Contaminated Sediments as a Cause of Coastal Water Pollution

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Indicator Bacteria:
Human vs. Environmental Sources

- Fecal indicator bacteria are present in human and animal fecal material.
- Total coliform and fecal coliform groups are well known to reproduce in the environment.
- Recent evidence has shown that in some cases more specific indicators, such as *E. coli* and *Enterococcus*,also reproduce in environment.
- High levels of environmental growth can confound water quality measurements by making tests non-specific for fecal material.

Indiana Freshwater Lake Beach

- *E. coli* can persist and replicate in soil, water and plants to 10^4 under even temperate conditions.
- Creek is source of bacteria to lakes.
- No point-source contamination in creeks, unidentified non-point source contamination.

Byappanahalli,M., M. Fowler, D. Shively and R. Whitman. 2003. Ubiquity and persistence of Escherichia coli in a Midwestern coastal stream. Appl. Environ. Microbiol. 69:4549-4555.

England Ocean Beach, sewage impacted

- *Enterococcus* to 10^3 found in intertidal sediments.
- Levels remain high in sediments and resuspension may be responsible for beach failures.

Obiri-Danso, K. and K. Jones. 2000. Intertidal sediments as reservoirs for hippurate negative Campylobacters, Salmonella and faecal indicators in three EU recognized bathing waters in North West England. Wat. Res. 34:519-527.

Florida Tide influenced river

- Elevated levels of *E. coli* (5×10^5) present in intertidal sediments along the riverbank.
- Laboratory experiments showed significant amount of regrowth of enterococci and *E. coli* associated with wetting and drying effects due to tidal cycles.

Desmairais, T. R., H. M. Solo-Gabriele, C. J. Palmer. 2002. Influence of soil on fecal indicator organisms in a tidally influenced subtropical environment. Appl. Environ. Microbiol. 66:230-237.

Hawaii Ocean beaches, streams

- Many studies established soil as source of enterococci and *E. coli* in environment. *Clostridium* is utilized as an additional indicator.
- Stream is the source of fecal indicator bacteria to Kailua Beach.
- Soil is the major source of fecal indicator bacteria to the stream.

Roll, B. M. and R. Fujioka. 1997. Sources of faecal indicator bacteria in a brackish, tropical stream and their impact on recreational water quality. Water Sci. Tech. 35:179-186.

New Zealand Ocean Beach

- Marine/intertidal sediments contain up to 220 CFU/10 g *Enterococcus*.
- Resuspension of sediments by waves transport bacteria into water column.

N. M. Le Fevre and G. D. Lewis. 2003. The role of resuspension in enterococci distribution in water at an urban beach. Wat. Sci. Tech 47:205-210.

Talbert Marsh & Newport Slough

- Sediments act as reservoirs of fecal indicator bacteria in wetlands to 10^4.
- Tidal channels are the largest repository of enterococci in slough wetland sediments.

Grant, S. B., B. F. Sanders, A. B. Boehm, F. Arega, S. Ensari, R. Mrse, H. Kang, R. Reeves, J. H. Kim, and J. Redman, 2002. Coastal runoff impact study phase II: Sources and dynamics of fecal indicators in lower Santa Ana River watershed.

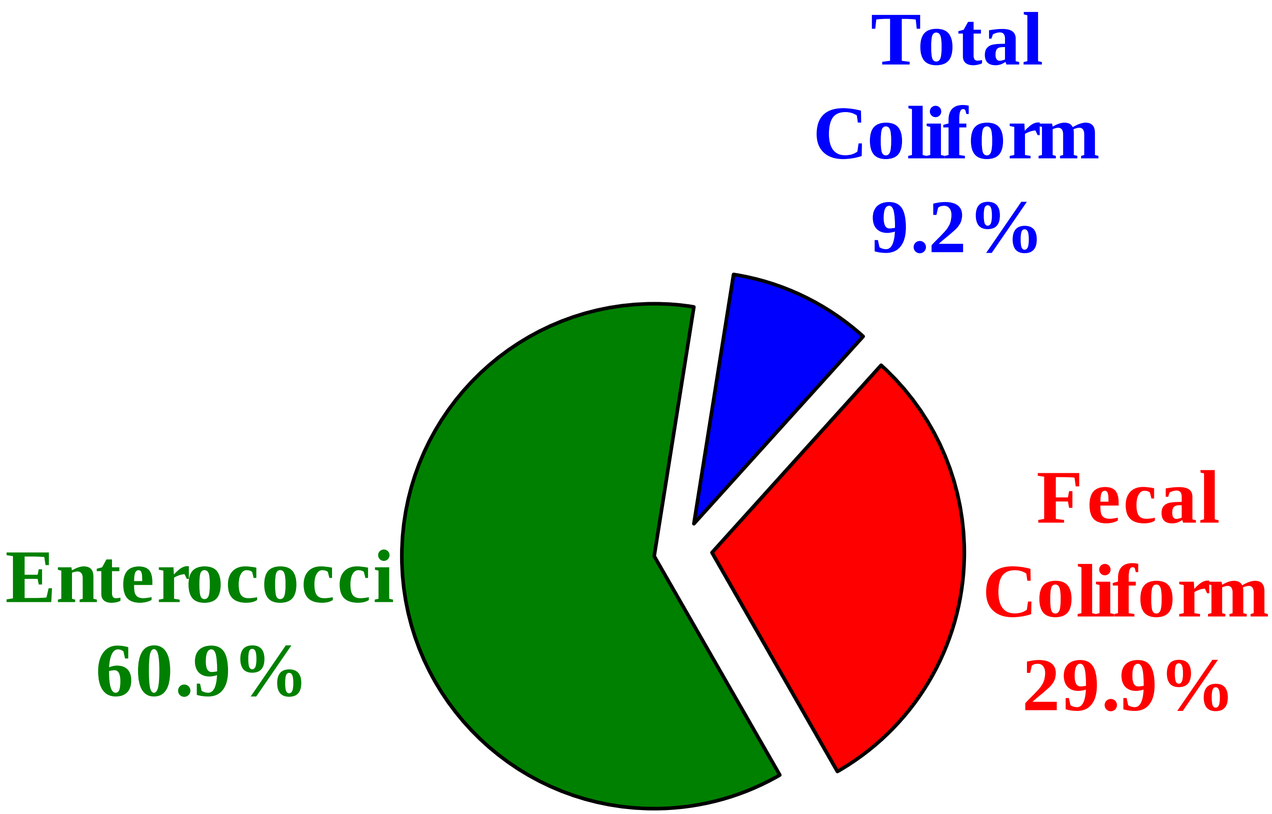
Location	Indicator	Maximum densities	Units	Type	Sewage impacted	Reference
Talbert Marsh	Ent	5×10^3	10 g	Wet	no	1
Newport Slough, Tidal Channel Sediments	Ent	1.6×10^4	10g	Dry	no	2
Florida	E. coli	$> 4.8 \times 10^5$	10 g	Dry	no	3
Buttermilk Bay, Mass.	FC	9.4×10^4	100 ml	NA	NA	4
Hanuma Bay, Hawaii	FC	1.8×10^4	10 g	Dry sand	no	5
	E. coli	1.6×10^4				
	Ent	3.2×10^3				
	FC	1.8×10^4				
	E. coli	1.6×10^4		Soil		
	Ent	3.2×10^3				
Morecambe, England	Fecal Strep	$\sim 2.0 \times 10^3$	10 g	Dry	yes	6
Lake Michigan, Indiana	E. coli	1×10^4	10 g	Dry	no	7
La Crosse, Wisconsin	FC	2.2×10^4	10 g	Mud	NA	8
Auckland, New Zealand	Ent	2.2×10^2	10g	Dry	NA	9

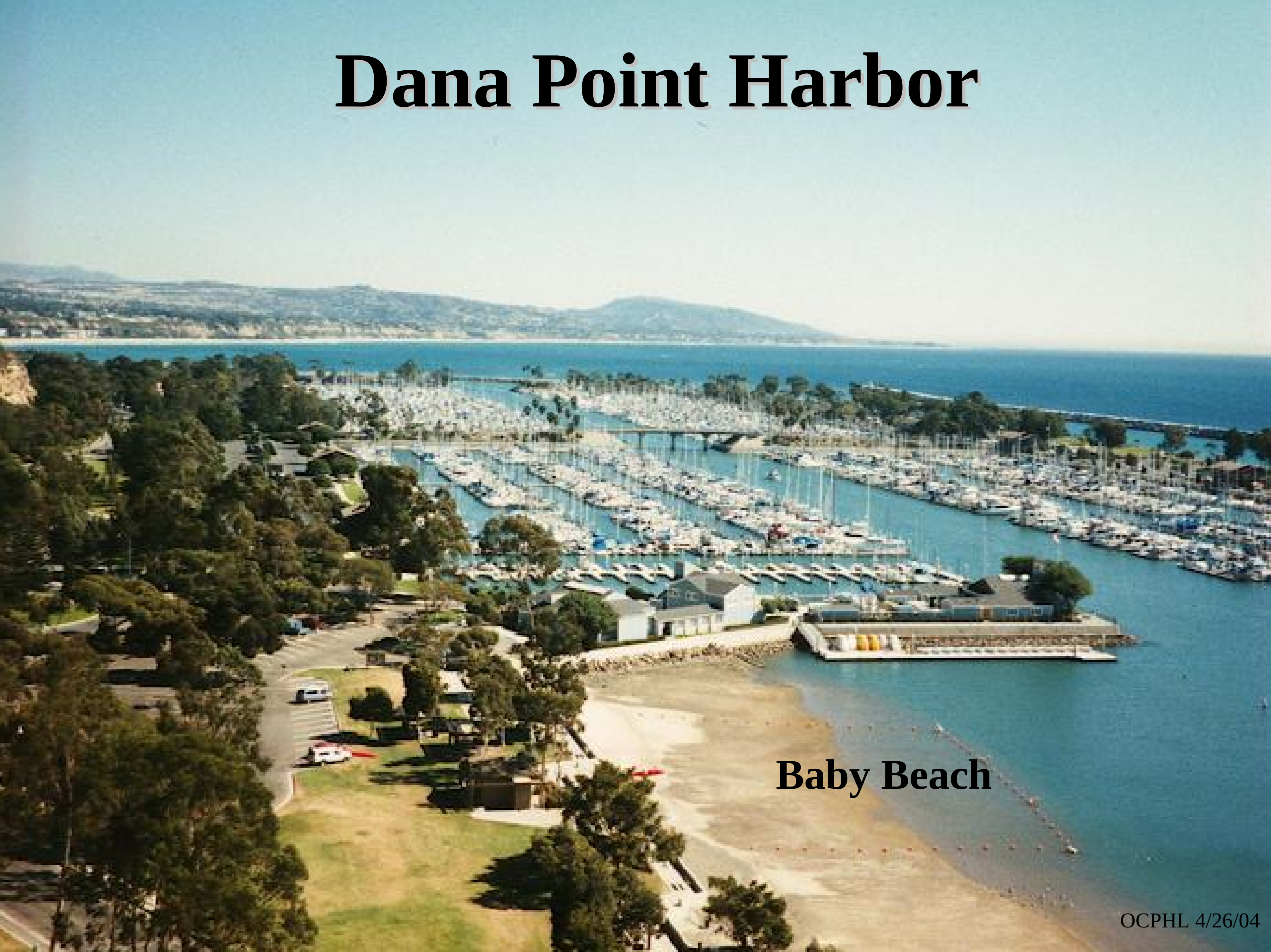
Working Hypothesis

- Storm drain, intertidal and marine sediments retain indicator bacteria which can re-grow under certain conditions.
- Concentrations found in sediments are often higher than in the overlying water.
- Tidal currents or runoff resuspends and transports bacteria in sediments to beach and surfzone sites leading to increased concentration of indicators and regulatory failures.

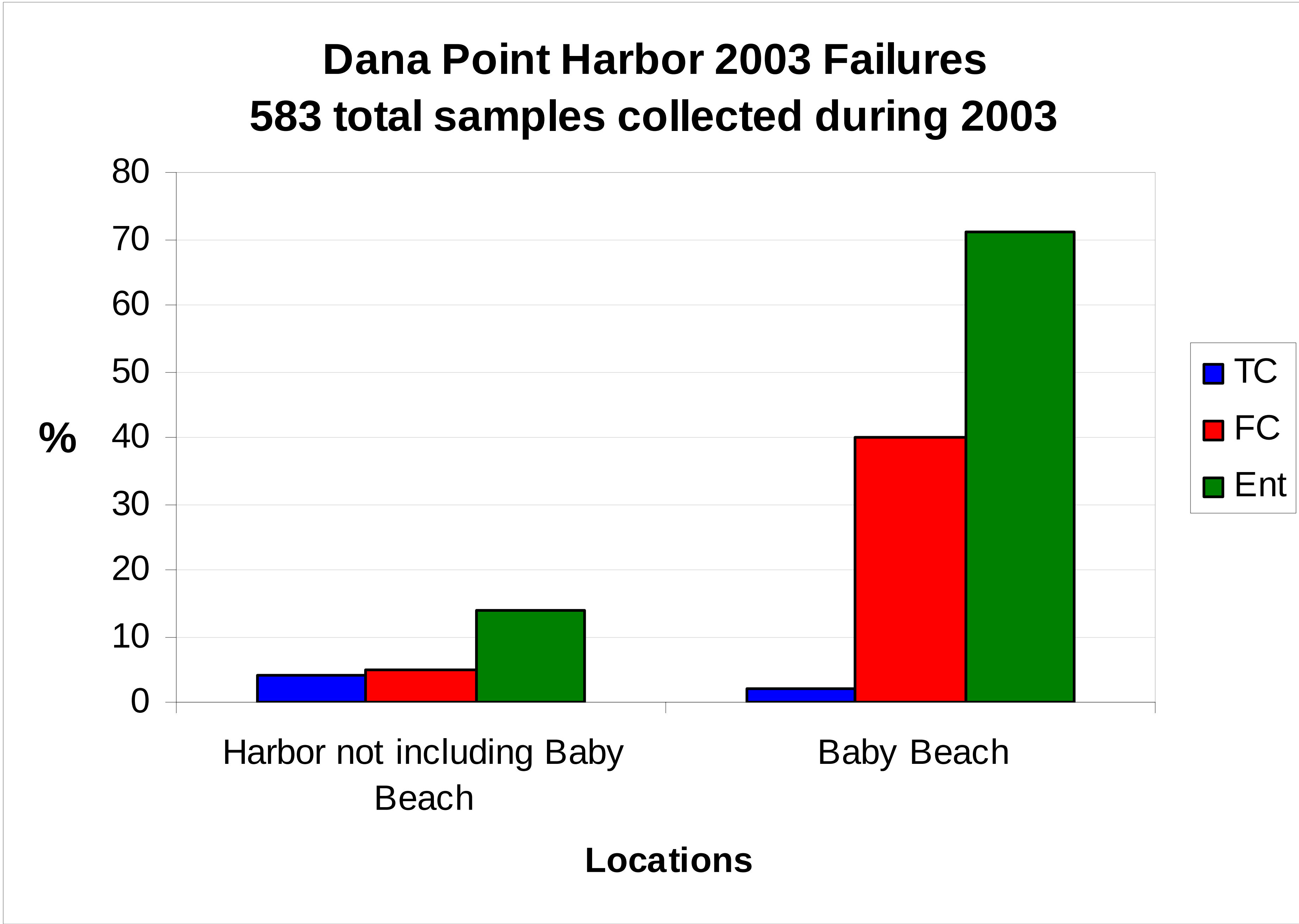
Indicator Failure Rate for OC

2000 - 2002 (April - October)




Dana Point Harbor
Baby Beach
OCPHL 4/26/04

Dana Point Harbor Sampling Sites


Dana Point Harbor 2003 Failures
583 total samples collected during 2003
%
80
70
60
50
40
30
20
10
0
Harbor not including Baby Beach
Baby Beach
Locations
TC
FC
Ent

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Baby Beach

Potential Sources:

1. Groundwater
2. Sewage
3. Birds
4. Storm Drains
5. Boats
6. Humans

Previous BMPs/studies:

