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A STUDY ON *LEGIONELLA PNEUMOPHILA*, WATER CHEMISTRY, AND ATMOSPHERIC CONDITIONS IN COOLING TOWERS AT SAVANNAH RIVER SITE

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1.0 EXECUTIVE SUMMARY

Legionnaires' disease is a pneumonia caused by the inhalation of the bacterium *Legionella pneumophila*. The majority of illnesses have been associated with cooling towers since these devices can harbor and disseminate the bacterium in the aerosolized mist generated by these systems. Historically, Savannah River Site (SRS) cooling towers have had occurrences of elevated levels of *Legionella* in all seasons of the year and in patterns that are difficult to predict. Since elevated *Legionella* in cooling tower water are a potential health concern a question has been raised as to the best control methodology. In this work we analyze available chemical, biological, and atmospheric data to determine the best method or key parameter for control. The SRS *4Q Industrial Hygiene Manual, 4Q-1203, 1 – G Cooling Tower Operation and the SRNL Legionella Sampling Program,* states that "Participation in the SRNL Legionella Sampling Program is MANDATORY for all operating cooling towers". The resulting reports include *L. pneumophila* concentration information in cells/L. *L. pneumophila* concentrations $>10^7$ cells/L are considered elevated and unsafe so action must be taken to reduce these densities. These remedial actions typically include increase biocide addition or "shocking". Sometimes additional actions are required if the problem persists including increase tower maintenance (e.g. cleaning).

Evaluation of 14 SRS cooling towers, seven water quality parameters, and five *Legionella* serogroups over a three-plus year time frame demonstrated that cooling tower water *Legionella* densities varied widely though out this time period. In fact there was no one common consistent significant variable across all towers. The significant factors that did show up most frequently were related to suspended particulates, conductivity, pH, and dissolved oxygen, not chlorine or bromine as might be expected. Analyses of atmospheric data showed that there were more frequent significant elevated *Legionella* concentrations when the dew point temperature was high--a summertime occurrence. However, analysis of the three years of *Legionella* monitoring data of the 14 different SRS Cooling Towers demonstrated that elevated concentrations are observed at all temperatures and seasons.

2.0 OBJECTIVE

The objective of this study is to evaluate the ecology of *L. pneumophila* including serogroups and population densities, chemical, and atmospheric data, on cooling towers at SRS to determine whether relationships exist among water chemistry, and atmospheric conditions. The goal is to more fully understand the conditions which inhibit or encourage *L. pneumophila* growth and supply this data and associated recommendations to SRS Cooling Tower personnel for improved management of operation. Hopefully this information could then be used to help control *L. pneumophila* growth more effectively in SRS cooling tower water.

3.0 METHODS

As part of the SRS monitoring program, all cooling towers are sampled and tested either monthly or quarterly for *Legionella pneumophila.*

For sampling sterilized 500 ml polycarbonate sample bottles are used to sample cooling tower water from these 14 individual towers on a monthly basis. A calibrated YSI MPS 552 multi-parameter meter (YSI, Yellow Springs, Ohio) are used to measure temperature (C°), conductivity (Co), pH, and dissolved oxygen (DO) on site. A Palintest 1000 test kit is used to measure bromine (Br) and/or Chlorine (Cl) (Palintest House, Kingsway, UK).

On return to the laboratory cooling tower water is concentrated by filtration using Nuclepore 0.2 µm filters (47 mm diameter) within four hours of collection (Nucleopore, Pleasanton, CA). One to three filters are used for filtration depending on the suspended solids concentration. The filter(s) are then cut aseptically and placed in 15-mL conical centrifuge tubes. One ml of the 0.2 µm sterile nano-pure water is then added and then the tube was vortexed for four (4) min. at high speed. Ten µl of the concentrated cooling tower water sample is then pipetted on four wells onto 8-well slides (CellLine [#10-55] Erie Scientific) that had been baked @ 90°C for 4 hours. Additionally, two separate slides are prepared daily for positive and negative controls. Slide one serves as the negative control and no sample is placed in any of the wells. Slide two serves as the positive control so 10 µl of the inactivated (heat killed) *Legionella* antigens, *L. pneumophila* Serogroups 1, 2, and/or 3, 4, and/or 6 (m-Tech™, Alpharetta, GA) are placed in each of 4 wells. All slides are then dried on a heating block at 80-90°C for 10-15 min. Ten µl of prepared filter- sterilized 2% hydrolyzed gelatin (Difco, Detroit, MI) is placed on all sample and control wells and the slides were again dried. The dried gelatin maintains the integrity of the sample throughout the staining and rinsing process. Slides are then placed face up on a wet paper towel and covered with a sterile Petri dish shielded from light to provide a humidity chamber while cooling (20 min). Wells on the slides are then stained with 20 ul of the appropriate FITC-labeled monoclonal antibodies for the Direct Fluorescent Antibody (DFA) method. DFA include *L. pneumophila* Serogroup 1, *L. pneumophila* Serogroup 2, *L. pneumophila* Serogroup 3, *L. pneumophila* Serogroup 4, or *L pneumophila* Serogroup 6 (m-Tech™, Alpharetta, GA). After 20 min slides are then rinsed gently with distilled water at room temperature and placed upright in clean sterile FA Buffer (DIFCO, Detroit, MI) at room temperature and stored overnight. Next morning slides are removed from FA Buffer, allowed to drain, are then dipped in sterile 5% Sodium Pyrophosphate buffer (DIFCO), and immediately removed and dried. Slides are then examined and cells counted directly using fluorescent microscopy.

If *Legionella* is found at elevated concentrations ($\geq 10^{7}$ cells/L) during any sampling, the cooling tower is shocked by biocide (free chlorine level of 1.5 ppm or applicable biocide) and retested weekly until *Legionella* concentrations are reduced to acceptable concentrations ($\leq 10^{6}$ cells/L) (4Q). In addition to quantitative results, SRNL also provides a color-coded *Legionella* system for summarizing results. Towers are assigned a color designation for each sampling based upon the total *Legionella* DFA concentrations. A tower is assigned a RED color if densities are $\geq 10^{7}$ cells/L. Red indicates that shocking with biocide is required. A tower is assigned a YELLLOW color if *Legionella* cell densities are 10^{6} cells/L. Yellow indicates that the tower has counts approaching trigger level and may need attention such as cleaning or additional biocide. A tower is assigned a GREEN color if *Legionella* densities are $< 10^{6}$ cells/L. This color-coding tracking system is useful for detecting and tracking trends for each cooling tower. It is also reported if water quality is observed to be poor indicated by high suspended solids. This is indicated in the reports if greater than 1 filter is used to prepare the cooling tower water for DFA analysis.

4.0 DISCUSSION

4.1 DATA ANALYSES

Data was available monthly from 2005 through 2008. Each cooling tower data set was evaluated and duplicate or incomplete data eliminated. The water chemistry data available includes dissolved oxygen levels, water temperature, conductivity, pH, residual chlorine, number of filters required for sample preparation (an indicator of total suspended solids [TSS] levels), concentrations of *L. pneumophila,* and bromine when applicable.

Cooling towers were individually evaluated or grouped according to such parameters as location, type of tower, or treatment method and then evaluated with stepwise regression and for correlations using Minitab version 14 for the calculations. *Squares and interactions between factors were included in the evaluation.*

Fourteen cooling towers were evaluated with up to 52 data points for some of the factors in a given tower available. However, the final evaluations used fewer data points because data on bromine levels was only available for the last several years and the computer program ignored any data point with incomplete values for the factors being evaluated.

Initial data included total *Legionella* concentrations (combining all serogroups). Subsequent data showed levels by Serogroup. Serogroups 1, 2, and 4 data were available for the length of the study. Serogroup 3 data was reported until 1/2007, when Serogroup 6 data was gathered instead of Serogroup 3 data. The calculations for both Sero 3 and Sero 6 use fewer data points than Serogroups 1, 2, 4, and the total count and that information is in the Minitab printouts included in the report.

For comparison purposes the coefficient of determination (R^2) was be taken as a single measure of the adequacy of the prediction. R^2 is a measure of the variability in the values of the response values which is explained by the prediction equation. Thus if R^2 was found to be 84%, it means that the prediction equation has explained 84% of the variability. Other factors, including unevaluated factors and random chance, are then 16% of the variability and are not explained by the prediction equation.

If the calculated R^2 for a cooling tower were 84, then 84% of the variation would be captured by the calculation equation provided by the program. The other 16% could be from factors not measured (atmospheric temperature, rotation of earth, cloud cover, human factors, rainfall events, barometric pressure, road dust, etc.) or random chance. This study examines limited atmospheric data (dew point temperature) but concentrates on water chemistry because that's the area where operations and maintenance can make an immediate difference.

When Minitab performs a step wise regression it is looking for significant predictors as defined by the program (alpha = .15 is the standard and what is used in this study). The program selects the most significant factor and then runs the regression again looking for subsequent significant factors. The program will continue to add factors until the next factor added does not improve the prediction equation by the amount required. It may delete items added earlier as it goes through iterations. If there are no significant factors identified the program will indicate "No variables entered or removed", and the R^2 will be reported as 0.

An R^2 value of less than 50% indicates that less than half of the variability is explained by the regression equation and is taken to be a poor correlation. A predictive equation with an R^2 of 70% or more, however, would be a good predictive equation, and an R^2 above 90% would be a very good predictive equation. Specific R^2 values are noted for each cooling tower/serogroup combination and they range from no variables being selected as significant ($R^2 = 0$) to $R^2 = 99$.

Seven water chemistry variables are measured for each cooling tower each month, as noted above. The statistical evaluations will use these variables, the square of the variables, and the first order interactions for a total of thirty-five variables. The first order interactions are derived by simply multiplying the values for two variables. Therefore, the first order interaction for pH and temperature would be pH x temperature. (Example pH = 7, temperature = 18, pH x temp = 7 x 18 = 126.) Higher orders of interactions are not normally significant and were not evaluated.

4.2 TESTING AND ANALYSIS OF WATER CHEMISTRY AND *L PNEUMOPHILA*

The Savannah River National Lab (SRNL) provides *Legionella* monitoring of SRS cooling towers to individual tower operators at an approximate ~$9K annual cost per tower (FY09). Although there is current discussion on the minimum acceptable microbiological method for quantifying *Legionella*, the immunofluorescence analyses performed by SRNL are accepted by the Center for Disease Control (CDC), and current research supports these methods as the most accurate currently available.

Most outbreaks from cooling towers and evaporative condensers have been associated with densities of *Legionella* at elevated levels 10 times above our current SRS "trigger" levels (Fliermans, 1985) of 10^7 cells/L. Current research indicates that 10^7 is the middle ground of what is defined as "high" and "threatening." Of the 15 serotypes of *Legionella*, most have been shown to cause disease. Serogroups 1, 2, 4, and 6 are the serogroups most often associated with *Legionella* disease outbreaks. However, all serotypes can be pathogenic. At SRS, SRNL tests for serogroups 1, 2, 4 and 6 in the cooling tower water. When those cell densities exceed the "trigger" level, that tower needs shock treatment with a free chlorine level of 1.5ppm requirement.

The SRNL program serves as an ongoing occupational protection to the worker and a verification of quality assurance/quality control (QA/QC) for the tower custodians. SRNL maintains a large database that indicates the *Legionella* history of each tower. This information is used to determine if cooling towers are operating at acceptable *Legionella* water densities. The detection or absence alone of *Legionella* does not determine needed action. The actual concentration of *Legionella* bacteria in the cooling water is the factor used to determine action needed. Water chemistry testing is also part of the QA/QC for the cooling towers. While all SRS towers are sampled on a regular monthly or quarterly basis, sampling on request occurs on an as needed basis.

High levels of human activities surround some SRS cooling towers since some towers are located within 20 feet of high pedestrian traffic areas including entry gates. Depending on atmospheric conditions, SRS workers continually come in contact with these water tower generated aerosols. Such close interaction with the towers further necessitates the QA/QC to insure that SRS towers do not have elevated levels of *Legionella.*

Historically, SRS cooling towers have had cases of elevated cooling tower levels of *Legionella* in all seasons of the year with predictable increases in warmer summer months. During FY06, 41.4% of cooling towers were elevated above "trigger" limit at least once during the year. In FY07 this frequency was reduced to 29% due to increase surveillance and diligence by SRS Tower Operators and management. SRS towers do not follow a predictable *Legionella* pattern for elevated concentrations, and but there is a distinct seasonal pattern to the densities with a general increase in counts in the summer due to warm temperatures. When *Legionella* levels are elevated, SRNL often investigates to determine cause. Increases are most often due to problems with biocide applications or with high organic load in the tower. High organic load can be caused by construction work (high dust levels), spring pollen increases, or autumn leaf falls. Additionally, months of drought or very high rainfall can increase organic load in the towers. Higher organic and suspended solid concentrations lead to an increase in disinfectant demand.

In the last two months of FY07, over 46% of SRS cooling towers did not contain the minimum required amount of biocide (chlorine and/or bromine) (0.2 ppm) at the time of *Legionella* sampling. Of the site cooling towers, 44.8% had high suspended solids on at least one sampling date in FY07 such that water obtained from these towers had tended to clog the membrane filter used to concentrate the sample. Towers with high suspended solids allow *Legionella* to be shielded from biocides, while at the same time supplement their growth by having increased food supplies and surface substrate. Seasonal issues including pollen can also influence *Legionella* activity.

4.3 SEASONAL EVALUATION

An observation of the frequency of high *L. pneumophila* concentrations (10^7 cells/L) showed that a lot of the excursions occurred in the summer months. Discussions with the Atmospheric Technology Center led to the conclusion that the best way to define or measure the actual occurrence of summer was to use the dew point temperature as the predictor variable.

An evaluation of seasonal implications was done using a composite sampling of all cooling towers on site. The number of samples with *L pneumophila* densities greater than 10^7 cells/L was plotted against the average dew point temperature for the month in question and running a step wise linear regression. The results of that calculation are in Figure 1.

