2019 BIG BEERS BELGIANS & BARLEYWINES FESTIVAL

Mad Fritz

Origin Beer

Demystifying Water Profiles: The Power of Minerality and Flavor Expression in Beer

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SIERRA NEVADA

CROOKED STAVE

ARTISAN BEER PROJECT

Our Objectives and Approach

1. The goal of this project was to explore various beer styles and the effects of brewing water chemistry on their resulting flavor expression.
2. How does past research apply in todays brew-scape?
3. Our approach was to have four breweries each brew a distinct style of beer twice using two completely different waters or treatments.
4. Water, wort, and finished beer samples were all analytically and sensorially analyzed at Sierra Nevada Brewing Co. in Chico

Water as an ingredient-it’s a pretty big deal and here's why:

Beer = **Water** + Malt + Hops + Yeast

The Acid/Base balance in brewing water is one of the most important measurements we use for successful brewing.

- What is it?
  - pH
  - Total Hardness
  - Alkalinity

What does it do?

- Enzyme optimization in mashing (proteinases-protein and saccharification (starch))
- Oxidation rates (redox reactions) in cellar side operations
- Settling/Precipitation rates hot and cold side

Water as an ingredient-it’s a pretty big deal and here's why:

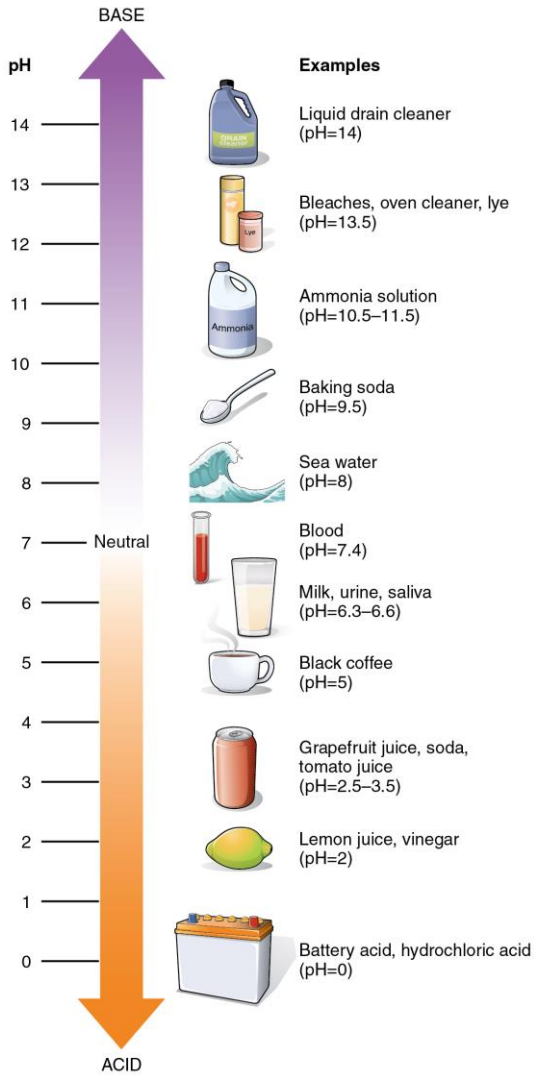
Minerals in water interact with brewing ingredients (i.e. ground up malt in mashing process) and accumulate in the extract that we eventually ferment, and can accentuate aromas and flavors in beer

- Cations (+ charge) Calcium, Magnesium, Sodium
- Anions (- charge) Sulfate, Chloride
- $CaCl_2$ in water is Ca^+ and $2Cl^-$

Water Analysis - pH

pH is the concentration of hydroxide ions in solution, typically coming from an acid donor

- HA -> H^+ + A^-
- Log base scale: pH 5 to pH 4 is 10 times more H^+
- Lactic and phosphoric acids are typically used for water pH adjustments as well as malts
- Wort and Mash ~5.1-5.5 pH
- Beer ~4.0-4.5 pH
- pH is important in many parts of the brewing process

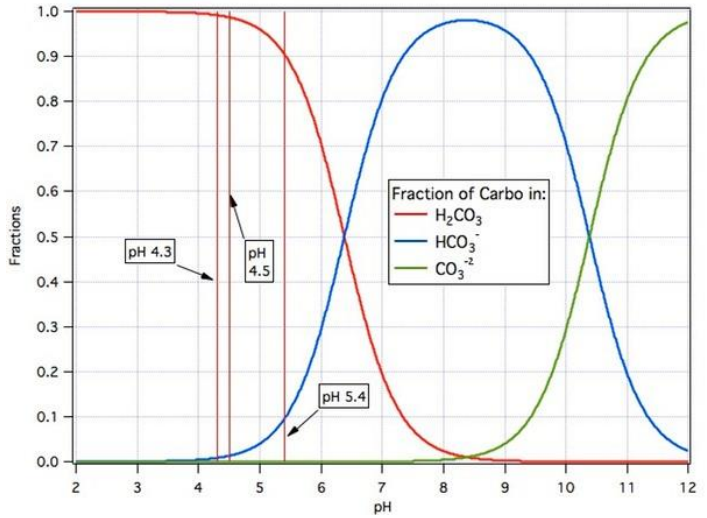


Water Analysis – Hardness and Alkalinity

- Hardness is the concentration of multivalent cations in solution
  - Commonly calcium and magnesium
  - Total hardness = calcium + magnesium
  - Can cause process issues when too high

Classification	hardness in ppm
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	≥ 181

- Alkalinity is the amount of basic species in solution that can be converted neutral species using a strong acid
  - Typically HCO_3^-
  - Can cause process issues when too high



Water Chemistry – Calcium

- During mashing, calcium reacts with and precipitates organic alkaline phosphates from malt, thereby reducing wort pH:
  - Low salt addition: $3CaSO_4 + 4K_2HPO_4 \rightarrow Ca_3(PO_4)_2\downarrow + 2KH_2PO_4 + 3K_2SO_4$
  - High salt addition: $CaSO4 + K_2HPO_4 \rightarrow CaHPO_4\downarrow + K_2SO_4$
- Increases β-amylase activity in mash (optimum pH 4.7)
- Increases protease activity (optimum pH 4.5-5.0), thereby increasing FAN & fermentation vigor
- Reduces extraction of tannins, silicates & polyphenols responsible for subsequent haze
- Improves microbiological stability
- But, reduces hop isomerization & utilization, thereby reducing BU's (likely a small effect because optimum pH for hop isomerization is ~10, vs. the drop from 5.8 to 5.1)

Water Chemistry – Calcium

- During mashing, protects α-amylase from heat inhibition (149-154°F optimum temperature)
  - The increased amylase activity raises saccharification rates and increases extract yields
    - The improved conversion reduces wort viscosity, reduces lautering times while increasing lautering extract recovery, and enhances trub separation after kettle boil (too much may result in excess phosphate precipitate & slow run-off)
- Interacts with and precipitates wort certain haze proteins during mashing, kettle boil & aging
  - Easier to settle & filter out
  - Precipitation increases as wort pH drops
- Interacts with and precipitates oxalates responsible for subsequent haze & gushing

Water Chemistry – Calcium

- Reduces the extraction of anthocyanogens & pro-anthocyanodins during sparging, thereby reducing color during kettle boil
- Inhibits melanoidin formation from reducing sugars
- As a phosphate precipitate, improves hot break flocculation & trub removal
- Improves yeast growth (important for membrane structure & function)
- Interacts with and aggregates yeast cells, thereby encouraging yeast flocculation
- Much of the calcium is lost as a phosphate, proteinate or oxalate precipitate during mashing/lautering, thereby requiring supplemental addition to the kettle (can introduce calcium in hot liquor)
- In beer, produces a clean, dry taste (ideal range is 40-100 mg/l

Water Chemistry – Magnesium

- Has some of the same enhancements as calcium, but to a lesser extent, due to the lower solubility of its alkaline phosphate salts
- Yeast nutrient (enzyme co-factor) at lower levels above 10 mg/l
  - important for yeast cell metabolism & enzyme activity
  - Provides some protection from osmotic pressure and alcohol tolerance
  - Important for membrane structure & function
- In excess, may actually increase wort pH by interfering with calcium
- Should be < 1/3 calcium concentration
- In foundation water,
  - 2 mg/l typical for stouts
  - 10 mg/k typical for porters & lagers & mild beers
  - 15 mg/l typical for bitter beers
- Ideal range is 10-50 mg/l, 40-80 mg/l max

Water Chemistry – Bicarbonate

- In foundation or sparge water:
  - Results in greater pH rise during sparging when wort buffering capacity drops
  - Alkalinity can be reduced by acidifying with HCl & H_2SO_4 (for ales, to increase chloride and sulfate), and with H_3PO_4 & lactic acid (for lagers, to reduce chloride and sulfate)
- In wort: Resists increases in mash acidity by neutralizing and precipitating acidic phosphates, thereby raising wort pH
- Low alkalinity: $Ca(HCO_3)_2 + 2KH_2PO_4 \rightarrow CaHPO_4\downarrow + K_2HPO_4 + 2H_2O + 2CO_2\uparrow$
- High Alkalinity: $3Ca(HCO_3)_2 + 4KH_2PO_4 \rightarrow Ca_3(PO_4)_2\downarrow + 2K_2HPO_4 + 6H_2O + 6CO_2\uparrow$
  - Opposes the beneficial effects of calcium
  - Impedes trub flocculation during cold break
  - Greater impact at raising mash pH than calcium at dropping mash pH
- In beer: Imparts harsh, bitter taste to delicate lagers

Water Chemistry – Sodium

- As a bicarbonate salt, raises alkalinity & pH
- May negatively affect yeast if in excess
- In beer:
  - Imparts palate fullness at 75-150 mg/l
  - But a sour, saline taste if > 150 mg/l (therefore 150 mg/l max)
  - Less sour, salty if a chloride vs. sulfate salt

Water Chemistry – Chloride

In beer imparts palate fullness and some sweetness if > 250 mg/l

- Saltiness if > 300 mg/l (less so as a calcium or magnesium salt)
- Ideal range is 50-200 mg/l, 250 mg/l max
- 100 mg/l max for light beers

Concentration and ratio to sulfate are important

Accentuates malt body character

NEIPAs tend to be chloride heavy

Water Chemistry – Sulfate

In beer, imparts a drier, more bitter taste (& possibly fuller & sharper)

- A ratio of 2:1 sulfate to chloride generally good for bitter beers
- A ratio of 1:2 sulfate to chloride generally good for mild ales
- A ratio of 1:3 sulfate to chloride generally good for stouts & porters
- 100-500 mg/l max, preferably < 150 mg/l (250 mg/l max in dilution water)

Concentration and ratio to chloride are important

Yeast may convert some sulfate to SO_2 or to sulfides & sulfur off-flavors during fermentation

West Coast IPAs tend to be sulfate heavy

Accentuates hop character and round out bitterness

Water Chemistry – Micro Nutrients

Zinc

- Can be added as $ZnSO_4$
- During fermentation:
  - Stimulates fermentation rate at 0.1-0.2 mg/l (increases EOF yeast cell viability in high-glucose worts)
  - Greater attenuation & alcohol
  - Stimulates uptake of maltose and maltotriose
  - Stabilizes protein & membrane systems
- Interacts with and aggregates yeast cells, thereby encouraging yeast flocculation

Iron

- Yeast nutrient at trace levels
- High levels are toxic to yeast
- Produces protein-tannin hazes in beer
- Imparts a metallic taste, harshness & palate thinness (0.2 mg/l max)
- In beer, contributes to product oxidation by catalyzing the Fenton Reaction

Water Chemistry – Micro Nutrients

Copper

- Dissolved copper reacts with sulfides to reduce sulfidic flavors in beer
- Yeast nutrient, but inhibits yeast growth above 0.6 mg/l and is toxic to yeast above 10 mg/l (should be < 0.25 mg/l in wort)
- In beer,
  - May impart a metallic taste
- May contribute to product oxidation by catalyzing the Haber-Weiss reaction

Manganese

- By enhancing mash enzymes, increases protein solubilization, but may effect color
- Yeast nutrient (enzyme co-factor) up to 0.2 mg/l
- May impart a metallic taste
- May contribute to product oxidation by catalyzing the Haber-Weiss reaction

