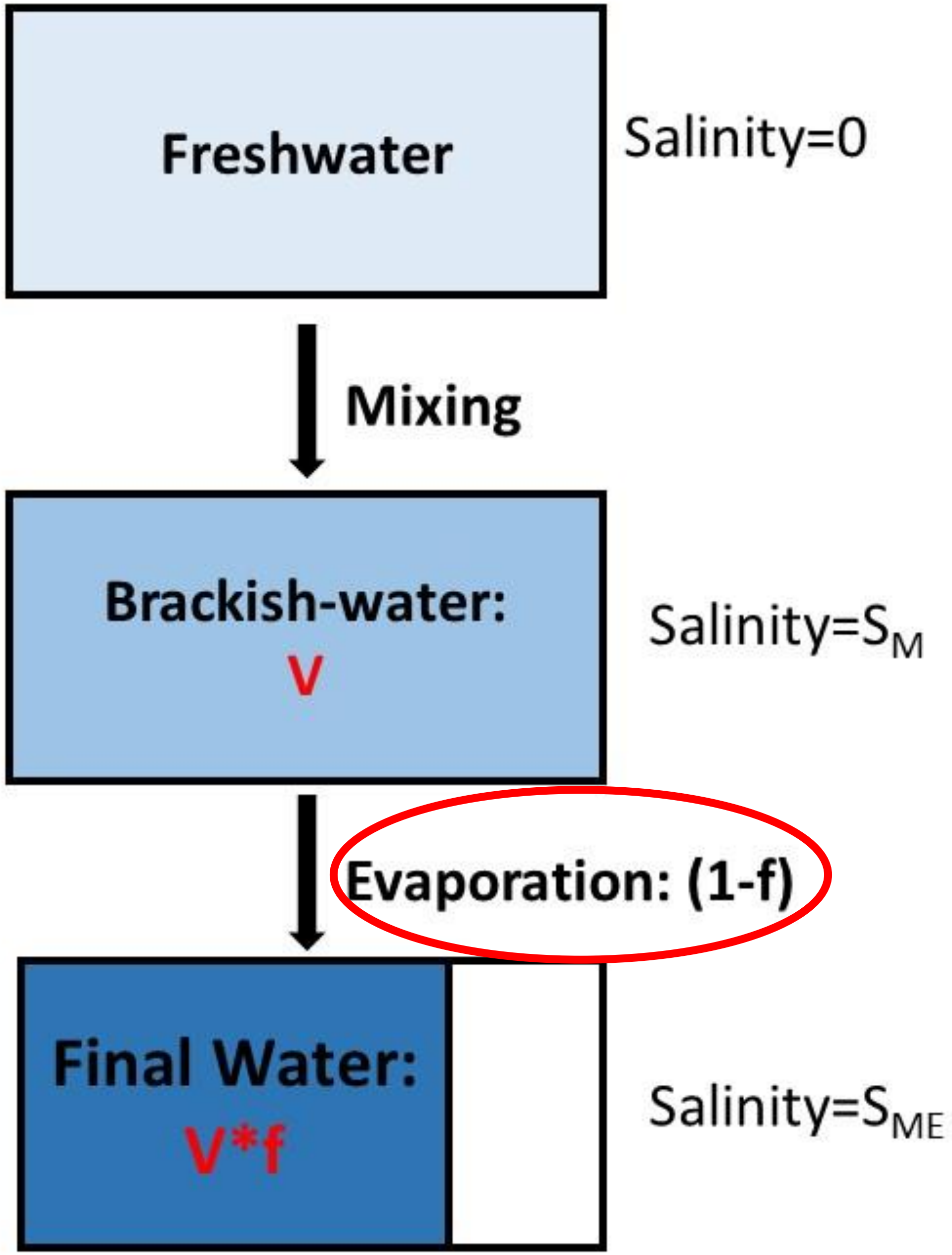

δD
Local Meteoric Water Line
Evaporative Water Line
Rain
δ18O

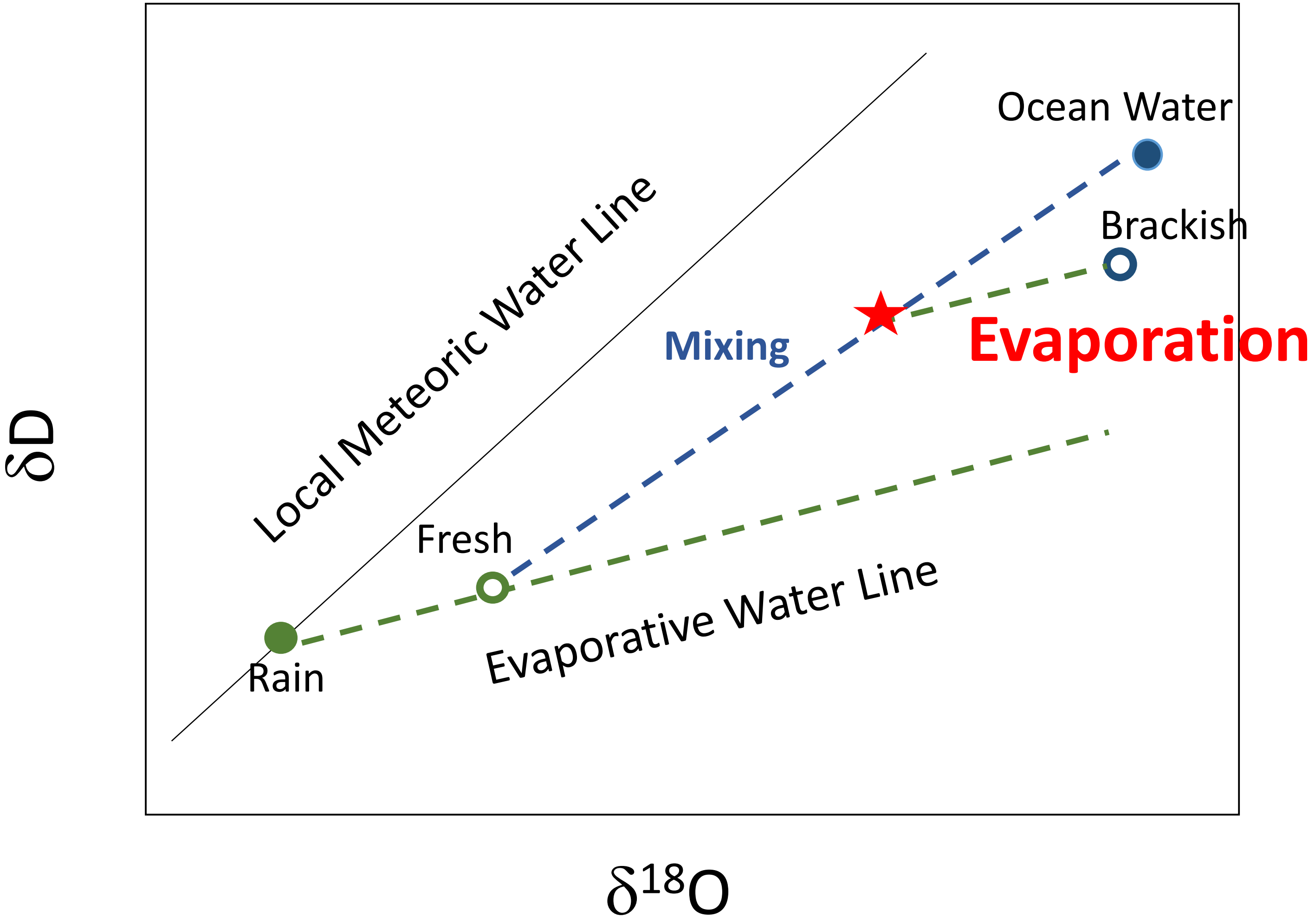

Freshwater
Salinity=0
Mixing
Brackish-water:
V
Salinity=S_M
Evaporation: (1-f)
Final Water:
V*f
Salinity=S_ME