Stepwise Regression: frequency versus Ave Temp2, Ave dewpt2, Ave RH2

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is frequency on 3 predictors, with N = 12

Step              1
Constant     -4.055

Ave dewpt2    0.135
T-Value        7.68
P-Value       0.000

S             0.761
R-Sq          85.51
R-Sq(adj)     84.06
Mallows C-p     0.1
```

Regression Analysis: frequency versus Ave dewpt2

```
The regression equation is
frequency = - 4.06 + 0.135 Ave dewpt2

Predictor      Coef   SE Coef      T      P
Constant    -4.0552   0.9445  -4.29  0.002
Ave dewpt2  0.13500  0.01758   7.68  0.000

S = 0.761443   R-Sq = 85.5%   R-Sq(adj) = 84.1%

Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  34.202  34.202  58.99  0.000
Residual Error  10   5.798   0.580
Total           11  40.000

Unusual Observations

        Ave
Obs  dewpt2  frequency    Fit  SE Fit  Residual  St Resid
  7    71.5      7.000  5.595   0.403     1.405     2.18R

R denotes an observation with a large standardized residual.
```

Figure 1. Minitab Output for Seasonal Evaluation

The information shows a substantial relationship between L pneumophila and warmer dew point temperatures. Further, the stepwise regression evaluating temperature and relative humidity suggested that they had little impact. This analysis confirms the anecdotal evidence that there is a higher incidence of *Legionella* during the summer or warm months.

4.4 COOLING TOWERS

A partial listing of cooling towers, chemicals utilized, materials of construction, and year entered in service is listed below. The list shows that a number of different chemicals are used and that the towers vary in age and materials of construction.

	Chemicals Routinely Added			Tower Information	
Tower ID	Biocide currently used	Target Concentration	Frequency of addition	Material of Construction	Year Placed In Service
218-2H	GEBETZ Spectrus OX1202	1-2 mg/L Total Chlorine	1/day	Galvanized frame, plastic fill	1998
285-9H 1&2	GEBETZ Spectrus OX1202	1-2 mg/L Total Chlorine	2/day	Stainless steel with plastic drift eliminators	2000
264-3H	Ozone	ORP Target of 550	Continuous	Stainless steel	2005
241 20F CT1, CT2, CT3	ChemTreat CL-49	0.2-0.5 ppm	Continuous	Galvanized frame, plastic fill	1997
981-S	Bulab 6122	.2-.5 ppm	Continuous Metering	Douglas fir frame PVC fill	1984
785-A / 785-2A	HTH	1.0 ± ppm (to be reduced to 0.2 - 0.5 ppm)	as needed via broadcast	Wood frame, plastic drift eliminators	1984
785-B	Ozone system	Ozone system setting	continuous	Galvanized frame, plastic fill	2001
285-11F	Nalco Stabrex ST-70	Not measured; addition controlled by timer	30 min every 8 hrs yields 0.34 gal per day; rate altered if necessary to control high counts.	Galvanized frame, plastic fill	2005
285-4F	Nalco ST-70 (Stabrex)	1 mg/L Total Chlorine	when needed	Galvanized frame, plastic fill	1999

4.5 COOLING TOWER 285-4F

4.5.1 Operation

Cooling tower 285-4F consists of a four-fan galvanized metal Marley cooling tower installed in 1999. It is fed with domestic water (chlorinated and pH adjusted) and has an automatic feed system which includes a NALCO TRASAR 3000 Corrosion Controller TRASAR 3D189 inhibitor at a target level of 100 ppm and a NALCO STAGREX ST70 biocide Cl/Br system controlled by a timer. The Blowdown is a Walchem WCT300-142 conductivity based Blowdown controller triggered at 800 micromhos and fifteen minutes between blowdowns. The tower flow rate is variable from 2250 gpm to 9000 gpm.

4.5.2 Data

Cooling tower 285-4F, near 772-F, had data available from 5/3/2005 to 9/2/2008 for forty-three (43) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated. It included twenty-six (26) data points for bromine levels. A stepwise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values. Results of the regression are in Figure 2.

Stepwise Regression: Total versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 35 predictors, with N = 26
N(cases with missing observations) = 17 N(all cases) = 43


Step           1         2
Constant   3.115  1897.356

COND.2       447       638
T-Value     2.36      3.53
P-Value    0.027     0.002

P.H.2                -26.5
T-Value              -2.78
P-Value              0.011

S            315       279
R-Sq       18.87     39.23
R-Sq(adj)  15.49     33.94
```

Stepwise Regression: Serogroup 1 versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 1 on 35 predictors, with N = 26
N(cases with missing observations) = 17 N(all cases) = 43
```

```
Step            1        2        3        4
Constant    576.3   5912.0   6040.2   5816.7

pH            -65    -1341    -1368    -1320
T-Value     -5.33   -11.81   -12.61   -12.07
P-Value     0.000    0.000    0.000    0.000

P.H.2                 76.1     77.3     74.5
T-Value              11.25    12.01    11.50
P-Value              0.000    0.000    0.000

DO*Cond                         2.7      3.3
T-Value                        1.91     2.30
P-Value                       0.070    0.032

TEMP.2                                 0.026
T-Value                                 1.58
P-Value                                0.129

S            23.0     9.23     8.74     8.46
R-Sq        54.25    92.96    93.96    94.60
R-Sq(adj)   52.34    92.35    93.14    93.57
```

Stepwise Regression: Serogroup 2 versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero  2 on 35 predictors, with N = 26
N(cases with missing observations) = 17 N(all cases) = 43


Step            1        2        3        4        5
Constant    372.8   4565.2   4824.6   4647.1   4738.7

pH            -42    -1045    -1094    -1059    -1079
T-Value     -3.15    -4.42    -8.27   -12.40   -13.29
P-Value     0.004    0.000    0.000    0.000    0.000

P.H.2                 59.8     61.7     60.7     61.7
T-Value               4.24     7.84    11.97    12.83
P-Value              0.000    0.000    0.000    0.000

COND.2                         50.2    140.0    141.8
T-Value                        7.19     8.49     9.10
```

```
P-Value                   0.000   0.000   0.000

Cond*PH                           -16.9   -16.6
T-Value                           -5.66   -5.88
P-Value                           0.000   0.000

D.O.2                                     0.124
T-Value                                    1.90
P-Value                                   0.071

S            25.1    19.2    10.7    6.91    6.52
R-Sq        29.20   60.29   88.16   95.31   96.03
R-Sq(adj)   26.25   56.83   86.54   94.42   95.04
```

Stepwise Regression: Serogroup 3 versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 3 on 27 predictors, with N = 24


Step            1      2
Constant    175.0  144.2

Temp*PH     -0.82  -0.78
T-Value     -3.83  -4.08
P-Value     0.001  0.001

F*Cond              18.1
T-Value             2.56
P-Value            0.018

S            25.4   22.7
R-Sq        40.01  54.28
R-Sq(adj)   37.29  49.92
```

Stepwise Regression: Serogroup 4 versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 4 on 35 predictors, with N = 26
N(cases with missing observations) = 17 N(all cases) = 43


Step             1       2       3       4      5      6
Constant    -115.8  1240.6  1143.1  1283.9  720.8  398.9

COND.2         520     657     669     618    547    626
T-Value       2.96    3.67    3.94    3.98   3.82   4.26
P-Value      0.007   0.001   0.001   0.001  0.001  0.000

P.H.2                -19.0   -19.9   -10.3
T-Value              -2.01   -2.21   -1.14
P-Value              0.056   0.037   0.266

F2                              37     264    311    242
T-Value                       1.89    2.76   3.55   2.55
P-Value                      0.072   0.012  0.002  0.019

F*PH                                  -106   -128   -206
```

```
T-Value                              -2.41  -3.22  -3.32
P-Value                              0.025  0.004  0.003

Filters                                             970
T-Value                                            1.60
P-Value                                           0.124

S              293     276     262     237    238    230
R-Sq         26.76   37.69   46.37   58.02  55.42  60.27
R-Sq(adj)    23.71   32.28   39.06   50.03  49.34  52.70
```

Stepwise Regression: Serogroup 6 versus Filters, Temp, ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 6 on 35 predictors, with N = 18
N(cases with missing observations) = 25 N(all cases) = 43


Step            1      2
Constant    813.9  940.4

Temp*PH      -3.7   -4.2
T-Value     -2.68  -3.15
P-Value     0.016  0.007

DO*Br               -9.1
T-Value            -1.81
P-Value            0.090

S             121    113
R-Sq        30.97  43.39
R-Sq(adj)   26.66  35.84
```

Figure 2. Minitab Output for Cooling Tower 285-4F Evaluation

Regression recap for cooling tower285-4F is as follows:

Table 1. Significant Variables for 285-4F Cooling Tower

	Significant Variables	Adjusted R^2
Total	Conductivity^2, pH^2	33.94
Sero 1	pH^2, pH, Dissolved Oxygen*Conductivity, Temperature^2	93.57
Sero 2	pH, pH^2, Conductivity^2, Conductivity*pH, Dissolved Oxygen^2	95.04
Sero 3	Temperature*pH, Filters*Conductivity	49.92
Sero 4	Conductivity^2, pH^2, Filters^2, Filters*pH, Filters	52.70
Sero 6	Temperature*pH, Dissolved Oxygen *Bromine	35.84

Evaluation of all of this data shows that conductivity and pH are significant in and of themselves or in a first order interaction with all serogroups, including total *Legionella*. Other factors may be significant with a specific serogroup, the most common other variables are temperature and dissolved oxygen. Serogroups 1 and 2 show very significant correlations with their variables with adjusted R^2 over 90.

A more detailed analysis of the significant variables shows that pH is involved in all cases for this cooling tower, including linear, quadratic, or first order interactions. Furthermore, conductivity is included as a significant variable in all but Sero 6. Number of filters is involved several times in the variables contributing to Sero 4, as first order, quadratic and second order with pH. It would appear that some of the things to include in an effort to control *Legionella* in this cooling tower are pH, conductivity, and number of filters (clean water).

The regression consistently indicates that a rise in pH will result in a lowering of *Legionella*, as long as pH is below 10, at which time the squared function takes over and the regression indicates more *Legionella* at higher pH.

When the water is dirty, more filters are required, and the *Legionella* levels are predicted by the regression to increase. The conclusion from that evaluation is that dirty or high solids water influences the level of *Legionella* in this cooling tower.

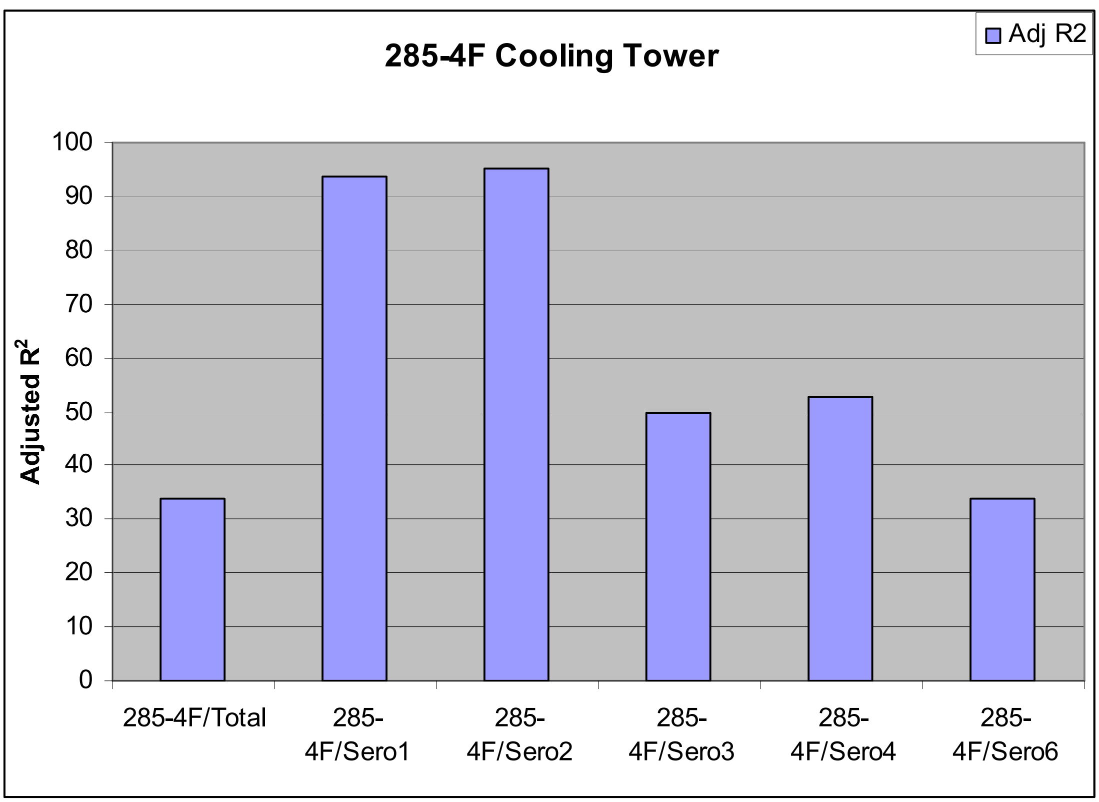

Figure 3. 285-4F Cooling Tower R^2 Graph

4.6 COOLING TOWER 285-11F

4.6.1 Operation

Cooling tower 285-11F consists of a two cell galvanized upper works/stainless steel basin Marley cross flow induced draft cooling tower (2500 gpm capacity) with plastic drift eliminators installed in 2005. It is fed with either service water (pH adjusted) or domestic water (chlorinated and pH adjusted) and has an automatic feed system which includes a NALCO TRASAR 3000 Corrosion Controller TRASAR 3D189 inhibitor at a target level of 150 ppm and a NALCO STAGREX ST70 biocide Cl/Br system controlled by a timer. The Blowdown is a Walchem WCT300-142 conductivity based Blowdown controller triggered at 800 micromhos and fifteen minutes between blowdowns. It has been operated on domestic water for about 18 months due to non availability of the service water system. Flow rate for the tower is 2500 gpm.

4.6.2 Data

Cooling tower 285-11F, near Building 235-F, had data available from 10/31/2005 to 9/2/2008 for forty-one (41) chemical and *L. pneumophila* level data points after duplicate or incomplete data were eliminated. Note: Serogroup 3 was dropped in February 2007 and Serogroup 6 data was substituted. This makes both of these data sets from a smaller sample than Serogroups 1, 2, and 4.

A stepwise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with values, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 4 followed by the regression recap for the cooling tower 285-11F in Table 2.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 27
N(cases with missing observations) = 14 N(all cases) = 41


No variables entered or removed
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 1 on 35 predictors, with N = 27
N(cases with missing observations) = 14 N(all cases) = 41


Step            1       2      3
Constant   -4.130  12.512  9.558

Cond*Cl      26.9   147.0  146.7
T-Value      2.89   13.08  13.46
P-Value     0.008   0.000  0.000

Cond*Br             -73.1  -65.0
T-Value            -11.34  -8.03
P-Value             0.000  0.000

Cl*Br                      -1.05
T-Value                    -1.59
P-Value                    0.126

S            52.9    21.4   20.8
R-Sq        25.07   88.22  89.38
R-Sq(adj)   22.07   87.24  88.00
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero 2 on 35 predictors, with N = 27
N(cases with missing observations) = 14 N(all cases) = 41

Step	1	2	3	4	5
Constant	23.49	93.79	1216.44	2057.16	2446.09
Cond*Cl	90	597	630	633	643
T-Value	1.81	5.80	6.69	7.13	8.05
P-Value	0.082	0.000	0.000	0.000	0.000
Cond*Br		-309	-343	-361	-385
T-Value		-5.23	-6.21	-6.83	-7.95
P-Value		0.000	0.000	0.000	0.000
pH			-134	-211	-269
T-Value			-2.49	-3.30	-4.34
P-Value			0.020	0.003	0.000
F2				-44	-63
T-Value				-1.96	-2.92
P-Value				0.062	0.008
DO*Cond					50
T-Value					2.50
P-Value					0.021
S	281	196	178	168	151
R-Sq	11.63	58.73	67.52	72.37	78.72
R-Sq(adj)	8.10	55.29	63.28	67.35	73.65

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero 3 on 35 predictors, with N = 27
N(cases with missing observations) = 14 N(all cases) = 41

Step	1	2
Constant	238.1	743.0
F*Br	-17.7	-21.0
T-Value	-1.83	-2.16
P-Value	0.080	0.041
TEMP.		-22
T-Value		-1.51
P-Value		0.144
S	298	291
R-Sq	11.77	19.43
R-Sq(adj)	8.24	12.71

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 4 on 27 predictors, with N = 17


Step              1        2
Constant   -1.8042  -0.9600

F*Temp       0.149    0.162
T-Value       1.85     2.11
P-Value      0.083    0.053

Cond*Cl               -0.64
T-Value               -1.63
P-Value               0.125

S             6.40     6.07
R-Sq         18.66    31.68
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 6 on 35 predictors, with N = 23
N(cases with missing observations) = 18 N(all cases) = 41


Step            1       2       3       4       5
Constant    835.3  1831.1  2388.9  2634.4  2570.2

P.H.          -96    -188    -241    -268    -279
T-Value     -1.65   -2.60   -3.34   -3.74   -4.15
P-Value     0.114   0.017   0.003   0.002   0.001

F2                    -55     -68     -65     -71
T-Value             -1.94   -2.53   -2.49   -2.88
P-Value             0.066   0.021   0.023   0.010

Temp*BR                     -1.41  -15.37  -18.46
T-Value                     -2.03   -1.71   -2.16
P-Value                     0.057   0.105   0.045

Temp*Cl                                29      35
T-Value                              1.56    1.98
P-Value                             0.137   0.064

COND.                                         353
T-Value                                      1.92
P-Value                                     0.071

S             200     188     175     169     158
R-Sq        11.48   25.52   38.78   46.03   55.67
R-Sq(adj)    7.27   18.07   29.11   34.03   42.63
```