Sensory Testing and Analytical Testing

Triangle Testing

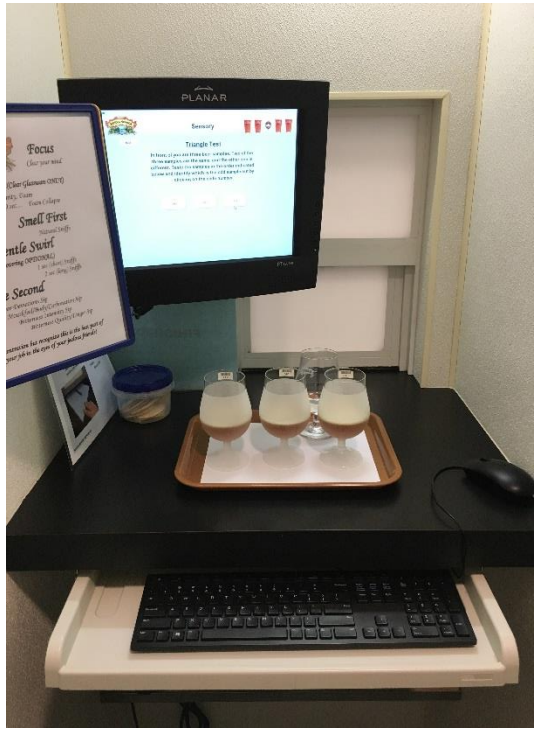
- Blind tasting, the taster must pick the odd sample out of three beers, two of which are the same
- Statistics can determine whether the beers are different

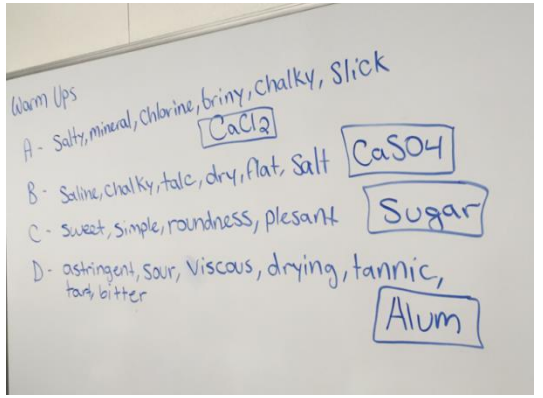
QDA (Quantitive Descriptive analysis)

- A trained and aligned panel quantifies organoleptic qualities of the product
- Statistics can determine which flavor attributes are different

Elemental Analysis was conducted on an Agilent ICP OES

Anion analysis was conducted on a Thermo Fisher HPIC





Beer Info – Saison SNBC Chico

- 2 10bbl Saison batches brewed brewed consecutively on the Sierra Nevada Brewing Co Pilot system.
- Malts: Pilsner, Wheat and Carapils
- Hops: Triple Pearl and Strata
- Brew Liquor from onsite well. Treated in the brewhouse to differentially feature Chloride and Sulfate in the respective brews.
- Light Saison = Blank slate to feature water (Maybe)

Beer Info – Saison SNBC Chico

- Step Mashed, 136°F-144°F-154°F, run off 1.5 hr
- 85 minute boil, Triple Pearl in the boil, Strata in hop back
- OGs of 11.3 & 11.1 (°P)
- Fermentation at 70°F with Saisonstein's Monster
- Final Gravity of 0.68 & 0.82 (°P)
- BUs 26 & 35

Water Treatment at Sierra Nevada Chico

Sediment Filter

-Removes any suspended solids

UV Treatment

-Turns chlorine into chloride

Activated Carbon

-Removes Organics

Water Treatment at Sierra Nevada Chico

From Carbon Filter

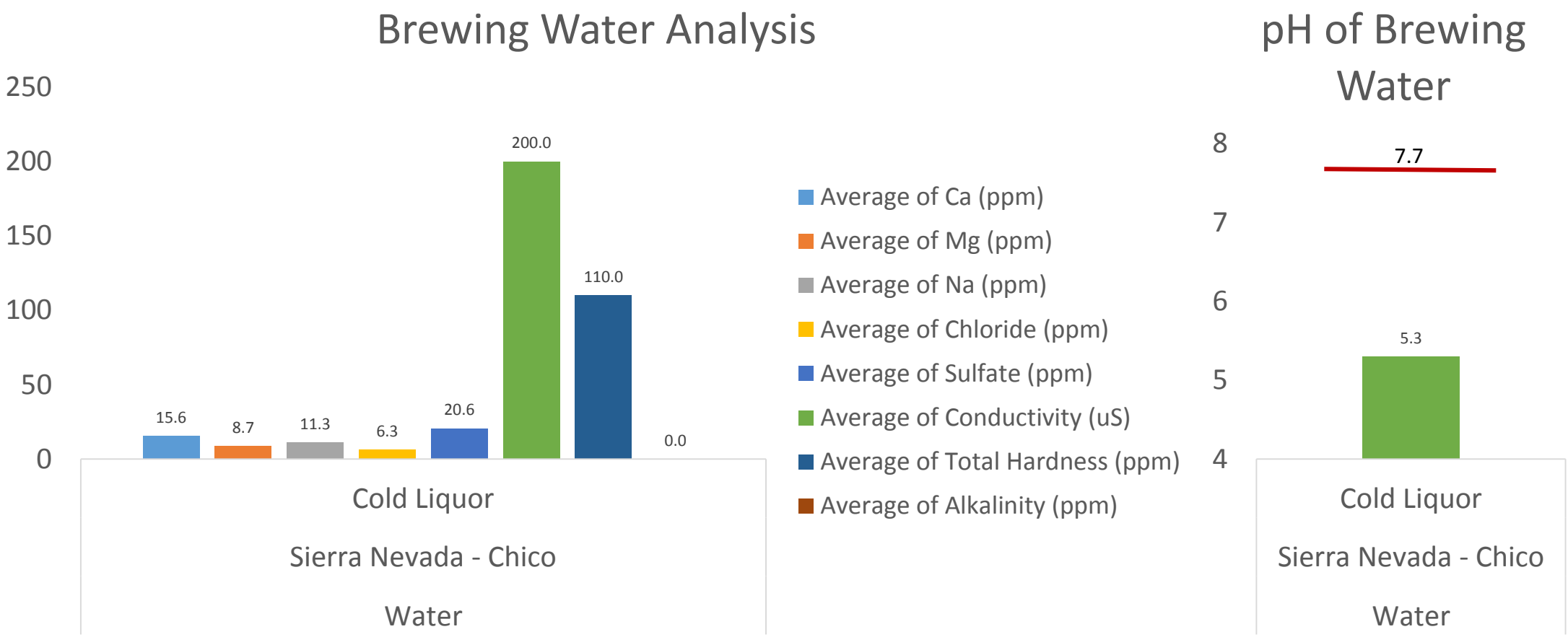
Phosphoric Acid Dosing and Oxygen Reduction

