Coupling Infrared Imaging from Aircraft and Drone with Radon Time Series: Mapping and Quantifying Groundwater and Nutrient Discharge in Coastal Waters

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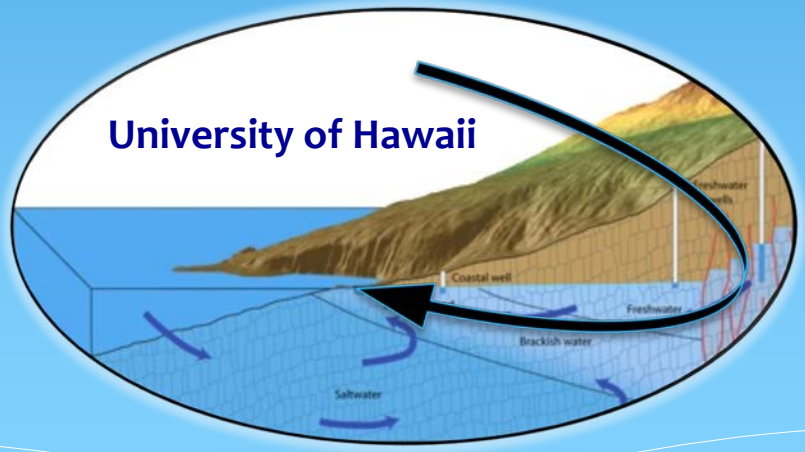
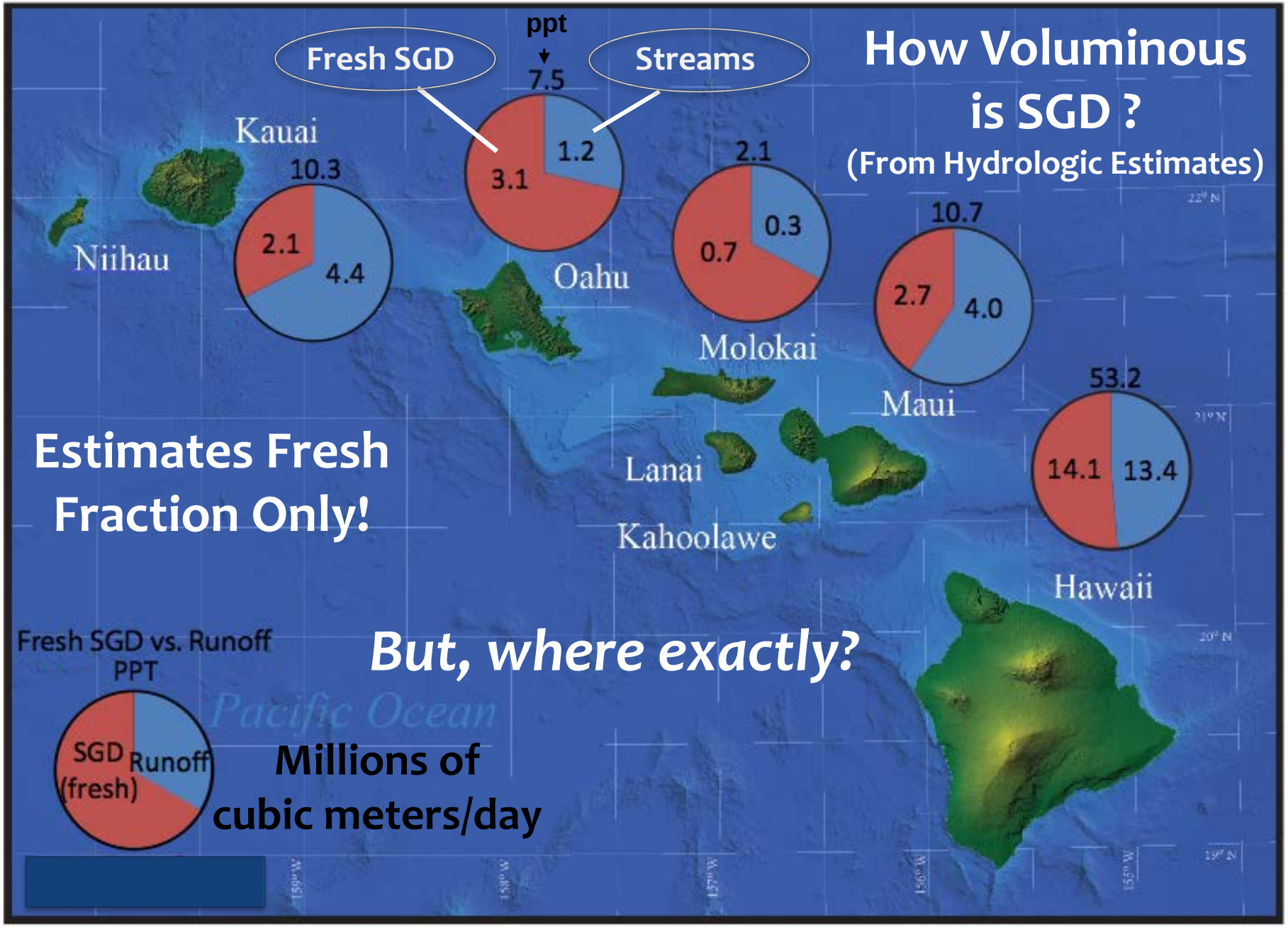


