The Lahaina Groundwater Tracer Study: Project Overview and Update

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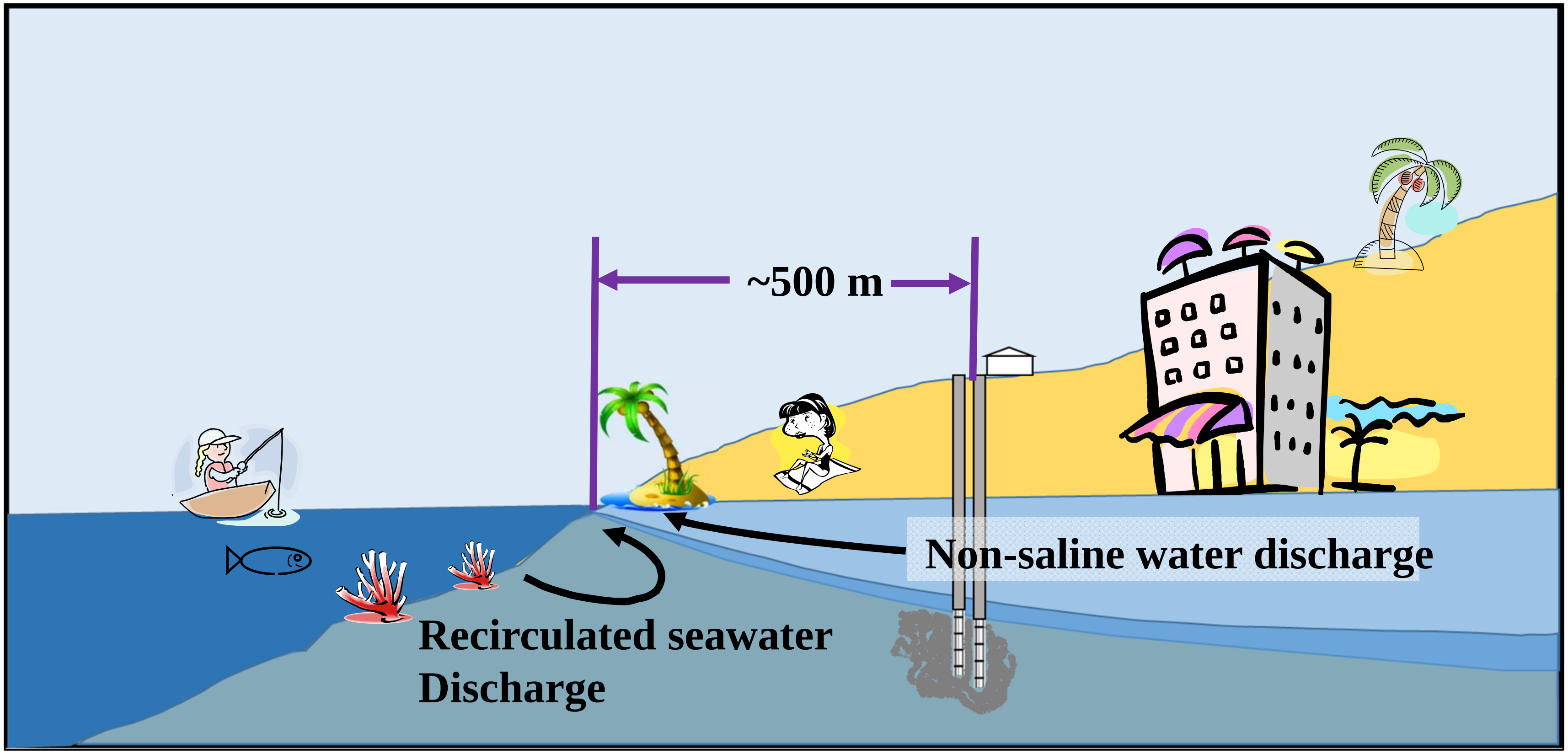
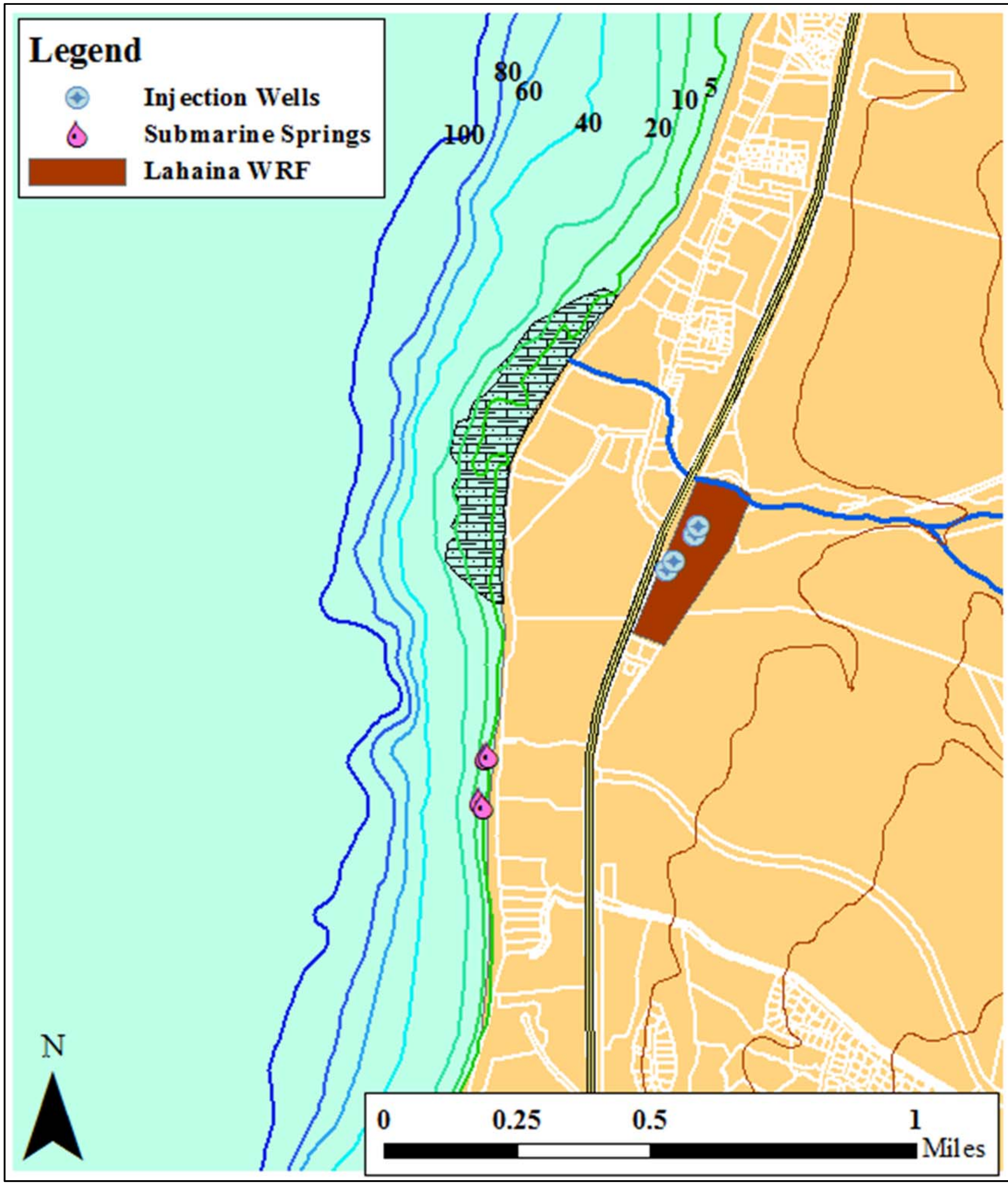
BACKGROUND

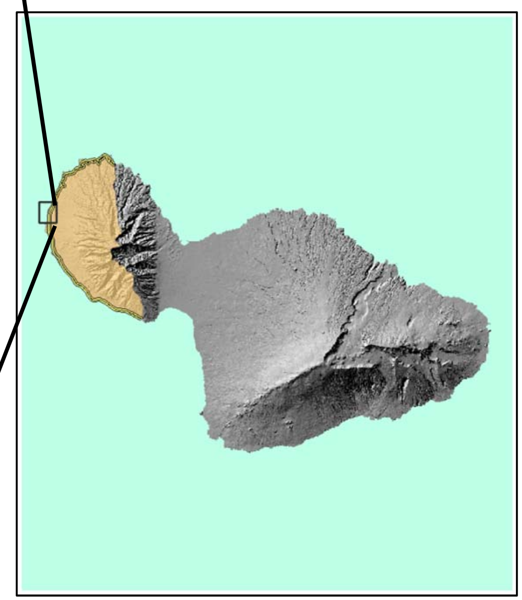


- Maui Co. Injects ~3.5 million gallons per day (mgd) of tertiary treated wastewater
    - The location of injectate discharge into the marine environment is a major concern
- Possible impacts could include:
    - Excessive algal growth resulting in reef degradation
    - Health impacts due to pathogens (time of travel is a factor)

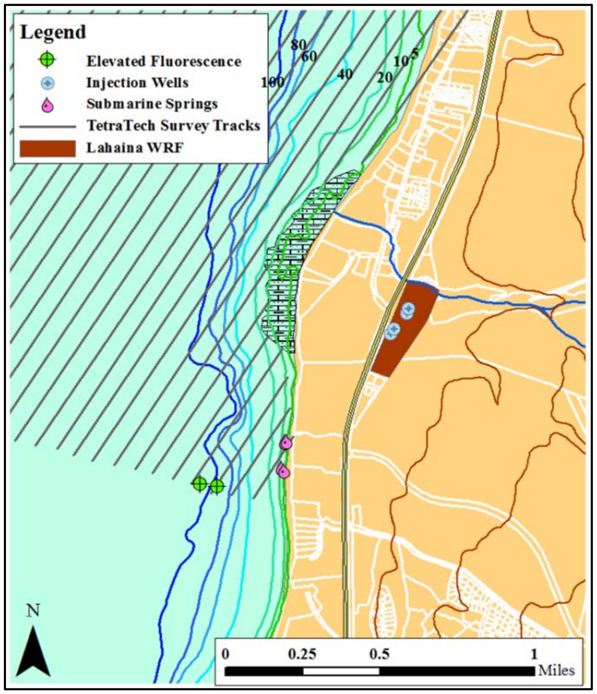


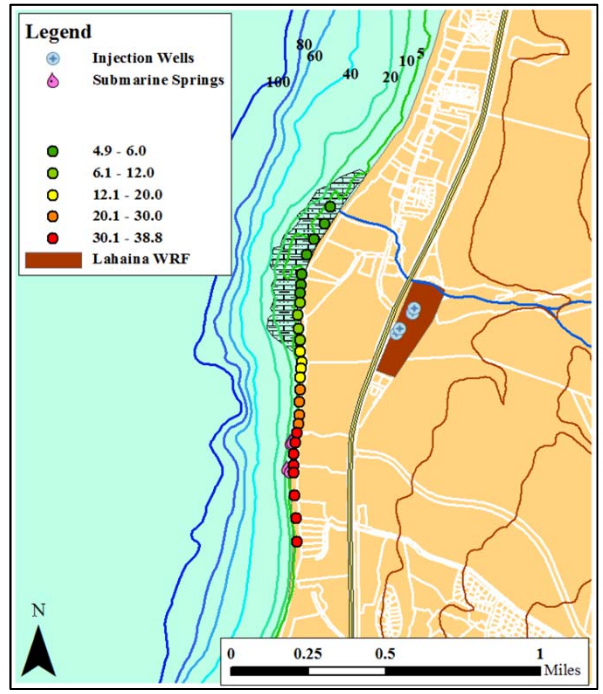
Study Area

- The Kaanapali area of the Lahaina District of Maui
- Site of historical algae blooms
- Area of documented reef degradation
- A center of tourism in Maui