-Reduces alkalinity and pH (~7.8 to ~5.3 pH) and dissolved oxygen

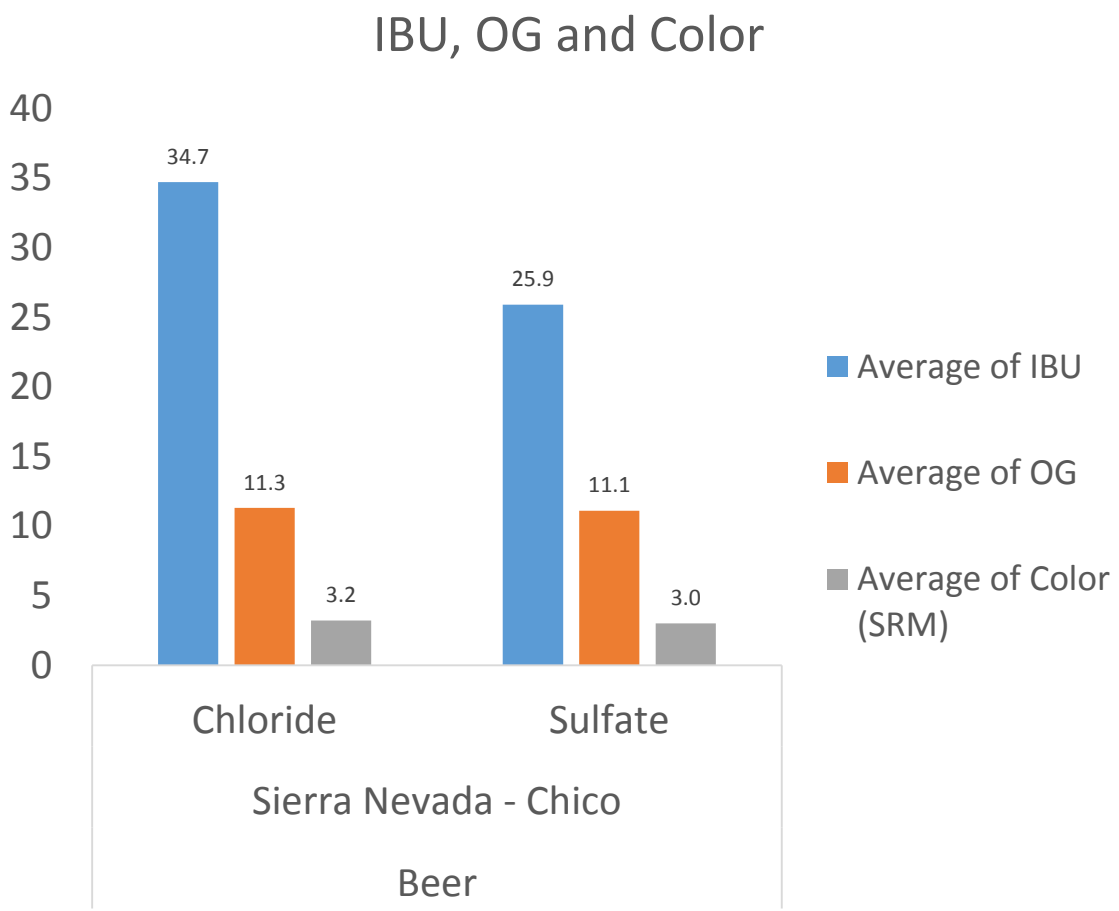
Cold Liquor Tank

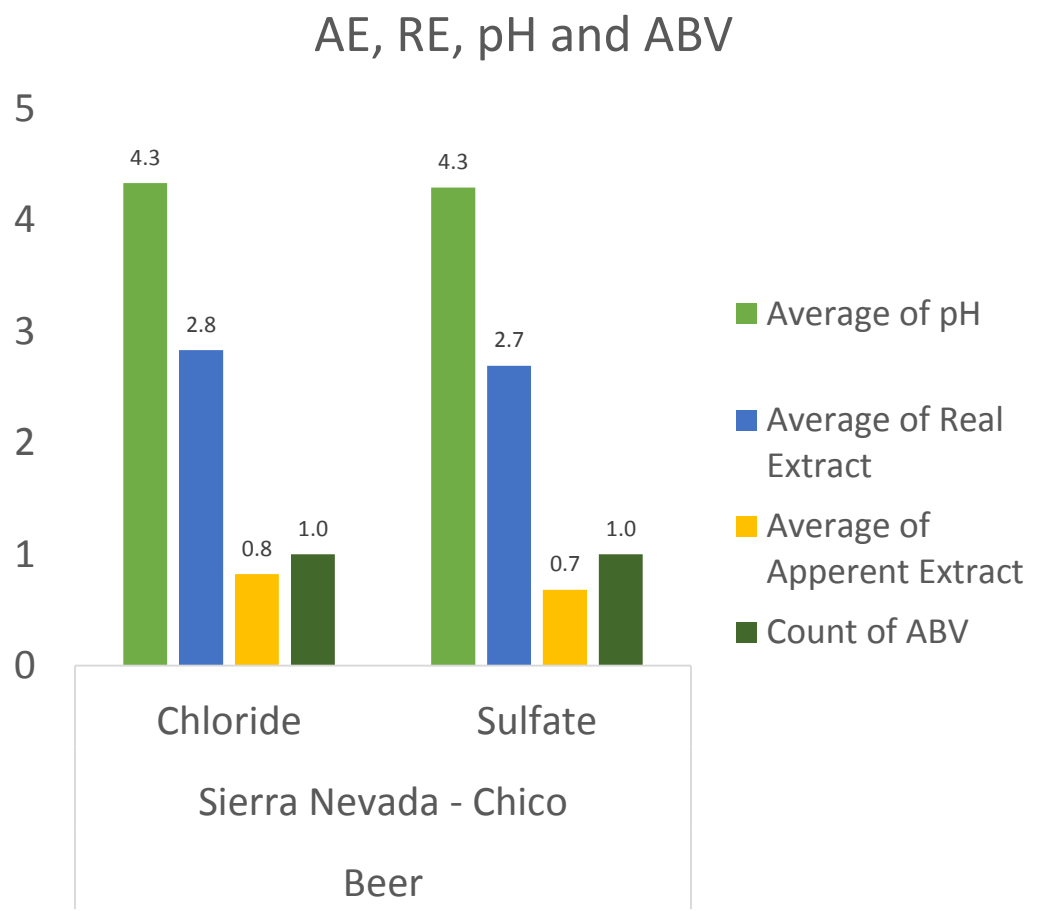
-Ready to brew

Analytical – Sierra Nevada Chico - Water Testing

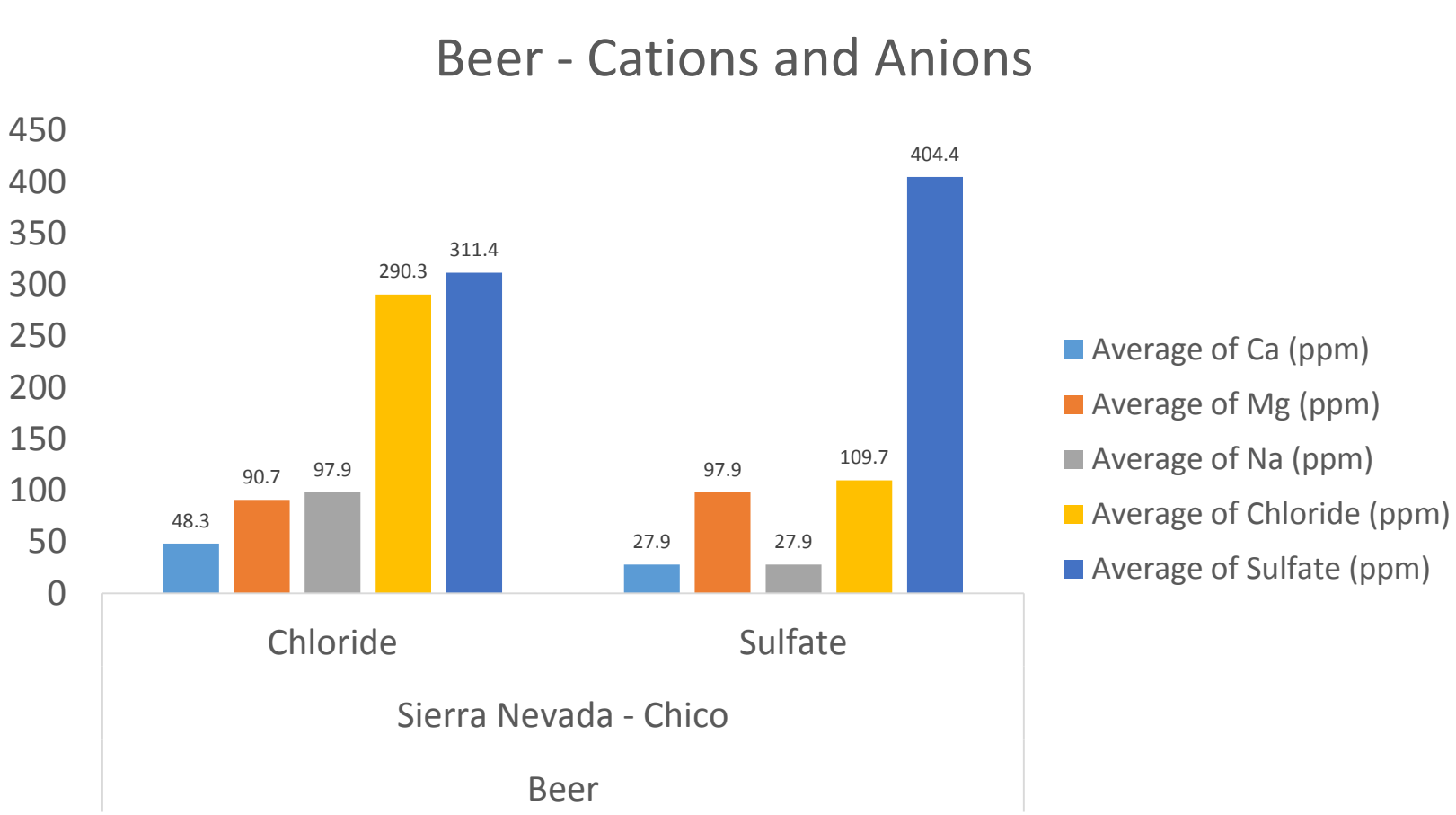


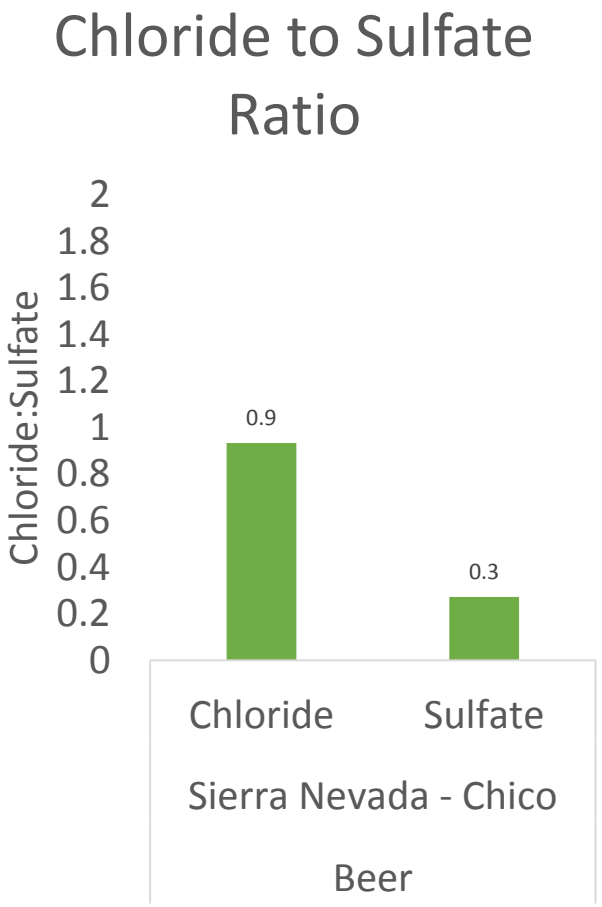
Analytical – Sierra Nevada Chico - Beer QA



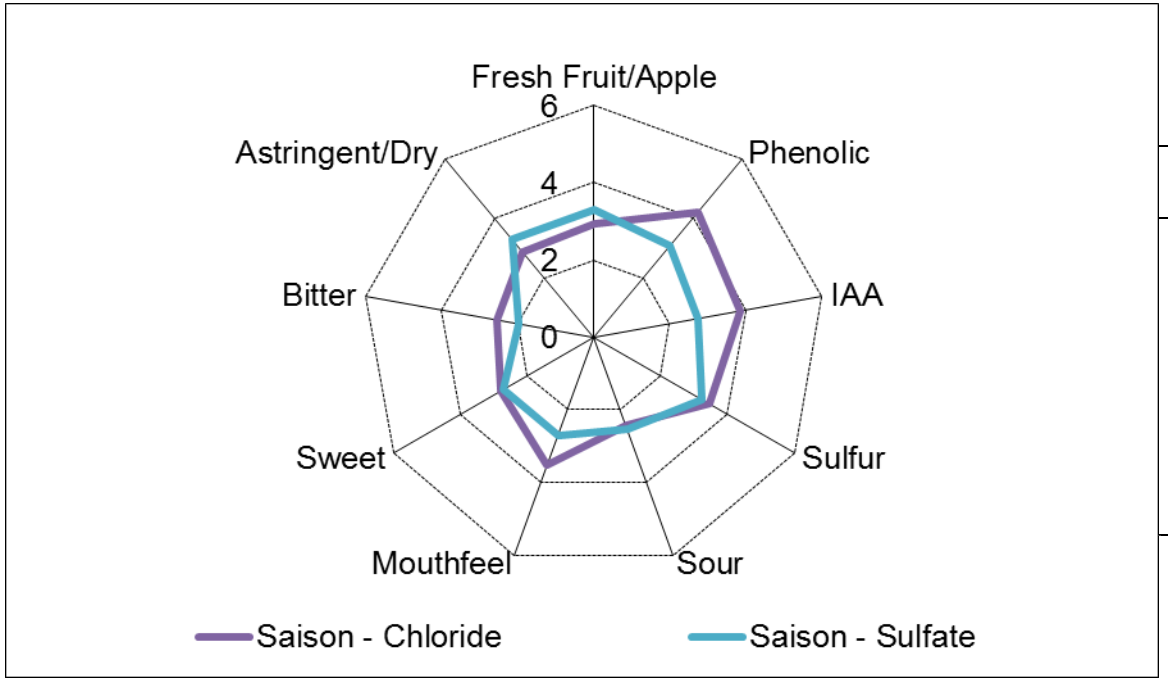


Analytical – Sierra Nevada Chico - Minerals in Beer





Sensory – Saison Sierra Nevada Chico



Flavor Attributes	Saison - Chloride	Saison - Sulfate	Sample p-Value
Fresh Fruit/Apple	2.9	3.3	0.286
Phenolic	4.2	3.1	**0.001*** **
IAA	3.9	2.8	**<0.001*** **
Sulfur	3.5	3.3	0.351
Sour	2.4	2.5	0.735
Mouthfeel	3.5	2.7	**0.004*** **
Sweet	2.8	2.7	0.807
Bitter	2.5	2.0	**0.001*** **
Astringent/Dry	2.9	3.3	0.312

The chloride and sulfate brews were **borderline significantly different** utilizing triangle testing with 22/50 panelists correctly identifying the odd sample on 12/11/18, (α=0.05, p=0.076).

Beer Info – Mad Fritz Pale Lager

- Two 4 BBL batches of our Pale Lager called the Donkey and Thistle (Mai Bock/Helles hybrid)
- Base Malt: Scarlet 2 Row grown and malted at Colorado Malting Co in Alamosa Colorado
- Hops: Crystal Pellets (4%AA) grown in Clear Lake, CA
- Two distinct waters sourced for brewing:
  - Soft –Angwin Spring Water
  - Hard- Lewelling Spring Water

Beer Info – Mad Fritz Pale Lager

- Low Temp Mashing 146-148 F for 1 hour, run off 1.5 hours
- Total Boil time 105 mins (Bittering), Aroma hops at flame out
- OGs ranged from 14.6 to 14.7 Plato
- Fermentation with Bohemian Lager at 50-52 F for 7-9 days, warmed to 56-58 for 4-5 days prior to racking to neutral French Oak for settling/lagering at 60-62 cellar temp for 3 weeks.
- Racked to BBT for packaging to bottles and kegs, primed with dextrose and spark champagne yeast. Both beers packaged on 11/08/18.
- TGs at 1.5 Plato at 7.1-7.2 %ABV