UH Hydrology and Coastal Groundwater Research Group


How Voluminous is SGD ?
(From Hydrologic Estimates)
Fresh SGD
ppt
Streams
7.5
3.1
1.2
Kauai
10.3
2.1
4.4
Niihau
Oahu
2.1
0.7
0.3
Molokai
10.7
2.7
4.0
Maui
53.2
14.1
13.4
Hawaii
Lanai
Kahoolawe
Estimates Fresh Fraction Only!
But, where exactly?
Fresh SGD vs. Runoff
PPT
SGD (fresh)
Runoff
Pacific Ocean
Millions of cubic meters/day

Searching for SGD with Aerial TIR Surveying

night

GPS-INS

Thermal blackbody calibration

Infrared camera (8-13.5 μm)

1100 m - 2133 m
0.5 m - 3.2 m resolution

Top < 1mm of water

Surface water temperature

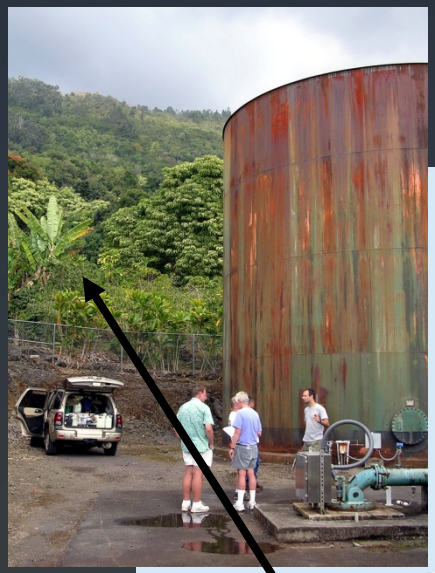
