Reflections of Ourselves
Sensing and Feedback to Inform Everyday Human Behavior

@jonfroehlich
Assistant Professor Computer Science
Let’s dance.
I thought I could dance.
A process of self-discovery and reflection enabled by...
sensing feedback you
How can we use **sensing** and **feedback** to improve people’s lives and the environment around them?
“Persuasive technology is any interactive computing system designed to change people’s attitudes or behaviors”

Persuasive Technology

Savvy, persuasive mortgage broker guy
circa 2008
Technology-mediated behavior change applications

Encompasses:
- Quantified self
- Personal informatics
- Eco-feedback

Eric Hekler
Assistant Prof, Health & Nutrition
Arizona State University
Occurrence of Behavior Change Research in the Last 10 Years of the CHI Proceedings

- "behavior change"
- "persuasive technology"

Number of Papers

CHI Proceedings

2003 (N=303)
2004 (N=374)
2005 (N=404)
2006 (N=497)
2007 (N=441)
2008 (N=580)
2009 (N=676)
2010 (N=686)
2011 (N=828)
2012 (N=823)

1
31
Occurrence of Behavior Change Research in the Last 10 Years of the CHI Proceedings

- "behavior change"
- "persuasive technology"
This is an incredibly interesting time to be working in this area.
sensing

Human Activities

Biometric Data
Nike+ Running Monitor

Nike+ Shoe Sensor

sensing

feedback
Fitbit Activity Level Tracker

Fitbit Activity Level Sensor

sensing feedback
Zeo Sleep Coach

sensing feedback
Recyclebank Recycling Tracker

RFID + Scale
Recycling Level
Sensor

sensing feedback
And this is just the **beginning**.
Overarching Questions

1. What **behaviors** to sense?
2. What aspects to **visualize**?
3. How should we approach & structure the design process?
Overarching Questions

1. What behaviors to sense? And how? And Why?
2. What aspects to visualize? And how? And Why?
3. How should we approach & structure the design process?

These are far from solved questions!
Motivations for healthy behavior may differ from motivations for proenvironmental behavior.
In particular, I will focus on **sensing** and **feedback** systems for residential **water** usage.
why water?

cheap
difficult to transport
usage often creates waste
fundamental ingredient of life
not energy

though water infrastructure requires lots of energy to run
two-thirds of the earth’s surface is covered by water
Ocean 96.5%

Polar Ice 1.7%

Brackish 1%

Drinkable Water 0.8%

number of people in urban environments surpassed the number of people in rural areas

[Barlow, 2007]
growing demand

in 2010, water consumption rose to 938 billion gallons in Beijing.

water supply = 576 billion gallons

[Guardian, Dec 2010]
“china melting snow to meet freshwater demand”
Lake Mead expected to drop below intake pipes in next five years

[Bloomberg News, Feb 2009]
new sources of water
more costly to extract
water utilities
governments
shift focus
This is an area where HCI researchers and designers can help
eco-feedback
sensing and visualizing behavior to reduce environmental impact
Looking at current sensing and feedback systems for water...
water sensing
Municipal Services Statement

UNDER HOLLINQUEST
7450 S KENWOOD DR
TEMPE AZ 85283-4021

Account Number: 100687-00164711
Utility Amount Due: 127.52
Voluntary Donation: 1.00
Total + Voluntary Donation: 128.52
Date Due: 1/8/2007

Account Activity

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/12</td>
<td>Water Service Charge</td>
<td>12.69</td>
</tr>
<tr>
<td>11/12</td>
<td>Water Consumption</td>
<td>28.11</td>
</tr>
<tr>
<td>12/12</td>
<td>Water Service Charge</td>
<td>10.69</td>
</tr>
<tr>
<td>12/12</td>
<td>Residential Rate</td>
<td>6.40</td>
</tr>
<tr>
<td>12/12</td>
<td>Residential HV</td>
<td>5.59</td>
</tr>
<tr>
<td>12/12</td>
<td>Residential Lw</td>
<td>5.41</td>
</tr>
</tbody>
</table>

Please fold before tearing.

Gallons delivered: 20,000

Water Feedback
Dubuque Water Portal:

Water report for
Anonymous

Usage Trend
0.1% increase

Your Rank
10th place

Green Points
168 points

Water usage by day in gallons | dollars | lbs CO₂

This graph depicts your hour-by-hour water usage on 2010-12-06.

Your team won on 2010-12-06.

