Results of Sampling for Wastewater Tracers At and Near Kealakehe WWTP, Kona, Hawaii

USGS / Hawaii Dept. of Health Cooperative Program

— Wastewater Source Tracking —

Briefing presentation, March 13, 2008

Chip Hunt

Ground-Water Hydrologist

U.S. Geological Survey, Honolulu, HI

cdhunt@usgs.gov

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Acknowledgments

- Thanks to **Mark Norman** and others at Kealakehe WWRF for sampling assistance, and Hawaii County for permission to sample the treated effluent
- Thanks to **Dave Tarnas** for recon and access to monitor wells, and Jacoby Development, Inc for permission to sample
- Thanks to **Nancy Nakata** (Hawaii Dept. of Health) for sampling assistance

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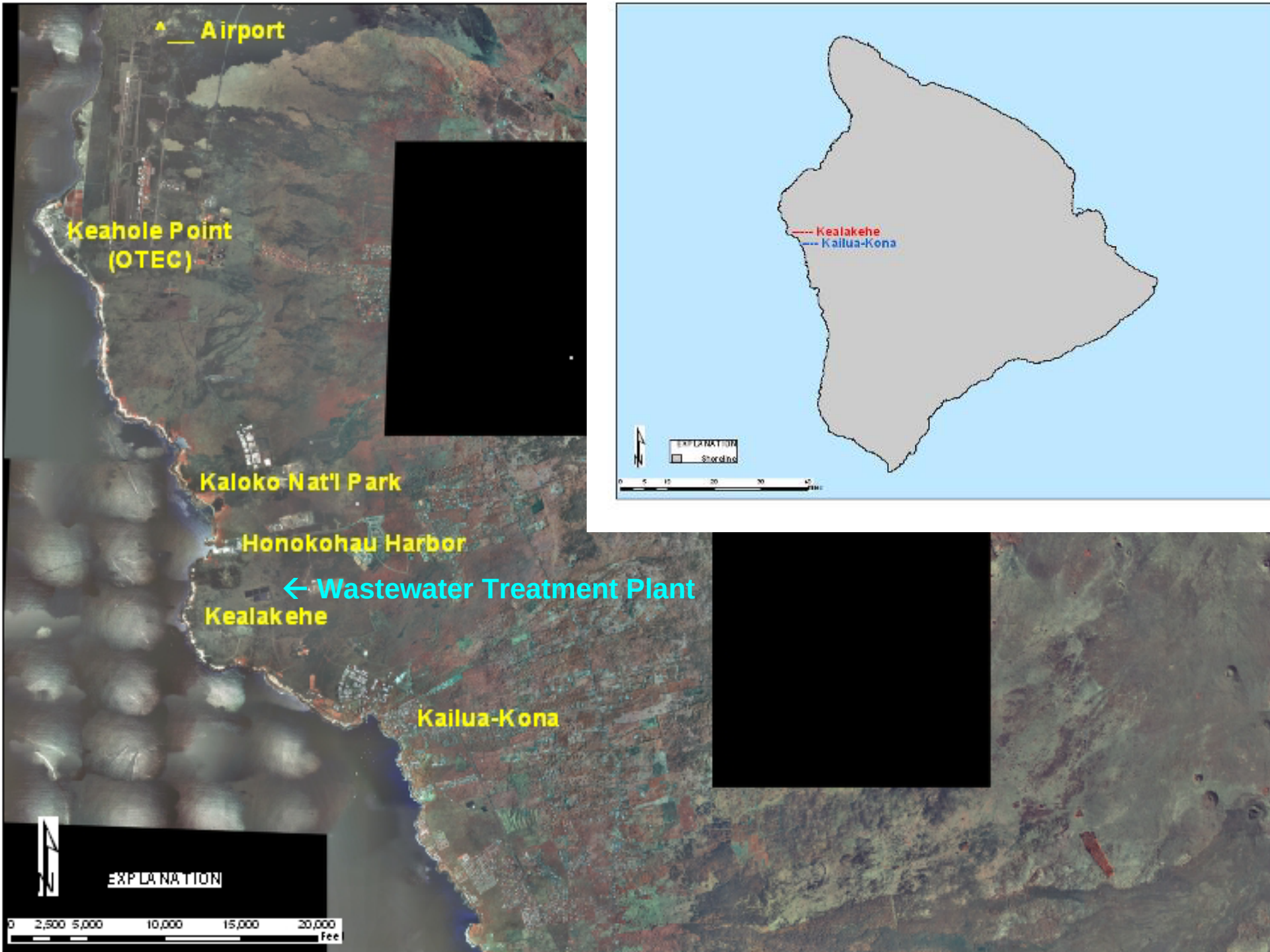
Airport
Keahole Point
(OTEC)
Kaloko Nat'l Park
Honokohau Harbor
← Wastewater Treatment Plant
Kealakehe
Kailua-Kona
EXPLANATION
0 2,500 5,000 10,000 15,000 20,000
Feet
Kealakehe
Kailua-Kona
EXPLANATION
Shoreline

Problem and Approach

- Treated wastewater effluent is discharged to disposal pit in lava field; disappears
- Where does it go? (expected to form a ground-water plume that discharges at nearby coast / Honokohau Harbor)
- Objective—Can we detect or map it?
- Approach—Sample nearby wells and springs for chemical wastewater tracers

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Multi-Tracer Approach

Tracer	Possible Indicator of:
NO_3, NH_4, PO_4	Animal / human waste, fertilizers
^{15}N	Animal / human N vs soil N
^{11}B	Laundry detergents (light ^{11}B)
UV fluorescence at 445 nm	Laundry detergents (optical brighteners) *or* DOM
Indicator bacteria	Fecal source
Pharmaceuticals	Domestic wastewater
WW indicators	Domestic wastewater

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What should a wastewater plume look like?

Municipal injection plume at Kihei, Maui provides a good example

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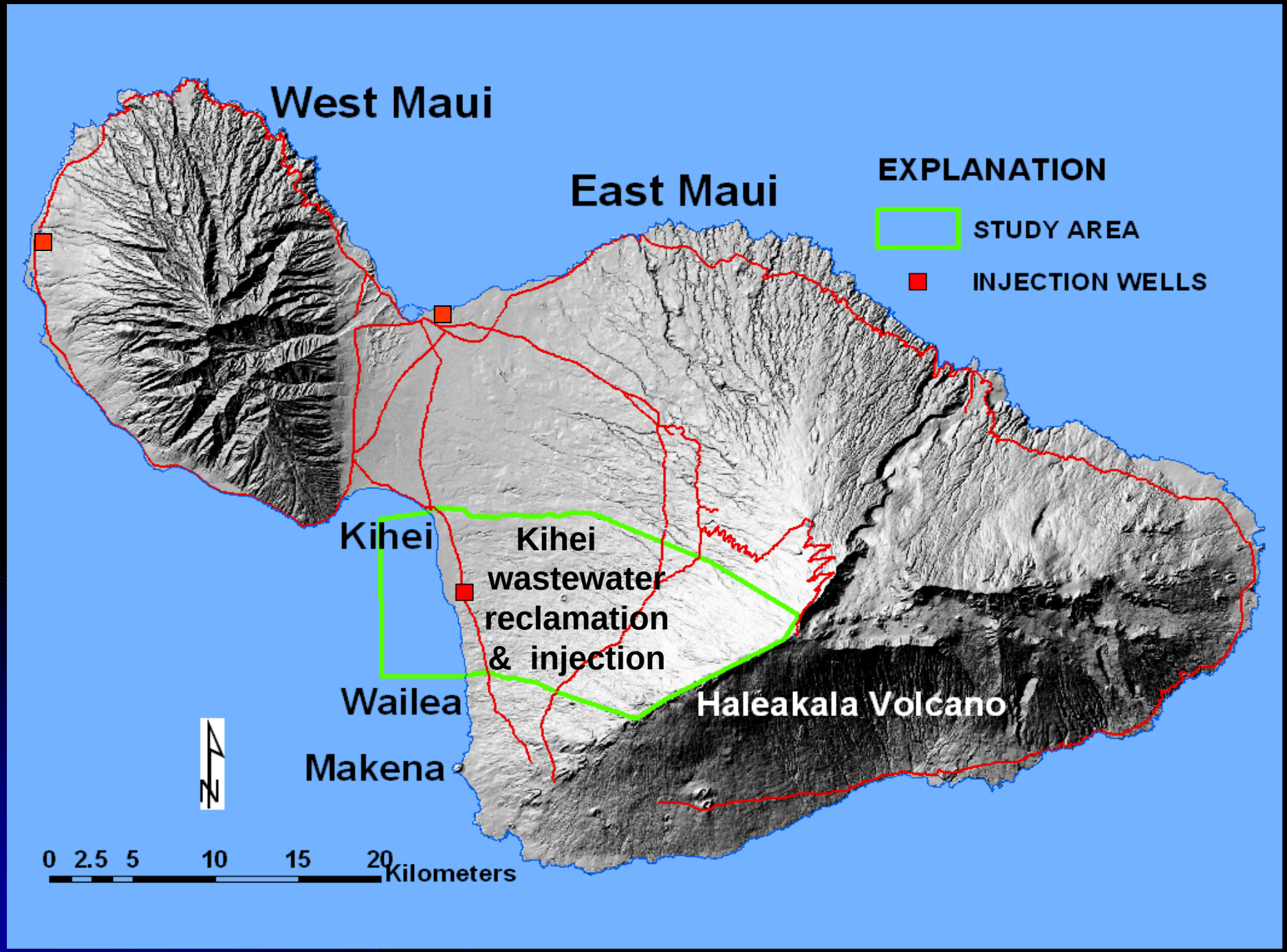
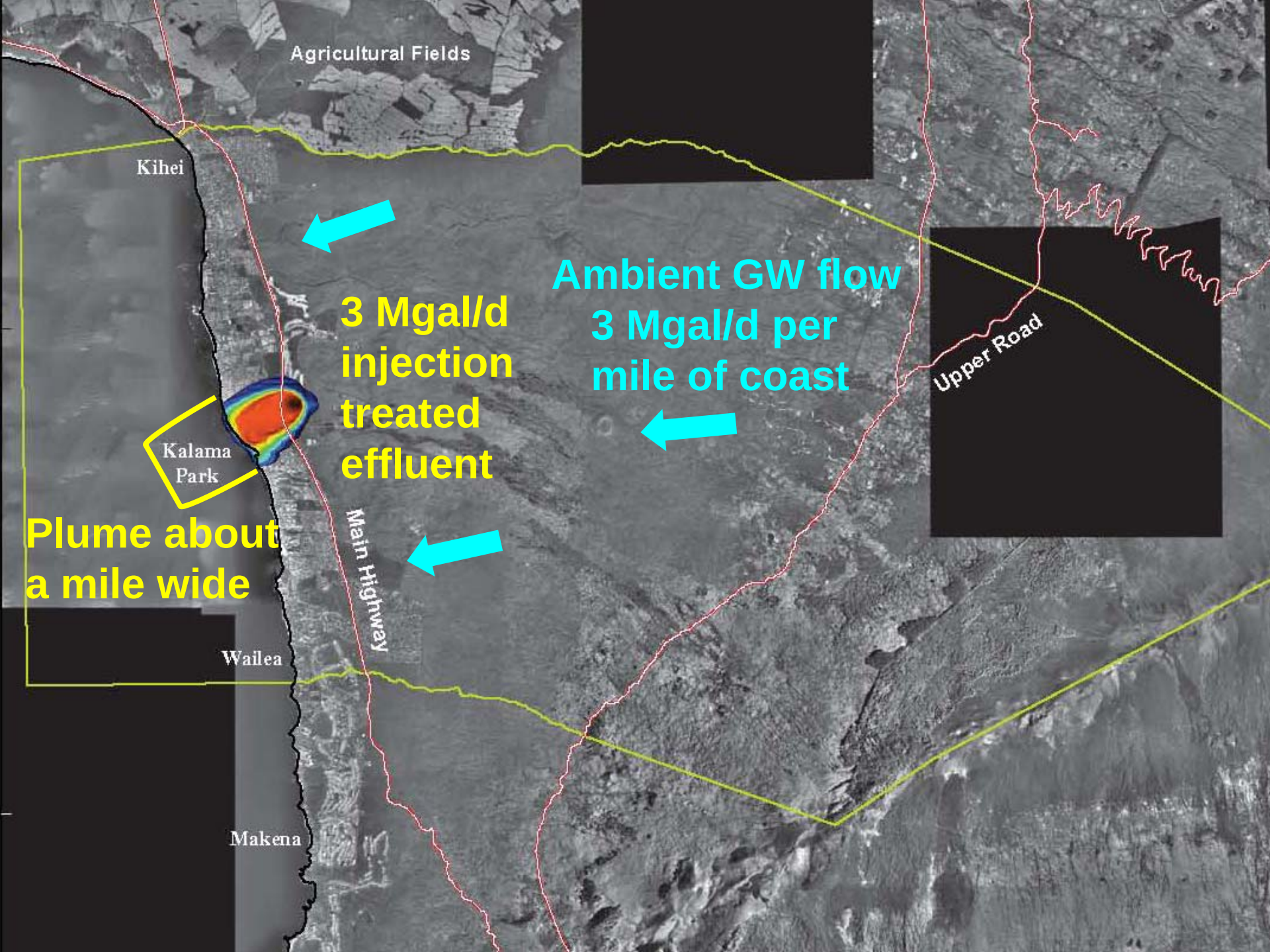
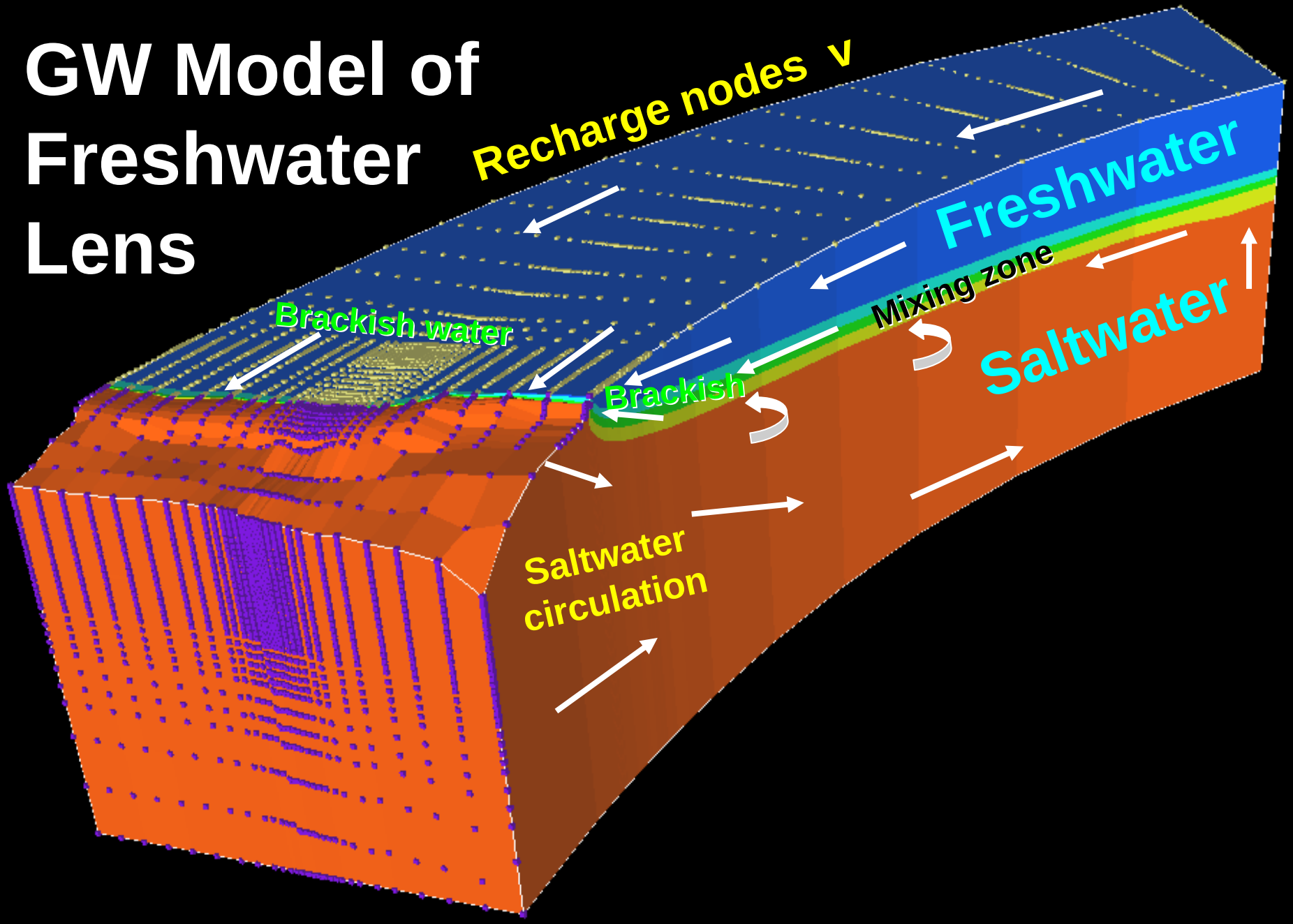

West Maui
East Maui
EXPLANATION
STUDY AREA
INJECTION WELLS
Kihei
Kihei wastewater reclamation & injection
Wailea
Makena
Haleakala Volcano
N
0 2.5 5 10 15 20 Kilometers

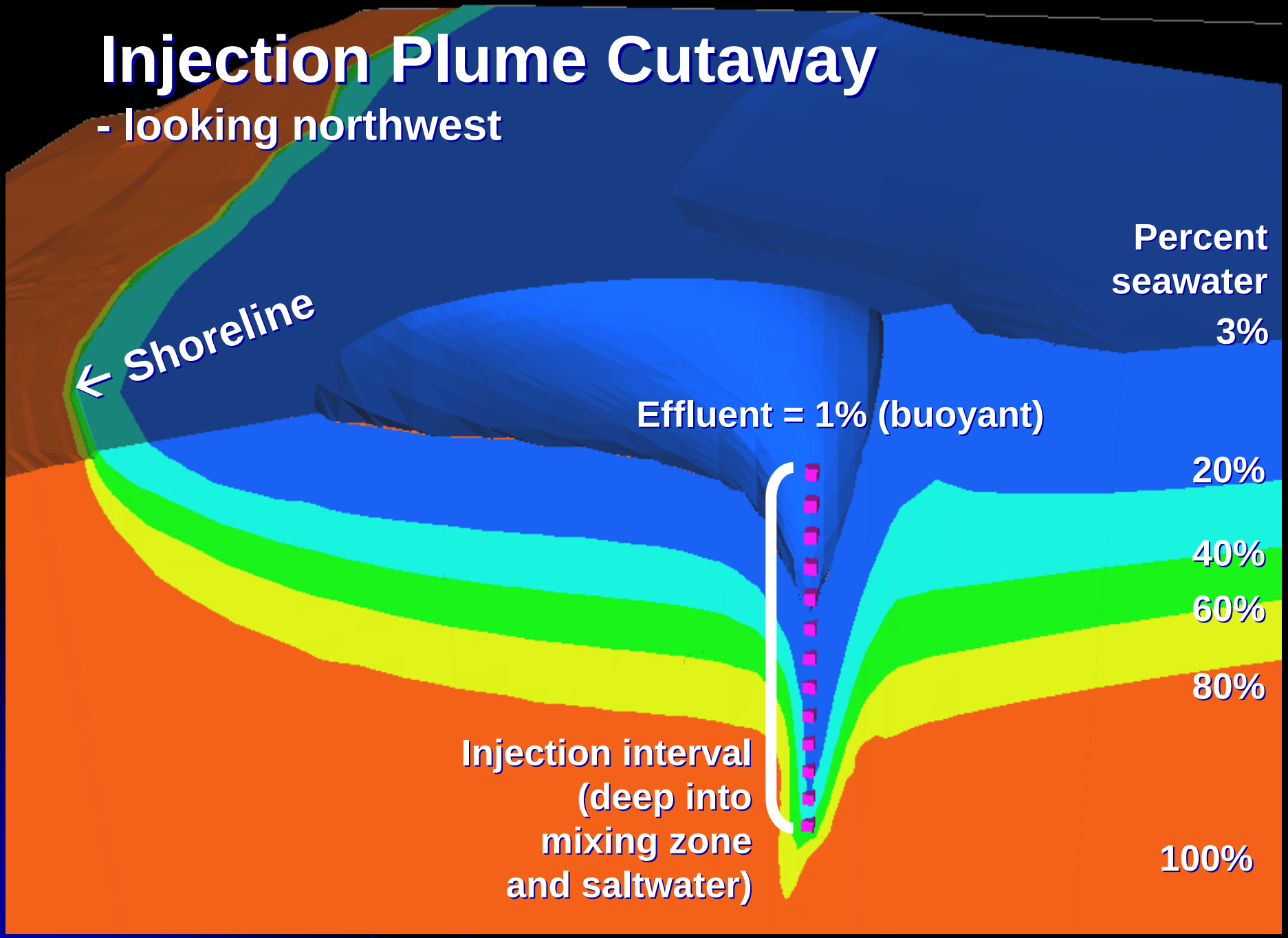

Agricultural Fields
Kihei
Ambient GW flow
3 Mgal/d per
mile of coast
3 Mgal/d
injection
treated
effluent
Upper Road
Kalama
Park
Plume about
a mile wide
Main Highway
Wailea
Makena