δD
δ18O
Local Meteoric Water Line
Fresh
Evaporative Water Line
Rain

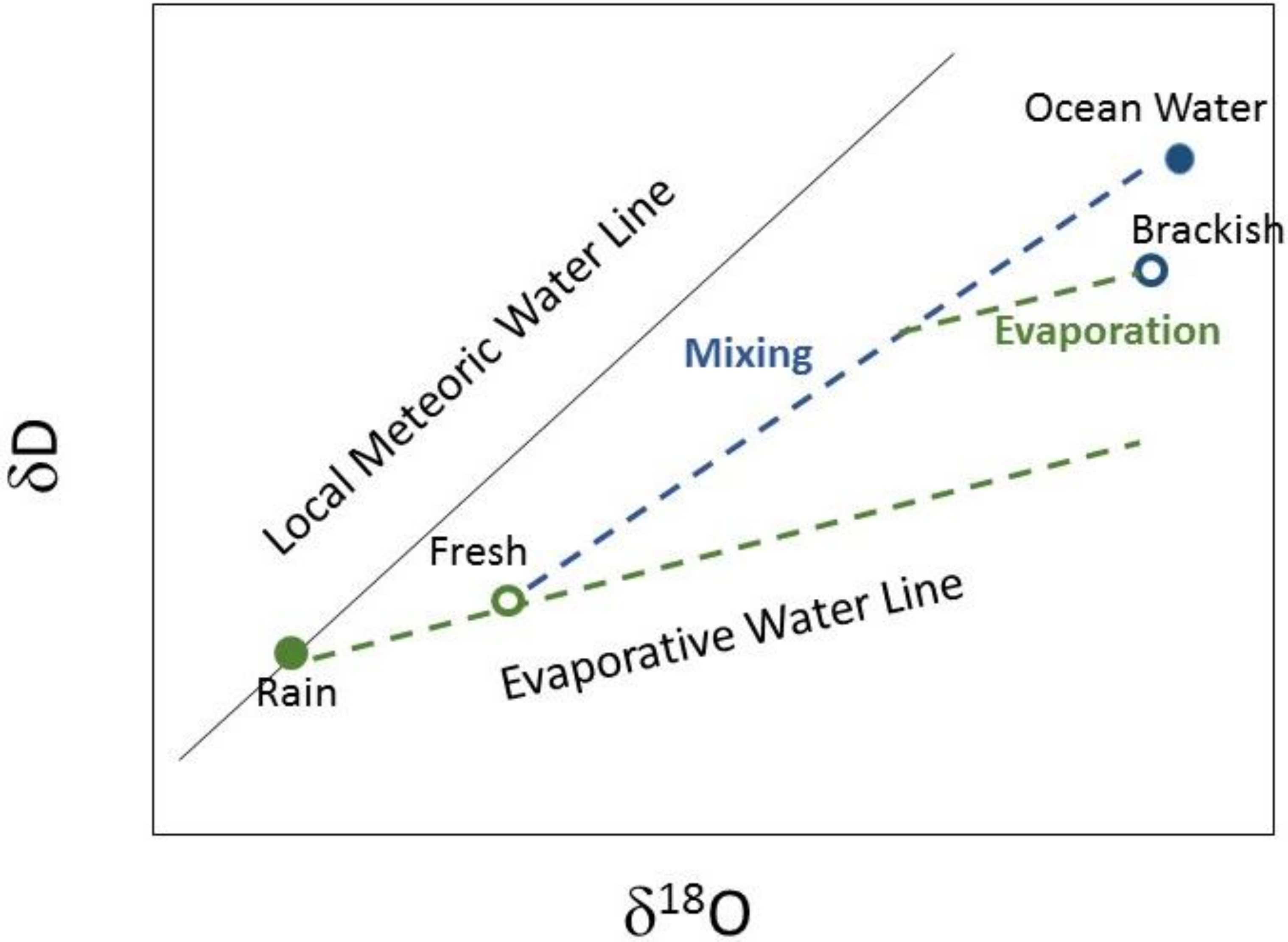


Freshwater
Salinity=0
Mixing
Brackish-water:
V
Salinity=S_M
Evaporation: (1-f)
Final Water:
V*f
Salinity=S_{ME}
Local Meteoric Water Line
Ocean Water
Mixing
δD
Fresh
Rain
Evaporative Water Line
$\delta^{18}O$

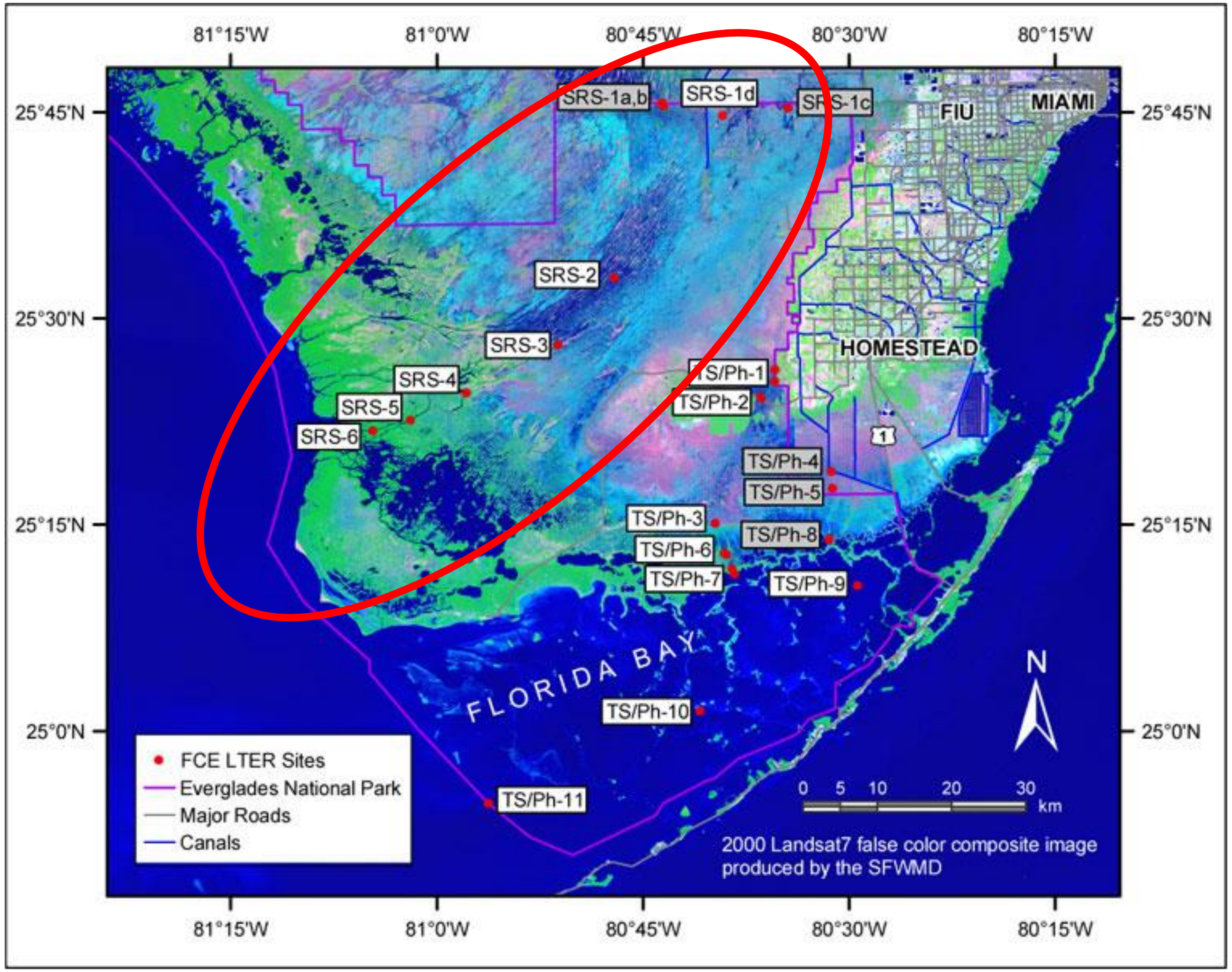

Freshwater
Salinity=0
Mixing
Brackish-water:
V
Salinity=S_M
Evaporation: (1-f)
Final Water:
V*f
Salinity=S_{ME}


Ocean Water
Brackish
Local Meteoric Water Line
Mixing
Evaporation
Fresh
Rain
Evaporative Water Line
δD
$\delta^{18}O$