[Erickson et al., CHI 2012]
10,230 gallons
Month: April 2006
Total Food Units: 1527

Total Price: $642
10,230 gallons

- Outdoor: 3,212 gals
- Toilets: 1,872 gals
- Laundry: 1,524 gals
- Showers: 1,176 gals
- Faucets: 1,105 gals
- Dishwasher: 102 gals
- Other: 1,248 gals
direct sensing

direct sensing

- **shower**: 62.4 gallons
- **bath**: 6.5 gallons
- **toilet**: 78.4 gallons
- **bathroom sink 1**: 4.2 gallons
- **bathroom sink 2**: 0.8 gallons
indirect sensing

- Shower: 52.4 gallons
- Bath: 6.5 gallons
- Bathroom sink 1: 3.2 gallons
- Bathroom sink 1: 4.2 gallons
- Bathroom sink 2: 2.4 gallons
- Toilet: 78.4 gallons

[HydroSense, UbiComp 2009]
HydroSense attempts to infer fixture-level usage for the entire home from a single point.

[HydroSense, UbiComp 2009]
This data presents new, rich opportunities for...

eco-feedback
sensing and visualizing behavior to reduce environmental impact
What do we do with all this data?

How should we approach this design process?
brief plumbing primer
plumbing primer
water tower

plumbing primer

incoming cold water from supply line
water tower

**pressure regulator**

incoming cold water from supply line

utility water meter

pressure regulator
plumbing layout

incoming cold water from supply line

water tower

utility water meter

pressure regulator
utility water meter
pressure regulator
thermal expansion tank
hot water heater
incoming cold water from supply line

closed pressure system

bathroom 1
bathroom 2
kitchen
dishwasher
laundry
Have another toilet as an example rather than kitchen sink.
bathroom sink pressure signal
bathroom sink pressure signal

flow rate related to pressure via Poiseuille’s Law

flow volume

open

Cold Line Pressure (Hose Spigot)

close
example open events

signature dependent on:
- fixture type
- valve type
- valve location in home
hydro study

#1

goal

study feasibility of using pressure to disaggregate water usage

approach

controlled experiments across 10 homes
controlled experiments
- 2 researchers per site
- 5 trials per valve

experimental script
- valve opened full stop
- pause for ~5 seconds
- valve closed
controlled data collection
data collection stats

- ten test sites
- 706 trials
- 155 flow trials
- 84 total fixtures tested
fixture classification results by home

10-fold cross validation
fixture classification results by home

10-fold cross validation
fixture classification results by fixture

- Sinks: 98% Open, 95% Close
- Toilets: 99% Open, 96% Close
- Showers: 99% Open, 96% Close
- Bathtubs: 100% Open, 100% Close
- Clothes Washer: 100% Open, 100% Close
- Dishwasher: 100% Open, 100% Close

Diagram showing percentage classifications for different fixtures.
hydro study

#1 contributions

built and evaluated wireless pressure sensor

first to show that pressure could be used to disaggregate water usage
brushing teeth
shaving
bathing
paw washing
compound events

incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater

bathroom 1
bathroom 2
kitchen
laundry

water tower
hydro study

#2 goal study how well hydrosense can classify real world water usage

approach
5 week deployment in 5 homes
in the first study, pressure waves were manually annotated with “ground truth labels” describing:

- the fixture used
- the water temperature
I’m about to flush the toilet!

Awesome!
Marked it. Thanks Mr. Johnson
can we record real-world water usage?
after many failed solutions
custom ground truth data collection system

- Xbee wireless modem
- Fixture usage sensor board
- Hall effect switch
- Reed switch
- 3-axis accelerometer
- Unidirectional ball switch
- Omnidirectional ball switch
- Xbee wireless modem
- Fixture usage sensor board
- Hall effect switch
- Reed switch
- 3-axis accelerometer
- Unidirectional ball switch
- Omnidirectional ball switch
custom ground truth data collection system

- xbee wireless modem
- fixture usage sensor board
- hall effect switch
- reed switch
- 3-axis accelerometer
- unidirectional ball switch
- omnidirectional ball switch

"wake up" sensors
custom ground truth data collection system

fixture handle position sensors

xbee wireless modem

fixture usage sensor board

hall effect
reed switch
3-axis accelerometer
unidirectional ball switch
omnidirectional ball switch
Accelerometer

Taped on

accelerometer

Accelerometer & Ball Switch Taped on
custom ground truth data collection system

- push button
- xbee wireless transmitter
- fixture usage sensor board
- modified kill-a-watt
- thermistor
- hall effect
- reed switch
- 3-axis accelerometer
- unidirectional ball switch
- omnidirectional ball switch
## Deployment Sites

