

# Identification of Sources of Fecal Pollution Impacting Pillar Point Harbor

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# Background

- Pillar Point Harbor (PPH) overview
  - Enclosed harbor
  - Popular recreational area
  - Vital commercial fishing industry
- Water quality concerns
  - Capistrano Beach impaired by coliform bacteria
- Our approach
  - Quantify bacteria
  - Understand their source
  - Consider hydrology





# Technical Advisory Committee

- Balance Hydrologics – *Barry Hecht*
- San Mateo County
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  - Environmental Health Division- *Dean Peterson, Greg Smith*
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- Keith Mangold, local citizen
- Surfrider– *Sarah Damron, Ed Larenas*
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- Santa Cruz County Environmental Health Services – *Steve Peters*
- Sewer Authority Midcoastside – *Steven Leonard*

# Outline

- Project objectives
- Monitoring design
- Fecal indicator bacteria (FIB)
- Microbial source tracking (MST)
- PhyloChip
- Conclusions



# Project objectives

- To provide information about the primary sources of fecal contamination in PPH
  - FIB monitoring
  - MST study
- To help the selection of remediation strategies for mitigation

# Monitoring parameters

- Fecal indicator bacteria (FIB)
  - Cultivation method: IDEXX
  - *Escherichia Coli*, *Enterococcus*
- Microbial source tracking (MST)
  - Molecular method: qPCR  
(quantitative polymerase chain reaction)
  - Genetic markers of source identifiers  
(human, canine, bovine, equine, gulls)



# Sampling locations

- 10 primary locations at PPH



Locations (Yellow):

1. Capistrano Outfall Pipe
2. Bathhouse Outfall Pipe
3. Capistrano Beach
4. Denniston Creek

5. Pillar Point Marsh Beach
6. Mavericks Beach
7. Beach House Beach
8. Deer Creek Outlet

9. Inner Harbor Beach
10. Yacht Club Beach



# Sampling locations (continued)

## Photos of inflow and beach sites

### 4 inflow sites



Capistrano  
Outfall Pipe



St. Augustine  
Creek Outlet



Denniston  
Creek



Deer Creek  
Outlet

### 6 beaches





# Sampling locations (continued)

- Live-aboard boat sampling sites



Locations (Yellow):

- |                         |                             |                      |
|-------------------------|-----------------------------|----------------------|
| 1. Dock A, Inner Harbor | 4. Sanitary pumping station | 5. OH1, Outer Harbor |
| 2. Dock B, Inner Harbor |                             | 6. OH2, Outer Harbor |
| 3. Dock C, Inner Harbor |                             | 7. OH3, Outer Harbor |



# Sampling locations (continued)

## Upstream sampling sites



Locations (Yellow):

- |                                |                                |                                |
|--------------------------------|--------------------------------|--------------------------------|
| 1. PPH-1B (upstream of PPH-1)  | 3. PPH-DN2 (upstream of PPH-4) | 6. PPH-DR4 (upstream of PPH-8) |
| 2. PPH-2B (upstream of PPH-2)  | 4. PPH-DN3 (upstream of PPH-4) | 7. PPH-DR6 (upstream of PPH-8) |
| 5. PPH-DN4 (upstream of PPH-4) |                                |                                |

# Sampling summary

- FIB sampling

- 514 FIB water samples
- 2008, 2011-2012
- (Bi)weekly + concurrently with MST

- MST monitoring

- 225 MST water, sediments, and biofilm samples
- 2008, 2011-2012
- Dry (May-Sep)+ wet (Oct-Mar) season + first flush



# Sampling summary (continued)

- Type and number of MST samples

Matrix	Season or condition	2008	2011	2012	Total
<b>Water</b>	Dry season	10	10	5	25
	Wet season	10	34	15	59
	First flush	30	30	11	71
	Live-aboard boat	-	7	3	10
	Upstream	-	-	13	13
<b>Sediment</b>	Dry	-	8	5	13
	Wet	-	-	15	15
<b>Biofilm</b>	Dry	-	11	2	13
	Wet	-	-	6	6
<b>Total</b>		<b>50</b>	<b>100</b>	<b>75</b>	<b>225</b>

# Monitoring results

- **Fecal indicator bacteria (FIB)**
  - Site-specific
  - Seasonal
  - Upstream
- **Microbial source tracking (MST)**
  - Universal
  - Canine
  - Human
  - Bovine
  - Equine
  - Gull
  - Sediments and biofilms
- **PhyloChip**