1. Storm drains: plugged in summer
2. Bird control: netting installed under pier
3. Sewage: ruled out as source

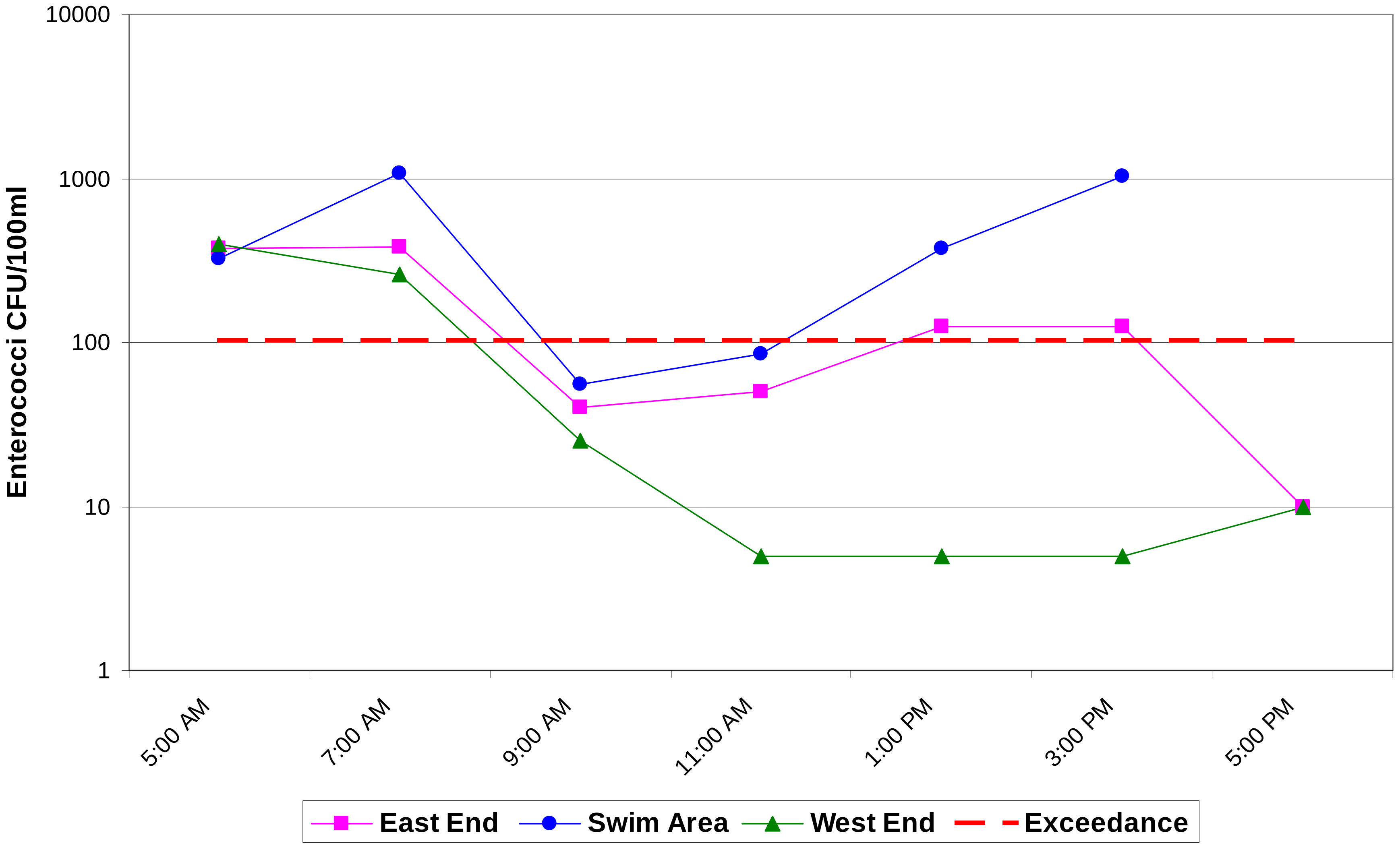
Baby Beach

<u>Special Studies Performed by OCPHL in 2002:</u>

- **Storm Drain Groundwater Seepage**
- **12-hour temporal variability**
- **10-Week study**
- **Sediment Analysis**
- **Boat Sewage Discharge/Surf study**
  - Reference: Baby Beach Bacteriological Special Studies Report Dana Point Harbor, California (June 2003)
- **Speciation of Enterococci**

Baby Beach 12 Hour Study

Enterococci Levels in Marine Water



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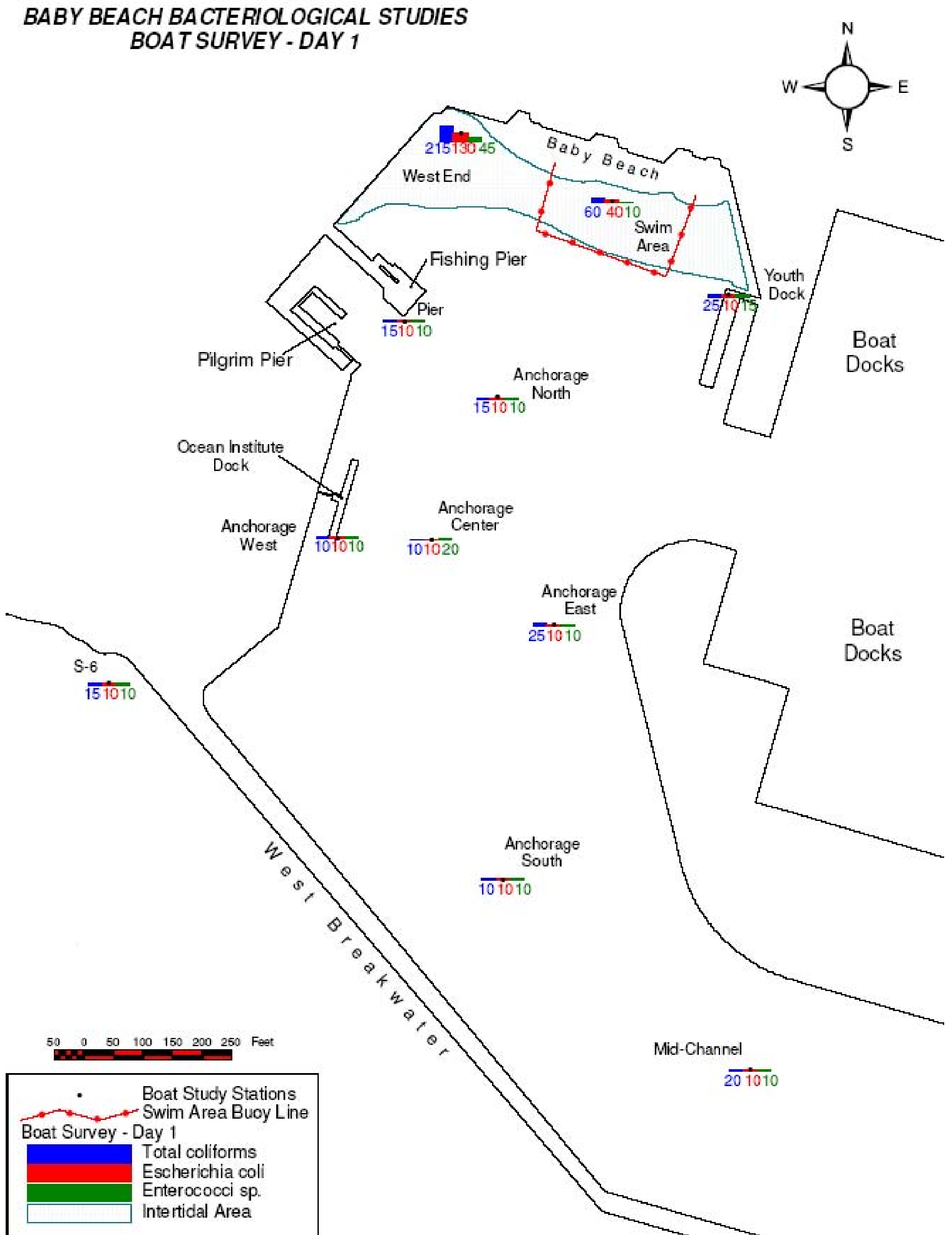


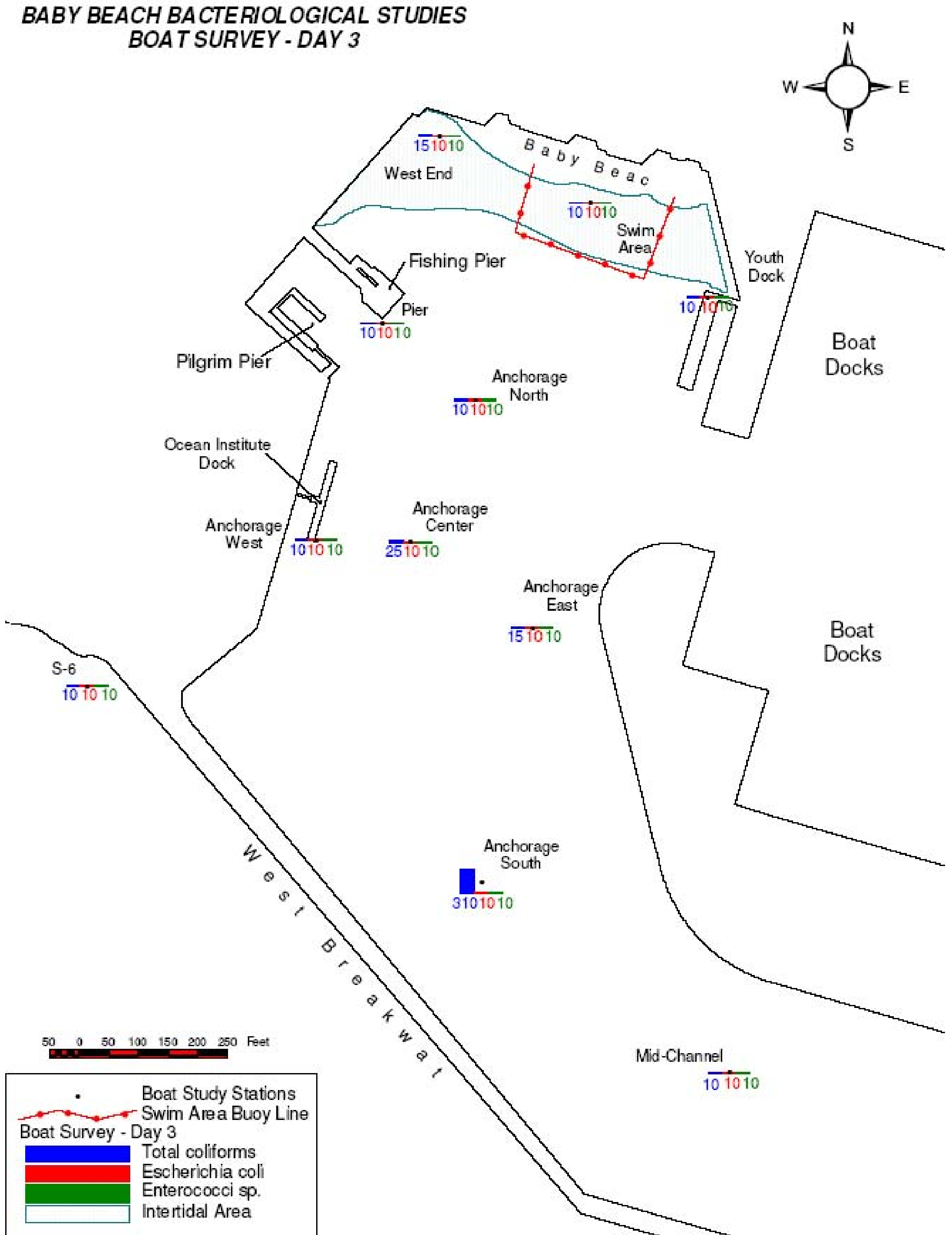
Additional Survey Information

People = 20

Boats = 3

Surf (ft) = 3

Graph created by Science Applications International Corporation (SAIC)



Additional Survey Information

People = 100

Boats = 30

Surf (ft) = 3

Graph created by Science Applications International Corporation (SAIC)

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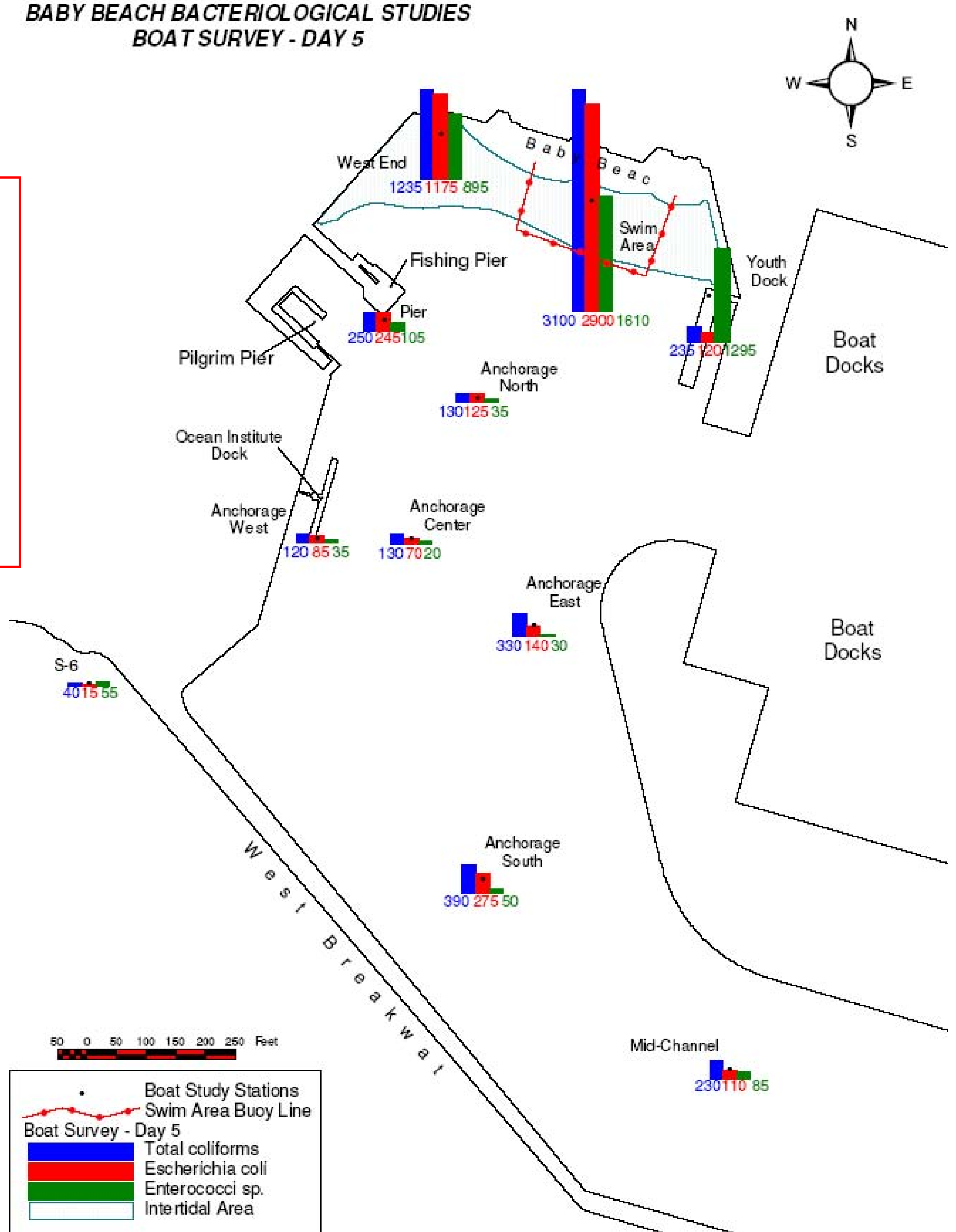

Additional Survey Information

People = 0

Boats = 4

Surf (ft) = 10

Graph created by Science Applications International Corporation (SAIC)