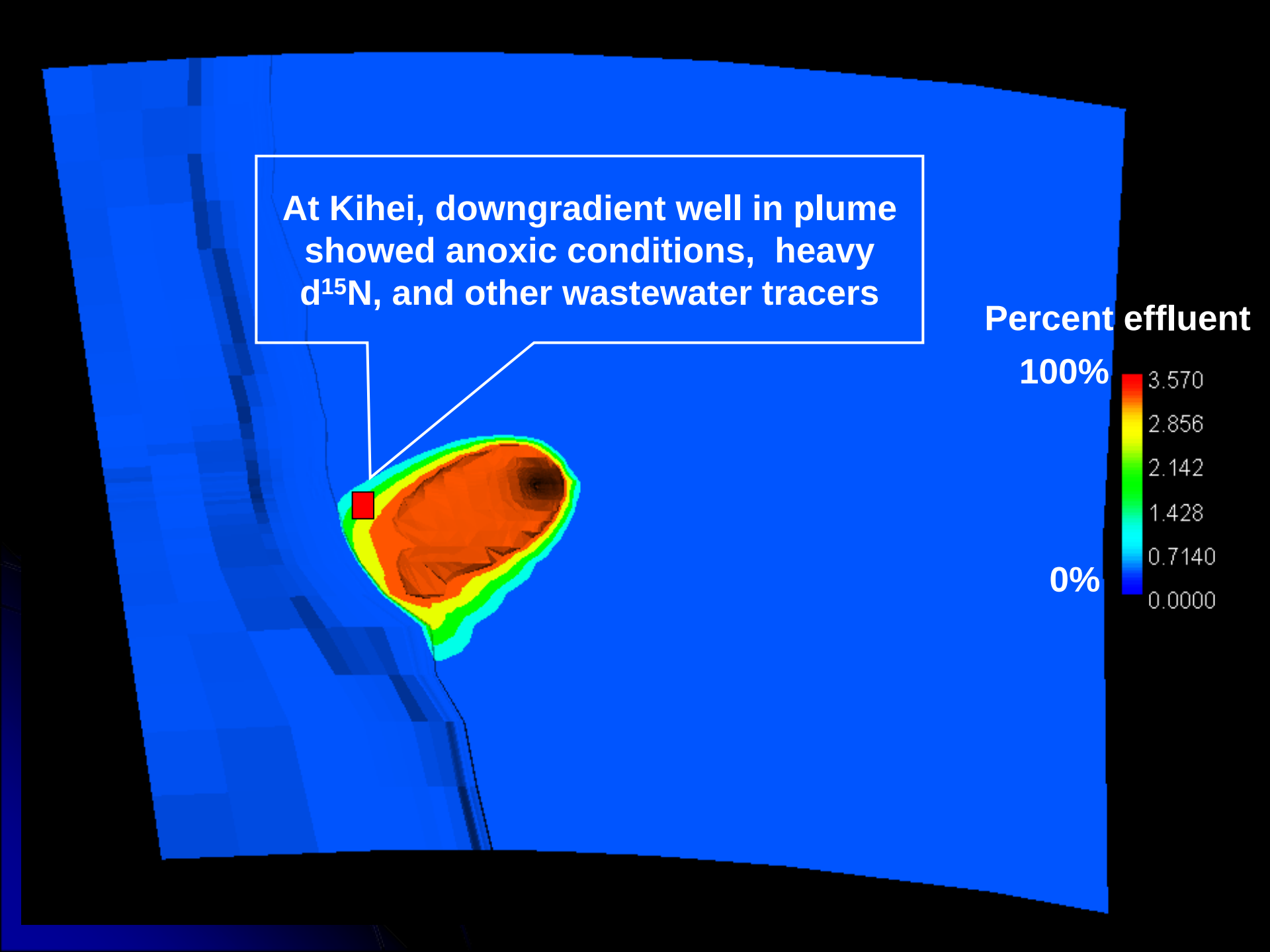
GW Model of Freshwater Lens

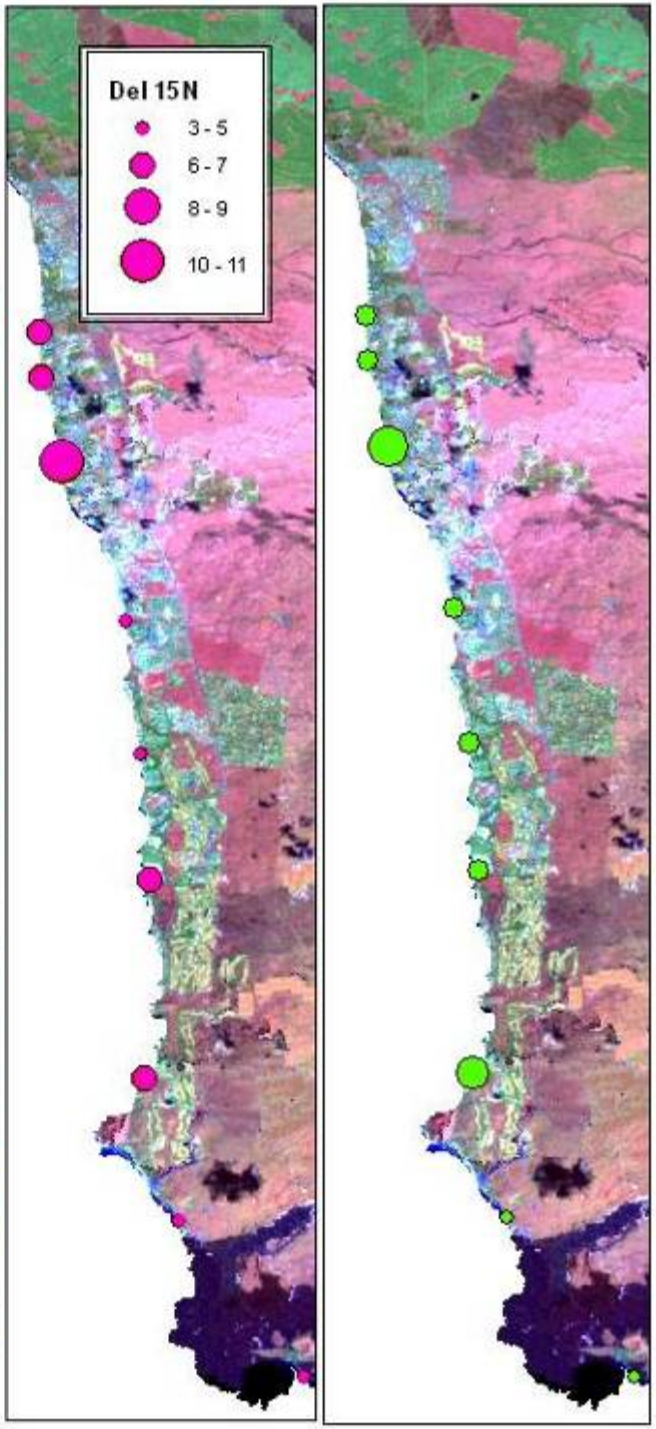


Injection Plume Cutaway

- looking northwest



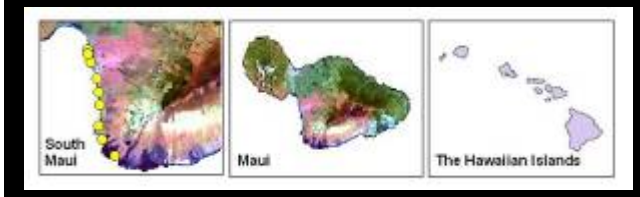

At Kihei, downgradient well in plume showed anoxic conditions, heavy d15N, and other wastewater tracers
Percent effluent
100%
0%
3.570
2.856
2.142
1.428
0.7140
0.0000



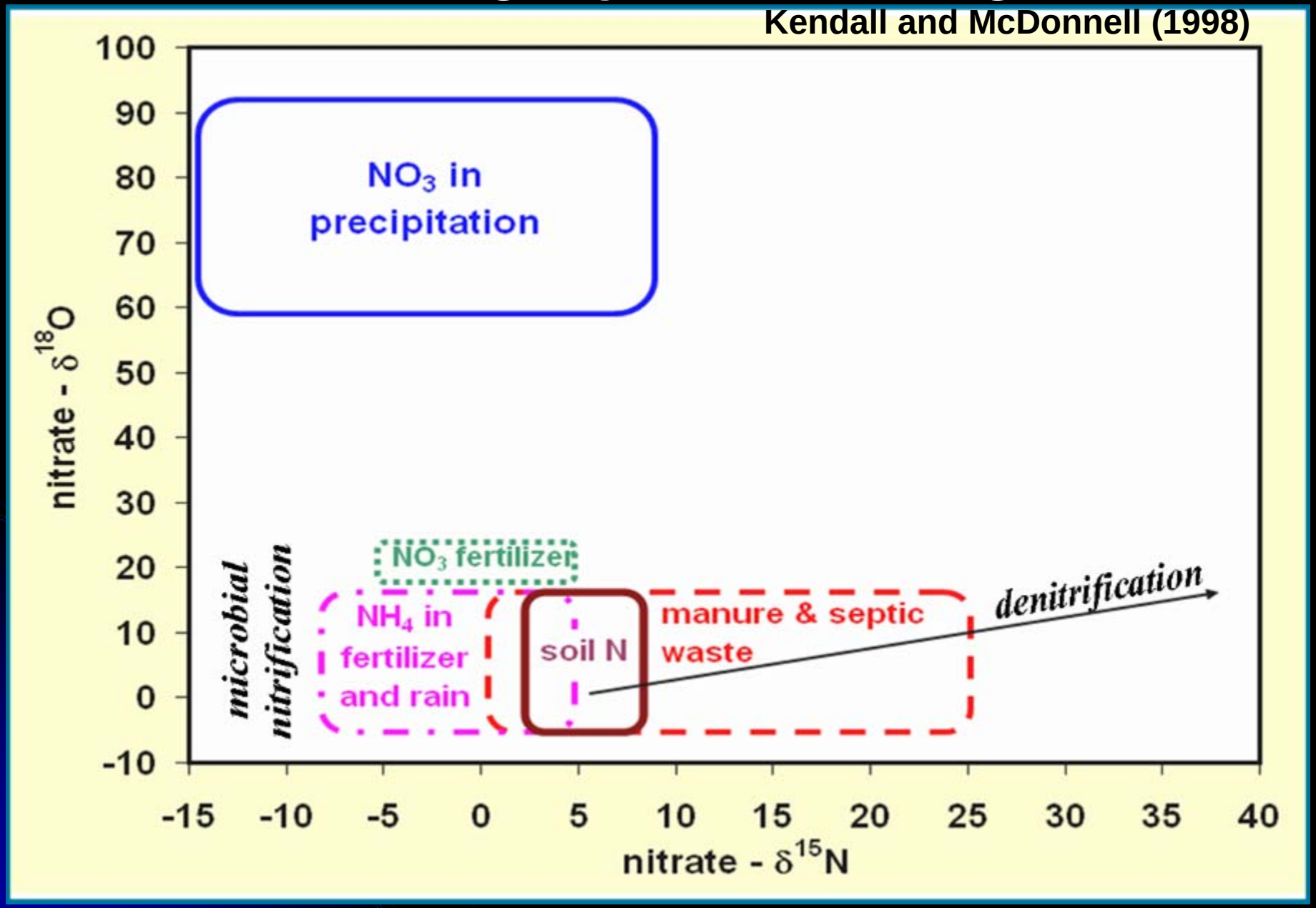
Heavy $\delta^{15}N$ also measured in marine algae near Kihei plume by UH scientists

- *Hypnea*
- *Ulva*

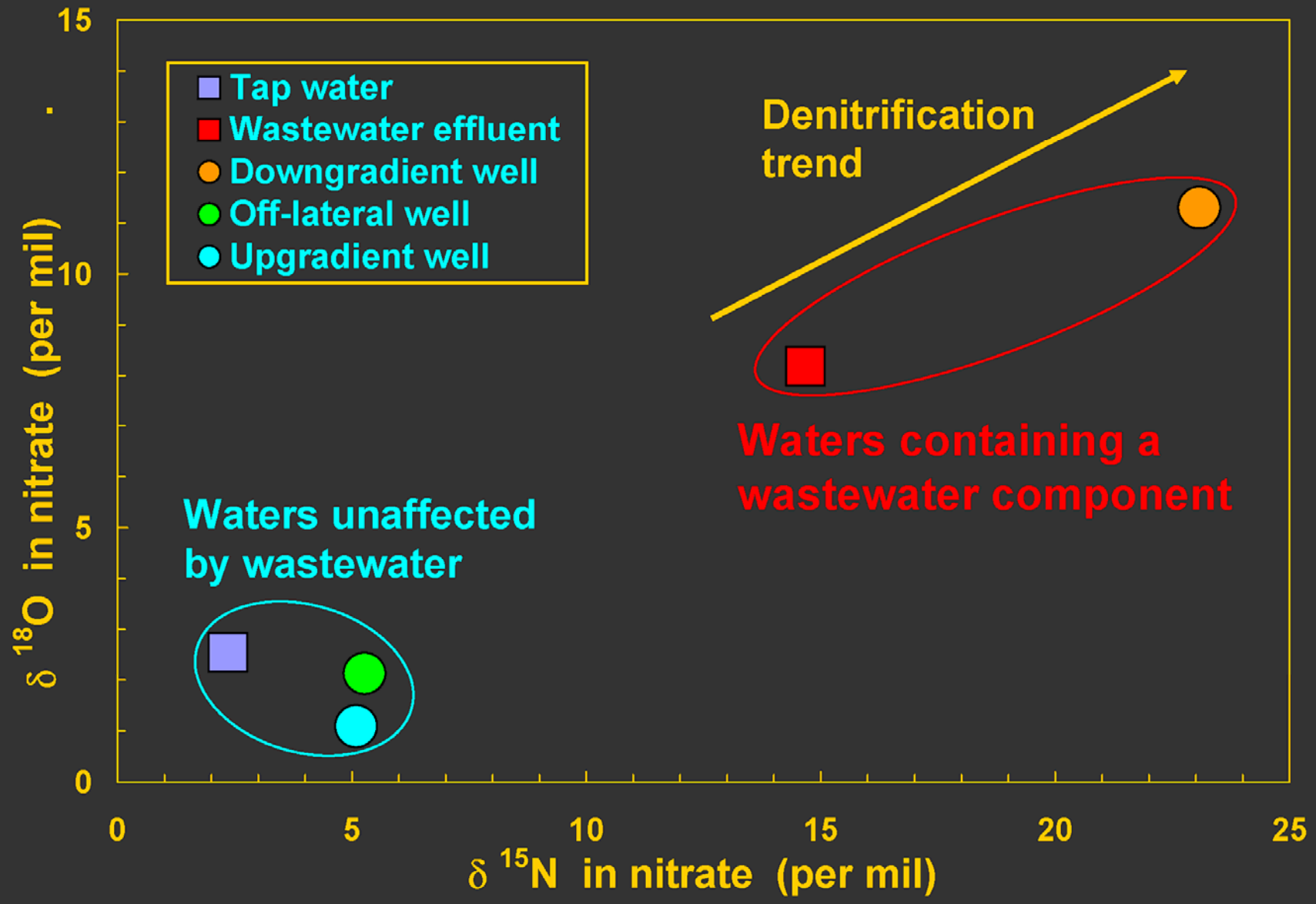
Celia Smith and Jennifer Smith, Univ. of Hawaii



What does ^{15}N signify? Ans: Nitrogen Source



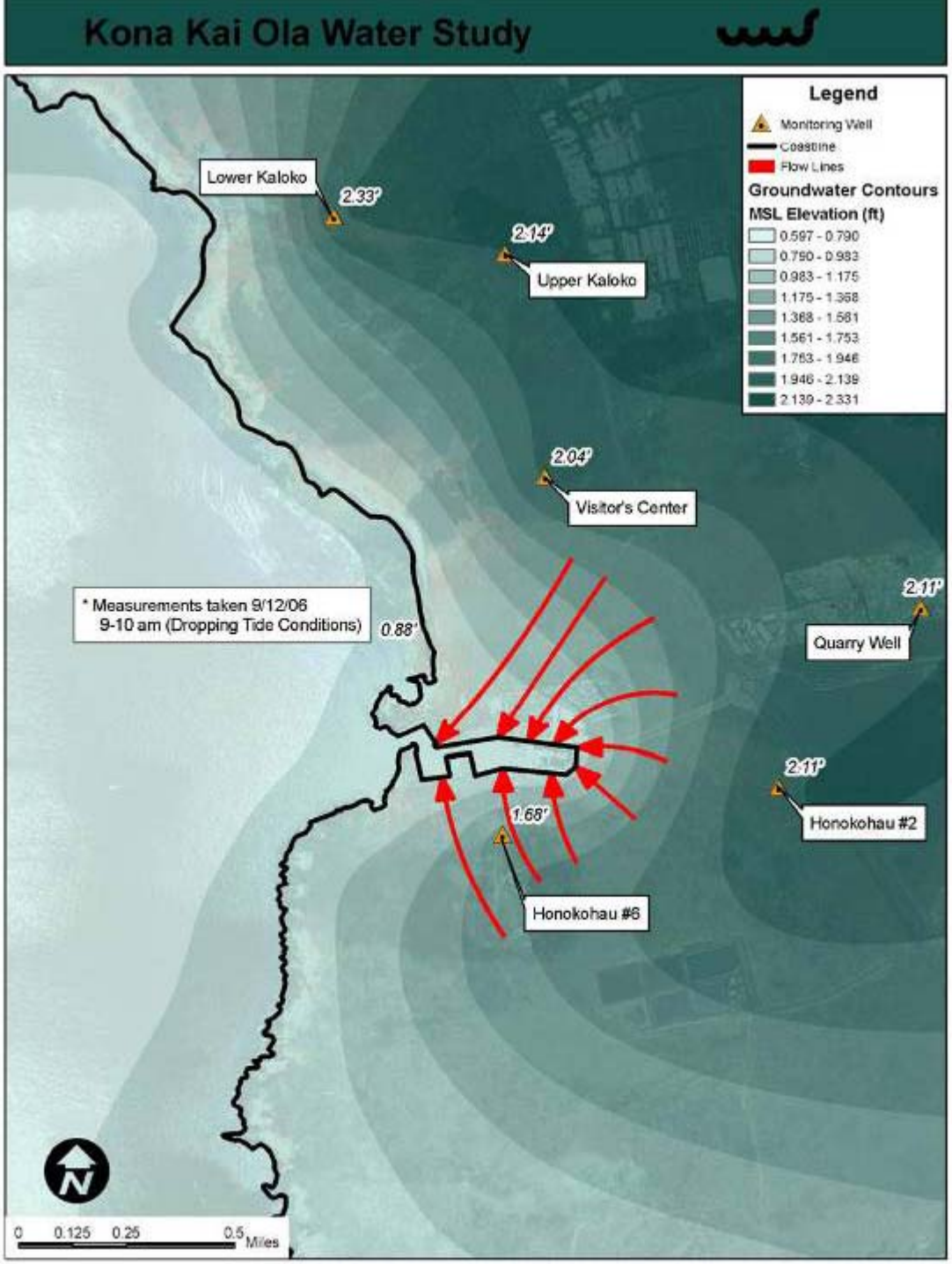
Here's how ^{15}N worked out at Kihei



Back to Kona …

Concept of ground-water convergence to harbor

(Bowles, Mink, & Yuen, 2006)



Thermal Infrared Imagery

Glenn (2006)