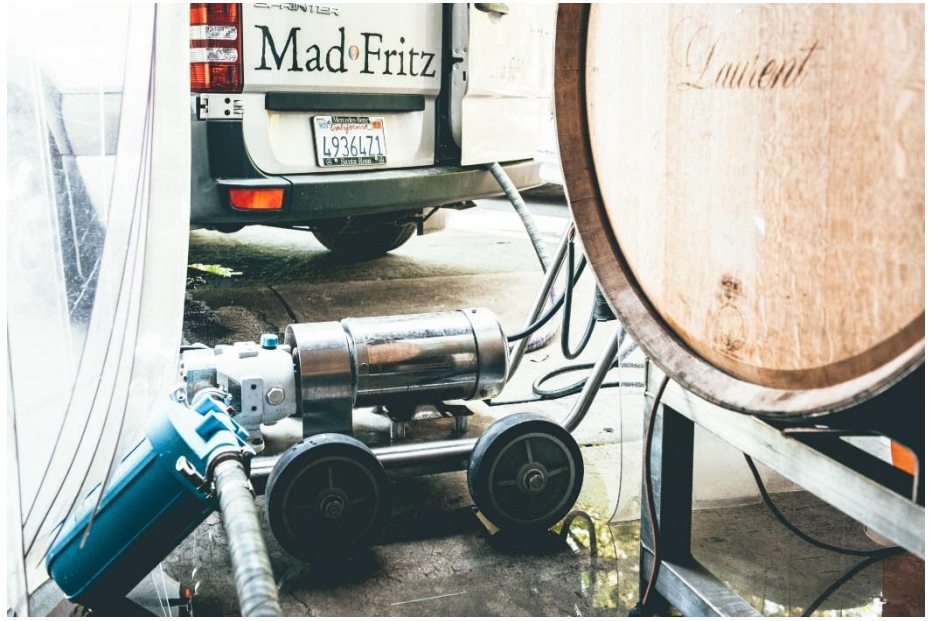
Water Sourcing at Mad Fritz

Angwin Spring Water
Howell Mtn Napa Valley

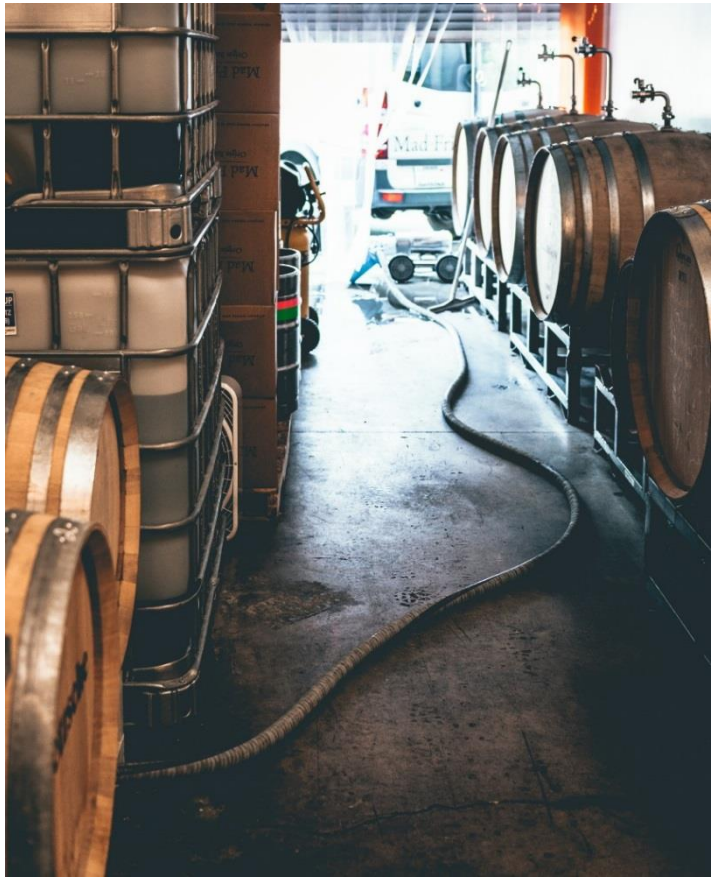
Lewelling Spring Water
St Helena, Napa Valley