Important Previous Research





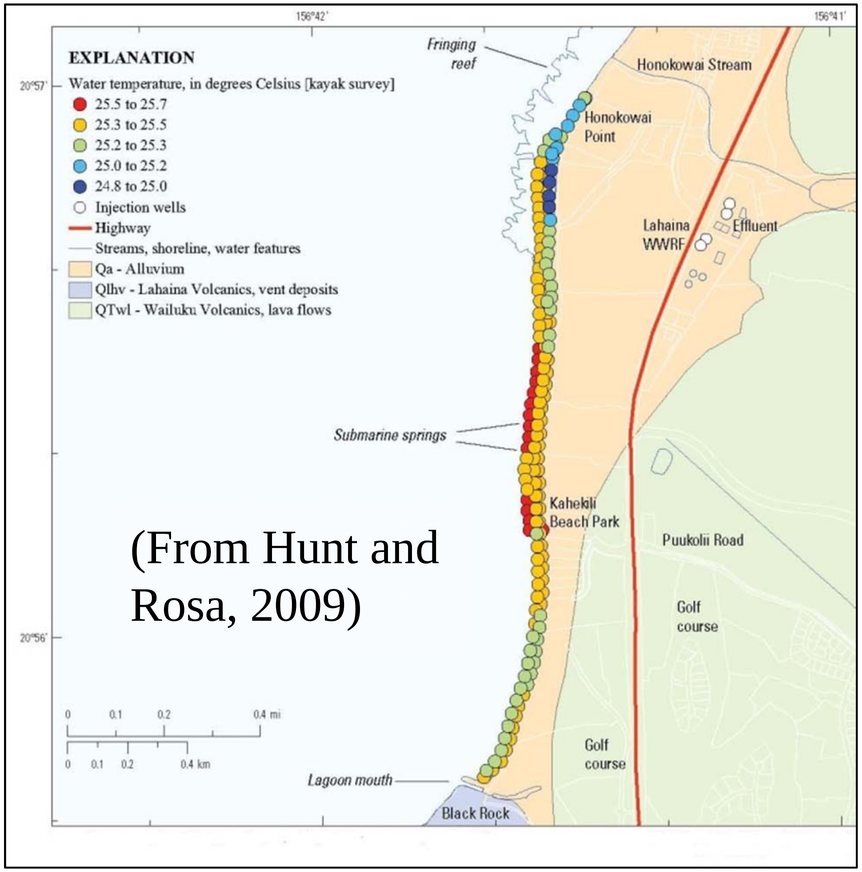
Tetra Tech, 1993-94

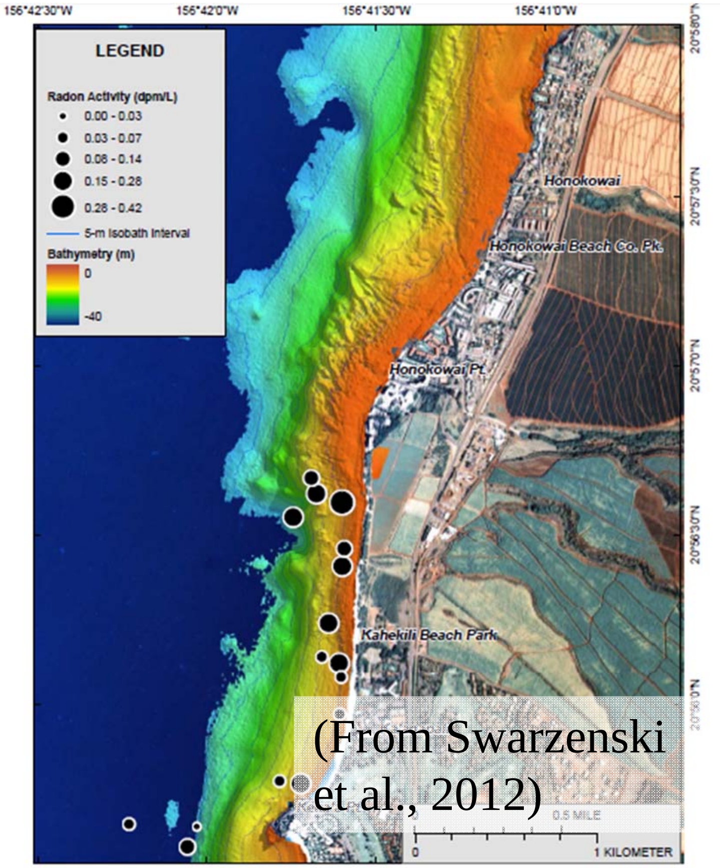
- Nutrient flux estimations
- Tracer test
  - Found slightly elevated fluorescence southwest of LWRF

Dailer et al. 2008, 2010, & 2012

- Coastal $\delta^{15}N$ survey using algal bioassays
- Found highly elevated $\delta^{15}N$ ratios Southwest of the LWRF

Important Previous Research





USGS - Hunt and Rosa, 2009;

- Water quality,
- Nutrient sampling,
- Stable isotope sampling, and
- pharmaceutical survey

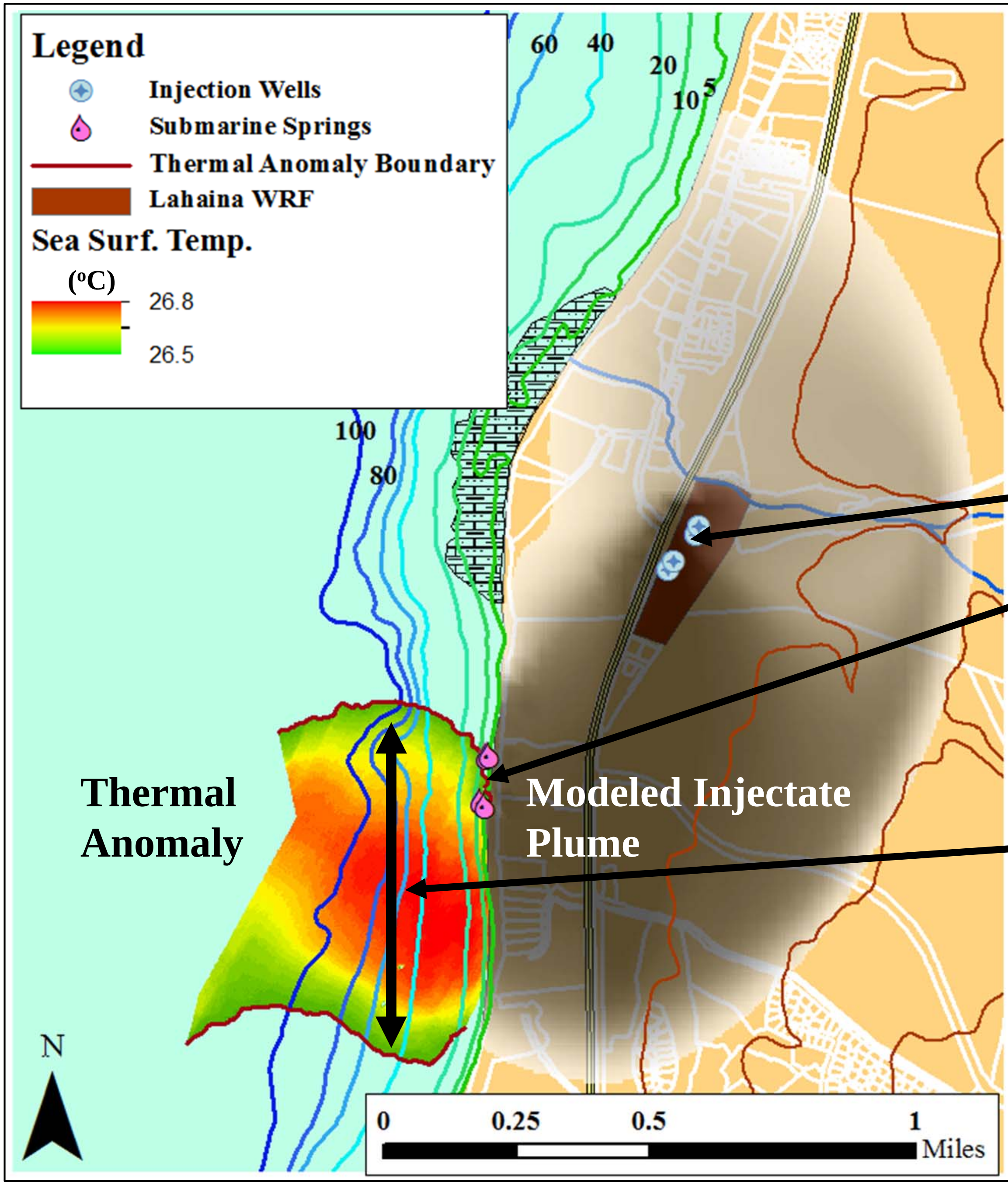
USGS – Swarzenski et al., 2012

- Submarine groundwater discharge (SGD) measurements
- Geophysics and side scan sonar imaging

UNIVERSITY of HAWAII LAHAINA GROUNDWATER TRACER STUDY

Research Tasks

1. Map the coastal zone sea surface temperature using an airborne infrared sensors.
2. Characterize aqueous chemistry of all relevant waters
3. Measure the Submarine Groundwater Discharge (SGD) flux at the submarine springs
4. Conduct a tracer test to evaluate the hydraulic connectivity between the LWRF and the coastal submarine springs
5. Continuously monitoring for the emergence of the injected tracer dye
6. Combine the tracer breakthrough curve with SGD flux to estimate the fraction of treated wastewater that discharges nearshore