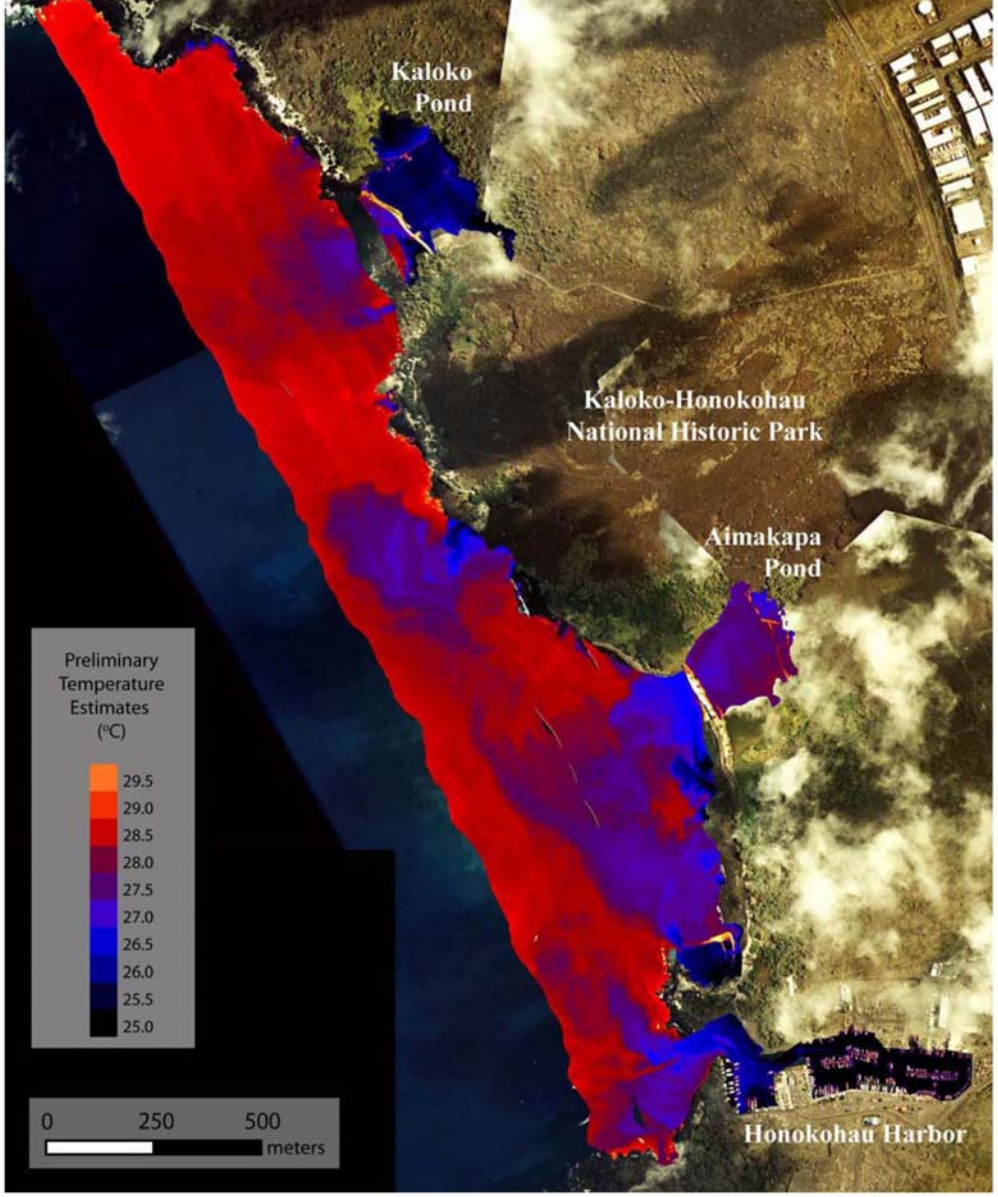
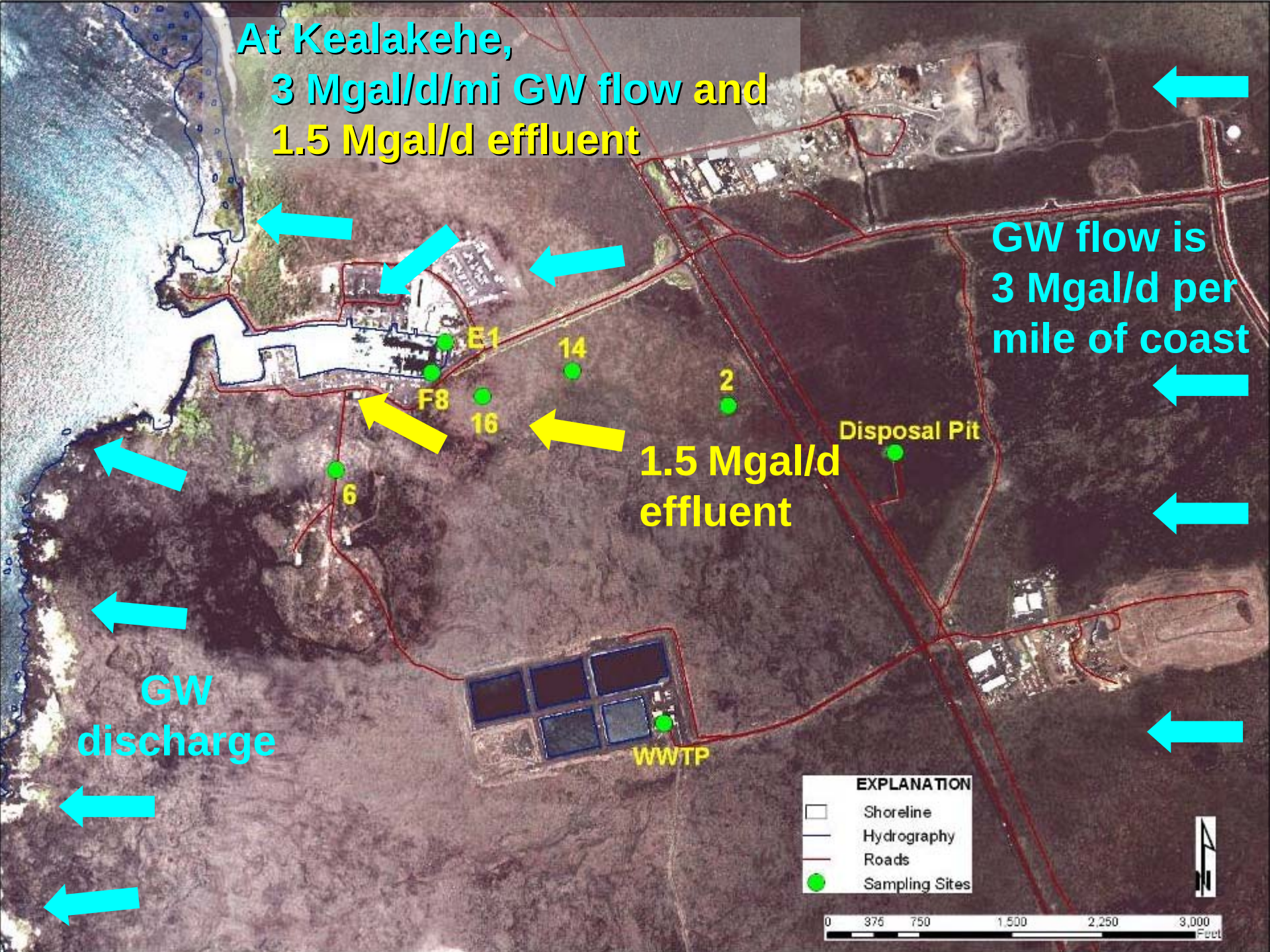


Figure 1. Surface water temperature map of Kaloko-Honokohau Park and Honokohau Harbor area produced from August 2005 aerial infrared survey. Temperatures shown are preliminary estimates pending surface layer and/or atmospheric corrections. Cooler brackish waters leaking as submarine groundwater discharge form buoyant nutrient-enriched plumes extending out from the shoreline.


At Kealakehe,
3 Mgal/d/mi GW flow and
1.5 Mgal/d effluent
GW flow is
3 Mgal/d per
mile of coast
E1
14
2
F8
16
Disposal Pit
1.5 Mgal/d
effluent
6
GW
discharge
WWTP
EXPLANATION
Shoreline
Hydrography
Roads
Sampling Sites
0
375
750
1,500
2,250
3,000
Feet

Potential sampling sites: monitor wells and borings drilled for harbor-expansion study (recon showed that many are now obstructed)

Source: MACTEC Engineering & Consulting, Inc.

Figure M: Boring Locations

Legend

- Deep Well Monitoring Location
- Boring Locations within Planned Marina
- General Subsurface Boring Locations

N W E S

0 2,000 4,000 Feet

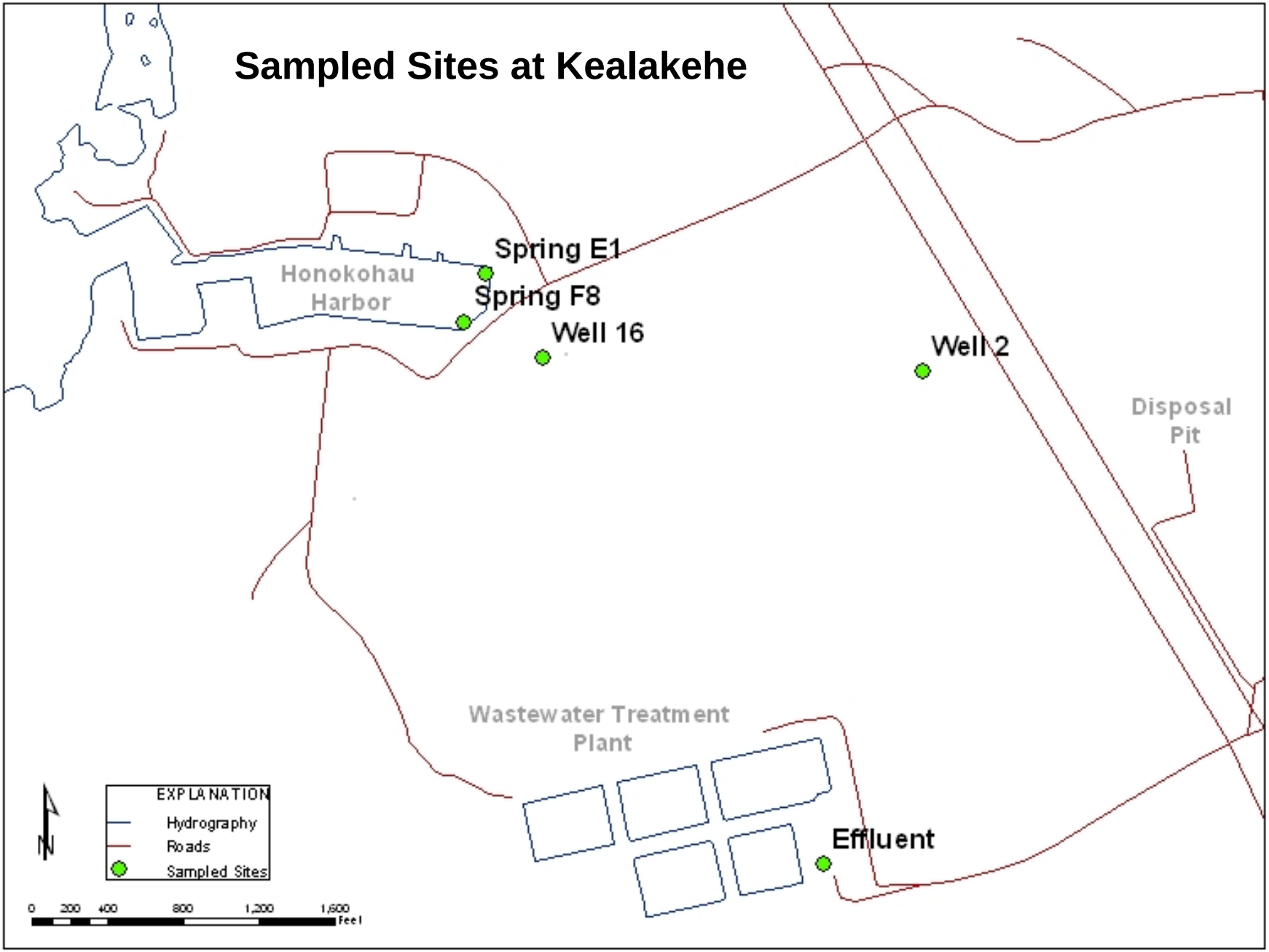
oceanit

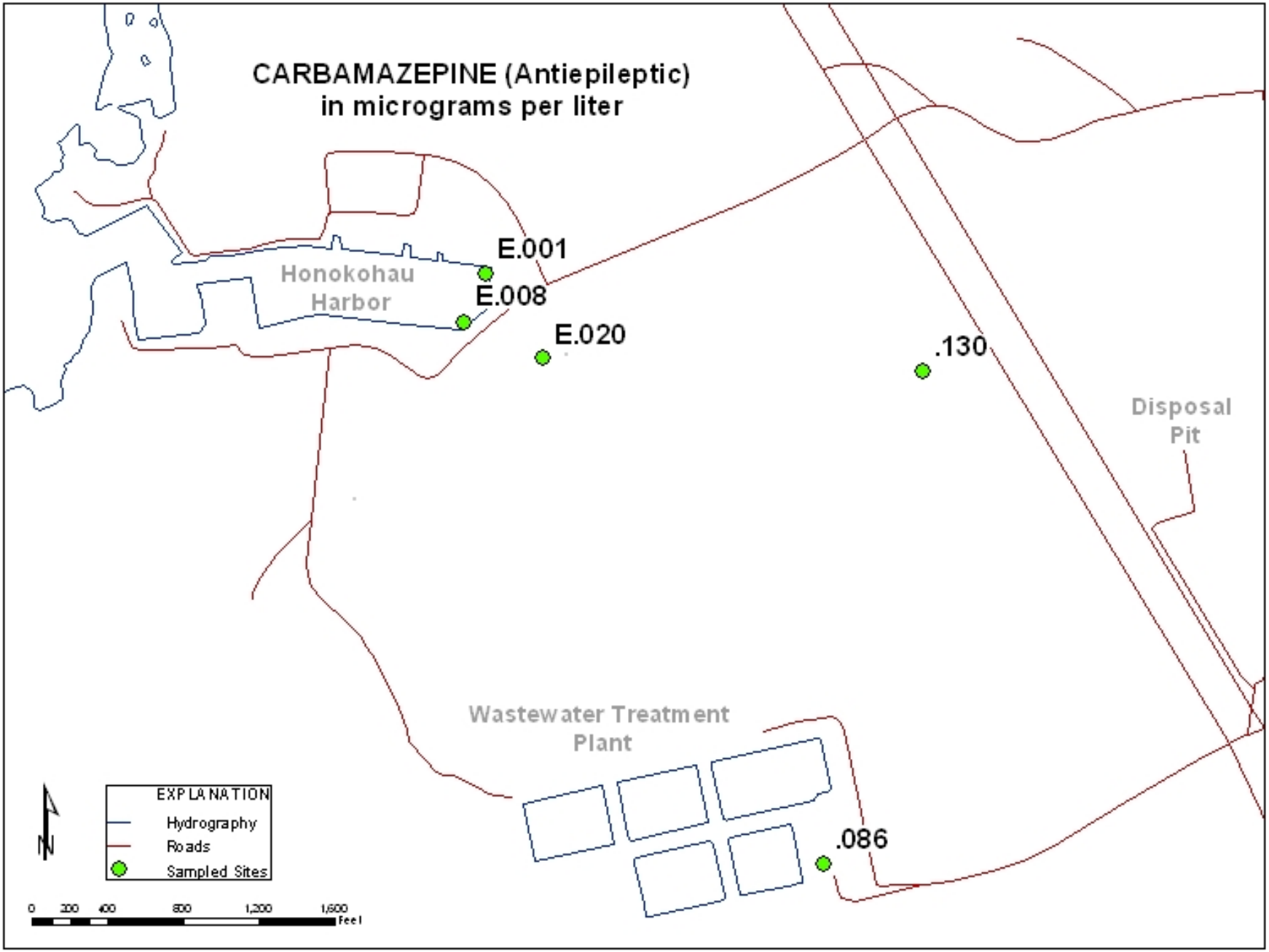
innovation through engineering & scientific excellence

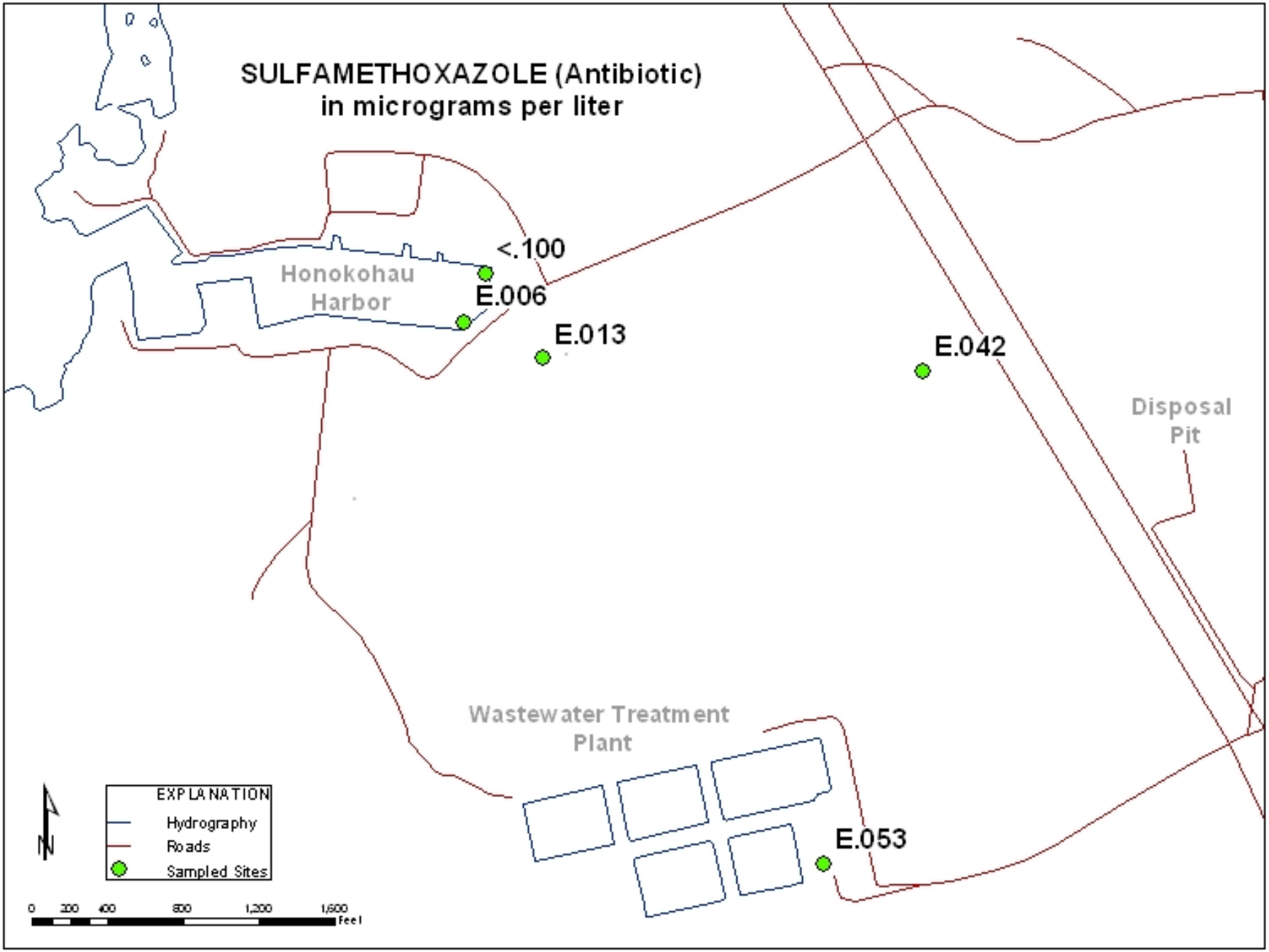
JDI

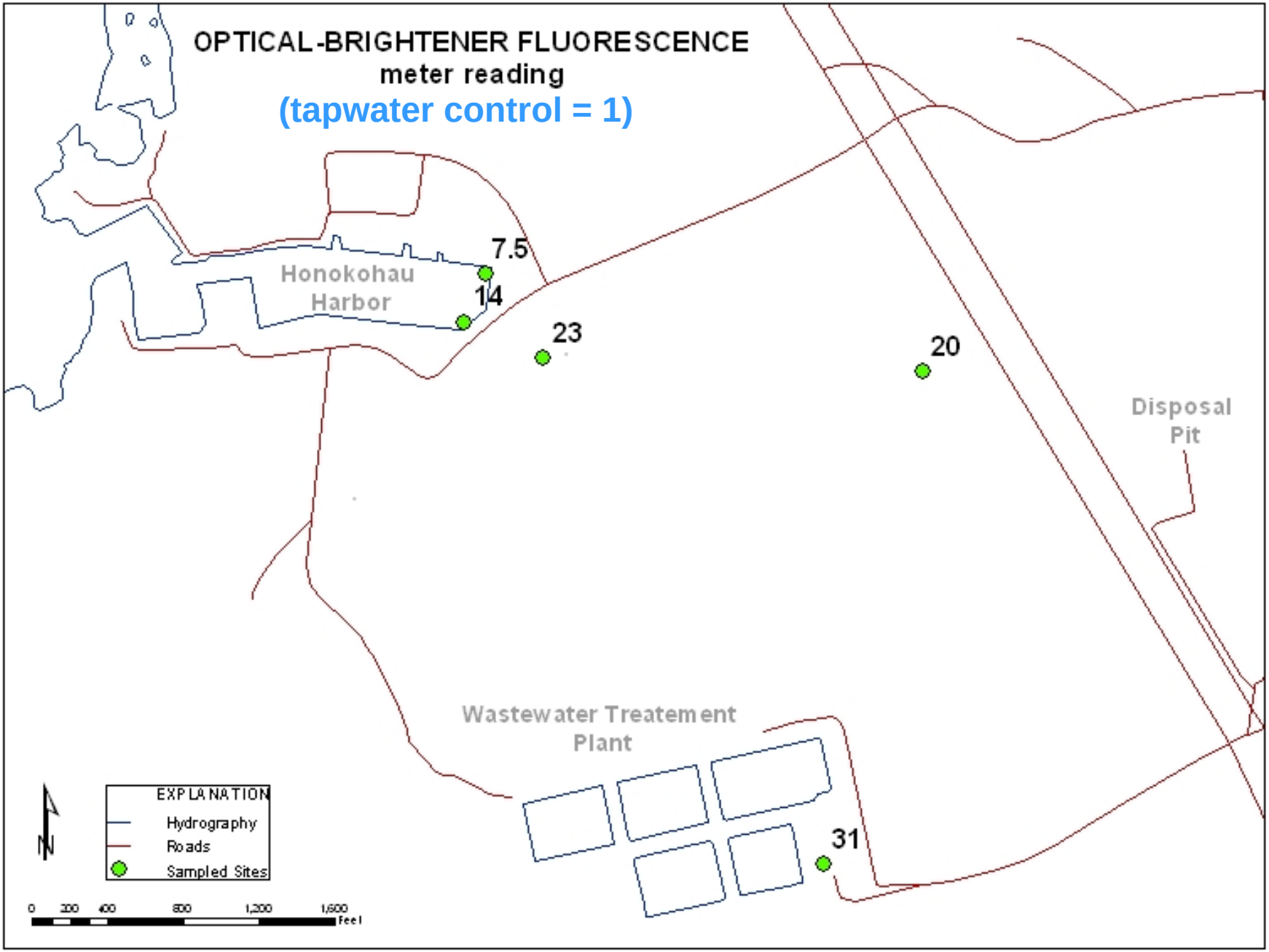
JACOBY DEVELOPMENT, INC.

