INTRODUCTION TO

BREWING WATER

A Learn2Brew Presentation

By

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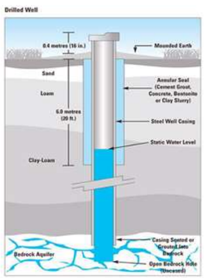
NOT JUST FOR BEER………

WATER SOURCES

Borehole water is rain that has been filtered through the rock strata and is held in water bearing rock underground.

- It is usually sterile.
- It may, however, have various types of salt dissolved in it from the surrounding rock.
- It is unlikely to be tainted or contaminated.
- There are likely to be plentiful consistent supplies.



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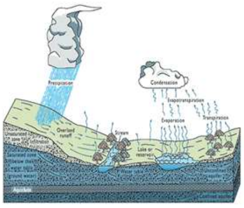
WATER SOURCES

Surface water is rain or snow/ice melt that collects in lakes or reservoirs via streams and rivers.

- It is unlikely to be sterile.
- It is unlikely to have salts dissolved in it.
- It could be contaminated, but this is unlikely if properly managed.
- The supply could be at risk in periods of drought.



WATER SOURCES

Town or mains water (public supply):

- Bacteria: Likely to be low because of treatment by the water authority
- Mineral content: Depends on whether the source is borehole or surface.
- Any anomalies should be known if the supplies alternate
- Low in taints because of treatment but chlorine likely to be present
- Consistent supply because of the water authority's legal obligations

WATER & BREWING

Some 94-96% of a pint of beer is water.

Understanding water composition is important to the success of the brewing process.

Quantity and nature of the dissolved substances can impact on Hardness, pH, Alkalinity and finally on beer flavour.

Beer styles originated around water source.

Effective water/mash treatment will enhance beer quality and improve process e.g. better efficiency/yields

Rule of thumb: 7 litres of water per kg of malt, 3 to mash and 4 to sparge.

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WATER QUALITY

Should have the following characteristics:

- Appearance - It should be clear and colourless
- Taste / Odour - It should have no off flavours or taints.
- Sterility - It should be free of any micro-organisms that would spoil the beer or affect people drinking it
- Reliability - plenty of water is available when needed
- Not all water supplies meet this standard, so very often some form of pre-treatment is needed.

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PRE-TREATMENT OF WATER

Key points

- Filters (cartridge filters) are used to improve clarity
- May be aerated to deposit iron which is removed on a sand filter.
- Carbon filters are used to eliminate off flavours or taints i.e. chlorine. (Home brewers tend to use Metabs)
- Trap filters are used to ensure no carbon is carried over especially if the water is going to be UV sterilised

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POSSIBLE WATER TAINTS

Metal contamination

- Notably iron but can be from copper too
- Water source or in-process
- Metallic note to beer
- Haze

Chlorophenols

- Contamination of brewing water with chlorine; removed by carbon filtration.
- Use of chlorine-based sterilants

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REASONS FOR LIQUOR TREATMENT

- Flavour enhancement
- Shelf life stability
- Process optimisation i.e. mash pH
- Economic: Efficiency and cost

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WATER HARDNESS

The combined contents of:

- Calcium
- Magnesium

In their various "salt" forms:

- Sulphates
- Chlorides
- Bicarbonates

High concentrations = Hard water
Low concentrations = Soft water




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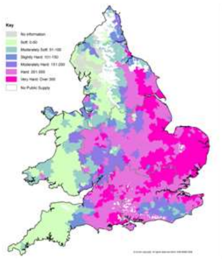
TOTAL HARDNESS SHOWN AS MG/LITRE EQUIVALENT OF $CACO_3$

As a very rough guide:

Water description	mg/litre
Soft	0-50
Medium Soft	51-100
Moderately Hard	101-200
Hard	201-300
Very Hard	301-600

NB: 1 degree of UK Hardness (H°) = 14.3mg/l



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WATER HARDNESS

Soft water
e.g. Plzn

Hard Water
e.g. London

The nature of your local water supply dictates the style of beer you brew

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WATER HARDNESS

- Hardness further split into 2 types: *Permanent and Temporary.*
- The latter is also known as *carbonate hardness or alkalinity.*
- Total hardness = Permanent + Temporary
- Temporary hardness removed/converted, generally, by boiling or addition of acid:

Permanent	**Temporary (Alkalinity, Carbonate)**
Calcium Sulphate	Calcium Carbonate
Calcium Chloride	Calcium Bicarbonate
Magnesium Chloride	Magnesium Bicarbonate
Magnesium Sulphate	Magnesium Carbonate

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TESTING WATER HARDNESS

If, after testing, the total hardness reading is greater than the alkalinity level, subtracting the alkalinity level from the total hardness reading will reveal the amount of permanent hardness but not its form i.e. sulphate, chloride etc.

