# Hamon Evaporation

April 17, 2018

## 1 Hamon Evaporation Estimation

The goal here is to take in the csv just as it is, and calculate the evaporation values for each month in the dataset. The result would be a table showing the total evaporation for each month in the dataset

```
In [1]: import numpy as np
        import pandas as pd
        import math
        import matplotlib.pyplot as plt
        import seaborn as sns
        %matplotlib inline
```

```
In [2]: hollis = pd.read_csv("data/Hollis.csv")
        hollis.head()
```

Out[2]:

| | Date / Time | AirTC (Avg) | RH | SlrkW (Avg) | SlrjJ (Tot) | WS ms (Avg) | Wind Dir | T108 C (Avg) | HBr3W | Rain mm (Tot) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 7/17/2014 15:30 | 26.94 | 67.85 | 0.412 | 609.3776 | 1.667 | 335.900 | 31.21 | 221.5 | 0.0 |
| 1 | 7/17/2014 16:00 | 26.89 | 69.88 | 0.387 | 696.9075 | 1.618 | 59.220 | 31.45 | 221.4 | 0.0 |
| 2 | 7/17/2014 16:30 | 26.45 | 73.05 | 0.154 | 277.9549 | 1.753 | 52.930 | 31.25 | 221.3 | 0.0 |
| 3 | 7/17/2014 17:00 | 26.27 | 73.78 | 0.183 | 328.9092 | 1.879 | 2.172 | 30.91 | 220.9 | 0.0 |
| 4 | 7/17/2014 17:30 | 25.95 | 75.34 | 0.060 | 107.9211 | 1.944 | 33.750 | 30.47 | 220.8 | 0.0 |

```
In [3]: hollis.describe()
```

Out[3]:

| | AirTC (Avg) | RH | SlrkW (Avg) | SlrjJ (Tot) | WS ms (Avg) |
|---|---|---|---|---|---|
| count | 20054.000000 | 20054.000000 | 20054.000000 | 20054.000000 | 20054.000000 |
| mean | -0.216621 | 80.269694 | 0.174742 | 314.413236 | 1.167754 |
| std | 25.307773 | 54.656236 | 0.262976 | 473.302872 | 0.797486 |
| min | -39.500000 | 0.612000 | 0.000000 | 0.000000 | 0.000000 |

```
25%      -36.300000      7.816250      0.000000      0.000000      0.429000
50%       10.825000     91.100000      0.003000      5.817208      1.087000
75%       21.300000    119.000000      0.294000    528.021650      1.739000
max       30.150000    217.200000      1.150000   2203.842000      4.445000

           Wind Dir  T108 C (Avg)         HBr3W  Rain mm (Tot)
count  20054.000000  20054.000000  20054.000000   20054.000000
mean     178.645908     27.002141    236.832355       0.170611
std      123.386771      2.911931     27.208633       1.073114
min       -0.990000     20.460000      0.548000       0.000000
25%       52.162500     24.770000    212.500000       0.000000
50%      186.000000     26.440000    247.500000       0.000000
75%      311.000000     28.960000    259.500000       0.000000
max      354.600000     37.270000    301.800000      30.480000
```

A few things to note. Readings are taken every 30 minutes, and so that obviously needs to get cut down to days. The Hamon evaporation method only takes into account the sunshine hours and daily average temperature, so I could probably get rid of the other columns for now.

```
In [4]: df = hollis[["Date / Time", "T108 C (Avg)"]]    #Using pan temp since air temp has som
        df.columns = ['date', 'temp']
        df.head()
```

```
Out[4]:              date   temp
        0  7/17/2014 15:30  31.21
        1  7/17/2014 16:00  31.45
        2  7/17/2014 16:30  31.25
        3  7/17/2014 17:00  30.91
        4  7/17/2014 17:30  30.47
```

Ok I would like to only have daily data. First I think I need to convert the first column to a date object. Check for any nulls first just in case

```
In [5]: any_nan = df.columns[df.isnull().any()]
        len(list(any_nan))
```

```
Out[5]: 2
```