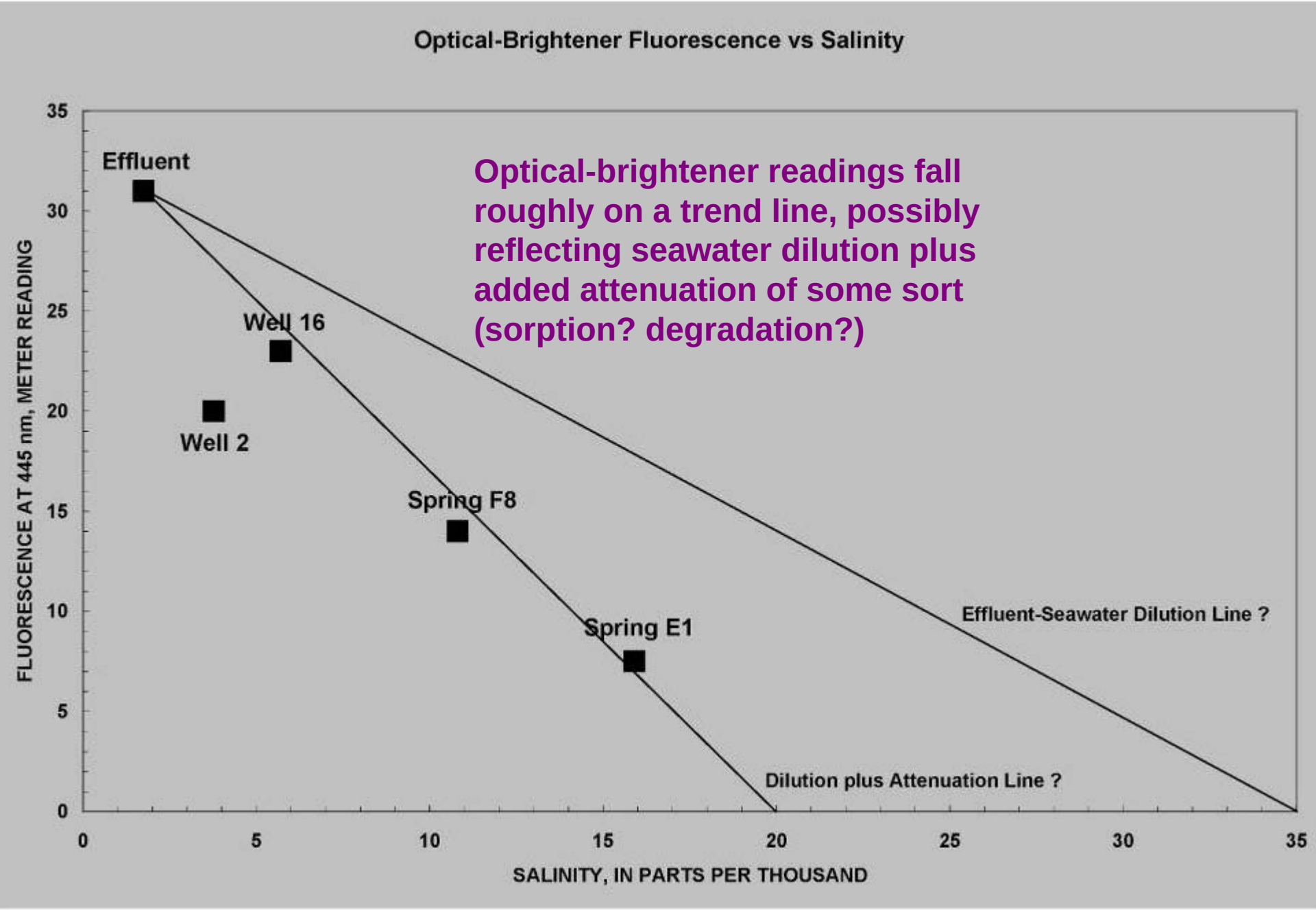
Sampled Sites at Kealakehe

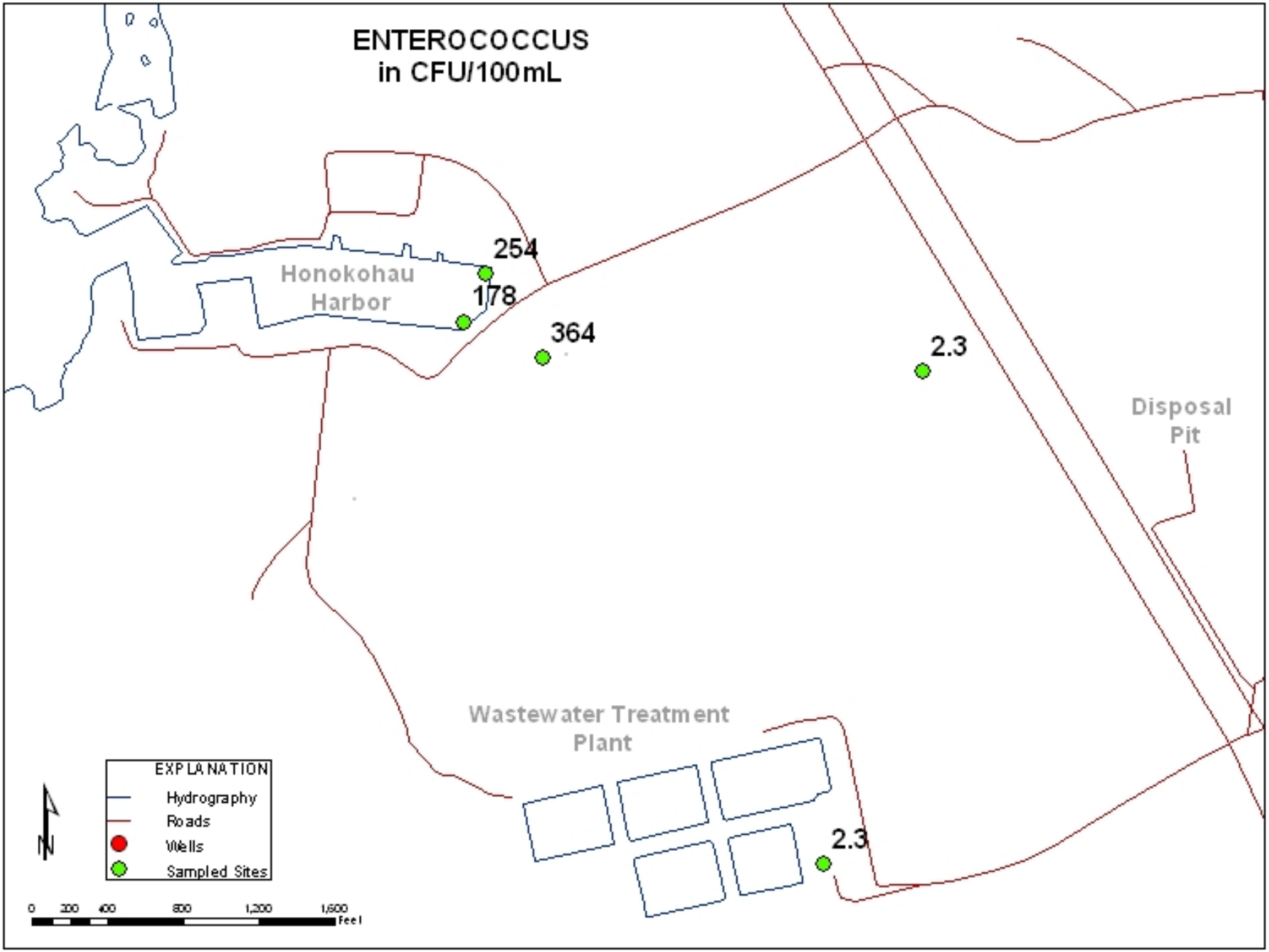


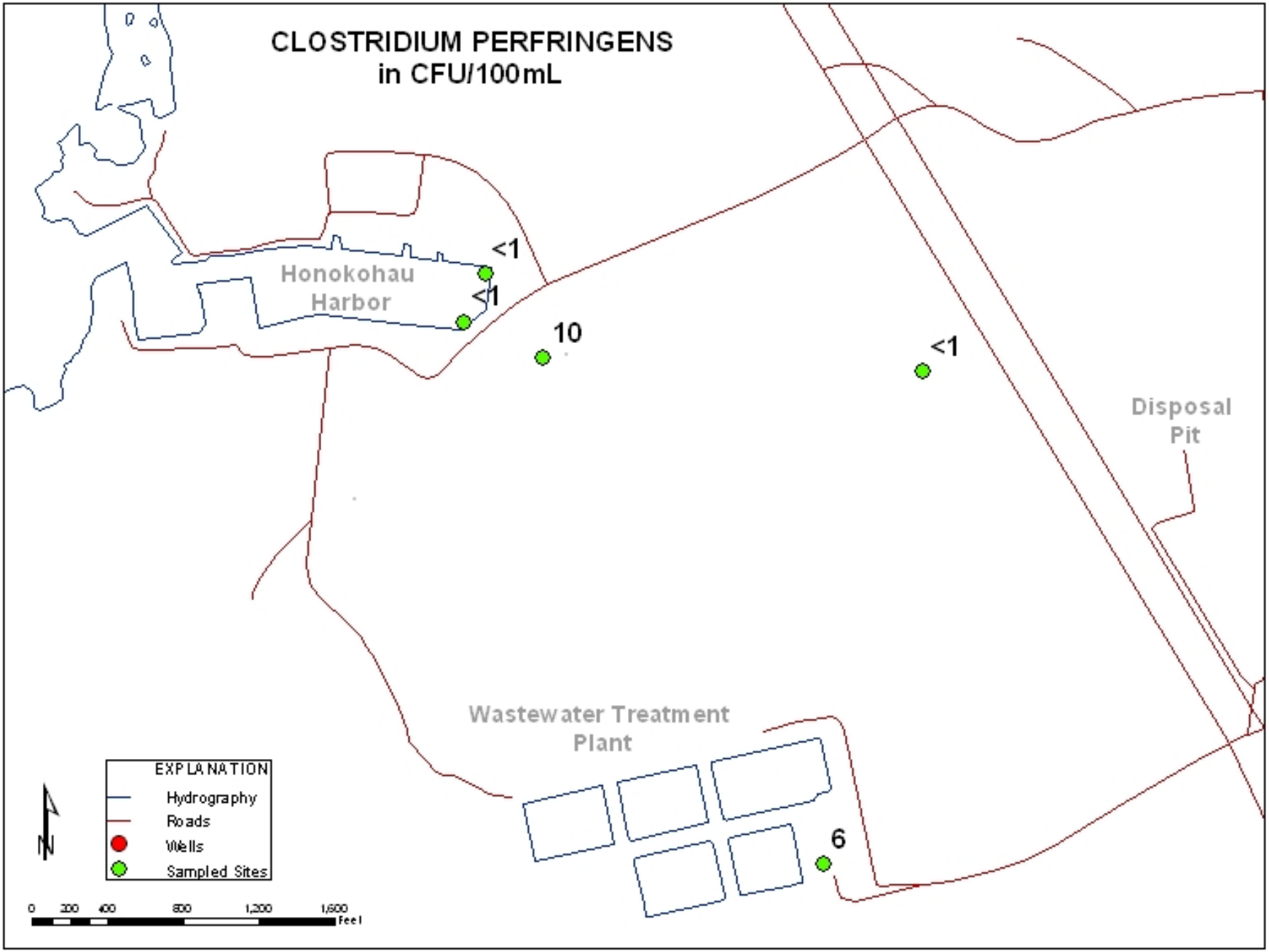

CARBAMAZEPINE (Antiepileptic)
in micrograms per liter
E.001
E.008
E.020
.130
.086
Honokohau
Harbor
Disposal
Pit
Wastewater Treatment
Plant
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

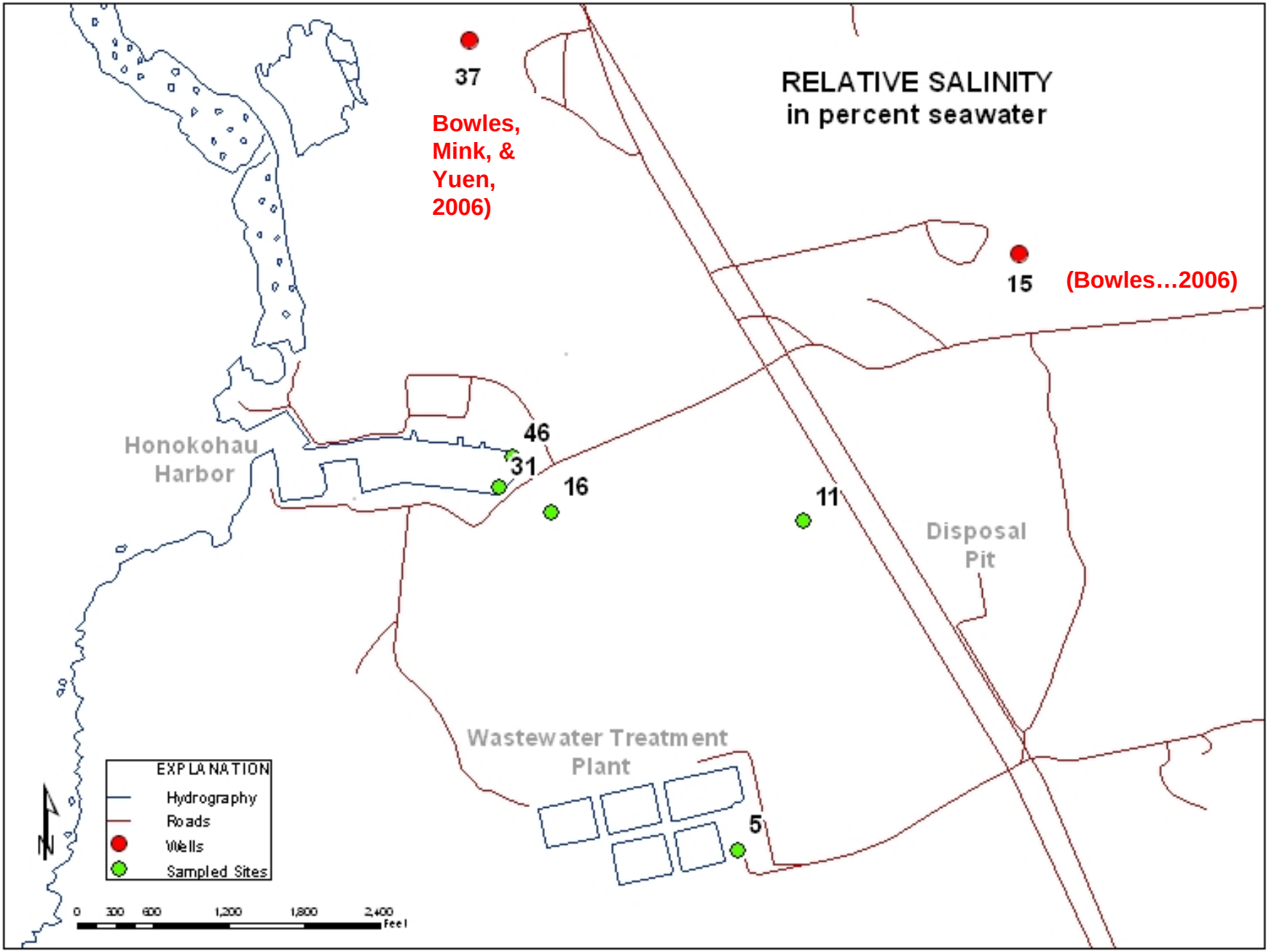

SULFAMETHOXAZOLE (Antibiotic)
in micrograms per liter
<.100
E.006
E.013
E.042
E.053
Honokohau
Harbor
Disposal
Pit
Wastewater Treatment
Plant
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0 200 400 800 1,200 1,600
Feet

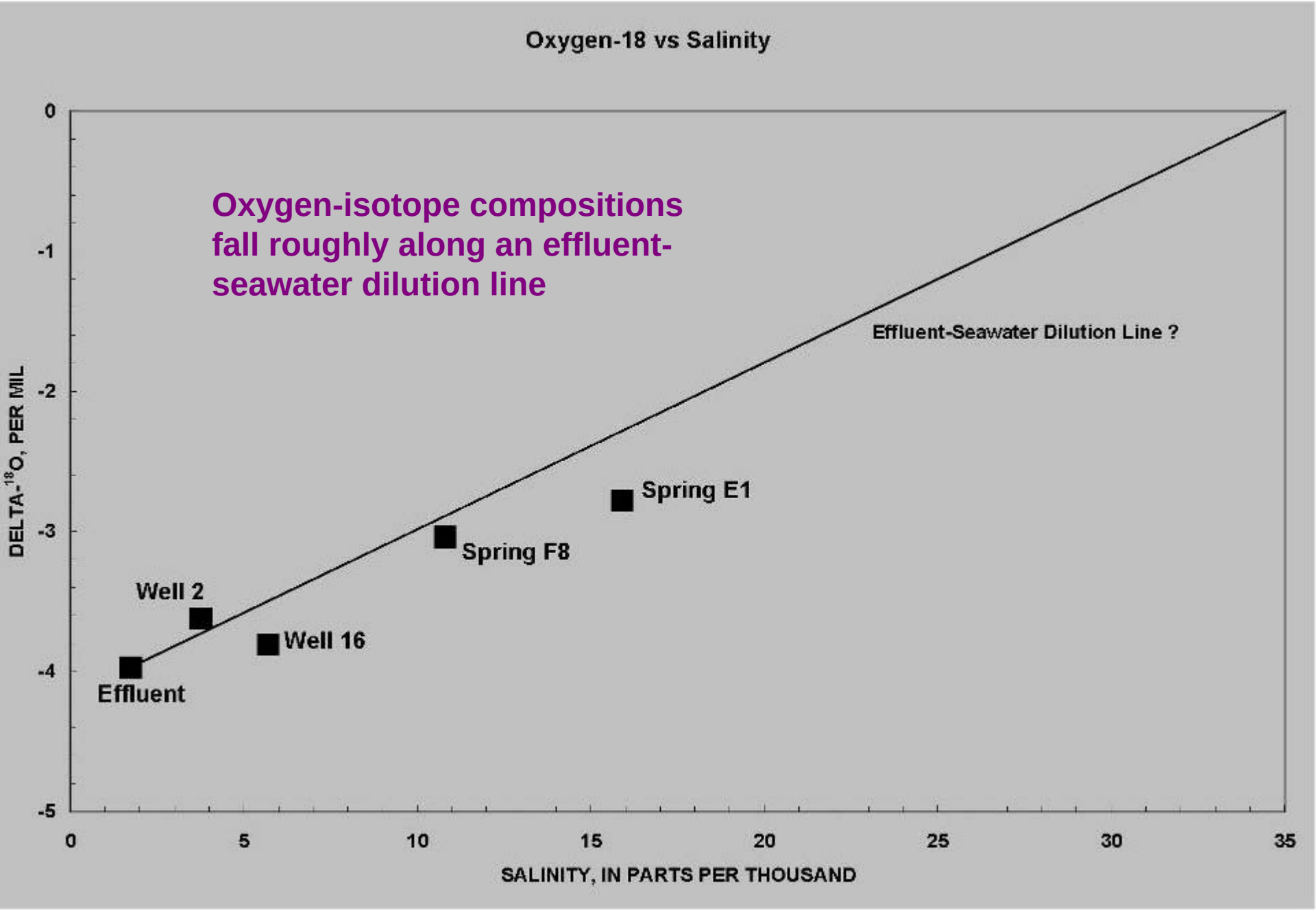

OPTICAL-BRIGHTENER FLUORESCENCE
meter reading
(tapwater control = 1)
Honokohau
Harbor
7.5
14
23
20
Disposal
Pit
Wastewater Treatement
Plant
31
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