Warm Water

Cold Water

Ground-truthing Thermistors 0.5°C

Main advantage: laterally continuous SGD mapping on regional scales

Integrated Science



SGD FLUX

STREAM FLOW DIFFERENTATION

COASTAL RESIDENCE TIME

Surface water temperature

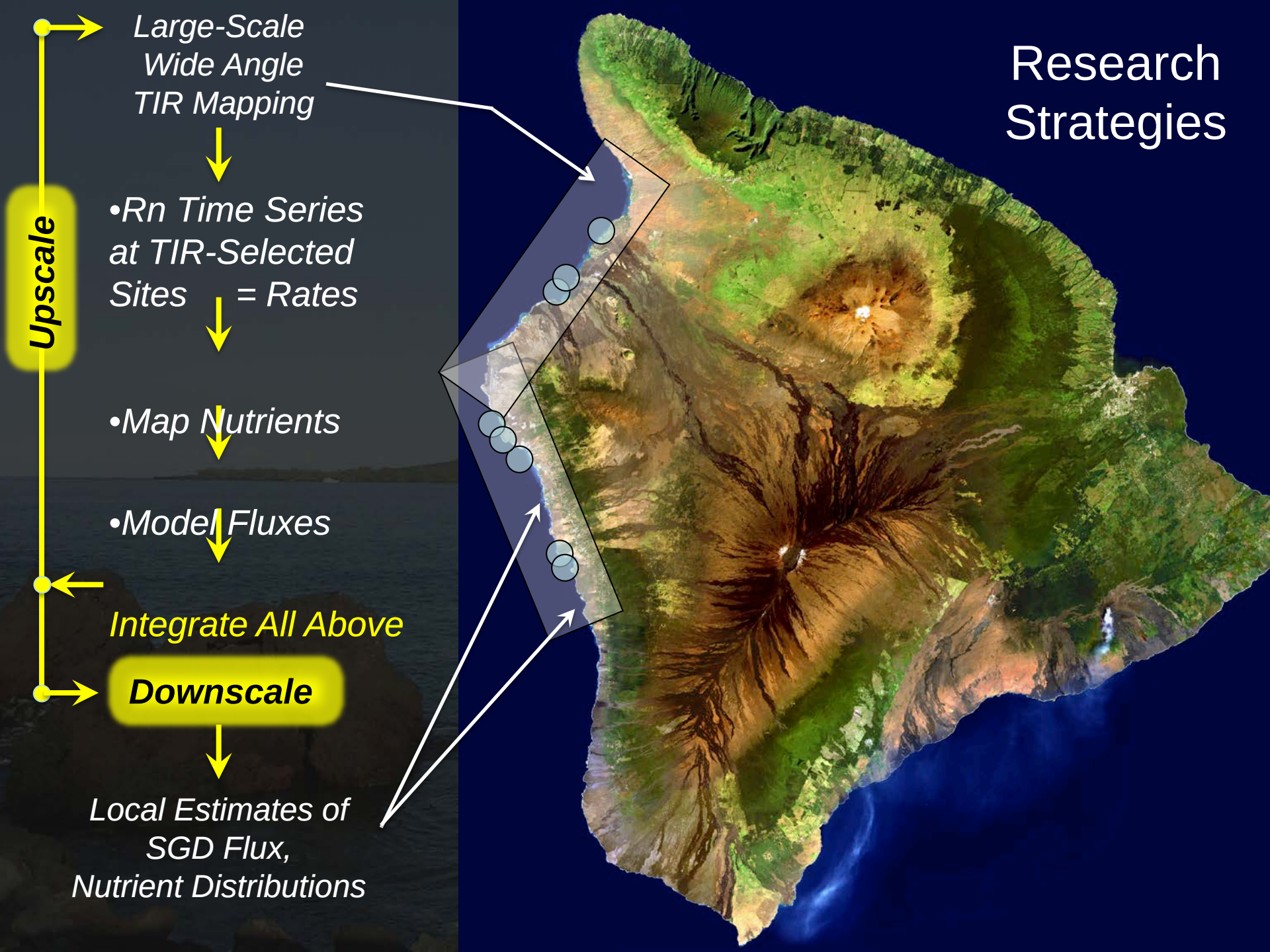
Water column mixing