Apparently there was a time where the station was down and a note was made. To remove the nulls

```
In [6]: df.dropna(axis=0, subset=["temp"], inplace=True)
        any_nan = df.columns[df.isnull().any()]
        len(list(any_nan))
```

```
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:1: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
  """Entry point for launching an IPython kernel.
```

```
Out[6]: 0
```

```
In [7]: df["date"] = pd.to_datetime(df.date).dt.normalize()
        df.head()
```

```
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:1: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
  """Entry point for launching an IPython kernel.
```

```
Out[7]:         date   temp
        0 2014-07-17  31.21
        1 2014-07-17  31.45
        2 2014-07-17  31.25
        3 2014-07-17  30.91
        4 2014-07-17  30.47
```

```
In [8]: df = df.groupby('date', as_index=False, sort=False)['temp'].mean()
        df.head()
```

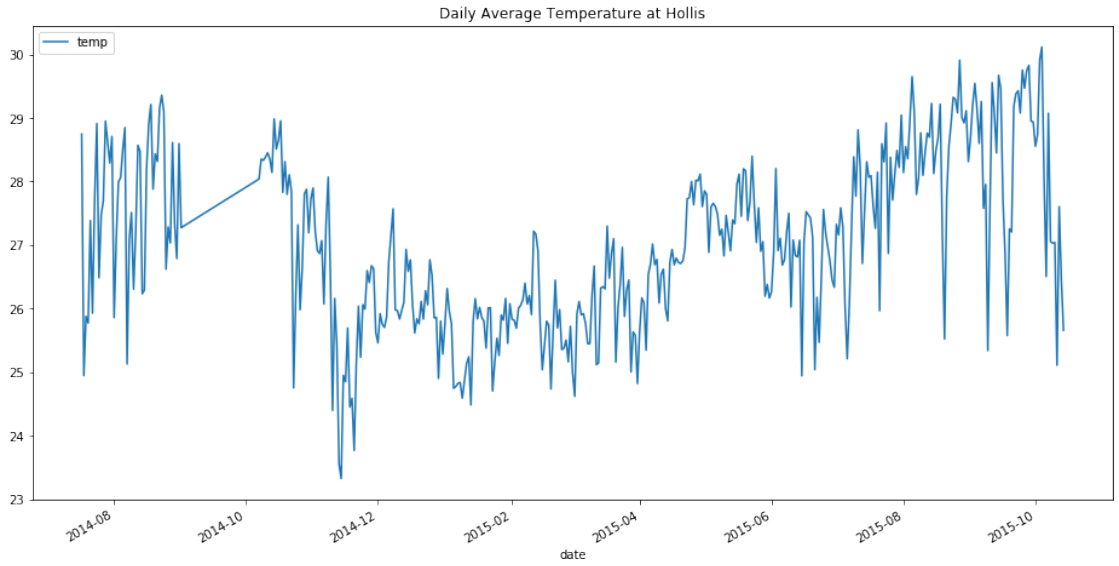
```
Out[8]:         date       temp
        0 2014-07-17  28.745294
        1 2014-07-18  24.944583
        2 2014-07-19  25.877708
        3 2014-07-20  25.772083
        4 2014-07-21  27.385000
```

```
In [9]: df['date'] = pd.to_datetime(df.date)
        df.describe()
```

```
Out[9]:              temp
        count  420.000000
        mean    27.004829
        std      1.336323
        min     23.325000
        25%     25.968125
        50%     26.921667
        75%     28.067812
        max     30.116458
```

```
In [10]: df.plot(x='date', y='temp', figsize=(16,8), title='Daily Average Temperature at Hollis
```

```
Out[10]: <matplotlib.axes._subplots.AxesSubplot at 0x7f7129227f28>
```