If the alkalinity level is greater than the total hardness, then all hardness is temporary and no permanent hardness is present.

NB: Both temporary and permanent hardness are shown usually as ppm of $CaCO_3$

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HARDNESS VS FLAVOUR

Sulphate

- Gives crisper, drier, more bitter beers; astringency in excess?
- Can react with yeast to form sulphury compounds – eggy!

Chloride

- Increases sweetness and fullness

Ratio seemingly more important than absolute content e.g.

2:1 or 3:1 sulphate to chloride for bitters

3:2 or 2:1 chloride to sulphate for milds

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FAMOUS WATER SOURCES

Ion concentrations in parts per million (ppm)

	Burton on Trent	Pilsen	Dortmund	Munich	Dublin	London
Calcium	270	7	260	80	80	90
Carbonate	140	9	270	165	170	130
Sulphate	640	6	280	20	55	20
Chloride	36	5	106	1	20	40






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IONIC COMPOSITION: BEER STYLES

Beer style	Water composition
Pilsner type lagers	• Soft water, low mineral content. • Low levels of carbonates, helping to bring out delicate flavours. • Low calcium ion level.
Ales (bitters, pale ales)	• Sulphates > chlorides to bring out bitter flavours. • Low carbonates (< 30 ppm) to help achieve low pH. • Higher calcium (> 150 ppm) for flavour and pH.
Milds, stouts, porters	• Chlorides > sulphates for enhanced fullness & sweetness. • Carbonates medium (<100 ppm). • Calcium levels lower around 100 ppm for mild and Stouts.

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ALKALINITY

The ability of a solution to resist (or buffer) a change in its pH value when acids are added.

Ions which contribute to alkalinity:

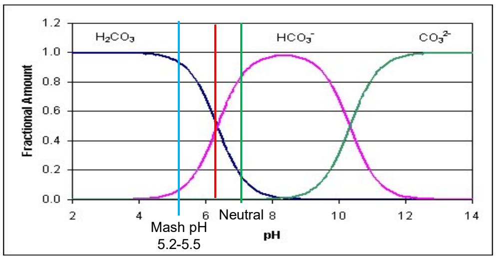
- Hydroxide ion (OH^-)
- Carbonate ion (CO_3^{2-})
- Bicarbonate ion (HCO^{3-})

In water, they react with acidic substances to form salts.

Alkalinity ions reduce acidity; they increase water's pH value.

Alkalinity is generally shown on an analysis as the equivalent amount of calcium carbonate ($CaCO_3$) in milligrams per litre

CARBON FORMS VS PH LEVELS



IMPACT OF HIGH ALKALINITY

Excess alkalinity levels will result in:

- Reduced extract due to poor enzyme activity in mash tun
- Harsh after-tastes in the finished beer – astringency from tannins
- Darker worts post boil
- Reduced protein precipitation in mash tun and boil
- Wort and beer more prone to infection due to bacteria growing in higher pH conditions
- Increased extraction of tannins (polyphenols), lipids and tannins during sparging

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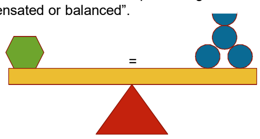
RESIDUAL ALKALINITY

Concept developed by Paul Kolbach back in the 1950s

"Water contains three ions which influence the pH of wort: bicarbonate, calcium and magnesium. The bicarbonate ion has a pH raising effect, the other two lower it. The pH lowering effect of magnesium ions is only half that of calcium ions.

Depending on the ratio of the water's content of bicarbonate on the one hand and calcium and magnesium on the other, the pH raising effect of the bicarbonate is more or less compensated or balanced".



1 equivalent of bicarbonate ion equals 3.5 equivalents of calcium ion (or 7 equivalents of magnesium ion).

Source: Paul Kolbach, Brewing Chemistry and Technology Department, VLB, Berlin, 1953

RESIDUAL ALKALINITY

Kolbach formula for residual alkalinity (RA) is:

RA ppm = ppm Alk – (calcium ppm/3.5) + (magnesium ppm/7).