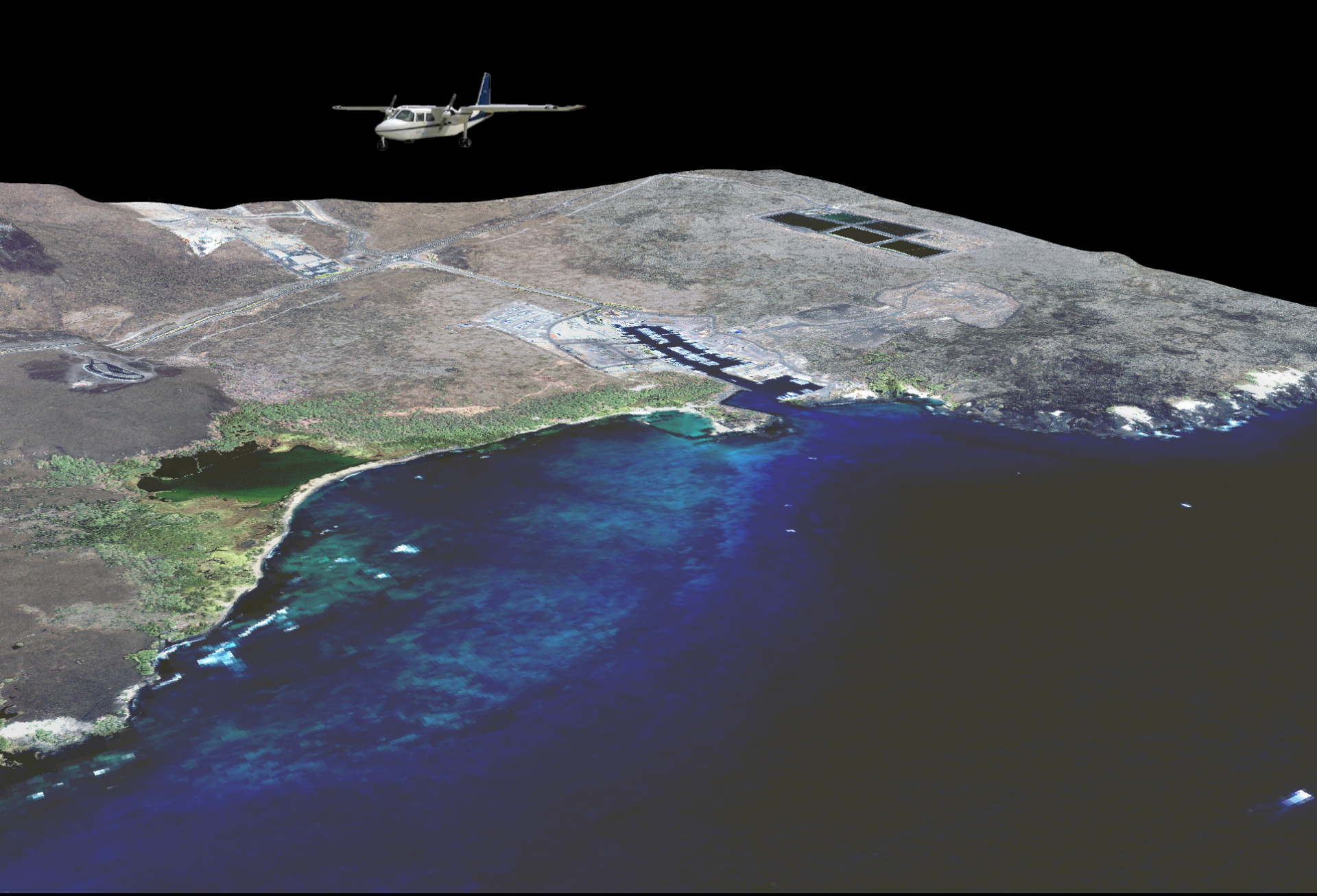
HYDROGEOLOGY

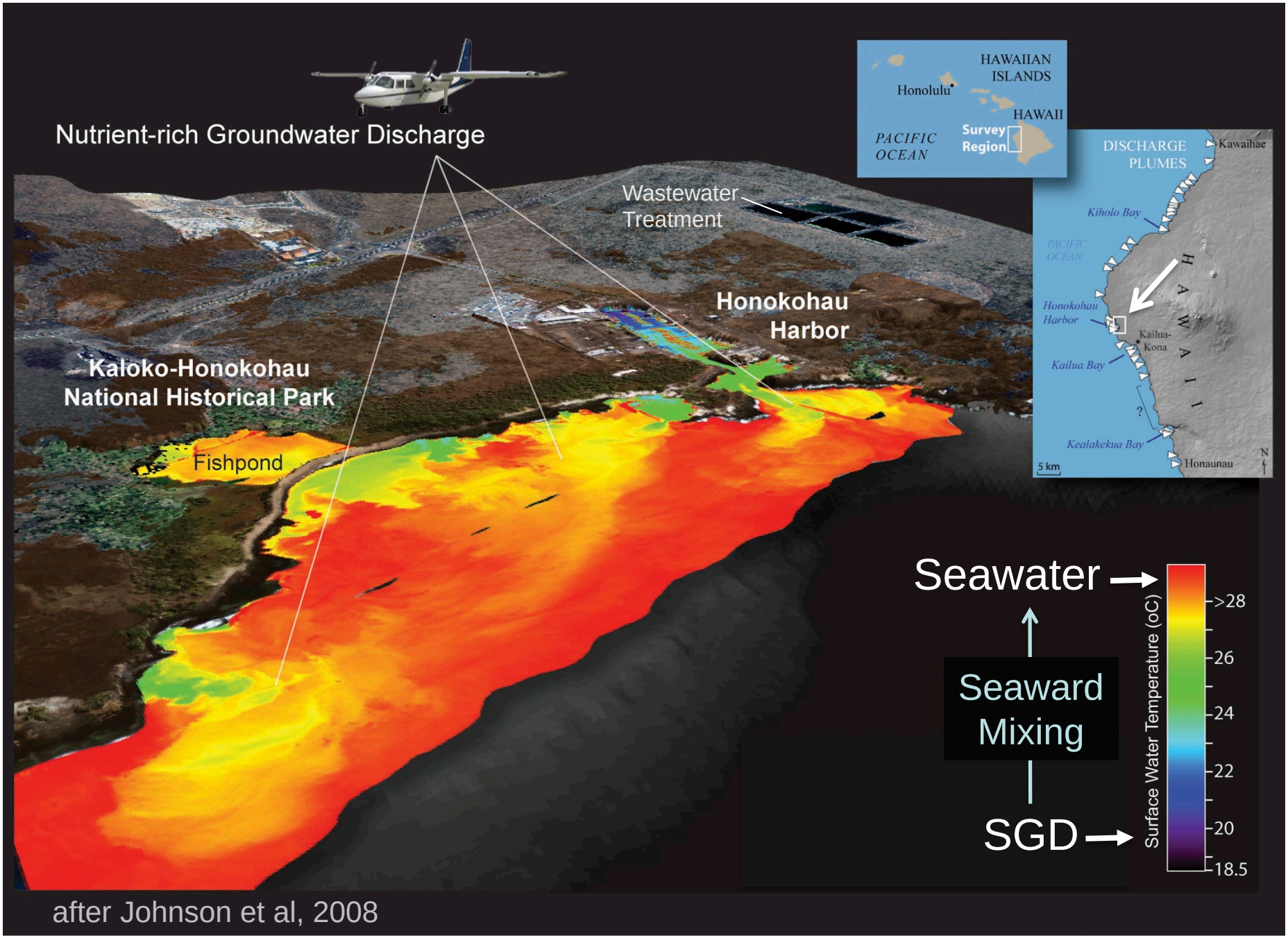
NUTRIENTS

BIOLOGICAL RESPONSE

Research Strategies





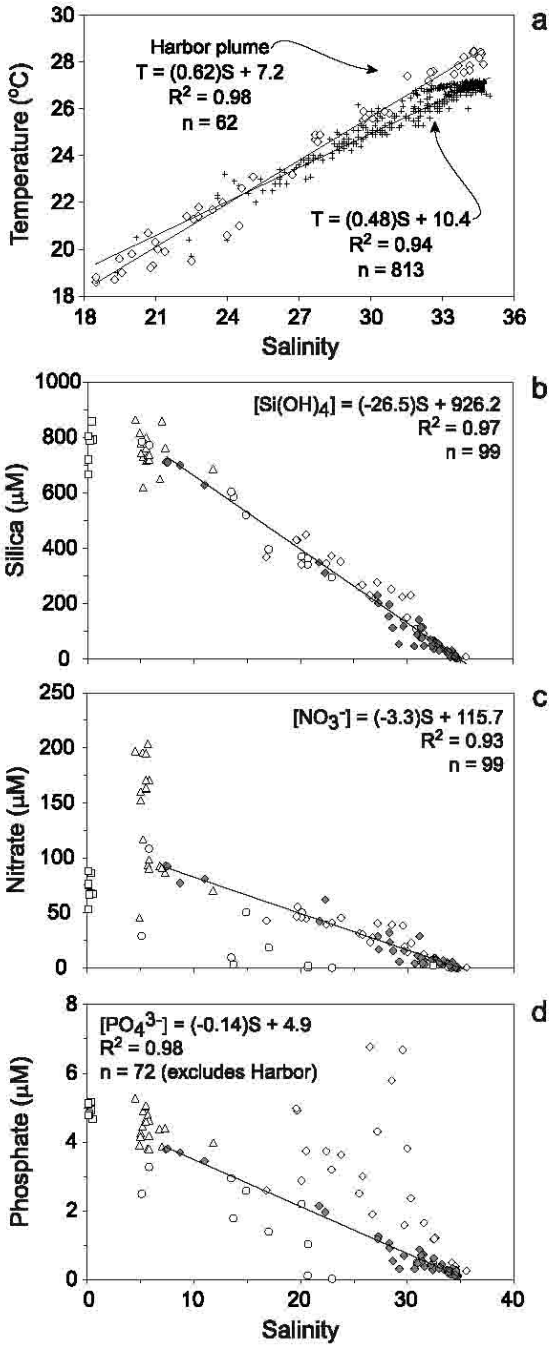


after Johnson et al, 2008

APPLICATION

Nutrients etc.

Cross-Correlations



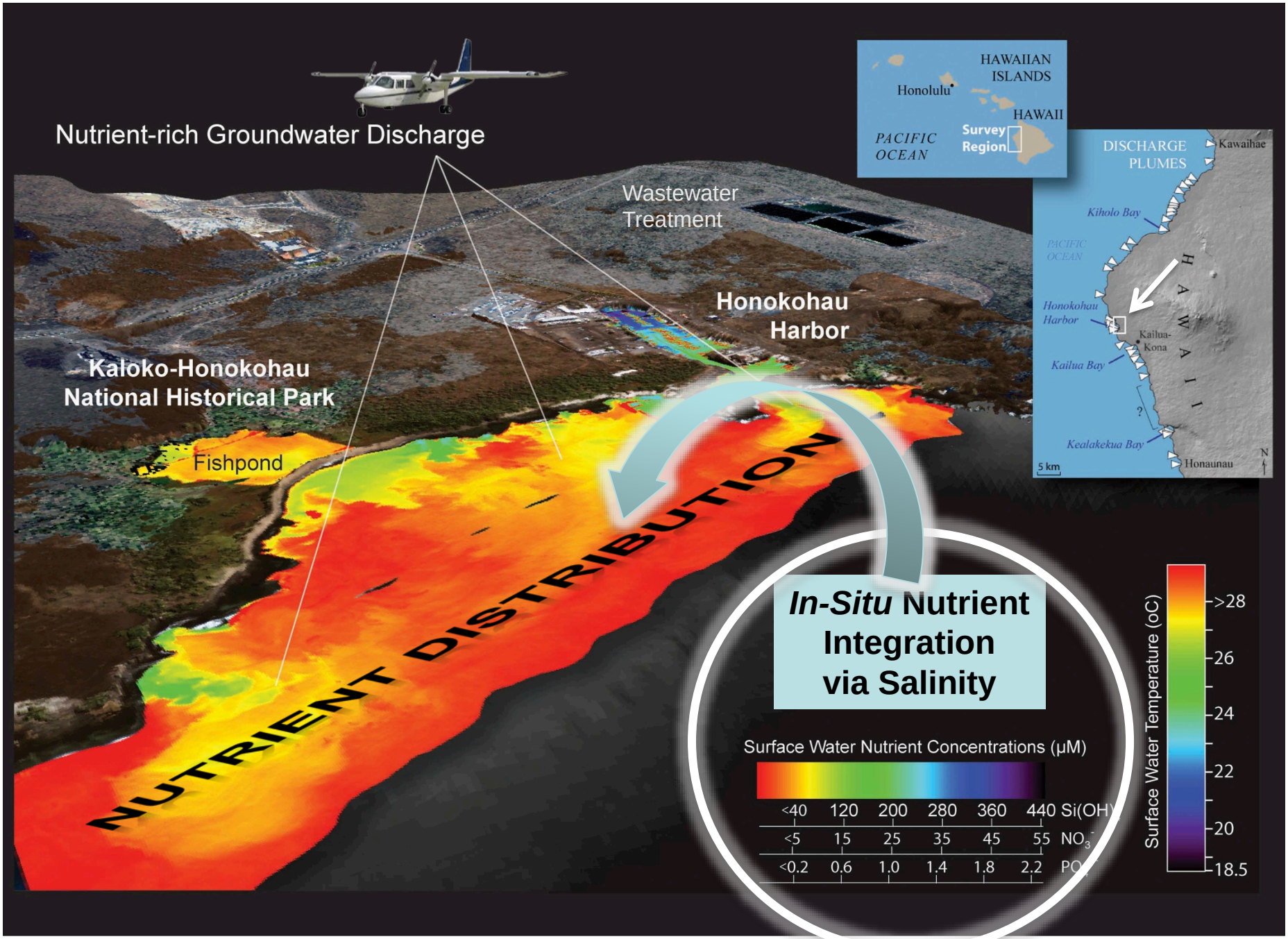
IN OPEN COASTAL WATERS:

⇨ **TEMP α SALINITY**
(r^2 = 0.98)

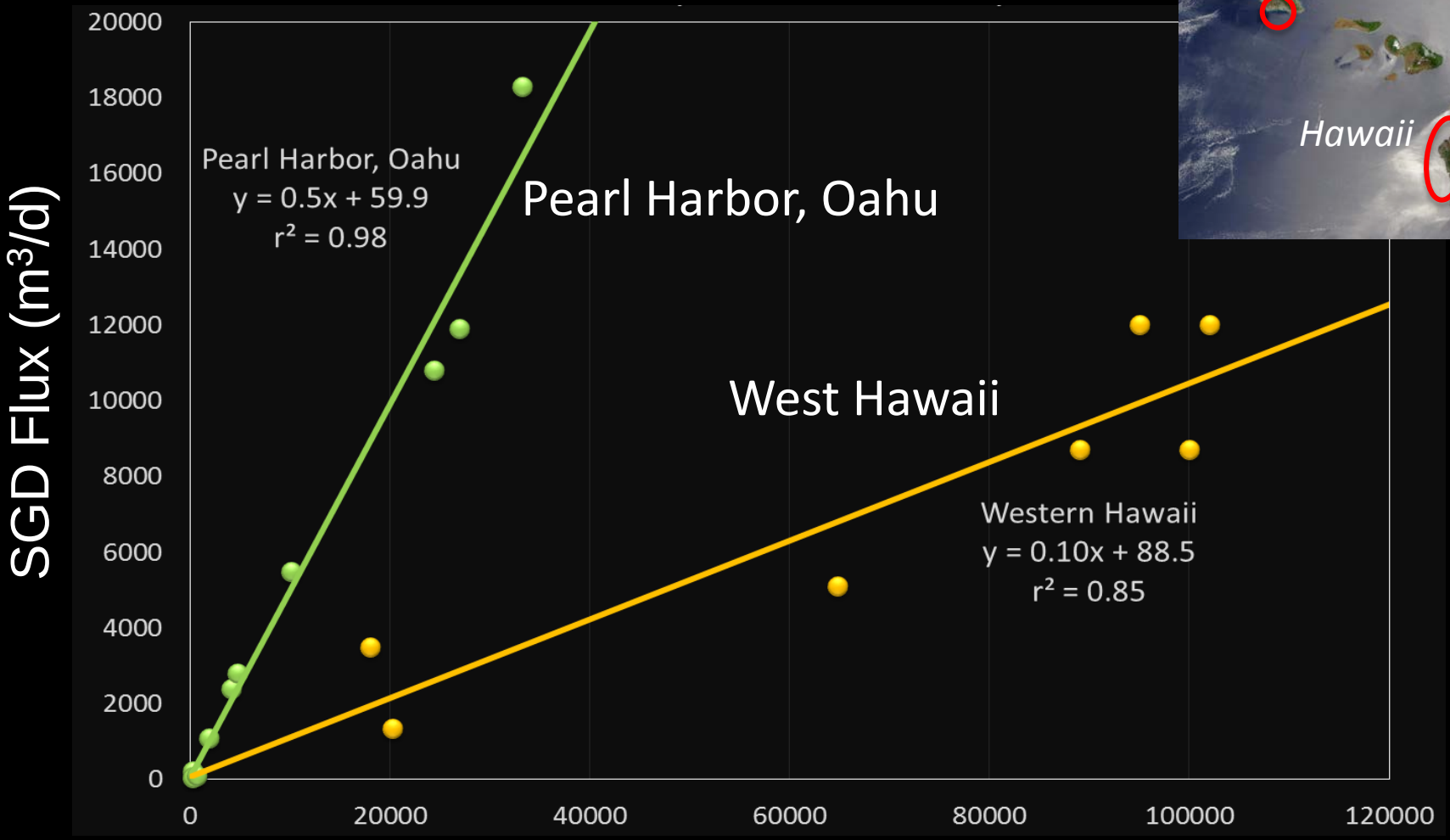
⇨ **[SILICA] α SALINITY**
(r^2 = 0.97)

⇨ **[NO_3^-] α SALINITY**
(r^2 = 0.93)

⇨ **[PO_4^{3-}] α SALINITY**
(r^2 = 0.98)