<table>
<thead>
<tr>
<th>Residents</th>
<th>Size</th>
<th>Floors</th>
<th>Fixtures</th>
<th>Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3000 sqft</td>
<td>3</td>
<td>17</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>750 sqft</td>
<td>2</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>1200 sqft</td>
<td>2</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>700 sqft</td>
<td>3rd flr</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>750 sqft</td>
<td>6th flr</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>
ground truth labels

manual

automatic

kitchen sink

cold open

cold close

kitchen sink

hot open

hot close

bathroom sink

cold open

cold close
two pressure sensors per home
hydrosense data logger
records ground truth sensor data plus
two pressure streams for each home

- pressure stream
  - red = hot line
  - blue = cold line

- reed switches
  - high = active
  - low = inactive
hydroSense data logger
reed switches
hydro deployment infrastructure

custom ground truth data collection system

hydroSense data logger records ground truth sensor data plus two pressure streams for each home.

two pressure sensors

on-site sensing infrastructure

python web backend

c# and matlab analysis tools
## 5-week dataset

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th><strong>totals</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>days</strong></td>
<td>33</td>
<td>33</td>
<td>30</td>
<td>27</td>
<td>33</td>
<td><strong>156</strong></td>
</tr>
<tr>
<td><strong>events</strong></td>
<td>2374</td>
<td>3075</td>
<td>4754</td>
<td>2499</td>
<td>2578</td>
<td><strong>14,960</strong></td>
</tr>
<tr>
<td><strong>events/day</strong></td>
<td>71.9</td>
<td>93.2</td>
<td>158.5</td>
<td>92.6</td>
<td>78.1</td>
<td><strong>95.9</strong></td>
</tr>
</tbody>
</table>
compound events

incoming cold water from supply line

utility water meter

pressure regulator

thermal expansion tank

hot water heater

compound events

bathroom 1

bathroom 2

kitchen
dishwasher

utility water meter

pressure regulator

thermal expansion tank

hot water heater

compound events

bathroom 1

bathroom 2

kitchen
dishwasher
22% of all water events were compound.

41.8% of all bathroom sink events were compound.
hydroSense classification results
real-world water usage data

- Valve level: 75.5%
- Fixture level: 89.5%
- Fixture category level: 95.9%
hydroSense classification results
real-world water usage data

- Valve level: 75.5% (one pressure sensor), 82.4% (two pressure sensors)
- Fixture level: 89.5% (one pressure sensor), 93.5% (two pressure sensors)
- Fixture category level: 95.9% (one pressure sensor), 97.7% (two pressure sensors)
What do we do with all this data?

How should we approach this design process?
Key Questions

1. **What** are the key gaps in water usage understanding?

2. **What** aspects of disaggregated data are potential users interested in and what sort of reactions do the visualizations provoke?

3. **How** might these visualizations impact behavior?
Key Questions

1. What are the key gaps in water usage understanding?

2. What aspects of disaggregated data are potential users interested in and what sort of reactions do the visualizations provoke?

3. How might these visualizations impact behavior?
Two sets of designs:

1. **Design Dimensions**
   Isolate eco-feedback design dimensions in the context of water usage

2. **Design Probes**
   Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)
Respondents (N=651) dramatically underestimated the amount of water used in common everyday activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Underestimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>toilet</td>
<td>by 15%</td>
</tr>
<tr>
<td>shower</td>
<td>by 30%</td>
</tr>
<tr>
<td>bath</td>
<td>by 55%</td>
</tr>
<tr>
<td>low-flow shower</td>
<td>by 60%</td>
</tr>
<tr>
<td>outdoor yard watering</td>
<td>by 83% to 95%</td>
</tr>
</tbody>
</table>

[Froehlich, UW PhD Dissertation, 2011]
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)

Informed by gathered data
Guided by eco-feedback design space
Iterative Design Process

- Sketch
- Lo-to-Mid Fidelity Mockup
- Higher Fidelity Mockup
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)

Informed by gathered data
Guided by eco-feedback design space

Diagram:
- Ideation
- Data Gathering
- Ideation / Sketch
- Pilot Studies
- Refinement
- Formative Evaluation

Design critique sessions with team
Three sets of pilot studies
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)

Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)
Using the Eco-Feedback Design Space
# Eco-Feedback Design Space

## Information Access
- **Update frequency**: real-time, monthly or less, user poll
- **Spatial proximity to behavior**: co-located, remote
- **Attentional demand**: glanceable, high attention
- **Effort to access**: low, high

## Display Medium
- **Manifestation**: webpage, mobile phone app, wearable interface, custom display, in-home display
- **Ambience**: not-ambient, ambient
- **Size**: small, large

