Analysis of Campus Water Base Flows Using Metering Data

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University of British Columbia

CIVL 592F

Themes: Water, Buildings

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ANALYSIS OF CAMPUS WATER BASE FLOWS USING METERING DATA

UBC SEEDS Directed Studies Research Report
By Aina Crozier
Sept. 6th, 2018
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Research focuses on tools to help inform and assist decision making in urban water system planning and management.

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September 6th, 2018
Water consumption in all buildings equipped with high-resolution meters has been analyzed in detail in this study, with focus on their contribution to the high campus base flow (minimum) consumption, estimated at 50% of total annual consumption. A systematic approach has been applied to estimate the base flow by assuming that whatever is consuming water when occupancy is minimal during the non-irrigation season is running continuously. Buildings have been identified and ranked accordingly.

Since data was not easily acquired and there has been limited previous analysis, a lot of the time was spent on organizing, cleaning and exploring the data, as well as gaining confidence by discussing findings with stakeholders. The 55 primary buildings for which good quality data was available for the study period from July 2017 to July 2018 (the majority Core buildings), consume 24% of the Campus total supply and 35% of the Campus base flows. This translated to current high-resolution metered base flow consumption of ~660,000 cubic meters annually, or potential annual cost savings of almost $600,000 (17% of total water costs) if eliminated completely. It was also found that, as expected, Core buildings with Lab as primary usage have the highest water usage intensities and contribute more to campus base flows. Further, it is stated that more than 70% of the Campus water consumption is currently not accounted for in high resolution (Skyspark data).

Recommendations from this study are to investigate whether the already high-resolution metered base flow water consumption in buildings can be reduced, by, first, clearing up any confusions regarding where meters are located and the area and purpose they cover, and, second, evaluating the cost and feasibility of conserving the water. Further, the recommendation is to make sure that already installed high-resolution meters are working properly and connected, and then prioritize additional meters in buildings with significant lab usage, as well as separate irrigation systems to help investigate potential leaks.

Additionally, a number of recommendations related to improving data availability and quality are listed in this report, as the overall impression is that there should be substantial opportunity for water conservation in buildings and other systems if reliable data is available. As a contribution to this goal, the report is accompanied by an Excel spreadsheet containing all numerical and descriptive data that have been gathered in this study, including various statistics, metrics and charts to help provide a deeper understanding at the building level.
1. Introduction
   1. Background & Previous Work
   2. Status & Objectives

2. Approach
   1. Challenges & Time Spent
   2. Data Availability: Campus Supply & Building Consumption
   3. Data Quality: Uncertainties & Sources of Error
   4. Technical & Analytical Methods

3. Results
   1. Spreadsheet with Metadata, Statistics and Metrics
   2. Building Consumption, Rankings & Benchmarks
   3. Nighttime Consumption & Estimated Base Flows
   4. Example: Forestry Sciences

4. Conclusions
   1. Findings Summary
   2. Recommendations
   3. Potential Projects

5. References & Resources

6. Appendices: Spreadsheet & Technical Work
Bud Fraser

Senior Planning & Sustainability Engineer

“Campus supply water meter data indicates base (minimum) water flows that approach 50% of average flows.

This indicates that there are buildings or systems that are consuming large amounts of water during the night when academic building occupancy is at a minimum.”
PREVIOUS WORK

UBC Water Base Flow Analysis (2011)

- Stantec Consulting engaged by Campus Sustainability Office (CSO)
- Defined baseflow as the lowest and most consistent water flow for a building at any one point during the study period (Sept 2010 to Sept 2011).
- Extensive study covering data from campus main supplies and sewer, buildings with digital meters (78) and analog meters (298), analog irrigation meters, and various manual readings.

<table>
<thead>
<tr>
<th>Total and Base Water Consumption of the Entire Campus (Stantec Consulting)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Water Consumption (m³)</strong></td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>16th Ave Meter</td>
</tr>
<tr>
<td>Powerhouse Meter</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Estimated base flow percentage of annual consumption is still around 50%.

Water is relatively cheap compared to electricity, which explains why efforts to reduce consumption may have been down-prioritized.


“Maintain UBC total water consumption at or below 2017 levels despite anticipated growth of 2%”

Makes sense to investigate sources of base flow (low-hanging fruit).