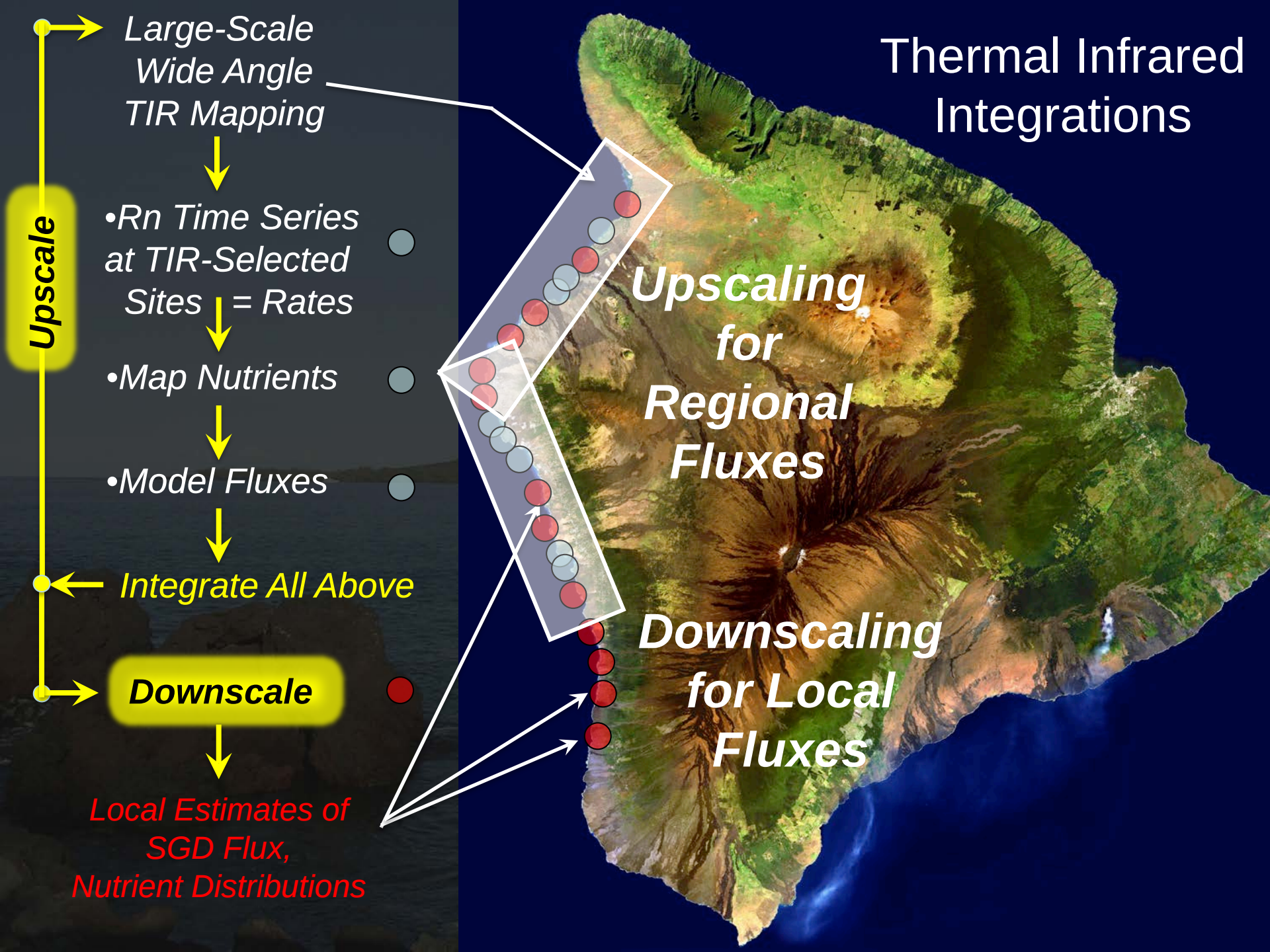

Nutrient-rich Groundwater Discharge
Wastewater Treatment
Honokohau Harbor
Kaloko-Honokohau National Historical Park
Fishpond
NUTRIENT DISTRIBUTION
HAWAIIAN ISLANDS
Honolulu
HAWAII
PACIFIC OCEAN
Survey Region
DISCHARGE PLUMES
Kawaihae
Kiholo Bay
PACIFIC OCEAN
HAWAII
Honokohau Harbor
Kailua-Kona
Kailua Bay
Kealakekua Bay
Honaunau
5 km
N
In-Situ Nutrient Integration via Salinity
Surface Water Nutrient Concentrations (µM)
<40 120 200 280 360 440 Si(OH)4
<5 15 25 35 45 55 NO3-
<0.2 0.6 1.0 1.4 1.8 2.2 PO4-
Surface Water Temperature (oC)
>28
26
24
22
20
18.5