To convert ppm or mg/litre to milliequivalents requires use of equivalents which are:

Calcium (Ca^{2+}): 20 / Magnesium (Mg^{2+}): 12.1 / Sulphate (SO_4^{2-}): 48
Chloride (Cl^-): 35.4 / Bicarbonate (HCO_3^-): 61

To convert mg/L or ppm to mEq/L divide ion concentration (in mg/L or ppm) by the equivalent values e.g. if your calcium is 120mg/L, divide by 20; thus mEq/L is 6.0.

To convert hardness and alkalinity values expressed "as $CaCO_3$" to mEq/L, multiply by 50 (molecular weight of calcium carbonate).

RESIDUAL ALKALINITY

Kolbach's second formula: pH shift due to RA

The shift in the mash pH due to the water residual alkalinity vs a mash made using de-ionised water:

pH shift = 0.00168 x RA (as ppm $CaCO_3$)

Or, if using the milliequivalents

pH shift = 0.084 x RA (as $CaCO_3$ mEq/L)

NB. Kolbach's work did not actually refer to mash pH but to knock out wort: A 170mg/L change in alkalinity, as $CaCO_3$ gives a 0.3 pH change to a 1048OG (12 Plato) knock out wort and not to mash pH.

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IONS VS FUNCTION & EFFECT

Cations	Contribution to beer
Calcium Ca	Helps to reduce the mash pH, needed by the yeast for metabolism and flocculation. Also for beer stability.
Magnesium Mg	Trace element required by the yeast. Bitter/sour above 80mg/l? Can be laxative
Iron Fe	Gives beer a metallic flavour Forms hazes.
Zinc Zn	Trace element required by the yeast.
Sodium Na	Palate: fullness and sweetness Salty in excess

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IONS OBTAINED FROM MALT

This analysis obtained from an all malt 1040OG wort made with de-ionised water.

Ion	Wort ppm	Beer ppm
Calcium	35	33
Magnesium	70	65
Sodium	10	12
Zinc	17	0
Chloride	125	130
Sulphate	5	15

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GUIDELINES ON STYLES (PPM)

	OG	Na	Mg	Ca	Cl	SO_4	Alkalinity
Bitter	1035-40	25	20	180	100	300	25
Best Bitter	1040-45	-	-	As for bitter	-	-	-
ESB	1045-60	25	20	180	100	200	50
IPA	1050-60	25	20	200	150	450	25
Mild	1030-45	50	20	100	150	50	100
Porter	1045-65	10	10	100	100	50	100
Stout	1040-70	25	10	100	50	25	100

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pH LEVELS

- pH of the raw liquor is of very little concern, within reason; impacts minimally on the process.
- pH tells us whether a solution is acid, alkaline or neutral and its relative acidity. It does not tell us how much acid or alkali is present.
- Other pH levels are of more importance.

Typical pH Measurements in the brewing process:

- Raw Liquor pH 6.0 - 8.0
- Treated Liquor pH 6.0 - 8.0
- Mash pH 5.2 - 5.5 (At mash temp)
- Sparge Liquor pH 5.5 – 6.2
- 1st Runnings pH 4.8 - 5.2 (At wort temp)
- Last Runnings pH 5.4 - 5.6 (At wort temp)
- Wort in Copper pre-boil pH 5.1 - 5.5
- Wort after Boil pH 4.9 - 5.3
- Beer after Fermentation pH 3.7 - 4.2

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IMPORTANCE OF LOW MASH pH

According to Kunze, 2007, the benefits of a mash at pH5.2 include:

- Enzyme activity/efficiency is increased.
- Extract yield (efficiency) is improved
- Raised zinc level – aids fermentation
- Protein coagulation and precipitation – clearer wort and beer
- Reduced colour formation
- Increased trub precipitation – assists fermentation
- Faster pH drop in FV: Improved fermentation and attenuation
- Beer flavour improved
- Hop bitterness is smoother, more pleasant.
- Increased foam stability and density.
- Mash oxidation is reduced; LOX enzyme inhibited at low mash pH conditions, optimal level 5.1?
- Susceptibility to microbial spoilage is reduced via:
  - Lower beer pH: beer spoilage organisms generally don't grow <pH4.4
  - Higher attenuation – lack of nutrients

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pH READINGS

It is important to understand that there is a chemical shift in pH as temperature increases. This is due to hydrogen ion dissociation.

At 20ºC the pH reading will be 0.35 higher than at 65ºC mash temp e.g.

pH 5.5 at 20ºC = pH 5.15 at 65ºC

At 20ºC the pH reading will be 0.45 higher than at 80ºC sparge temp e.g.

pH 6.5 at 20ºC = pH 6.05 at 80ºC

Ideally all pH readings should be checked at 20ºC and then compensated for due to the shift in temperature. ATC does not compensate!