Figure 4. Minitab Output for Cooling Tower 285-11F Evaluation

Table 2. Significant Variables for Cooling Tower285-11F

	Significant Variables	Adjusted R^2
Total	None	NA
Sero 1	Conductivity* Chlorine, Conductivity*Bromine, Chlorine*Bromine	88.00
Sero 2	Conductivity*Chlorine, Conductivity* Bromine, pH, Filters^2, Dissolved Oxygen*Conductivity	73.65
Sero 3	Filters*Bromine, Temperature	12.71
Sero 4	Filters*Temperature, Conductivity* Chlorine	21.92
Sero 6	pH, Filters^2, Temperature*Bromine, Temperature*Chlorine, Conductivity	42.63

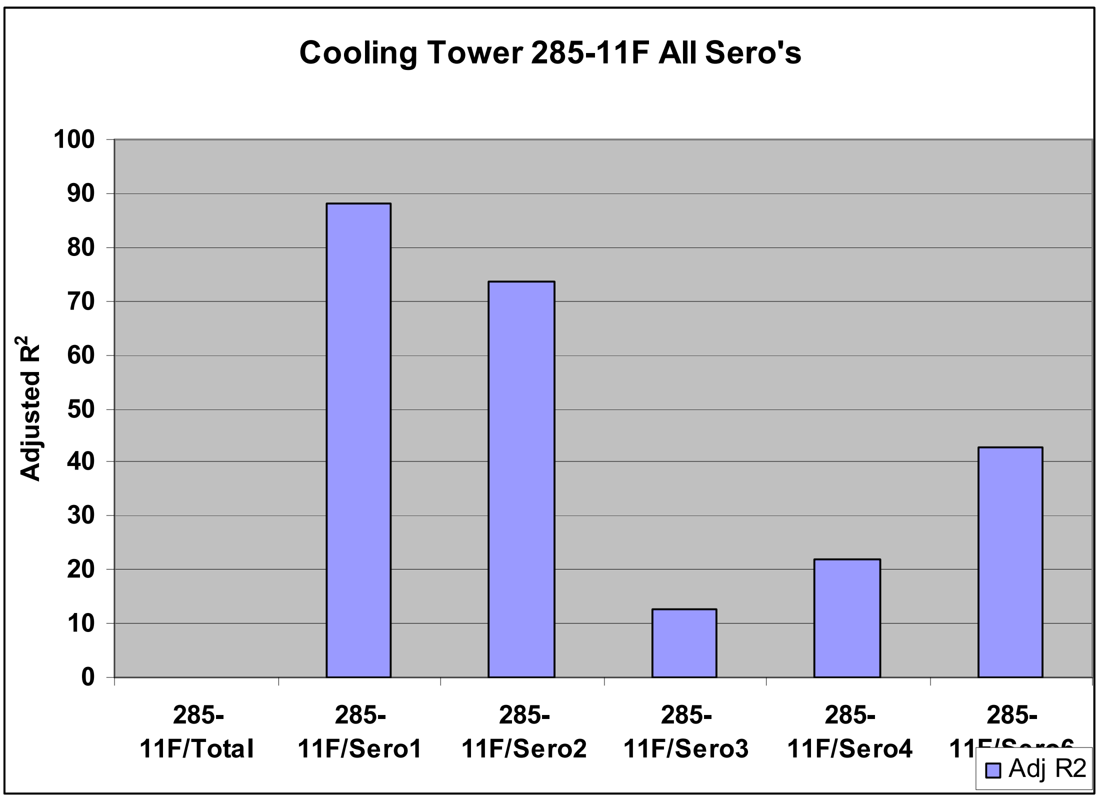

Figure 5. 285-11F Cooling Tower R^2 Graph

Evaluation of all the data from this cooling tower shows that conductivity, chlorine, and bromine levels are significant in and of themselves or in a first order interaction with all serogroups. Other factors may be significant with a specific serogroup. Also, the total does not show any significant variables. Perhaps any significance is masked by putting all of the serogroups together indicating a specific serogroup response.

The various serogroups show a significant difference in that the significant factors vary from serogroup to serogroup.

Serogroup 1 shows a relationship involving conductivity, chlorine, and bromine in several interactions. When the conductivity and chlorine interaction rises, the level of *Legionella* also rises. The opposite is true with the interaction of conductivity and bromine—when the interaction rises, the cooling tower water *Legionella* concentration drops. Also when the interaction of chlorine and bromine rises, the *Legionella* concentration drops. The conclusion here is that a rise in conductivity may be correlated with a rise in *Legionella*, but a rise in chlorine and/or bromine is probably correlated with a *Legionella* decrease. The R^2 for this relationship shows a high coefficient of determination.

Serogroup 2 shows a relationship with a number of other factors, which includes conductivity and chlorine or bromine, like Sero 1. The interactions including conductivity; however they are not always the same direction. Higher conductivity with chlorine and dissolved oxygen indicates a higher level of *Legionella,* while the opposite is true of the conductivity/bromine interaction. The interactions with chlorine and bromine are similar to that noted for Serogroup 1. However, pH and the square of the number of filters is also noted as significant, with *Legionella* levels falling with a rise in pH and the square of the number of filters used. The R^2 for these relationships shows a fairly high coefficient of determination.

Serogroup 3 shows a relationship between temperature and the number of filters used and the bromine levels. Both relationships show a reduced level of *Legionella* with raised levels of the variables. The R^2 for this set of relationships is very weak, indicating some other factor(s) is (are) significant but are not included in the analysis.

Serogroup 4 shows a relationship with the interactions of temperature/number of filters and conductivity/chlorine levels. An increase in temperature/filters produces a higher level of *Legionella*, while an increase in conductivity/chlorine level produces a lower level of *Legionella*. The R^2 for this set of relationships is weak, indicating that these variables explain little of the variation in the response.

Serogroup 6 shows relationships with a number of different variables, including the interactions temperature/bromine levels and temperature/chlorine levels. It indicates a rise in temperature/bromine lowers the *Legionella* levels, while a rise in temperature/chlorine interaction predicts a rising *Legionella* level. Other significant factors include pH (rise in pH predicts lower *Legionella*), square of filters (rise in number of filters predicts lower *Legionella*) and conductivity (rise in conductivity predicts raised *Legionella* levels). The R^2 for this set of relationships is weak, indicating that these variables explain little of the variation in the response.

Analysis of all serogroups for this cooling tower indicates that each specific serogroup has different significant factors influencing cooling water concentrations, with some of the relationships fairly strong while others are very weak. Some factors are consistent between serogroups, but most are not. See Figures 30 through 54 for graphical representations of factors.

4.7 COOLING TOWER 285-11H

4.7.1 Operation

Cooling tower 285-11H consists of a four cell galvanized metal frame cross flow induced draft cooling tower with plastic drift eliminators installed in 2005. It is fed with service water (pH adjusted) and is treated with Chemtreat C-2189 with a target concentration of between 0.2 and 0.5 ppm with continuous addition. Flow rate is 12,000 gpm maximum, or 3000 gpm per cell.

4.7.2 Data

Cooling tower 285-11H had data available from 10/31/2005 to 9/2/2008 for forty-one (41) chemical and *L. pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 6 followed by the regression recap for the cooling tower 285-11H in Table 3.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 24
N(cases with missing observations) = 17 N(all cases) = 41


No variables entered or removed
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 1 on 35 predictors, with N = 24
N(cases with missing observations) = 17 N(all cases) = 41


Step             1        2
Constant    -5.939  153.714

Temp2       0.0133   0.3135
T-Value       2.88     7.16
P-Value      0.009    0.000

TEMP.                 -13.9
T-Value               -6.87
P-Value               0.000

S             2.33     1.32
R-Sq         27.44    77.66
R-Sq(adj)    24.14    75.53
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 2 on 35 predictors, with N = 24
N(cases with missing observations) = 17 N(all cases) = 41


Step             1        2
Constant    -4.200  110.291

Temp2       0.0093   0.2246
T-Value       2.69     6.23
P-Value      0.013    0.000

TEMP.                 -10.0
T-Value               -5.98
P-Value               0.000

S             1.75     1.09
R-Sq         24.77    72.19
R-Sq(adj)    21.35    69.54
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 20
N(cases with missing observations) = 1 N(all cases) = 21

Step            1       2       3       4
Constant   -2.050  -6.091  28.627  39.724

Temp2      0.0106  0.0143  0.0082
T-Value      1.73    2.27    1.39
P-Value     0.101   0.036   0.185

DO2                 0.075   0.771   0.897
T-Value              1.61    2.88    3.47
P-Value             0.127   0.011   0.003

D.O.                         -9.9   -11.9
T-Value                     -2.63   -3.37
P-Value                     0.018   0.004

S            3.45    3.31    2.85    2.93
R-Sq        14.25   25.54   48.01   41.76
R-Sq(adj)    9.49   16.78   38.26   34.91
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 4 on 35 predictors, with N = 24
N(cases with missing observations) = 17 N(all cases) = 41

No variables entered or removed
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 6 on 35 predictors, with N = 18
N(cases with missing observations) = 23 N(all cases) = 41

Step            1       2
Constant    1.478  22.456

P.H.       -0.181  -5.880
T-Value     -2.69   -3.62
P-Value     0.016   0.003

pH2                  0.38
T-Value              3.51
P-Value             0.003

S           0.202   0.154
R-Sq        31.09   62.13
R-Sq(adj)   26.79   57.08
```

Figure 6. Minitab Output for Cooling Tower 285-11H Evaluation

Table 3. Significant Variables for 285-11H Cooling Tower

	Significant Variables	Adjusted R^2
Total	None	NA
Sero 1	Temp, $Temp^2$	75.53
Sero 2	Temp, $Temp^2$	69.54
Sero 3	DO, DO^2	34.91
Sero 4	None	NA
Sero 6	pH, pH^2	57.08

Evaluation of all of this data shows that temperature, dissolved oxygen, and pH levels are significant in and of themselves (main effects), or squares or first order interactions with all serogroups (Table 3). Other factors may be significant with a specific serogroup. Also, the total does not show any significant variables. Perhaps any significance is masked by putting all of the serogroups together.

Serogroups 1 and 2 have the same significant variables, acting the same way and the estimated effects have the same sign for each serogroup. In both cases, temperature and the square of the temperature are significant with a rise in the square predicting a rise in *Legionella*, and a rise in temperature predicting a drop in *Legionella*. Both correlations predict a lowering of *Legionella* as temperature rises from 10^oC to 20^oC, with an increase above 20^oC. Calculations show all factors are very significant (p=0.000), and have fairly similar and fairly strong R^2's.

Serogroup 3 evaluation shows dissolved oxygen levels and the square of the dissolved oxygen levels are the only significant factors, again in opposite ways, which indicates some variety of downward open parabola, with the high (turning) point at about 7. Both factors are significant ($p<0.005$) with a fairly weak R^2.

Serogroup 4 has no significant predictors for this data set.

Serogroup 6 evaluation shows pH and the square of pH to be the significant factors, again with opposite impacts. In this case, the coefficients of the two variables are so different that the predicted *Legionella* concentration drops significantly as the pH rises. The coefficient of the square value is so small as to render the calculation close to a straight line over the zone of interest. The point of inflection is above pH of 8.0. Both factors are significant ($p = 0.003$) with an R^2 of 57.08.

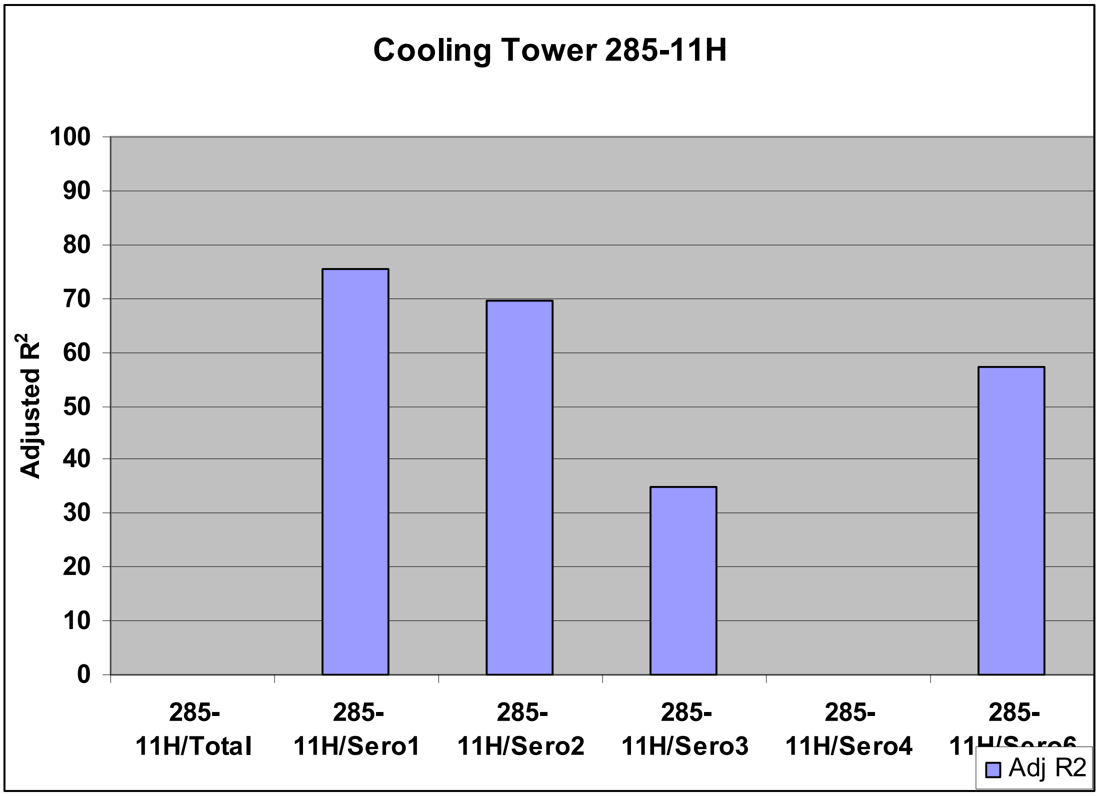

Figure 7. 285-11H Cooling Tower R^2 Graph

4.8 COOLING TOWER 264-3H

4.8.1 Operation

Cooling tower 264-3H consists of a three cell stainless steel cooling tower installed in 2005. It is fed with domestic water (chlorinated and pH adjusted) and includes a continuous feed system which introduces ozone with an ORP Target of 625. Maximum flow rate is 780 gpm per cell.

4.8.2 Data

Cooling tower 264-3H had data available from 10/31/2005 to 9/2/2008 for forty-two (42) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 8.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 35 predictors, with N = 24
N(cases with missing observations) = 18 N(all cases) = 42

Step            1         2         3          4
Constant   -17.63  -407.12  8014.83  12676.42

Temp*Br      20.3      18.9      14.7       42.9
T-Value      3.06      2.97      2.24       2.65
P-Value     0.006     0.007     0.036      0.016

pH2                    5.1     123.4      179.2
T-Value               1.78      1.81       2.54
P-Value              0.090     0.085      0.020

P.H.                           -1998      -3019
T-Value                        -1.74      -2.49
P-Value                        0.097      0.022

F*Br                                       -607
T-Value                                   -1.88
P-Value                                   0.075

S            92.6      88.4      84.4       79.5
R-Sq        29.92     39.08     47.08      55.40
R-Sq(adj)   26.73     33.28     39.14      46.01
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 1 on 35 predictors, with N = 24
N(cases with missing observations) = 18 N(all cases) = 42

Step           1      2
Constant   22.12  22.36

D.O.        -2.5   -3.4
T-Value    -1.69  -2.28
P-Value    0.105  0.033

Cond*Cl             97
T-Value           1.87
P-Value          0.075

S           11.2   10.6
R-Sq       11.52  24.18
R-Sq(adj)   7.50  16.96
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 2 on 35 predictors, with N = 24
N(cases with missing observations) = 18 N(all cases) = 42


Step              1
Constant    -0.5610

Temp2        0.0030
T-Value        1.79
P-Value       0.088

S              1.27
R-Sq          12.68
R-Sq(adj)      8.71
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero3 on 35 predictors, with N = 5
N(cases with missing observations) = 17 N(all cases) = 22


Step            1
Constant    7.346

Cond*Cl       222
T-Value      2.09
P-Value     0.127

S            11.2
R-Sq        59.40
R-Sq(adj)   45.86
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 4 on 35 predictors, with N = 24
N(cases with missing observations) = 18 N(all cases) = 42

Step            1        2        3         4
Constant   -28.98  -402.01  6434.04  10548.91

Temp*Br      20.5     19.2     15.8      40.7
T-Value      3.50     3.44     2.72      2.83
P-Value     0.002    0.002    0.013     0.011

pH2                    4.9    100.9     150.1
T-Value               1.94     1.67      2.39
P-Value              0.066    0.110     0.027

P.H.                          -1622     -2523
T-Value                       -1.59     -2.35
P-Value                       0.127     0.030

F*Br                                     -535
T-Value                                 -1.87
P-Value                                 0.077

S            82.3     77.6     74.9      70.6
R-Sq        35.72    45.49    51.61     59.15
R-Sq(adj)   32.80    40.30    44.35     50.55
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 6 on 35 predictors, with N = 19
N(cases with missing observations) = 23 N(all cases) = 42

Step            1       2       3       4
Constant   -4.153  -2.183   9.327  75.536

Br2           205     488     674     664
T-Value      4.20    8.68   15.23   16.14
P-Value     0.001   0.000   0.000   0.000

Cl*Br                -790    -770    -760
T-Value             -5.84  -10.14  -10.84
P-Value             0.000   0.000   0.000

Temp*Br                     -4.94   -4.63
T-Value                     -5.99   -5.96
P-Value                     0.000   0.000

P.H.                                 -7.6
T-Value                             -1.92
P-Value                             0.076

S            13.8    8.02    4.50    4.14
R-Sq        50.91   84.32   95.38   96.35
R-Sq(adj)   48.02   82.36   94.46   95.30
```