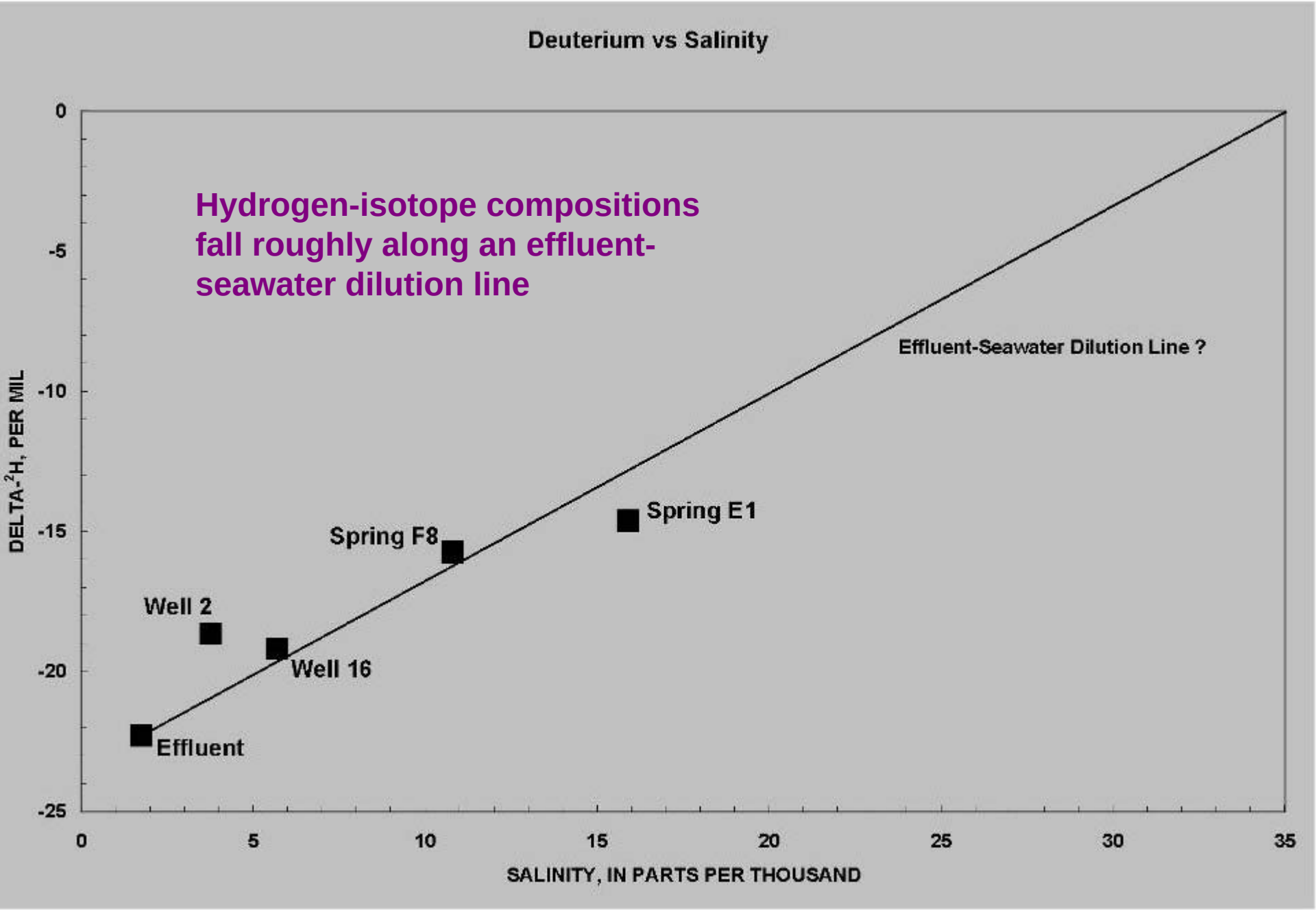

Optical-Brightener Fluorescence vs Salinity
Optical-brightener readings fall roughly on a trend line, possibly reflecting seawater dilution plus added attenuation of some sort (sorption? degradation?)
Effluent
Well 16
Well 2
Spring F8
Spring E1
Effluent-Seawater Dilution Line ?
Dilution plus Attenuation Line ?
FLUORESCENCE AT 445 nm, METER READING
SALINITY, IN PARTS PER THOUSAND
0
5
10
15
20
25
30
35

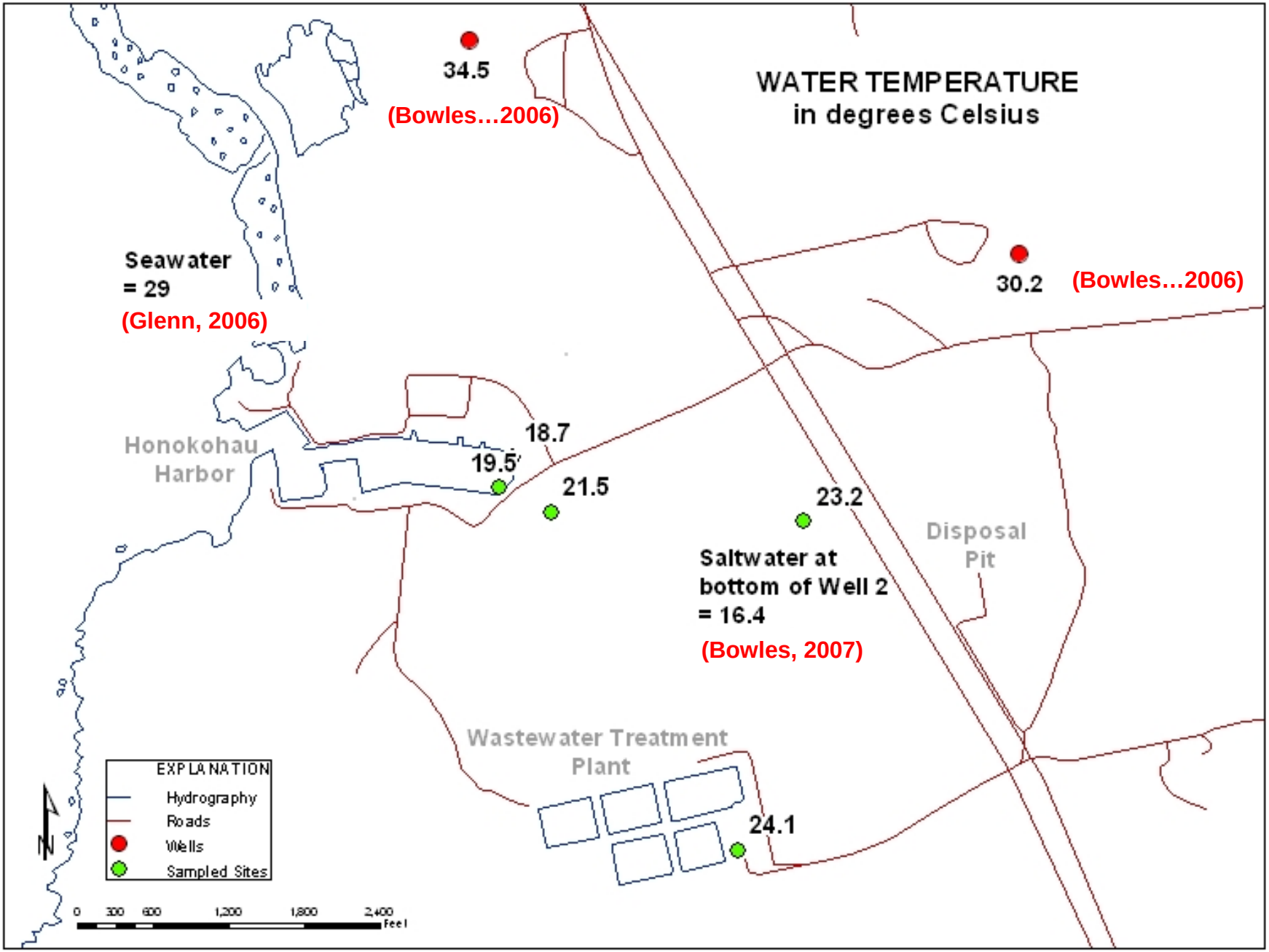

ENTEROCOCCUS
in CFU/100mL
254
178
364
2.3
2.3
Honokohau
Harbor
Disposal
Pit
Wastewater Treatment
Plant
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

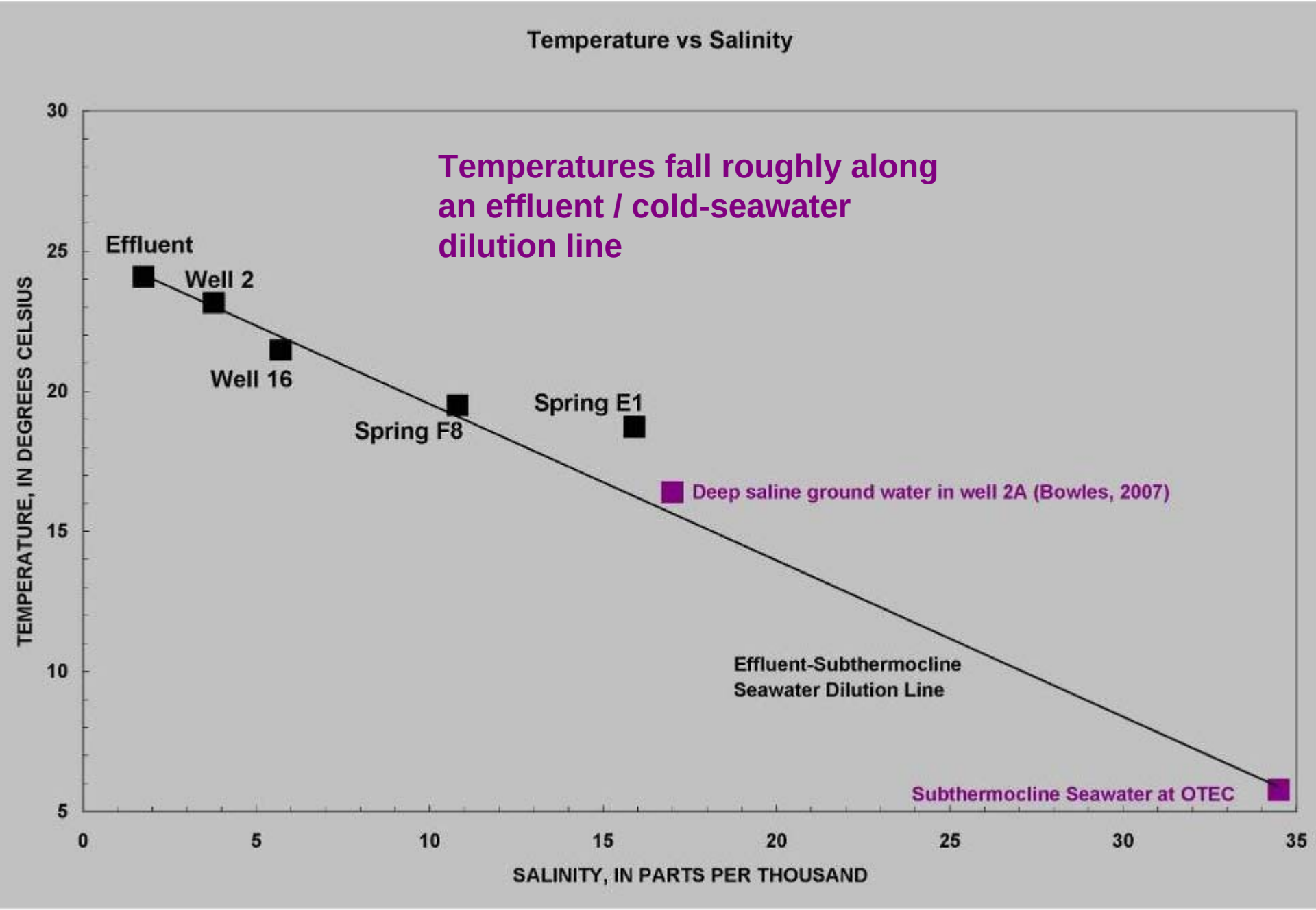

CLOSTRIDIUM PERFRINGENS
in CFU/100mL
Honokohau
Harbor
<1
<1
10
<1
Disposal
Pit
Wastewater Treatment
Plant
6
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 200 400 800 1,200 1,600
Feet

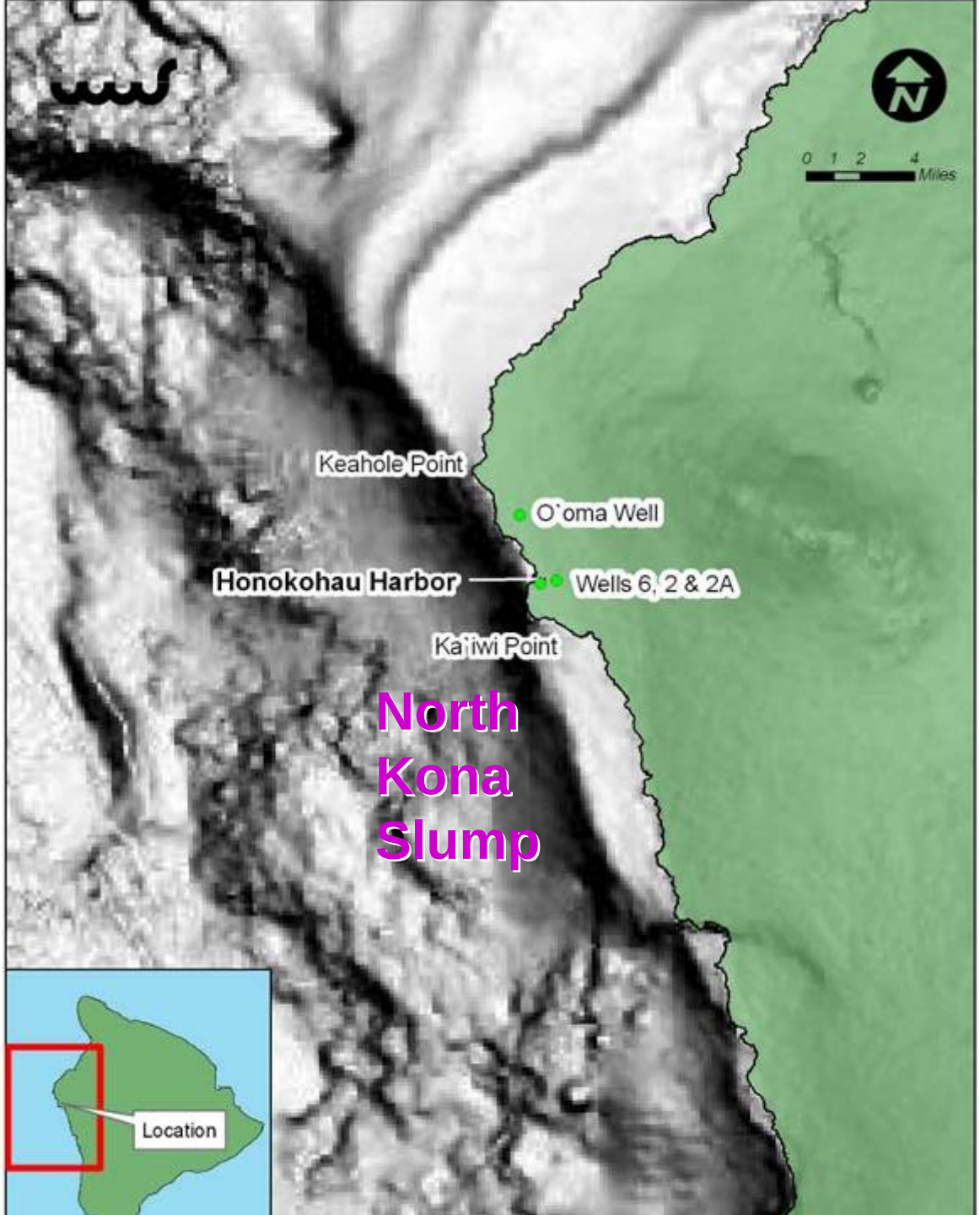

RELATIVE SALINITY
in percent seawater
37
Bowles, Mink, & Yuen, 2006)
15
(Bowles…2006)
46
31
16
11
Honokohau Harbor
Disposal Pit
Wastewater Treatment Plant
5
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 300 600 1,200 1,800 2,400 feet


Oxygen-18 vs Salinity
Oxygen-isotope compositions fall roughly along an effluent-seawater dilution line
Effluent-Seawater Dilution Line ?
Spring E1
Spring F8
Well 2
Well 16
Effluent
DELTA-18O, PER MIL
0
-1
-2
-3
-4
-5
0
5
10
15
20
25
30
35
SALINITY, IN PARTS PER THOUSAND


Deuterium vs Salinity
Hydrogen-isotope compositions fall roughly along an effluent-seawater dilution line
Effluent-Seawater Dilution Line ?
Spring E1
Spring F8
Well 2
Well 16
Effluent
DELTA-2H, PER MIL
0
-5
-10
-15
-20
-25
0
5
10
15
20
25
30
35
SALINITY, IN PARTS PER THOUSAND

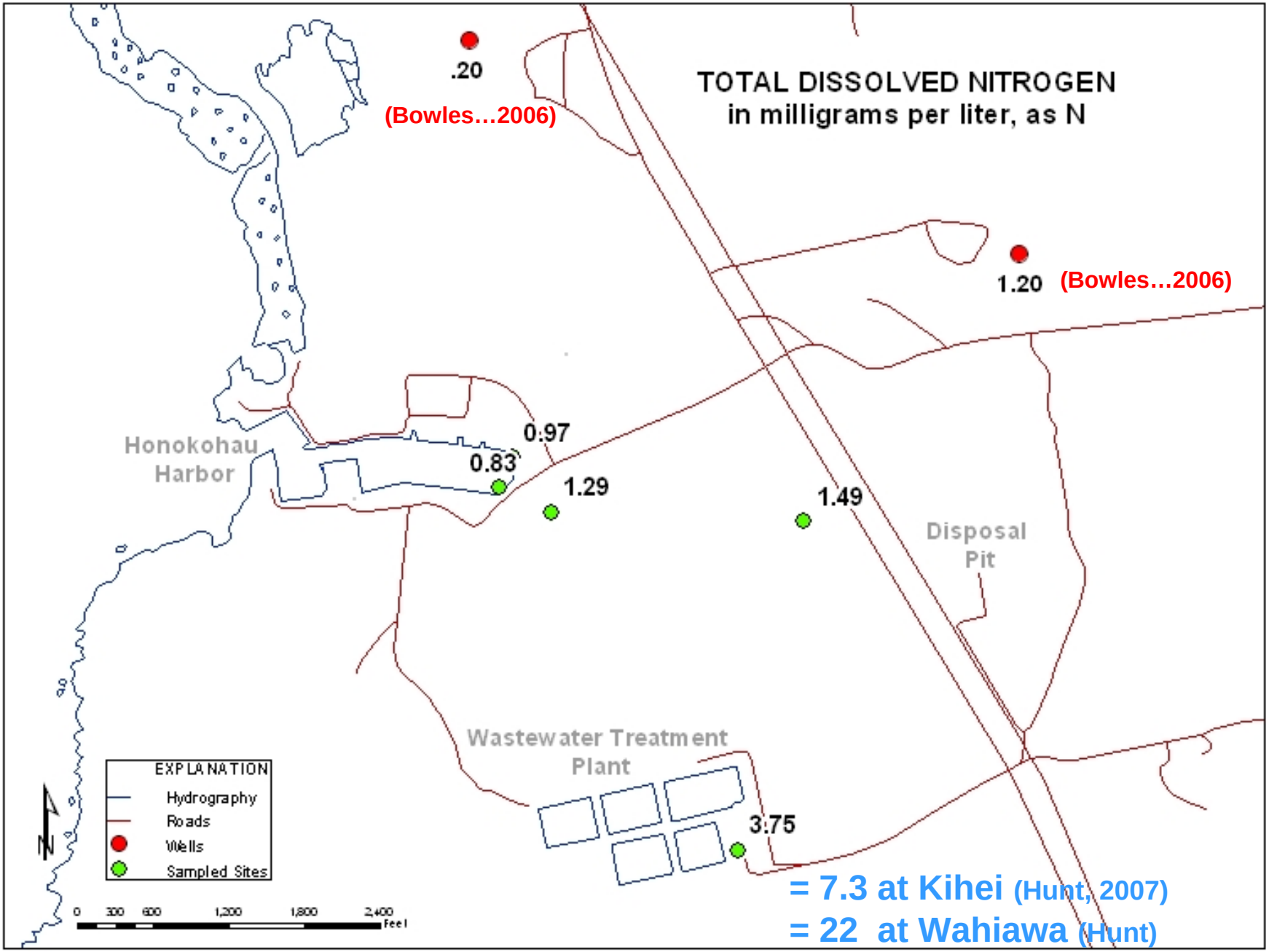

WATER TEMPERATURE
in degrees Celsius
34.5
(Bowles…2006)
30.2
(Bowles…2006)
Seawater
= 29
(Glenn, 2006)
Honokohau
Harbor
18.7
19.5
21.5
23.2
Saltwater at
bottom of Well 2
= 16.4
(Bowles, 2007)
Disposal
Pit
Wastewater Treatment
Plant
24.1
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 300 600 1,200 1,800 2,400
feet