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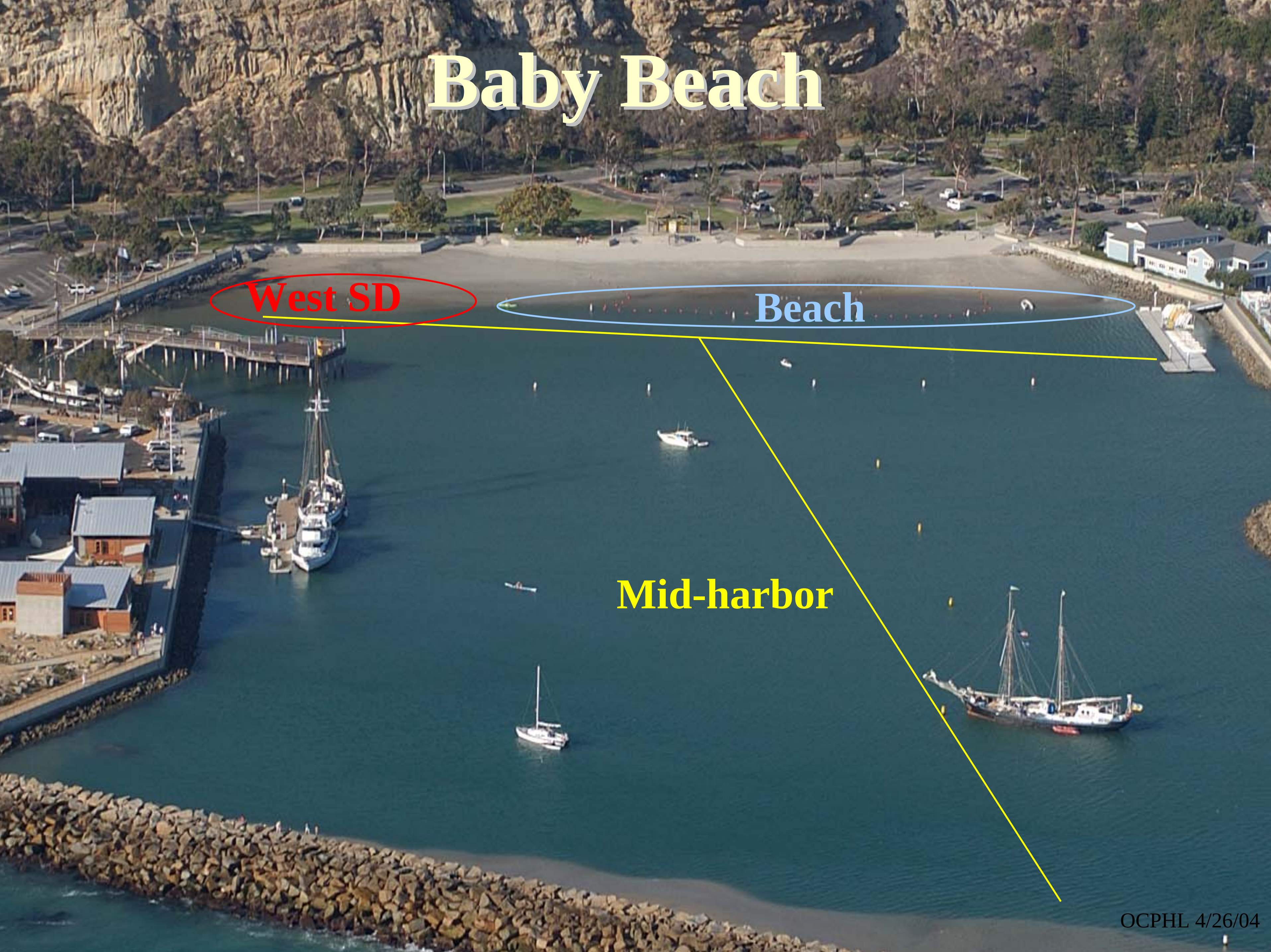
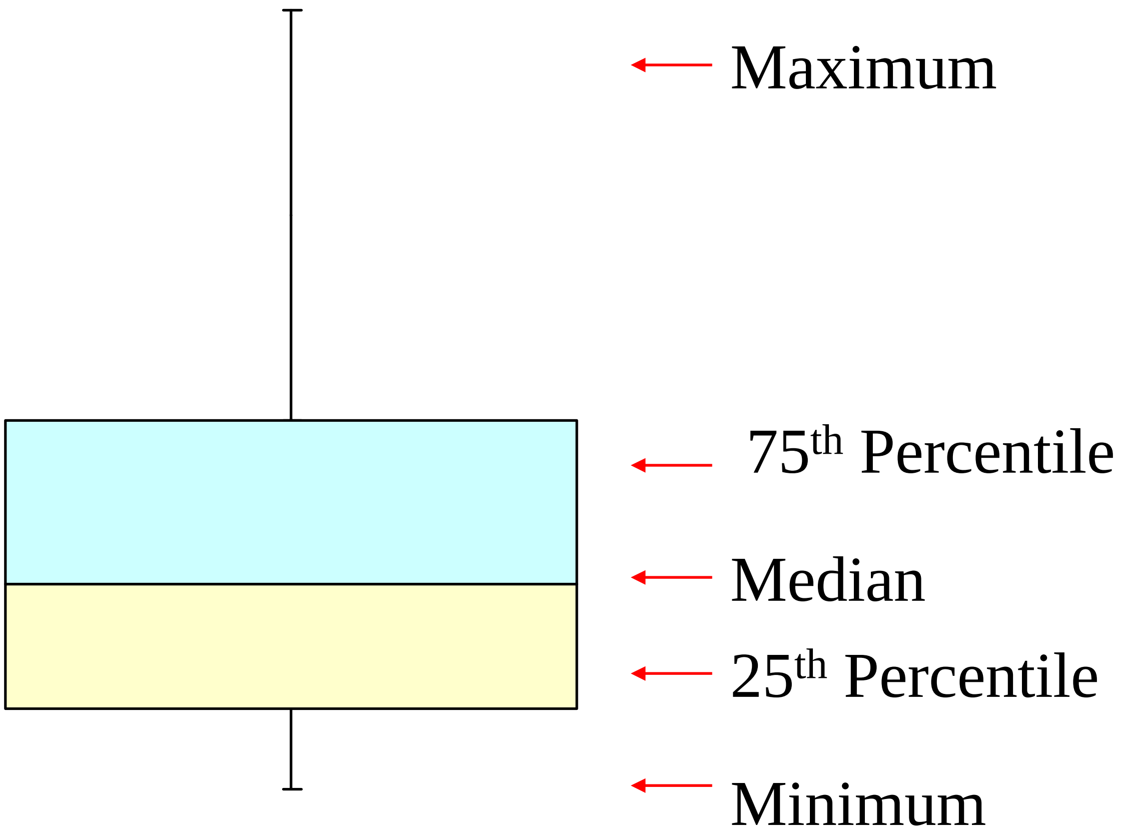
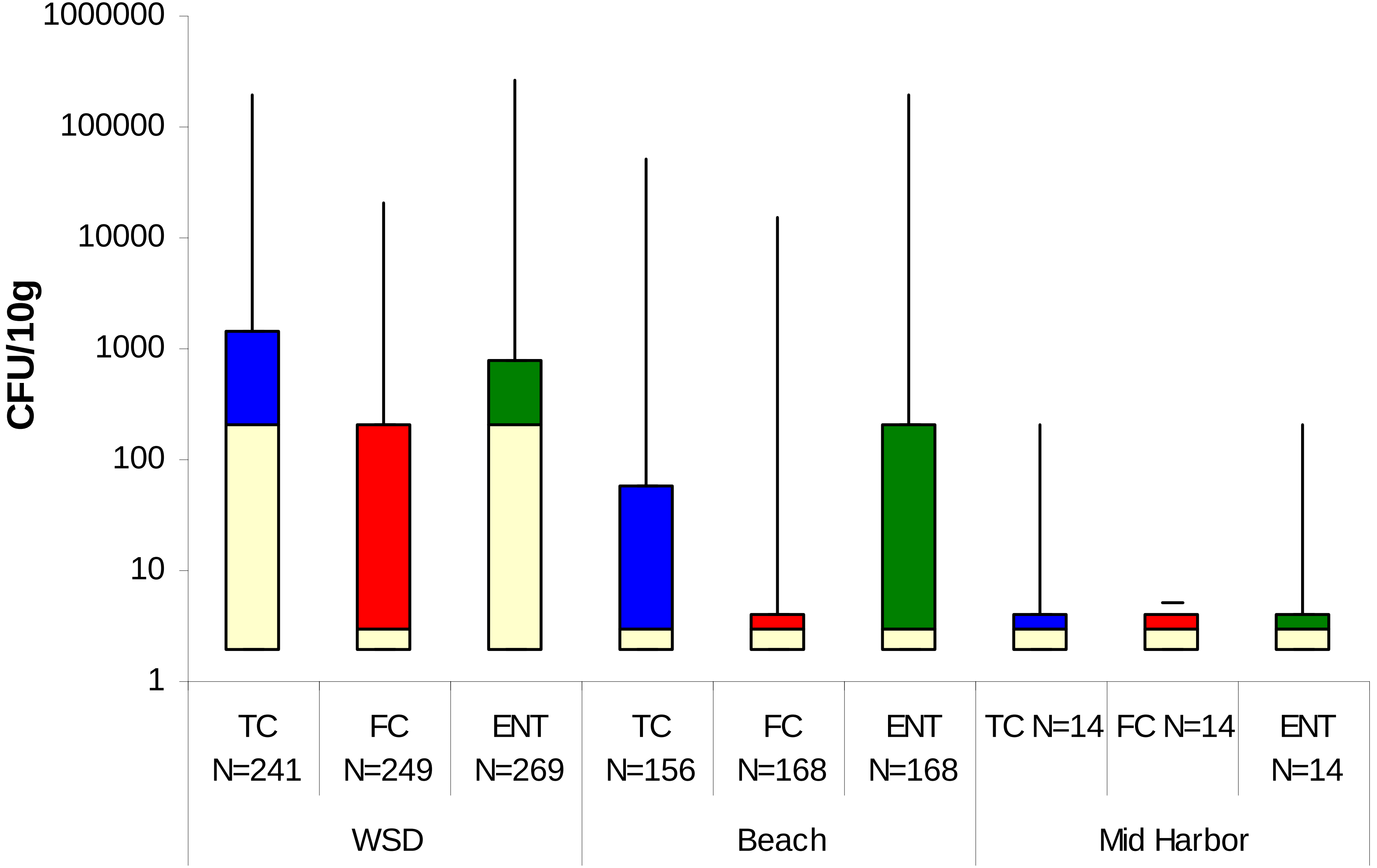

Baby Beach
West SD
Beach
Mid-harbor
OCPHL 4/26/04

Box and Whisker Plots



Baby Beach Sediment Indicators



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Baby Beach Summary

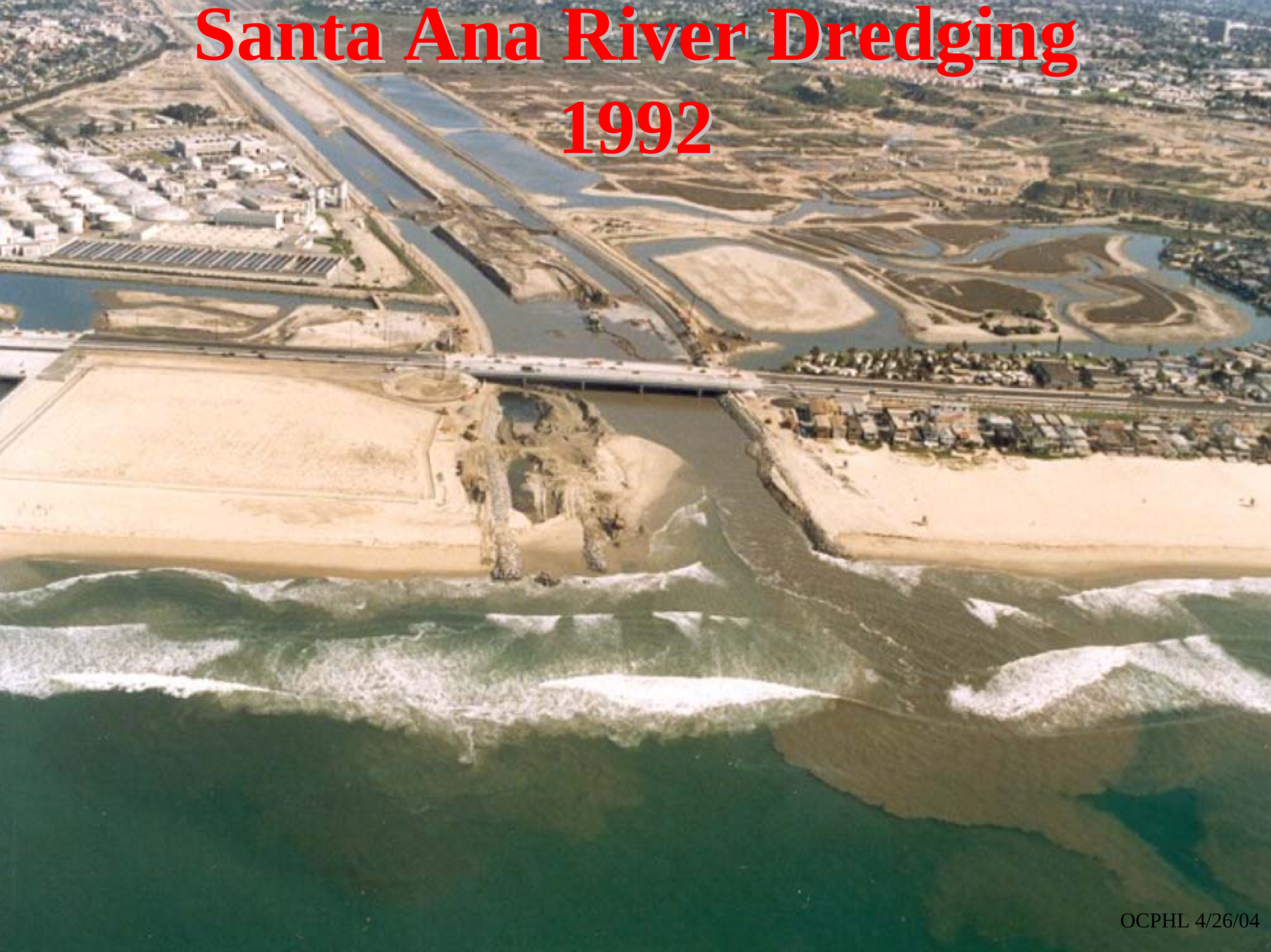
- Direct storm drain input contaminates swim area.
- Storm drain feeds nutrients, sediments and bacteria into baby beach area.
- Bacteria in sediments persist or replicate.
- Bacteria become resuspended and cause constant loading and failures at swim area.