Figure 8.   Minitab Output for 264-3H Cooling Tower Evaluation

Regression recap for 264-3H cooling tower is as follows:

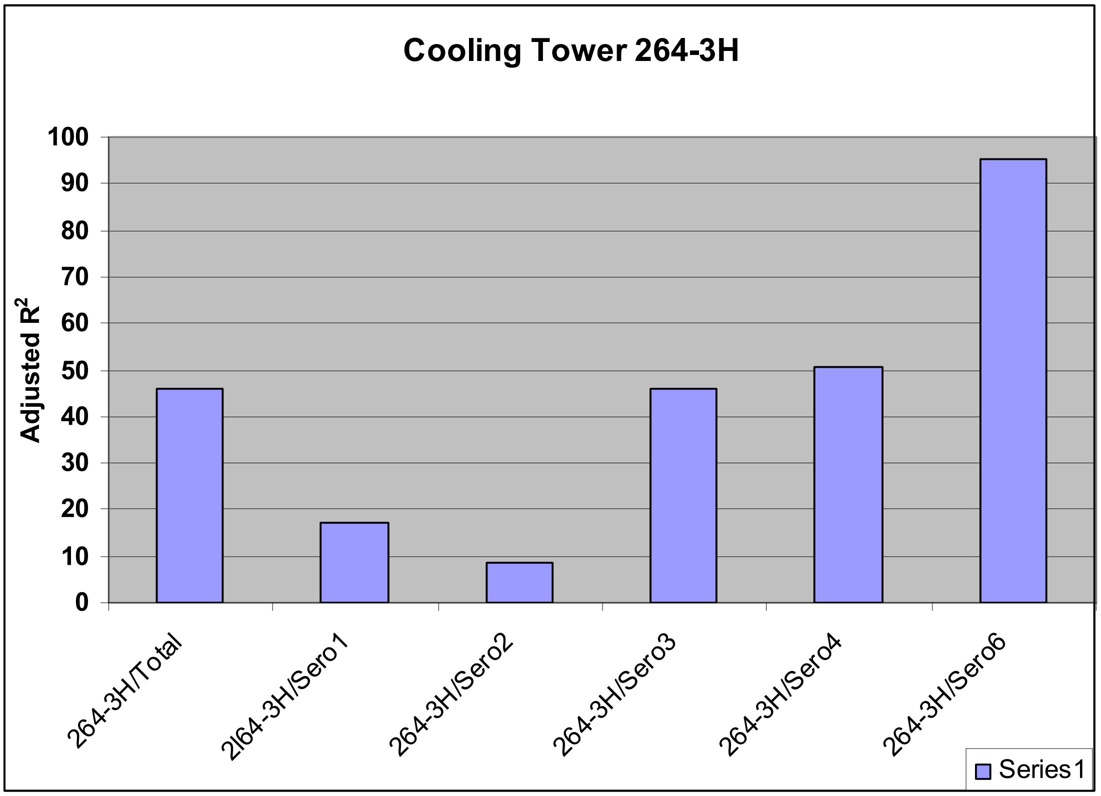

Figure 9. 264-3H Cooling Tower R^2 Graph

Table 4. Significant Variables for 264-3H Cooling Tower

	Significant Variables	Adjusted R^2
Total	Temp*Br, pH^2, pH, Filters*Br	46.01
Sero 1	DO, Cond*Cl	16.96
Sero 2	$Temp^2$	8.71
Sero 3	Cond*Cl	45.86
Sero 4	Temp*Br, pH^2, pH, F*Br	50.55
Sero 6	pH, Br^2, Cl*Br, Temp*Br	95.30

Evaluation of the significant variables for this cooling tower shows a number of factors which are significant; in fact every water chemistry variable is included at least once in some variety or combination in the analysis. The most frequently-found variable is bromine, which shows up seven times in some combination with other variables, or as a square function. The only variable which shows up as a stand-alone variable is pH with Sero 4, and pH^2 is also a variable for that serogroup.

The only serogroup to show a strong R^2 is Serogroup 6, which includes pH, temperature, and chlorine/bromine as significant variables. Total L*egionella*, Serogroup 3 and Serogroup 4 all have R^2's which indicate some relationship exists with their variables, but the models only explain about half of the variation in the response data.

4.9 COOLING TOWER 218-2H

4.9.1 Operation

Cooling tower 218-2H consists of a four cell galvanized cooling tower with plastic drift eliminators and fill installed in 1998. It is fed with domestic water (chlorinated and pH adjusted) and includes a feed system which adds GEBETZ Spectrus OX1212 four times per day with a target of 1-2 mg/L total chlorine and 0.2-0.5 mg/L free chlorine level. Additional chemicals include GEBETZ Dianodic 2470 20-30 mg/L. Flow rate is 1350 gpm per cell, for a total capacity of 5,400 gpm.

4.9.2 Data

Cooling tower 218-2H had data available from 4/5/2005 to 9/2/2008 for forty-five (45) chemical and *L. pneumophila* monitoring data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 10.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 35 predictors, with N = 26
N(cases with missing observations) = 19 N(all cases) = 45

Step            1        2
Constant   -881.2  -1213.1

pH2          13.1     19.0
T-Value      1.98     2.69
P-Value     0.059    0.013

F*Cond                 -90
T-Value              -1.84
P-Value              0.079

S             150      143
R-Sq        14.05    25.05
R-Sq(adj)   10.47    18.53
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 1 on 35 predictors, with N = 26
N(cases with missing observations) = 19 N(all cases) = 45

Step            1      2       3
Constant   10.810  9.930  15.965

Temp*Br      3.50   8.09    4.76
T-Value      3.59   3.89    1.78
P-Value     0.001  0.001   0.089

F*Br                 -57     -86
T-Value            -2.44   -3.17
P-Value            0.023   0.004

Br2                          338
T-Value                     1.86
P-Value                    0.077

S            18.2   16.6    15.8
R-Sq        34.97  48.32   55.32
R-Sq(adj)   32.26  43.83   49.23
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 2 on 35 predictors, with N = 26
N(cases with missing observations) = 19 N(all cases) = 45

Step           1      2      3      4        5        6
Constant   36.37  67.09  54.14  18.35  -130.86  -193.42

COND.        -29    -97   -100    -65      350      500
T-Value    -2.62  -3.16  -3.34  -1.79     1.85     2.61
P-Value    0.015  0.004  0.003  0.088    0.080    0.017

Cond 2                33     34     45       77       88
T-Value             2.34   2.45   2.96     3.83     4.50
P-Value            0.028  0.023  0.008    0.001    0.000

F*Temp                     0.32   1.39     5.10     5.77
T-Value                    1.51   1.94     2.85     3.39
P-Value                   0.144  0.066    0.010    0.003

F*Cond                             -33     -152     -216
T-Value                          -1.56    -2.67    -3.49
P-Value                          0.134    0.015    0.002

Temp*Cond                                  -9.9    -11.7
T-Value                                   -2.23    -2.77
P-Value                                   0.038    0.012

F2                                                   9.4
T-Value                                             2.01
P-Value                                            0.059

S           14.7   13.5   13.1   12.7     11.7     10.9
R-Sq       22.30  37.26  43.18  49.07    59.19    66.36
R-Sq(adj)  19.06  31.81  35.43  39.37    48.99    55.74
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 23

Step           1
Constant   257.5

Filters     -105
T-Value    -1.87
P-Value    0.076

S            131
R-Sq       14.26
R-Sq(adj)  10.17
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 4 on 35 predictors, with N = 26
N(cases with missing observations) = 19 N(all cases) = 45

Step           1       2
Constant   376.7  4718.0

P.H.         -41   -1008
T-Value    -3.07   -2.13
P-Value    0.005   0.044

pH2                   54
T-Value             2.04
P-Value            0.053

S           16.8    15.8
R-Sq       28.17   39.19
R-Sq(adj)  25.18   33.90
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 6 on 35 predictors, with N = 21
N(cases with missing observations) = 24 N(all cases) = 45