This is just our model strategy, **but does nature work as we think?**



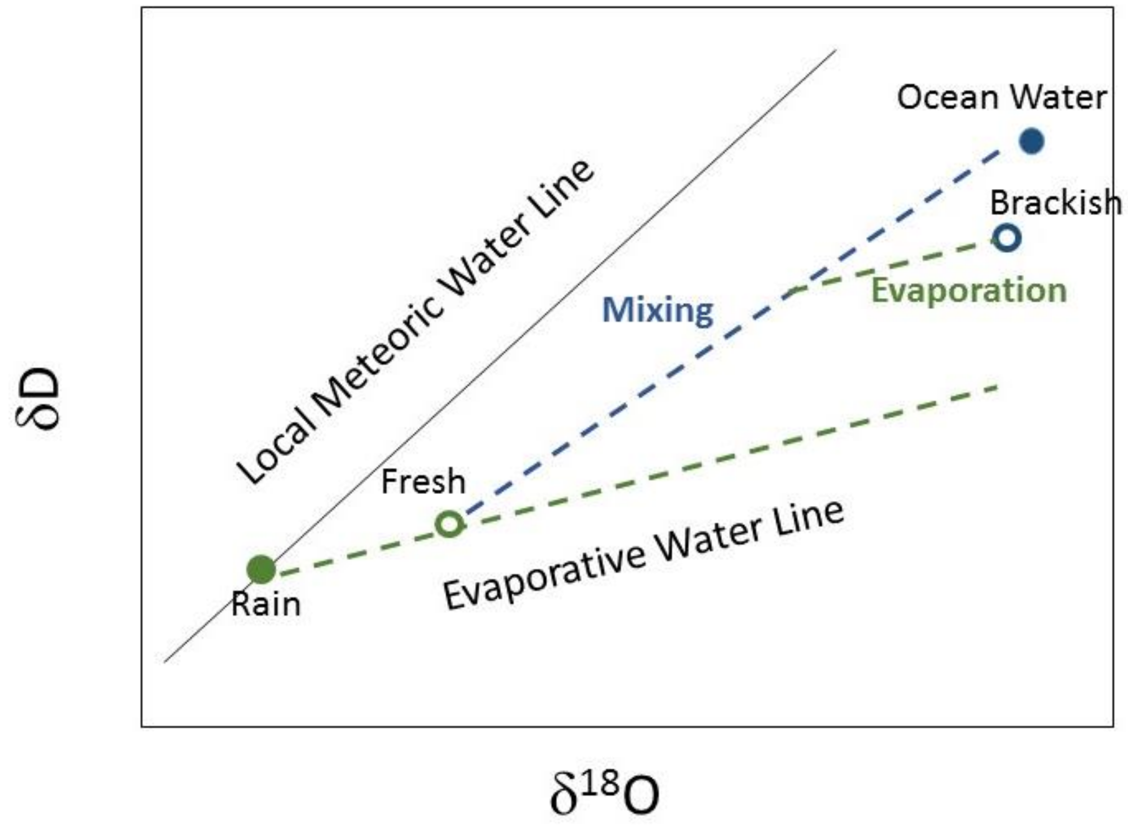
Field data in October from SRS



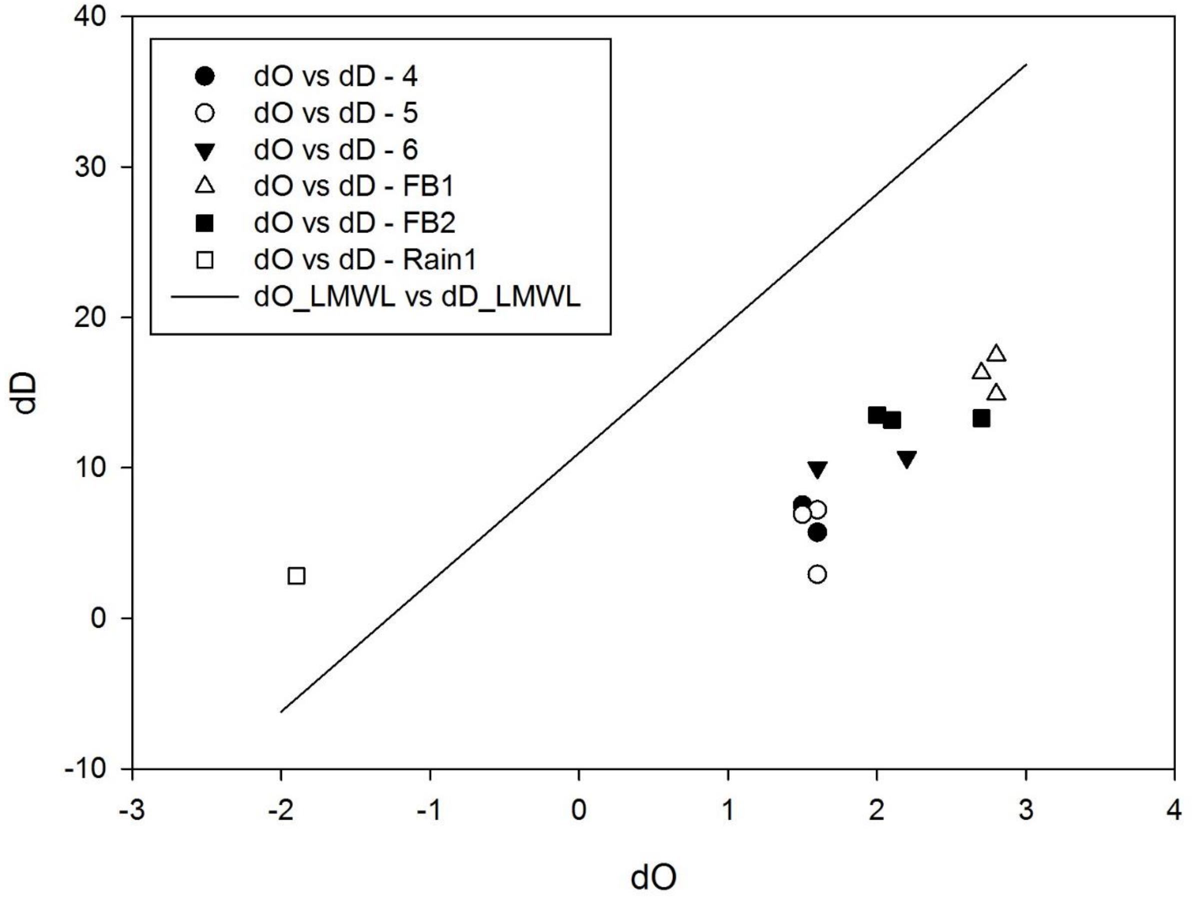
There are 6 sites along SRS, SRS 1~6.

SRS 5 and 6 are brackish water site.