# Fecal indicator bacteria (FIB)

## Site-specific FIB counts

- 2-yr (2008, 2011) results
- **Highest overall FIB counts at inflow sites**
  - PPH 1, 2, 4 & 8
  - Above the water quality criteria
- Consistently **highest beach FIB at Capistrano Beach (PPH-3)**
  - FIB levels above criteria often found
  - Directly affected by PPH-1 and 2
- **Low FIB counts in other beaches**
  - FIB counts usually low at all beaches except for Capistrano Beach



Locations (Yellow):

- |                            |                             |                       |
|----------------------------|-----------------------------|-----------------------|
| 1. Capistrano Outfall Pipe | 5. Pillar Point Marsh Beach | 9. Inner Harbor Beach |
| 2. Bathhouse Outfall Pipe  | 6. Mavericks Beach          | 10. Yacht Club Beach  |
| 3. Capistrano Beach        | 7. Beach House Beach        |                       |
| 4. Denniston Creek         | 8. Deer Creek Outlet        |                       |



# FIB (continued)

## Seasonal FIB counts

- 2-yr (2011-2012) (bi)weekly monitoring at **5 key sites**
- **Seasonal variation at Capistrano Beach (PPH-3)**
  - **Higher** FIB counts in **wet** season
  - fast die-off rates of FIB in dry season
  - Increased flow rate of inflows in wet season
- **Less seasonality at Inflow sites**
  - **Higher** *E. coli* levels at **Deer Creek Outlet (PPH-8)** during **dry** season
  - No FIB seasonal variation found in other inflow sites

dry season



wet season



Capistrano Outfall Pipe (PPH-1)

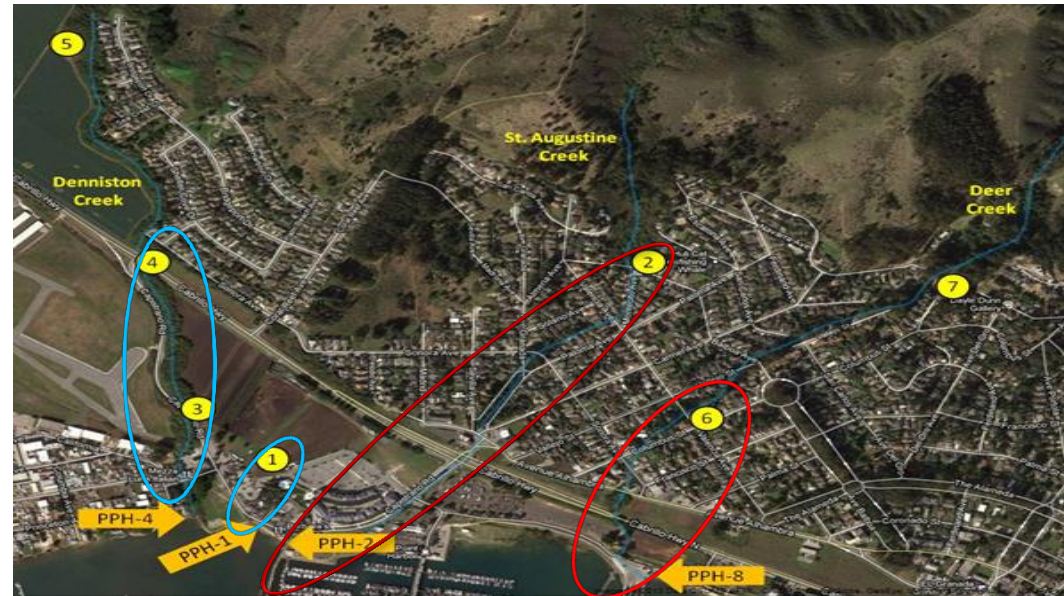


St. Augustine Creek Outlet (PPH-2)

# FIB (continued)

## Upstream monitoring

- 2012 (May-Dec) weekly at **inflow** and corresponding **upstream** sites
- Significantly **different FIB counts (red circle)**
  - **St. Augustine Outfall Outlet (PPH-2)** and **Deer Creek Outlet (PPH-8)**
  - Considerable amounts of **fecal input within the urban area**
- **Similar FIB counts (blue circle)**
  - **Capistrano Outfall Pipe (PPH-1)** and **Denniston Creek (PPH-4)**
- Added two new upstream sites for MST upstream monitoring (#5, 7)