Step           1      2
Constant   -2773  -4244

P.H.         323    504
T-Value     2.07   2.81
P-Value    0.052  0.011

F*Cond              -98
T-Value           -1.79
P-Value           0.091

S            152    144
R-Sq       18.41  30.71
R-Sq(adj)  14.11  23.01
```

Figure 10. Minitab Output for 218-2H Cooling Tower Evaluation

Regression recap for 218-2H cooling tower is shown in Table 5.

Table 5. Significant Variables for 218-2H Cooling Tower

	Significant Variables	Adjusted R^2
Total	Temp*Br, Filters*Bromine, Br^2	18.53
Sero 1	Cond, $Cond^2$, Filters*Temp, Filters*Cond, Temp*Cond, $Filters^2$	49.23
Sero 2	$Temp^2$	55.74
Sero 3	Filters	10.17
Sero 4	pH, pH^2	33.90
Sero 6	pH, Filters*Conductivity	23.01

Analysis of the variables and various serogroups reveals no significant information. The best R^2's are in the 50% range (Serogroups 1 and 2) showing that approximately 50% of the variance is not explained, and the total and other serogroups have such a low R^2 that they are very poor models. It is noted that a good number of the identified significant variables include conductivity and the number of filters used in evaluation of the samples. Both of these items could be related to water quality, a piece of information which is seen in some other cooling towers.

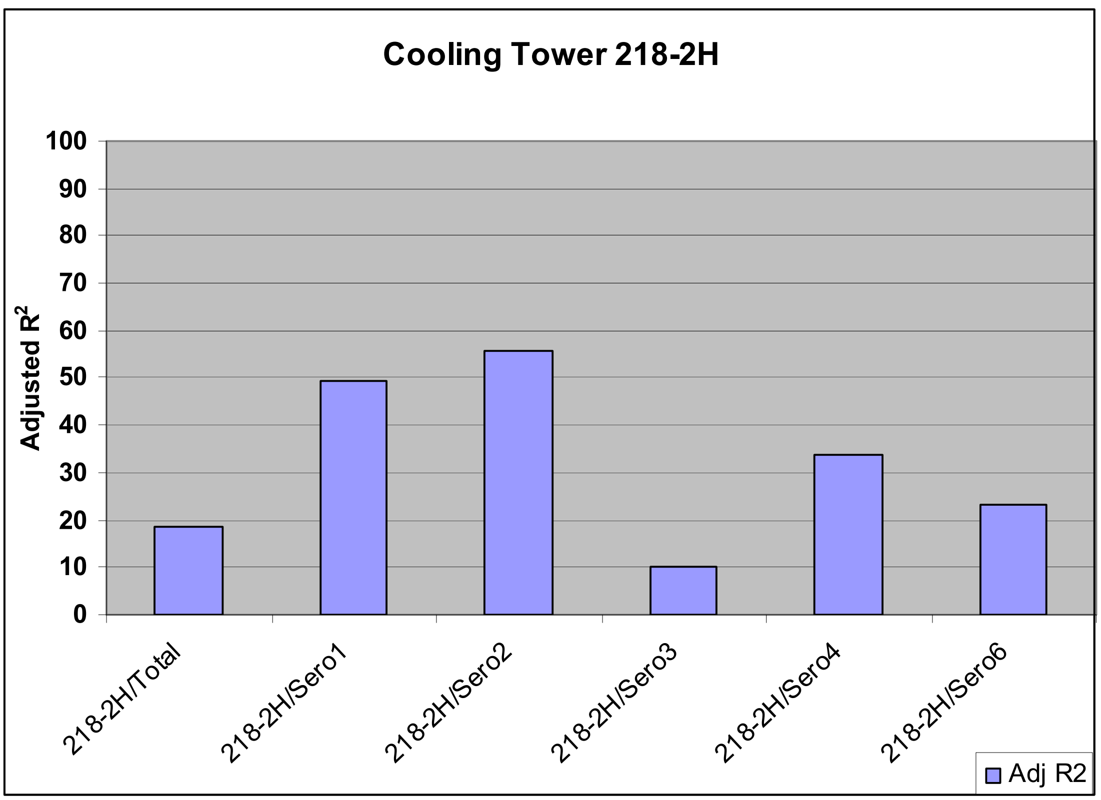

Figure 11. Cooling Tower R^2 218-2H Graph

4.10 COOLING TOWER 785-A

4.10.1 Operation

Cooling tower 785-A consists of a three cell wooden frame on concrete basin cooling tower with plastic drift eliminators installed in 1984. It is fed with service water (pH adjusted) and includes an automatic feed system which includes a NALCO TRASAR 3000 Corrosion Controller TRASAR 3D189 inhibitor. Capacity is 9,000 gpm (3000 gpm per cell) at maximum flow.

4.10.2 Data

Cooling tower 785-A had data available from 10/31/2005 to 9/2/2008 for forty-one (41) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 12.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 25
N(cases with missing observations) = 16 N(all cases) = 41


Step            1
Constant   -89.30

F*Temp        3.0
T-Value      2.48
P-Value     0.021

S            88.5
R-Sq        21.12
R-Sq(adj)   17.69
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 1 on 35 predictors, with N = 25
N(cases with missing observations) = 16 N(all cases) = 41


No variables entered or removed
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 2 on 35 predictors, with N = 25
N(cases with missing observations) = 16 N(all cases) = 41


Step            1       2
Constant   0.2387  6.3331

F2           1.74    1.80
T-Value      1.91    2.04
P-Value     0.069   0.054

DO*Cond             -1.10
T-Value             -1.56
P-Value             0.133

S            10.1    9.78
R-Sq        13.66   22.28
R-Sq(adj)    9.90   15.21
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero3 on 27 predictors, with N = 20
N(cases with missing observations) = 1 N(all cases) = 21


Step            1       2
Constant   -18.67  165.36

F2           13.4    64.6
T-Value      1.82    2.14
P-Value     0.085   0.047

F*Temp               -8.5
T-Value             -1.74
P-Value             0.100

S            84.8    80.4
R-Sq        15.60   28.36
R-Sq(adj)   10.91   19.93
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 4 on 35 predictors, with N = 25
N(cases with missing observations) = 16 N(all cases) = 41


Step            1
Constant   -99.37

F*Temp        2.7
T-Value      2.28
P-Value     0.032

S            87.9
R-Sq        18.49
R-Sq(adj)   14.95
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 6 on 35 predictors, with N = 19
N(cases with missing observations) = 22 N(all cases) = 41


No variables entered or removed
```

Figure 12. Minitab Output for 785-A Cooling Tower Evaluation

Regression recap for 785-A cooling tower is as follows:

Table 6. Significant Variables for Cooling Tower 785-A

	Significant Variables	Adjusted R^2
Total	Filters*Temp	17.69
Sero 1	None	NA
Sero 2	DO*Cond, $Filters^2$	15.21
Sero 3	$Filters^2$, Filters*Temp	19.93
Sero 4	Filters*Temp	14.95
Sero 6	None	NA

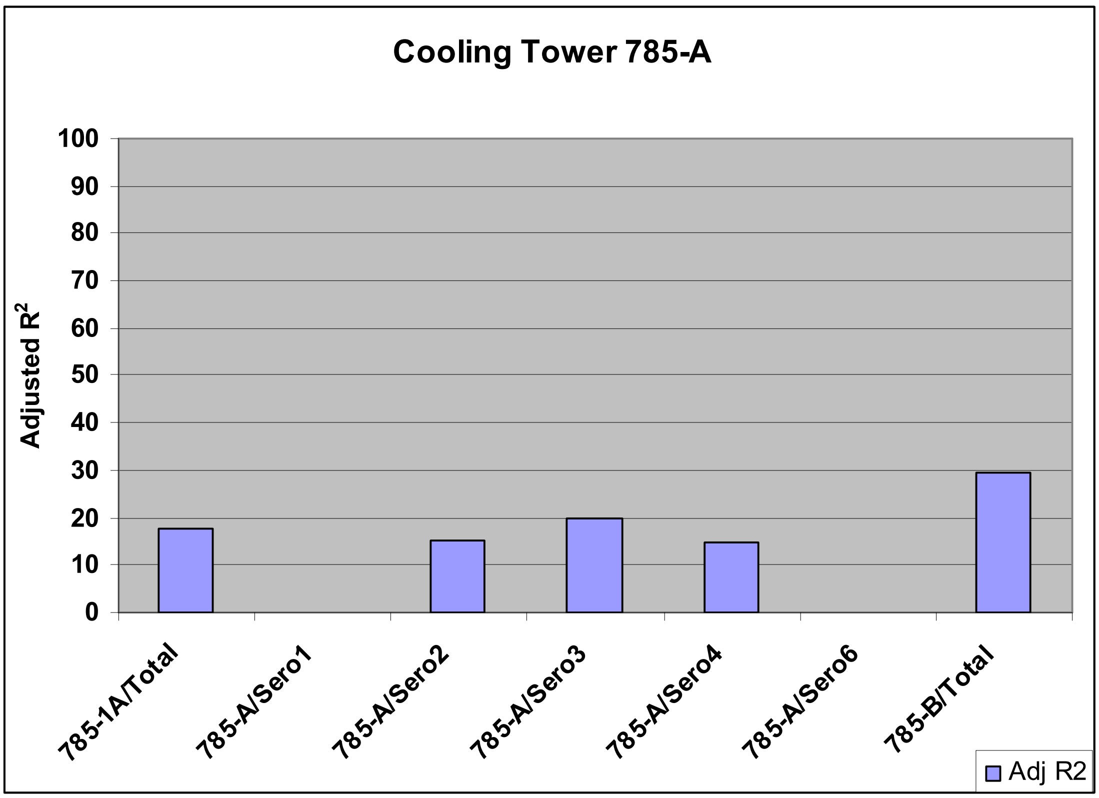

Figure 13. 785-A Cooling Tower R^2 Graph

Review of the results of the statistical evaluation of this cooling tower shows only weakly (R^2<20) effective models total and all serogroups. The evaluation did flag temperature and number of filters as being significant factors in the total and some serogroups.

4.11 COOLING TOWER 785-B

4.11.1 Operation

Cooling tower 785-B consists of a three cell galvanized cross flow induced draft cooling tower with plastic drift eliminators and fill installed in 2001. It is fed with domestic water (chlorinated and pH adjusted) and contains an automatic feed system which includes ozone for biocide. The Blowdown is a conductivity based Blowdown controller triggered at 750 micromhos. Capacity is 2200 gpm per cell, for a total capacity of 6600 gpm.

4.11.2 Data

Cooling tower 785-B had data available from 10/31/2005 to 9/2/2008 for thirty-four (34) chemical and *L pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 14.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 35 predictors, with N = 28
N(cases with missing observations) = 6 N(all cases) = 34

Step           1      2
Constant   437.0  437.9

DO*Cond      -49    -57
T-Value    -2.42  -3.05
P-Value    0.023  0.005

DO*Cl                45
T-Value            2.50
P-Value           0.019

S            209    191
R-Sq       18.41  34.73
R-Sq(adj)  15.27  29.51
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 1 on 35 predictors, with N = 28
N(cases with missing observations) = 6 N(all cases) = 34


Step           1      2       3       4
Constant   160.9  888.0  1074.8  1083.1
```

```
TEMP.        -6.2  -70.2   -83.1   -82.1
T-Value     -2.67  -1.97   -2.44   -2.53
P-Value     0.013  0.060   0.023   0.019

Temp2               1.39    1.65    1.60
T-Value             1.80    2.25    2.28
P-Value            0.085   0.034   0.032

DO*Cond                     -6.3   -12.1
T-Value                    -2.08   -2.87
P-Value                    0.049   0.009

F*Cond                                22
T-Value                             1.89
P-Value                            0.072

S            33.9   32.5    30.6    29.1
R-Sq        21.57  30.52   41.10   49.00
R-Sq(adj)   18.55  24.97   33.74   40.13
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero 2 on 35 predictors, with N = 28
N(cases with missing observations) = 6 N(all cases) = 34


Step            1
Constant    80.63

Temp*pH     -0.33
T-Value     -1.68
P-Value     0.105

S            27.7
R-Sq         9.77
R-Sq(adj)    6.30
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 11


Step             1       2       3       4
Constant    -46.44  239.20  242.75  227.29

F2            24.8   120.0   120.0   113.8
T-Value       4.15   17.30   19.87   21.35
P-Value      0.002   0.000   0.000   0.000

Filters               -354    -336    -305
T-Value             -13.96  -13.90  -13.52
P-Value              0.000   0.000   0.000

F*DO                          -4.2    -5.5
T-Value                      -1.89   -3.07
```

```
P-Value                    0.101   0.022

Cond*Cl                              -26
T-Value                            -2.39
P-Value                            0.054

S            46.6    9.81    8.54    6.60
R-Sq        65.73   98.65   99.10   99.54
R-Sq(adj)   61.92   98.31   98.72   99.24
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 4 on 35 predictors, with N = 28
N(cases with missing observations) = 6 N(all cases) = 34