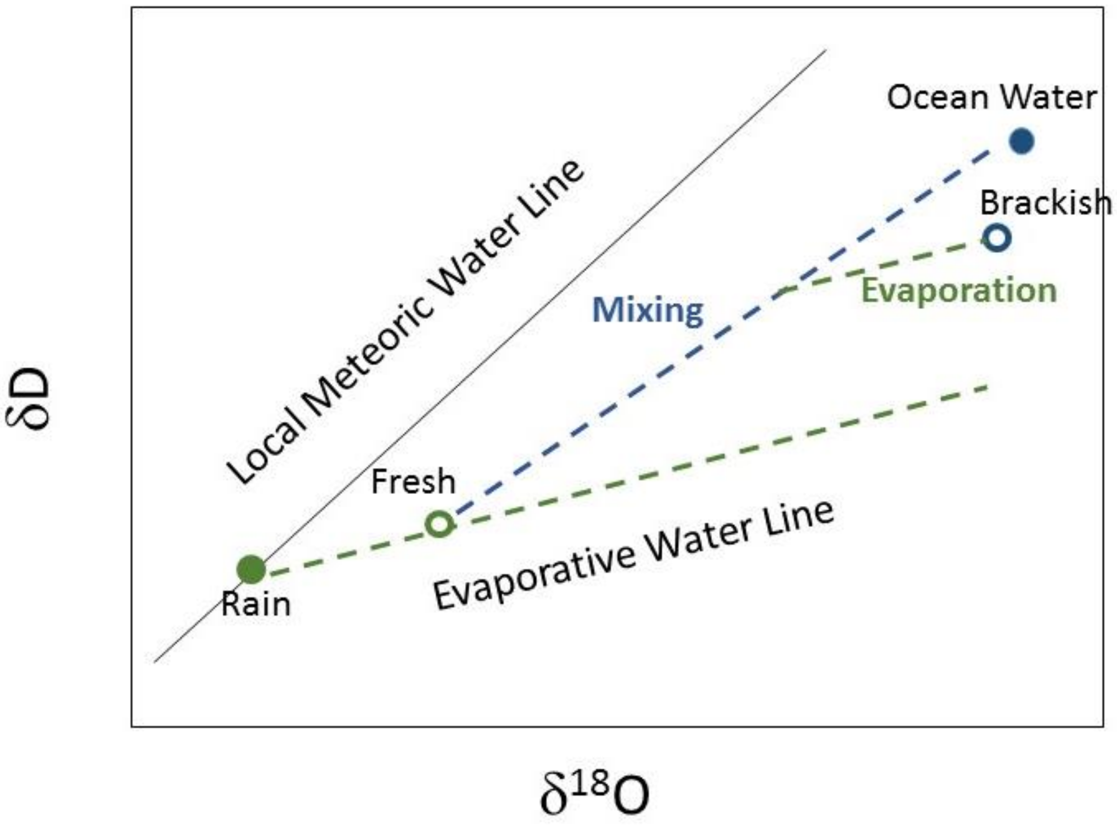
Conceptual figure



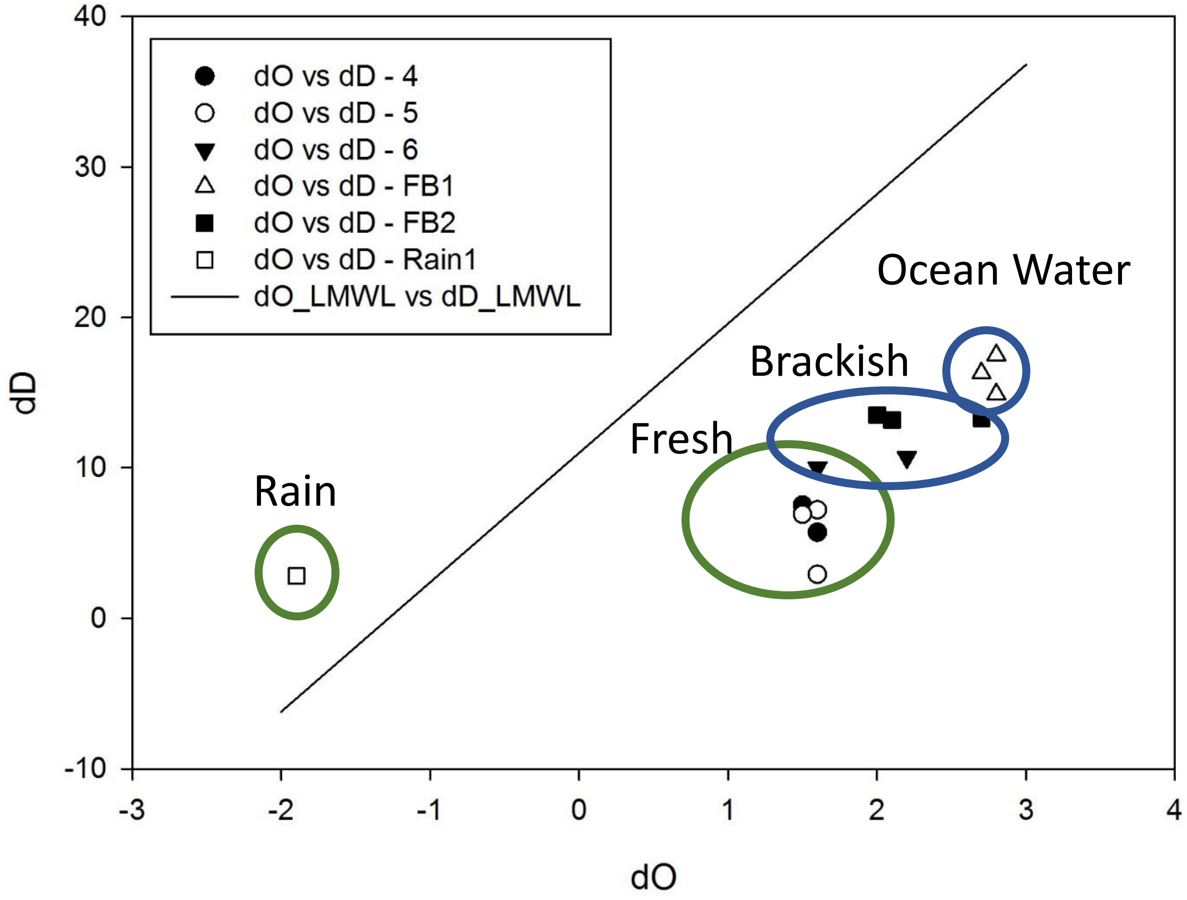
Field data figure



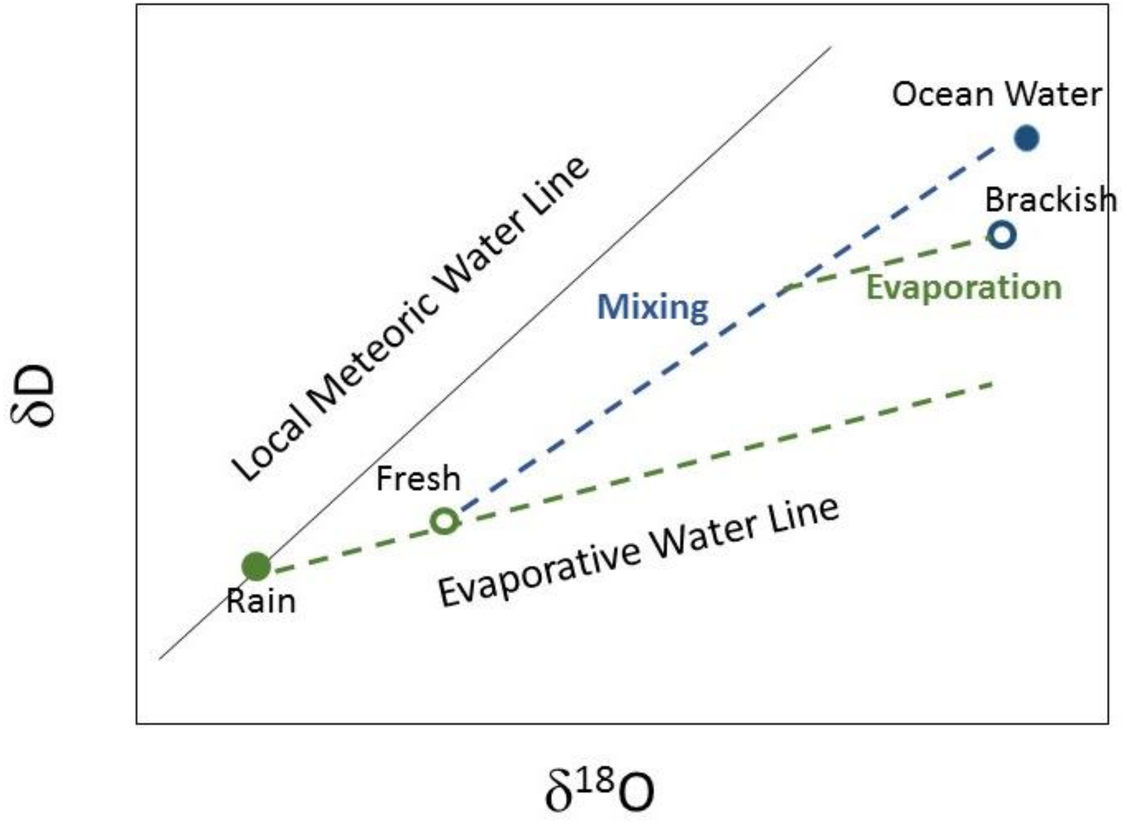
Conceptual figure