Thermal Infrared Imagining

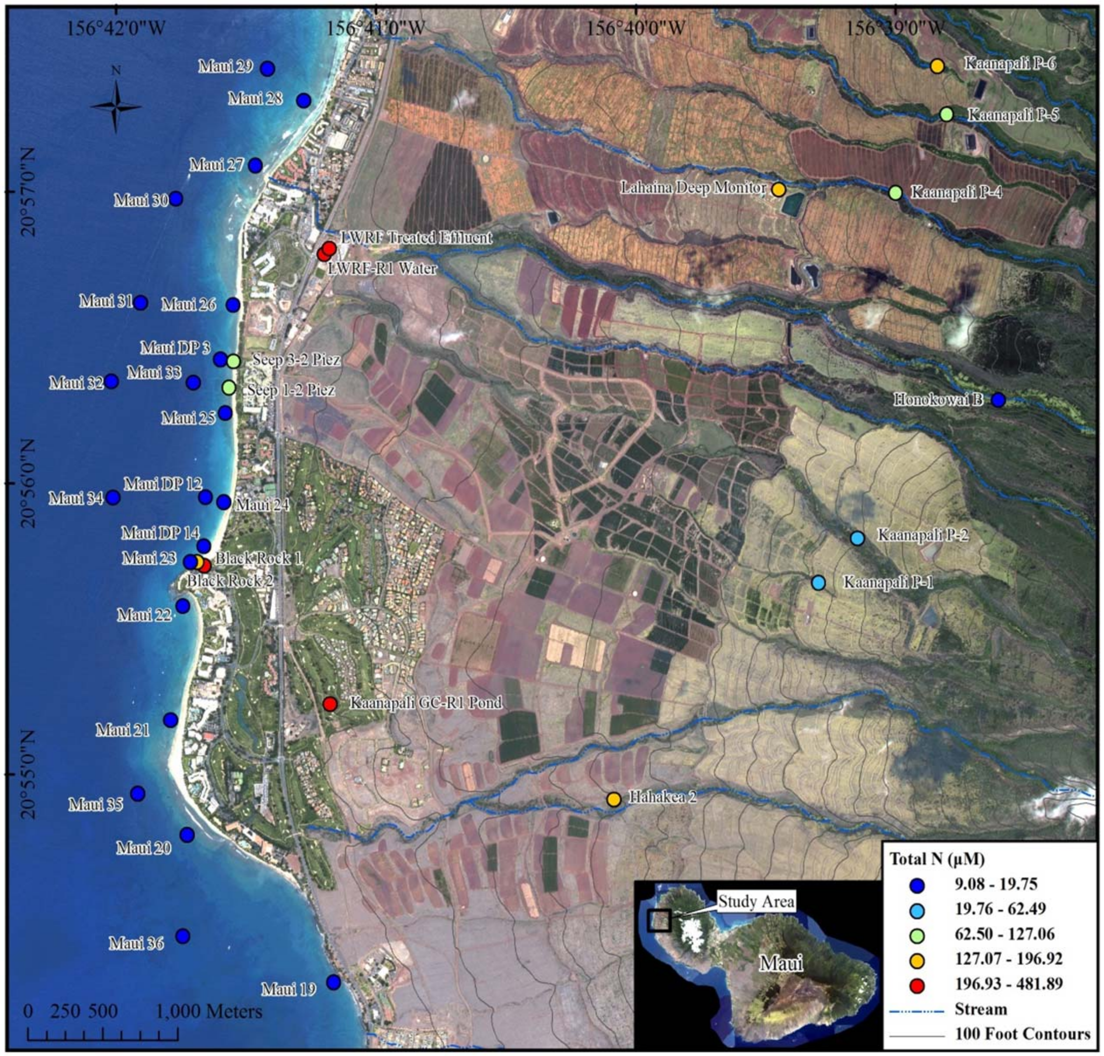
- Night-time survey from an aircraft with thermal infrared sensors

- WWTP Effluent daytime Temp = 30°C
- Known seep locations correspond to hot water "boils"
- Vents Temp. >28°C

- Plume area = 166+ acres
- Plume boundary temperature = 26.5°C
- Normal sea surface temperature ~25 °C

Comprehensive Aqueous Chemistry Survey

(Craig et al., 2012 and 2013)



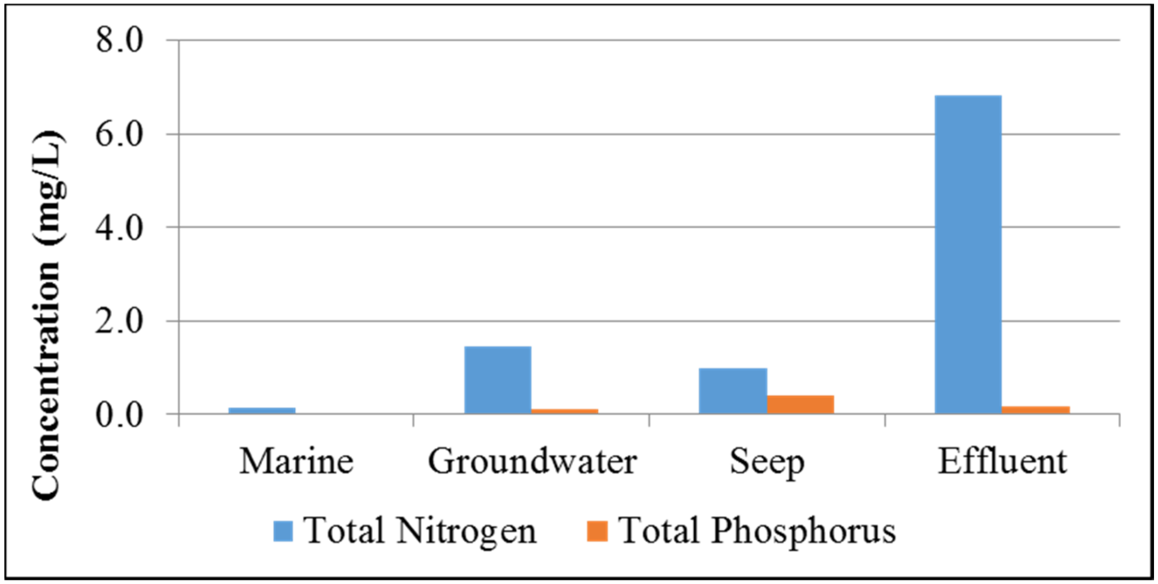
- Sampled:
  - Injected wastewater
  - Upgradient groundwater
  - Discharge at the submarine springs
  - Nearshore marine waters
- Analyzed for:
  - Basic water quality parameters
  - Nutrients
  - Stable isotopes
  - Major ions
  - Radon & Radium

Aqueous Chemistry Survey Principal Findings

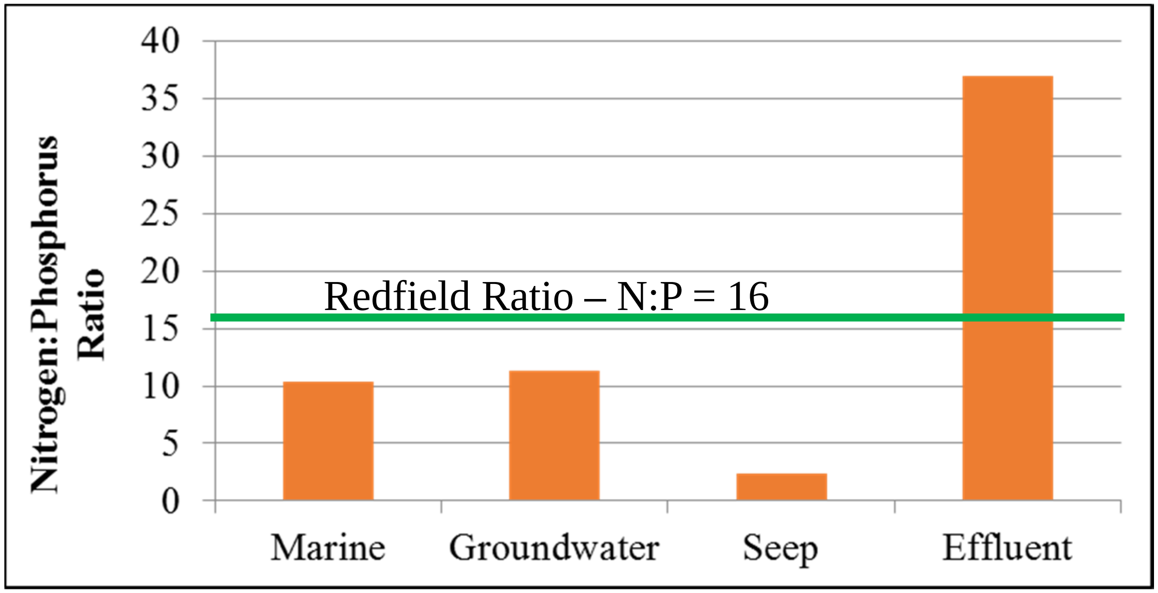
- The N concentration of the submarine springs is reduced compared to LWRF treated wastewater, while the P concentration appeared to be enriched.
- The apparent P enrichment was due to low number of LWRF samples collected by the study (2). Follow-on sampling indicates that the P at the springs is close to that injected.
- The chemistry of the affected seeps is distinct from other groundwater discharge sites in West Maui due to their low TN:TP and DIN:DIP ratios. The N:P ratios show that the seeps are enriched in P relative to N, when compared to other SGD sites