Regional Upscaling



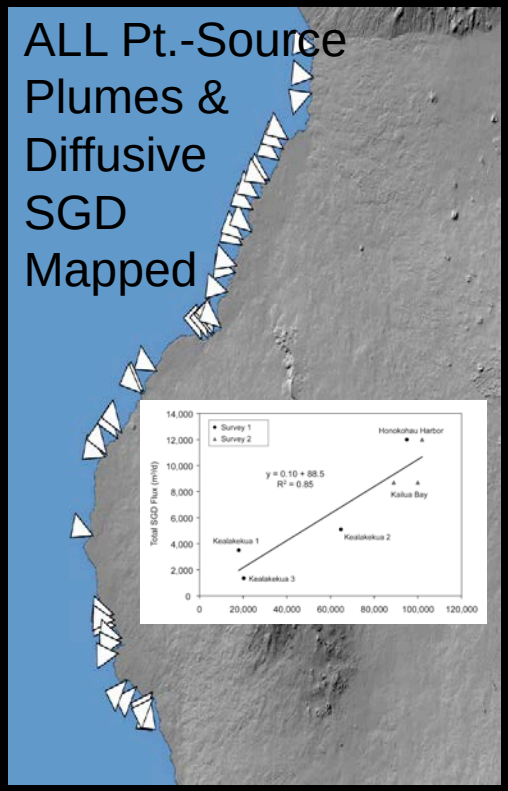
Plume area *is* proportional to SGD Flux

f (Hydrol., Geol, Waves, Tides, etc.)


Large-Scale
Wide Angle
TIR Mapping
Upscale
•Rn Time Series at TIR-Selected Sites = Rates
•Map Nutrients
•Model Fluxes
Integrate All Above
Downscale
Local Estimates of SGD Flux, Nutrient Distributions
Thermal Infrared Integrations
Upscaling for Regional Fluxes
Downscaling for Local Fluxes

Downscale

ALL Pt.-Source Plumes & Diffusive SGD Mapped



USING PLUME AREA, CALCULATE ESTIMATIMATED SGD FLUX FOR EACH

General Location	Plume	Latititude	Longitude	Point or diffuse	Plume Area (m^2)	SGD flux ($m^3 d^{-1}$)
Waikui Beach	1	20° 01' 24"	155° 49' 22"	P	30,000	3,089
Mauna Kea Beach	2	20° 00' 12"	155° 49' 33"	P	70,000	7,089
N. Hapuna Beach	3	19° 59' 32"	155° 50' 03"	P	22,000	2,289
Puako Pt.	4	19° 58' 22"	155° 50' 20"	D	50,000	-
N Waima Pt.	5	19° 58' 06"	155° 50' 57"	P	5,400	629
Waima Pt.	6	19° 58' 6"	155° 50' 57"	P	4,100	499
Kapuniau Pt.	7	19° 57' 49"	155° 51' 20"	D	79,800	-
Pauoa Bay	8	19° 57' 7"	155° 51' 43"	P	44,000	4,489
Nanuku Inlet	9	19° 56' 49"	155° 52' 07"	P	83,600	8,449
Hopeaia Fishpond	10	19° 56' 35"	155° 52' 14"	P	20,600	2,149
Manoku Fishpond	11	19° 56' 33"	155° 52' 22"	P	5,200	609
Waawaa Pt.	12	19° 56' 24"	155° 52' 37"	D	?	-
Waiulua Bay	13	19° 55' 34"	155° 53' 17"	P	22,000	2,289
Anaehoomalu Bay	14	19° 54' 48"	155° 53' 18"	P	780,000	78,089
South of Anaehoomalu Bay	15	19° 54' 21"	155° 53' 3"	D	?	-
N. Akahu Kaimu	16	19° 54' 11"	155° 54' 04"	P	28,700	2,859
S. Akahu Kaimu	17	19° 54' 01"	155° 54' 04"	P	77,900	6,779
Weliweli Pt.	18	19° 53' 52"	155° 54' 17"	P	?	-
Pueo Bay	19	19° 53' 35"	155° 54' 16"	P	121,500	12,239
Keawaiki Bay	20	19° 53' 17"	155° 54' 16"	P	112,000	11,289
S. Keawaiki Bay	21	19° 53' 17"	155° 54' 31"	P	45,000	4,649
Kaiwi Pt.	22	19° 53' 17"	155° 54' 45"	D	?	-
Ohiki Bay	23	19° 52' 33"	155° 54' 54"	D	?	-
Kiholo Bay	**24**	**19° 51' 35"**	**155° 55' 19"**	**P**	**252,000**	**25,289**
Mid-N Kiholo Bay	25	19° 51' 11"	155° 55' 40"	P	16,000	1,689
Mid-S Kiholo Bay	26	19° 51' 02"	155° 56' 4"	P	2,400	329
S Kiholo Bay	27	19° 51' 01"	155° 56' 04"	P	82,000	8,289
SS Kiholo Bay	28	19° 50' 58"	155° 56' 19"	P	63,300	6,419
Kahuwai Bay	29	19° 49' 52"	155° 59' 13"	P	55,000	5,589
Kukio Bay	30	19° 49' 09"	155° 59' 33"	P	90,000	9,089
Kikaua Pt.	31	19° 49' 04"	156° 00' 03"	P	7,700	859
Kakapa Bay	32	19° 48' 51"	156° 00' 10"	D	45,000	-
Kua to Kahoiawa Bay	33	19° 48' 30"	156° 00' 49"	D	?	-
Awakee	34	19° 47' 45"	156° 01' 20"	P	4,700	559

Measured Discharge Area

Predicted Discharge for Each