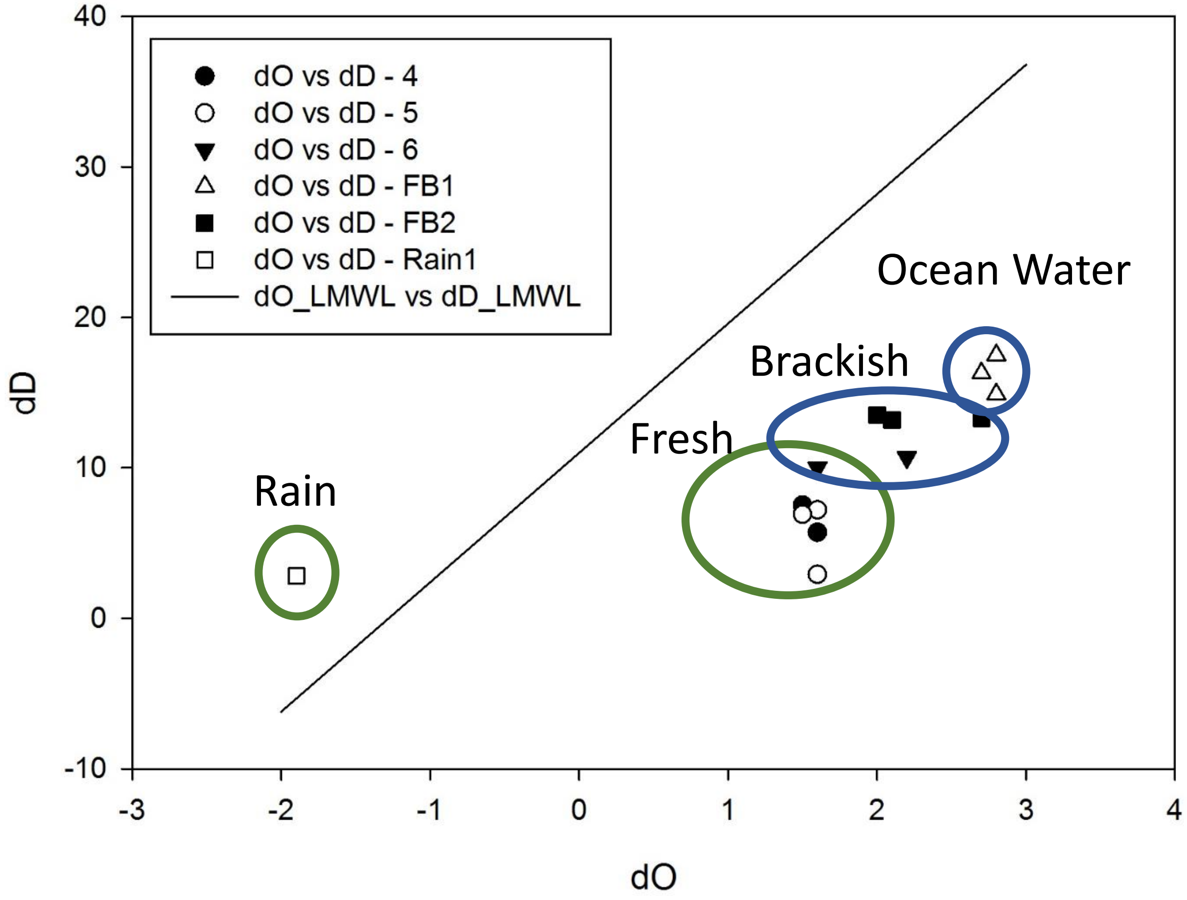
Field data figure



Conceptual figure

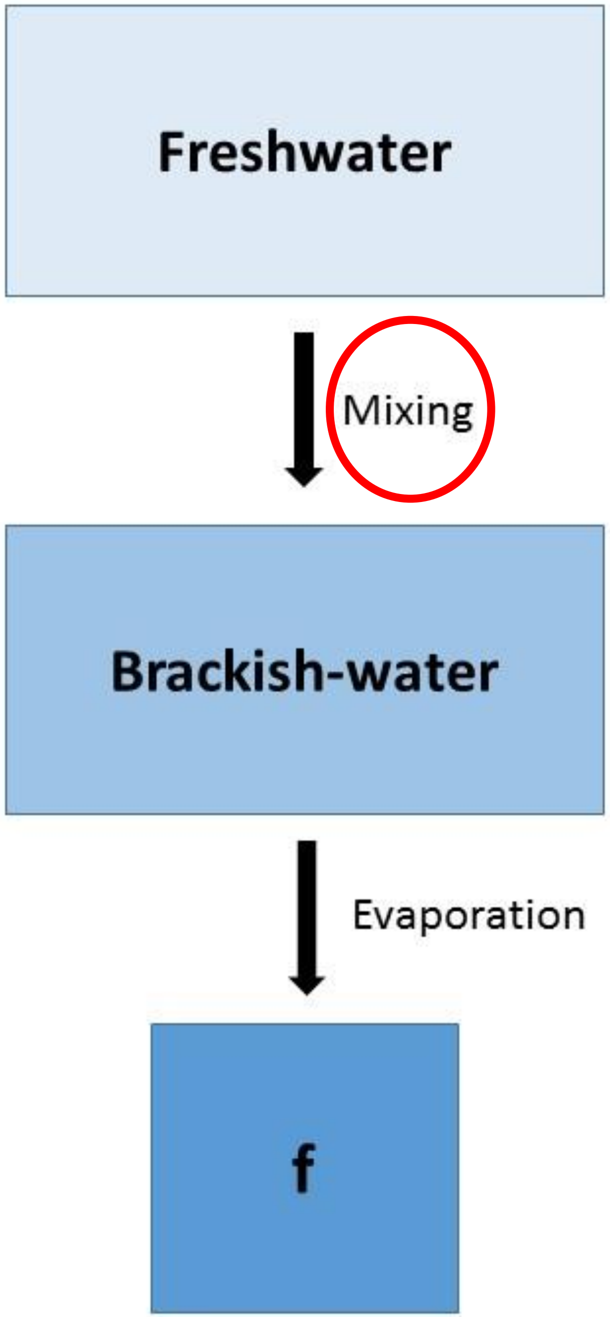


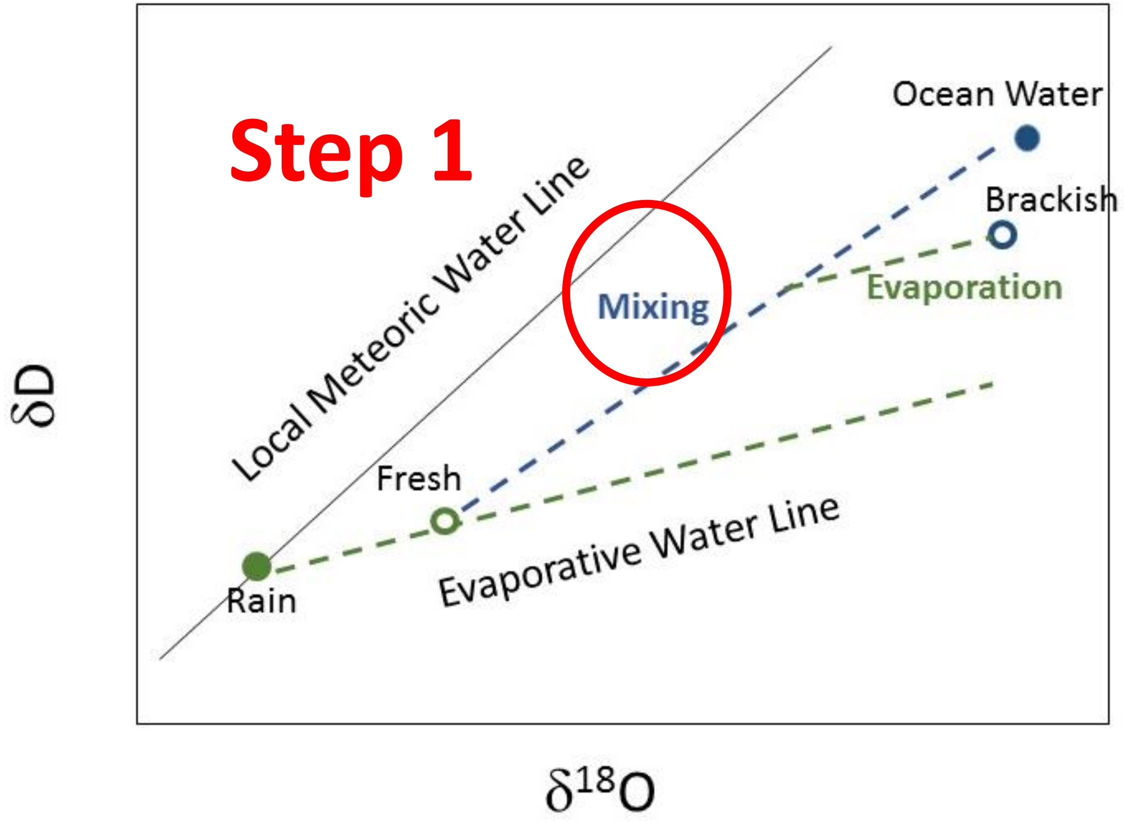
Field data figure