<table>
<thead>
<tr>
<th></th>
<th>2011 Water Consumption (m³)</th>
<th>2018 Estimated Baseflow (m³)</th>
<th>Baseflow/Annual Consumption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Avenue Meter</td>
<td>404,000* 970,895</td>
<td>315,000* 403,103</td>
<td>78%* 42%</td>
</tr>
<tr>
<td>U Blvd Meter</td>
<td>3,500,000* 2,799,096</td>
<td>1,730,000* 1,483,914</td>
<td>50%* 53%</td>
</tr>
<tr>
<td>Total</td>
<td>3,900,000* 3,769,991</td>
<td>2,050,000* 1,887,017</td>
<td>53%* 50%</td>
</tr>
</tbody>
</table>

*Stantec Consulting: Total and Base Water Consumption of the Entire Campus

Price of water per cubic meter: $0.891 (Increasing 5% annually)

Cost of base flow:

$1,298,095 (2011)
$1,681,332 (2018)
OBJECTIVES

1. Gain a deeper understanding of water consumption across campus buildings by analyzing Skyspark high-resolution data along with data from campus main supply meters.
   - Identifying and ranking buildings with the largest contribution to campus base flow rates.
   - Identifying potential sources of the base flows.

2. Estimate how much of the total water flow within core academic buildings on campus is metered and if possible, provide recommendations for additional metering locations.

These evolved from the various actions listed in the new UBC Water Action Plan.
CHALLENGES & TIME SPENT

Systematic approach instead of reading off base flow graphically:
• Easier to reproduce and update numbers.
• Apply analytical technique to get deeper understanding of characteristics and trends for building consumption.

Acquiring, exploring and cleaning data (gaining confidence) took longer than anticipated and triggered many questions.

Data has been organized in single spreadsheet, providing a good baseline for further analysis.

Summary of data availability and quality, methods, results and recommendations are presented in the following slides.
DATA AVAILABILITY

Time period: July 1st 2017 – July 1st 2018
- Steam boiler in Power House shut down on June 7th 2017

Campus Water Supply:
- No direct access to data (TrendReader)
- 15 min resolution data
- U Blvd and 16th Ave supplies (high- and low-pressure zones)
- Available as average flow rates (liters per second)
- Consumption readings Sept 27th, Dec 20th and March 28th (cubic feet for 16th Ave and cubic meters for U Blvd)

Building Water Consumption:
- Access to Skyspark platform
- 15 min resolution data
- 80 buildings listed with water consumption data
- Available as cumulative consumption (cubic meters)
DATA QUALITY: CAMPUS SUPPLY

Interpretation challenging due to automated interaction between high and low-pressure zones through seven pressure-reducing values (PRVs).

Uncertainties & Sources of Error:
- When and how much of U Blvd supply feeds low-pressure zone.
- Offset between consumption computed from flow rate measurements and manual readings.
- Conversion between metric and imperial units.

See Appendix 2: Technical Work for more details on how these were handled.
Main challenge is understanding where data is coming from and how it has been acquired and treated before being presented in Skyspark.

Uncertainties & Sources of Error:

- Understanding which meter the data is coming from.
- Ensuring correct area and space usage of buildings due to sub-fed buildings.
- Missing data and confidence factors (communication issues water meter/ION meter/server).
- Interpreting and handling consumption spikes (cumulative consumption or calculation error).
- Interpreting zeros (malfunctioning meter or accounted for in following datapoints).

See Appendix 2: Technical Work for more details on how these were handled.
TECHNICAL & ANALYTICAL METHODS

1. Organized data in single Excel spreadsheet\(^1\).
2. Included metadata by cross-referencing different sources.
3. Cleaned and updated data \(^2\):
   - Building usage and total areas adjusted for meters covering sub-fed buildings
   - Consumption spikes after missing data removed from the dataset
   - Confidence factors and zero percentages used to filter out poor quality data
4. Computed statistics and metrics to get building ranking

Base flow consumption estimate found by extracting nighttime consumption in non-irrigation months and scaling up to the whole year.

Assuming that whatever is consuming water when occupancy is minimal in non-irrigation season, is running continuously.