Mad Fritz Incoming Water

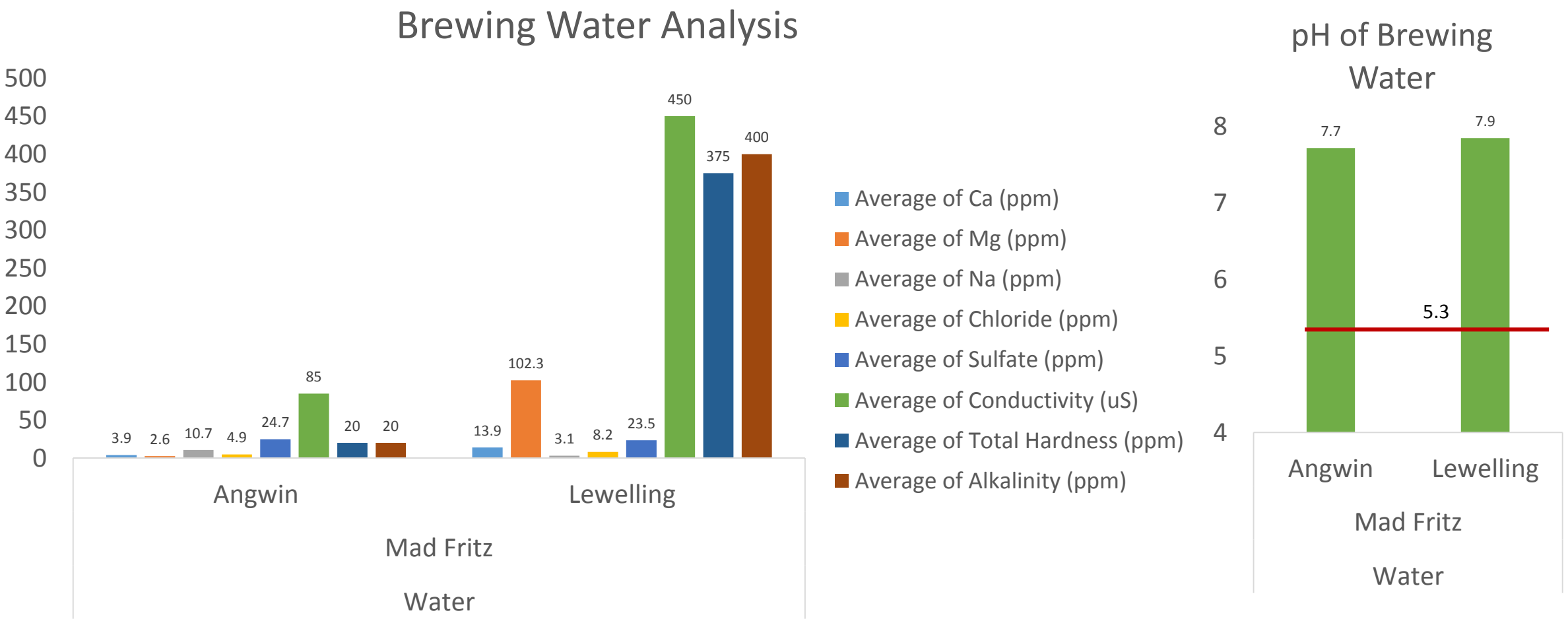
Filtration - 5 um Carbon Block



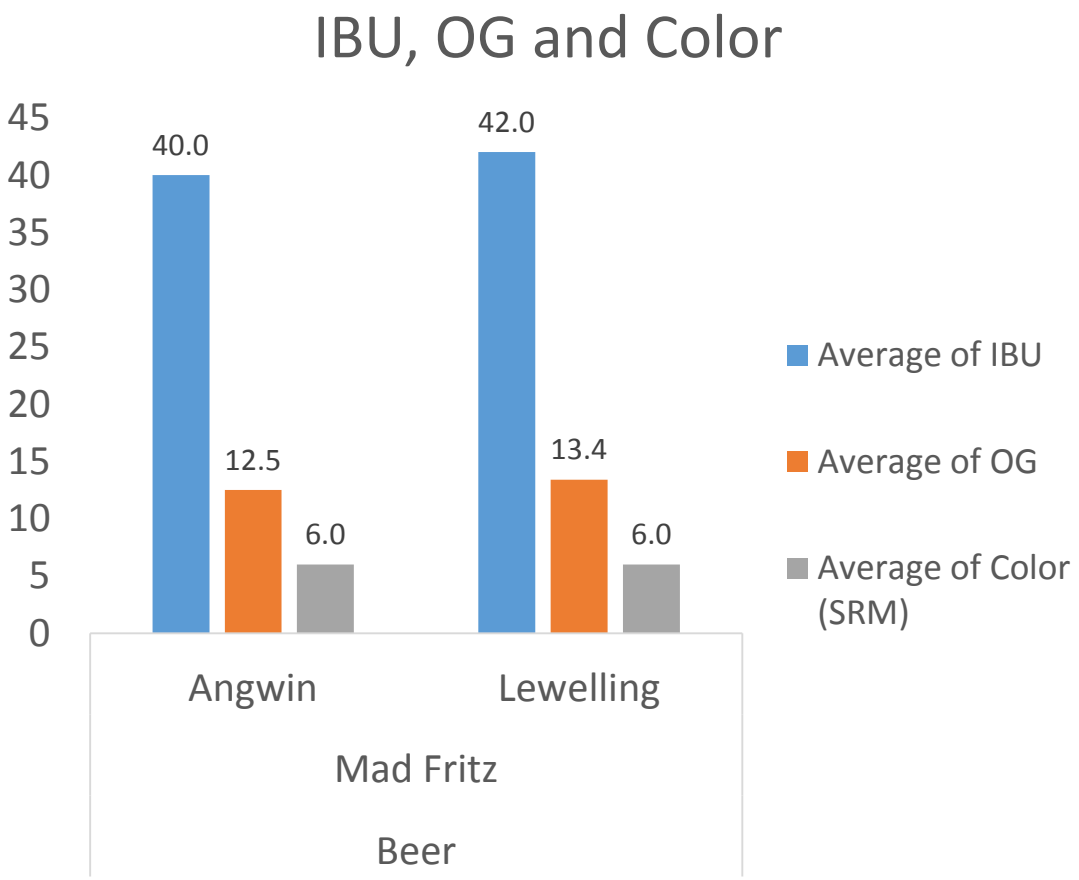
Holding Tank

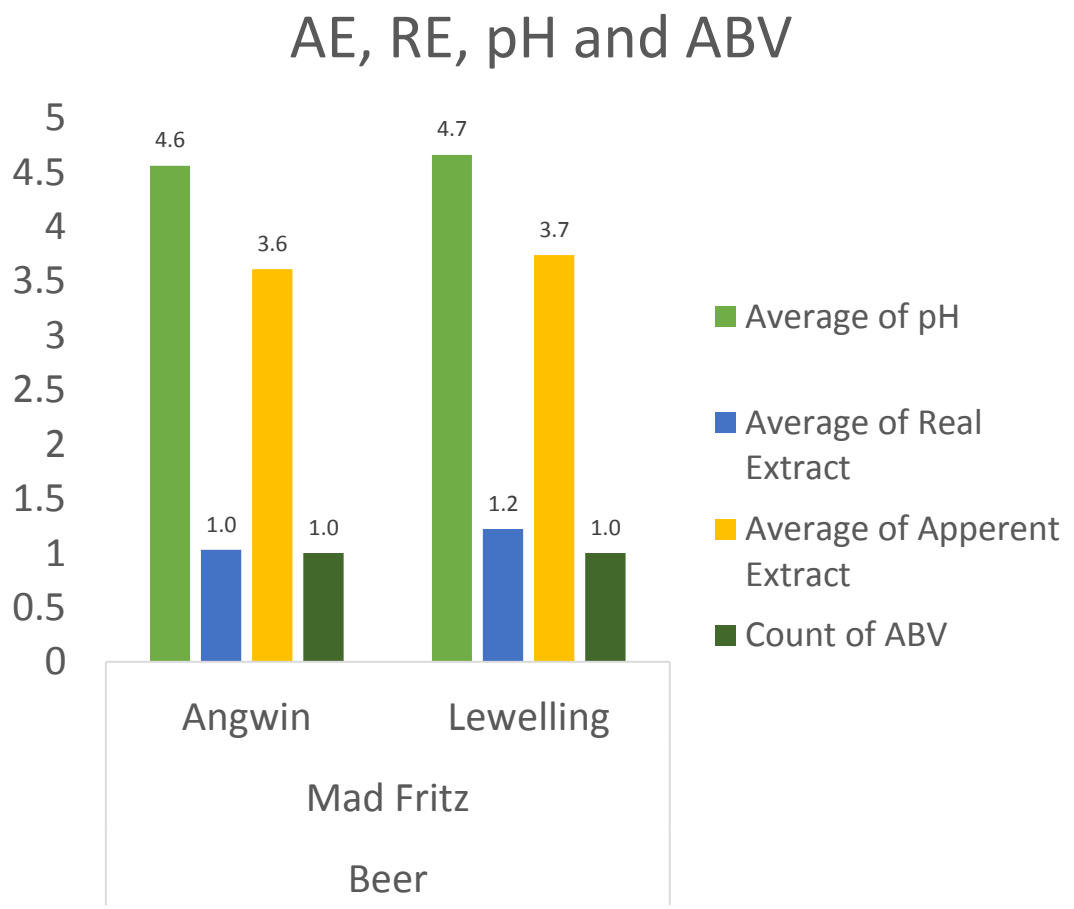


Analytical – Mad Fritz- Water Testing

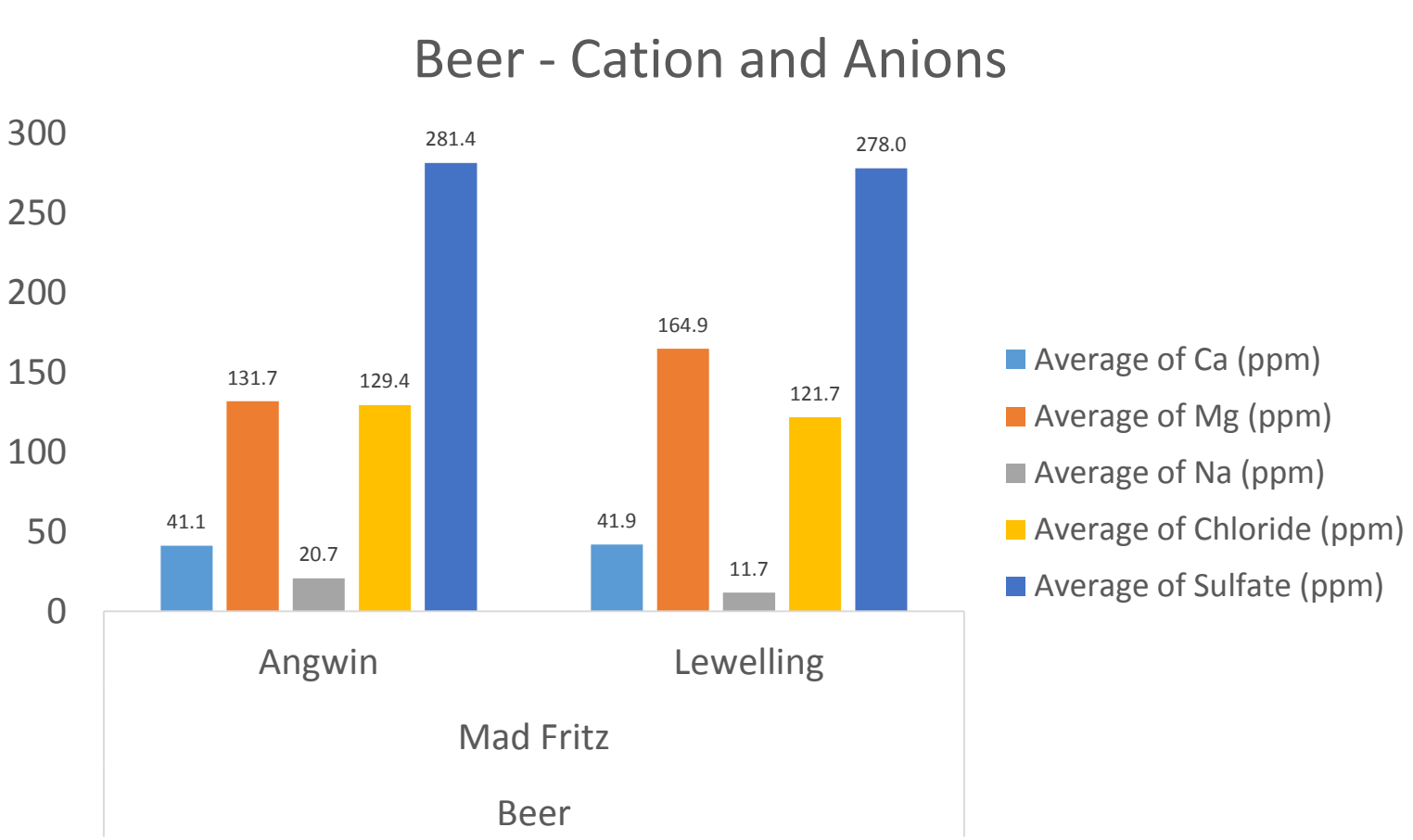


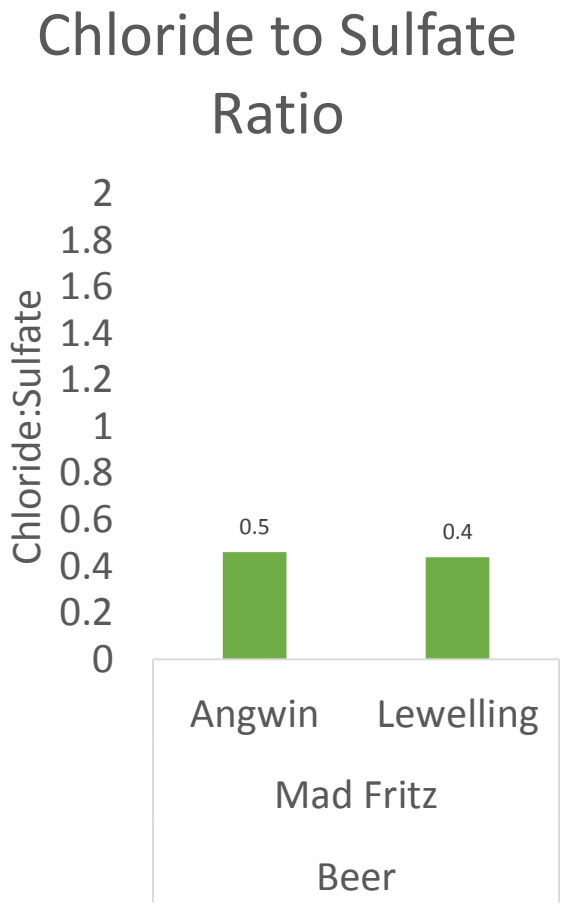
Analytical – Mad Fritz- Beer QA



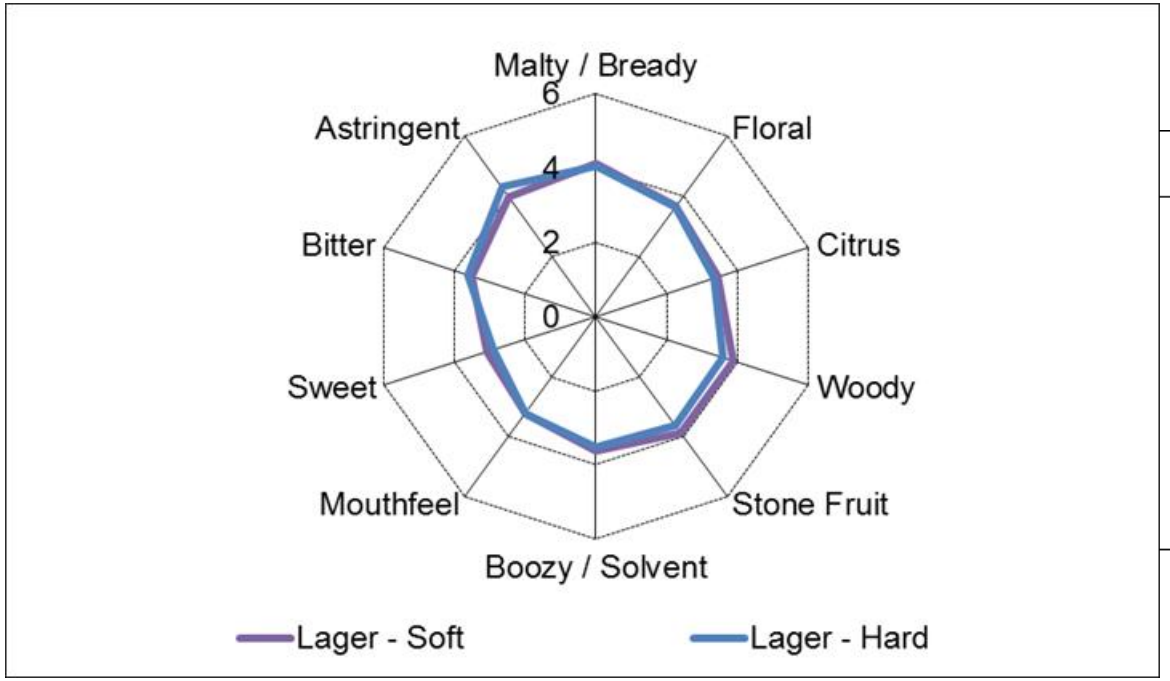


Analytical – Mad Fritz - Minerals in Beer





Sensory – Pale Lager Mad Fritz



Flavor Attributes	Lager - Soft	Lager - Hard	Sample p-Value
Malty / Bready	4.1	4.0	0.678
Floral	3.7	3.6	0.939
Citrus	3.5	3.3	0.682
Woody	3.9	3.6	0.283
Stone Fruit	3.9	3.6	0.513
Boozy / Solvent	3.6	3.5	0.711
Mouthfeel	3.3	3.3	1.000
Sweet	3.1	2.9	0.529
Bitter	3.5	3.6	0.722
Astringent	4.0	4.3	0.263

The chloride and sulfate brews were **borderline significantly different** utilizing triangle testing with 21/46 panelists correctly identifying the odd sample on 12/21/18, (α=0.05, p=0.055).

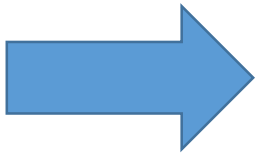
Beer Info – Crooked Stave NEIPA

- 2, 25hL IPA batches brewed in consecutive weeks on the Crooked Stave brewhouse
- Base Malt: Rahr – Prem Pilsner and Colorado Malting Company - ColoPils
- Hops: Strisselspalt, Cascade, Wakatu, Motueka, Simcoe & Cascade
- Brew Liquor straight from the Rockies (via city water). Treated in the brewhouse to differentially feature Chloride and Sulfate in the respective brews.