Straight line indicates some missing data in September 2014

## 1.1 Solar Declination

Looks like we now have the average temperature of each day. Now to start the formulas. First up is the solar declination delta, given by:

$$\delta = 0.4093 \sin\left(\frac{2\pi}{365} J - 1.405\right)$$

where J is the Julian Day, or the number of days from the start of the year in other words. So lets make a column with the Julian day

```
In [11]: df['julian'] = df['date'].dt.dayofyear
         df.head()
```

```
Out[11]:         date       temp  julian
         0 2014-07-17  28.745294     198
         1 2014-07-18  24.944583     199
         2 2014-07-19  25.877708     200
         3 2014-07-20  25.772083     201
         4 2014-07-21  27.385000     202
```

```
In [12]: df['delta'] = df['julian'].apply(lambda x: 0.4093*math.sin(2*math.pi*x/365-1.405))
         df.head()
```

```
Out[12]:         date       temp  julian     delta
         0 2014-07-17  28.745294     198  0.371592
         1 2014-07-18  24.944583     199  0.368583
         2 2014-07-19  25.877708     200  0.365465
         3 2014-07-20  25.772083     201  0.362239
         4 2014-07-21  27.385000     202  0.358905
```

## 1.2 Sunset hour angle

The formula is:

$$\omega = arccos(-tan\phi(tan\delta))$$

where phi is the latitude of the resevoir in decimal degrees. For Hollis reservoir it is approximately 10.690243. Be sure to convert to radians in the formula

```
In [13]: phi = 10.690243    #latitude of reservoir in decimal degrees
```

```
In [14]: df['sunset'] = df['delta'].apply(lambda x: math.acos(-math.radians(math.tan(phi))*mat
         df.head()
```

Out[14]:

| | date | temp | julian | delta | sunset |
|---|---|---|---|---|---|
| 0 | 2014-07-17 | 28.745294 | 198 | 0.371592 | 1.592377 |
| 1 | 2014-07-18 | 24.944583 | 199 | 0.368583 | 1.592185 |
| 2 | 2014-07-19 | 25.877708 | 200 | 0.365465 | 1.591987 |
| 3 | 2014-07-20 | 25.772083 | 201 | 0.362239 | 1.591783 |
| 4 | 2014-07-21 | 27.385000 | 202 | 0.358905 | 1.591572 |

## 1.3 Maximum daylight hours

Maximum daylight hours D, is given by:

$$D = \frac{24\omega}{\pi}$$

```
In [15]: df['daylight'] = df['sunset'].apply(lambda x: 24*x/math.pi)
         df.head()
```

Out[15]:

| | date | temp | julian | delta | sunset | daylight |
|---|---|---|---|---|---|---|
| 0 | 2014-07-17 | 28.745294 | 198 | 0.371592 | 1.592377 | 12.164865 |
| 1 | 2014-07-18 | 24.944583 | 199 | 0.368583 | 1.592185 | 12.163401 |
| 2 | 2014-07-19 | 25.877708 | 200 | 0.365465 | 1.591987 | 12.161886 |
| 3 | 2014-07-20 | 25.772083 | 201 | 0.362239 | 1.591783 | 12.160323 |
| 4 | 2014-07-21 | 27.385000 | 202 | 0.358905 | 1.591572 | 12.158712 |

## 1.4 Saturation Vapour Pressure

In Kilopascals

$$e_s = 0.6108exp\left(\frac{17.27T_a}{237.3 + T_a}\right)$$

```
In [16]: df['vpressure'] = df['temp'].apply(lambda x: 0.6108*math.exp((17.27*x)/(237.3+x)))
         df.head()
```

Out[16]:

| | date | temp | julian | delta | sunset | daylight | vpressure |
|---|---|---|---|---|---|---|---|
| 0 | 2014-07-17 | 28.745294 | 198 | 0.371592 | 1.592377 | 12.164865 | 3.947093 |
| 1 | 2014-07-18 | 24.944583 | 199 | 0.368583 | 1.592185 | 12.163401 | 3.157336 |
| 2 | 2014-07-19 | 25.877708 | 200 | 0.365465 | 1.591987 | 12.161886 | 3.337216 |
| 3 | 2014-07-20 | 25.772083 | 201 | 0.362239 | 1.591783 | 12.160323 | 3.316416 |
| 4 | 2014-07-21 | 27.385000 | 202 | 0.358905 | 1.591572 | 12.158712 | 3.646667 |