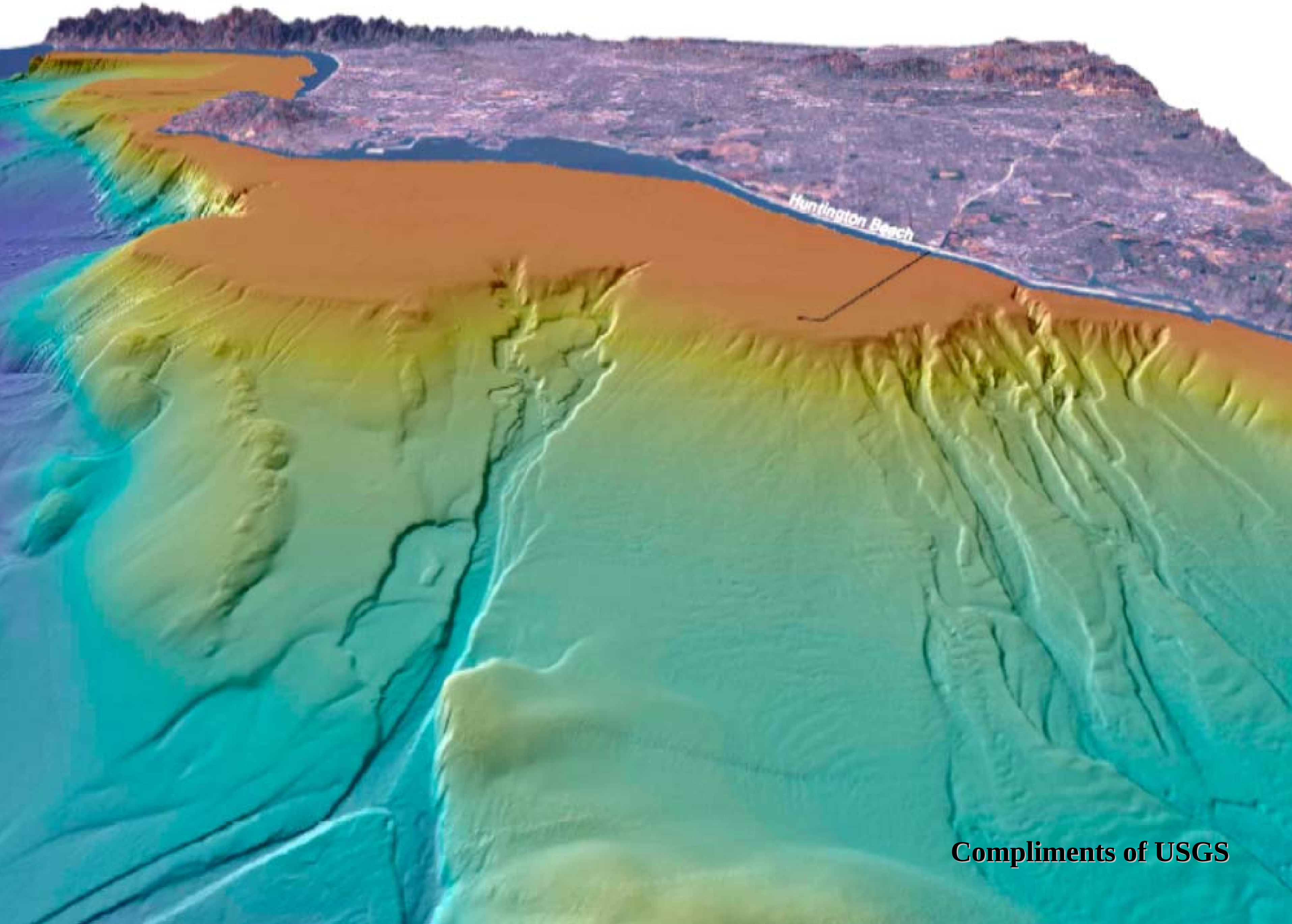
Huntington Beach

Santa Ana River-Beach Blvd

- **Episodic failures in summer dry weather period caused mainly by *Enterococcus*.**
- **These are correlated with spring tide periods.**
- **Previous studies have pointed to SA River and Talbert Marsh as sources with transport due to currents.**
- **No river flow in summer and storm drains feeding into SA river and Talbert Marsh are diverted.**

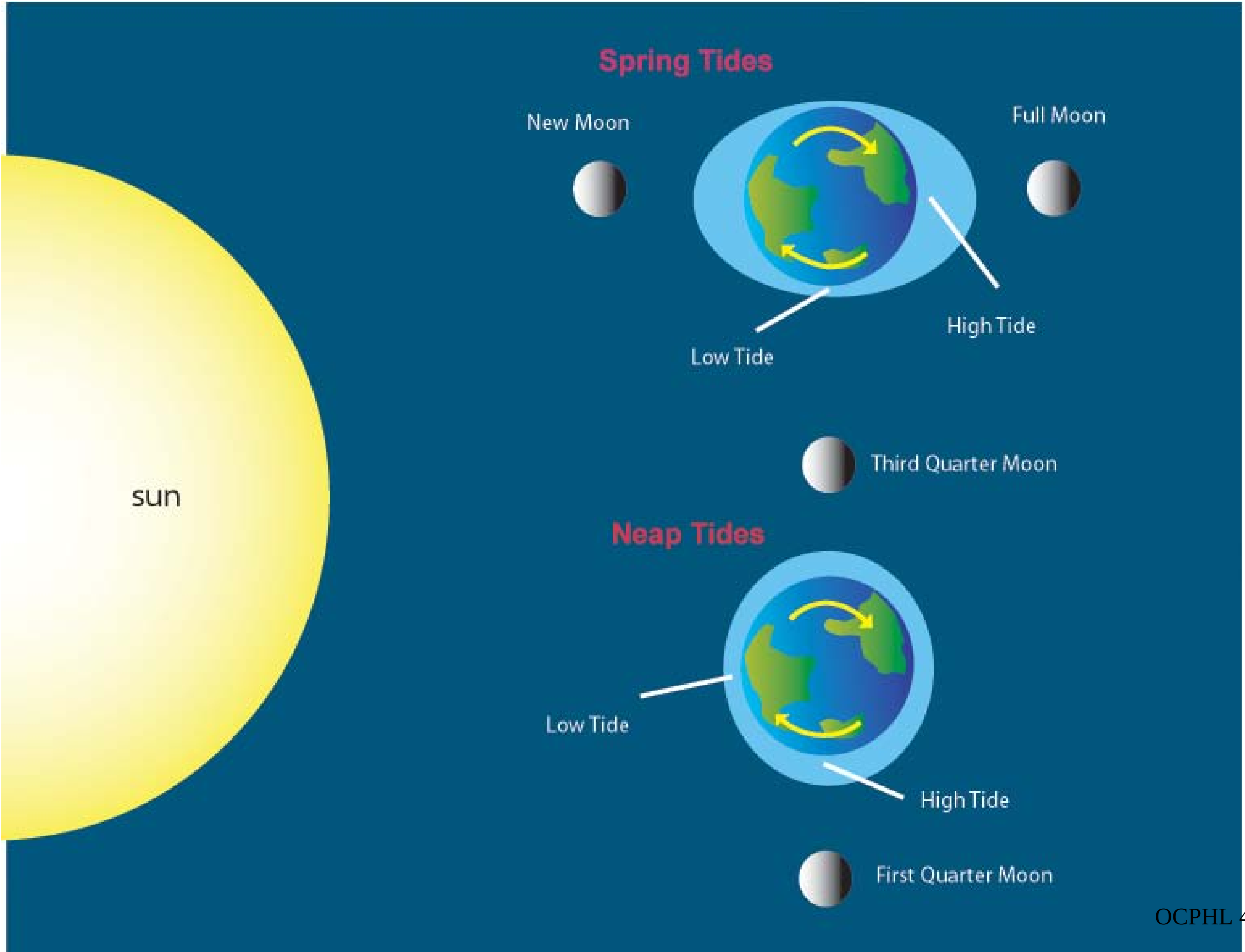
Santa Ana River Dredging 1992

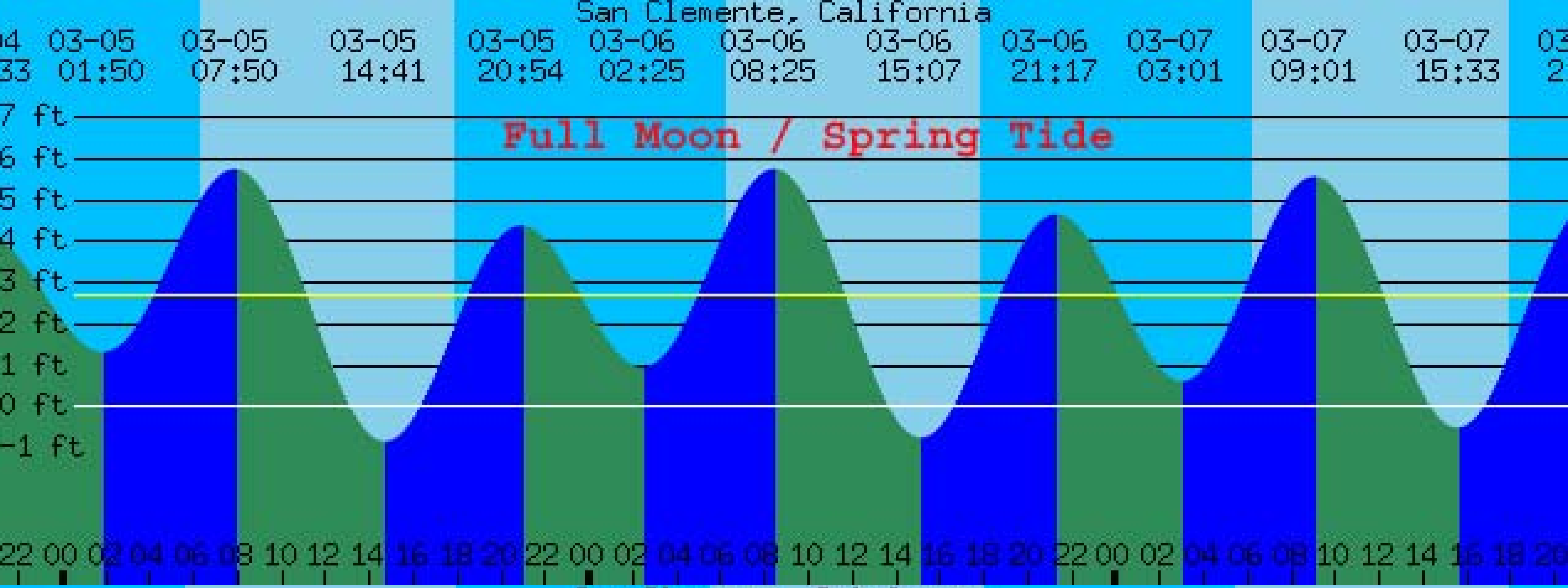


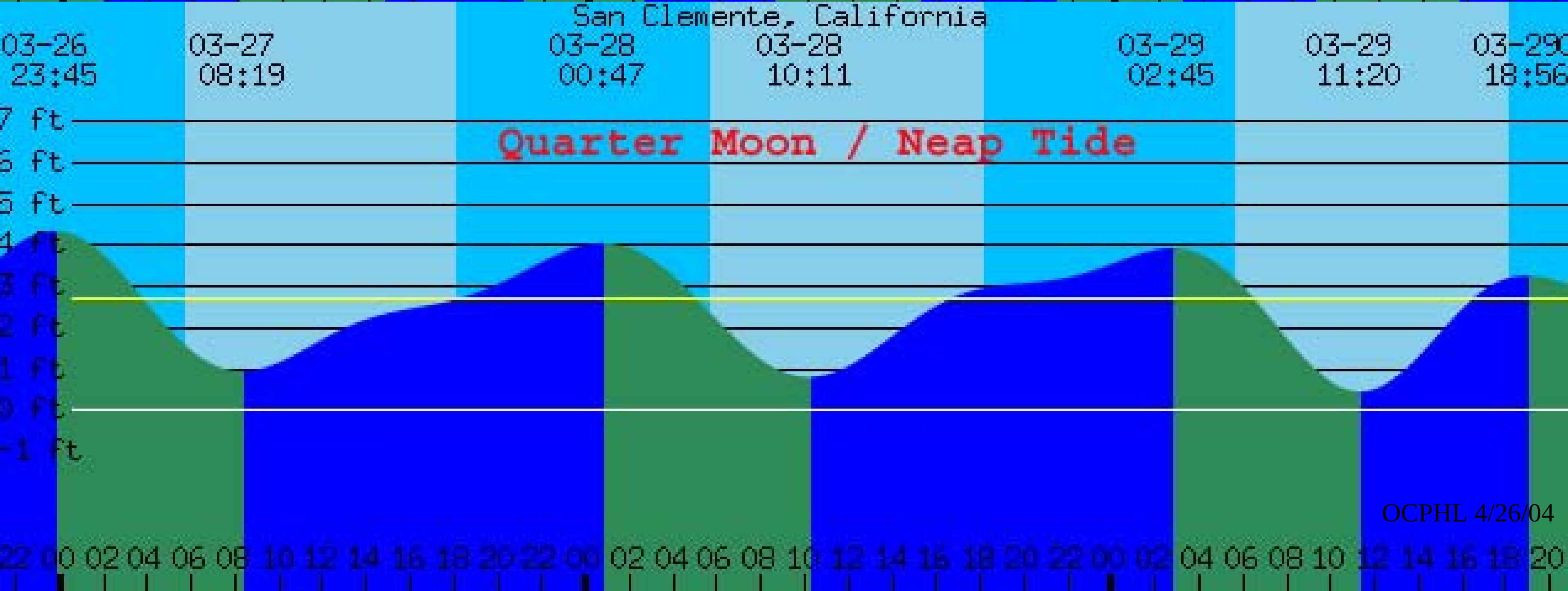


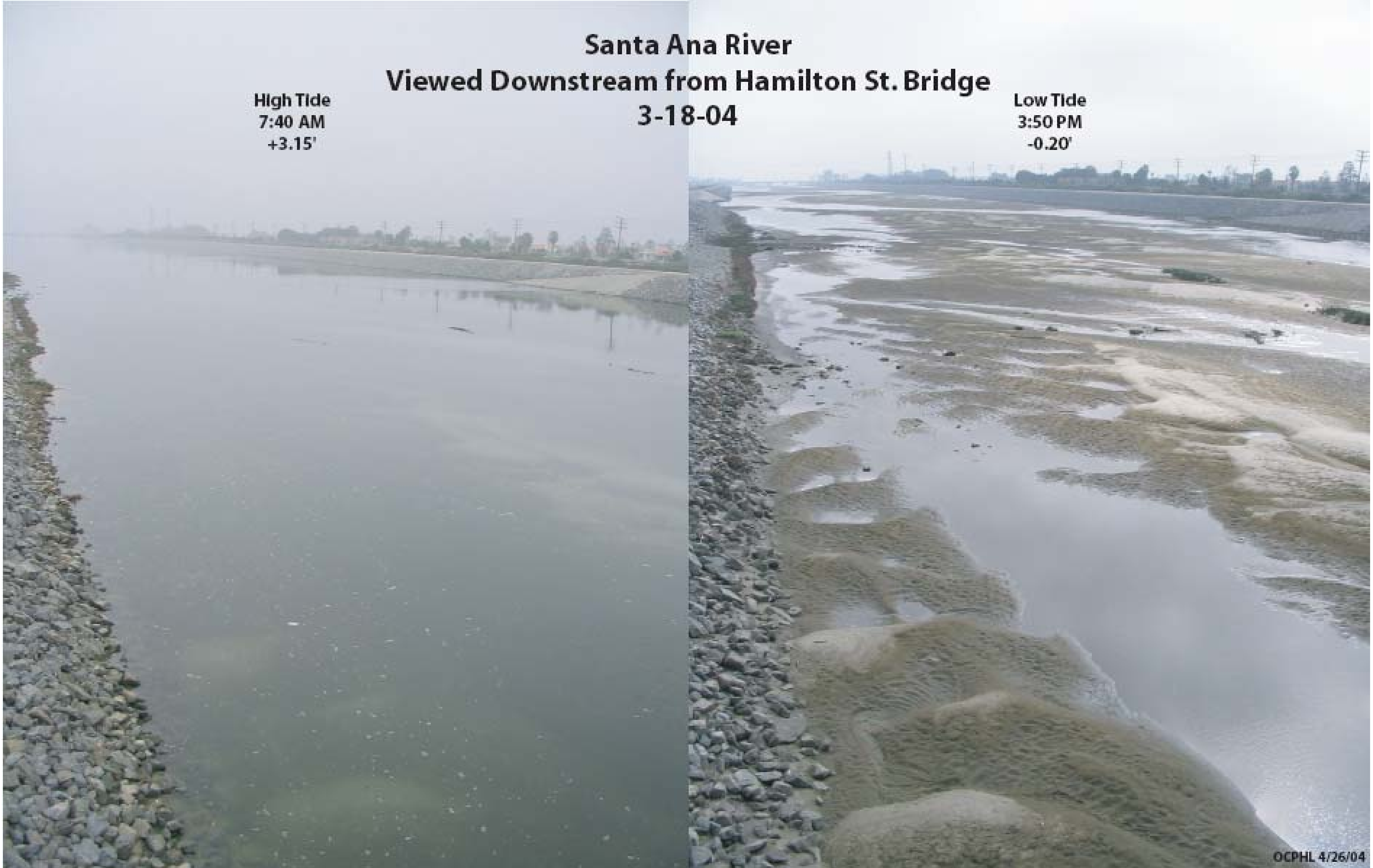
Compliments of USGS

Spring & Neap Tides




San Clemente, California
03-05 01:50
03-05 07:50
03-05 14:41
03-05 20:54
03-06 02:25
03-06 08:25
03-06 15:07
03-06 21:17
03-07 03:01
03-07 09:01
03-07 15:33
Full Moon / Spring Tide
7 ft
6 ft
5 ft
4 ft
3 ft
2 ft
1 ft
0 ft
-1 ft
22 00 02 04 06 08 10 12 14 16 18 20 22 00 02 04 06 08 10 12 14 16 18 20 22 00 02 04 06 08 10 12 14 16 18 20