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\(^1\) See Appendix 1: Spreadsheet for more details.
\(^2\) See Appendix 2: Technical Work for more details.
## Results

### September 6th, 2018

**ANALYSIS OF CAMPUS WATER BASE FLOWS**

<table>
<thead>
<tr>
<th>Building</th>
<th>Area (m²)</th>
<th>Lab</th>
<th>Office</th>
<th>Classroom</th>
<th>Residential</th>
<th>Pressure Zone</th>
<th>Number of Zones</th>
<th>Date Extracted</th>
<th>Data Column</th>
<th>Vegetation Code</th>
<th>Location Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumni Centre</td>
<td>777</td>
<td>Auxiliary</td>
<td>2010</td>
<td>3700</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>AMS Beet</td>
<td>795</td>
<td>Other</td>
<td>2013</td>
<td>2039</td>
<td>0%</td>
<td>0%</td>
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<tr>
<td>Aquatic Centre</td>
<td>213</td>
<td>Ancillary</td>
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<td>8041</td>
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<td>0%</td>
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<tr>
<td>Aquatic Ecosystems Research Lab</td>
<td>316</td>
<td>Core</td>
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<td>5130</td>
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<td>1%</td>
<td>High</td>
<td>MWS-05-316</td>
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<td>15 min</td>
</tr>
<tr>
<td>Atrium</td>
<td>46</td>
<td>Library</td>
<td>1970</td>
<td>4298</td>
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<td>1%</td>
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<td>12016</td>
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<tr>
<td>Biological Sciences Building South</td>
<td>68</td>
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<td>2015</td>
<td>5491</td>
<td>4%</td>
<td>4%</td>
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<tr>
<td>Biological Sciences Building West</td>
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<td>Buchanan &amp; A.C.</td>
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<td>Centre for Comparative Medicine</td>
<td>57</td>
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<td>10967</td>
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<td>52%</td>
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<td>Civil &amp; Mechanical Engineering</td>
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<td>4091</td>
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<td>Earth and Ocean Sciences</td>
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<td>15909</td>
<td>2%</td>
<td>2%</td>
<td>High</td>
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<tr>
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<td>2013</td>
<td>2009</td>
<td>4%</td>
<td>4%</td>
<td>High</td>
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<td>First Nations House</td>
<td>357</td>
<td>Core</td>
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<td>2282</td>
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<tr>
<td>Food, Nutrition and Health</td>
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<td>Core</td>
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<td>8987</td>
<td>2%</td>
<td>2%</td>
<td>High</td>
<td>MWS-08-325-2</td>
<td>July 1st 2018</td>
<td>M</td>
<td>15 min</td>
</tr>
</tbody>
</table>
**Results**

### Total Monthly Consumption

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>253.60</td>
<td>0.27</td>
<td>0.00</td>
<td>0.30</td>
<td>0.10</td>
<td>0.01</td>
<td>3541</td>
<td>3541</td>
<td>3541</td>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>2</td>
<td>325.80</td>
<td>0.08</td>
<td>0.00</td>
<td>0.05</td>
<td>0.30</td>
<td>0.08</td>
<td>2976</td>
<td>2976</td>
<td>2976</td>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>141.90</td>
<td>0.08</td>
<td>0.00</td>
<td>0.05</td>
<td>0.30</td>
<td>0.06</td>
<td>2976</td>
<td>2976</td>
<td>2976</td>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>167.90</td>
<td>0.08</td>
<td>0.00</td>
<td>0.05</td>
<td>0.30</td>
<td>0.06</td>
<td>2976</td>
<td>2976</td>
<td>2976</td>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>5</td>
<td>210.00</td>
<td>0.08</td>
<td>0.00</td>
<td>0.05</td>
<td>0.30</td>
<td>0.06</td>
<td>2976</td>
<td>2976</td>
<td>2976</td>
<td>0</td>
<td>0.72</td>
</tr>
</tbody>
</table>

### Hourly Average over Year

#### Hourly Average by Month

- **Month**: 1, 2, 3, 4, 5
- **Days**: 0.27, 0.08, 0.08, 0.08, 0.08
- **Average**: 0.07, 0.06, 0.06, 0.06, 0.06
- **Daily Average**: 0.72

#### Hourly Average over Selected Month

- **Month**: 3
- **Days**: 0.08
- **Average**: 0.08
- **Daily Average**: 0.72

### Weekday Average over Year

- **Month**: Mon, Tue, Wed, Thu, Fri
- **Days**: 0.07, 0.05, 0.06, 0.07, 0.07
- **Average**: 0.06
- **Daily Average**: 0.63

### Daily Average by Month

- **Month**: 1, 2, 3, 4, 5
- **Days**: 0.27, 0.08, 0.08, 0.08, 0.08
- **Average**: 0.07
- **Daily Average**: 0.72
### SKYSPARK BUILDING DATA

- 55 primary buildings with high-resolution data of good quality in the study period from July 2017 to July 2018 (25 deemed poor quality).
- The majority are Core buildings located in the High pressure zone, consuming water from the U Blvd campus supply only.
- 64 of the 218 core buildings on campus are metered with high resolution when including sub-fed buildings into the count.