### 1.5 Celsius to Kelvins

This doesn't need an explanation

```
In [17]: df['kelvin'] = df['temp']+273.15
         df.head()
```

```
Out[17]:         date       temp  julian     delta    sunset   daylight  vpressure  \
         0 2014-07-17  28.745294     198  0.371592  1.592377  12.164865   3.947093
         1 2014-07-18  24.944583     199  0.368583  1.592185  12.163401   3.157336
         2 2014-07-19  25.877708     200  0.365465  1.591987  12.161886   3.337216
         3 2014-07-20  25.772083     201  0.362239  1.591783  12.160323   3.316416
         4 2014-07-21  27.385000     202  0.358905  1.591572  12.158712   3.646667

                kelvin
         0  301.895294
         1  298.094583
         2  299.027708
         3  298.922083
         4  300.535000
```

### 1.6 Saturation Vapour Density

$$SVD = 2166.74 \left( \frac{e_s}{T_a} \right)$$

SVD is in grams per cubic meter and Ta is in kelvins

```
In [18]: df['SVD'] = 2166.74*(df['vpressure']/df['kelvin'])
         df.head()
```

```
Out[18]:         date       temp  julian     delta    sunset   daylight  vpressure  \
         0 2014-07-17  28.745294     198  0.371592  1.592377  12.164865   3.947093
         1 2014-07-18  24.944583     199  0.368583  1.592185  12.163401   3.157336
         2 2014-07-19  25.877708     200  0.365465  1.591987  12.161886   3.337216
         3 2014-07-20  25.772083     201  0.362239  1.591783  12.160323   3.316416
         4 2014-07-21  27.385000     202  0.358905  1.591572  12.158712   3.646667

                kelvin        SVD
         0  301.895294  28.328777
         1  298.094583  22.949517
         2  299.027708  24.181302
         3  298.922083  24.039079
         4  300.535000  26.291043
```

### 1.7 Evaporation

$$E = 0.55 \left( \frac{D}{12} \right)^2 \left( \frac{SVD}{100} \right)$$

where E is in inches per day. I don't know what's with all these unit changes. I'll convert it to mm one time

```
In [19]: df['E'] = 0.55*((df['daylight']/12)**2)*(df['SVD']/100)*25.4
         df.head()
```

Out[19]:

| | date | temp | julian | delta | sunset | daylight | vpressure | \ |
|---|---|---|---|---|---|---|---|---|
| 0 | 2014-07-17 | 28.745294 | 198 | 0.371592 | 1.592377 | 12.164865 | 3.947093 | |
| 1 | 2014-07-18 | 24.944583 | 199 | 0.368583 | 1.592185 | 12.163401 | 3.157336 | |
| 2 | 2014-07-19 | 25.877708 | 200 | 0.365465 | 1.591987 | 12.161886 | 3.337216 | |
| 3 | 2014-07-20 | 25.772083 | 201 | 0.362239 | 1.591783 | 12.160323 | 3.316416 | |
| 4 | 2014-07-21 | 27.385000 | 202 | 0.358905 | 1.591572 | 12.158712 | 3.646667 | |

| | kelvin | SVD | E |
|---|---|---|---|
| 0 | 301.895294 | 28.328777 | 4.067020 |
| 1 | 298.094583 | 22.949517 | 3.293954 |
| 2 | 299.027708 | 24.181302 | 3.469888 |
| 3 | 298.922083 | 24.039079 | 3.448593 |
| 4 | 300.535000 | 26.291043 | 3.770656 |

Now we have estimated daily evaporation values.

### 1.8 Monthly Evaporation

```
In [20]: month_df = df[['date', 'E']]
         month_df.set_index('date', inplace=True)
         month_df.head()
```

Out[20]:

| date | E |
|---|---|
| 2014-07-17 | 4.067020 |
| 2014-07-18 | 3.293954 |
| 2014-07-19 | 3.469888 |
| 2014-07-20 | 3.448593 |
| 2014-07-21 | 3.770656 |

```
In [21]: month_df_sum = month_df.groupby(pd.Grouper(freq="M")).sum()
         month_df_sum.head()
```

Out[21]:

| date | E |
|---|---|
| 2014-07-31 | 56.776961 |
| 2014-08-31 | 118.274630 |
| 2014-09-30 | 3.686294 |
| 2014-10-31 | 92.720948 |
| 2014-11-30 | 98.963824 |

```
In [22]: month_df_sum.describe()
```

