Beach Water Quality: New Testing Methods & Surfer Health Study Update

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So Cal Beach Water Quality Facts

- 175 million beach-goers every year
  - An estimated $41B in beach tourism

- Over 90,000 analyses per year for beach monitoring to protect public health
  - Approximately $5M

- Beach water quality isn’t as bad as you might think in dry weather
  - Wet weather may be a different story
Water Quality Standard Exceedences
(All Southern California)

All Beaches

In Front of Storm Drains
Water Quality Standard Exceedences
*(All Southern California)*

- **Dry Weather**
- **Wet Weather**

For all beaches and in front of storm drains, the exceedences are significantly higher in wet weather compared to dry weather.
Current Beach Water Quality Monitoring Basics

- Agencies monitor for Fecal Indicator Bacteria
  - *Enterococcus*, Fecal and Total Coliforms

- Fecal Indicator Bacteria do not make you sick
  - Covary in sewage with the pathogens that do

- Cheap and easy to conduct
  - Incubate bacteria with selective media
Current Beach Water Quality Monitoring Problems

- Methods are over 50 years old
  - Growing bacteria is slow, one day minimum

- Fecal Indicator Bacteria are not just from sewage
  - Any warm-blooded animal
  - Survive and regrow in the environment

- Non-human sources of Fecal Indicator Bacteria assumed to carry less risk
Beachgoers feel protected

Culture Methods
Results in 24-96 hours

Reality

Genetic Methods (qPCR)
Results in <2hrs
Integrating Genetic Testing Into Beach Monitoring

- Side-by-side testing between qPCR and culture methods
  - accuracy, precision, bias, inhibition

- Moving from research to mainstream laboratories
  - Capital equipment staff training

- Implement into monitoring programs
Rapid Method Demonstration Project

- Summer of 2010 at three beaches and three labs
  - South Orange County

- Samples run by both culture and qPCR methods

- Goal was to take samples in the morning and have signage decisions by noon
  - Laboratory analysis was not the primary impediment
Beach Decisions By Lunch?

Date

Time

Sampler Start

Samples @ Lab

qPCR Plate In

qPCR Plate Out

Data Out

6/2/2010
6/9/2010
6/16/2010
6/23/2010
6/30/2010
7/7/2010
7/14/2010
7/21/2010
7/28/2010
8/4/2010
8/11/2010
8/18/2010
8/25/2010
Doheny State Beach

WARNING!
Ocean and bay waters are posted with warning signs when bacteria levels exceed state health standards and may cause illness to swimmers, surfers and divers.

updated July 2, 2010 10:30am
Demonstration Project: Beach Decisions Using Culture vs. qPCR Methods

Methods Agree (93%)

False Positives (7%)

False Negatives (1%)
Next Steps for Genetic Testing

- Training for routine labs
  - Bight’13 Regional Monitoring

- Next generation qPCR; Droplet Digital PCR (ddPCR)

- Portability
Droplet Digital PCR (ddPCR)

**Old qPCR**

20µl PCR (tube/well) → 96 wells → Compare to Standard Curve

**New ddPCR**

20µl PCR (tube/well) → 10000 - 20000 droplets or chambers → Direct quantification using statistics
Enterococcus Highly Correlated Between qPCR and ddPCR Methods

$R^2 = 0.97$

The Briefcase Instrument

A) The portable brief-case format with external power & recharge outlet, B) The tablet PC with control and data analysis GUI, C) The sample injection port, D) The rapid-replace consumable reagent bay, and E) The target primer library.
ddPCR Is Resistant To Inhibition (false negatives)

<table>
<thead>
<tr>
<th>Humic acid concentration (ng/ul)</th>
<th>Old qPCR Method (gene copies)</th>
<th>New ddPCR Method (gene copies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1810</td>
<td>1810</td>
</tr>
<tr>
<td>1</td>
<td>1165</td>
<td>1680</td>
</tr>
<tr>
<td>2.5</td>
<td>184</td>
<td>1700</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1870</td>
</tr>
</tbody>
</table>
Why Stop Genetic Testing at Just Indicator Bacteria?

- Once you’re genetic testing for *Enterococcus*, you can substitute any genetic sequence
- Genetic markers of sources (hosts)
- Pathogens themselves
  - viruses, protists, eukaryotes
Developing a Source Identification Toolbox

- State has invested >$100M cleaning up beaches
  - Many challenging beaches remain

- Need reliable source tracking methods
  - Sensitive, specific, reproducible

- SCCWRP led the evaluation study that changed the landscape
  - Produced the SWRCB’s Source Identification Manual
Method Evaluation Study Design

- 50 source tracking methods evaluated
  - 26 top labs around the globe

- Challenge each method with 64 blind samples
  - 12 different sources
  - Varying mixtures and concentrations
  - Duplicates and blanks