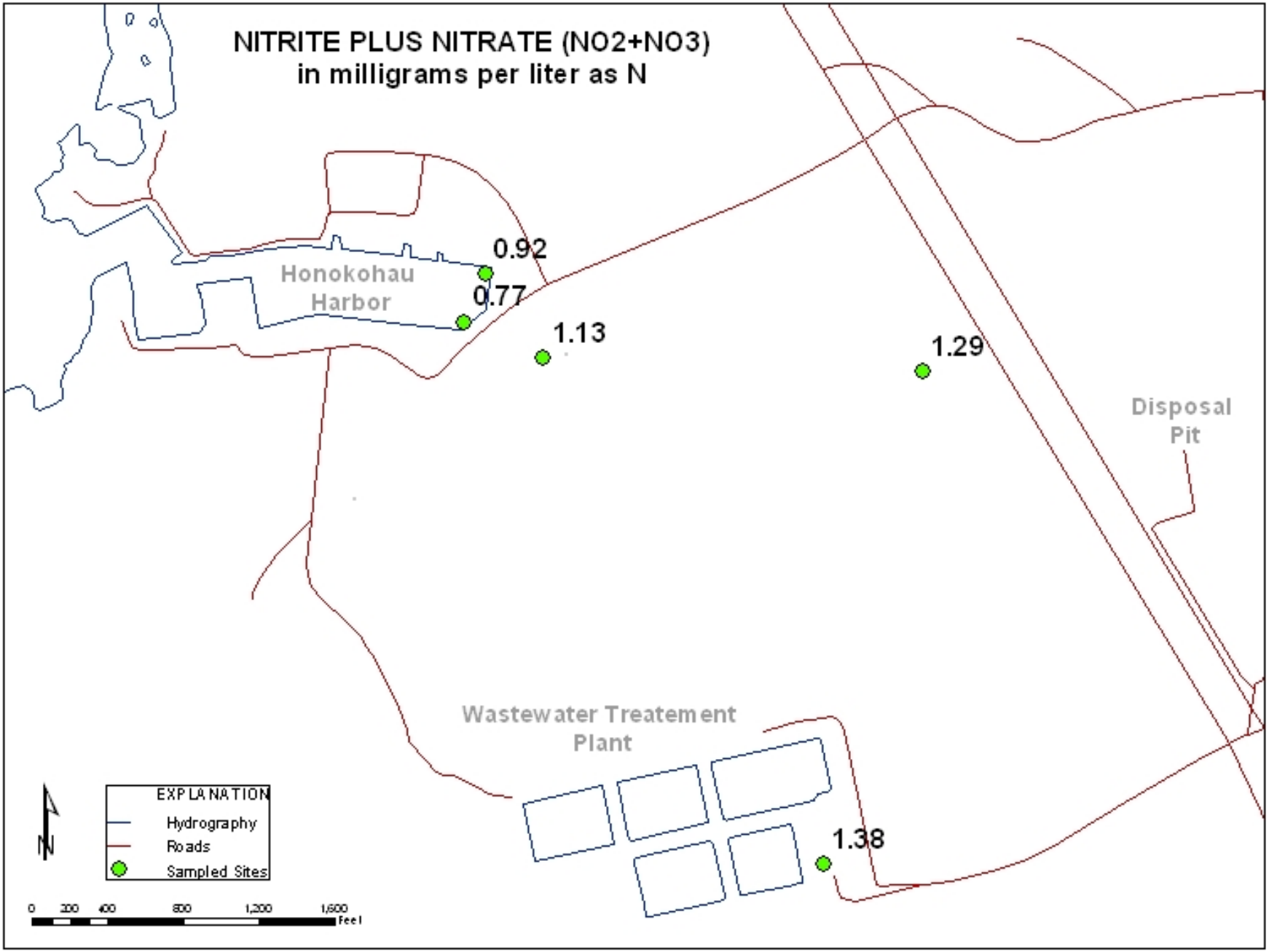

Temperature vs Salinity
Temperatures fall roughly along an effluent / cold-seawater dilution line
Effluent
Well 2
Well 16
Spring F8
Spring E1
Deep saline ground water in well 2A (Bowles, 2007)
Effluent-Subthermocline Seawater Dilution Line
Subthermocline Seawater at OTEC
TEMPERATURE, IN DEGREES CELSIUS
SALINITY, IN PARTS PER THOUSAND
30
25
20
15
10
5
0
5
10
15
20
25
30
35

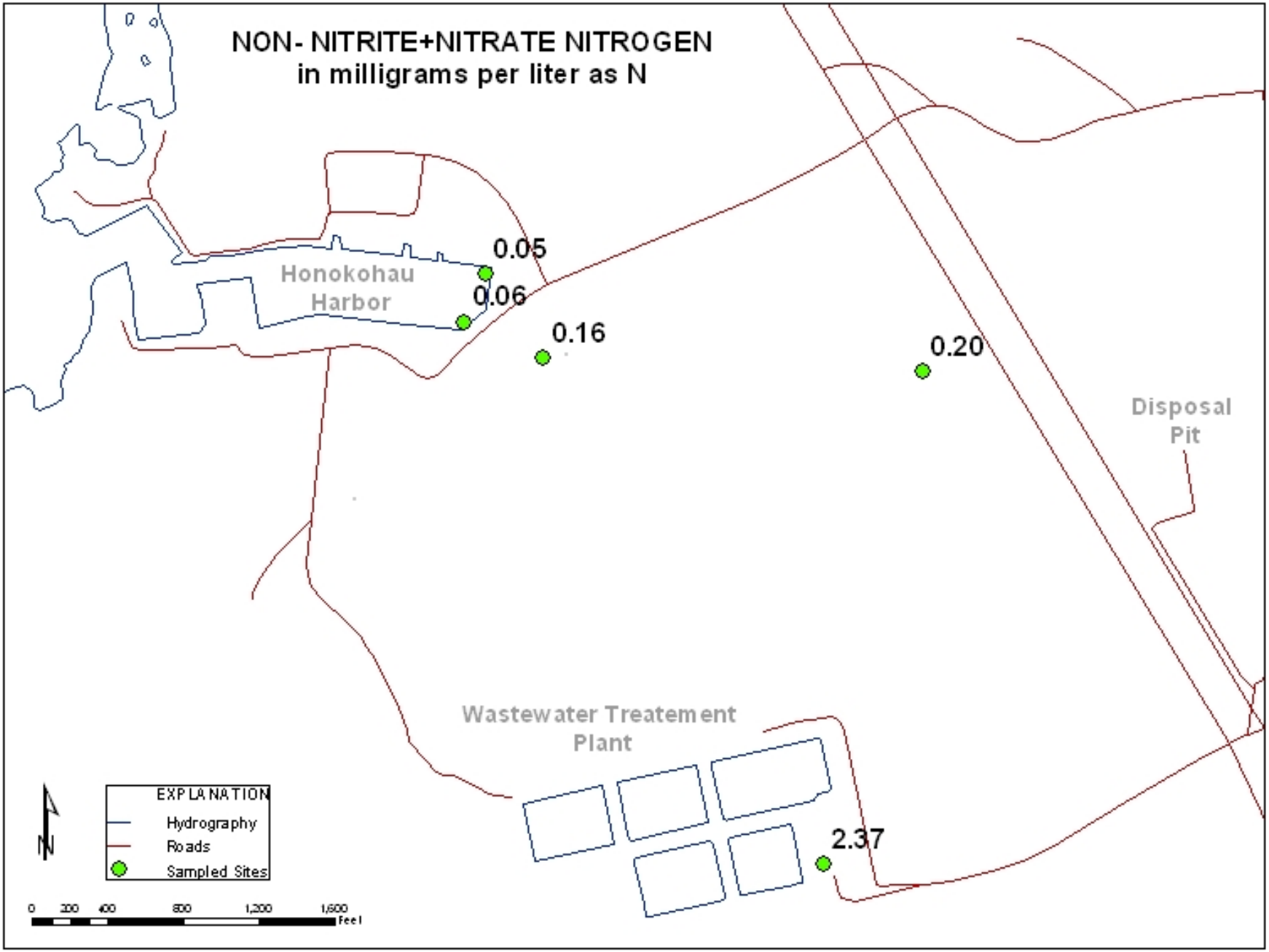


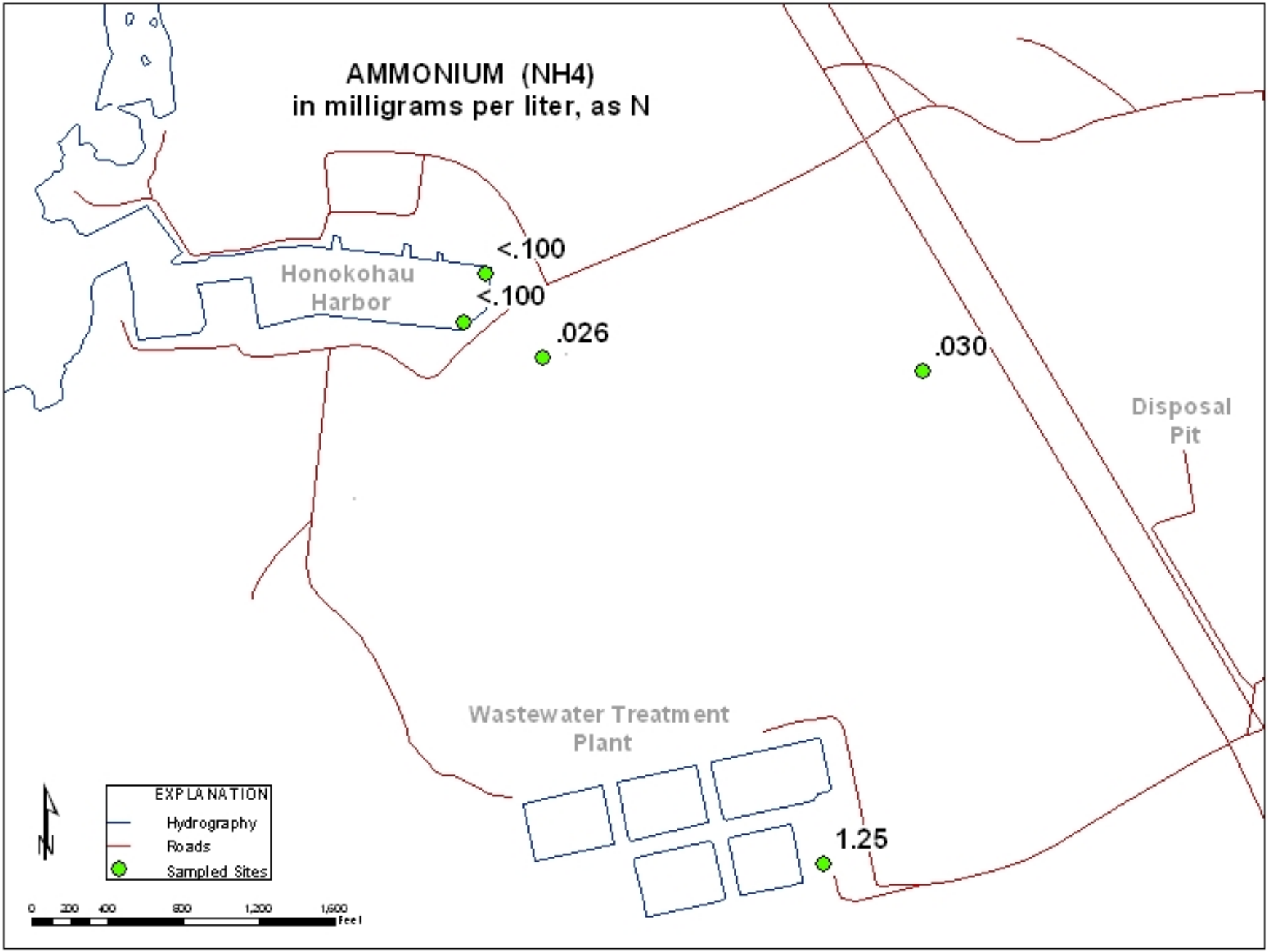
Headwall of submarine slump may allow easy entry of cold, sub-thermocline seawater into lava aquifer

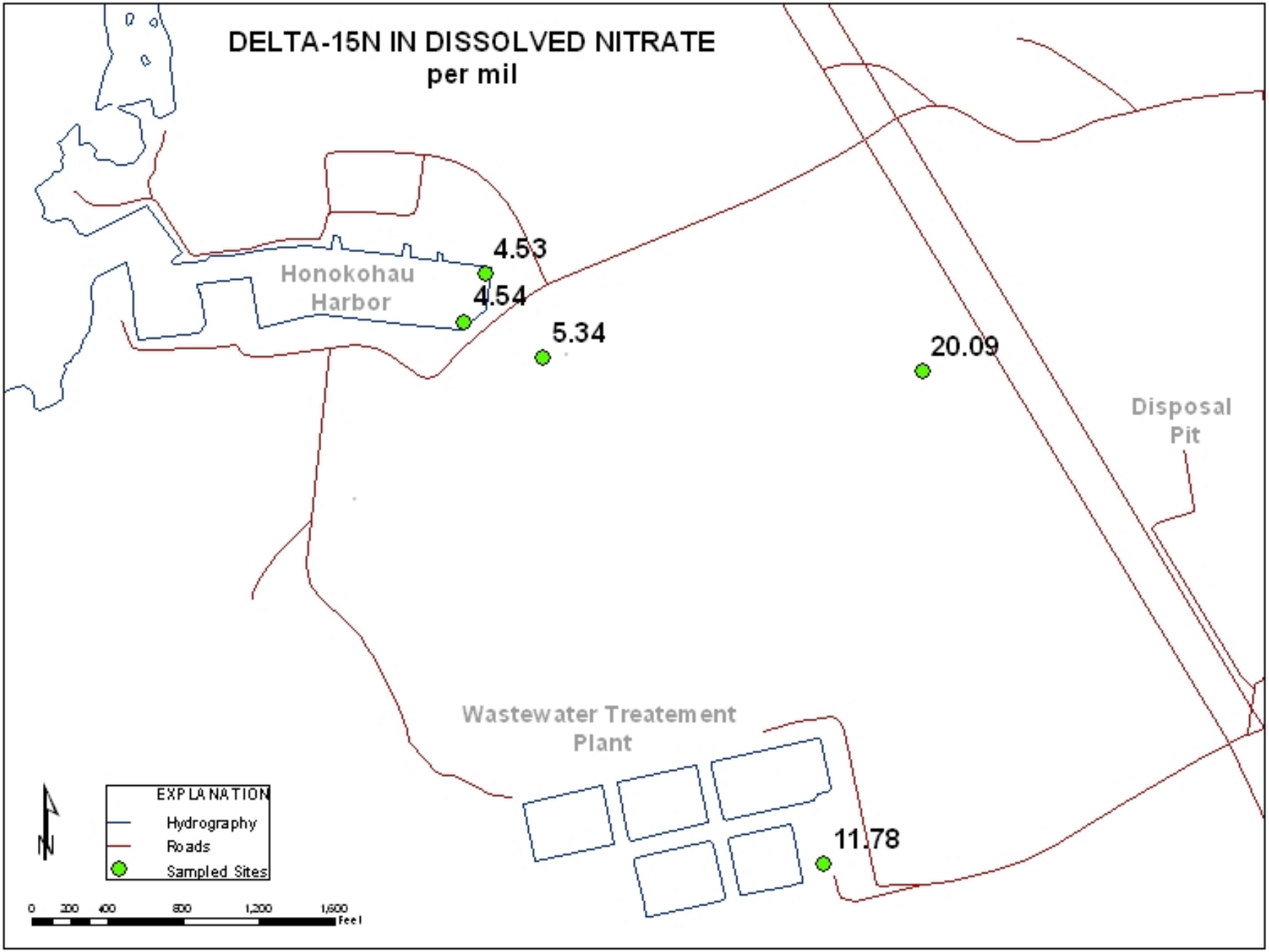
(Bowles, 2007)

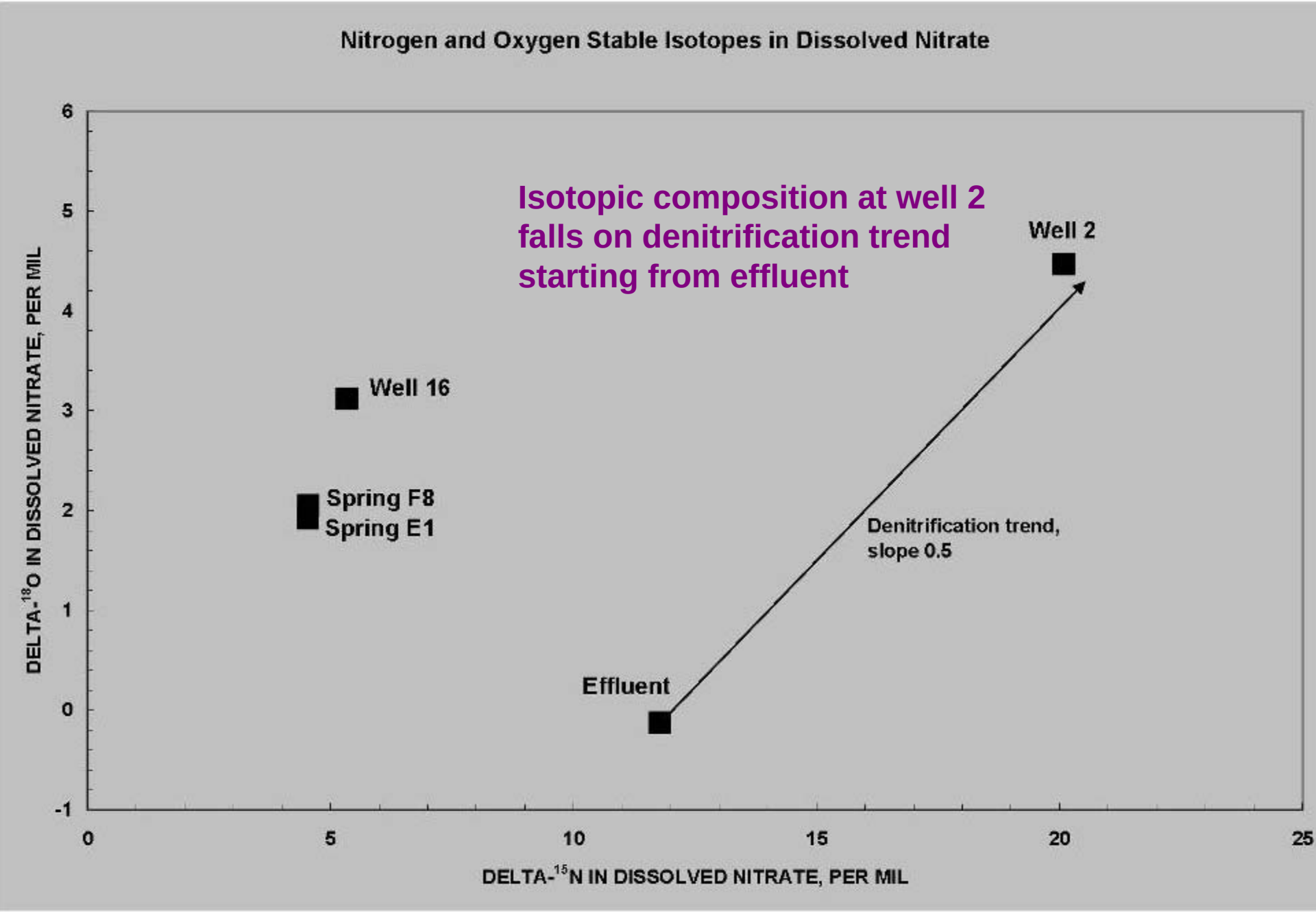

TOTAL DISSOLVED NITROGEN
in milligrams per liter, as N
.20
(Bowles…2006)
1.20
(Bowles…2006)
0.97
0.83
1.29
1.49
3.75
Honokohau
Harbor
Disposal
Pit
Wastewater Treatment
Plant
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0
300
600
1,200
1,800
2,400
feet
= 7.3 at Kihei (Hunt, 2007)
= 22 at Wahiawa (Hunt)


NITRITE PLUS NITRATE (NO2+NO3)
in milligrams per liter as N
Honokohau
Harbor
0.92
0.77
1.13
1.29
Disposal
Pit
Wastewater Treatement
Plant
1.38
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

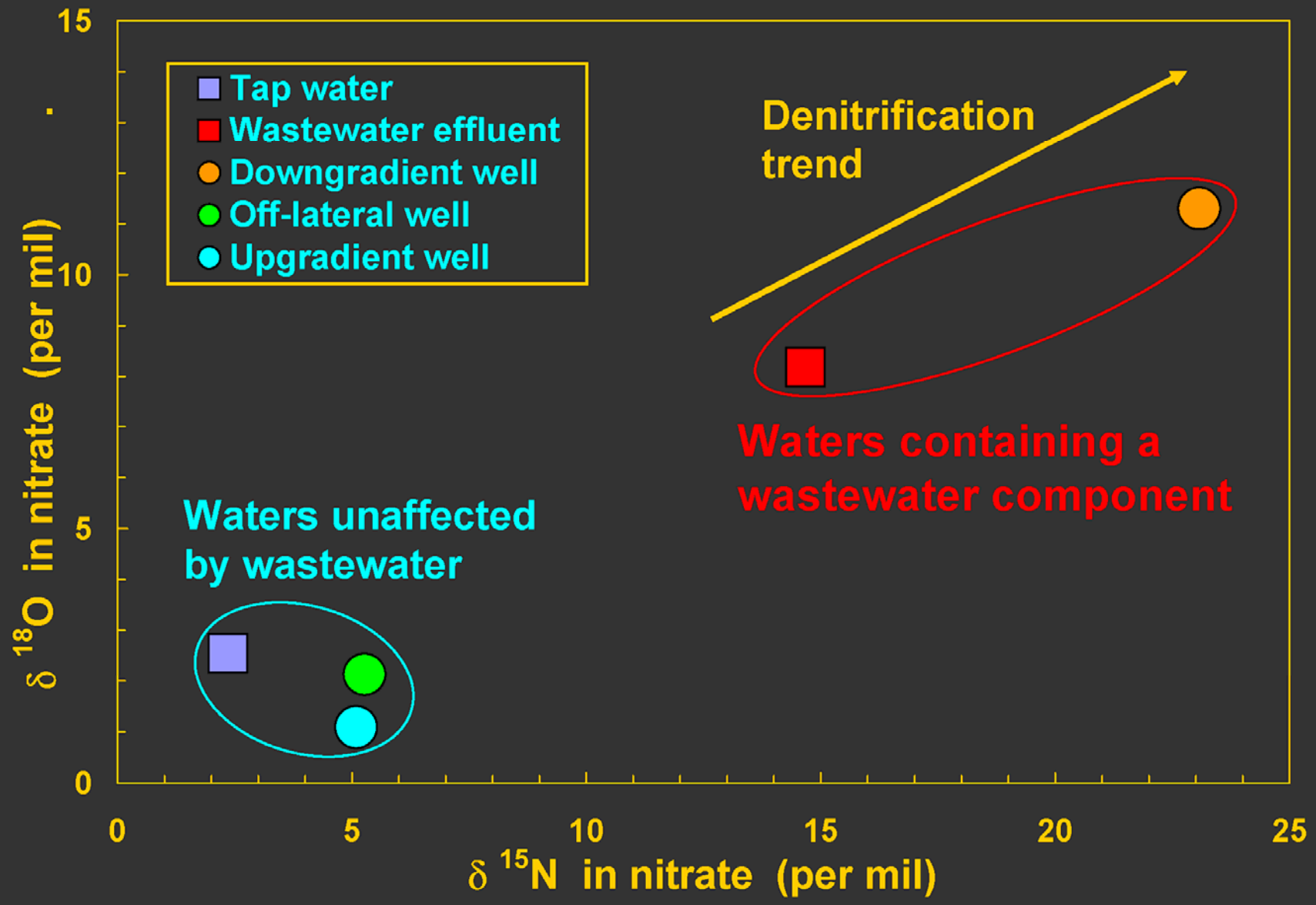

NON- NITRITE+NITRATE NITROGEN
in milligrams per liter as N
Honokohau
Harbor
0.05
0.06
0.16
0.20
Disposal
Pit
Wastewater Treatement
Plant
2.37
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