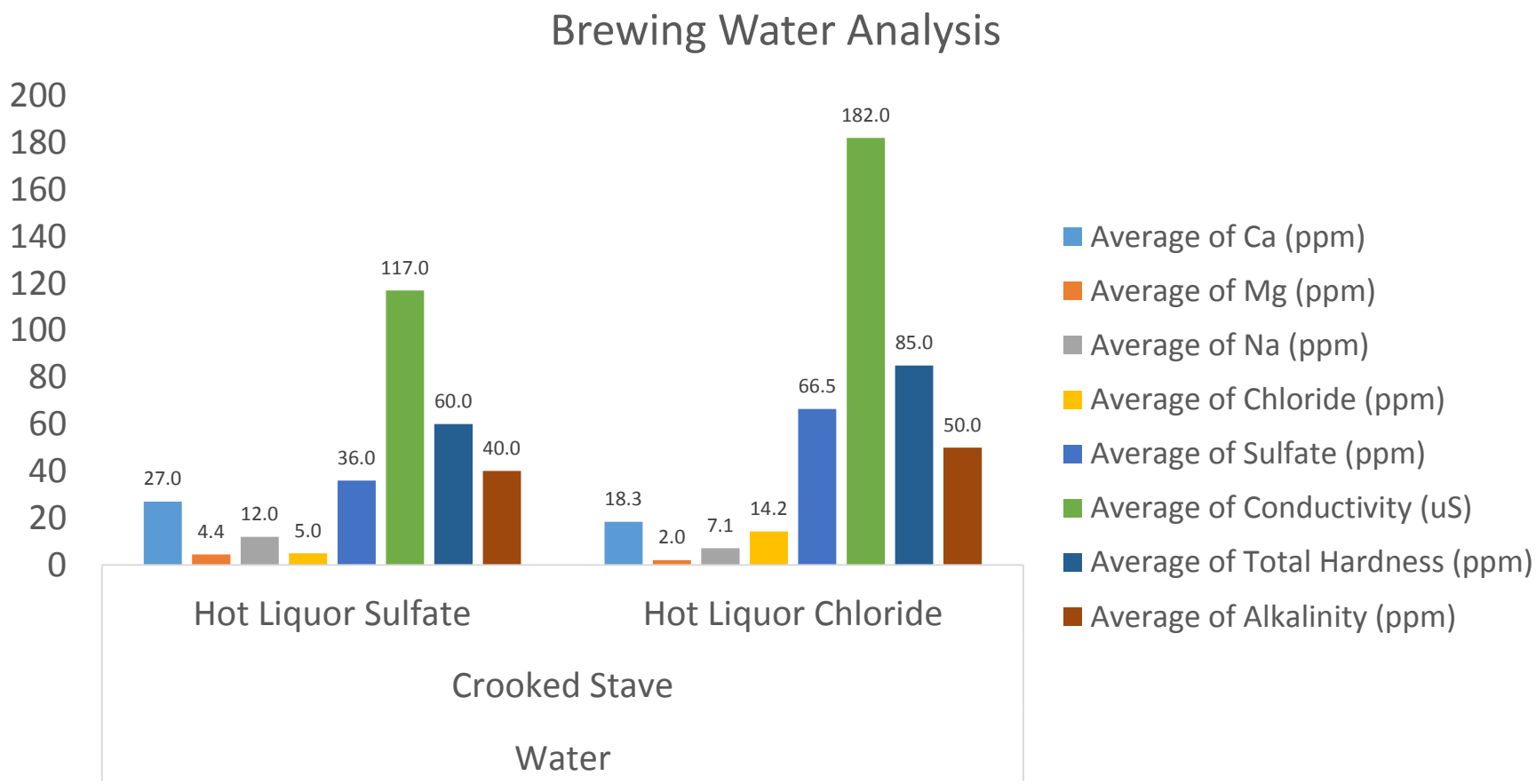
Beer Info – Crooked Stave NEIPA

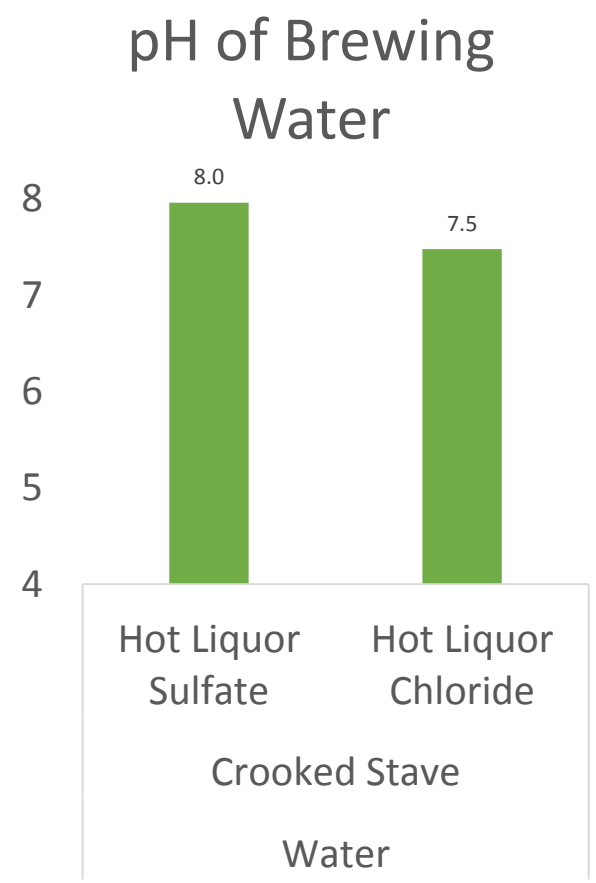
- Mashing @ 68°C for 20-25 min, vorlauf for 15 mins, run off for 90 mins
- Total Boil time 90 mins, Aroma hops at whirlpool for 15 mins, transfer to Coolship and add whole cones for more aromatics
- Starting Gravity @ 13° Plato
- Fermentation with House Ale at 20° C for 6 days, cooled to 18° C for 2 days for yeast harvest. Allowed to free rise to 20° C for dry hopping. 3 days of step crashing at 5° C per day, then held at 0° C for cold conditioning.
- Transfer to bright @ day 15 for packaging to cans and kegs.
- Final Gravity at 2.0° Plato at 6.0 %ABV

Water Treatment at Crooked Stave

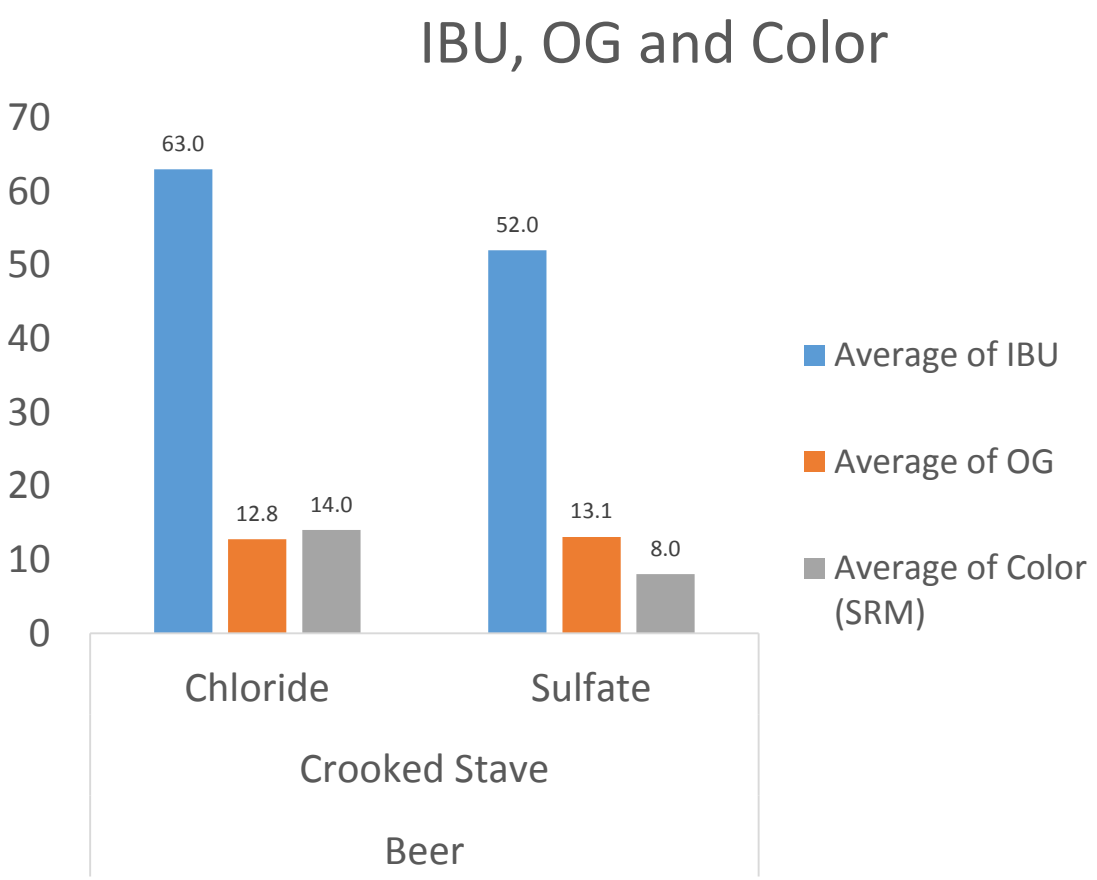


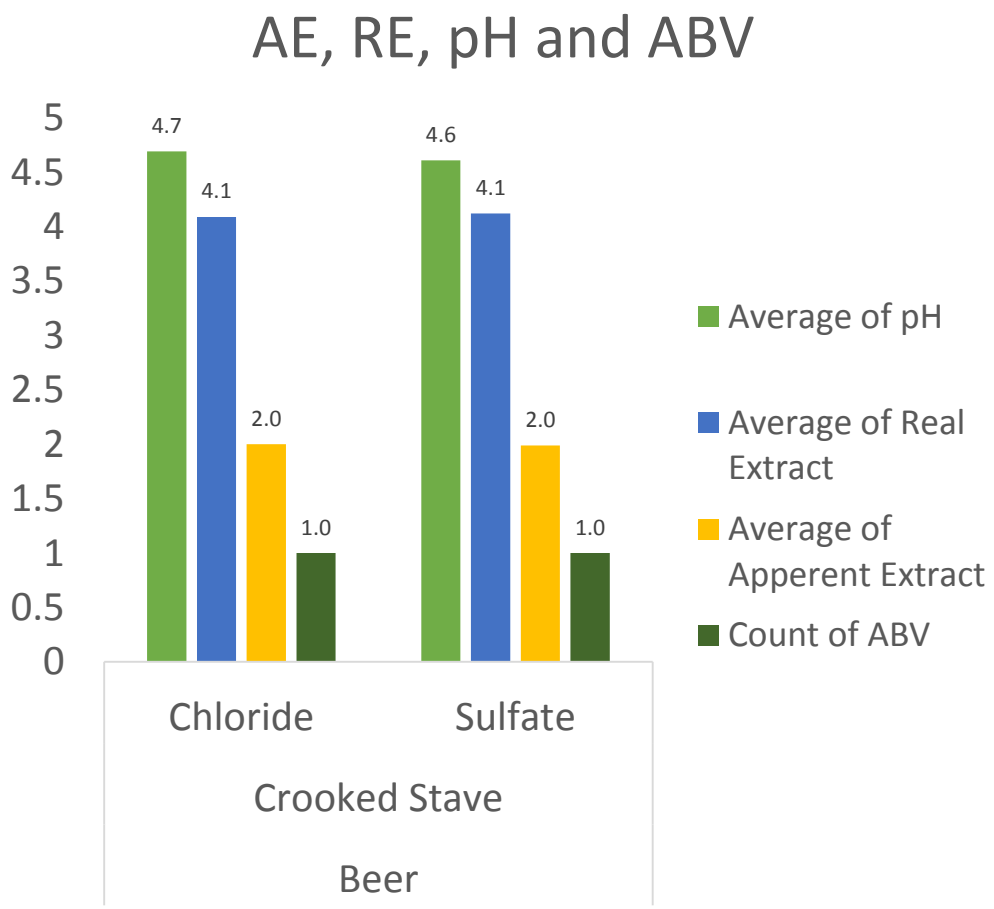
Analytical – Crooked Stave - Water Testing