UH Nutrient Sampling Results

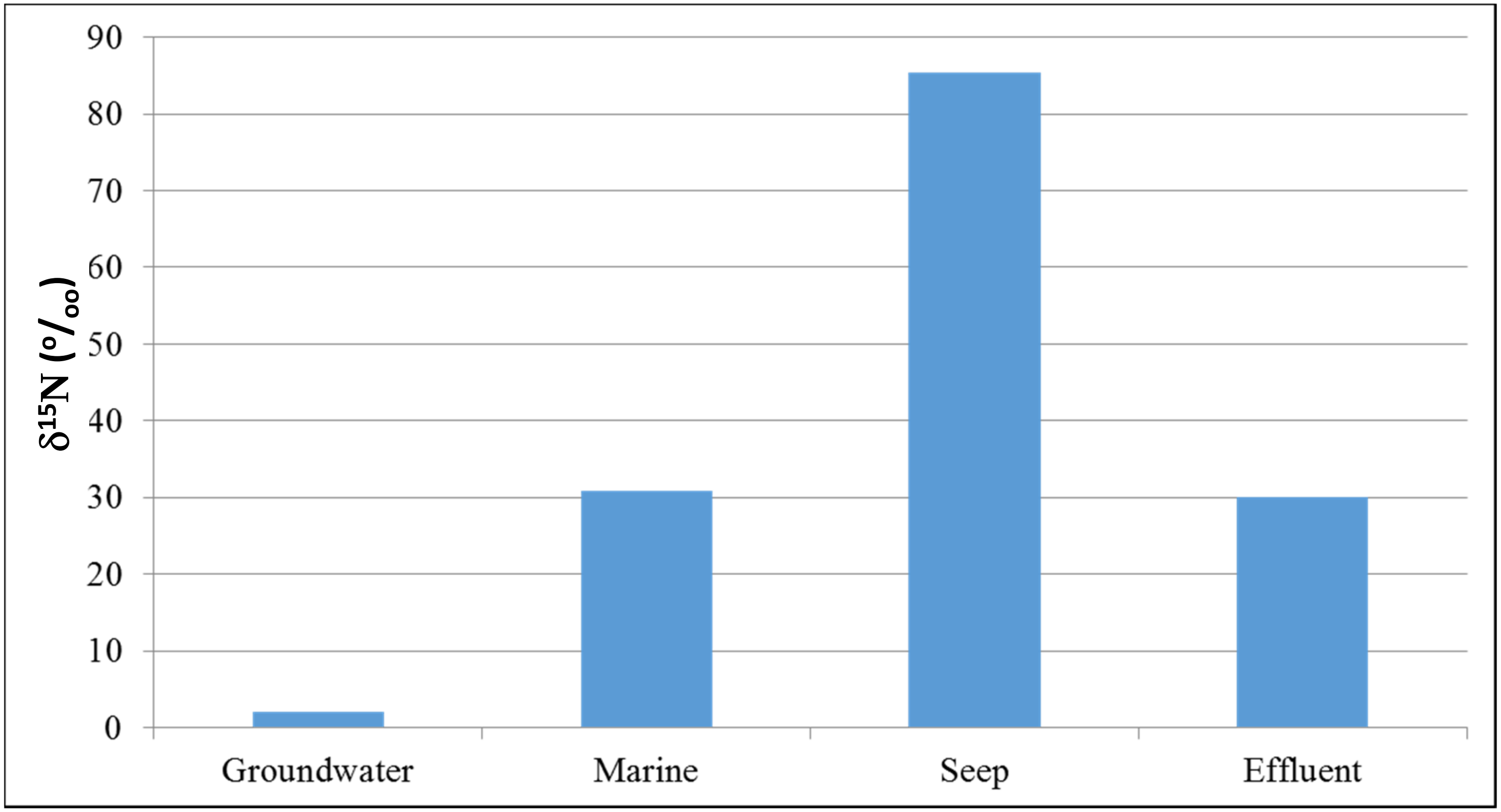
(Craig et al., 2012 and 2013)



- Nitrogen:
  - Seep conc. much reduced from effluent
  - Seep conc. < upgradient groundwater
- Phosphorus
  - Seep conc >= effluent
  - Seep conc. > upgradient groundwater



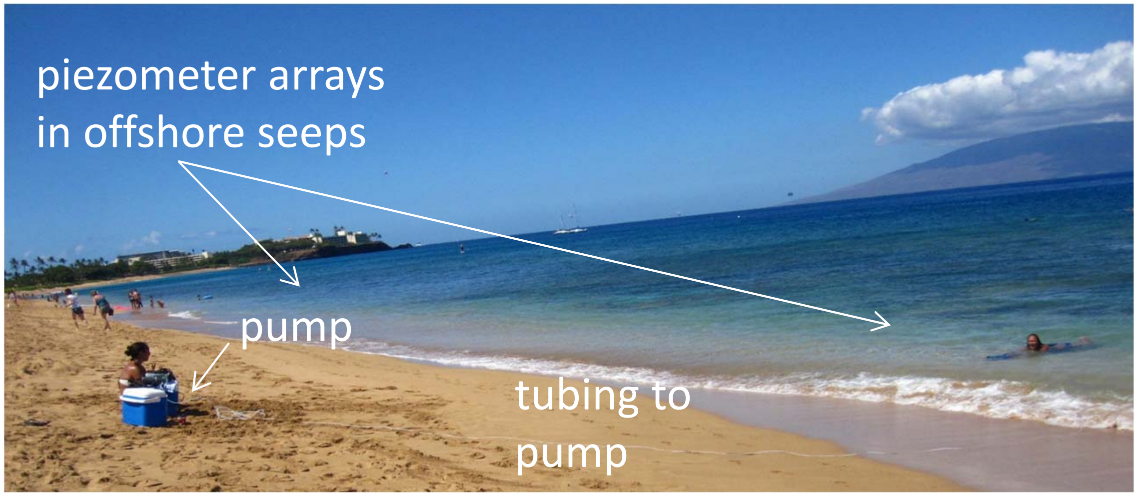
- N:P Ratios
  - Seeps << effluent or groundwater
- Redfield Ratio
  - N:P = 16 Generally viewed as the optimum ratio for bio-productivity
  - N:P at seeps << Redfield Ratio

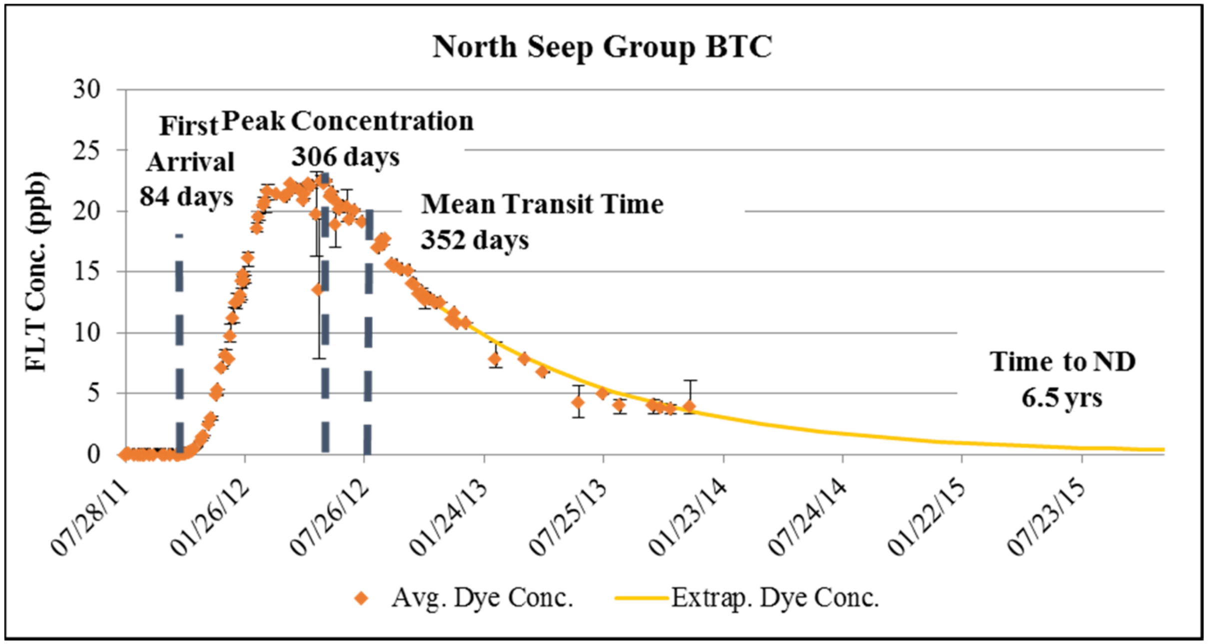


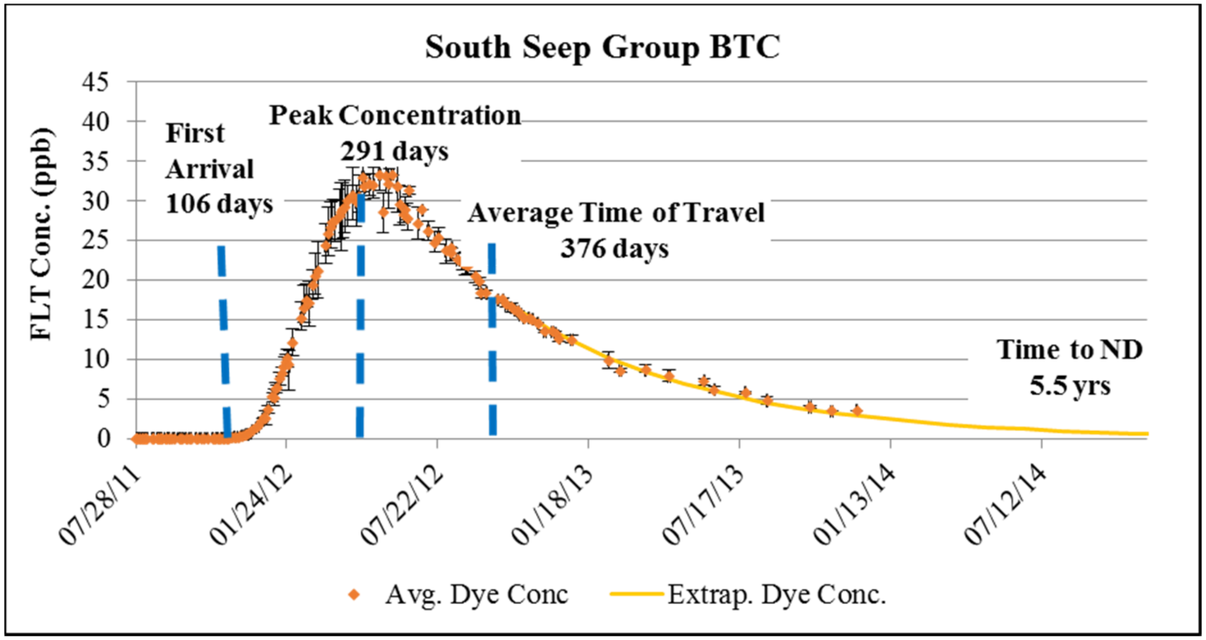
- Seep discharge is highly enriched in the heavier Nitrogen-15 isotope
- The N-15 enrichment relative to the effluent strongly suggests denitrification is occurring

The Tracer Test

- 350 lbs of Fluorescein powder were mixed with 1700 gal of water
- Added to Wells 3 & 4 over a period of 20 hours
- Seep locations were sampled regularly to acquire time series data
- Three rounds of shoreline/nearshore sampling to define extend of dye plume