- Some methods run by multiple labs
<table>
<thead>
<tr>
<th>Marker</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
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<tbody>
<tr>
<td>HF183 endpoint [7]</td>
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<td>HF183 SYBR [4]</td>
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<tr>
<td>HF183 Taqman [5]</td>
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<td>BacHum [7]</td>
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<td>HumM2 [6]</td>
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<td>BsterIF1 [4]</td>
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<td>nifH [5]</td>
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<td>Btheta [1]</td>
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<td>fecal Bacteroides [1]</td>
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<td>enterovirus [5]</td>
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<td>adenovirus [3]</td>
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<td>norovirus G1 [1]</td>
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<td>norovirus G2 [2]</td>
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<td>GB124 phage [1]</td>
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<td>MB55 phage [1]</td>
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<td>Canine scent [2]</td>
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<td>Phylochip [1]</td>
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<tr>
<td>Univ TRFLP [2]</td>
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<td></td>
</tr>
<tr>
<td>Bac TRFLP [2]</td>
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</table>
New Methods Need To Be Tested Against Human Health

- Epidemiology studies are the Gold Standard for evaluating beachgoer risk
  - Cornerstone of US EPA’s new beach criteria

- SCCWRP and UC Berkeley have been conducting epidemiology studies since 2003

- Highly comparable study designs, but different foci
  - Treated wastewater vs. non-point discharges
Synopsis of Four California Summer Epidemiology Studies

- **Avalon Bay**: risk of gastrointestinal illness (GI) significant
  - Correlation with *Enterococcus* at low tide

- **Doheny State Beach**: risk of GI significant
  - Correlation with *Enterococcus* when beach berm is open

- **Malibu Surfrider Beach**: risk of GI significant
  - No correlation with *Enterococcus*

- **Mission Bay**: risk of GI measurable, but not significant
  - No correlation with *Enterococcus*
Prospective Cohort Epidemiology: Traditional Approach

- Recruit swimmers (and non-swimmers) on crowded summer weekends and holidays
  - Collect same day water quality samples to assess exposure

- Call beachgoers 10 to 14 days later
  - Ask about their health status since their day at the beach

- Compare health outcomes between swimmers and non-swimmers
  - Look for relationships to water quality results
Wet Weather Changes Everything

- Wet weather fecal indicator bacteria contamination levels always seem high

- Likelihood that some sources are not human
  - Assumption that non-human sources carry less risk

- Remediation strategies are expensive
  - Regulatory compliance deadlines are on the horizon
Surfer Health Study Questions

- Is surfing associated with an increased risk of illness?
- Is illness risk greater when surfing following wet weather compared to dry weather?
- What is the association between water quality and illness following wet weather events?
- What level of water quality corresponds to the same risk of illness as current water quality objectives?
Longitudinal Cohort Epidemiology Study Approach

- Recruit >250-300 surfers across any San Diego County beach

- Two sentinel beaches
  - Ocean Beach and Tourmaline Surfing Park

- Daily water quality at sentinel beaches
  - Discharge during storm events

- Follow daily surfing activity and health status each week for three months using web or cell phone app
  - Compare illness rates when surfing vs. not surfing
  - Compare illness rates surfing in dry vs. wet weather
Enrollment Strategy

Did you enter the ocean on any days in the past week?

- Today
- Thursday
- Wednesday
- Tuesday
- Monday
- Sunday
- Saturday
- Did not Enter
## Enrollment in Other Beach Epi Studies

<table>
<thead>
<tr>
<th>Location</th>
<th>No. People Enrolled</th>
<th>No. Days of Follow-up</th>
<th>No. Exposure Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boqueron, PR</td>
<td>15,726</td>
<td>172,986</td>
<td>12,111</td>
</tr>
<tr>
<td><strong>Surfer Health Study</strong></td>
<td>654</td>
<td>33,377</td>
<td>10,081</td>
</tr>
<tr>
<td>Surfside, SC</td>
<td>11,159</td>
<td>122,749</td>
<td>8,073</td>
</tr>
<tr>
<td>Silver, MI</td>
<td>10,921</td>
<td>120,131</td>
<td>5,651</td>
</tr>
<tr>
<td>Mission Bay, CA</td>
<td>12,469</td>
<td>137,159</td>
<td>4,524</td>
</tr>
<tr>
<td>Doheny, CA</td>
<td>9,525</td>
<td>104,775</td>
<td>4,335</td>
</tr>
<tr>
<td>Avalon, CA</td>
<td>6,165</td>
<td>67,815</td>
<td>3,891</td>
</tr>
<tr>
<td>Malibu, CA</td>
<td>5,674</td>
<td>62,414</td>
<td>2,559</td>
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<tr>
<td>Washington Park, IN</td>
<td>4,377</td>
<td>48,147</td>
<td>2,360</td>
</tr>
<tr>
<td>West, IN</td>
<td>2,877</td>
<td>31,647</td>
<td>1,668</td>
</tr>
<tr>
<td>Goddard, RI</td>
<td>2,977</td>
<td>32,747</td>
<td>1,080</td>
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<tr>
<td>Fairhope, MS</td>
<td>2,022</td>
<td>22,242</td>
<td>823</td>
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<tr>
<td>Huntington, OH</td>
<td>2,840</td>
<td>31,240</td>
<td>757</td>
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<tr>
<td>Edgewater, AL</td>
<td>1,351</td>
<td>14,861</td>
<td>741</td>
</tr>
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</table>
80% of Surfers enter the ocean ≤ every three days

Distribution of days since last confirmed ocean exposure
Population characteristics

- **79%** male
- **76%** employed
- **63%** college educated
- Median age (IQR): **34 (27, 45)**

![Histogram of age distribution with a median of 34 years.](chart.png)
Majority of surf sessions were in the morning
Distribution of entry times

![Graph showing frequency distribution of entry times across different hours of the day.](chart.png)
Surfers typically spent 1-2 hours in the water.