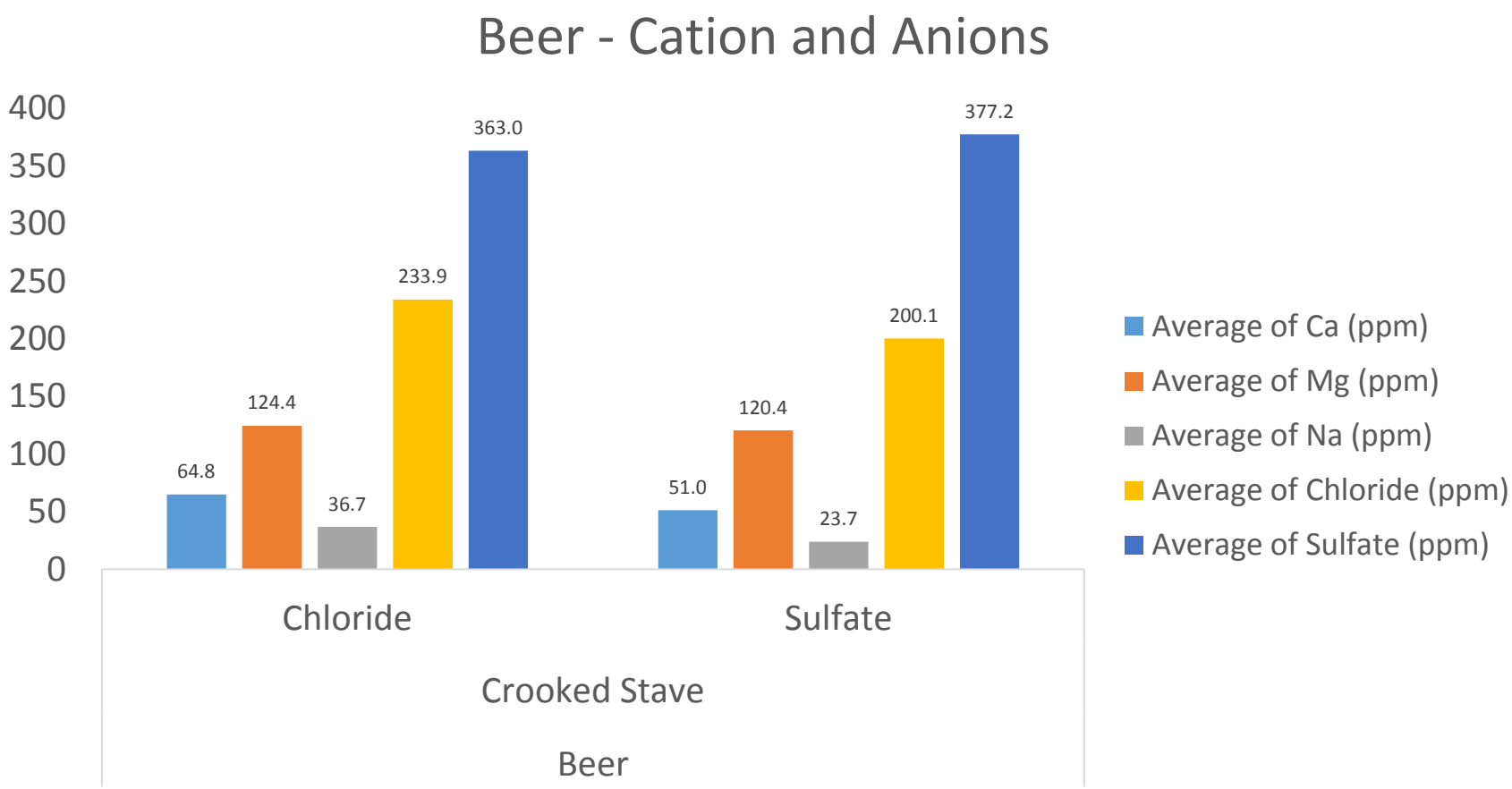


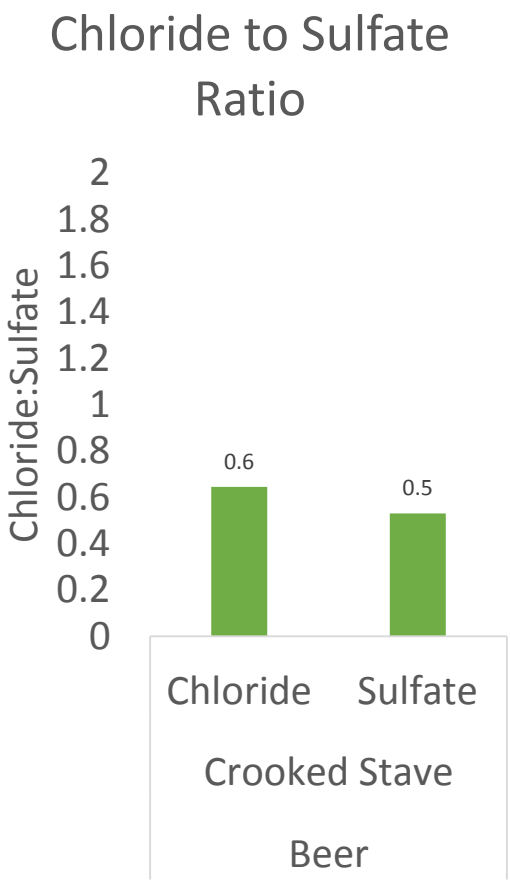
Analytical – Crooked Stave - Beer QA



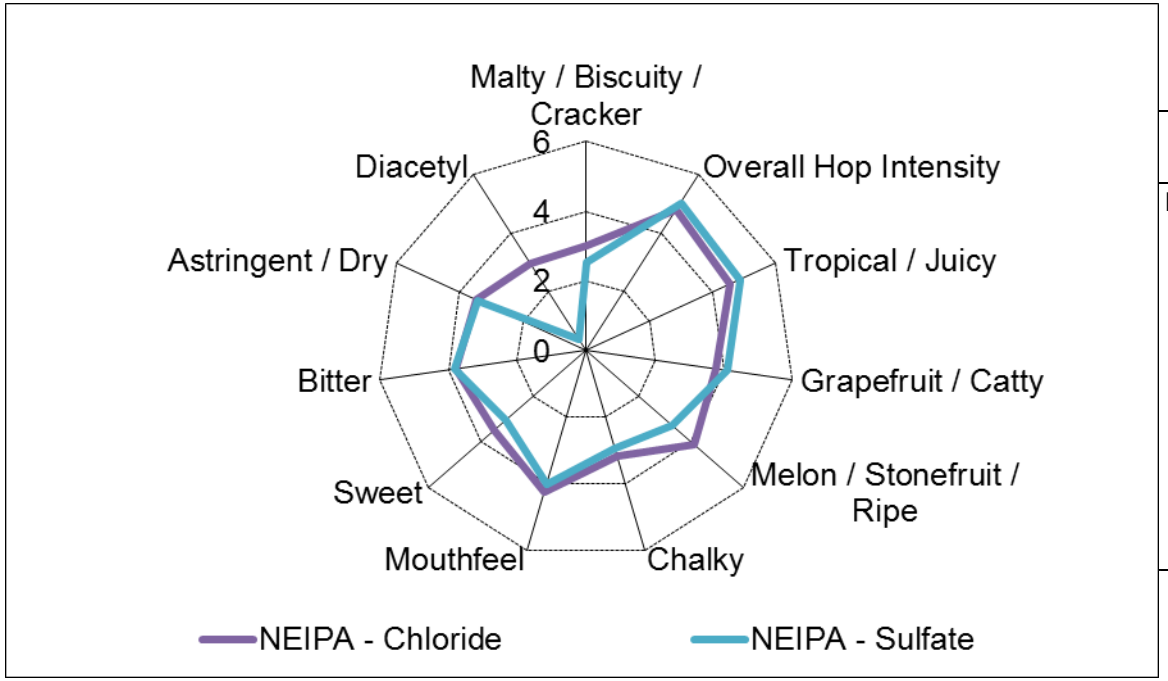


Analytical – Crooked Stave - Minerals in Beer





Sensory – NEIPA Crooked Stave



Flavor Attributes	NEIPA - Chloride	NEIPA - Sulfate	Sample p-Value
Malty / Biscuity / Cracker	3.0	2.5	**0.034****
Overall Hop Intensity	4.8	5.0	0.525
Tropical / Juicy	4.6	4.9	0.341
Grapefruit / Catty	3.8	4.1	0.398
Melon / Stonefruit / Ripe	4.1	3.3	**0.043****
Chalky	3.2	2.9	0.611
Mouthfeel	4.3	4.0	0.467
Sweet	3.5	3.1	0.129
Bitter	3.8	3.8	0.905
Astringent / Dry	3.5	3.4	0.928
Diacetyl	3.0	0.4	**<0.001****

The sulfate and chloride brews were **significantly different** utilizing triangle testing with 29/48 panelists correctly identifying the odd sample on 12/18/18, (α=0.05, p>0.001).

Beer Info – Foreign Export Stout SNBC Mills River

- Two 20 BBL batches of Foreign Export Stout.
- Malt: Malteurop 2 Row, Fawcett Optic 2 Row, Fawcett Roasted Barley, CMC Flaked Barley, Franco-Belges Kiln Coffee, Castle Special B, Briess Black Prinz
- Whole Cone Hops: Bravo (17.5% AA), Sterling (8.3% AA), Spalt Spalter (4.0% AA)
- Well water sourced onsite for use in brewing
  - Chloride vs Sulfate added in mash and kettle

Beer Info – Foreign Export Stout SNBC Mills River

- Single Infusion Mash 152.5 F for 1 hour, run off 2.5 hours.
- Total Boil time 75 mins. Bravo added at start, Sterling & Spalt Spalter at 45 mins.
- OGs ranged from 17.2 to 17.3 Plato.
- Fermentation with house ale yeast at 66 F for 10 days, chilled after 13 days.
- Centrifuged to BBT after 28 days, both beers racked to kegs on 12/05/18.
- TGs at 4.7 Plato, 7.0% ABV. Finished bitterness after packaging is 45 IBU.

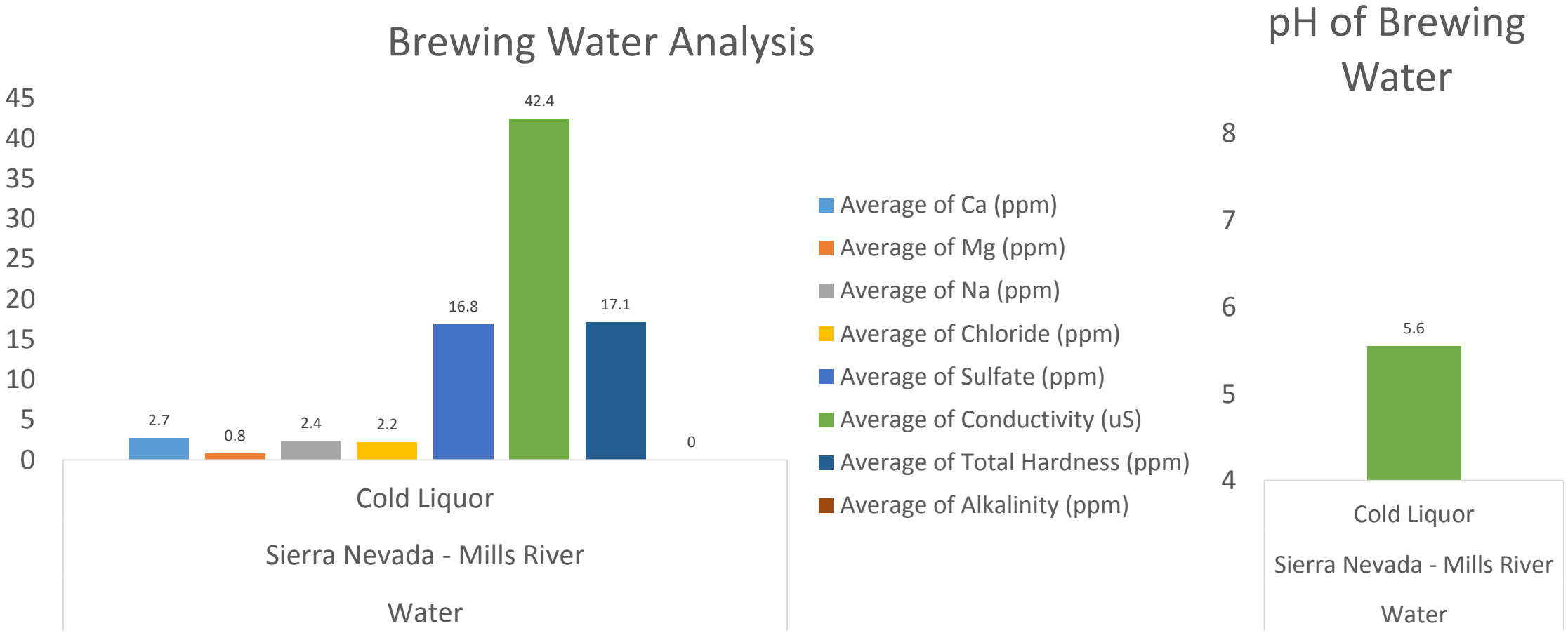
Water Treatment at Sierra Nevada Mills River