San Clemente, California
03-26 23:45
03-27 08:19
03-28 00:47
03-28 10:11
03-29 02:45
03-29 11:20
03-29 18:56
Quarter Moon / Neap Tide
7 ft
6 ft
5 ft
4 ft
3 ft
2 ft
1 ft
0 ft
-1 ft
22 00 02 04 06 08 10 12 14 16 18 20 22 00 02 04 06 08 10 12 14 16 18 20 22 00 02 04 06 08 10 12 14 16 18 20


Santa Ana River
Viewed Downstream from Hamilton St. Bridge
3-18-04
High Tide
7:40 AM
+3.15'
Low Tide
3:50 PM
-0.20'
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Correlation of Indicator Failures with Spring Tides

2002-2004 (April 1st to October 31st)

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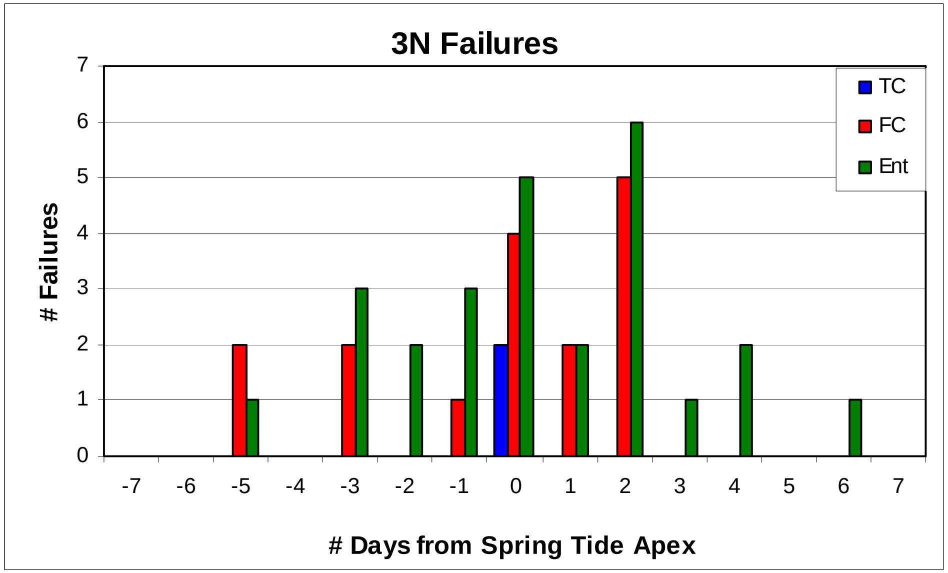

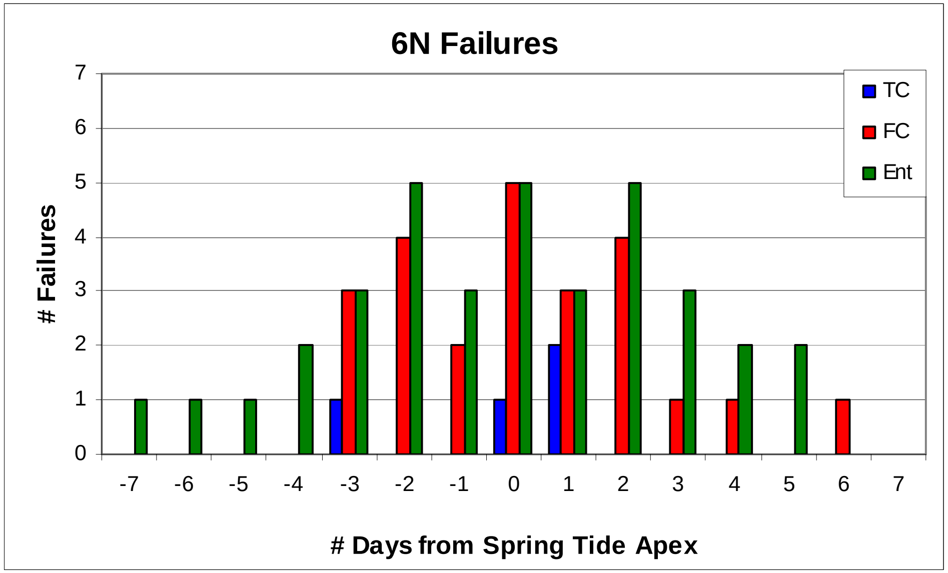

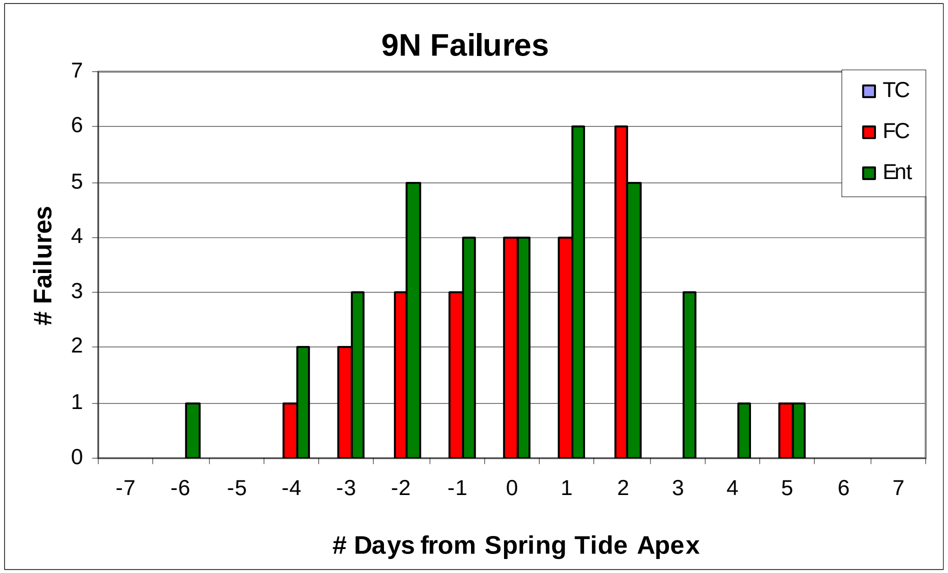

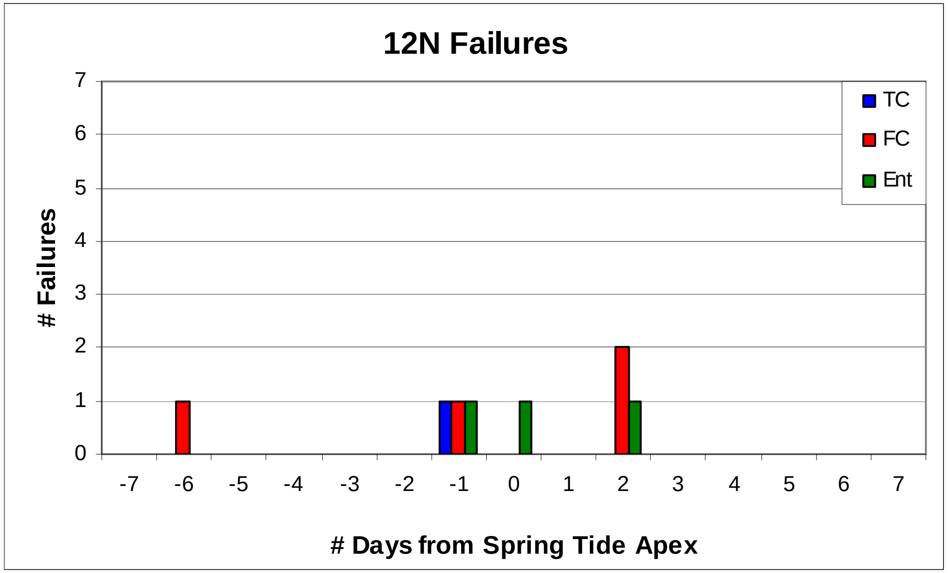

Correlation of Indicator Failures with Spring Tides

2002-2004 (November-March)

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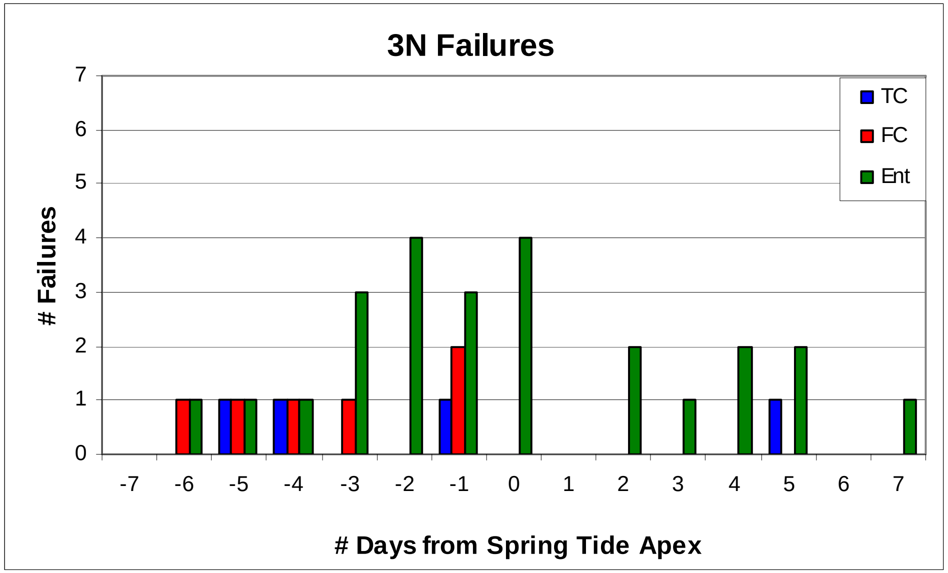
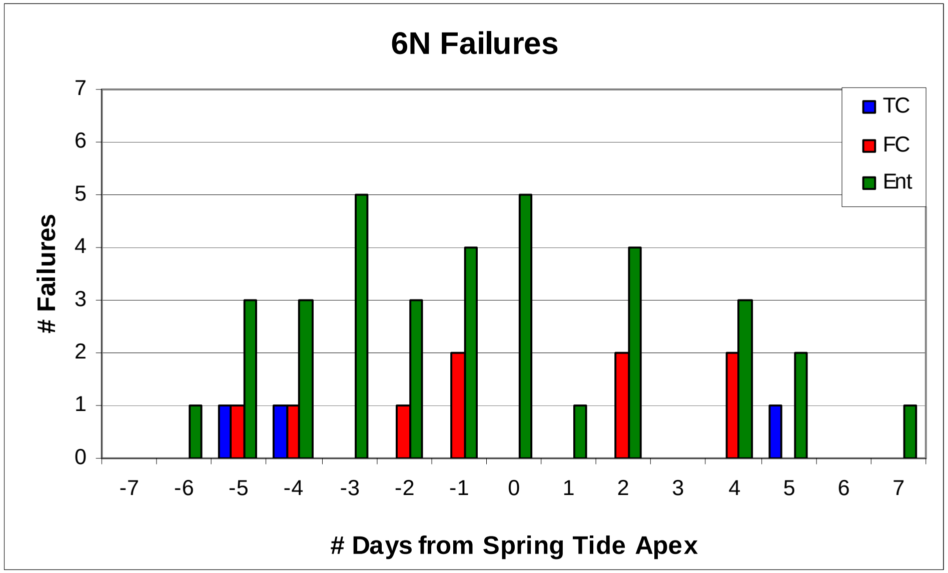
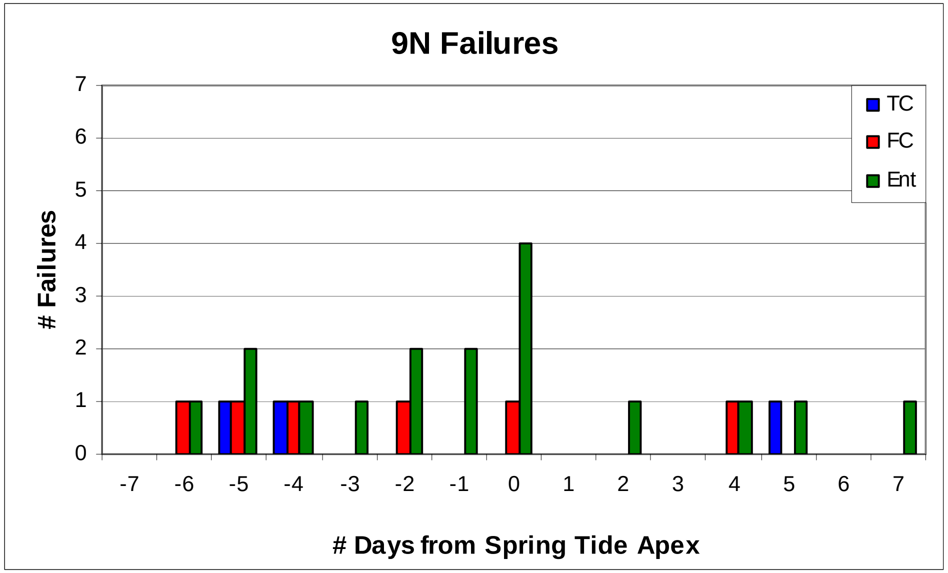
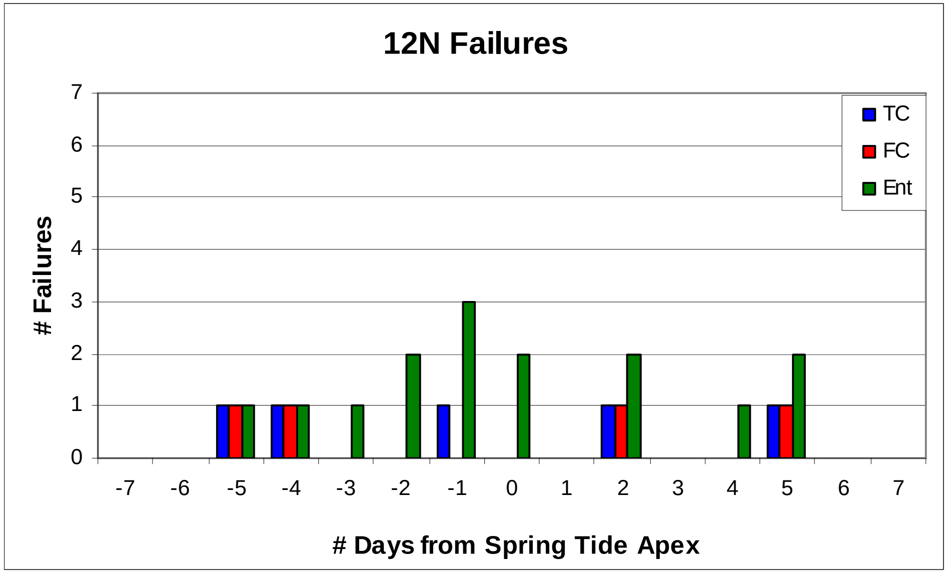