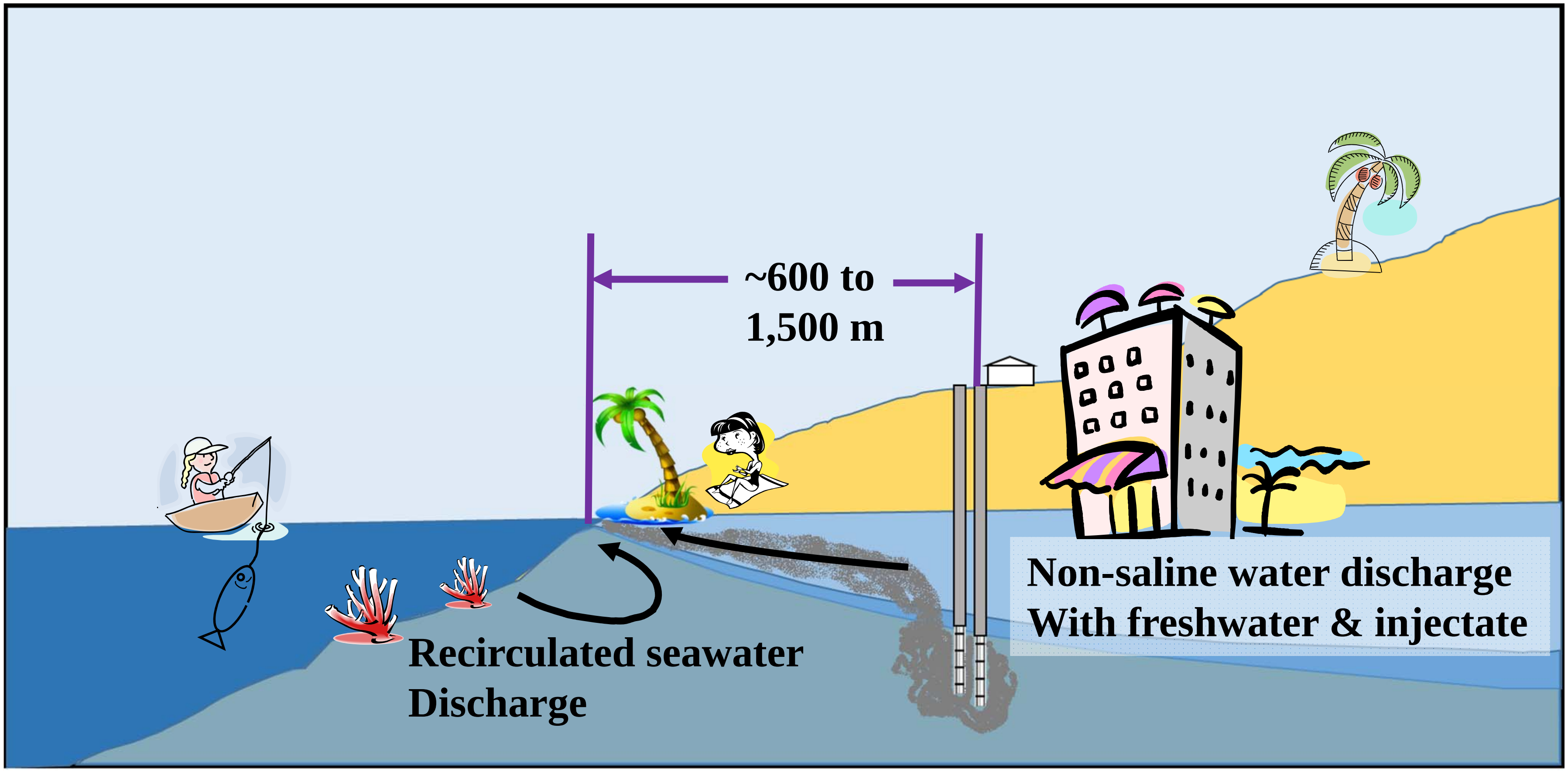






Breakthrough Curve

- Documented Two multi-year breakthrough curves (BTC)
- Time of first arrival ~ 3 months
- Average time of travel ~ 1 year
- Time for dye conc. to decay below detection limits > 5 years
- BTC can be used to portion seep discharge between ambient groundwater and injectate



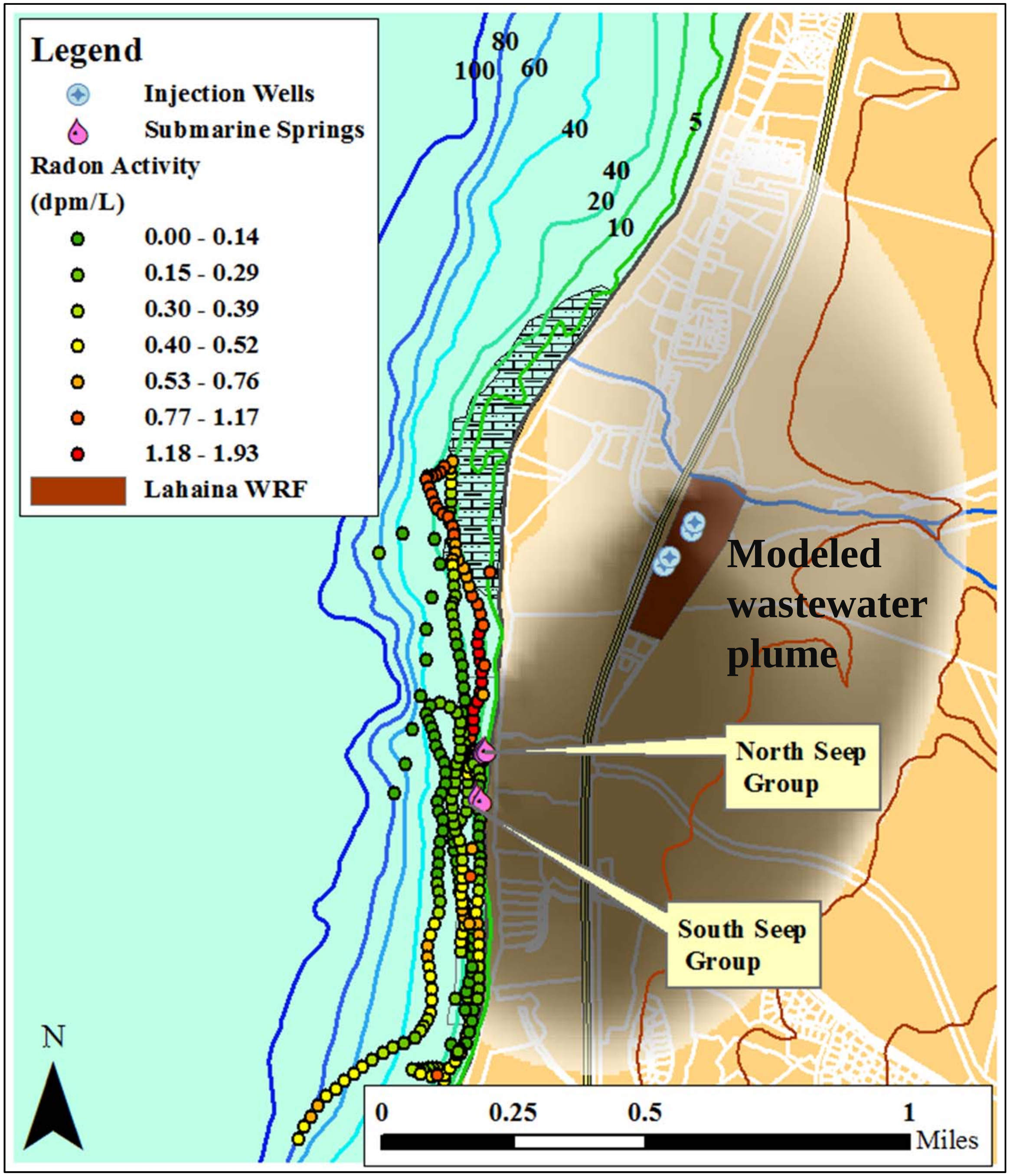
Summary of Important Tracer Test Findings

- At least some fraction of the injectate is discharged nearshore
- Travel distance varies from about 600 to 1,500 m (due to width of plume)
- Average effluent travel time is about a year

ESTIMATING THE COASTAL EFFLUENT & NUTRIENT FLUX

Nutrient Loading Estimate Consists of Three Elements

1. Computing total submarine groundwater discharge (SGD)
   a. From Radon surveys
2. Determining fraction of SGD that is attributable to wastewater injection
   a. Tracer test BTC
3. Measuring the nutrient concentrations at the points of injectate discharge
   a. Coastal nutrient sampling