# Monitoring results

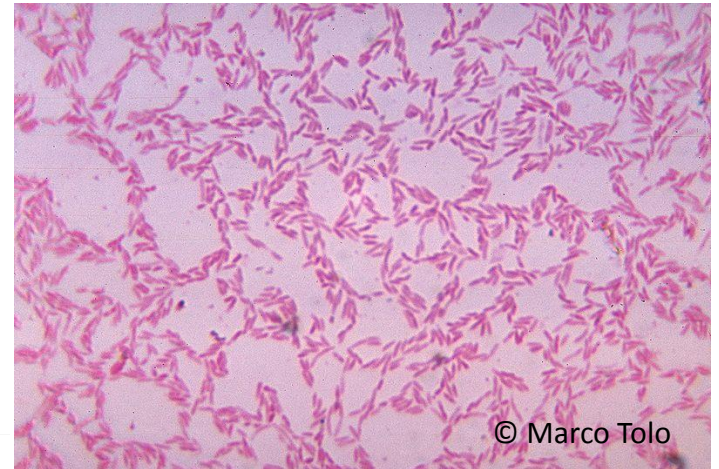
- Fecal indicator bacteria (FIB)
  - Site-specific
  - Seasonal
  - Upstream
- **Microbial source tracking (MST)**
  - **Universal**
  - **Canine**
  - **Human**
  - **Bovine**
  - **Equine**
  - **Gull**
  - **Sediments and biofilms**
- PhyloChip



# Microbial source tracking (MST)

## Universal *Bacteroidales*

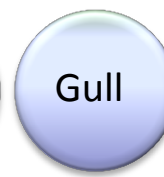
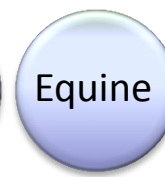
- Universal *Bacteroidales* (BacUni)
  - Derived from all warm-blooded animals
  - **Detected** in **all** MST samples
- **Site-specific** variation at 10 sites (2008, 2011)
  - **High** levels at all **inflow** sites (PPH-1, 2, 4, 8)
  - Relatively **high** at **Capistrano Beach** (PPH-3)
  - Usually **low** at **other beaches** except PPH-3



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# MST (continued)

## Canine fecal pollution



- Canine-associated *Bacteroidales* (BacCan)
- Inflow sites
  - Marker **sometimes** (PPH-1, PPH-4) or **frequently** (PPH-2, PPH-8) detected at **high** levels
- Mavericks Beach
  - Marker **often** detected (27%)
  - When FIB counts were high, canine marker concentration was high
  - Dog waste on the beach **affected water quality**, but counts were **rarely high**
- Capistrano Beach
  - Marker **often** detected in **wet** season (33%) at **high** levels
  - Introduced from **inflows** (PPH-1, PPH-2) rather than Mavericks Beach



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# MST (continued)

## Canine fecal pollution



- Upstream MST sampling
  - Samples collected at **first flush** events (Nov 2012) and **wet** season (Dec 2012)
- Monitoring results
  - Detected at **high** levels **during rain** at upstream sites of Capistrano Outfall Pipe and Deer Creek Outlet (**red star**)
  - Detected **before rain** but significantly **decreased during and after rain** at upstream site of St. Augustine Creek Outlet (**orange star**)
  - **Not** detected at upstream sites of Denniston Creek (**green star**)

➔ **Canine feces is a significant, but not primary, source of bacteria at Capistrano Beach**





# MST (continued)

## Human fecal pollution



- Human-associated *Bacteroidales* (BacHum)
- Inflow sites
  - **Sometimes** detected (<20%) at inflow sites in wet season but its concentrations were **minor**
  - High concentration found only one time at **Capistrano Outfall Pipe**. However, **not an influence** to Capistrano Beach due to low water flow.
- Beaches
  - **Rarely** detected
- Second human marker assay (HF183 TaqMan)
  - Another validated human marker applied

➔ **Human feces is not a significant source of bacteria at Capistrano Beach**

# MST (continued)

## Human fecal pollution



- Live-aboard boat sampling
  - Samples collected at boat docks in **Inner Harbor, pumping station and Outer Harbor**
  - **Low FIB** counts
  - **Low** human marker at boat docks in **2011**
  - **No** human marker in **2012**
  - **Limited potential effect** of human fecal release from live-aboard boats to Capistrano Beach based on low counts and circulation study.