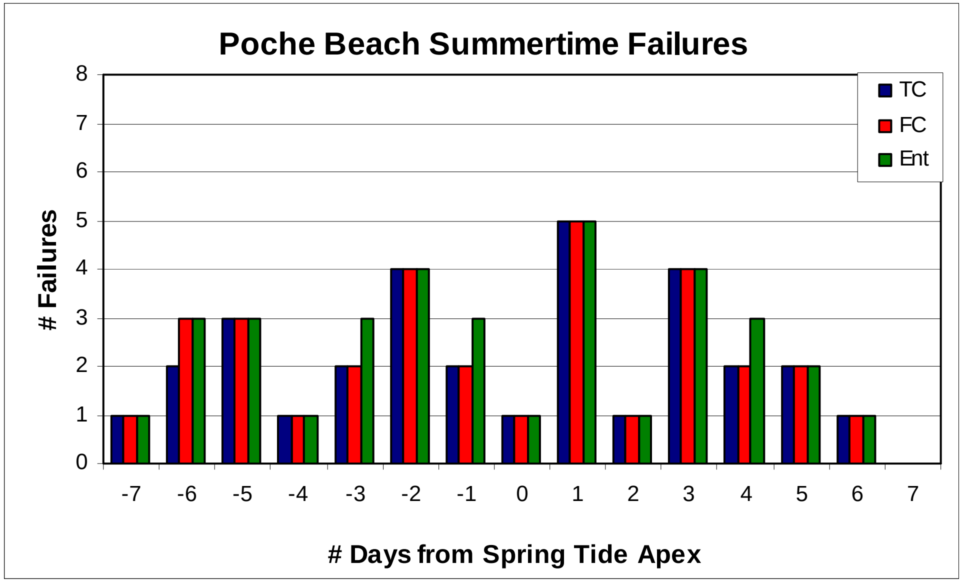


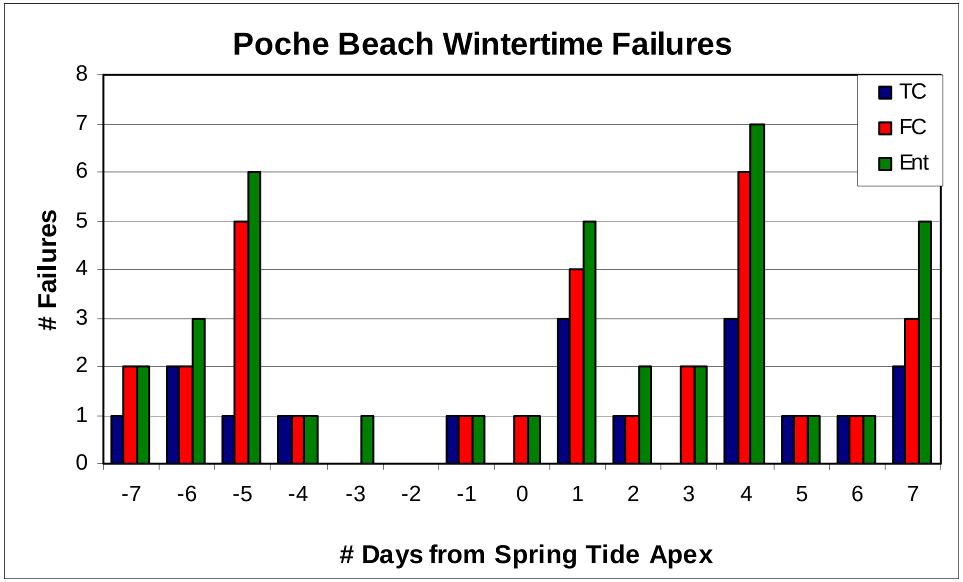




Poche Beach (2002-2004)

Correlation of Indicator Failures with Spring Tides





HB Sediment Study

- **Sediment bacterial concentration studies (7/03-1/04)**
  - OCSD Sewage Outfall
  - HB 30 foot depth line (0.2 mile offshore)
  - Santa Ana River
  - Huntington Beach Surfzone
  - Newport Beach 30 foot depth line (control)
- **Enterococci Speciation**
  - Predominant species were identified (5 colonies/filter)
  - Molecular typing of predominant species currently in progress

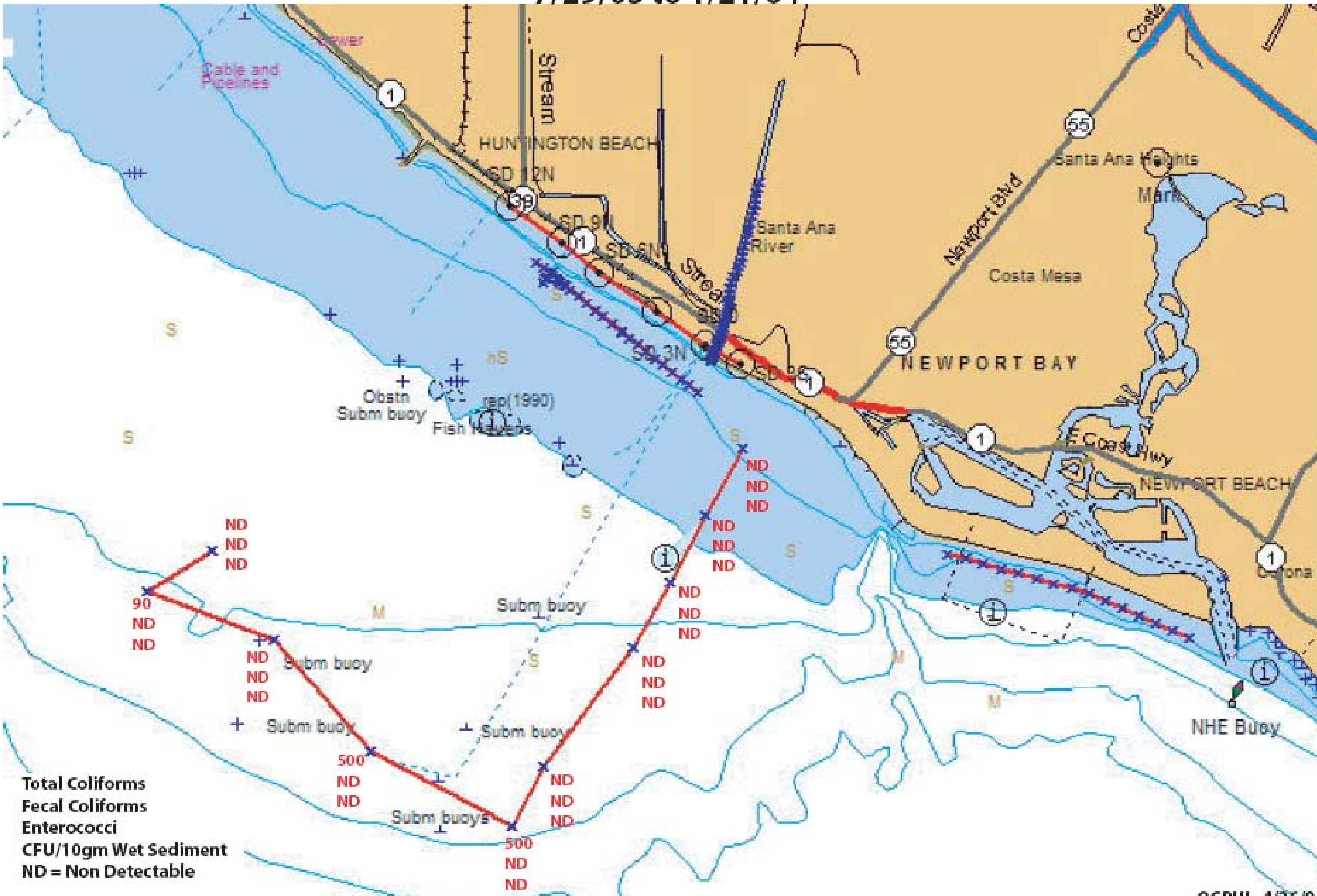
Sediment Methods

- Sediment Sample Collection.
  - Approximately 100 grams of sediment was collected in sterile plastic bottles.
  - Offshore sediment samples were collected using a clamshell sampler along a 10m depth contour. SAR sediment samples were collected using sterile collection bottle without sodium thiosulfate from the top 1” layer.

- Sediment Processing.
  - Bacteria were separated from sediment particles by suspending 10g of sediment in 100 ml 1% sodium metaphosphate sonicating for 30s at 30% output using a Branson® Sonifier 450.

- Bacterial Enumeration.
  - All enterococci were enumerated using the EPA Method 1600, membrane filtration using m-EI media.
  - Values expressed in CFU/10g wet

Huntington Beach / Santa Ana River
Transect Locations
7/29/03 to 1/21/04



Total Coliforms
Fecal Coliforms
Enterococci
CFU/10gm Wet Sediment
ND = Non Detectable

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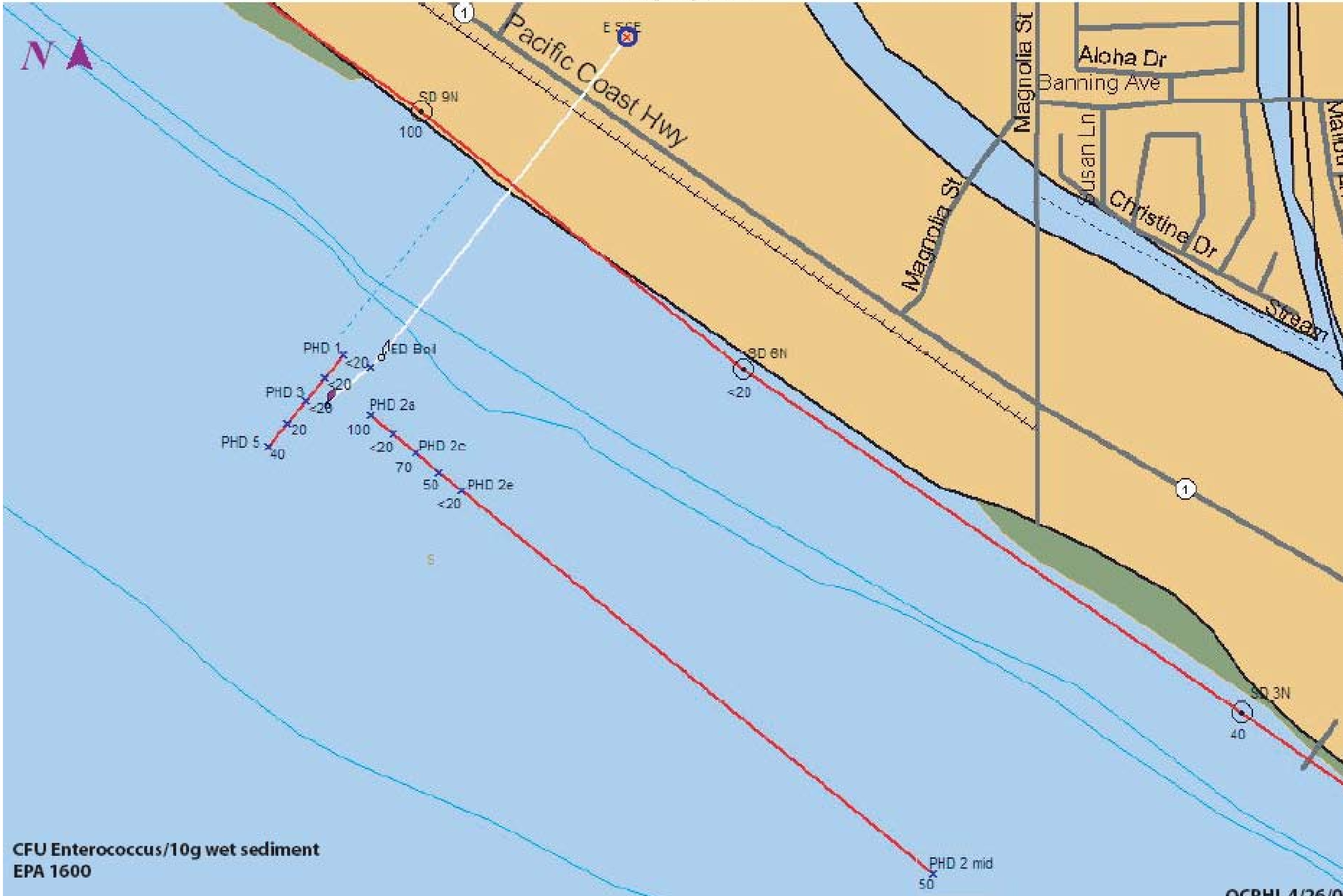
AES Outfall
Offshore Transect
10/9/03



CFU Enterococcus/10g wet sediment
EPA 1600

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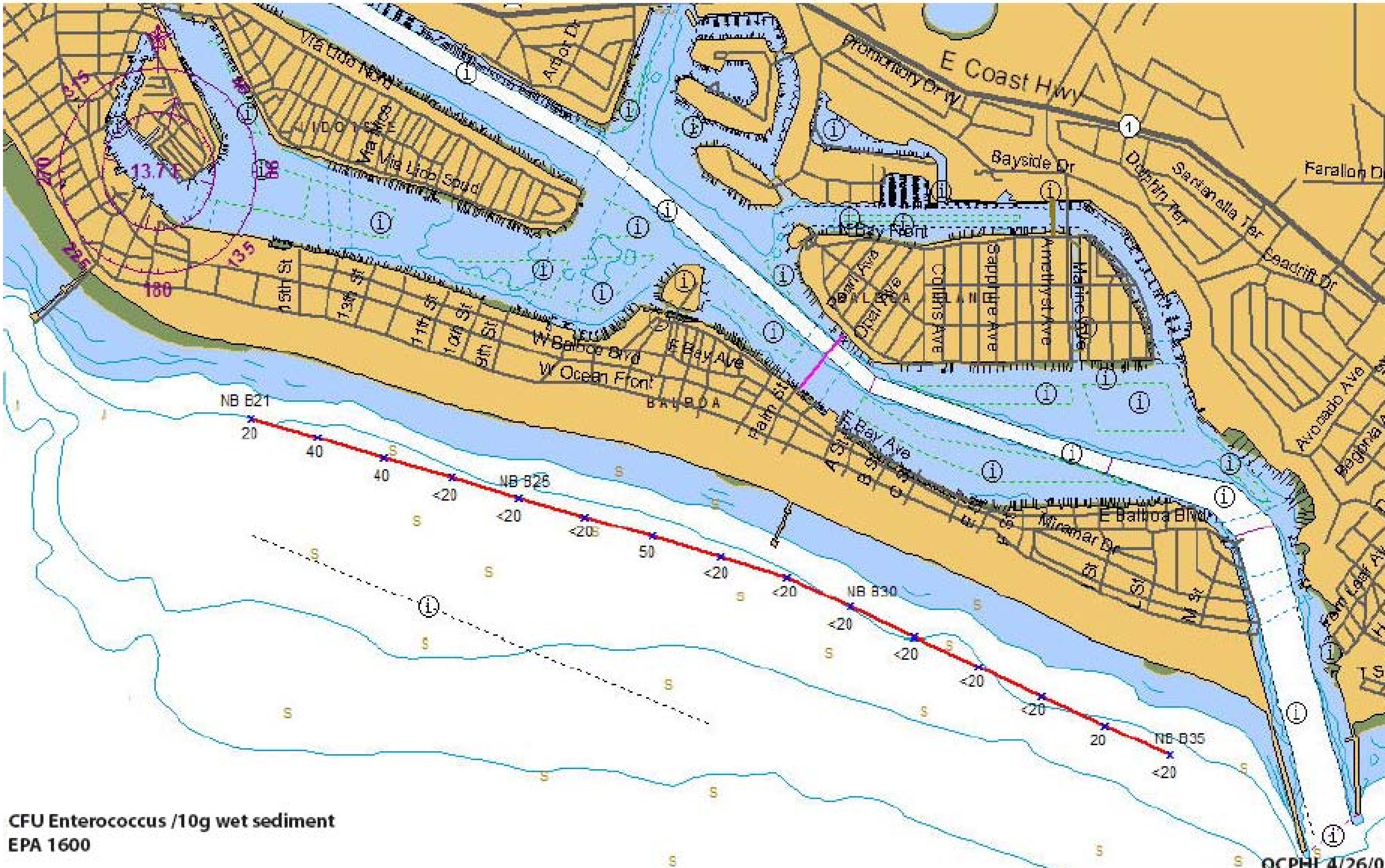
Newport Beach
30' Deep Offshore Transect
12/17/03



Enterococci Levels in Lower Santa Ana River Sediment

All values presented as CFU/10g wet sediment

Lower SAR "B" Collected on 12-23-03 (100' Intervals)

Mid SAR "A" Collected on 1-6-04 (150' Intervals)

Upper SAR Collected on 1-21-04 (300' Intervals)