Step           1      2
Constant   370.6  390.1

DO*Cond      -42    -49
T-Value    -2.00  -2.57
P-Value    0.056  0.016

Cl2                 170
T-Value            2.51
P-Value           0.019

S            216    197
R-Sq       13.30  30.80
R-Sq(adj)   9.97  25.26
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero 6 on 35 predictors, with N = 22
N(cases with missing observations) = 12 N(all cases) = 34
No variables entered or removed
```

Figure 14. Minitab Output for 785-B Cooling Tower Evaluation

The regression recap for Cooling Tower 785-B is as follows:

Table 7. Significant Variables for 785-A Cooling Tower

	Significant Variables	Adjusted R^2
Total	DO*Cond, DO*Br	29.51
Sero 1	Temp, $Temp^2$, Filters*Cond, DO*Cond	40.13
Sero 2	Temp*pH	6.30
Sero 3	$Filters^2$, Filters, Filters*DO, Cond*Cl	99.24
Sero 4	DO*Cond, Cl^2	25.26
Sero 6	None	NA

Inspection of the regression data shows Serogroup 3 as the only serogroup to have a strong R^2. The variables of interest with that serogroup are filters and conductivity indicating water quality, and dissolved oxygen and chlorine content. The factors on the filter values are such that one or two filters give similar results, but three filters would give a significant increase in predicted *L. Legionella* concentration of this serogroup.

The total and serogroups 1, 2, 4, and 6 provide fairly poor R^2's, with differing significant variables. No obvious conclusions can be reached from this data beyond the importance of dissolved solids from the number of filters and interactions demonstrated for *L. pneumophila* Serogroup 3.

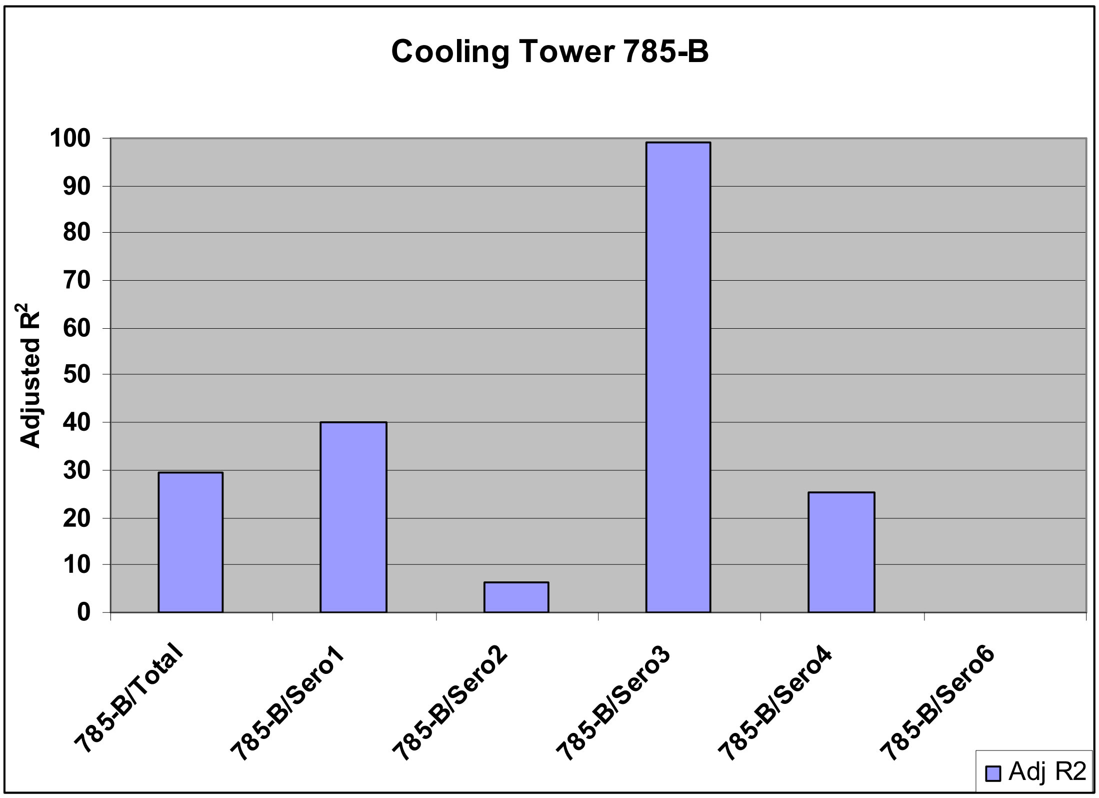

Figure 15. 785-B Cooling Tower785-B R^2 Graph

4.12 285-9H 1&2 COOLING TOWERS

4.12.1 Operation

Cooling tower 285-9H 1&2 consists of a two cell stainless steel cooling tower with plastic drift eliminators and fill installed in 2000. It is fed with domestic water (chlorinated and pH adjusted) and contains an automatic feed system which includes GEBETZ Spectrus OX1212 with a target of 1-2 mg/L total chlorine and 0.2-0.5 mg/L free chlorine level. Additional chemicals include GEBETZ Dianodic 2470 20-30 mg/L. Capacity is 4500 gpm per cell for a total capacity of 9000 gpm.

4.12.2 Data

Cooling tower 285-9H 1&2 had data available from 10/31/2005 to 9/2/2008 for forty-eight (48) chemical and *L. pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with values, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 16.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 30
N(cases with missing observations) = 18 N(all cases) = 48


Step            1       2      3       4
Constant   222.14  262.10  27.24  121.27

F*Cond         56     325    381     536
T-Value      2.04    3.25   3.70    4.09
P-Value     0.051   0.003  0.001   0.000

DO*Cond               -93   -123    -166
T-Value             -2.77  -3.29   -3.85
P-Value             0.010  0.003   0.001

DO2                          7.5    20.7
T-Value                     1.64    2.42
P-Value                    0.113   0.023

F*DO                                 -54
T-Value                            -1.80
P-Value                            0.084

S             495     444    431     414
R-Sq        12.92   32.21  38.57   45.60
R-Sq(adj)    9.81   27.19  31.48   36.90
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero1 on 35 predictors, with N = 30
N(cases with missing observations) = 18 N(all cases) = 48
```

```
Step                1          2        3       4        5          6
Constant      -41.582    -49.832   23.446   5.606   -8.549   -506.300

F*Cond             55         77      161      65
T-Value          3.76       5.23     5.51    1.35
P-Value         0.001      0.000    0.000   0.188

Cond*Cl                     -187     -186    -190     -183       -211
T-Value                    -3.04    -3.51   -3.87    -3.70      -5.00
P-Value                    0.005    0.002   0.001    0.001      0.000

Temp*Cond                           -10.3   -32.4    -40.9      -63.7
T-Value                             -3.19   -3.30    -5.35      -6.98
P-Value                             0.004   0.003    0.000      0.000

Cond*pH                                        87      128        189
T-Value                                      2.37     6.19       7.70
P-Value                                     0.026    0.000      0.000

Temp2                                                            0.84
T-Value                                                          3.50
P-Value                                                         0.002

S                 260        229      198     182      185        155
R-Sq            33.58      50.54    64.44   70.94    68.82      79.08
R-Sq(adj)       31.20      46.88    60.33   66.29    65.22      75.73

Step               7         8        9       10       11       12
Constant      -455.6    -482.9   -840.9   -264.6   -456.1   -612.6

F*Cond
T-Value
P-Value

Cond*Cl         -340      -309     -252     -239     -123
T-Value        -5.00     -4.68    -3.73    -3.96    -1.46
P-Value        0.000     0.000    0.001    0.001    0.160

Temp*Cond      -60.9     -72.6    -83.8    -89.7    -94.5   -100.2
T-Value        -7.15     -7.32    -7.80    -9.11    -9.78   -11.06
P-Value        0.000     0.000    0.000    0.000    0.000    0.000

Cond*pH          184       240      309      347      371      401
T-Value         8.11      6.81     6.62     7.86     8.49    10.09
P-Value        0.000     0.000    0.000    0.000    0.000    0.000

Temp2           0.68      0.70     0.93     1.03     1.15     1.28
T-Value         2.96      3.23     4.03     4.92     5.52     6.64
P-Value        0.007     0.004    0.001    0.000    0.000    0.000

F*Br              50        49       38       39      291      423
T-Value         2.32      2.43     1.95     2.23     2.14     4.05
P-Value        0.029     0.023    0.064    0.037    0.045    0.001

DO*Cond                    -31      -83     -108     -129     -153
T-Value                  -2.00    -2.86    -3.90    -4.52    -6.38
P-Value                  0.057    0.009    0.001    0.000    0.000

DO2                                 5.7     23.6     27.0     30.3
T-Value                            2.07     3.21     3.75     4.34
P-Value                           0.050    0.004    0.001    0.000

DO*pH                                      -25.6    -25.0    -25.4
```

```
T-Value                                    -2.58   -2.67   -2.64
P-Value                                    0.017   0.015   0.015

DO*Br                                                -96    -152
T-Value                                            -1.86   -4.24
P-Value                                            0.077   0.000

S               143     134     126     112     106     109
R-Sq          82.90   85.44   87.82   90.76   92.13   91.29
R-Sq(adj)     79.34   81.65   83.95   87.24   88.58   87.97

Step             13
Constant     -624.8

F*Cond
T-Value
P-Value

Cond*Cl
T-Value
P-Value

Temp*Cond    -103.5
T-Value      -12.50
P-Value       0.000

Cond*pH         409
T-Value       11.36
P-Value       0.000

Temp2          1.27
T-Value        7.28
P-Value       0.000

F*Br            628
T-Value        4.96
P-Value       0.000

DO*Cond        -150
T-Value       -6.93
P-Value       0.000

DO2            28.3
T-Value        4.46
P-Value       0.000

DO*pH         -19.4
T-Value       -2.14
P-Value       0.045

DO*Br          -221
T-Value       -5.12
P-Value       0.000

F*pH          -12.8
T-Value       -2.42
P-Value       0.025

S              98.1
R-Sq          93.26
R-Sq(adj)     90.23
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero2 on 35 predictors, with N = 30
N(cases with missing observations) = 18 N(all cases) = 48

No variables entered or removed

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 20
N(cases with missing observations) = 2 N(all cases) = 22

Step	1	2	3	4	5
Constant	61.81	118.86	-118.90	-116.51	1478.11
Cl2	43	138	156	156	153
T-Value	4.05	4.19	5.58	5.84	6.05
P-Value	0.001	0.001	0.000	0.000	0.000
DO*Cl		-71	-86	-72	-67
T-Value		-3.01	-4.28	-3.39	-3.28
P-Value		0.008	0.001	0.004	0.006
Temp2			0.46	0.54	3.43
T-Value			2.99	3.46	2.01
P-Value			0.009	0.003	0.064
Cond*pH				-8.5	-9.6
T-Value				-1.55	-1.85
P-Value				0.142	0.086
TEMP.					-136
T-Value					-1.70
P-Value					0.111
S	112	93.5	77.2	74.0	69.8
R-Sq	47.73	65.89	78.11	81.14	84.36
R-Sq(adj)	44.83	61.88	74.00	76.10	78.77

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero4 on 35 predictors, with N = 30
N(cases with missing observations) = 18 N(all cases) = 48

No variables entered or removed

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero6 on 35 predictors, with N = 25
N(cases with missing observations) = 23 N(all cases) = 48

Step             1        2        3         4         5         6
Constant    29.353   37.134   -7.995   -35.823   -35.019   -19.265

Br2            8.7    333.6    801.5     935.9     854.5     583.1
T-Value       3.28     2.19     3.01      3.63      3.35      2.36
P-Value      0.003    0.040    0.007     0.002     0.003     0.030

Cl2                   -1712    -4484     -5198     -4753     -3252
T-Value               -2.13    -2.93     -3.53     -3.26     -2.32
P-Value               0.044    0.008     0.002     0.004     0.032

Temp*Cl                         24.0      24.5      23.2      17.7
T-Value                         2.08      2.27      2.21      1.88
P-Value                        0.050     0.034     0.039     0.077

Temp*Cond                                 0.90      2.36      1.84
T-Value                                   2.01      2.23      1.93
P-Value                                  0.058     0.038     0.069

DO*Cond                                             -5.0     -16.3
T-Value                                            -1.51     -3.13
P-Value                                            0.146     0.006

F*Cond                                                          37
T-Value                                                       2.60
P-Value                                                      0.018

S             77.2     71.9     67.0      62.6      60.7      53.1
R-Sq         31.90    43.56    53.19     61.06     65.25     74.76
R-Sq(adj)    28.94    38.42    46.50     53.27     56.11     66.34

Step             7        8        9        10
Constant    -278.6   -286.1   -167.6    -189.7

Br2            373      186      138       261
T-Value       2.01     1.78     1.81      2.39
P-Value      0.061    0.092    0.088     0.030

Cl2          -2027     -928     -674     -1332
T-Value      -1.92    -1.69    -1.68     -2.30
P-Value      0.072    0.109    0.111     0.035

Temp*Cl        8.7
T-Value       1.21
P-Value      0.242

Temp*Cond     5.09     5.38     4.11      4.58
T-Value       4.88     5.25     5.14      5.52
P-Value      0.000    0.000    0.000     0.000

DO*Cond      -34.3    -36.9    -42.1     -42.8
T-Value      -5.97    -6.83   -10.30    -10.79
```

```
P-Value     0.000   0.000   0.000   0.000

F*Cond         52      56      89      85
T-Value      4.79    5.34    8.17    7.78
P-Value     0.000   0.000   0.000   0.000

D.O.         43.4    47.3    49.4    51.8
T-Value      4.16    4.68    6.77    7.19
P-Value     0.001   0.000   0.000   0.000

F*pH                         -7.6    -7.1
T-Value                     -4.20   -4.02
P-Value                     0.001   0.001

Cond*Cl                                22
T-Value                              1.52
P-Value                             0.148

S            38.5    39.0    28.1    27.1
R-Sq        87.48   86.39   93.32   94.16
R-Sq(adj)   82.32   81.86   90.57   91.25
```

Figure 16. Minitab Output for 285-9H 1&2 Cooling Tower Evaluation

Regression recap for 285-9H 1&2 cooling towers is as follows:

Table 8. Significant Variables for 285-9H 1&2 Cooling Tower

	Significant Variables	Adjusted R^2
Total	DO*Cond, DO*Br	36.90
Sero 1	Temp*Cond, Cond*pH, $Temp^2$, Filters*Br, DO*Cond, DO^2, DO*pH, DO*Br, Filters*pH	90.23
Sero 2	None	NA
Sero 3	Cl^2, $Temp^2$, DO*Cl, Cond*pH, Temp	78.77
Sero 4	None	NA
Sero 6	Br^2, Cl^2, Cl, Temp*Cond, DO*Cond, Filters*Cond, DO, Filters*pH, Cond*Cl	91.25

Both Serogroups 1 and 6 show very strong R^2's for Cooling Tower 285-9H 1&2. However, the variables involved include every piece of water chemistry data plotted, including some which do not show up as significant most of the time. This particular set of data indicates the relationship between the variables and these *Legionella* serogroups is very complex.

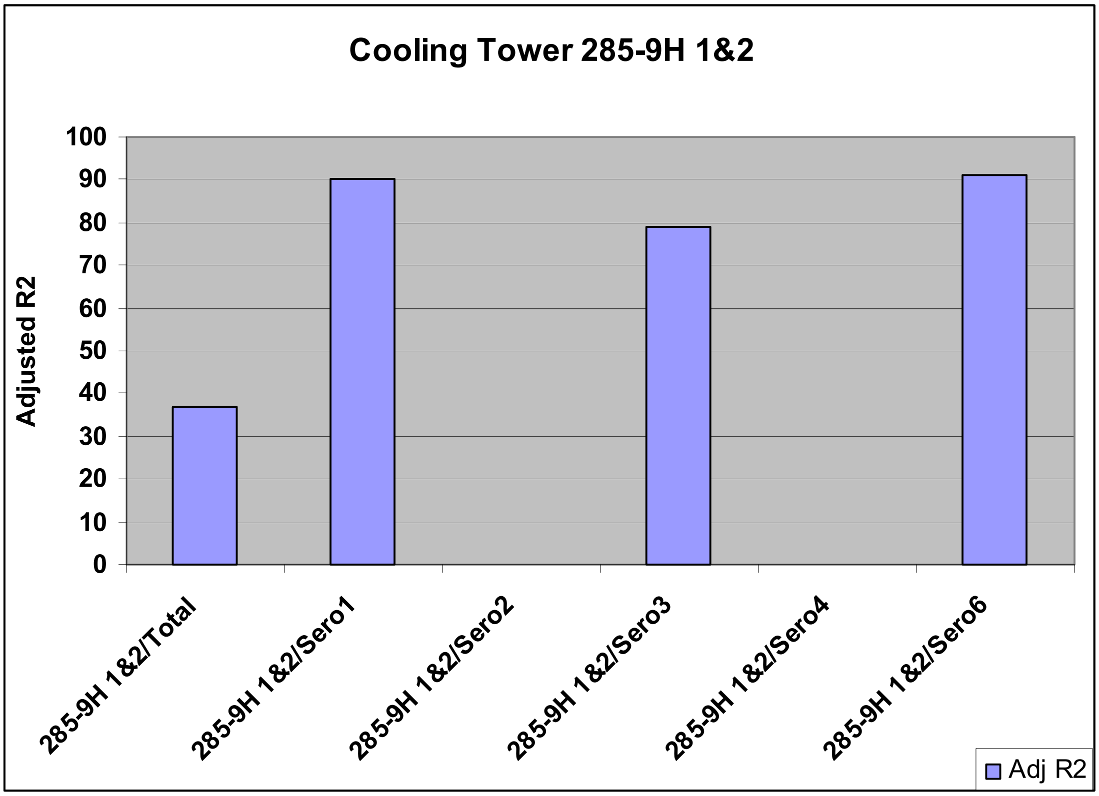

Figure 17. 285-9H 1&2 Cooling Tower R^2 Graph

4.13 COOLING TOWER 785-2A

4.13.1 Operation

Cooling tower 785-2A consists of a one cell wood frame with fiberglass fill and plastic drift eliminators installed in 1984. It is fed with domestic water (chlorinated and pH adjusted) and contains an automatic feed system which includes a NALCO TRASAR 3000 Corrosion Controller TRASAR 3D189 inhibitor at a target level of 150 ppm and a NALCO STAGREX ST70 biocide Cl/Br system controlled by a timer. The Blowdown is a conductivity based Blowdown controller triggered at 750 micromhos. The tower has a 3000 gpm capacity.