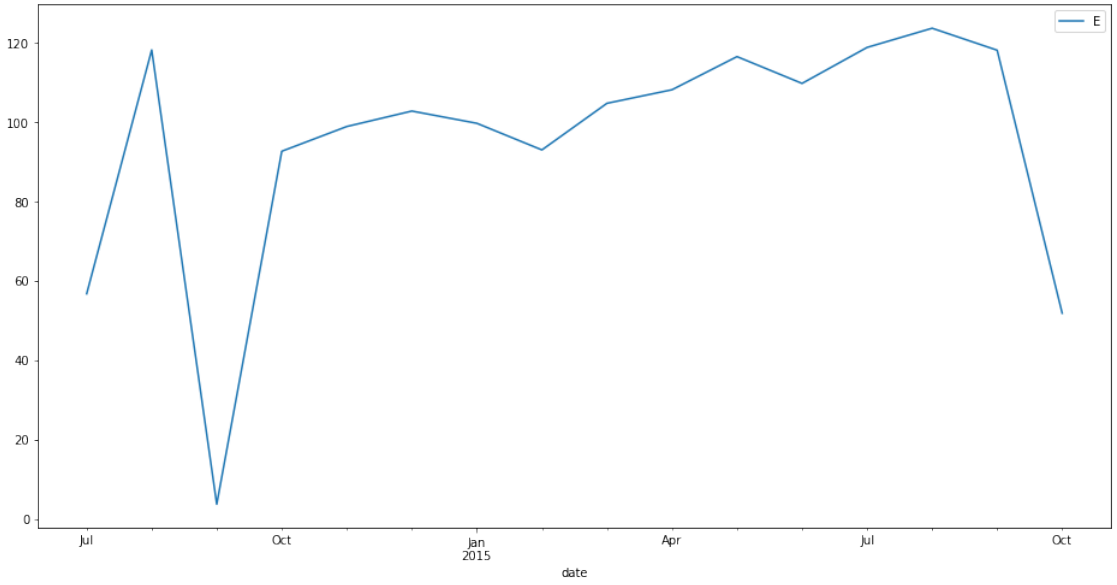
Out[22]:

| | E |
|---|---|
| count | 16.000000 |
| mean | 94.896673 |

```
std     31.838822
min      3.686294
25%     92.975482
50%    103.838681
75%    116.998409
max    123.755762
```

```
In [23]: month_df_sum.plot(figsize=(16,8))
```

```
Out[23]: <matplotlib.axes._subplots.AxesSubplot at 0x7f711cec2cc0>
```