## Interactivity
- **Degree of interactivity**: none, high
- **Interface customizability**: none, high
- **User additions**: user annotations, user corrections

## Interactionality
- **Degree of actionability**: low, high
- **Decision support**: suggests, purchase decisions, anomaly alerts
- **Personalization**: no personalization, highly personalized
- **Information intent**: informs one action, informs many actions
- **Automation/control**: no control, system controls resource use

## Data Representation
- **Aesthetic**: pragmatic, artistic
- **Time window**: <hour, >year
- **Temporal grouping**: sec, by hour, by day, by week, by month, year
- **Data granularity**: coarse-grain, fine-grain
- **Visual complexity**: simple, complex
- **Primary visual encoding**: textual, graphical
- **Primary view**: temporal, spatial, categorical
- **Data grouping**: by resource, by person, by time, by activity, by consumption category

## Comparison
- **Comparison target**: self, social, goal
- **Comparison by time**: past, projected
- **Social-comp. target**: geographically similar, demographically similar, selected social network
- **Goal-setting strategy**: self-set, system-set, externally-set
- **Difficulty to reach comparison target**: easy, hard

## Motivational/Persuasive Strategies
- Persuasive tactics from psychology and applied social psychology disciplines:
  - Persuasive design
  - Persuasive technology
  - Behavioral science/economics
  - Environmental psychology
  - Game design
  - Social marketing
  - Health behavior change
  - Rewards
  - Punishment
  - Public commitment
  - Written commitment
  - Loss aversion
  - Karios
  - Encouragement
  - Descriptive norms
  - Scarcity principle
  - Framing
  - Anchoring bias
  - Defaults

- Persuasive tactics include:
  - Goal-setting
  - Narrative
  - Likeability
  - Reputation
  - Competition
  - Social proof
  - Authority
  - Emotional appeals
  - Door-in-face
  - Unlock features
  - Endowment effect
  - Collection building

## Social Aspects
- **Target**: person, household, community, state, country
- **Private/public**: private, public
- **Data sharing**: none, everyone
- **Social-comparison**: available, (see COMPARISON), unavailable

---

[Froehlich et al., HCIC2009; CHI2010; UW PhD Dissertation 2011]
My own experiences

Existing frameworks
(in persuasive tech and infovis)

Psychology
(particularly behavioral economics and environ. psych)
## Eco-Feedback Design Space

### INFORMATION ACCESS
- **update frequency**
  - real-time
  - monthly or less
  - user poll
- **spatial proximity to behavior**
  - co-located
  - remote
- **attentional demand**
  - glanceable
  - high attention
- **effort to access**
  - low
  - high

### INTERACTIVITY
- **degree of interactivity**
  - none
  - high
- **interface customizability**
  - none
  - high
- **user additions**
  - user annotations
  - user corrections

### DISPLAY MEDIUM
- **manifestation**
  - webpage
  - mobile
  - wearable
  - interface
  - custom display
  - in-home display
- **ambience**
  - not-ambient
  - ambient
- **size**
  - small
  - large

### ACTIONABILITY/UTILITY
- **degree of actionability**
  - low
  - high
- **decision support**
  - suggests actions
  - purchase decisions
  - anomaly alerts
- **personalization**
  - no personalization
  - highly personalized
- **information intent**
  - informs one action
  - informs many actions
- **automation/ control**
  - no control
  - system controls resource use

### DATA REPRESENTATION
- **aesthetic**
  - pragmatic
  - artistic
- **time window**
  - <hour
  - >year
- **temporal grouping**
  - sec
  - by hour
  - by day
  - by week
  - by month
  - year
- **data granularity**
  - coarse-grain
  - fine-grain
- **visual complexity**
  - simple
  - complex
- **primary visual encoding**
  - textual
  - graphical
- **measurement unit**
  - resource cost
  - environmental activity
  - time metaphor
  - impact
- **primary view**
  - temporal
  - spatial
  - categorical
- **data grouping**
  - by resource
  - by person
  - by time
  - by space
  - by activity
  - by consumption
  - category

### COMPARISON
- **comparison target**
  - self
  - social
  - goal
- **comparison by time**
  - past
  - projected
- **social-comp. target**
  - geographically
  - demographically
  - selected
  - social network
- **goal-setting strategy**
  - self-set
  - system-set
  - externally-set
- **difficulty to reach comparison target**
  - easy
  - hard
- **comparison variables**
  - time window
  - time granularity
  - data grouping
  - data granularity
  - measurement unit
- **statistic**
  - raw value
  - average
  - median
  - mode
  - other
- **computation**
  - @ this time [yest, last wk, mo, yr]
  - over past [X] days
  - this day type [weekday, weekend]
  - this day of week (e.g., mondays)