4.13.2 Data

Cooling tower 785-2A had data available from 10/31/2005 to 9/2/2008 for twenty-six (26) chemical and *L. pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 18.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 19
N(cases with missing observations) = 7 N(all cases) = 26


Step           1      2
Constant   16.33  86.80

Cl2           50    120
T-Value     3.70   6.48
P-Value    0.002  0.000

F*Cl               -143
T-Value           -4.40
P-Value           0.000

S            107   74.5
R-Sq       44.57  74.91
R-Sq(adj)  41.31  71.78
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero1 on 35 predictors, with N = 19
N(cases with missing observations) = 7 N(all cases) = 26

Step	1	2	3	4	5
Constant	-6.424	-4.492	46.007	34.819	-51.000
Cl2	53	862	819	1031	1156
T-Value	4.51	5.99	7.49	7.98	8.88
P-Value	0.000	0.000	0.000	0.000	0.000
Cl*Br		-351	-303	-398	-458
T-Value		-5.62	-6.18	-6.86	-7.73
P-Value		0.000	0.000	0.000	0.000
Cond*Cl			-231	-573	-628
T-Value			-3.61	-3.78	-4.53
P-Value			0.003	0.002	0.001
Cond*Br				162	211
T-Value				2.42	3.28
P-Value				0.030	0.006
F*DO					5.8
T-Value					2.10
P-Value					0.055
S	95.1	56.8	42.9	37.3	33.4
R-Sq	54.48	84.71	91.82	94.23	95.70
R-Sq(adj)	51.80	82.80	90.18	92.59	94.04

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

Alpha-to-Enter: 0.15 Alpha-to-Remove: 0.15

Response is Sero2 on 35 predictors, with N = 19
N(cases with missing observations) = 7 N(all cases) = 26

Step	1
Constant	-29.28
Temp2	0.066
T-Value	2.02
P-Value	0.059
S	17.6
R-Sq	19.36
R-Sq(adj)	14.62

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero3 on 27 predictors, with N = 11


Step             1       2       3
Constant    -104.1  -154.3  1228.9

Temp2        0.196   0.244   2.466
T-Value       2.83    5.27    3.54
P-Value      0.020   0.001   0.010

DO2                   0.80    0.85
T-Value               3.73    5.80
P-Value              0.006   0.001

TEMP.                         -111
T-Value                      -3.19
P-Value                      0.015

S             16.5    10.6    7.20
R-Sq         47.00   80.65   92.12
R-Sq(adj)    41.11   75.81   88.74
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero4 on 35 predictors, with N = 19
N(cases with missing observations) = 7 N(all cases) = 26


Step             1
Constant    -31.21

Temp2        0.066
T-Value       2.13
P-Value      0.048

S             16.6
R-Sq         21.03
R-Sq(adj)    16.38
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero6 on 35 predictors, with N = 13
N(cases with missing observations) = 13 N(all cases) = 26

No variables entered or removed
```

Figure 18. Minitab Output for Cooling Tower 785-2A Evaluation

Table 9. Significant Variables for 785-2A Cooling Tower

	Significant Variables	Adjusted R^2
Total	Cl^2, Filters*Cl	71.78
Sero 1	Cl^2, Cl*Br, Cond*Cl, Cond*Br, Filters*DO	94.04
Sero 2	$Temp^2$	14.62
Sero 3	DO^2, $Temp^2$, Temp	88.74
Sero 4	$Temp^2$	16.38
Sero 6	None	NA

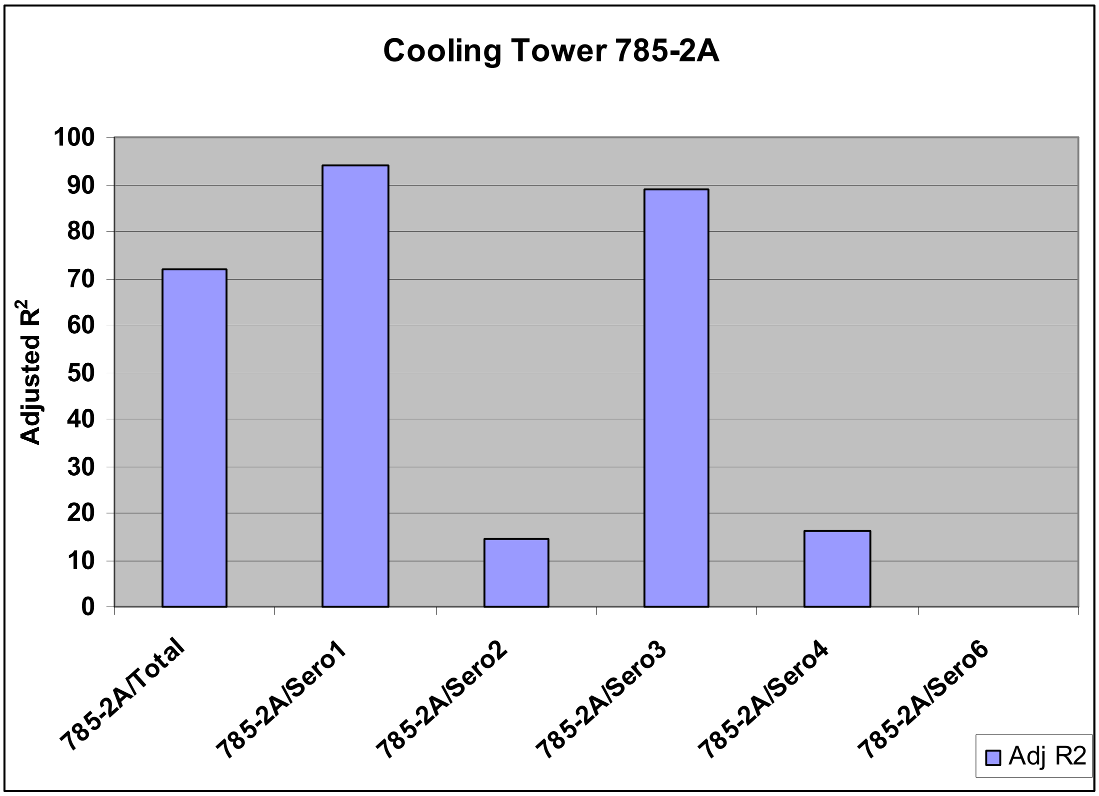

Figure 19. 785-2A Cooling Tower R^2 Graph

4.14 COOLING TOWER 785-1B

4.14.1 Operation

Cooling tower 785-1B consists of a three cell galvanized upper works/stainless steel basin Marley cross flow induced draft cooling tower with plastic drift eliminators and fill installed in 2001. It is fed with domestic water (chlorinated and pH adjusted) and includes a continuous feed system which injects ozone. The capacity of the system is 2200 gpm per cell for a total capacity of 6600 gpm.

4.14.2 Data

Cooling tower 785-1B had data available from 4/4/2005 to 5/4/2006 for fourteen (14) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated. Serogroup 6 is not included because it was not part of the monitoring program until after 5/4/2006. Bromine was not utilized in the time frame evaluated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, and pH levels included as shown in Figure 20.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 27 predictors, with N = 14

Step            1        2        3        4        5       6
Constant   -494.4  -1607.3  -2216.8  -1819.3  -1493.5  9161.4

F*Temp       29.4     28.0     28.5    180.1    224.1   224.5
T-Value      4.98     5.88     7.02     4.21     6.76    9.16
P-Value     0.000    0.000    0.000    0.002    0.000   0.000

Temp*Cond               41       40     -106     -113     605
T-Value               2.76     3.16    -2.51    -3.81    2.32
P-Value              0.019    0.010    0.033    0.005   0.053

DO*Cond                          85      614      756     724
T-Value                        2.29     4.06     6.55    8.41
P-Value                       0.045    0.003    0.000   0.000

F*DO                                    -600     -771    -771
T-Value                                -3.55    -5.90   -7.99
P-Value                                0.006    0.000   0.000

Temp2                                           -2.22  -21.56
T-Value                                         -3.19   -3.07
P-Value                                         0.013   0.018

COND.                                                  -16690
T-Value                                                 -2.76
P-Value                                                 0.028

S             286      230      195      133     93.7    69.2
R-Sq        67.39    80.73    87.34    94.72    97.67   98.89
R-Sq(adj)   64.67    77.23    83.54    92.38    96.22   97.93
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero1 on 27 predictors, with N = 14


Step             1       2      3      4       5
Constant    -238.3  -215.4  276.7  401.8   186.6

F*Temp        10.9    24.8    7.4
T-Value       8.58    4.71   1.36
P-Value      0.000   0.001  0.203

F*pH                 -37.5  -68.4  -69.1   -92.9
T-Value              -2.70  -5.92  -5.76  -10.92
P-Value              0.021  0.000  0.000   0.000

F2                            177    222     276
T-Value                      4.15   8.06   14.18
P-Value                     0.002  0.000   0.000

pH2                                         4.77
T-Value                                     4.81
P-Value                                    0.001

S             61.3    49.6   31.6   32.8    18.9
R-Sq         85.97   91.57  96.90  96.32   98.89
R-Sq(adj)    84.80   90.04  95.97  95.65   98.56
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero2 on 27 predictors, with N = 14


Step             1       2
Constant    -35.64  702.50

F2            61.9   315.6
T-Value       6.36    6.26
P-Value      0.000   0.000

Filters               -981
T-Value              -5.06
P-Value              0.000

S             78.1    44.7
R-Sq         77.11   93.13
R-Sq(adj)    75.20   91.88
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 14

Step             1       2      3      4       5
Constant    -242.9  -217.1  275.3  435.0   454.3

F*Temp        10.9    26.6    9.1  -87.5  -112.7
T-Value       8.11    4.93   1.59  -2.47   -7.27
P-Value      0.000   0.000  0.142  0.036   0.000

F*pH                   -42    -73    -18
T-Value              -2.96  -5.97  -0.80
P-Value              0.013  0.000  0.446

F2                            177    628     738
T-Value                      3.92   3.74    7.96
P-Value                     0.003  0.005   0.000

Temp2                                2.11    2.66
T-Value                              2.75    8.27
P-Value                             0.023   0.000

S             65.2    50.7   33.4   26.0    25.5
R-Sq         84.58   91.43  96.62  98.16   98.03
R-Sq(adj)    83.30   89.87  95.61  97.34   97.44
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero4 on 27 predictors, with N = 14


Step             1        2        3        4        5
Constant    -701.1  10107.2  11927.5  15406.3  15322.3

Cond 2         535     7110     8004    -1145
T-Value       4.45     3.43     4.10    -0.28
P-Value      0.001    0.006    0.002    0.789

COND.               -16938   -20125   -25919   -25756
T-Value              -3.17    -3.89    -5.28    -5.55
P-Value              0.009    0.003    0.001    0.000

Temp*Cond                        27     1295     1160
T-Value                        1.80     2.44     5.83
P-Value                       0.101    0.038    0.000

Temp2                                  -34.6    -30.9
T-Value                                -2.39    -5.78
P-Value                                0.041    0.000

S              131     99.2     90.3     74.5     71.0
R-Sq         62.27    80.31    85.14    90.90    90.82
R-Sq(adj)    59.13    76.72    80.68    86.86    88.07
```

Figure 20. Minitab Output for 785-1B Cooling Tower Evaluation

Table 10. Significant Variables for 785-1B Cooling Tower

	Significant Variables	Adjusted R^2
Total	Filters*Temp, Temp*Cond, DO*Cond, Filters*DO, $Temp^2$, Cond	97.93
Sero 1	Filters*pH, $Filters^2$, pH^2	98.56
Sero 2	Filters, $Filters^2$	91.88
Sero 3	Filters*Temp, $Filters^2$, $Temp^2$	97.44
Sero 4	Cond, Temp*Cond,$Temp^2$	88.07

Both the total and all serogroups in this cooling tower had very strong R^2's. However, in evaluating the group, number of filters (alone or in some combination) was the most common variable identified as significant, with temperature being the second. Chlorine was not identified as a significant variable at any time in this cooling tower.

One concern with this set of data is the size of the database. Fourteen points is a small sample especially when compared to the other cooling tower data bases of about forty points or longer time periods. Some SRS Cooling Towers are operated periodically for shorter periods of time, only when necessary.

Total *Legionella* in this cooling tower is predicted by six variables/combination of variables, all of which are significant (largest $p = 0.053$) and an R^2 of 97.93. This suggests a very good prediction fit. The variables included in the model include filters, temperature, conductivity, and dissolved oxygen. They include a square (temperature), one main effect (conductivity), and four first order interactions.

Serogroup 1 concentrations are predicted by three significant factors ($p<0.001$) involving either number of filters or pH. Both the interaction and the squares are identified as significant. This particular analysis produced one of the highest R^2 (98.56) in the entire project.

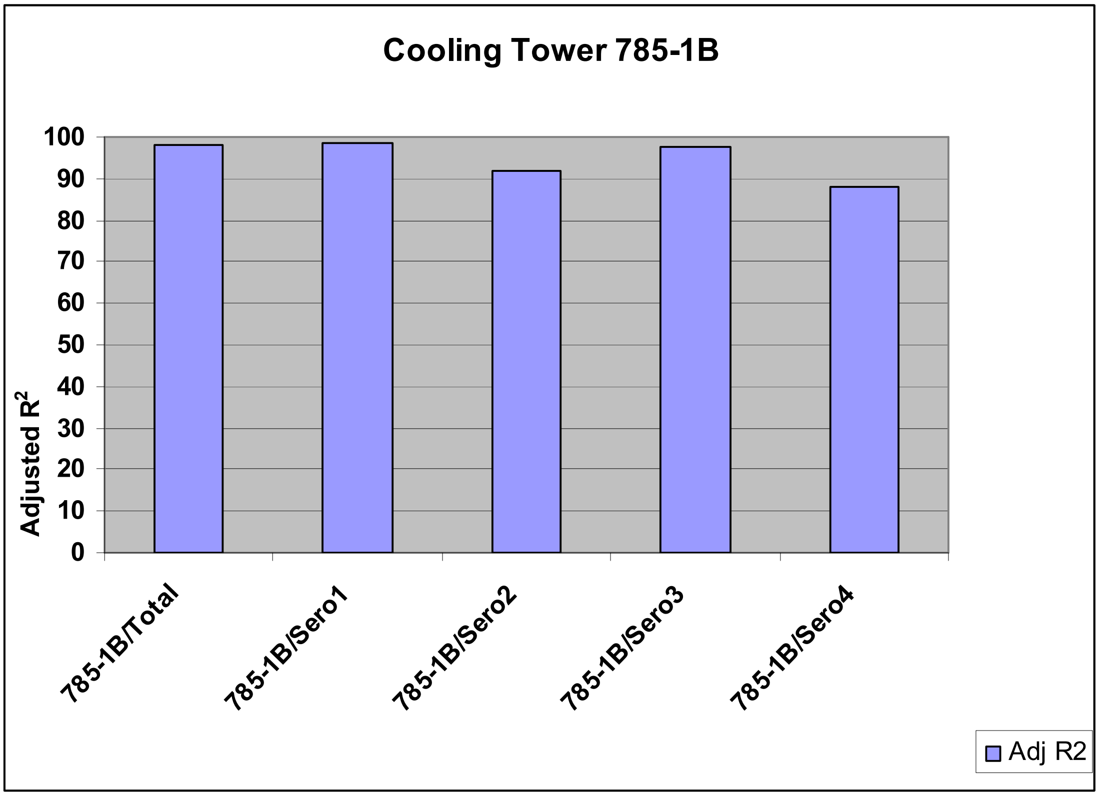

Figure 21. Cooling Tower785-1B R^2 Graph

Serogroup 2 levels are predicted by two significant factors, ($p = 0.000$) number of filters and the square of the number of filters.

Serogroup 3 levels are predicted by three significant factors ($p = 0.000$) which are the interaction between temperature and filters and the squares of temperature and filters. Here again the R^2 (97.44) is one of the higher ones in the study.

Serogroup 4 levels are predicted ($p = 0.000$) by conductivity, conductivity/temperature interaction, and the square of the temperature. Once again, in this data set, the analysis identified two factors with interactions and squares being part of the evaluation.

4.15 COOLING TOWER CT-460M

4.15.1 Operation

Cooling tower CT-460M consists of a package Marley cross flow induced draft cooling tower with plastic drift eliminators installed in 2004. It is fed with domestic water (chlorinated and pH adjusted) and includes metered feed system which has a Chem-Treat CL-49 Bromine Chloride biocide with a target concentration of 1 ppm with a meter pump set to every ten minutes and a Chem-Treat CL-1468 Potassium Hydroxide Corrosion Controller. The capacity of the cooling tower is 60 gpm.