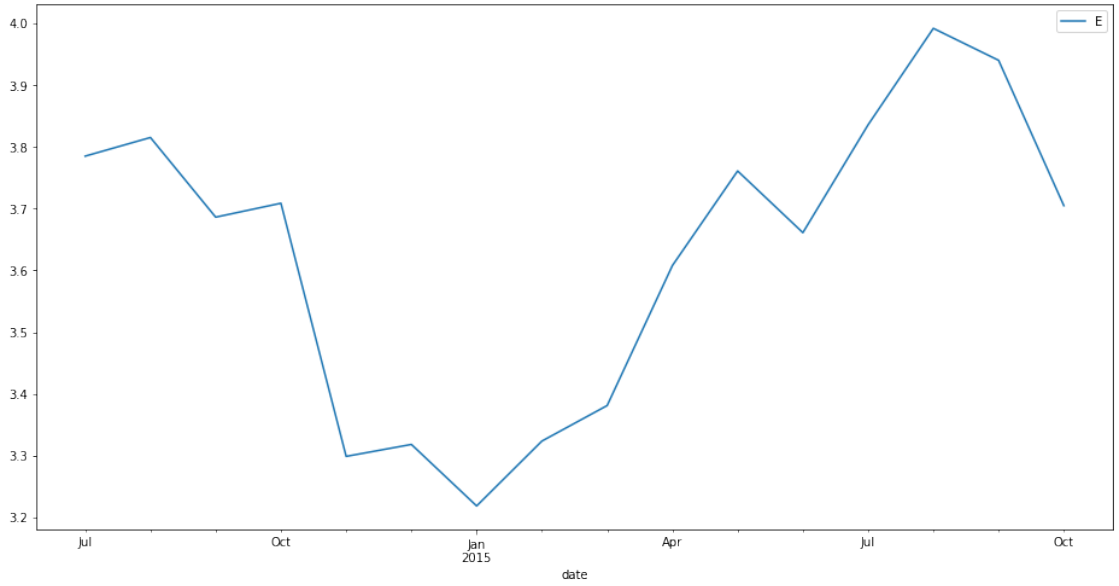

We have the problem of incomplete months to deal with, as shown by the drastic changes. Maybe find the mean?

```
In [24]: month_df_avg = month_df.groupby(pd.Grouper(freq="M")).mean()
         month_df_avg.head()
```

```
Out[24]:                    E
         date
         2014-07-31  3.785131
         2014-08-31  3.815311
         2014-09-30  3.686294
         2014-10-31  3.708838
         2014-11-30  3.298794
```

```
In [25]: month_df_avg.plot(figsize=(16,8))
```

```
Out[25]: <matplotlib.axes._subplots.AxesSubplot at 0x7f711ce8de10>
```




Now it may seem that there are huge changes, but that's just some vertical exaggeration here. Everybody is falling between 3 - 4mm, which is a very tiny range.

### 1.9 Print useable table of values

```
In [26]: month_df_sum.to_csv("results/Hamon_month_total.csv")
         month_df_avg.to_csv("results/Hamon_month_average.csv")
```

### 1.10 Comparison

How does this compare with the actual recorded loss from the evaporation pan? Let's find out. We want the date, water level, and rainfall columns

```
In [28]: loss_df = hollis[["Date / Time", "HBr3W", "Rain mm (Tot)"]]
         loss_df.columns = ['date', 'level', 'rainfall']
         loss_df.dropna(axis=0, subset=['rainfall'], inplace=True)
         loss_df['date'] = pd.to_datetime(loss_df.date).dt.normalize()
         loss_df.head()
```

```
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:3: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
  This is separate from the ipykernel package so we can avoid doing imports until
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:4: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
```

```
  after removing the cwd from sys.path.
```

Out[28]:

| | date | level | rainfall |
|---|---|---|---|
| 0 | 2014-07-17 | 221.5 | 0.0 |
| 1 | 2014-07-17 | 221.4 | 0.0 |
| 2 | 2014-07-17 | 221.3 | 0.0 |
| 3 | 2014-07-17 | 220.9 | 0.0 |
| 4 | 2014-07-17 | 220.8 | 0.0 |

```
In [29]: loss_df = loss_df.groupby('date', as_index=False, sort=False).agg({'level':'first', '
         loss_df.head()
```

Out[29]:

| | date | rainfall | level |
|---|---|---|---|
| 0 | 2014-07-17 | 4.572 | 221.5 |
| 1 | 2014-07-18 | 25.398 | 223.8 |
| 2 | 2014-07-19 | 14.478 | 247.1 |
| 3 | 2014-07-20 | 56.646 | 259.8 |
| 4 | 2014-07-21 | 1.524 | 269.2 |

Need to somehow get the daily change in water level. Diff() function is perfect. Thanks Pandas

```
In [30]: loss_df['diff'] = loss_df.level.diff(periods=1)
         loss_df.head()
```

Out[30]:

| | date | rainfall | level | diff |
|---|---|---|---|---|
| 0 | 2014-07-17 | 4.572 | 221.5 | NaN |
| 1 | 2014-07-18 | 25.398 | 223.8 | 2.3 |
| 2 | 2014-07-19 | 14.478 | 247.1 | 23.3 |
| 3 | 2014-07-20 | 56.646 | 259.8 | 12.7 |
| 4 | 2014-07-21 | 1.524 | 269.2 | 9.4 |

And now a rough estimate for evaporation. How often is the evap pan topped up, and to what level? Assume that the pan is not topped up at all in this dataset. The pan overflows at 270