### SOCIAL ASPECTS
- **target**
  - person
  - household
  - community
  - state
  - country
- **private/public**
  - private
  - public
- **data sharing**
  - none
  - everyone
- **social-comparison**
  - available
  - (see COMPARISON)
  - unavailable

---

[Froehlich et al., HCIC2009; CHI2010; UW PhD Dissertation 2011]
behavioral models
inputs
social
motivational strategies
information access
display medium
comparison
actionability
data representation
the eco-feedback design space
behavioral models
social inputs
data representation
information access
display medium
comparison
actionability
motivational strategies
eco-feedback
design space
inputs
The eco-feedback design space

- inputs
- social
- motivational strategies
- actionability
- comparison
- display medium
- information access
- data representation
- behavioral models
social data representation
information access
display medium
inputs
behavioral models
social
motivational strategies
actionability
comparison
the eco-feedback design space
behavioral models
social inputs
data representation
information access
display medium
comparison
actionability
motivational strategies
the eco-feedback design space
Two sets of designs:

1. **Design Dimensions**
   Isolate eco-feedback design dimensions in the context of water usage

2. **Design Probes**
   Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.
Design Dimensions Explored

1. **Data**  Granularity
2. **Time**  Granularity
3. **Measurement**  Unit
4. **Comparison**

Part of “Data Representation” in the eco-feedback design space
behavioral models
inputs
data representation
information access
display medium
comparison
actionability
motivational strategies
social
the eco-feedback design space
inputs

social behavioral models
data representation
information access
display medium
comparison actionability

motivational strategies
eco-feedback
design space
the

pragmatic artistic

aesthetic

visual complexity simple complex

time granularity < hour > year

data granularity coarse-grain fine-grain

measurement unit
resource cost environmental time activity metaphor
impact

time granularity < hour > year

primary view temporal spatial categorical
DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

Data Granularity

course-grain  ≥ neighborhood  home  room  activity  fixture category  fixture  ≤ valve  fine-grain

Today's Water Usage in Gallons

Friday June 15th | 9:30 PM

Today's Water Usage in Gallons

Friday June 15th | 9:30 PM

Today's Water Usage in Gallons

Friday June 15th | 9:30 PM

Today's Water Usage in Gallons

Friday June 15th | 9:30 PM
Today's Water Usage in Gallons

Activity View

Showering & Bathing: 96 gallons
Hygiene (e.g., shaving): 26 gallons
Toilet: 68 gallons
Cooking & Dishes: 34 gallons
Laundry: 43 gallons
Other Chores (e.g., cleaning): 5 gallons
Watering Lawn: 80 gallons
Other Outdoor Use: 0 gallons

Friday June 15th | 9:30 PM
Today's Water Usage in Gallons
Fixture Category View

- Showers: 96 gallons
- Bathtubs: 2 gallons
- Toilets: 68 gallons
- Bathroom Sinks: 37 gallons
- Kitchen Sink: 12 gallons
- Dishwasher: 14 gallons
- Laundry Machine: 43 gallons
- Outdoor: 80 gallons

Friday June 15th | 9:30 PM
Today’s Water Usage in Gallons

Individual Fixture View

Friday June 15th | 9:30 PM

<table>
<thead>
<tr>
<th>Fixture</th>
<th>Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Bathroom</td>
<td>26</td>
</tr>
<tr>
<td>Upstairs Bathroom</td>
<td>70</td>
</tr>
<tr>
<td>Downstairs Bathroom</td>
<td>31</td>
</tr>
<tr>
<td>Kitchen</td>
<td>12</td>
</tr>
<tr>
<td>Laundry</td>
<td>14</td>
</tr>
<tr>
<td>Outdoors</td>
<td>80</td>
</tr>
</tbody>
</table>

- Master Bathroom: 26 gallons
- Upstairs Bathroom: 70 gallons
- Downstairs Bathroom: 31 gallons
- Kitchen: 12 gallons
- Laundry: 14 gallons
- Outdoors: 80 gallons
Today’s Water Usage in Gallons
Fixture Category View: Hot vs Cold

Friday June 15th | 9:30 PM
- cold water usage
- hot water usage

- Showers: 96 gallons, 30% cold, 70% hot
- Bathtubs: 2 gallons, both cold
- Toilets: 68 gallons, 40% cold, 60% hot
- Bathroom Sinks: 37 gallons, 41% cold, 59% hot
- Kitchen Sink: 12 gallons, 41% cold, 59% hot
- Dishwasher: 14 gallons, 77% cold, 23% hot
- Laundry Machine: 43 gallons, 77% cold, 23% hot
- Outdoor: 80 gallons, both cold
**Measurement Unit**