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TESTING & TREATMENT

STARTING POINTS

1. Obtain overall annual analysis from your water supplier. Get tested by lab (every 3 months?).
2. Look at the calcium, sulphate, chloride and alkalinity levels.
3. Is there a pattern over the year?
4. Test water before each brew for alkalinity (and hardness if possible).
5. Treat to adjust alkalinity level: removal or conversion. Short cut: Acidulate to pH6.2-6.5 in HLT (at 20ºC).
6. Burtonisation: Add salts to grist or mash. Amounts added on the volume of beer being brewed i.e. the brewlength.

BASIC LIQUOR TREATMENT

Two stages:

Removal/reduction of alkalinity:

- Involves addition of acid to HLT volume

Adjustment of ion content (Burtonisation):

- Involves addition of various salts to grist/mash and sometimes the copper.
- Based on brewlength

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ALKALINITY CONTROL

Common methods of removal, reduction and conversion of temporary hardness/alkalinity:

- Boiling precipitates insoluble calcium carbonate (removal):

$$Ca(HCO_3)_2 = CaCO_3\downarrow + H_2O$$

- Addition of acids (conversion):

$$H_2SO_4 + Ca(HCO_3)_2 = CaSO_4 + 2H_2O + 2CO_2\uparrow$$

- Blend with distilled/dionised water (dilution)

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ALKALINITY TABLET TEST KITS

35

Simple tablet colour indicator tests available e.g. Lovibond and Palintest. Reasonably accurate for everyday use.

Follow supplier's instructions, can vary, but in general:

- Take 50ml of water from HLT and leave to cool to 20ºC.
- Add tablets one at a time and shake gently to dissolve.
- When permanent colour change takes say from yellow red, stop tablet addition and count up number of tablets used.

- Perform calculation to obtain alkalinity level usually expressed as ppm of $CaCO_3$

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ALKALINITY METERS

Accurate to +/- 10% of reading in general.

Requires reagent – additional cost

Colorimetric method. The reaction causes a distinctive range of colours from yellow to green to blue to develop.

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FULL DIY TEST KIT

Image and details from: www.camlab.co.uk

Covers tests for:

Free & Total Chlorine / Calcium & Hardness / Alkalinity / pH / Temperature / Sulphate / Specific Gravity

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ACID TREATMENT EXAMPLE

Using AMS/CRS solution:

Your HLT (Hot Liquor Tank) contains 1000 litres

The alkalinity test shows a level of 180mg/l. Desired level is 50mg/l.

So amount of alkalinity to be removed =

(180 – 50) x 1000 = 130,000 mg

Neutralisation power of CRS/AMS = 183mg/ml. Amount to add to HLT =

130,000/183 = 710.4ml

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ACID TREATMENT EXAMPLE

Resulting changes in the levels of sulphate and chloride following the addition of AMS/CRS need to be known prior to making any further salt additions to the grist:

Every 1 ml of AMS/CRS will add:

- 89.6mg of SO_4 (sulphate)
- 56mg of Cl (chloride)

In the previous example the addition of 710.4ml of AMS would, therefore, have increased the total SO_4 level per litre by:

89.6 x 710.4/1000 = 63.7mg/litre

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VARIOUS ACIDS VS ALKALINITY

Acid	MW	Val	g Eq	Density g/ml – 20°C	Pure Acid mg/ml	$-CaCO_3$ mg/ml acid
Hydrochloric 37%	36.46	1	36.46	1.190	440.3	604.4
Adds Cl mg/ml	359					
Sulphuric 25%	98.08	2	49.04	1.168	292.0	298.0
Adds SO_4 mg/ml	238					
Lactic 88%	90.08	1	90.08	1.210	1064.8	591.6

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REMOVING PERMANENT HARDNESS

Adding sodium carbonate

Sodium bicarbonate ($NaHCO_3$) can be used to remove permanent hardness.

Sodium bicarbonate is soluble but calcium carbonate and magnesium carbonate are not.

The carbonate ions from the sodium carbonate react with the calcium and magnesium ions in the water. For example:

calcium ions + sodium bicarbonate → calcium carbonate + sodium ions

$Ca^{2+}(aq) + NaHCO_3(aq) \rightarrow CaCO_3(s) + Na^+(aq)$

The water is softened because it no longer contains dissolved calcium and magnesium ions. As mentioned the calcium carbonate and magnesium carbonate are not soluble and will precipitate to form limescale

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STEP 2 - "BURTONISATION"

- Originally the addition of calcium sulphate (gypsum) to brewing water to replicate the deep well water of Burton-upon-Trent.
- Now generally refers to addition of any salts.