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Poor quality</th>
<th>Good quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 Buildings</td>
<td>25</td>
<td>55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Faults</th>
<th>High pressure zone (U Blvd)</th>
<th>Low pressure zone (Both supplies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Mach fault</td>
<td>47 Core (18 sub-fed)</td>
<td>5 Ancillary (2 sub-fed)</td>
</tr>
<tr>
<td>1 Elec fault</td>
<td>4 Ancillary</td>
<td></td>
</tr>
<tr>
<td>6 Comm fault</td>
<td>3 Core</td>
<td>1 Lab</td>
</tr>
<tr>
<td>8 Syst fault</td>
<td>1 Residential</td>
<td>3 Other Primary Usage</td>
</tr>
</tbody>
</table>

#### Results

- 27 Lab
- 16 Other Primary Usage
- 1 Residential
- 3 Other Primary Usage
- 1 Lab
- 3 Other Primary Usage
- 5 Residential
TOP 10 WATER CONSUMERS

High-resolution metered buildings account for 24% of total campus supply and Top 10 buildings account for 14%.

If only considering buildings located in the high-pressure zone (47 buildings), these account for 29% of the U Blvd supply.

Metered Core buildings account for 18% of total campus supply and Top 10 Core buildings account for 11%.

If only considering core buildings with lab as primary usage (28 buildings), these account for 15% of total campus supply.

More than 70% of campus consumption is not accounted for in high resolution (Skyspark).
WUI BENCHMARK

▪ Water Usage Intensity (WUI) is defined as annual consumption divided by total area (m3/yr/m2).

▪ Biological Sciences Building South stands out even more as Orchard Commons drops to the bottom.

▪ Chemistry South, CEME, Biomedical Research Centre and Frank Forward (all Lab buildings) replace other buildings.

▪ Buildings with Lab as primary usage have highest WUI.

<table>
<thead>
<tr>
<th>Building Type</th>
<th>WUI Average (m3/yr/m2)</th>
<th>WUI Range (m3/yr/m2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core (excl. Bio Sci South)</td>
<td>1.8 (1.4)</td>
<td>0.2-9.8</td>
</tr>
<tr>
<td>Core Lab (excl. Bio Sci South)</td>
<td>2.5 (1.7)</td>
<td>0.2-9.8</td>
</tr>
<tr>
<td>Ancillary</td>
<td>1.3</td>
<td>0.4-3.6</td>
</tr>
<tr>
<td>Ancillary Residential</td>
<td>1.0</td>
<td>0.4-2.0</td>
</tr>
</tbody>
</table>

Top 10 Water Intensive Consumers

Metered consumption most likely includes water usage in Biological Sciences Building West, thus the area should be more than doubled.
NIGHTTIME CONSUMPTION

- 23% of campus total nighttime supply metered with high resolution (14% in Top 10)
  - Metered buildings contribute similarly as for whole year.
- 35% of campus total nighttime supply metered in non-irrigation season (23% in Top 10)
  - Metered buildings contribute more to nighttime consumption outside of irrigation season.
  - Separate irrigation systems thus account for 12% of nighttime consumption during irrigation season*.
- CEME and H.R. Macmillan replace AMS Nest and Hennings in Top 10 consumers.

- 41% of U Blvd nighttime supply metered in high pressure zone in non-irrigation season (29% in Top 10)
  - Almost 60% not captured (some in low-pressure zone).
  - Metered consumption accounts for almost 90,000 cubic meters.