Distribution of hours spent in the water:

- ≤1 hour: 2700 sessions
- 2 hours: 5400 sessions
- 3 hours: 1200 sessions
- 4 hours: 100 sessions
- 5+ hours: 50 sessions
<table>
<thead>
<tr>
<th>Beach</th>
<th>Dry</th>
<th>Wet</th>
<th>Total Surf Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tourmaline</td>
<td></td>
<td></td>
<td>2613</td>
</tr>
<tr>
<td>Ocean Beach</td>
<td></td>
<td></td>
<td>1645</td>
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<tr>
<td>Sunset Cliffs</td>
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<td>1028</td>
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<tr>
<td>Scripps</td>
<td></td>
<td></td>
<td>646</td>
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<tr>
<td>15th St Del Mar</td>
<td></td>
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<td>474</td>
</tr>
<tr>
<td>Mission Beach</td>
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<td>443</td>
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<tr>
<td>Pacific Beach</td>
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<td>437</td>
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<td>San Elijo</td>
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<td>378</td>
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<tr>
<td>La Jolla Shores</td>
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<td>Cardiff</td>
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<td>Wind and Sea</td>
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<td>PB Point</td>
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<tr>
<td>Blacks</td>
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<td></td>
<td>184</td>
</tr>
</tbody>
</table>
Wet Weather at Ocean Beach, Winter 2014-15

Log Enterococcus (cfu/100 mL)

Discharge  Dog Beach  Jetty Mouth  Tower  Pier

Single Sample Threshold
### Wet Weather Discharges: Detection Frequency for Pathogens and Human Markers

<table>
<thead>
<tr>
<th></th>
<th>Norovirus</th>
<th>Adenovirus</th>
<th>Enterovirus</th>
<th>Campylobacter</th>
<th>Salmonella</th>
<th>HF183</th>
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</thead>
<tbody>
<tr>
<td><strong>San Diego River</strong></td>
<td>96%</td>
<td>22%</td>
<td>0%</td>
<td>100%</td>
<td>25%</td>
<td>86%</td>
</tr>
<tr>
<td><strong>Tourmaline Creek</strong></td>
<td>72%</td>
<td>9%</td>
<td>0%</td>
<td>45%</td>
<td>9.5%</td>
<td>95%</td>
</tr>
</tbody>
</table>
Our Next Steps

- Complete data analysis
  - Health effects
  - Relationships to water quality

- Quantitative Microbial Risk Assessment
  - US EPA’s newest tool for site-specific thresholds

- Full report by spring 2016
QMRA Background

- This type of risk modeling is not new
  - Commonly used for other EPA criteria

- QMRA for recreational water contact following wet weather is new
  - No other coastal QMRA in the US

- Other attempts at new thresholds for beaches have not succeeded
QMRA Requires Four Steps to Estimate Probability of Illness

- Pathogen concentration at exposure point
- Volume of water ingested
- Relationship between number of pathogens ingested and adverse health effect
  - dose-response curve
- Proportion of infections that result in illness
Our Next Steps

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  - Health effects
  - Relationships to water quality

- Quantitative Microbial Risk Assessment
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The Surfer Health Study
Winter 2014 - 2015

For more information and to enroll visit our study website:
www.sccwrp.org/shs

What is the study about?
This will be the first research study to measure the health risks (if any) associated with surfing on the California coast during the winter months.

How can you help?
We are enrolling hundreds of surfers in the San Diego area to participate in 5-10 minute online surveys over the 2014-2015 winter. For every 4 weekly surveys you complete, we will give you a $20 gift card to Swell.com.

You can help us by enrolling and by getting the word out!

School of Public Health
UNIVERSITY OF CALIFORNIA BERKELEY
SCHOOL OF CULTURAL WATERSHEDS RESEARCH PROJECT
SURFRIDER FOUNDATION

This study is funded by the City and County of San Diego
FIGURE 1. Swimming-associated GI illness rate (rate in swimmers minus rate in nonswimmers) among all subjects as a function of daily average Enterococcus QPCR Cell Equivalent exposure. Swimming-associated illness rate estimated from linear regression model, adjusting for factors described in Table 5. Swimming-associated GI illness = −0.0091816 + log 10 Enterococcus QPCR CE × 0.0213998. Solid line indicates rate; dashed line indicates 95% confidence interval.
50% of surfers surfed at ≤ 3 breaks