Stainless Steel Sediment Filter

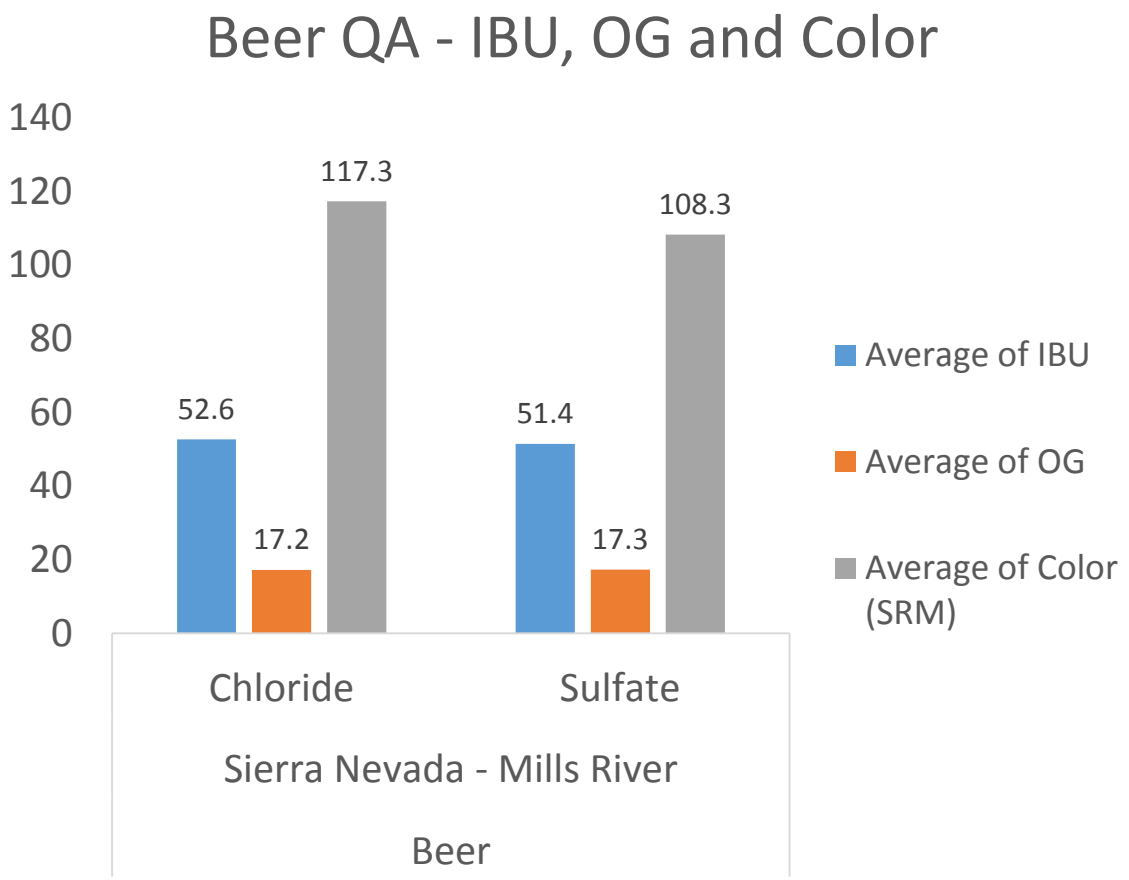
Paper Cartridge Sediment Filter

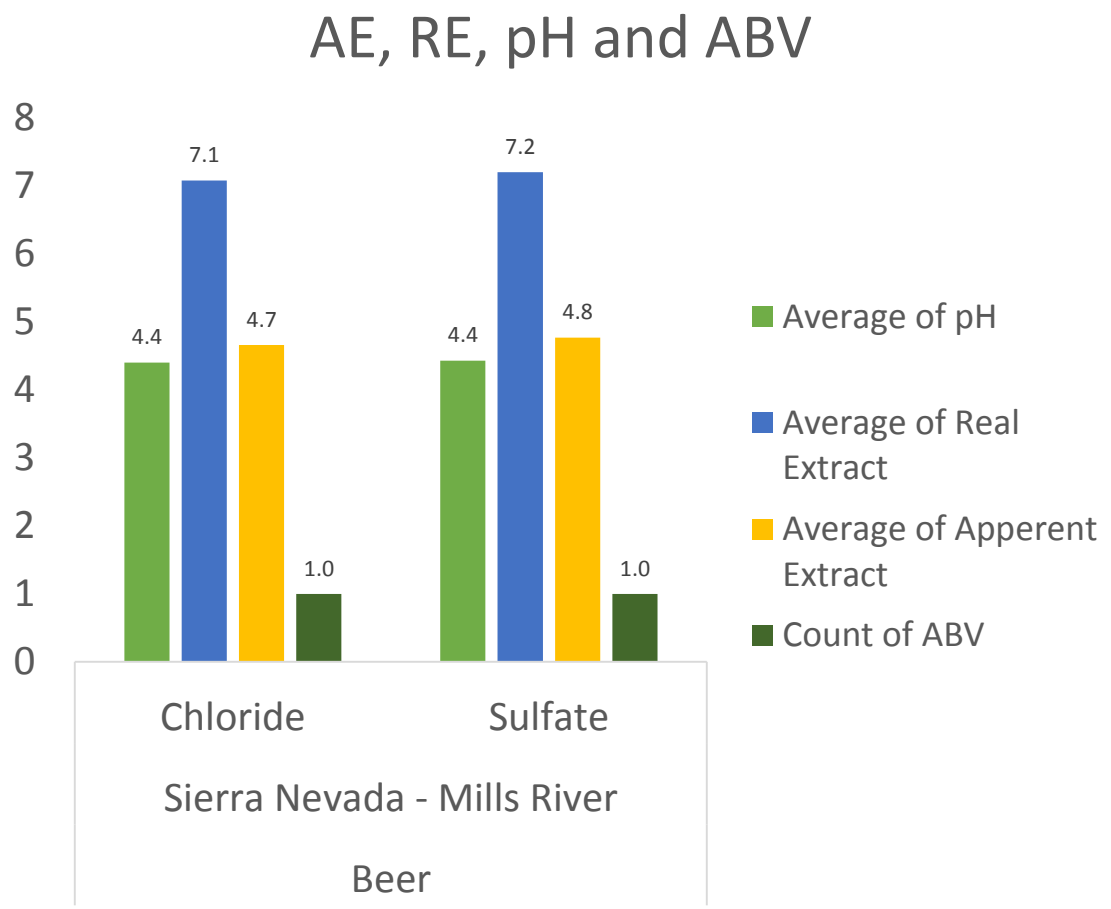
UV Treatment

Analytical – Sierra Nevada Mills River - Water Testing

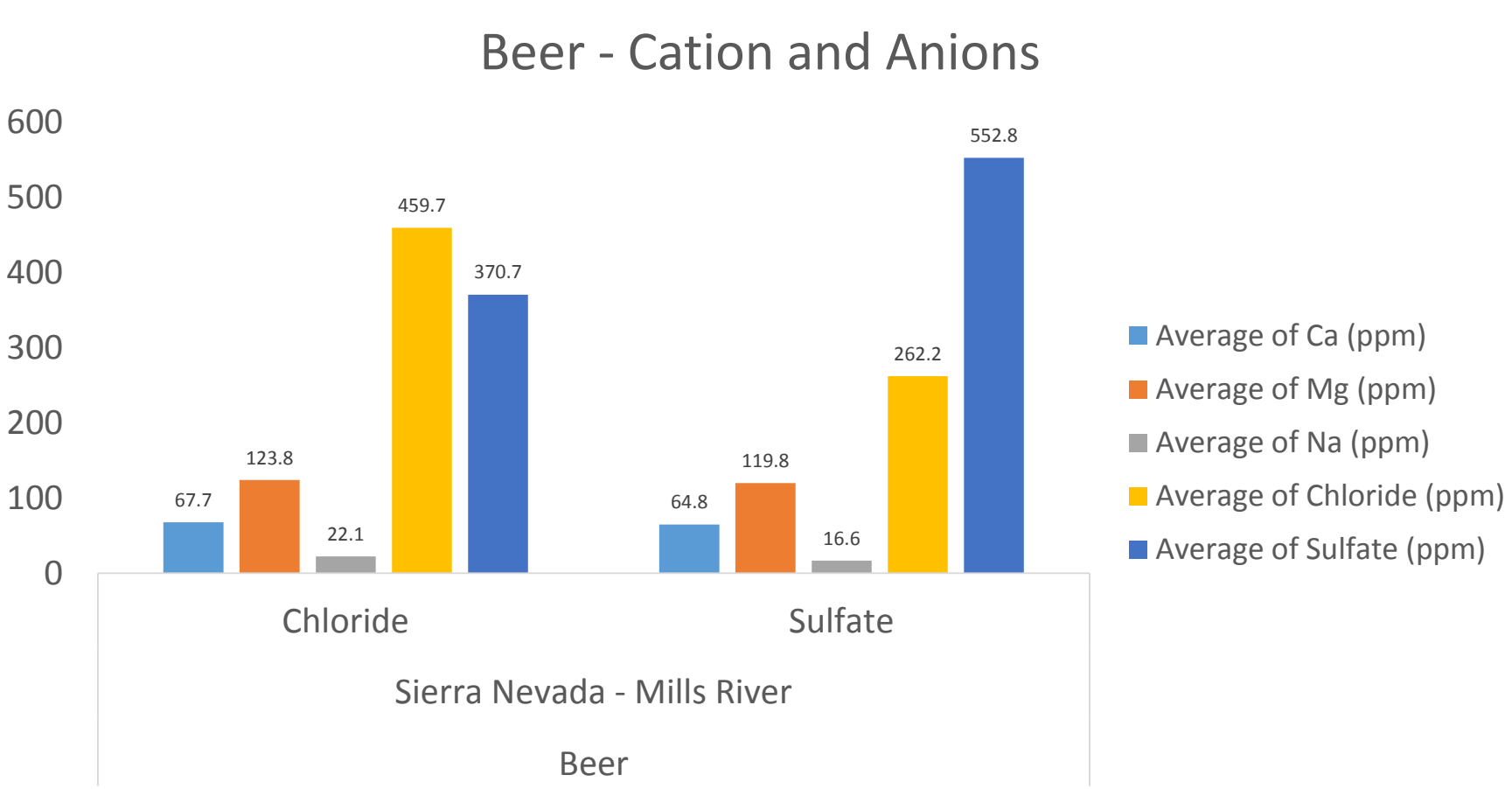


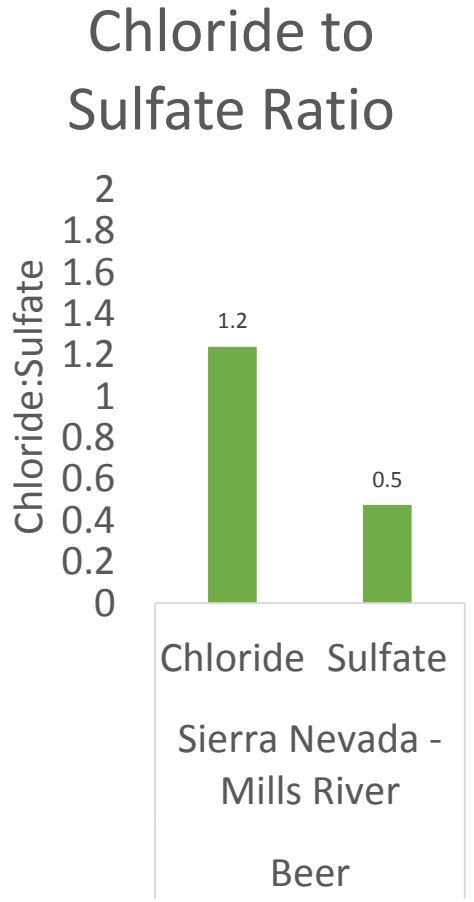
Analytical – Sierra Nevada Mills River - Beer QA



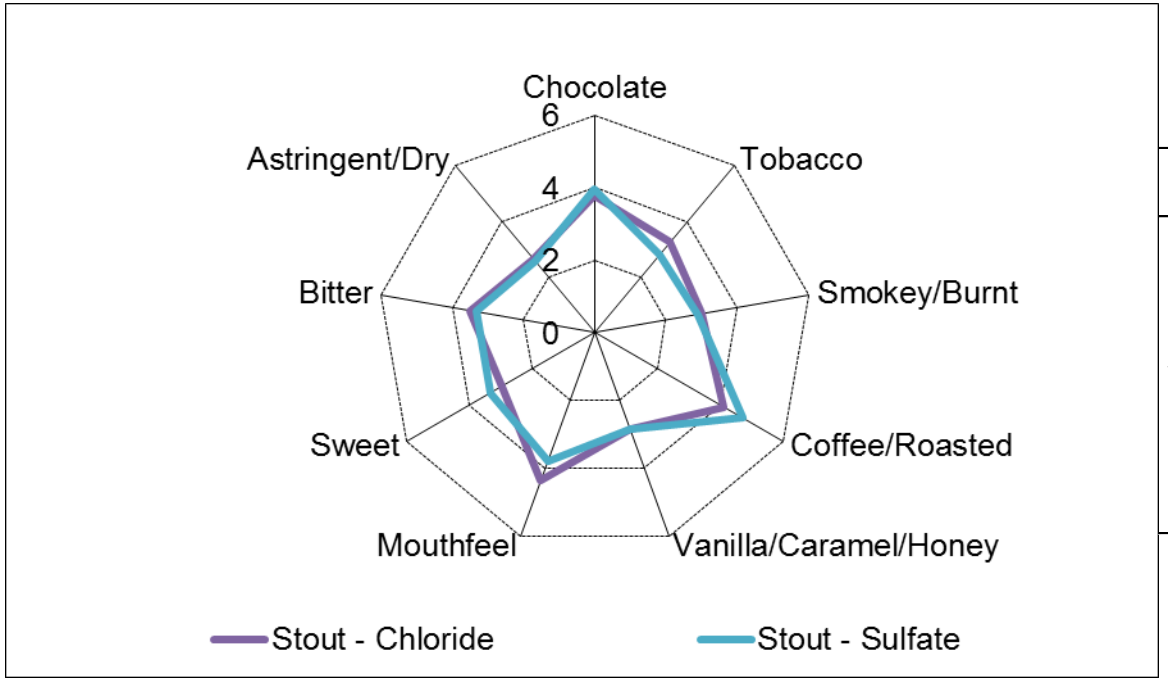


Analytical – Sierra Nevada Mills River - Minerals in Beer





Sensory – Sierra Nevada Mills River



Flavor Attribute	Stout - Chloride	Stout - Sulfate	Sample p-Value
Chocolate	3.8	4.0	0.456
Tobacco	3.3	2.8	0.443
Smokey/Burnt	3.0	2.9	0.844
Coffee/Roasted	4.1	4.7	0.142
Vanilla/Caramel/Honey	2.9	2.9	1.000
Mouthfeel	4.4	3.8	**0.033****
Sweet	3.0	3.3	0.177
Bitter	3.5	3.3	0.301
Astringent/Dry	2.6	2.6	0.784

The chloride and sulfate brews were **not significantly different** utilizing triangle testing with 17/48 panelists correctly identifying the odd sample on 12/13/18, (α=0.05, p=0.433).

Conclusions

- Don’t be over worry about incoming water minerals (ie MF Pale Lager)
  - Reduce alkalinity, and brew, add salts to style
- Salting to extremes ratios will show bigger results (ie CS NEPA)
  - The precipitation of Ca^{2+} throughout the brewing process tends to limit its finished beer impact unless more is added in the kettle
- Textbook example Mills River Stout (Chloride vs Sulfate)
  - A trained panel can taste differences
- Differences in other elements of the brewing process could result in larger sensory impacts regardless of your water inputs
  - Fermentation Temp
  - Pitch Rates and Aeration
  - Fermentation vessel
  - Raw Material Homogeneity (Hops- ie SN-C Saison)
- Follow-up
  - Brew Beer with Deionized Water

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- Chico QA
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- Gil Sanchez