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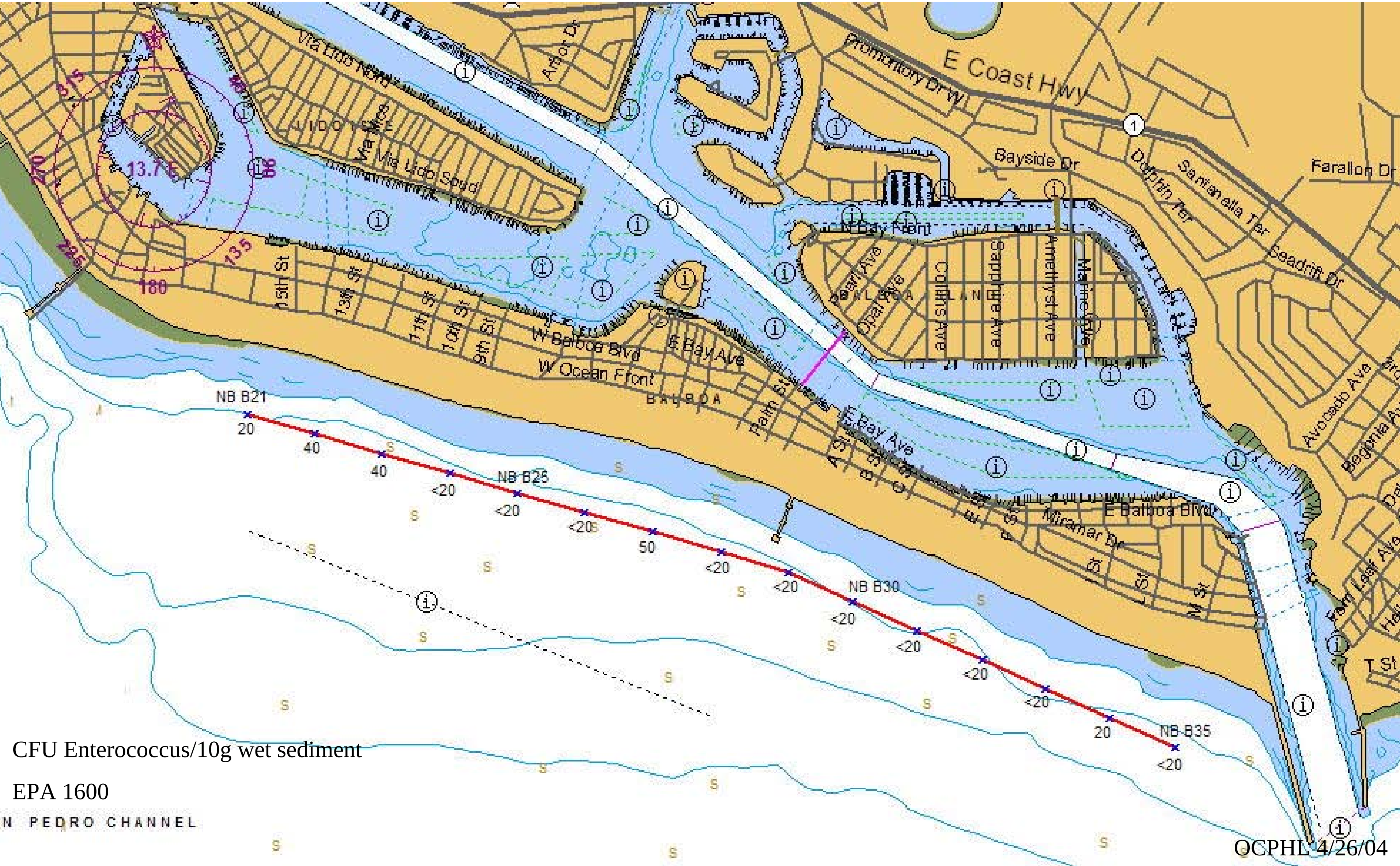
Newport Beach
30' Deep Offshore Transect
12/17/04

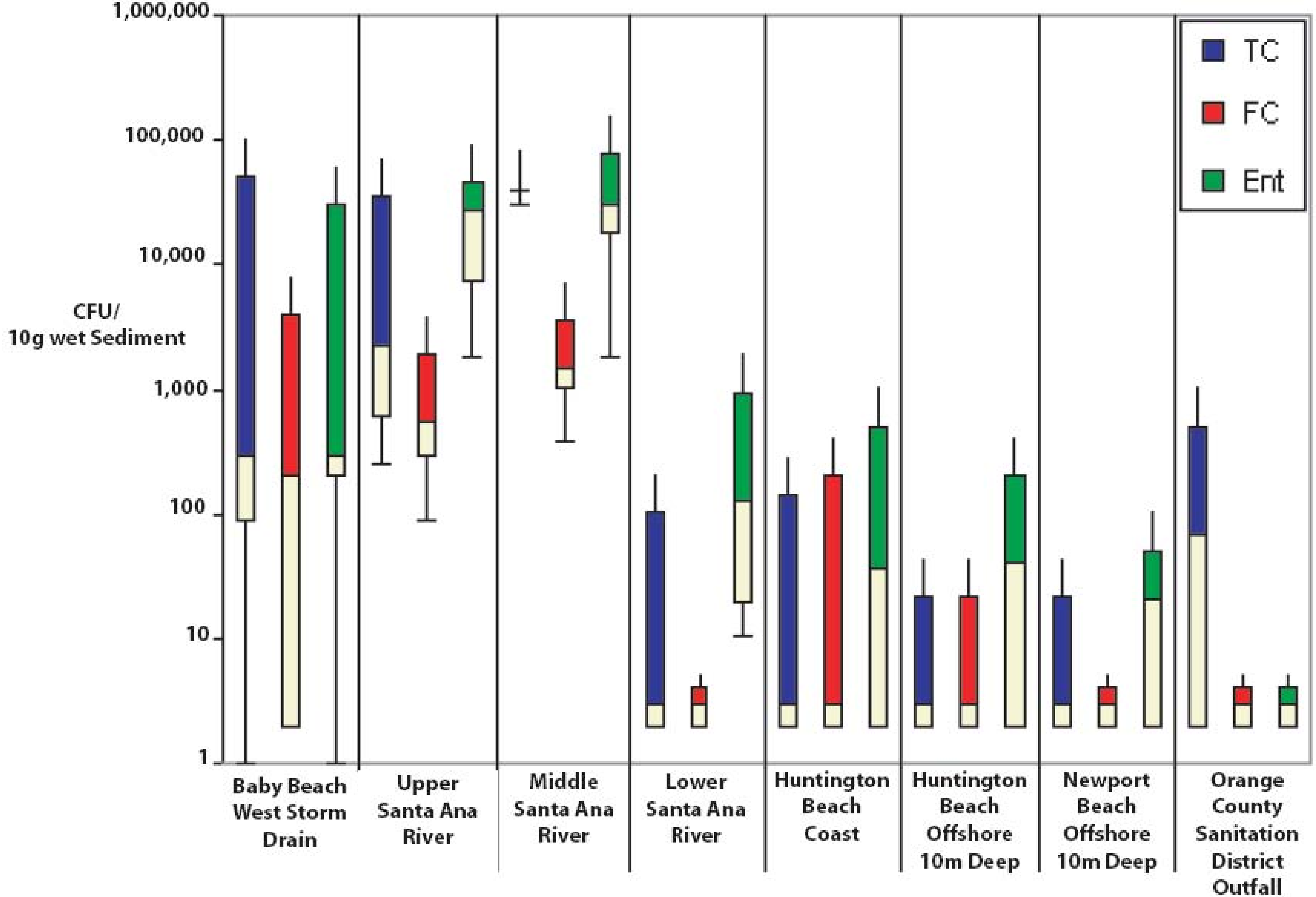


CFU Enterococcus/10g wet sediment

EPA 1600

OCPHL 4/26/04

Fecal Indicator Bacteria Levels found in Sediment Transects



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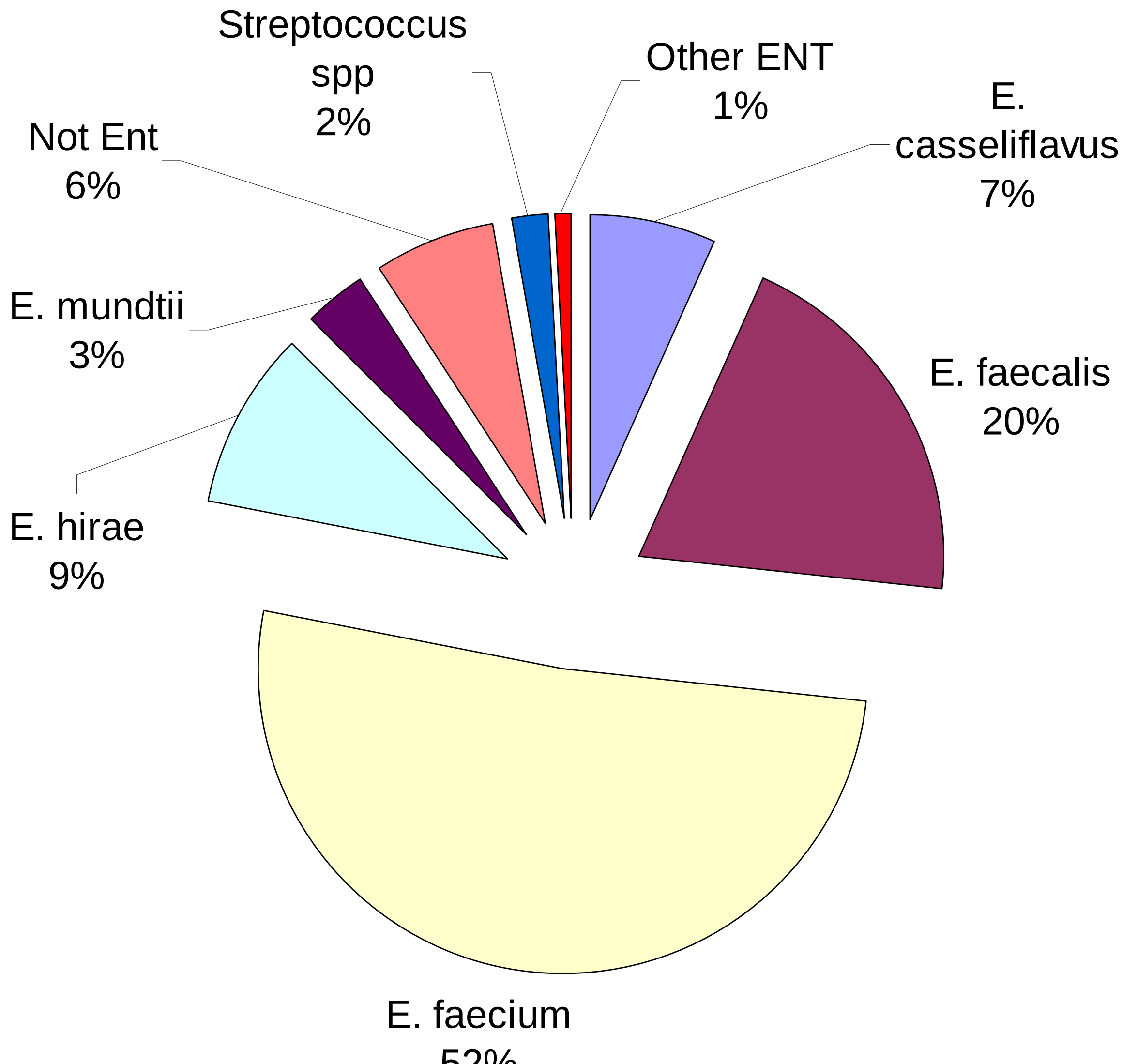
Enterococcus Speciation

- Determine accuracy of screening techniques.
- Determine prevalence of species.
- Look for trends in species found in sediments and marine water.
- Use speciation data to select isolates for molecular typing techniques.

HB Surfzone Study

- From 8/5/03 thru 9/15/03, SARN, SARS, 3N, 6N, 9N, and 21N
- OCSD collected and analyzed 144 samples using Membrane Filtration (EPA Method 1600 for Enterococci)
- Samples were brought to OCPHL and up to 5 isolates were picked from mEI media for further analysis
- 576 isolates were speciated using API 20 Strep and supplemental tests

Santa Ana River Sediments
(206 Isolates)



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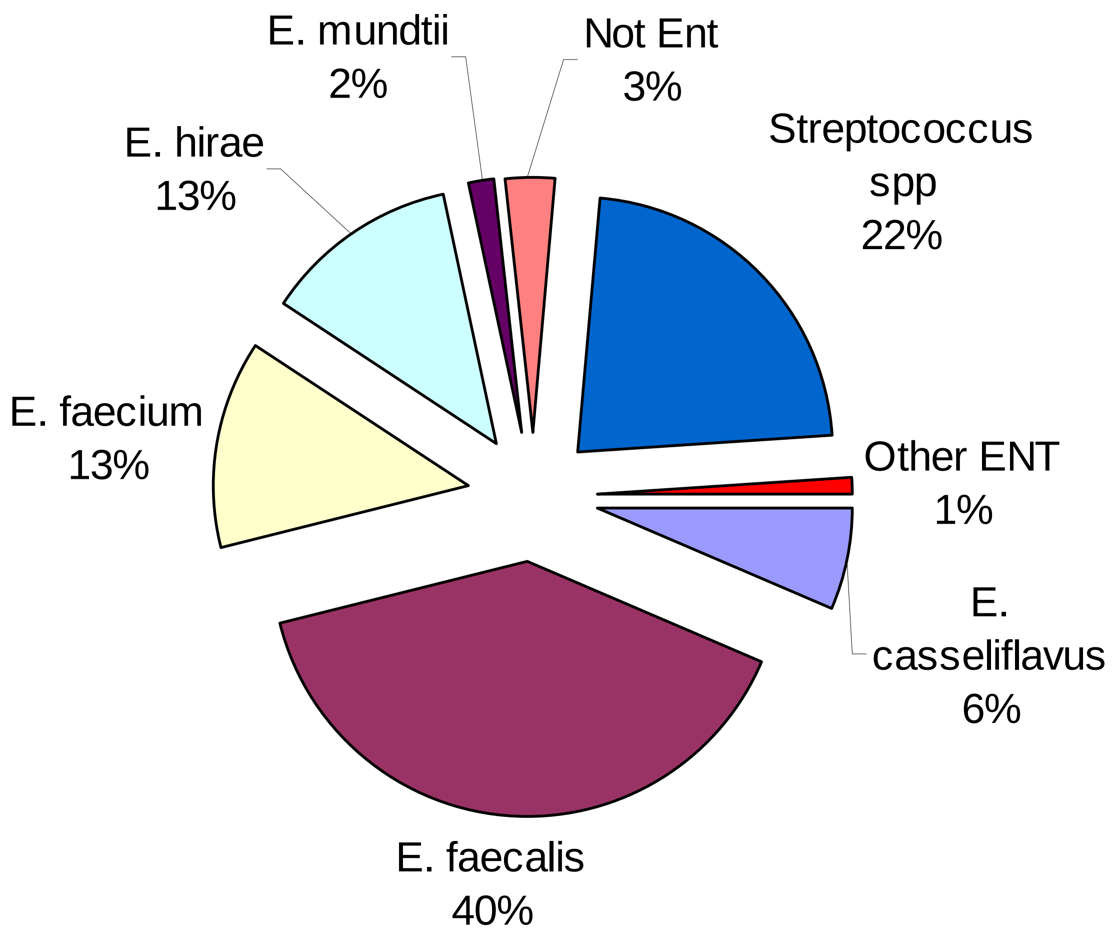
HB Surfzone Water
(576 Isolates)