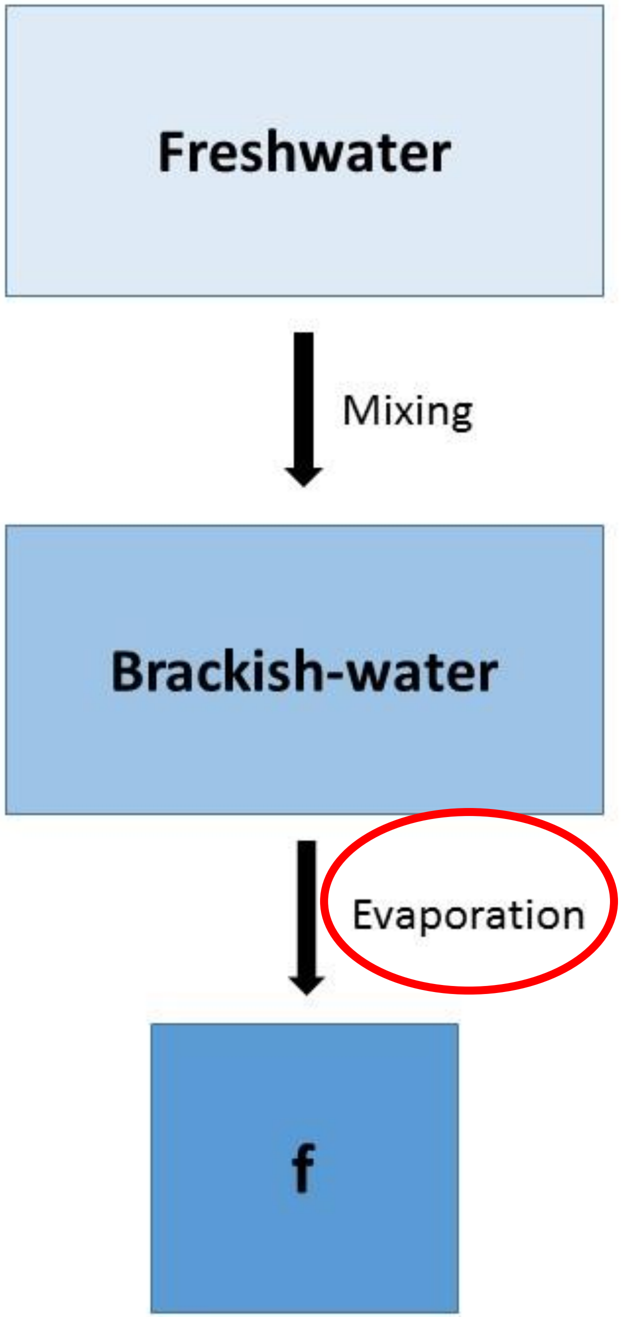
The relative locations of different water match!

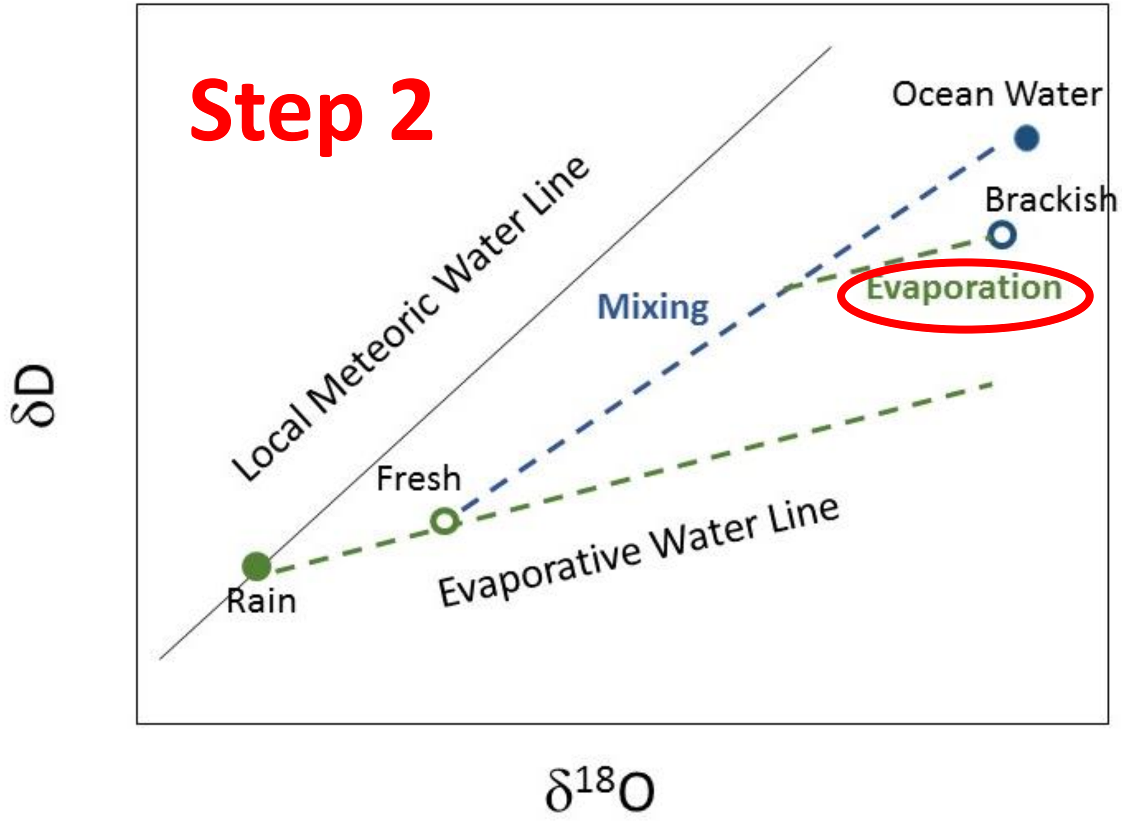
Begin to calculate the mixing and evaporation based on the isotope-based model