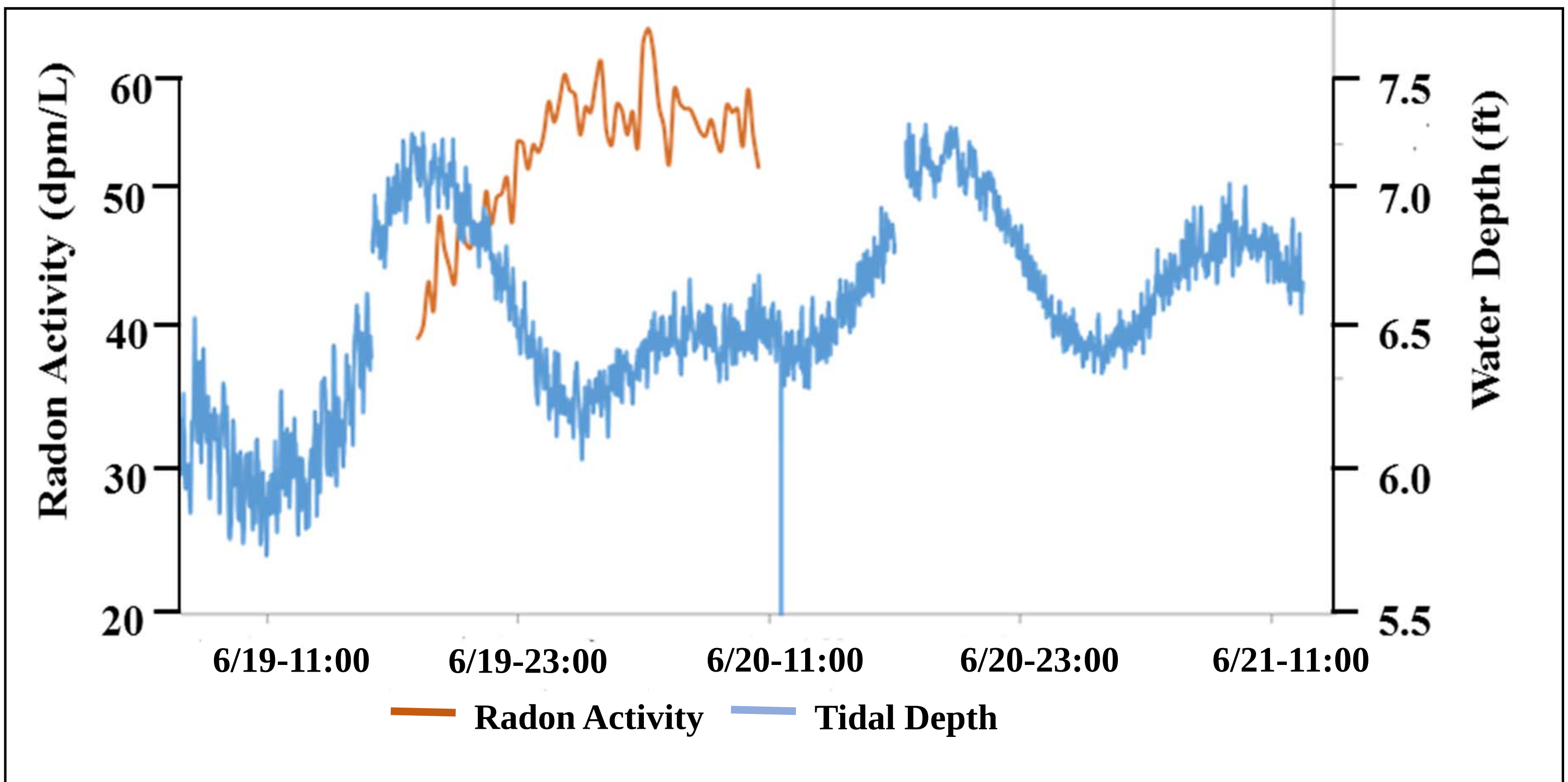


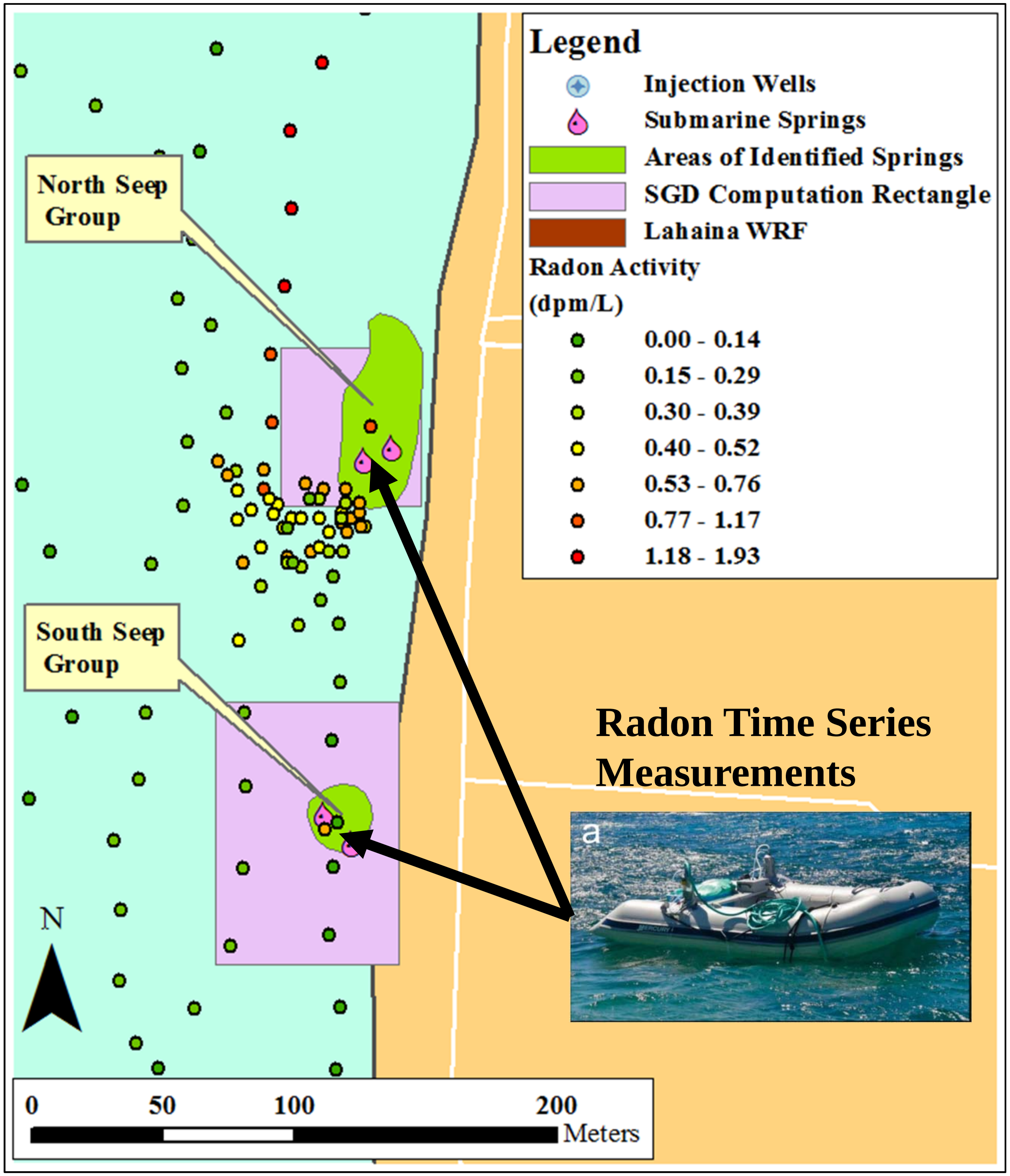
Seawater Radon Survey

- Radon
  - Trace gas
  - Radioactive with a half of 3.8 days
  - Enriched in groundwater
  - Nearly absent in seawater
  - **Indicator of SGD**
- Coastal survey (at left)
- Non-green points represent areas of SGD
- Fixed point time series measurements at each seep group (next slide)

Radon Time Series Measurements

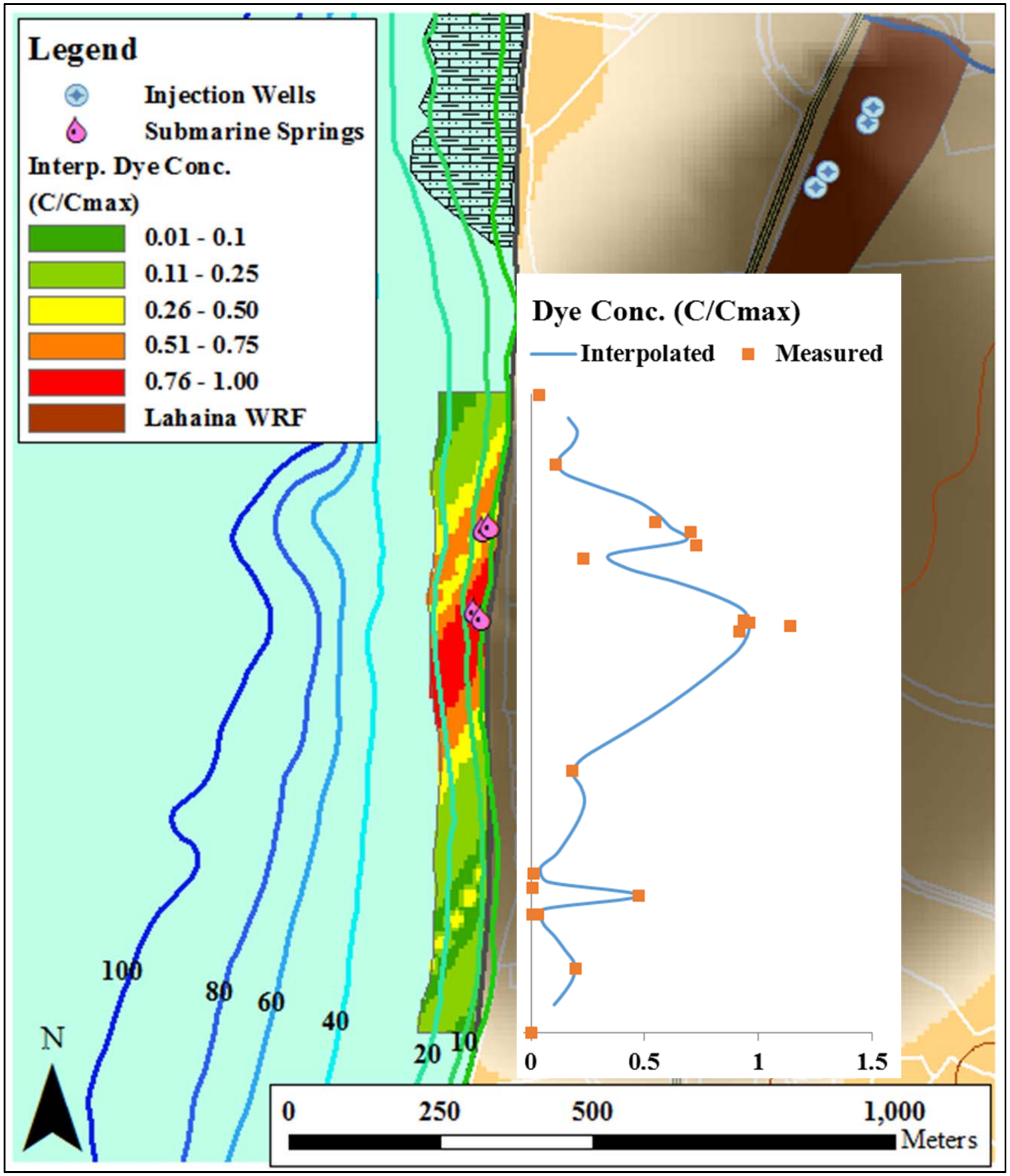
- Measure discharge at a single location for an extended period
- Accounts for variability of discharge during tidal fluctuations