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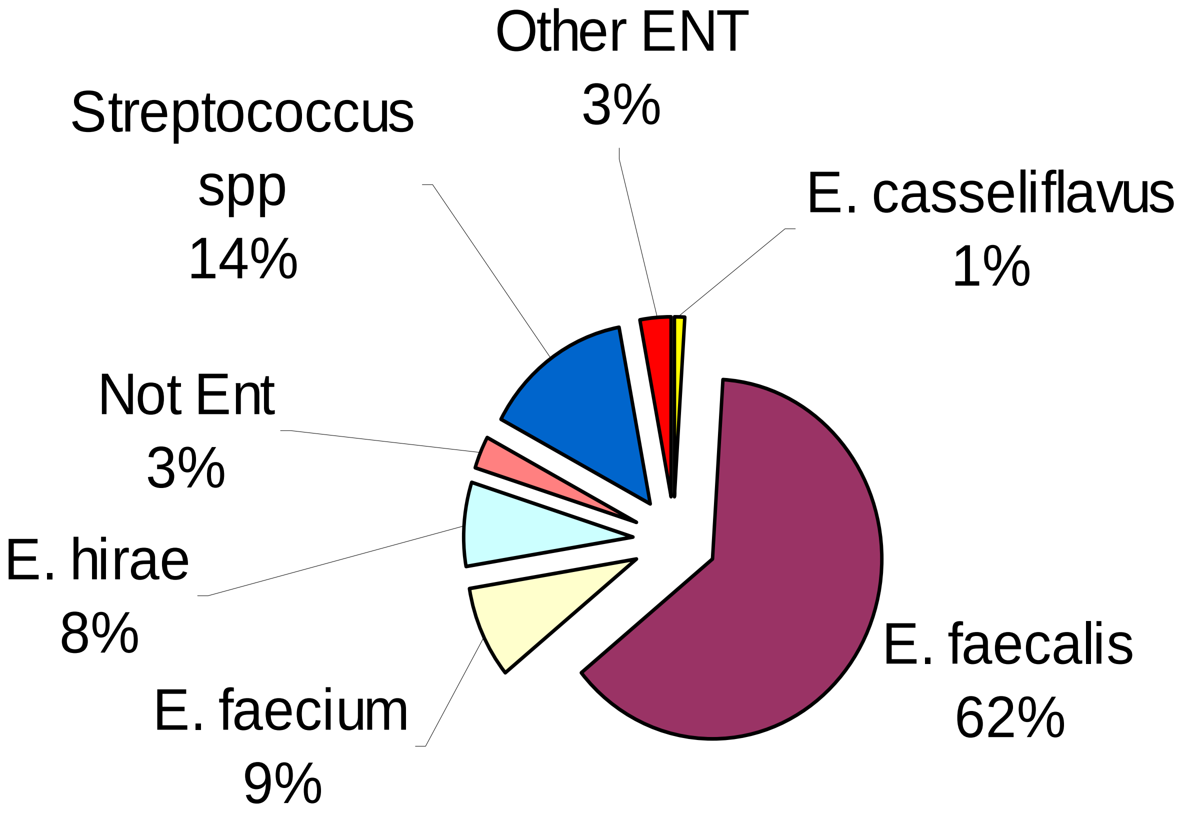
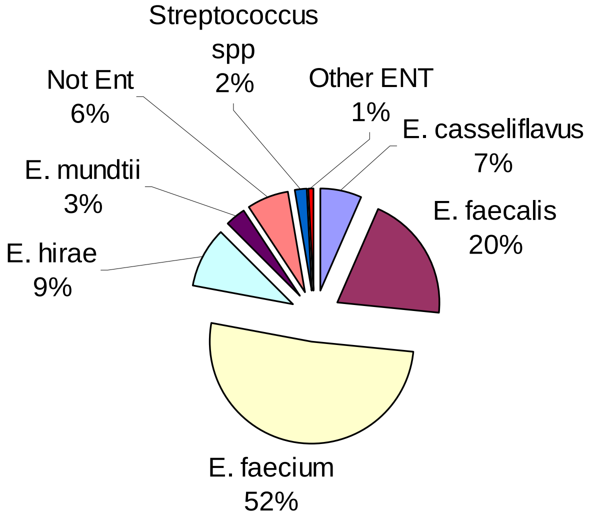
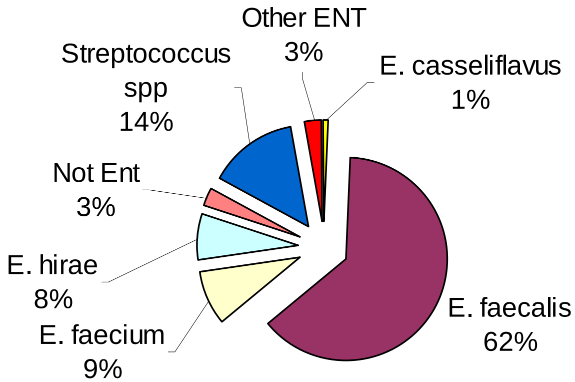
HB 10m Offshore Sediments
(105 Isolates)



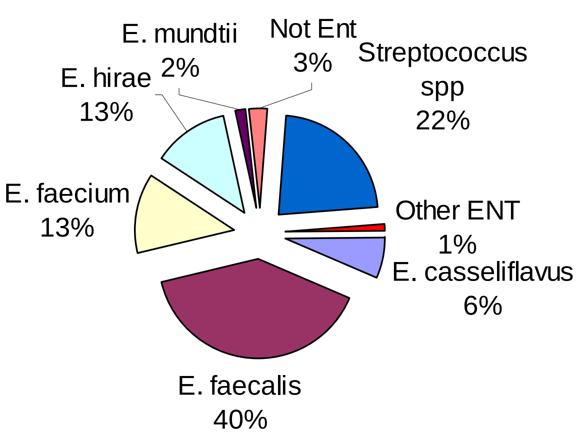
SAR Sed (206 isolates)



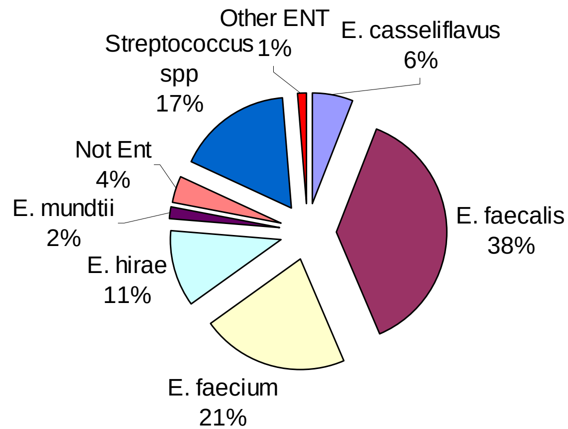
HB 10m Sediments (105 isolates)



HB Surfzone Water (576 isolates)

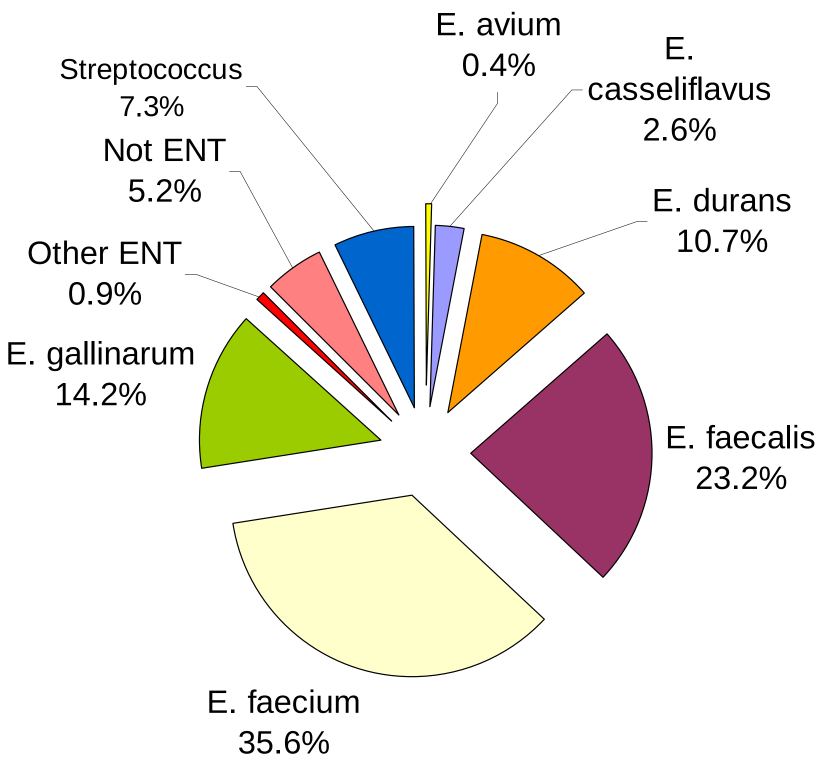


All sites (887 isolates)

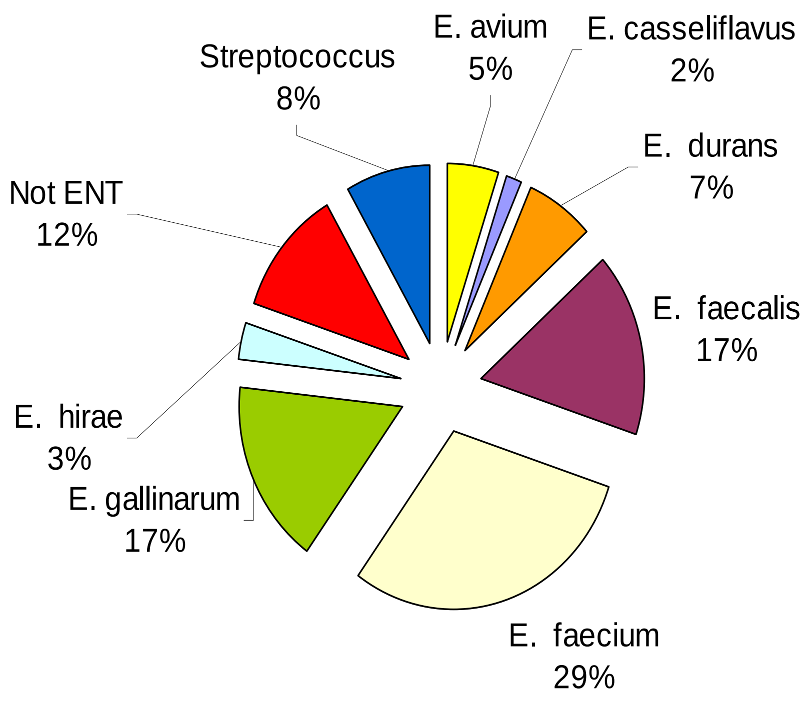


Baby Beach Speciation

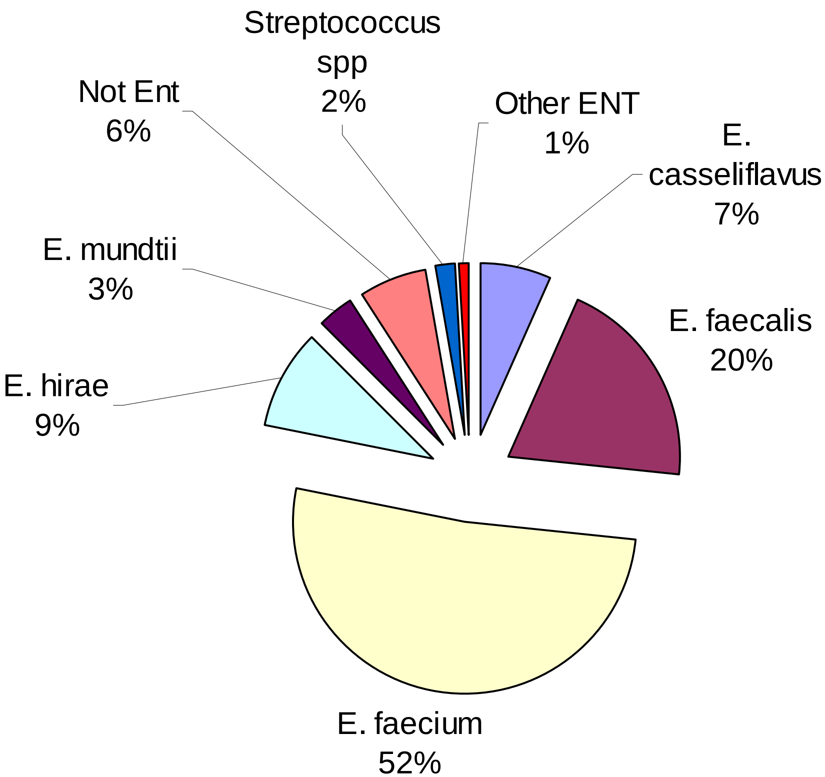
Marine Water – Baby Beach: 8/7/02 thru 4/28/03 (121 samples, 265 isolates)



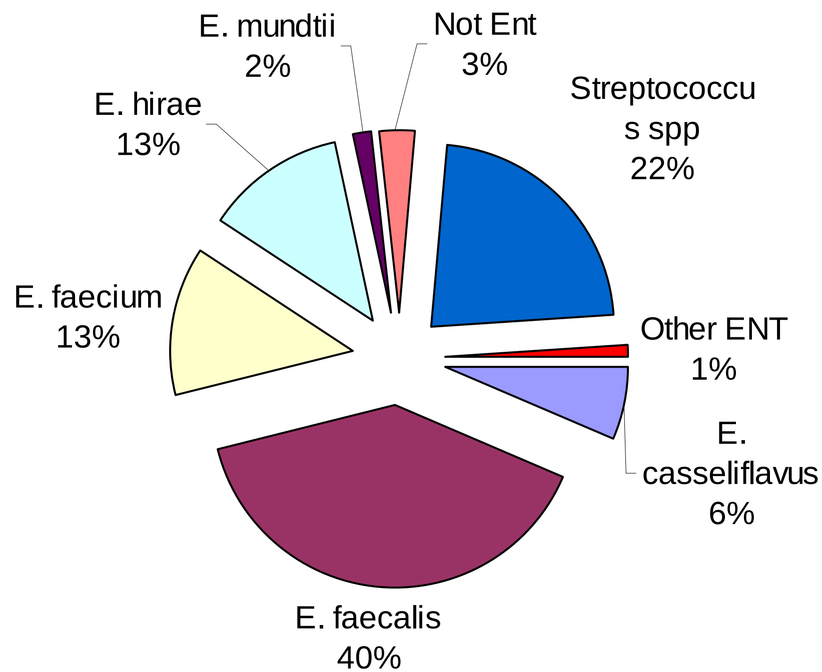
Sediment – Baby Beach: 10/7/02 thru 4/28/03 (55 samples, 74 isolates)



Santa Ana River Sediments (206 isolates)



HB Surfzone Water (576 isolates)



ENT Facts...

- *E. faecalis* and *E. faecium* are the common ENT found in gastrointestinal tracts of humans and animals.

- Not all ENT are found in feces.
  - *E. casseliflavus*, *E. mundtii* and *E. gallinarum* are more commonly found in plants and soil.

Enterococcus Species

Ideal Temperature Range	10°C - 45°C
pH	4.8 – 9.6
NaCl	Up to 28%
Survival	•Extended survival in sediments •Prolonged dessication •Heating at 65°C for 20 min •Resists detergents (sodium hypochlorite = bleach) •Adhesive properties

HB Pollution Sediment Theory

1. Lower SA River is seeded with sediment, nutrients and indicator bacteria.
2. Intertidal conditions provide favorable conditions (high nutrient & salinity levels) for enterococci to persist and replicate to high concentrations.
3. Currents caused by high flow or spring tides resuspend and transport sediment particles with attached bacteria.
4. Bacteria are separated from sediment particles due to hydraulic and mechanical agitation as a result of flow and surf.
5. Increase in bacterial counts at 3N, 6N, 9N and 12N occur when current is moving upcoast. Contaminated sediments are also deposited in the near offshore.

Possible Reasons for High Bacterial Levels in Sediments

- Constant loading and accumulation from storm drains.
- Direct fecal contamination from birds.
- Prolonged survival due to protection from UV and predators.
- Replication due to nutrient availability and conditions which support growth.

Summary of HB Studies

- High levels of *Enterococcus* found in Santa Ana River sediments suggesting regrowth.
- Low levels found in near offshore sediments indicating transport and survival.
- Same *Enterococcus* species present in both sediment and surf zone water samples.
- Pollution events correlate with spring tide transport conditions.
- Follow up studies necessary to confirm and extend results.

Factors to be Determined in Further Studies

- What is the temporal/seasonal/geographic/geologic variability?
- What conditions are required for regrowth of enterococci in sediments?
- Is indicator bacteria regrowth in sediment a common condition?
- How are bacteria attached to particles?
- Is this caused by storm drain input or does it occur naturally?

Possible Long-Term Implications: Storm Drain/Flood Control

- Systems designed to avoid conditions which replicate or transport indicator bacteria.
  - Diversions in summer may not prevent all pollution as conditions may be due to long term flow.
  - System maintained or designed to remove growth conditions (sediment, moisture, tidal flushing).
  - Transport mechanisms (flow, tidal flushing) removed.
  - Routing storm drains into natural marshes may convert marsh into pollution source.

Possible Long-Term Implications: Utility of Fecal Indicators

- Breakpoints for indicators were determined by epidemiological studies of sewage impacted water where sewage was the only source of indicators.
- If regrowth of indicator bacteria in environment is common:
  - Indicator failure levels may have to be adjusted upward to be more specific for some areas.
  - Indicator may not be useful to determine actual fecal pollution.
  - Illness frequency may not be correlated with indicator levels.

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