- **resource**: 36 gallons of water
- **rate of consumption**: 3 gpm
- **cost**: 9 cents
- **time**: 12 minutes
- **activity**: 1 shower
- **metaphor**: 24 jugs of water
This Month’s Water Usage
Fixture Category View | In Gallons

Friday June 15th | 9:30 PM

- **Showers**: 1,814 gallons
- **Bathtubs**: 177 gallons
- **Toilets**: 614 gallons
- **Bathroom Sinks**: 1,323 gallons
- **Kitchen Sink**: 150 gallons
- **Dishwasher**: 2,346 gallons
- **Laundry Machine**: 4,310 gallons
- **Outdoor**:
This Month’s Water Usage
Fixture Category View | In Dollars

Friday June 15th | 9:30 PM
Your Current Water Rate:
1,000 gal = $7.68

- Showers: $13.93
- Bathtubs: $1.36
- Toilets: $22.31
- Bathroom Sinks: $4.72
- Kitchen Sink: $10.16
- Dishwasher: $1.15
- Laundry Machine: $18.02
- Outdoor: $33.10
This Month’s Water Usage
Fixture Category View | In Dollars & Gallons

Friday June 15th | 9:30 PM
Your Current Water Rate:
1,000 gal = $7.68

- **Showers**: $13.93, 1,814 gallons
- **Bathtubs**: $1.36, 177 gallons
- **Toilets**: $22.31, 2,905 gallons
- **Bathroom Sinks**: $4.72, 614 gallons
- **Kitchen Sink**: $10.16, 1,323 gallons
- **Dishwasher**: $1.15, 150 gallons
- **Laundry Machine**: $18.02, 2,346 gallons
- **Outdoor**: $33.10, 4,310 gallons
comparison

comparison target

comparison by time

social comparison target

goal-setting strategy

difficulty to reach comparison target

self

social

goal

comparison

past

projected

generically proximal

demographically similar

selected social network

self-set

system-set

externally set

easy

hard
DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

**Design Dimensions Explored**

**Data Granularity**
- Individual Fixture
- Fixture Category
- Activity
- Hot and Cold

**Time Granularity**
- So Far Today
- So Far This Week
- So Far This Month

**Comparison**
- Self Comparison
- To Others
- To A Goal
- Social/Self

**Measurement Unit**
- In Gallons
- In Dollars
- Dollars / Gallons
- Including Sewage
Two sets of designs:

1. **Design Dimensions**
   - Isolate eco-feedback design dimensions in the context of water usage

2. **Design Probes**
   - Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

Time-Series

Spatial

Aquatic Eco-system

Rainflow

Per-Occupant

Other

Water Usage in Gallons Today

Water Usage in Gallons This Year

Today's Water Usage in Gallons

Person Usage Totals

Analysis - Export All歷期 lane channel 1

Your Daily Water Use Compared to State Averages in Gallons
Design Probes Explored

Time-Series

Aquatic Eco-system

Spatial

Rainflow

Per-Occupant

Other
Daily Patterns of Water Usage

[Adapted from Butler, Building and Environment, 1993]
DESIGN SET 2: DESIGN PROBES

Time-Series Views

Water Usage in Gallons
Today's Usage

When Water Used

gal/min

Cumulative Water Used

gallons

12 am 6 am 12 pm 6 pm 12 am

Water Usage in Gallons
This Year's Usage

When Water Used

Faucets
Toilets
Showers & Baths
Outdoor

gal/month

now

1,500

15,000

now

avg

Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

Today's Real-Time Water Usage
Fixture Category View

Fixture

Today's Usage Over Time

12 am 6 am 12 pm 6 pm 12 am

Today's Total

Shower

Bathtubs

Toilets

Bathroom Sinks

Kitchen Sink

Dishwasher

Laundry Machine

Outdoor

14

68

37

12

10

49

50

now

avg
Design Probes Explored

Spatial

Time-Series

Aquatic Eco-system

Rainflow

Per-Occupant

Other
### Today's Water Usage in Gallons

#### Room View

<table>
<thead>
<tr>
<th>Component</th>
<th>Today</th>
<th>Avg</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bathroom</strong></td>
<td></td>
<td></td>
<td>81.2 gal</td>
</tr>
<tr>
<td>Shower</td>
<td>40</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Toilet</td>
<td>30</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Bathroom Sink</td>
<td>10</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Bath</td>
<td>1.2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>Kitchen</strong></td>
<td>25</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Kitchen Sink</td>
<td>13</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Dishwasher</td>
<td>12</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><strong>Laundry</strong></td>
<td>40.6</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Laundry Machine</td>
<td>40</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Laundry Sink</td>
<td>0.6</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Friday June 15th | 9:30 PM*
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