➔ **Live-aboard boats not a significant source of bacteria at Capistrano Beach**

# MST (continued)

## Bovine fecal pollution



- Bovine-associated *Bacteroidales* (BacBov)
- **Deer Creek Outlet (PPH-8)**
  - **High** concentrations detected consistently in **dry season (100%)** and frequently in **wet season (50%)**
  - Upstream sites also showed high levels
- **Other inflows and beaches**
  - Bovine detected only once and at low concentration-**not significant**

➔ **Bovine feces is the main bacteria source at Deer Creek Outlet**





# MST (continued)

## Equine fecal pollution



- Equine-associated *Bacteroidales* (HorseBact)
- Assay validation
  - Positive for horse fecal samples (6) collected in San Mateo County
  - Negative for any other feces from humans (5), cows (5), dogs (5), and gulls (6)
  - **HorseBact** assay **works** well
- MST samples analyzed
  - Collected at **4 inflow** sites and **Capistrano Beach** in 2011 and wet season of 2012
- Results
  - **Not detected** in any of MST samples tested

➡ **Horse feces is not a source of bacteria in the PPH**

# MST (continued)

## Seagull fecal pollution



- Large flocks of gulls and other birds at PPH
- Gull MST assays
  - *Catelicoccus marimammalium* SYBR green assay (UCD)
  - *Catelicoccus* spp. TaqMan assay (OSU)
  - Independently tested in the two laboratories
  - **Not detected** in any samples

➔ **Gull feces not a significant source of bacteria in PPH**



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# MST (continued)

## Sediments and biofilms

- Sediment: very fine to coarse sand beneath water
  - Biofilm : submerged aquatic vegetation beneath water surface
  - Universal *Bacteroidales* in sediments and biofilms
    - Detected in all **sediment** and **biofilm** samples
    - **Biofilm** > **sediments** > water
    - **Dry** season > wet season
- ➔ Fecal bacteria accumulate in sediments and biofilms
- In wet season, BacUni in sediments **decreased** when it **rained**
- ➔ **Release** (re-suspension) of bacteria by natural turbulence during high flow



(Example of biofilm samples)



# MST (continued)

## Sediments and biofilms

- Host-associated *Bacteroidales*
  - **Canine** marker detected in sediments and biofilms at **St. Augustine Creek Outlet** (PPH-2) in **wet** season. Also detected in water samples.
  - **High** levels of **canine** marker found in sediments at **Capistrano Beach** (PPH-3) and **Deer Creek Outlet** (PPH-8) in **dry** season.
  - **Canine** marker detected in **sediments** even when **not** detected in **water** at Capistrano Beach

### Fecal bacteria in sediments and biofilms:



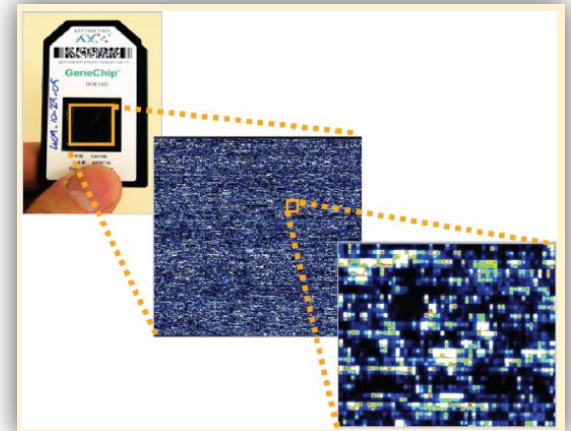
**Influence bacteria levels in PPH**

# Monitoring results

- Fecal indicator bacteria (FIB)
  - Site-specific
  - Seasonal
  - Upstream
- Microbial source tracking (MST)
  - Universal
  - Canine
  - Human
  - Bovine
  - Equine
  - Seagull
  - Sediments and biofilms
- **PhyloChip**

# PhyloChip

- PhyloChip microarray analysis
  - Developed at Lawrence Berkeley National Laboratory
  - Analyze **relative proportions of microorganisms** in samples
  - Compare specific bacterial taxa in samples with **fecal source identifiers** including sewer, septage, human stool, shorebird, cat, dog, cow, horse, elk/deer, pig, raccoon, seal/sea lion
- MST samples for PhyloChip analysis
  - **50** DNA extracts of MST water samples chosen
  - Capistrano Outfall Pipe (PPH-1)
  - St. Augustine Creek Outlet (PPH-2)
  - Capistrano Beach (PPH-3)