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SALT ADDITION EXAMPLE

Example 1

After acid treatment your calculations show a chloride content of 85mg/L and you require 125mg/L in a 2.5BBL (410L) brewlength.

Calcium chloride (dihydrate) contains 48% chloride and 27% calcium or 1g (1000mg) contains 480mg of chloride and 270mg of calcium

Additional amount of chloride required =

(125 – 85) x 410 = 16400mg

Remembering that 1g CaCl = 480mg of chloride, therefore:

16400/480 = 34.2g of CaCl to be added to grist/mash/boil

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SALT ADDITION EXAMPLE

Example 2

After acid treatment your water shows a sulphate content of 150mg/L and you require 400mg/L in an 8BBL (1312L) brewlength.

Calcium sulphate (dihydrate) contains 56% sulphate and 23% calcium or 1g (1000mg) contains 560mg of sulphate and 230mg of calcium.

Additional sulphate required =

(400 -150) x 1312 litres (brewlength) = 328000mg

Remembering that 1g of $CaSO_4$ contains 560mg of sulphate, therefore:

328000/560 = 585.7g of $CaSO_4$ to be added to mash.

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IMPORTANCE OF CALCIUM

1. Key role in controlling pH of mash: Reduces pH
2. Increases the amount of nitrogen available as TSN and FAN: proteolysis enhanced
3. Improves wort run off: gelprotein formation is hindered
4. Limits extraction of polyphenols, lipids and silicates
5. Protects alpha amylase from effects of heat
6. Improves wort clarification; aids protein coagulation
7. Aids yeast flocculation
8. Precipitates oxalate: Prevents gushing / vessel cleaning
9. Prevents haze formation

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EFFECTS OF CALCIUM

Calcium content mg/l	0	100	200	300
pH	5.74	5.48	5.39	5.28
Extract - Litre degrees	287	291	292	292
Total Soluble Nitrogen (TSN) (1040OG)	904	973	983	1062
Free Amino Nitrogen (FAN) (1040OG)	188	195	207	220

The effects of calcium ions, added as CaCl, on the pH, extract and soluble nitrogen fractions given by mashes made with one malt at 65C (After Taylor, 1981)

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NOW THE CALCIUM ADDITION

In the previous examples the amount of Calcium added in each case would be calculated as follows:

Example 1:

Taking it that 1g CaCl = 270mg calcium:

34.2g of CaCl x 270 = 9234mg/410 litres = 22.5mg/litre

Example 2:

Taking it that 1g $CaSO_4$ = 230mg calcium

585.7g of $CaSO_4$ x 230 = 134,711mg/1312 litres = 102.7mg/litre

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COMMON BREWING SALTS

		Typical Salt Components Per Gram		
	Anion %	= per gram	Cation %	= per gram
$CaCl_2$	48	480mg Chloride	27	270mg Calcium
$CaSO_4$	56	560mg Sulphate	23	230mg Calcium
*$CaCO_3$	60	600mg Carbonate	40	400mg Calcium
$MgSO_4$	39	389mg Sulphate	10	10mg Magnesium
NaCl	61	610mg Chloride	39	390mg Sodium
$NaHCO_3$	73	730mg Bicarbonate	27	270mg Sodium
$ZnSO_4$	33	330mg Sulphate	23	230mg Zinc

*** Approx. only 50% will dissolve on addition to mash**

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HOW MUCH WATER IS REQUIRED?

Rule of thumb is that 2.1L of HLT liquor produces 1.64L of beer. Approximate loss in the mash tun is 0.9 litres per kilo of malt grist, loss on boiling between 5-10%. (Water of hydrolysis and absorption by the dry hops is usually covered by this rough guide).

Example using 275kg grist weight, 7kg dried hop cones and 10% copper evaporation (1 hour boil) would be:

Final desired wort volume i.e. brewlength	= 1640.0 litres
Copper up volume = 1640/90%	= 1822.0 litres
Plus mash tun loss @ 0.9L/kg	= 247.5 litres
Plus hop rehydration @ 4.5L/kg	= 31.5 litres
Means total HLT liquor volume (approx.)	= 2101.0 litres

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THANK YOU

ANY QUESTIONS?

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