- **Time-Series**
  - Water Usage in Gallons Today
  - Water Usage in Gallons This Year

- **Spatial**
  - Today's Water Usage in Gallons

- **Aquatic Eco-system**

- **Rainflow**

- **Per-Occupant**
  - Personal Usage Totals

- **Other**
  - Your Daily Water Use Compared to State Averages in Gallons
# Design Set 2: Design Probes

## Per-Occupant View

### Personal Usage Totals

<table>
<thead>
<tr>
<th>Person</th>
<th>Overall Usage So Far Today</th>
<th>Showers So Far Today</th>
<th>Last 30 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>overall daily avg</td>
<td>showers daily avg</td>
<td>daily total  daily avg</td>
</tr>
<tr>
<td>Son</td>
<td>42</td>
<td>24</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Mom</td>
<td>50</td>
<td>22</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Dad</td>
<td>67</td>
<td>26</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>129</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Daughter</td>
<td>70</td>
<td>53</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>
Design Probes Explored

**Spatial**
- Occupant

**Time-Series**
- Water Usage in Gallons Today
- Water Usage in Gallons This Year

**Rainflow**
- Water Usage Today
- Water Usage This Year

**Other**
- Aquatic Eco-system

**Per-Occupant**
- Personal Usage Today
- Personal Usage This Year

**Design Set 2: Design Probes**
DESIGN SET 2: DESIGN PROBES

Aquatic Ecosystem Design Influences

ubifit
Consolvo et al., CHI2008
Consolvo et al., UbiComp2008

ubigreen
Froehlich et al., CHI 2009
“Frank” the fish meets his mate

Frank and his mate have children

and so on...

Display is also interactive, so fish respond to touch.

New water savings goal met

Water savings tracker
DESIGN SET 2: DESIGN PROBES

**Design Probes Explored**

- **Time-Series**
- **Aquatic Eco-system**
- **Spatial**
- **Rainflow**
- **Per-Occupant**
- **Other**

![Graphs and visualizations related to water usage, spatial data, time-series analysis, and aquatic ecosystems.](image-url)
DESIGN SET 2: DESIGN PROBES

Rainflow View Movie
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

Time-Series

Spatial

Aquatic Eco-system

Rainflow

Per-Occupant

Other
DESIGN SET 2: DESIGN PROBES

Other Design Probes

Geographic Comparisons

Dashboards

Metaphorical Unit Designs

Recommendations
Evaluation
Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)

Informal interviews with water experts (e.g., SPU, Amy Vickers)
UW Environmental Practicum on water
Literature review of water resource management, environmental psychology
Our own online survey of water usage attitudes & knowledge (N=656 respondents)

Informed by gathered data
Guided by eco-feedback design space

Design critique sessions with team
Three sets of pilot studies

Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)
Online Survey

Recruitment
- Online postings and word-of-mouth

Survey Design
- 63 questions (10 optional)
- Question and answer order randomized when possible

Collected Data
- 712 completed surveys (651 from US or Canada)
- Nearly 6,000 qualitative responses
Most people receive information on their water usage from a monthly or bi-monthly bill. We are working on a new type of system that can **immediately show people how much water they are using** at each fixture in their home. This information could be viewed, for example, on a mobile phone, on a laptop, a digital picture frame, or on an in-home touchscreen display.

In this survey, we’ll explore different ways of visually displaying water usage information. Unless otherwise noted, each design is based on an average North American household of four people with two adults and two teenagers.

First, though, we need to ask some demographic questions.
Water Feedback Evaluation Survey
Hot and Cold Breakdown

We are also interested in whether people want information on hot water usage vs. cold water usage. Display (a) treats all water usage the same (whether hot or cold), while display (b) breaks down water usage by hot water and cold water amounts.

Like before, please mouse over the thumbnails on the left below to see enlarged versions of the display so that you can easily compare the two designs.

22. Which display do you prefer? *
Click on the image below to make your selection.

Overall water usage by fixture type
Hot and cold usage for each type of fixture
I would prefer to have both displays and be able to switch between them
All of the above
In-Home Interviews

Recruitment
- Online postings and word-of-mouth
- Specifically recruited families

Interview Method
- Semi-structured with two researchers
- 90-minutes, 3-phases
- Data coded by two researchers into themes

Participants
- 10 households (20 adults)
- 11 female/9 male
- Diff. socio-economic backgrounds & occupations
- 18 had college degrees
Findings
This display lets you more easily identify the specific areas that need attention.