Top 10 Nighttime Consumers Non-Irr Season

<table>
<thead>
<tr>
<th>Skyspark Name</th>
<th>Category</th>
<th>Primary Usage</th>
<th>Meter Number</th>
<th>Subbed Buildings</th>
<th>Pressure Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Sciences Building South</td>
<td>Core</td>
<td>Lab</td>
<td>Null</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Orchard Commons</td>
<td>Ancillary</td>
<td>Residential</td>
<td>MW10-31</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Forestry Sciences</td>
<td>Core</td>
<td>Lab</td>
<td>MW10-17</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Earth and Ocean Sciences</td>
<td>Core</td>
<td>Lab</td>
<td>MW10E-2</td>
<td>403</td>
<td>High</td>
</tr>
<tr>
<td>Robert F. Osborne Centre 1</td>
<td>Core</td>
<td>Lab</td>
<td>Null</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Life Science Centre</td>
<td>Core</td>
<td>Lab</td>
<td>MW11-8</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Ponderosa North</td>
<td>Ancillary</td>
<td>Residential</td>
<td>MW8E-2 783</td>
<td>Null</td>
<td>Low</td>
</tr>
<tr>
<td>H.R. Macmillan</td>
<td>Core</td>
<td>Lab</td>
<td>MW10E-11</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Aquatic Centre</td>
<td>Ancillary</td>
<td>Athletics</td>
<td>Null</td>
<td>Null</td>
<td>High</td>
</tr>
<tr>
<td>Civil &amp; Mechanical Engineering</td>
<td>Core</td>
<td>Lab</td>
<td>MW10E-5</td>
<td>Null</td>
<td>High</td>
</tr>
</tbody>
</table>

Nighttime is here defined as time period between midnight and six in the morning and irrigation season as beginning of May to end of September.

Potential annual savings of 616,000 cubic meters or $550,000 (16% of annual water costs) if currently metered base flow consumption in high-pressure zone is eliminated completely.

* In range of Stantec Consulting estimate in 2011.
ESTIMATED BASE FLOW CONSUMPTION

Main assumption: whatever is consuming water when occupancy is minimal in non-irrigation season, runs continuously.

35% of estimated campus base flow consumption metered (664,105/1,887,017 m³).

Almost $600,000 annually already metered (Campus total $1,681,332).

Uncertainty related to absolute values from scaling, but relative size indicates base flow contribution.

Except for Orchard Commons, Ponderosa North and the Aquatic Centre, Core Lab buildings are the biggest contributors.

Need to investigate Aquatics Lab in Biological Sciences Building South and the distribution of dechlorinated water to the Building West.

Colors indicate high and low pressure zones.
The Aquatic Ecology Lab (fish tank) has a flow-through water system.

Lab had an incident that put it out of operation at the end of last year.

In operation the minimum consumption of 2 cubic meters every 15 minutes converts to 70,000 cubic meters annually.

Indicates annual cost of $62,000 to EWS for running the lab – compare to cost of installing recirculating system.
FINDINGS SUMMARY

- Total Campus base flow is estimated at 1,887,017 cubic meters (~50% of annual consumption).
  - U Blvd main supply accounts for 1,483,914 cubic meters of base flow alone (78%).

- 55 of the 80 buildings listed with water consumption data in Skyspark are deemed good quality and considered in this study.
  - The majority are Core Buildings located in the High pressure zone and consume water from the U Blvd campus supply only.
  - 18% of campus total supply is metered in core buildings (64 of the 218 core buildings when considering sub-fed buildings).

- High-resolution metered buildings account for approx. 24% of campus total supply (14% in Top 10 consumers).

- Outside of irrigation season, the contribution to nighttime consumption increases to 35% (23% in Top 10 consumers).
  - 41% of U Blvd supply when only considering buildings located in high-pressure zone (29% in Top 10 consumers).

- If main assumption holds, this converts to 664,105 cubic meters of annual base flow consumption.
  - High-pressure zone (Core building area) annual base flow estimate alone is 616,000 cubic meters.

- Potential annual savings of almost $600,000 (17% of total water costs) if currently metered base flow consumption is eliminated completely.

- Core Lab buildings have the highest water usage intensities and contribute more to campus base flows.

- More than 70% of the Campus water consumption is currently not accounted for in high resolution (Skyspark).
RECOMMENDATIONS

- Clear up any confusions regarding where meter is located and the area/purpose it covers.
- Investigate whether already-metered base flow consumption can be reduced (cost and feasibility).
- Make sure already installed high-resolution meters are working properly and connected.
- Prioritize installing high-resolution meters in buildings with lab space and separate irrigation systems.

- Improve data access:
  - High-resolution data download of all buildings less time-consuming.
  - Direct access to campus water supply and sewer data. (PRV data available?)
  - Include descriptions (metadata) on meters, logging, conversions, areas and buildings covered etc.
  - Gather data from already installed high-resolution meters on campus irrigation systems, if any.

- Improve data quality:
  - Investigate why campus supply flow rates are off by 10% when compared to consumption readings.
  - Minimize uncertainties regarding missing data, zeros and consumption spikes for building meter data.