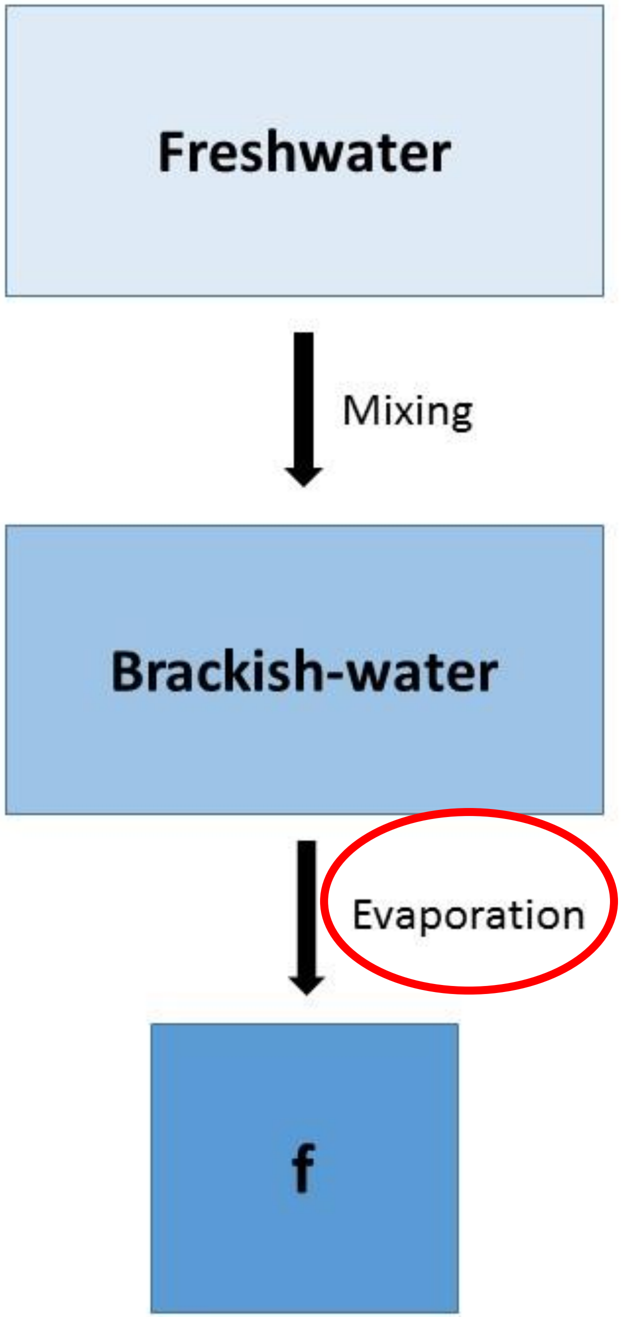


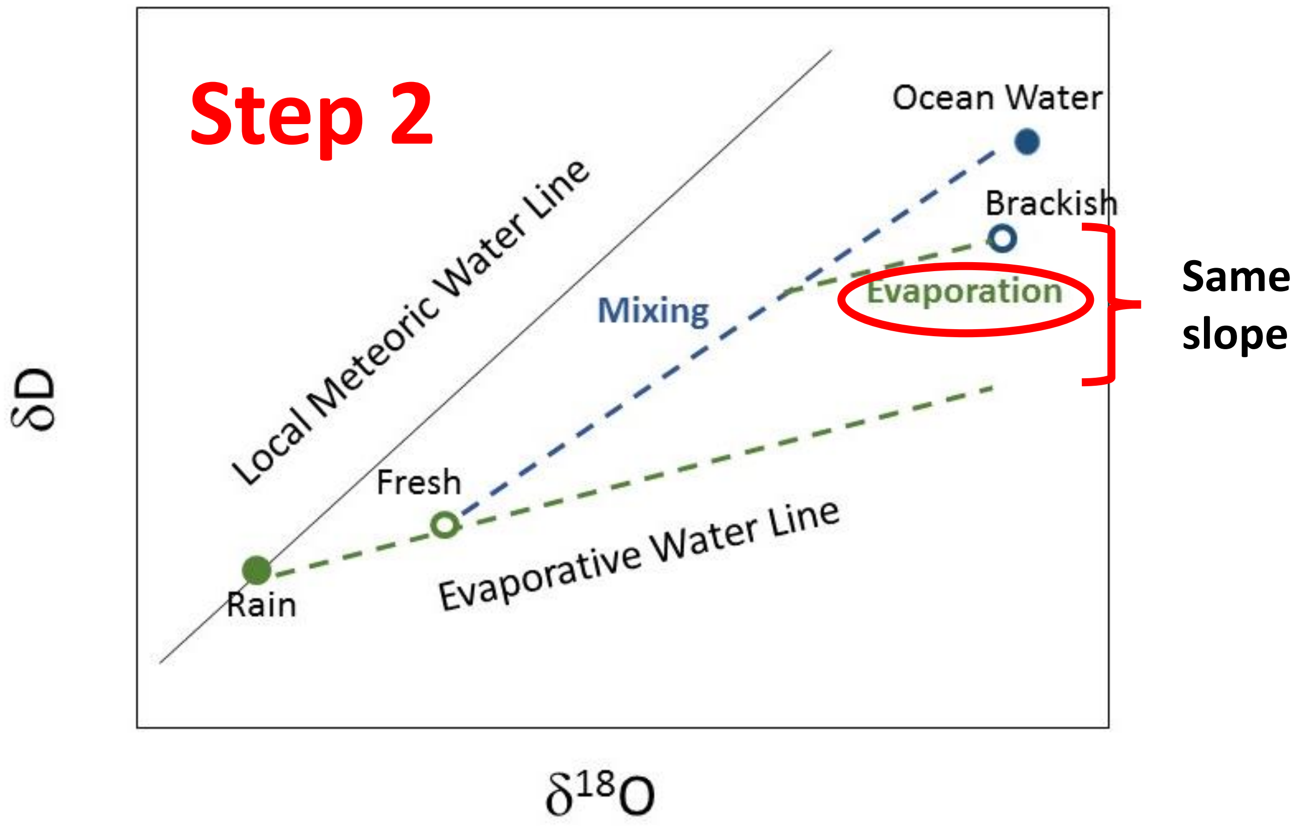
Fresh Ocean Mixing Water Line:
FOMWL (**Blue Line**)



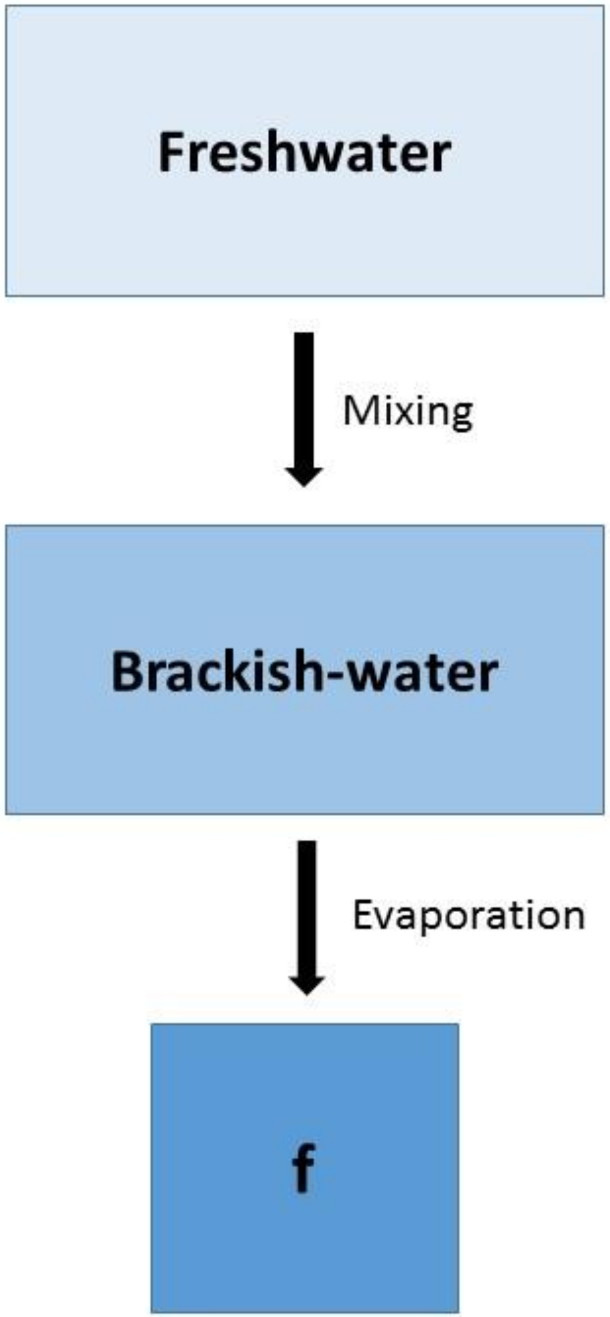


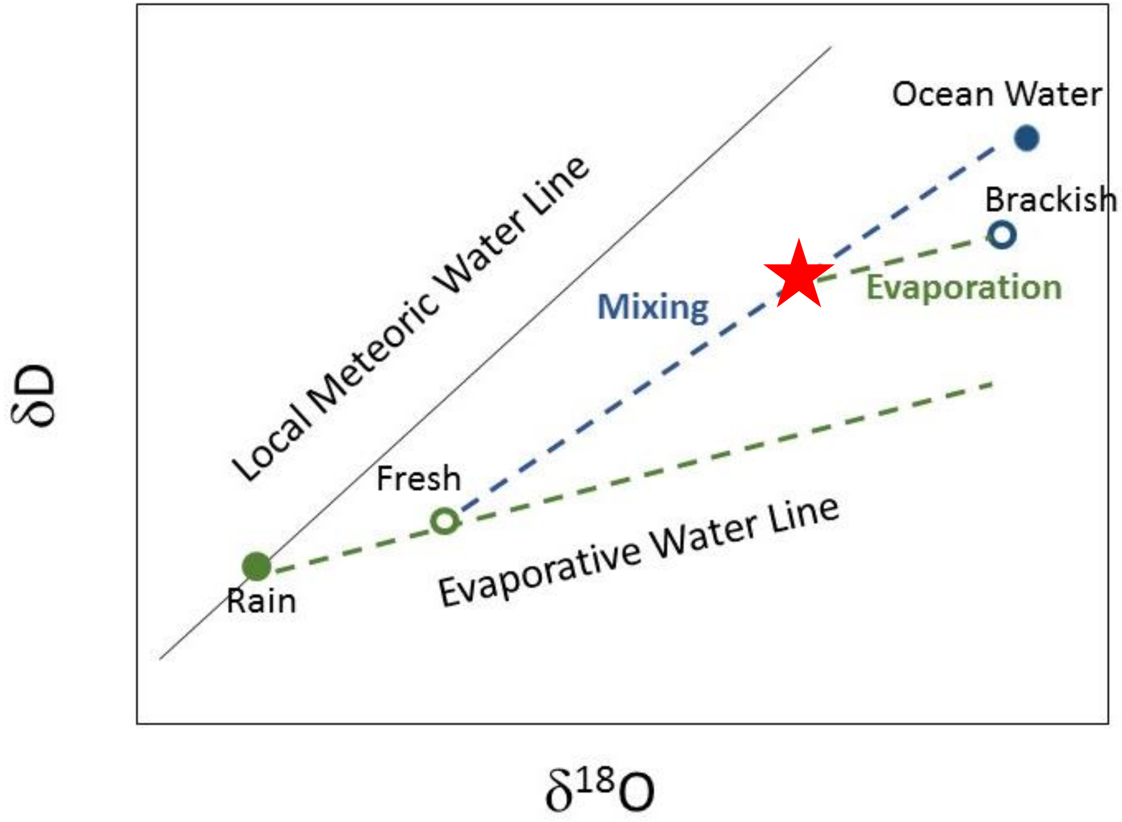
Brackish Evaporation Water Line: BEWL (**Green Line**)