Majority preferred the Individual Fixture Display
This display lets you more easily identify the specific areas that need attention.

Majority preferred the Individual Fixture Display.
20% preferred the Activity Display
71% of respondents preferred to see both gallons and cost.

Seeing the gallon amount triggers the ‘save the environment’ impulse to conserve, while the dollar amount is helpful because almost everyone is motivated by money to some extent.

R143: I don't think very well in ‘thousands of gallons’, but $20 I can understand. That’s a case of beer down the drain, if you will.
Comparisons were the most uniformly desired pieces of information of all the dimensions.
Self-comparison was most preferred

91%
Emergent Themes

1. Competition and Cooperation
2. Accountability and Blame
3. Playfulness and Functionality
4. Sense of Privacy
5. Display Placement
Competition and Cooperation

You can compare usage to others, and create friendly competition.

It pits the family members against each other rather than encouraging collaboration.

[It] sets up a ‘competitive’ environment that we are trying not to create in our household.
Accountability and Blame

It holds each individual accountable for water usage

There is no reason to add an element of ‘blame’ to conservation efforts within a family

Would seem to lead to plenty of arguments about usage
I like the idea of getting rewards for saving water

It’s like unlocking badges in Foursquare. No matter how trivial it can be to make a fish appear on this screen, you still want to do it

It doesn’t appeal to me as much. I don’t do Foursquare. This distracts me a little bit and it doesn’t make me think about my usage.
Useful as an educational tool?
Privacy Spectrum

“This display could set up a ‘competitive’ environment that we are trying not to create in our household.”

Would seem to lead to plenty of arguments about usage.

Least Invasive

Most Invasive
It’s incredibly invasive. And other people’s water consumption is not my business.
Water usage for many purposes can be very personal, and shouldn’t be automatically shared.
This display could set up a 'competitive' environment that we are trying not to create in our household.

Would seem to lead to plenty of arguments about usage.

Least Invasive

Most Invasive
Display Location Preferences
If we placed the display here, the kids couldn’t see it.
Display Location Preferences

kitchen

near thermostat

high traffic areas

accessible when needed
In Closing
Generation 1
feedback

sensing feedback

become a better

you
Come work with us!

CS grad applications are due Dec 15th
iSchool grad applications are due Dec 1st

Now in our 30th year!
The Water Eco-Feedback Team!

Acknowledgements:
Austin Polebitski, Assistant Professor of Civil and Environmental Engineering, UMass
David Hsu, Assistant Professor City and Regional Planning, UPenn
Sara Sheridan for her early design work
The **HydroSense** Team!

**Acknowledgements:**
Seattle Public Utilities: Ray Hoffman, Director; Al Diettemann, Water Conservation Expert; Bob Alpers
Amy Vickers, Water Conservation Expert
Austin Polebitski, Assistant Professor of Civil and Environmental Engineering, UMass
David Hsu, Assistant Professor City and Regional Planning, UPenn
Sara Sheridan for her early design work
The HydroSense Team!

Acknowledgements:
Seattle Public Utilities: Ray Hoffman, Director; Al Diettemann, Water Conservation Expert; Bob Alpers; Amy Vickers, Water Conservation Expert
Austin Polebitski, Assistant Professor of Civil and Environmental Engineering, UMass
David Hsu, Assistant Professor City and Regional Planning, UPenn
Sara Sheridan for her early design work

CV Highlights
Health and sustainability sensing expert. Signal processing guru.

16 conference papers
4 journal papers
4 best paper nominations
Multiple research awards

On the job market this year!
Reflections of Ourselves
Sensing and Feedback to Inform Everyday Human Behavior

@jonfroehlich
Assistant Professor Computer Science
Persuasiveness Scale

- Information rendered neutrally
- Information rendered persuasively
Does your car render MPH persuasively?
Is this more persuasive?
Are Vehicle-Activated Signs **Effective**?

Average speed reduction of ~7 mph
Statistically significant 1/3\(^{rd}\) reduction in accidents

Why are the signs effective?
Do drivers habituate to them?
At what point past the sign, do drivers speed up?
Would speed reductions last if the sign were removed?
How could you make a more effective sign?

Enabling direct comparison
A rationale!
Could it be Boulder, CO?
Persuasiveness Scale

speedometer

information rendered neutrally

plain

information rendered persuasively

rationale

comparison

fear

reinforcement

reward

punishment

DAYS IN HOSPITAL BED

YOUR SPEED

22
What other types of spectrums exist?

How could they be represented to help the process of design?