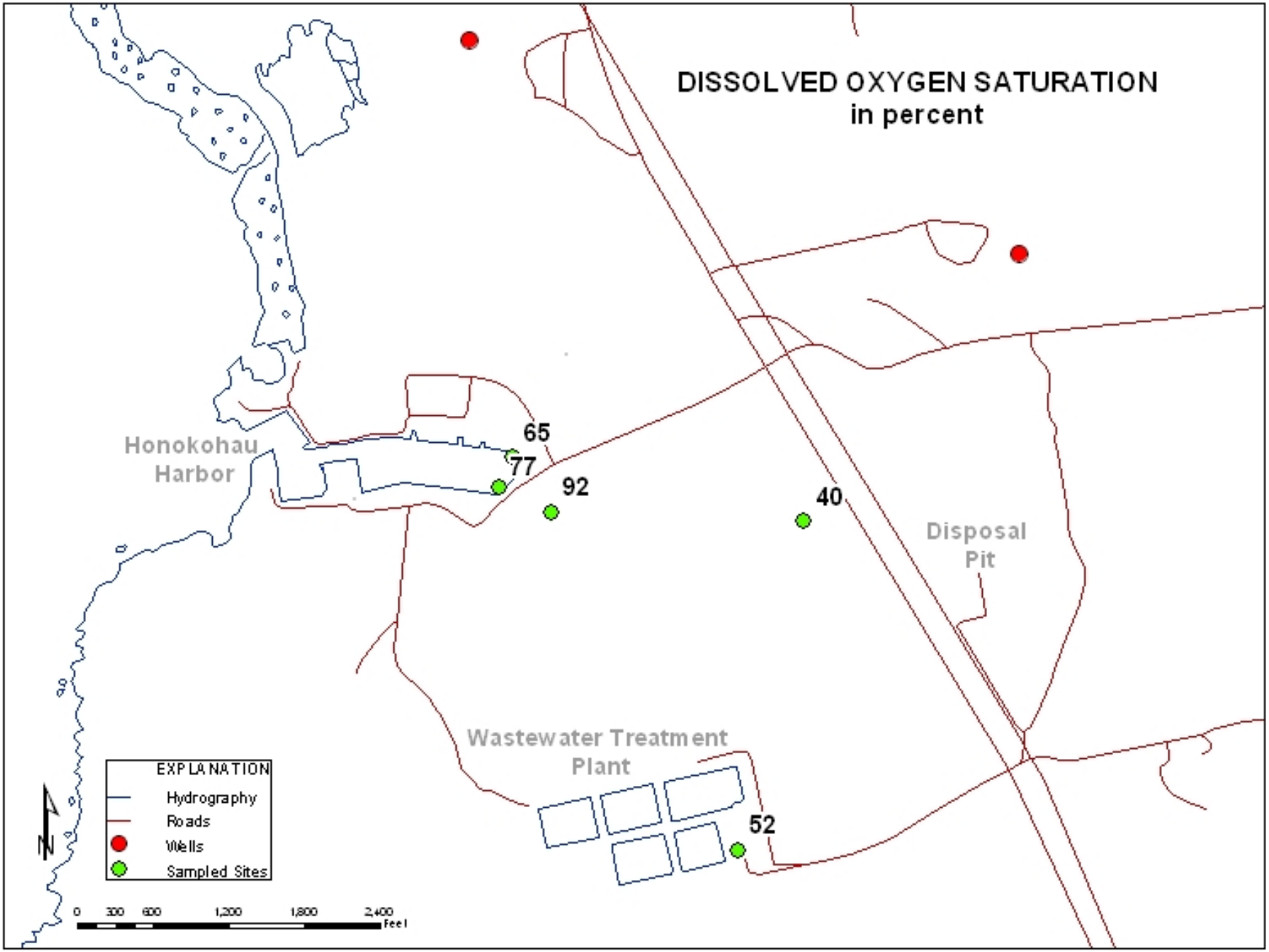

AMMONIUM (NH4)
in milligrams per liter, as N
Honokohau
Harbor
<.100
<.100
.026
.030
Disposal
Pit
Wastewater Treatment
Plant
1.25
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0 200 400 800 1,200 1,600
Feet

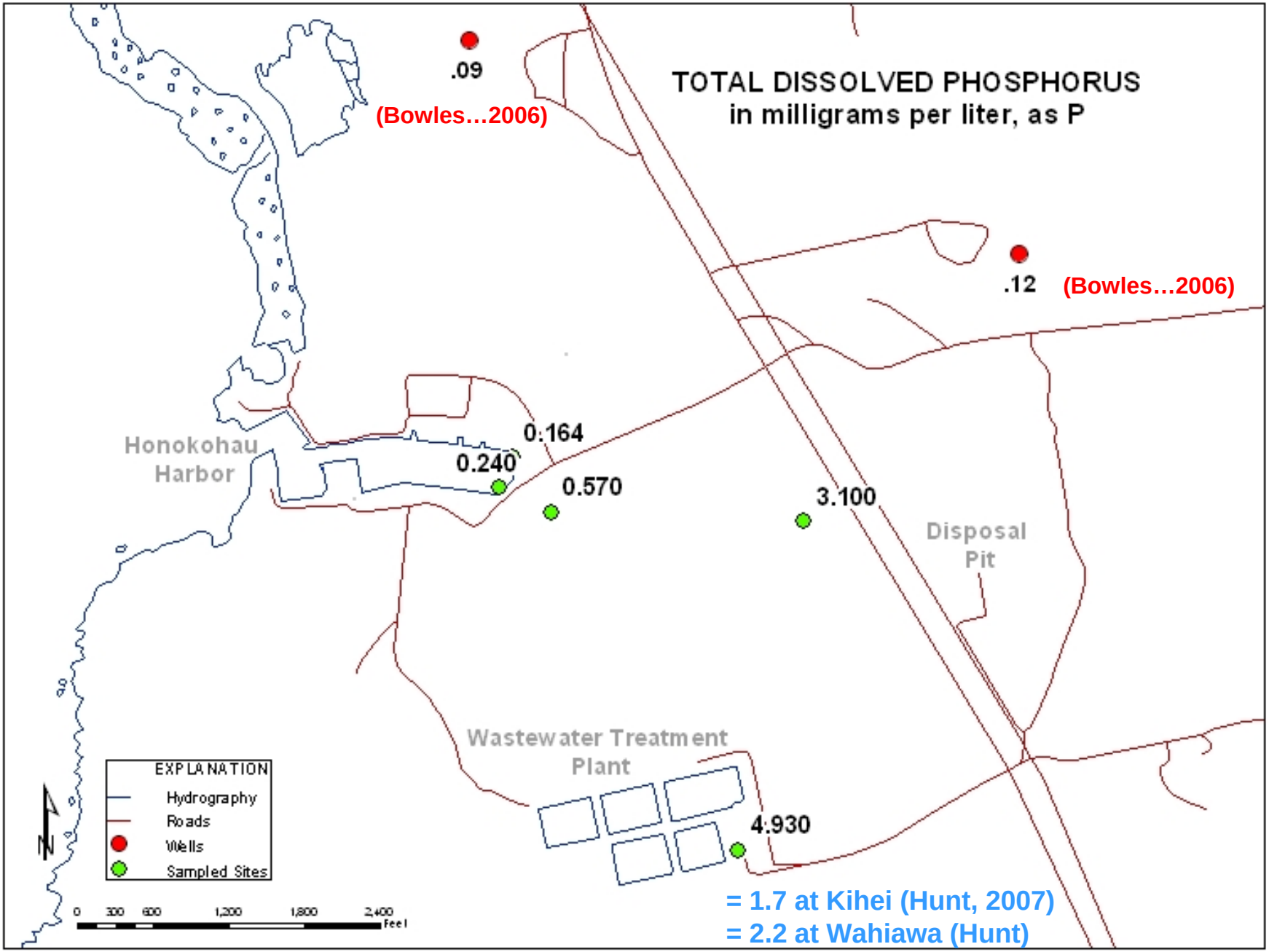

DELTA-15N IN DISSOLVED NITRATE
per mil
Honokohau
Harbor
4.53
4.54
5.34
20.09
Disposal
Pit
Wastewater Treatement
Plant
11.78
EXPLANATION
Hydrography
Roads
Sampled Sites
N
0
200
400
800
1,200
1,600
Feet

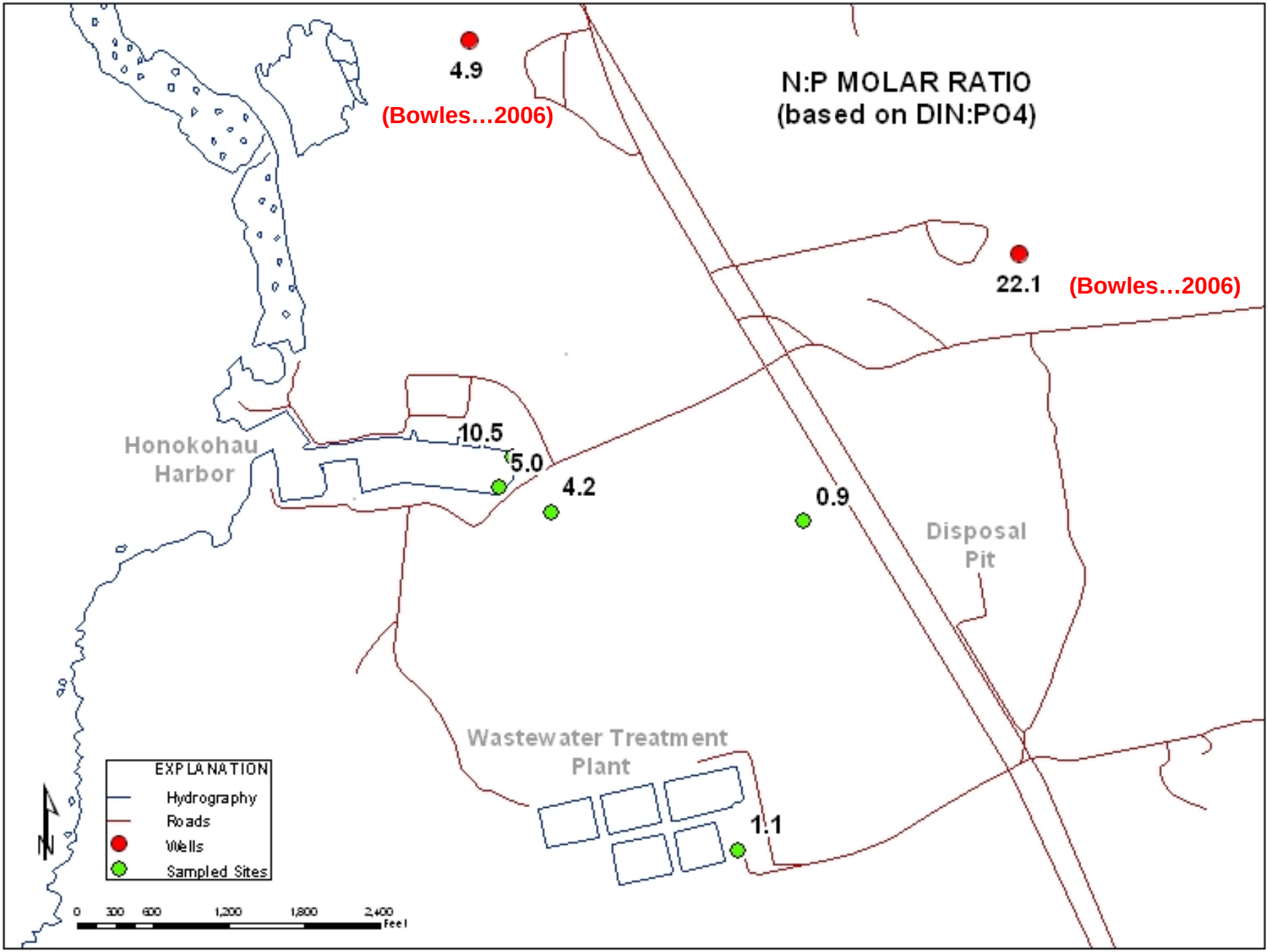

Nitrogen and Oxygen Stable Isotopes in Dissolved Nitrate
Isotopic composition at well 2 falls on denitrification trend starting from effluent
Well 2
Well 16
Spring F8
Spring E1
Denitrification trend, slope 0.5
Effluent
DELTA-18O IN DISSOLVED NITRATE, PER MIL
DELTA-15N IN DISSOLVED NITRATE, PER MIL
6
5
4
3
2
1
0
-1
0
5
10
15
20
25

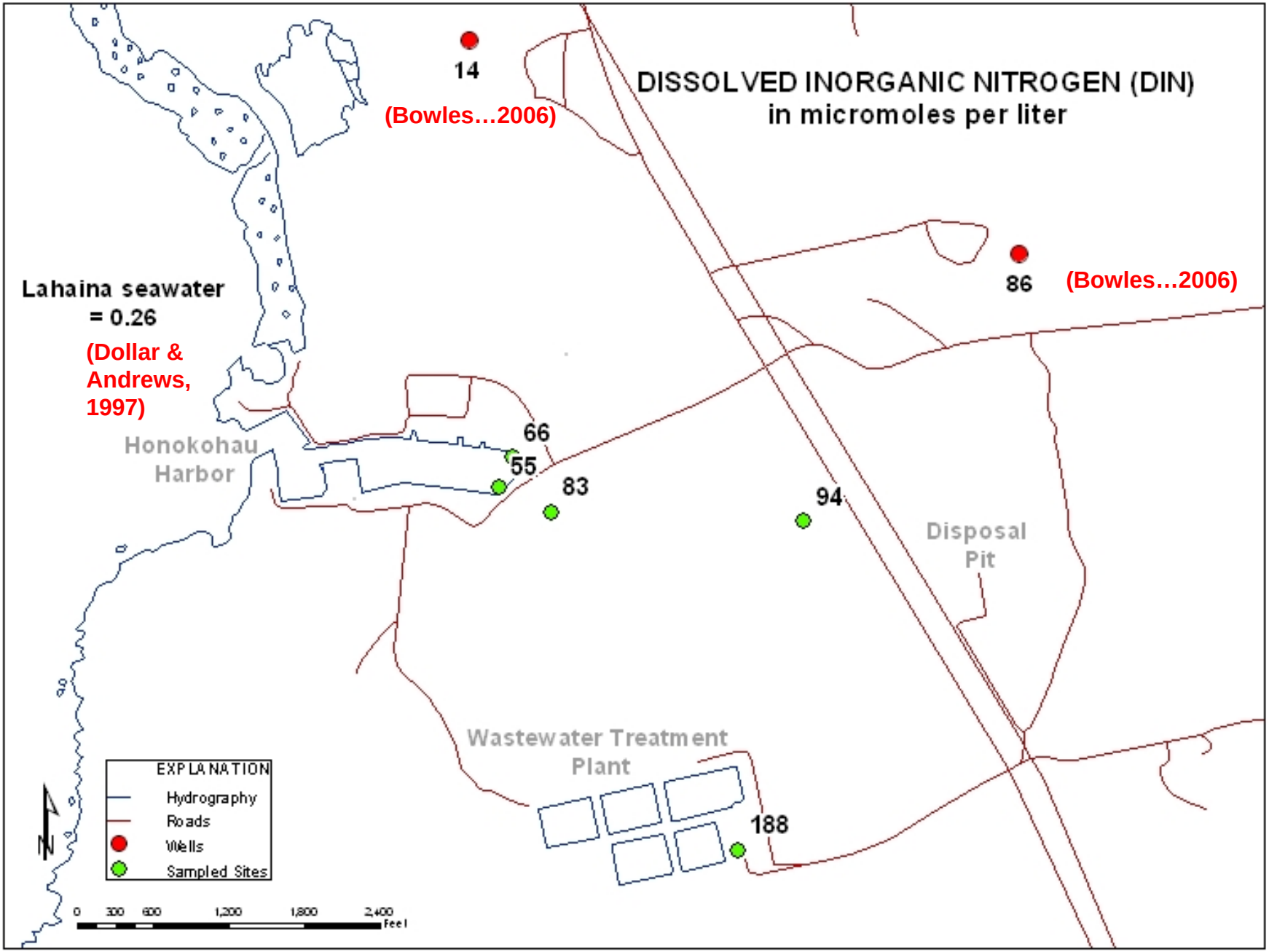
Kihei again, for comparison

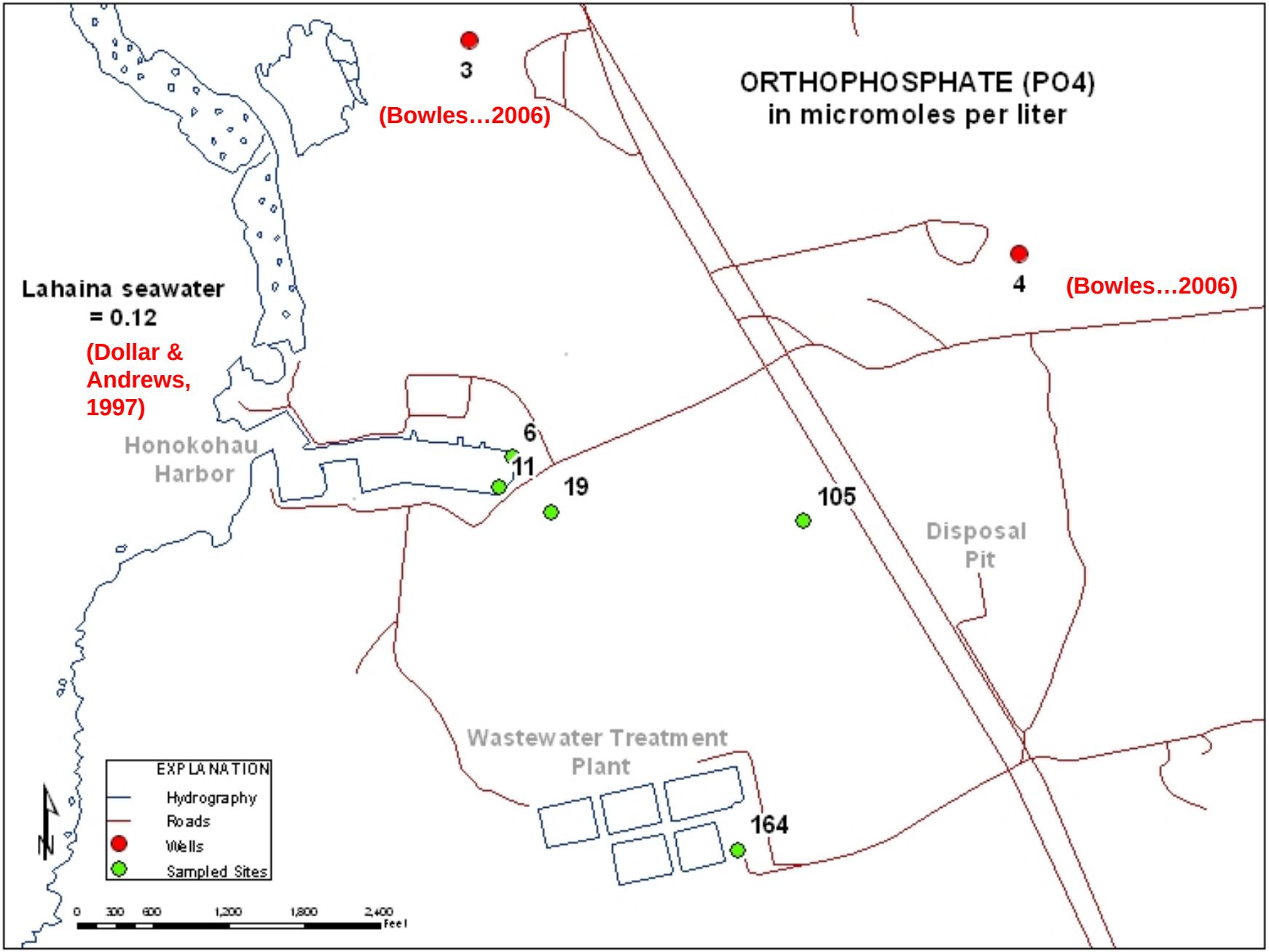



DISSOLVED OXYGEN SATURATION
in percent
Honokohau
Harbor
65
77
92
40
Disposal
Pit
Wastewater Treatment
Plant
52
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 300 600 1,200 1,800 2,400
feet