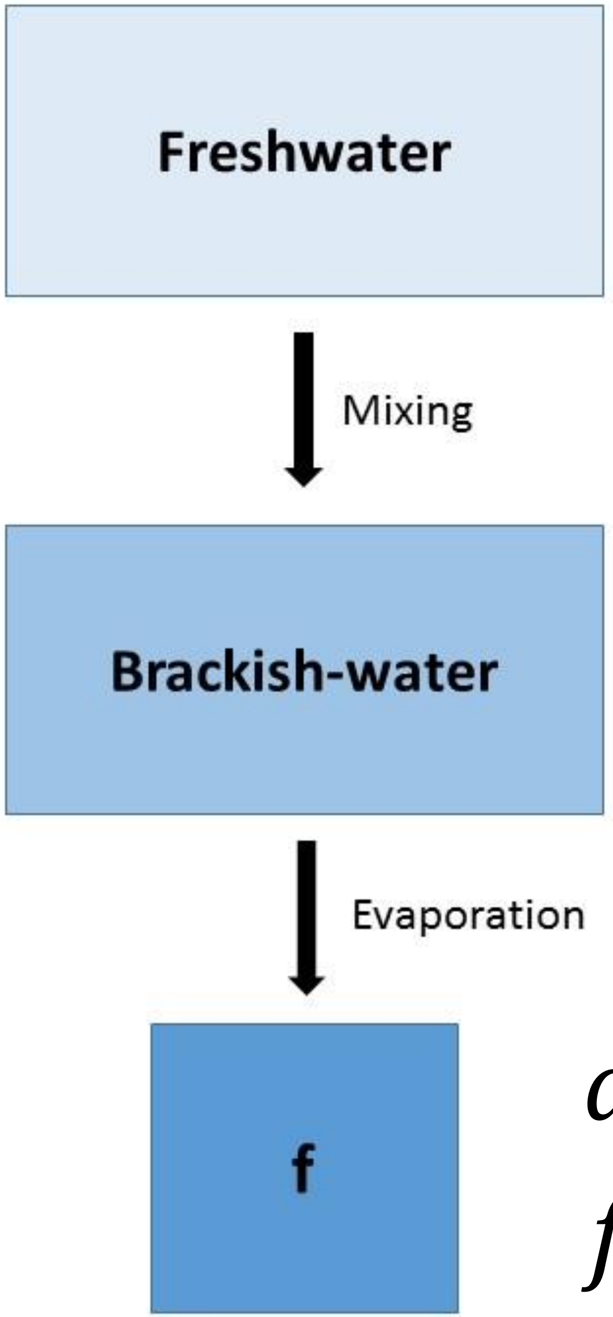


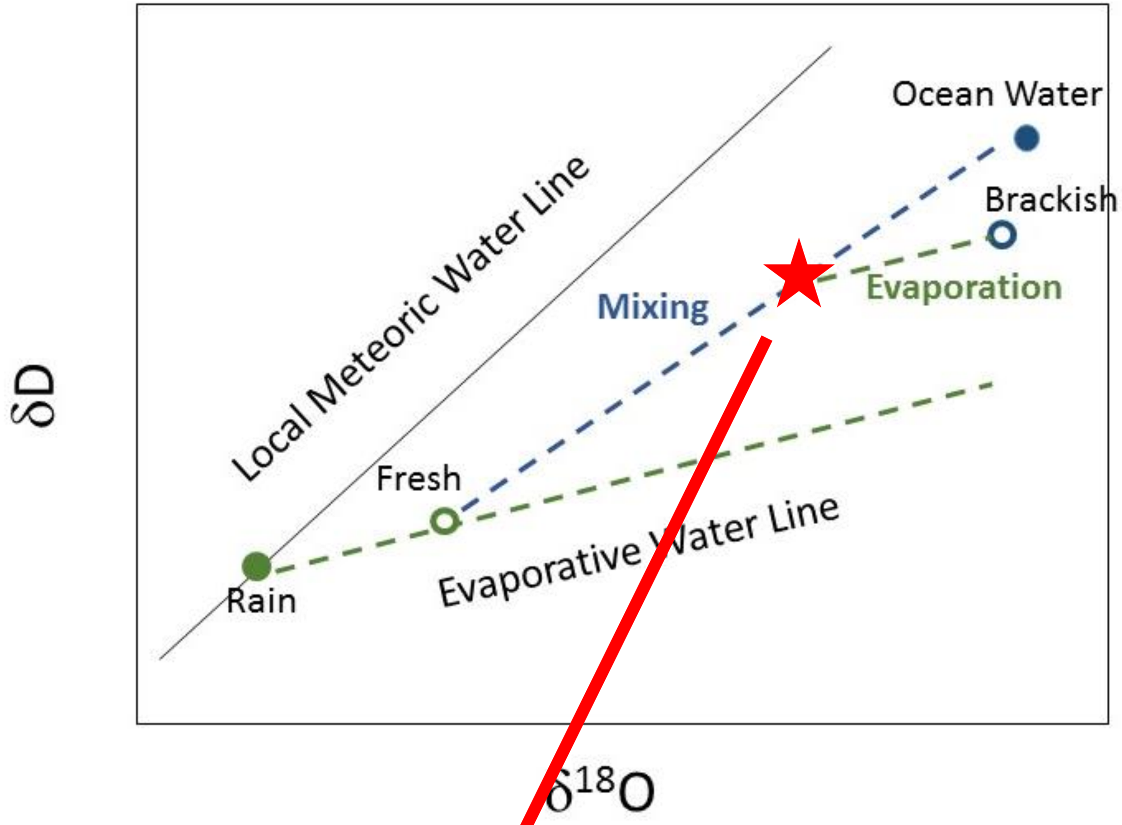
Brackish Evaporation Water Line: BEWL (Green Line)





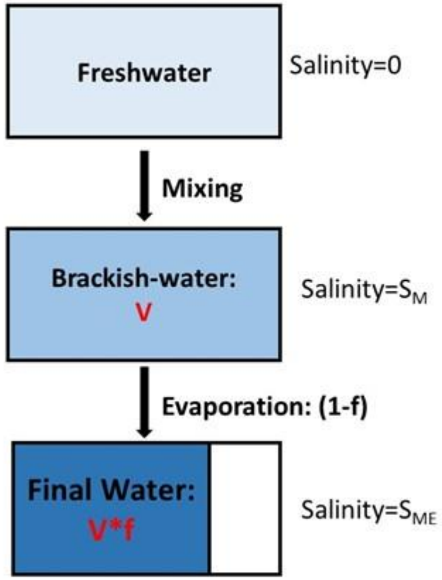
Step 3: Intersect of FOMWL and BEWL





$$d_i = \delta D_i - 8.6 \cdot \delta^{18}O_i$$

$$f_i = e^{\left[\left(d_i - \delta_0 D + 8.6\delta_0^{18}O\right)/\left(8.6\Delta^{18}O - \Delta D\right)\right]}$$



Salt Mass Balance:

$V * S_M = V * f * S_{ME}$

⬇

$S_M = f * S_{ME}$

Salinity increase from Evaporation:

$$= \frac{S_{ME} - S_M}{S_{ME}}$$

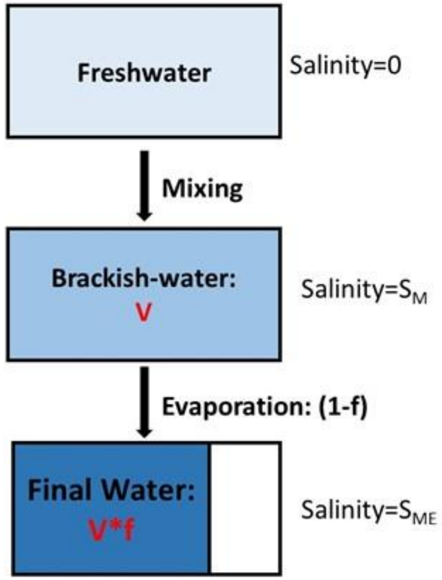
$$= \frac{S_{ME} - f \times S_{ME}}{S_{ME}}$$

$$= 1 - f$$

Salinity increase from Mixing:

$$= 1 - (1 - f)$$

$$= f$$



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Salinity of SRS6: ~90% from Saltwater intrusion, ~10% form Evaporation in Oct

On-going work

- Collecting river and rain water of SRS .
- Collecting ocean water from Gulf.
- SRS weather data.
- From Oct2016 to Oct2017: cover wet and dry season
- Long-term simulation of the contribution changes under sea level rise and increasing temperature

Thank you!