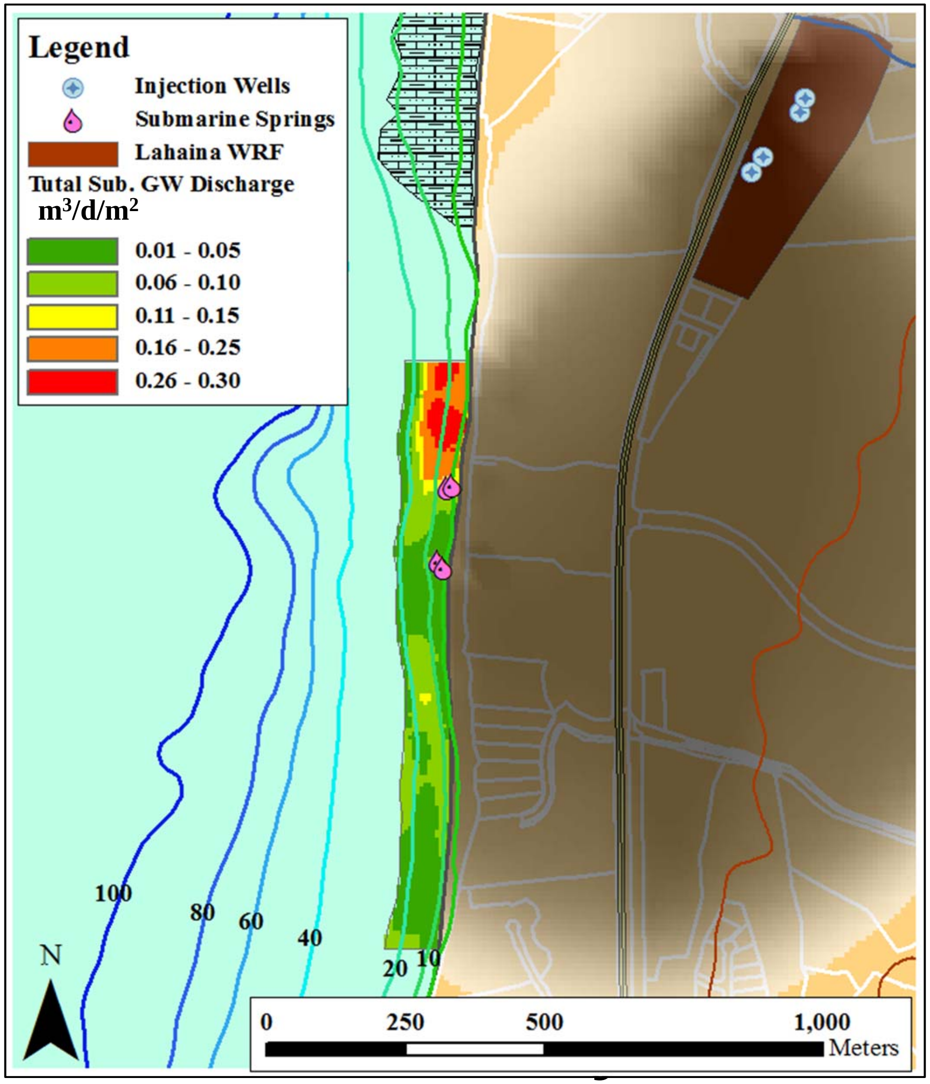
Upscaling Point Measurements

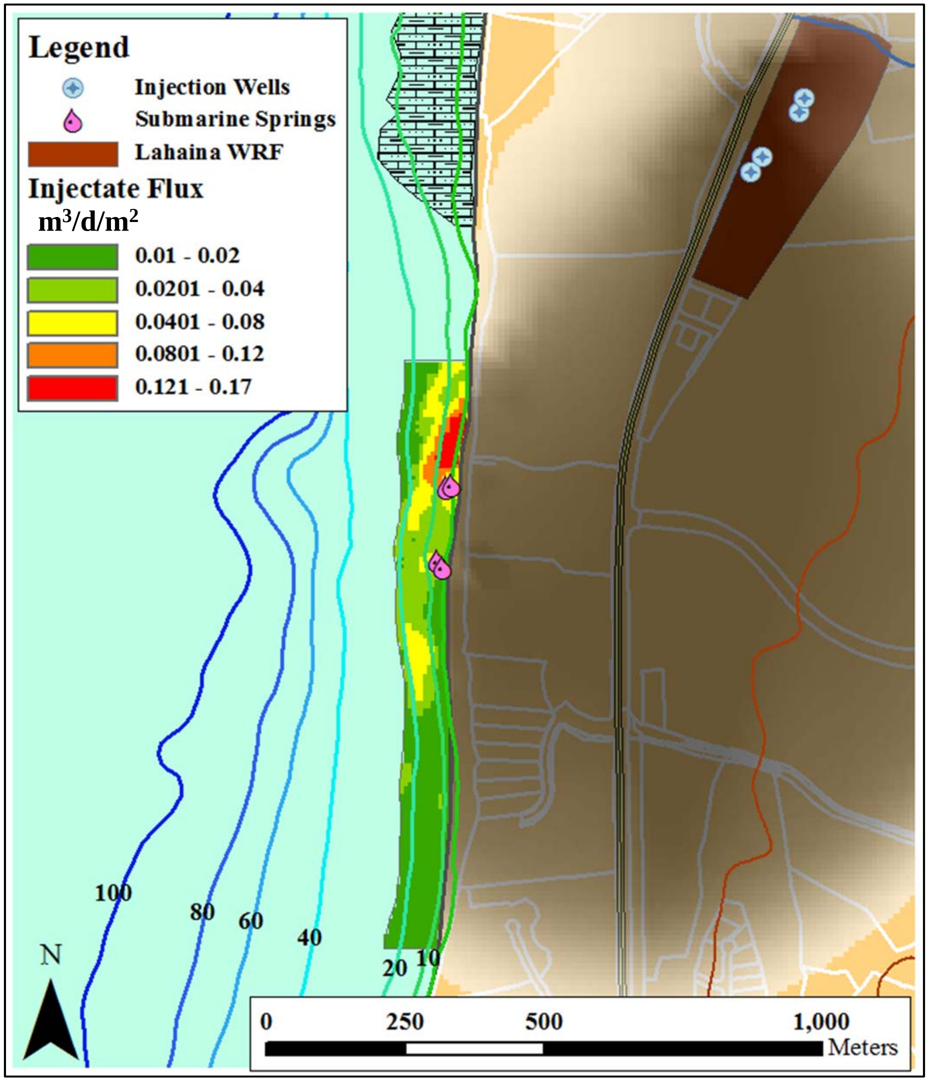
- Radon time series measurements done at each seep group in June and Sept., 2011
- What is the appropriate area to extrapolate the point measurements up to?
- Flux values were extrapolated to boxes (violet) in Craig et al., 2012
- Green polygons represent the perimeters of the active spring area as identified in Craig et al., 2013



Tracer Plume Delineation

- Nearshore sea bottom survey
- Three rounds of shoreline sampling
- Showed the width of the tracer plume at the shoreline was about 1050 m
- Units are $C/C_{seep\ 3}$
- Where $C_{seep\ 3}$ was concentration measured at Seep 3 on the day plume delineation sample was collected
- Seep 3 was the time series sampling point with the highest peak concentration



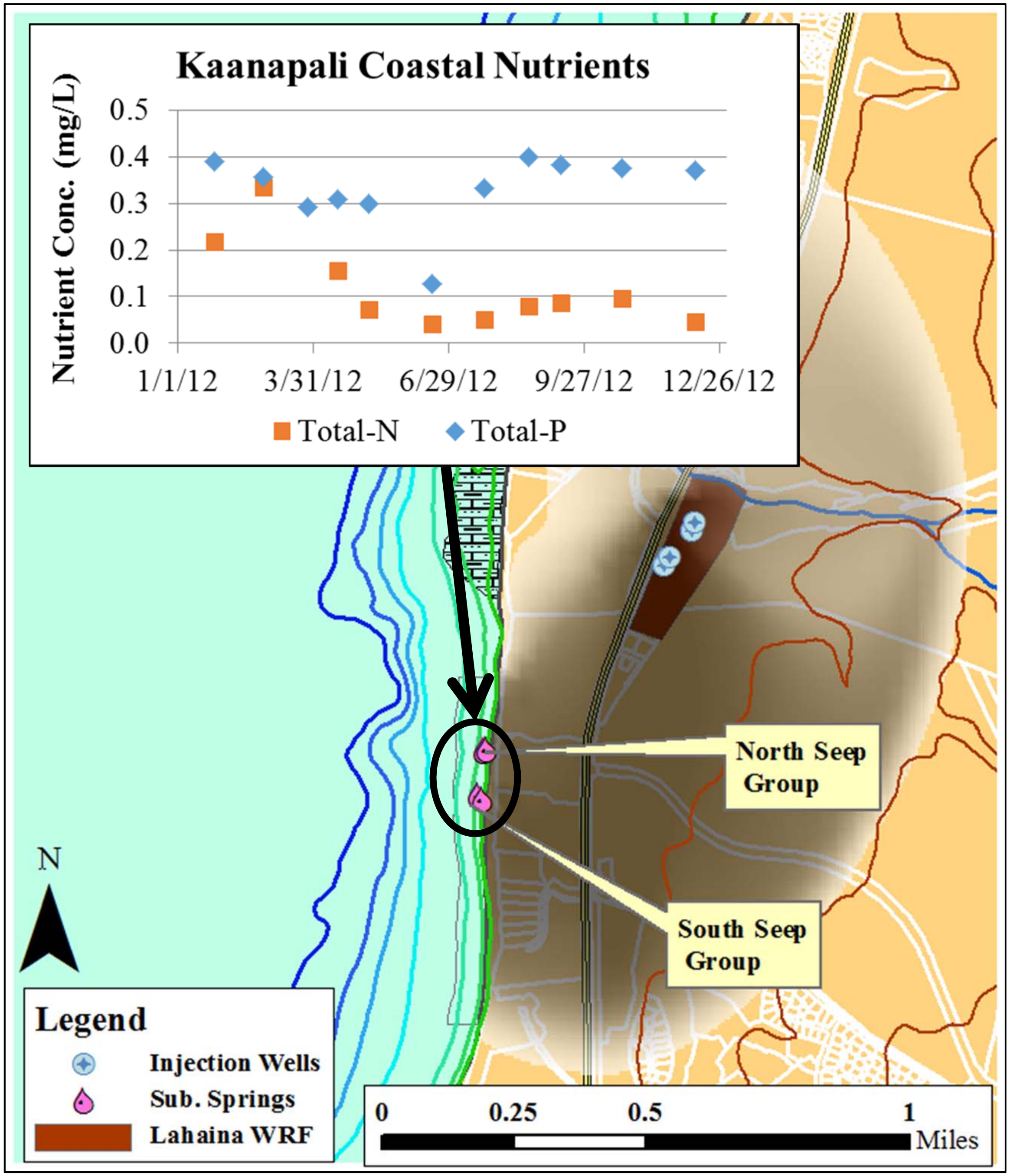


Total SGD Distribution

- Units are discharge per square meter
- Sum of discharge at all TIN vertices

Injectate Discharge Distribution

- Fraction of injectate in SGD using dye distribution and % dye recovery
- Significant injectate discharge to the south



Coastal Nutrient Sampling

- UH sampled in June and Sept., 2011
- HDOH has collected monthly samples since Jan., 2012
- Period used for this analysis is from Jan. through Dec., 2012
- Sampled at submarine springs only
- Distribution of nutrient discharge estimated using tracer dye distribution
- Sample results show significant nitrogen loss between injection and discharge

Estimated Nutrient Loads

Parameter	Coastal Survey Only	Large Polygon	Small Polygon	Honokawai Aquifer*
Total SGD (mgd):	1.96	4.09	2.72	23.5
Length of Shoreline (mi):	0.66	0.66	0.66	7.34
SGD per mi of shoreline (mgd/mi)	3.0	6.2	4.1	3.20
Percent of Wastewater Injected into Wells 3&4:	24%	88%	42%	
Injectate Discharge (mgd):	0.69	2.51	1.21	
Nitrogen Flux (kg/d):	0.39	1.42	0.69	
Phosphorus Flux (kg/d):	1.05	3.80	1.83	