- Include some of the metrics used in this study in further development of Skyspark.
POTENTIAL PROJECTS

Should be substantial opportunity for water conservation and system optimization if reliable data at hand:

1. Explore correlations and establish building benchmarks when utilizing water consumption and occupancy data along with building specifics and seasonality.
2. Create map visualizations of building consumption for easier analysis and interpretations.
3. Investigate potential leaks by analyzing high-resolution campus supply, sanitation, building and irrigation data.
4. Apply clustering technique and machine learning to predict performance and highlight abnormalities.
5. Multi-objective optimization of complete system (PhD research goal).

September 6th, 2018
REFERENCES & RESOURCES


2. UBC Water Action Plan (TBC 2018): Bud Fraser (Senior Planning & Sustainability Engineer, S&E)

3. Water Consumption in Buildings:
   - Water Meters: Colin Mingus (Climate & Energy Engineer, EWS)
   - Data Logging: Blair Antcliffe (Energy Engineer, EWS)
   - Skyspark Platform: Arthur de Robert (Energy Data Analyst, EWS)
   - Maps and Schematics: Erin Kastner (Geospatial Information Manager, EWS)

4. Water Supply on Campus:
   - Water Mains Data: Jenny Liu (Mechanical Utilities Engineer, EWS)
   - Operational Questions: Aleks Paderewski (Mechanical Utilities Manager, EWS)

5. Spreadsheet “Campus Building Data v9.0 2018 working_20180418_NM”: Nicole Montgomery (Coordinator, Reporting, Monitoring & Systems Review, S&E)
APPENDIX 1: SPREADSHEET

The accompanying “Building Consumption Data Analysis” spreadsheet (~70 MB) contains the following:

**Summary & Rankings:** Summary of metadata, statistics and metrics for each listed building in Skyspark (each water meter).

**Building Analysis:** The option to choose one Skyspark listed building (water meter) to see summary and additional charts for detailed analysis.

**Campus Analysis:** Data and cost analysis for the campus water supplies.

**Data:** Gathered and treated data from the Skyspark Buildings App (under Building Utilities) for the time period July 1st 2017 to June 30th 2018.

**16th Ave Supply:** Gathered data on flow rate measurements and computed consumption for the campus supply for the same time period.

**U Blvd Supply:** Gathered data on flow rate measurements and computed consumption for the campus supply for the same time period.

**CCP Building List:** Data extracted from the spreadsheet “Campus Building Data v9.0 2018working_20180418_NM” by filtering on existing buildings only.

One can find a number of comments explaining more details in the spreadsheet.
University of Cincinnati Water Management Project

APPENDIX 2: TECHNICAL WORK

Campus Supply Data:

- When comparing consumption computed from average flow rate measurements and the manual readings, a constant error of ~10% was found. Assuming that the offset originates from the flow rate measurements or conversion factors, the error was corrected for by adding 10% to every datapoint for the computed consumption.

Building Consumption Data:

- Initially, building area and usage percentages were gathered from Skyspark, but encountering inconsistencies between these numbers and the CCP Spreadsheet that was used as input, it was decided to use this list directly. A lot of manual work was required by cross-referencing buildings with campus map of meters and distribution pipes, to make sure that the complete area covered by each meter (due to subfed buildings) was included, as well as usage percentages updated accordingly.

- All water meters are configured to send a pulse to the ION meter (data logger) when 0.1 cubic meters of water has been consumed. A server communicating with the ION meters, converts the pulse count into accumulated consumption with a resolution of 15 minutes, which is the data made available in Skyspark. If communication issues are experienced in the data logging process, this result in missing datapoints during the affected time period, and depending on the cause behind, the first datapoint recorded may represent cumulative consumption during the missing time period or it could be a pulse count conversion error. Since there is no way of easily determining the case, and the timing of the consumption is relevant for this study, it was decided to remove all consumption spikes after a period of missing data.

- It was discovered that some meters had a very high percentage of zero measurements, which can be due to malfunction meter or low consumption (less than 0.1 cubic meters in 15 minutes). Further, in some cases large spikes in consumption were identified after a longer period of zeros and these were removed using the same rationale as for first record after missing datapoints above. Overall, distinguishing these events is not straight forward, and again, since timing of consumption is relevant for this study, the percentage of zero measurements was used along with confidence factors (missing datapoints) to determine the quality of the data. Manually adjusting and reviewing the results, the requirement for Good quality data was set to confidence above 85% and percentage of zeros during the day less than 75%. The latter translates to minimum hourly data resolution.

September 6th, 2018
ANALYSIS OF CAMPUS WATER BASE FLOWS