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# PhyloChip results

- Site-specific results
  - Inflow sites (PPH-1, 2) had **similar** microbial community but **different** from Capistrano Beach (PPH-3)
  - Bacterial community in freshwater and seawater were **more similar** during **contamination** events (high FIB counts)
- Estimation of fecal source identifiers
  - **Shorebird** source found in **25%** of PhyloChip samples  
**Not consistent** with the findings of MST assays, but **not a significant source** PhyloChip (relative abundance) vs. MST (absolute concentration)
  - Mammal and human source found in **4 of the 50** samples but signals weak
  - No other fecal sources appeared

➔ **PhyloChip analysis confirmed MST results: human, equine and bovine feces not significant sources of bacteria at Capistrano Beach.**

**Other sources like cats, pigs, raccoons, pinnipeds were not found in PhyloChip analysis**

# Beach-by-Beach Results



# Conclusions

- Capistrano Beach has **higher FIB** than other beaches and highest in the **wet** season.
- Human: not a major source of fecal contamination
  - Marker was detected but **is not a significant source** of bacteria at Capistrano Beach.
  - The application of a **second MST** assay and **PhyloChip** method both confirmed that human marker is not a significant source.
  - **Live-aboard boats** were not a major source of fecal bacteria at Harbor beaches during the study period.
- Bovine: main fecal source at Deer Creek
  - Bovine marker was **frequently found** at Deer Creek Outlet and its upstream sites with high concentrations.
  - Bovine is **predominant** source of fecal pollution at Deer Creek.

# Conclusions (continued)

- Canine: considerably affects water quality
  - Canine is a **significant, but not primary** fecal source at **Capistrano Beach**.
  - Canine fecal bacteria at Capistrano Beach was introduced from freshwater **inflows** rather than other nearby beaches.
  - Upstream MST monitoring revealed that **canine feces** entered into the waterway of Capistrano Outfall Pipe and Deer Creek Outlet in the **urban area**.
  - Canine represents a significant source at Deer Creek Outlet during wet weather.
- Gull: minor impact on water quality
  - Although there are large flocks of gulls, two gull-associated MST assays **not detected** gull feces in PPH.
  - Qualitative PhyloChip analysis found shorebird signals in several samples; however, their contribution to high bacteria counts is **insignificant**.
- Equine: no evidence of fecal pollution
  - Equine-associated *Bacteroidales* were **not detected** in any of MST samples.



# Conclusions (continued)

- Sediments and biofilms: play an important role
  - FIB **accumulate** and **persist** longer when associated with sediments and biofilms.
  - FIB in sediments and biofilms are periodically **resuspended** by turbulence and lead to increases in FIB levels in water.
- The monitoring study
  - Provided **significant insights** into fecal contamination in PPH
  - Will assist with the selection of appropriate **recommendations** to reduce fecal pollution
- What we do know vs. what we don't know- what we ruled out and ruled in, what we didn't test.

# Thoughts about recommendations

- Pursue stormwater filtering technologies.
- Reduce sediment and biofilm reduction in stormwater drainage system.
- Encourage proper disposal of dog feces.
- Further investigate fecal sources from wildlife and stormwater drainage system.
- Continue upstream bovine best management practices.

# Acknowledgements

- San Mateo County Resource Conservation District (SMCRCD) staff and volunteers (conceiving the idea of a source tracking study, selecting specific sampling sites, collecting FIB samples and much else)
- Balance Hydrologics (conducting circulation study and modeling hydrology)
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- Prof. Jiyoung Lee at Ohio State University (analyzing PPH samples with a gull assay recently developed in her research group)
- Dr. Orin Shanks at United States Environmental Protection Agency (providing guidance in the use of a human source tracking assay)
- Dr. Yvette Piceno, Dr. Lauren Tom, Dr. Eric Dubinsky, Dr. Gary Andersen at Lawrence Berkeley National Laboratory (conducting PhyloChip analysis)
- Technical Advisory Board members (providing helpful advice)
- Wuertz lab : Dan Wang (developing the probabilistic source tracking model) and group members (assisting sampling and lab processing, reviewing monitoring results)

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**Thank you!**