TOTAL DISSOLVED PHOSPHORUS
in milligrams per liter, as P
.09
(Bowles…2006)
.12
(Bowles…2006)
Honokohau
Harbor
0.164
0.240
0.570
3.100
Disposal
Pit
Wastewater Treatment
Plant
4.930
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 300 600 1,200 1,800 2,400
feet
= 1.7 at Kihei (Hunt, 2007)
= 2.2 at Wahiawa (Hunt)


N:P MOLAR RATIO
(based on DIN:PO4)
4.9
(Bowles…2006)
22.1
(Bowles…2006)
10.5
5.0
4.2
0.9
1.1
Honokohau
Harbor
Disposal
Pit
Wastewater Treatment
Plant
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0
300
600
1,200
1,800
2,400
feet


DISSOLVED INORGANIC NITROGEN (DIN)
in micromoles per liter
14
(Bowles…2006)
86
(Bowles…2006)
Lahaina seawater
= 0.26
(Dollar & Andrews, 1997)
Honokohau Harbor
66
55
83
94
Disposal Pit
Wastewater Treatment Plant
188
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0 300 600 1,200 1,800 2,400 feet


ORTHOPHOSPHATE (PO4)
in micromoles per liter
3
(Bowles…2006)
4
(Bowles…2006)
Lahaina seawater
= 0.12
(Dollar &
Andrews,
1997)
Honokohau
Harbor
6
11
19
105
Disposal
Pit
Wastewater Treatment
Plant
164
EXPLANATION
Hydrography
Roads
Wells
Sampled Sites
N
0
300
600
1,200
1,800
2,400
feet

Glenn (2006) showed elevated phosphorus in harbor waters compared to a regional dilution trend between wells and seawater

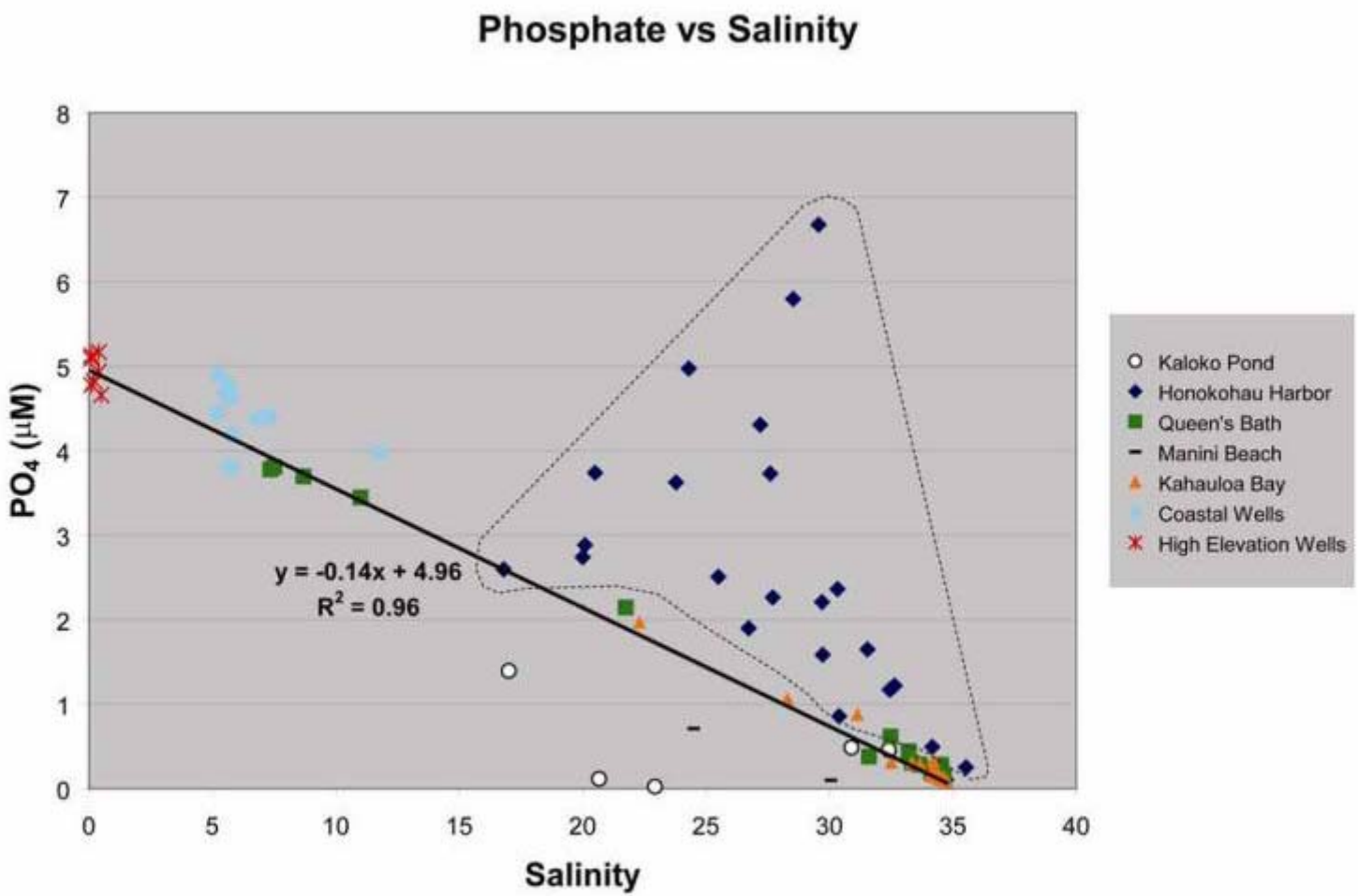


Figure 10. Regional dissolved phosphate concentrations in wells and coastal waters. The linear regression line excludes samples from Honokohau Harbor, which have been enclosed in dashed lines.

Thermal Infrared Imagery

Glenn (2006)

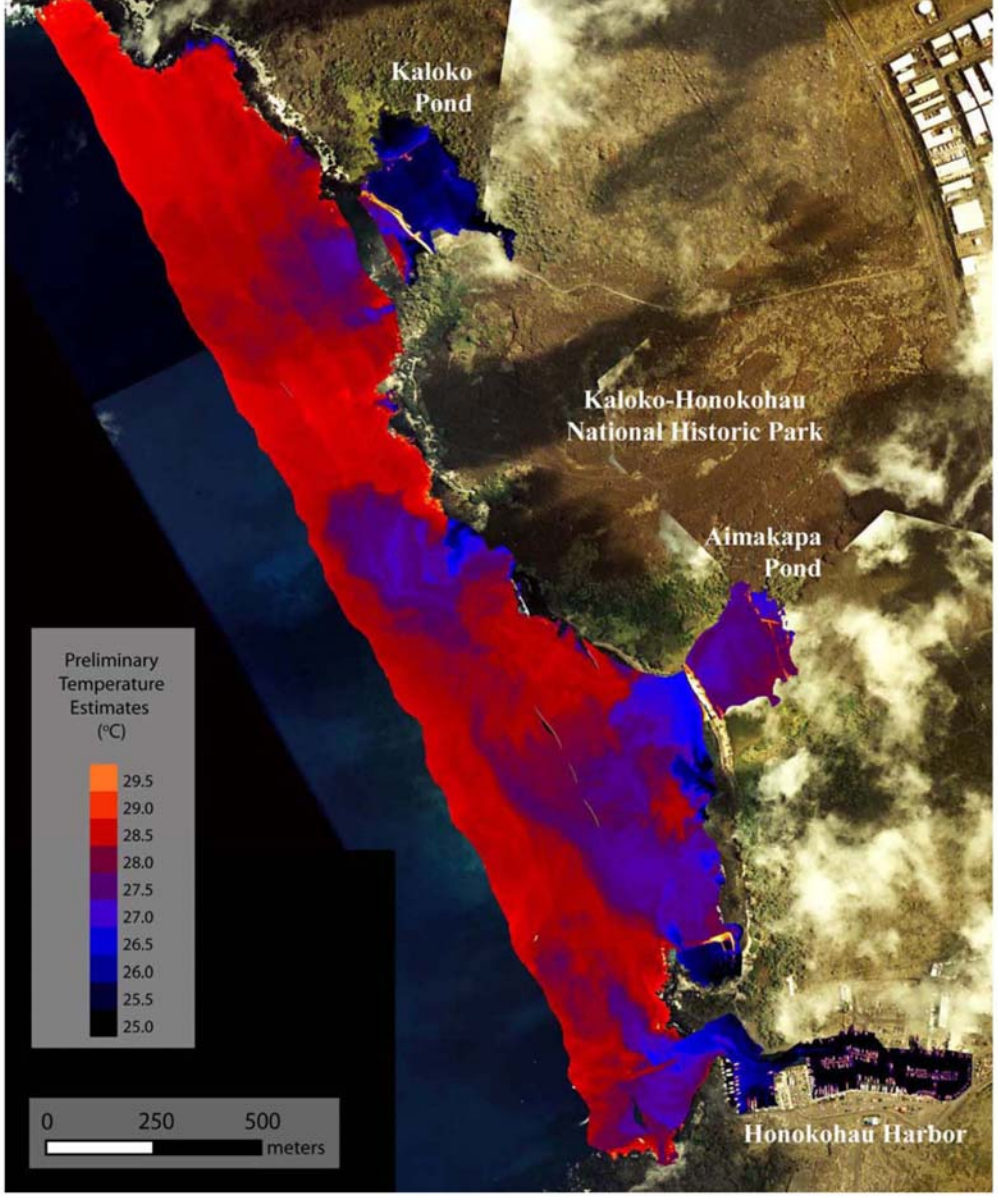
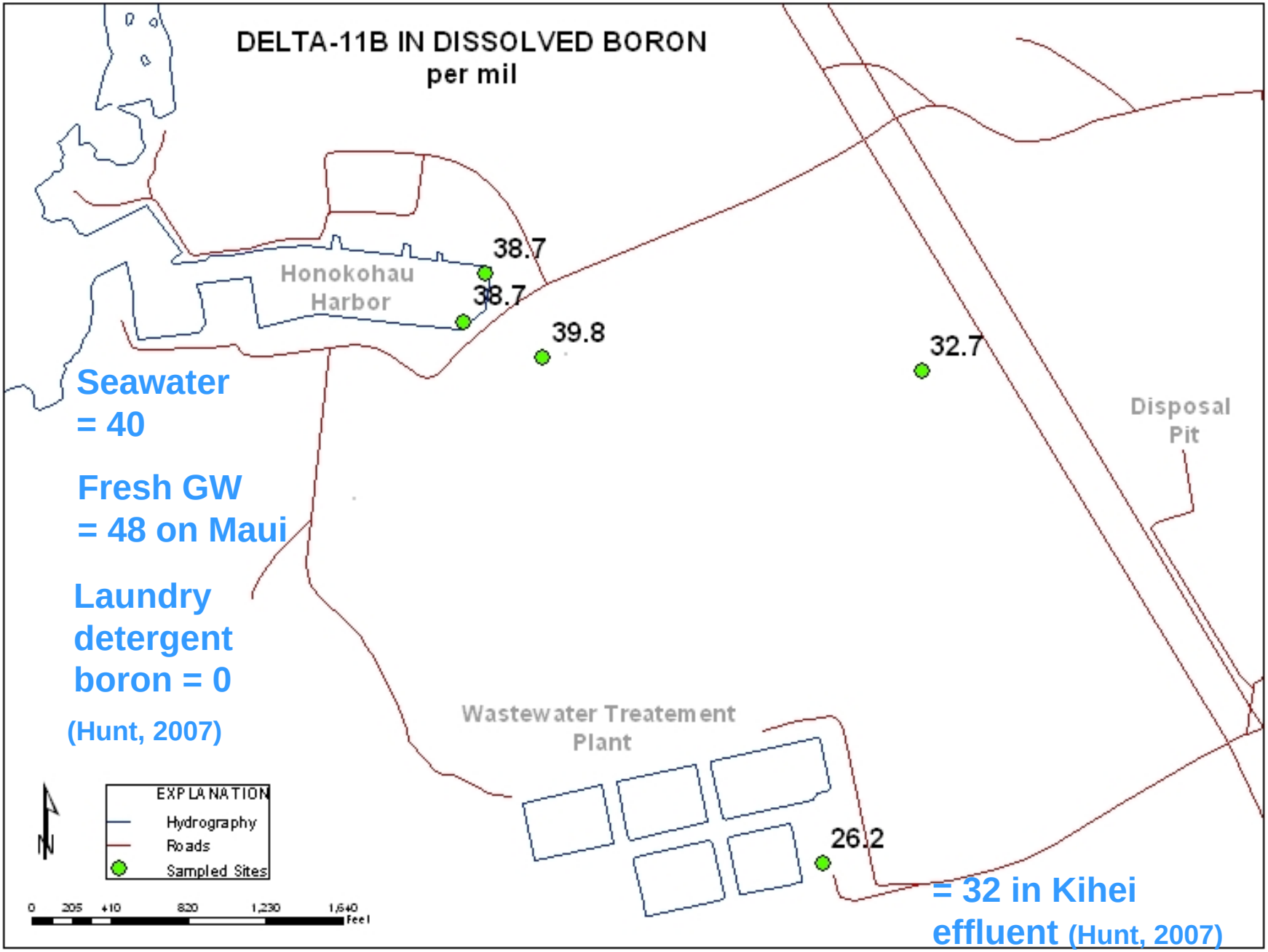


Figure 1. Surface water temperature map of Kaloko-Honokohau Park and Honokohau Harbor area produced from August 2005 aerial infrared survey. Temperatures shown are preliminary estimates pending surface layer and/or atmospheric corrections. Cooler brackish waters leaking as submarine groundwater discharge form buoyant nutrient-enriched plumes extending out from the shoreline.



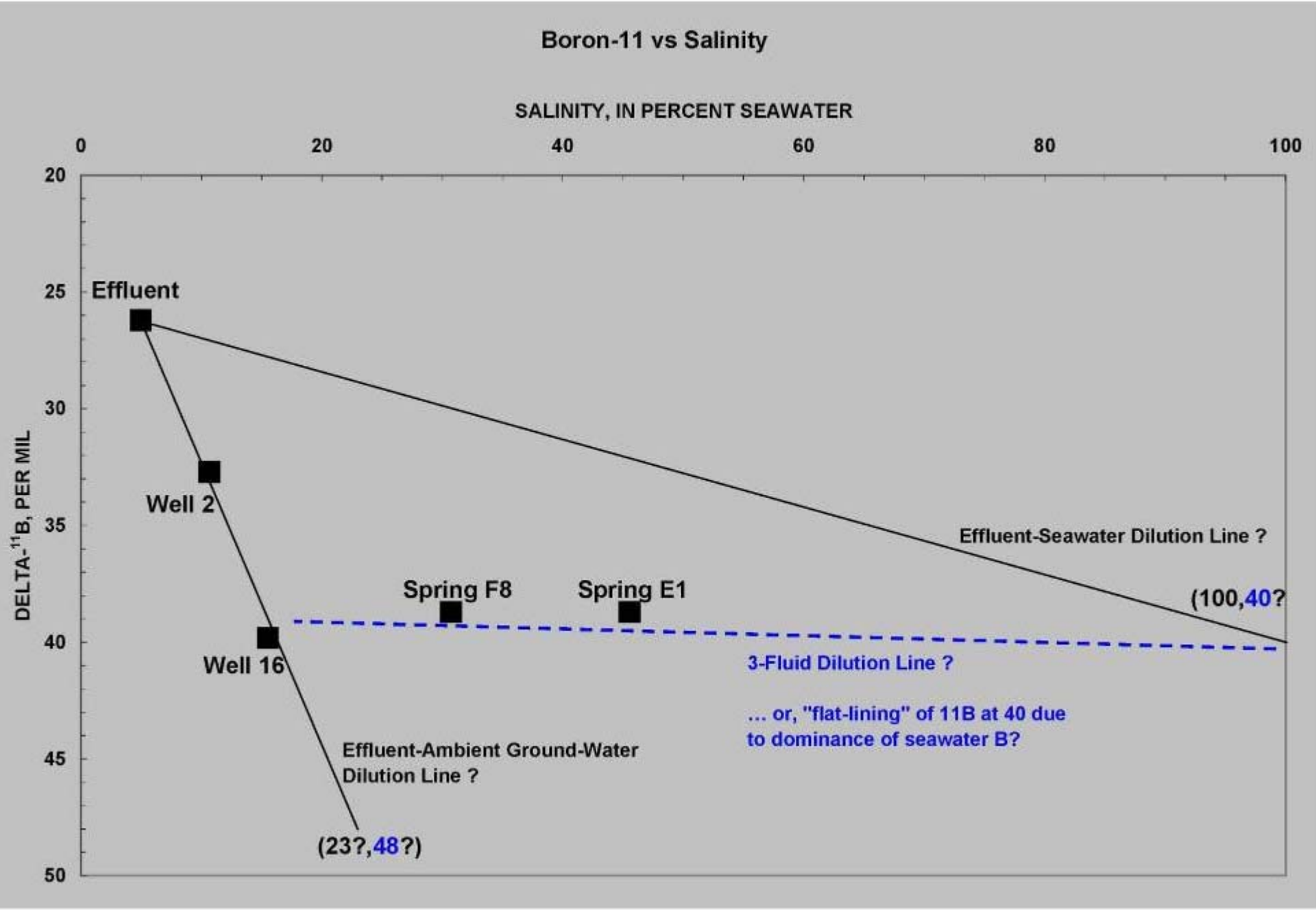
Seawater = 40

Fresh GW = 48 on Maui

Laundry detergent boron = 0

(Hunt, 2007)

= 32 in Kihei effluent (Hunt, 2007)


Boron-11 vs Salinity
SALINITY, IN PERCENT SEAWATER
0
20
40
60
80
100
20
25
30
35
40
45
50
DELTA-11B, PER MIL
Effluent
Well 2
Well 16
Spring F8
Spring E1
Effluent-Seawater Dilution Line ?
(100,40?
3-Fluid Dilution Line ?
... or, "flat-lining" of 11B at 40 due
to dominance of seawater B?
Effluent-Ambient Ground-Water
Dilution Line ?
(23?,48?)

Summary of Results

- Samples included treated effluent, 2 wells, 2 harbor springs, and a blank
- Most measures decreased or increased strongly from effluent to harbor
  - salinity increased
  - temperature, nutrients, and most “contaminants” decreased
- The pharmaceutical carbamazepine was detected in all samples and sulfamethoxazole in all samples but one (spring E1); carbamazepine is a persistent chemical commonly detected in other studies
- Several compounds in effluent were detected at just one other site: the anticorrosive 5-Methyl-1H-benzotriazole and the fire retardant Tris(dichloro_i-pr) phosphate at well 2; and the plasticizer triphenyl phosphate at boring 16
- Other pharmaceuticals and waste indicator compounds were detected in effluent but not offsite (for example, caffeine and the nicotine metabolite cotinine); this is not uncommon in other studies; compounds can degrade, and concentrations in effluent often are low to begin with

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Summary of Results—Continued

- Nutrients were highest in effluent and decreased toward the harbor
  - phosphorus in all samples was well above “background” in 2 nearby wells
  - nitrogen in all samples was well above that in one nearby well but not the other; nitrogen “background” is uncertain because the 2 nearby wells differ so greatly from each other in concentration
  - ammonium was highest in effluent and detected in wells but not the springs
  - ^{15}N isotope composition at well 2 is consistent with denitrification of effluent
- Fabric-brightener fluorescence in all samples was highly elevated (above a tapwater control) and was highest in effluent
- ^{11}B showed light “laundry detergent” signature in effluent and at well 2; enough salinity at other sites to “swamp out” signature with seawater boron
- Various measures fall along an effluent-seawater mixing line, consistent with mixing of effluent and saltwater from beneath the brackish lens
- Fecal-indicator bacteria counts were erratic, with possible interference from surface infiltration into the aquifer and overland runoff into uncased boreholes

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Strategies and Possible Future Work

- The strategy followed here was to sample for what can be termed ***"inherent or ambient tracers"***
  - that is, things already in wastewater that can be sought for the expense of sampling, and with no concern for timing (sampling too soon? too late?)
  - there is ambiguity in assessing "background" against which elevated concentrations are apparent; there also may be interference from other sewage sources in the watershed (cesspools, etc.)
  - but there is strength in the multi-tracer emphasis (concurrence of multiple lines of evidence and spatial patterns; initial evidence of processes at work)
  - a more extensive areal study with the inherent-tracer approach might better define background concentrations and influences of other sewage sources
- Alternately, a ***"forced tracer"*** test might also be conducted, such as with rhodamine fluorescent dye. Results might be more conclusive than inherent tracers, but such a test would need to be well planned and executed, and would require repeat sampling over the necessary time span for ground water to flow from disposal pit to wells to harbor

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