* Recharge from Engott and Vana (2007) minus pumpage

Nutrient Loading Results Compared With Other Studies

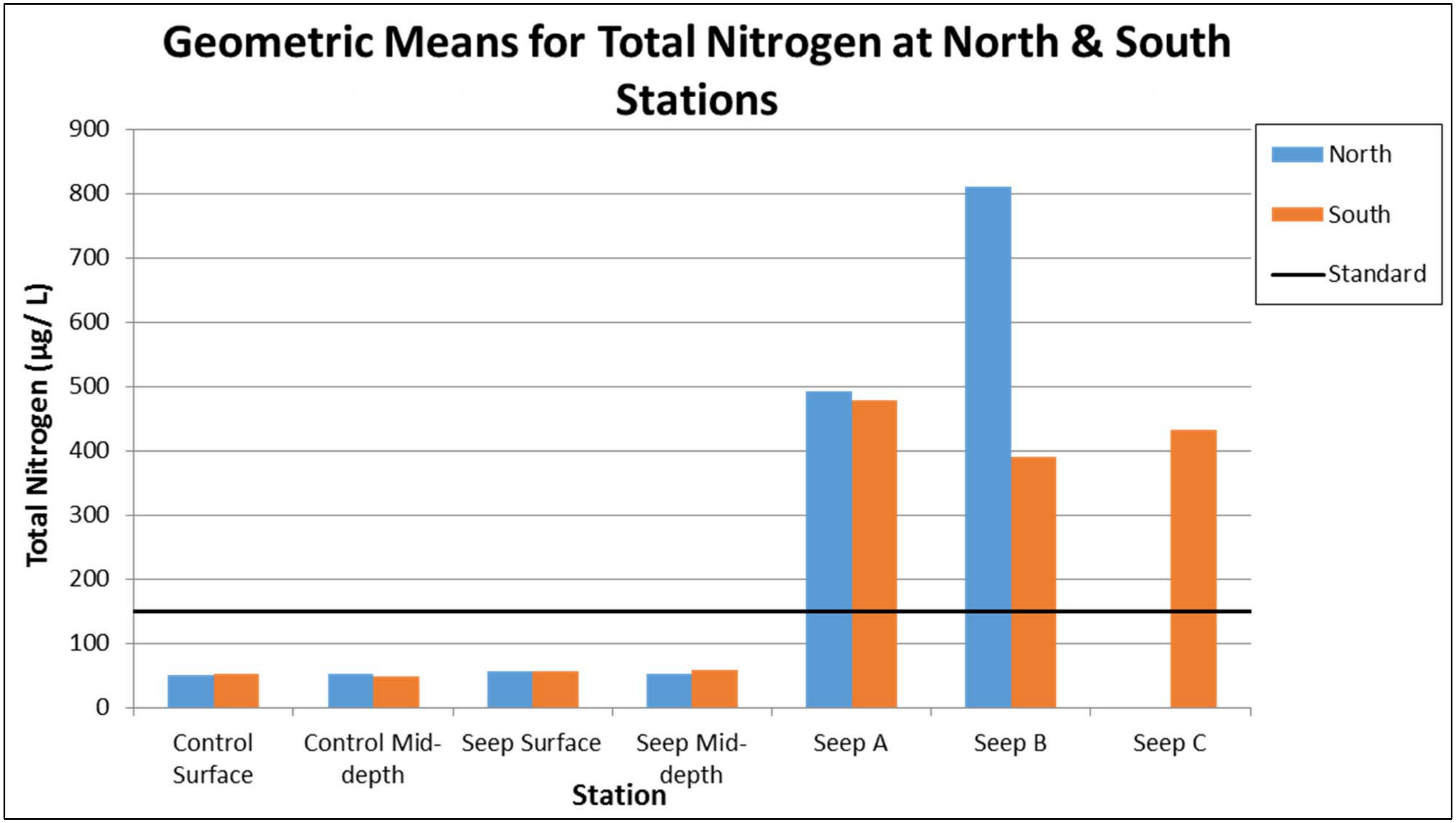
Study	Total N Conc. mg/L	Total P Conc. mg/L	N Flux lbs/yr	P Flux lbs/yr	Comments
TetraTech, 1993	12.0	10.2	150,000	130,000	Plant upgrades have since improved injectate chemistry
Swarzenski et al., 2012	**0.66**	**0.37**	**1,535**	**834**	**Seep discharge extrapolated to an assumed plume width of 50 m**
Craig et al., 2013	1.1	0.44	7,577	3,074	Total N & P flux in delineated seep rectangles
This Analysis	**0.15**	**0.40**	**949**	**2,530**	**Includes contribution of Wells 1 & 2**

Somewhat like comparing apples and oranges!

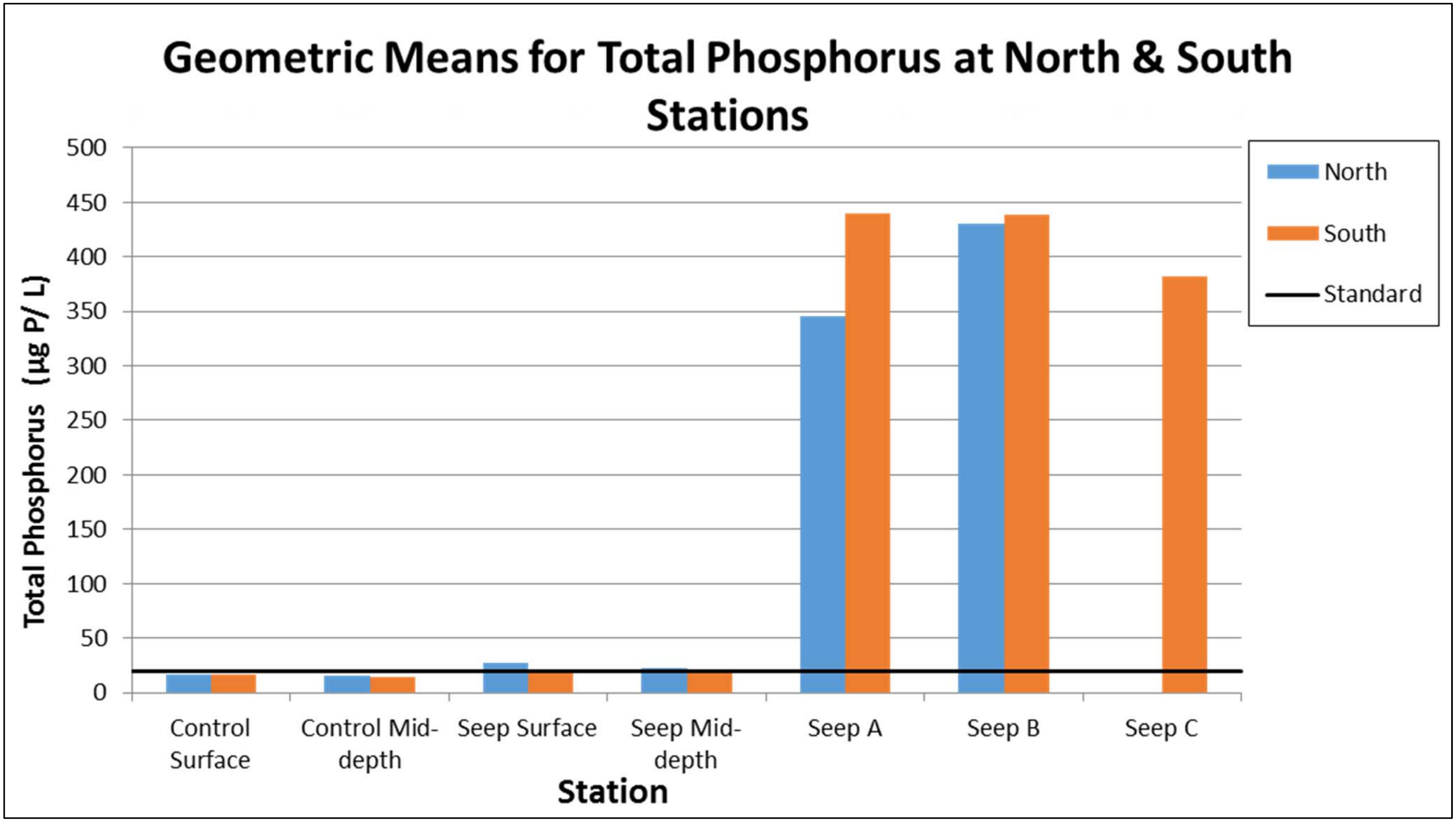
Continuing Work Investigating the Coastal Chemistry Due to Wastewater Injection

HDOH Coastal Seep Sampling

- Monthly sampling:
  - Nutrients
  - Water quality parameters
  - Seep and control sites
  - Residual chlorine
- Special sampling:
  - Indicator bacteria
  - Organic contaminants and metals
  - Pharmaceuticals
  - Molecular indicators of wastewater
- From Jan. 2012 to the present
- Expect to end sampling December, 2014



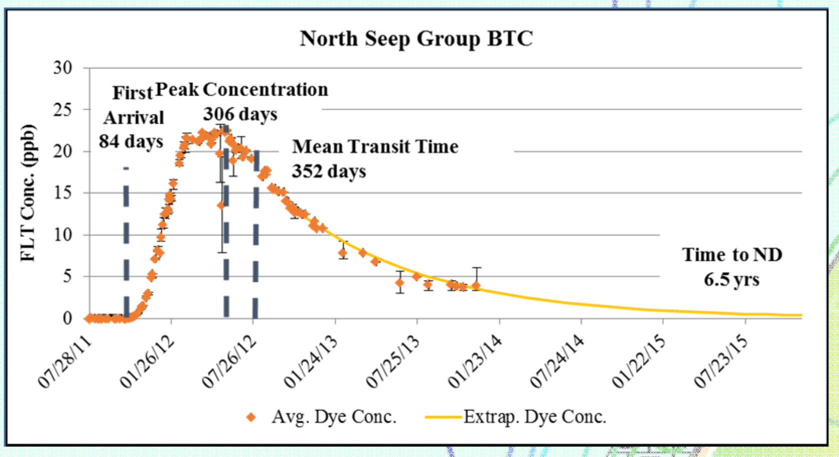
Geometric means for Total Nitrogen are represented for control and seep locations. The solid line depicts the open coastal standard of 150 µg N/ L for Total Nitrogen.



Geometric means for Total Phosphorus are represented for control and seep locations. The solid line depicts the open coastal standard of 20 µg P/ L for Total Phosphorus.

Conclusions

- Approximately half of the injected wastewater discharges in broad plume near the shoreline
- Nitrogen loading is low due to losses during the one-year travel time to the coast
  - The nitrogen is likely due to denitrification
- There is no apparent loss of phosphorus between injection and discharge at the coast
- Combining a tracer test with a radon survey and nutrient sampling is an optimum approach to estimate coastal nutrient loading from wastewater injection



North Seep Group BTC
FLT Conc. (ppb)
30
25
20
15
10
5
0
First Arrival 84 days
Peak Concentration 306 days
Mean Transit Time 352 days
Time to ND 6.5 yrs
07/28/11
01/26/12
07/26/12
01/24/13
07/25/13
01/23/14
07/24/14
01/22/15
07/23/15
Avg. Dye Conc.
Extrap. Dye Conc.

MAHALO!