4.15.2 Data

Cooling tower CT-460M had data available from 10/31/2005 to 9/2/2008 for thirty-eight (38) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 22.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 34 predictors, with N = 25
N(cases with missing observations) = 13 N(all cases) = 38


Step            1      2
Constant     3187  41211

P.H.         -359  -9263
T-Value     -2.59  -2.07
P-Value     0.017  0.050

pH2                  521
T-Value             1.99
P-Value            0.059

S             220    207
R-Sq        22.53  34.38
R-Sq(adj)   19.16  28.42
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero1 on 35 predictors, with N = 25
N(cases with missing observations) = 13 N(all cases) = 38


Step           1      2
Constant    1573  24019

P.H.        -179  -5435
T-Value    -2.63  -2.58
P-Value    0.015  0.017

pH2                 307
T-Value            2.50
P-Value           0.020

S            108   97.3
R-Sq       23.09  40.12
R-Sq(adj)  19.75  34.67
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero2 on 35 predictors, with N = 25
N(cases with missing observations) = 13 N(all cases) = 38


No variables entered or removed
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero3 on 27 predictors, with N = 19


Step            1
Constant   -20.84

F*Cond        147
T-Value      1.79
P-Value     0.091

S             138
R-Sq        15.93
R-Sq(adj)   10.98
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero4 on 35 predictors, with N = 25
N(cases with missing observations) = 13 N(all cases) = 38


Step            1      2
Constant    79.28  95.57

Filters       -34    -36
T-Value     -2.01  -2.23
P-Value     0.056  0.036

CL.                -16.2
T-Value            -1.73
P-Value            0.098

S            47.2   45.3
R-Sq        14.97  25.13
R-Sq(adj)   11.27  18.32
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero6 on 35 predictors, with N = 18
N(cases with missing observations) = 20 N(all cases) = 38


Step             1        2        3        4
Constant    0.3646   0.3581   0.5911   0.8200

F*Br         0.127    0.274    0.166    0.365
T-Value       1.89     3.04     1.73     2.71
P-Value      0.078    0.008    0.106    0.018

DO*Cl               -0.048   -0.134   -0.124
T-Value              -2.20    -2.99    -3.00
P-Value              0.044    0.010    0.010

Cl2                            0.41     0.78
T-Value                        2.13     3.01
P-Value                       0.052    0.010

pH*Br                                 -0.095
T-Value                                -1.95
P-Value                                0.074

S             1.00    0.900    0.809    0.739
R-Sq         18.19    38.11    53.24    63.79
R-Sq(adj)    13.07    29.86    43.22    52.64
```

Figure 22. Minitab Output for CT-460M Cooling Tower Evaluation

Table 11. Significant Variables for CT-460M Cooling Tower

	Significant Variables	Adjusted R^2
Total	pH,pH^2	28.42
Sero 1	pH,pH^2	34.67
Sero 2	None	NA
Sero 3	Filters*Conductivity	10.98
Sero 4	Filters, Chlorine	18.32
Sero 6	Filters*Bromine, Dissolved Oxygen*Chlorine, Cl^2, pH*Bromine	52.64

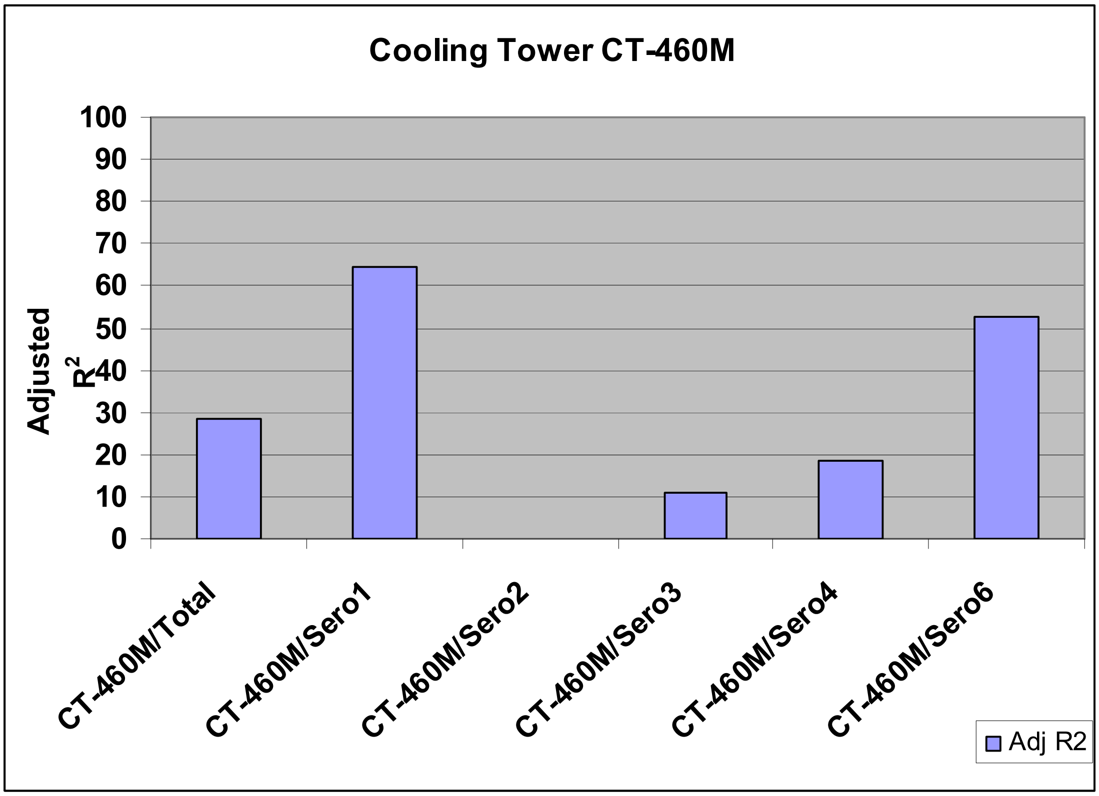

Figure 23. CT-460M Cooling Tower R^2 Graph

The total *L. pneumophila* concentration is predicted in this cooling tower by one factor, pH, and the square of the pH. Both have p-values near 0.05 and the R^2 is not strong.

Significant factors identified for Serogroup 1 are the same as for the total for this cooling tower, with a slightly stronger p-value and R^2. The R^2 is not very strong but is stronger than for the total.

No significant factors were identified to predict Serogroup 2 concentrations.

Serogroups 3 and 4 have very weak R^2 values so are of little interest in predicting *L. pneumophila* levels from water chemistry data.

Serogroup 6 has an R^2 value of >50, with a number of significant variables. All variables include halogens in some first order interaction, making this an unusual set of data—where chlorine or bromine is significant.

4.16 COOLING TOWER 981-S

4.16.1 Operation

Cooling tower 981-S consists of a three cell treated Douglas fir wood frame and PVC fill cooling tower with plastic drift eliminators installed in 1984. It is fed with either service water (pH adjusted) or domestic water (chlorinated and pH adjusted) and includes a continuous feed system which has a Bulab 9328 corrosion inhibitor and a Bulab 6122 biocide. Total capacity is 10,000 gpm.

4.16.2 Data

Cooling tower 981-S had data available from 10/31/2005 to 9/2/2008 for forty-seven (47) chemical and *L. pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 24.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 35 predictors, with N = 29
N(cases with missing observations) = 18 N(all cases) = 47

Step            1
Constant   -42.16

F2             51
T-Value      2.58
P-Value     0.016

S             209
R-Sq        19.80
R-Sq(adj)   16.83
```

Stepwise Regression: Sero1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero1 on 35 predictors, with N = 29
N(cases with missing observations) = 18 N(all cases) = 47

Step            1      2       3        4
Constant   -33.15  69.72  -12.07  -548.35

F2           14.3   45.8   119.8    118.7
T-Value      2.37   3.83    4.64     6.29
P-Value     0.025  0.001   0.000    0.000

F*Temp              -4.8   -18.3    -41.5
T-Value            -2.94   -4.03    -7.04
P-Value            0.007   0.000    0.000

Temp2                       0.72     1.70
T-Value                     3.13     6.39
P-Value                    0.004    0.000

Filters                               545
T-Value                              4.76
P-Value                             0.000

S            63.5   56.0    48.5     35.5
R-Sq        17.22  37.89   55.35    77.04
R-Sq(adj)   14.16  33.11   49.99    73.21
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero2 on 35 predictors, with N = 29
N(cases with missing observations) = 18 N(all cases) = 47

No variables entered or removed
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 23
N(cases with missing observations) = 1 N(all cases) = 24

Step            1
Constant   -42.14

Temp2       0.118
T-Value      1.86
P-Value     0.077

S            45.3
R-Sq        14.12
R-Sq(adj)   10.03
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero4 on 35 predictors, with N = 29
N(cases with missing observations) = 18 N(all cases) = 47


Step             1       2      3
Constant   -106.19  285.97  82.83

F2            42.3   142.2  163.9
T-Value       4.45    3.58   4.51
P-Value      0.000   0.001  0.000

Filters               -408   -531
T-Value              -2.57  -3.58
P-Value              0.016  0.001

Temp*pH                      1.78
T-Value                      2.76
P-Value                     0.011

S              100    90.9   81.2
R-Sq         42.30   54.02  64.76
R-Sq(adj)    40.16   50.48  60.53
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero6 on 35 predictors, with N = 22
N(cases with missing observations) = 25 N(all cases) = 47

No variables entered or removed
```

Figure 24. Minitab Output for 981-S Cooling Tower Evaluation

Table 12. Significant Variables for 981-S Cooling Tower

	Significant Variables	Adjusted R^2
Total	$Filters^2$	16.83
Sero 1	$Filters^2$, Filters*Temp, $Temp^2$, Filters	73.21
Sero 2	None	NA
Sero 3	$Temp^2$	10.03
Sero 4	$Filters^2$, Filters, Temp*pH	60.53
Sero 6	None	NA

Significant variables in predicting *L. pneumophila* water concentrations for this cooling tower appear to be temperature and filters in some configuration. Serogroup 4 includes pH in its significant variable list. Serogroups 2 and 6 did not show any relationship, but Serogroup 1 (R^2 = 73.21) and Sero 4 (R^2 = 60.53) demonstrated some significant relationships.

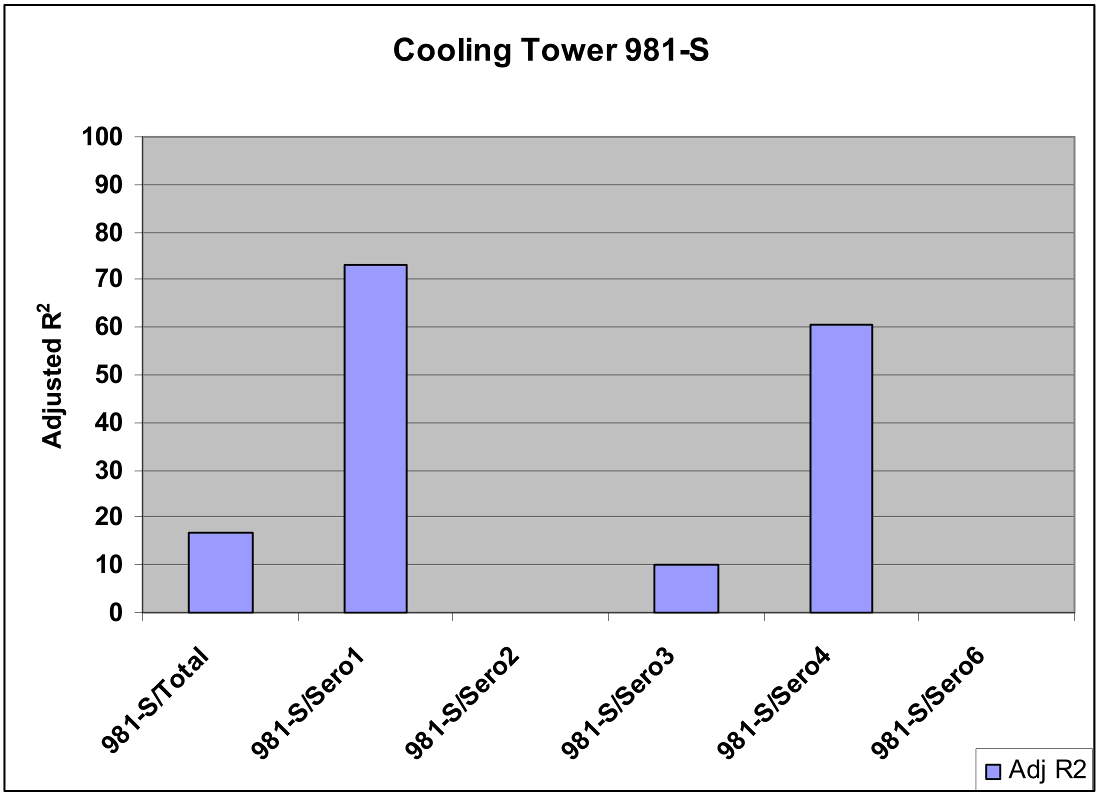

Figure 25. 981-S Cooling Tower R^2 Graph

4.17 COOLING TOWER 241-20F/1

Cooling Tower 241-20F/1

4.17.1 Operation

Cooling tower 241-20F/1 consists of a two cell galvanized cooling tower with plastic drift eliminators and fill put into service in 1997. It is fed with domestic water (chlorinated and pH adjusted) and includes a continuous feed system which has a Valugard 250D corrosion inhibitor and a Chemtreat CL-49 biocide system. The capacity is 1400 gpm.

4.17.2 Data

Cooling tower 241-20F/1 had data available from 10/31/2005 to 9/2/2008 for fifty-two (52) chemical and *L. pneumophila* concentration data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 26.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Total on 35 predictors, with N = 31
N(cases with missing observations) = 21 N(all cases) = 52


Step            1
Constant    415.0

Temp*Br      -2.5
T-Value     -2.25
P-Value     0.032

S             336
R-Sq        14.91
R-Sq(adj)   11.97
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15


Response is Sero1 on 35 predictors, with N = 31
N(cases with missing observations) = 21 N(all cases) = 52


Step            1      2      3
Constant    198.1  331.4  391.0

Temp*Cond   -12.9  -21.3  -49.5
T-Value     -1.61  -2.56  -2.75
P-Value     0.118  0.016  0.010

pH*Br               -2.6   -3.0
T-Value            -2.30  -2.64
P-Value            0.029  0.014

Temp2                      0.56
T-Value                    1.75
P-Value                   0.091

S             157    147    142
R-Sq         8.23  22.77  30.64
R-Sq(adj)    5.07  17.25  22.94
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero2 on 35 predictors, with N = 31
N(cases with missing observations) = 21 N(all cases) = 52

No variables entered or removed
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 28
N(cases with missing observations) = 3 N(all cases) = 31

Step           1       2
Constant   95.55  209.38

Temp*Cond   -6.2    -9.8
T-Value    -2.06   -2.66
P-Value    0.049   0.013

DO*pH              -1.50
T-Value            -1.61
P-Value            0.120

S           58.2    56.5
R-Sq       14.06   22.12
R-Sq(adj)  10.75   15.89
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero4 on 35 predictors, with N = 31
N(cases with missing observations) = 21 N(all cases) = 52

Step            1
Constant   -960.3

pH2          17.0
T-Value      3.37
P-Value     0.002

S             213
R-Sq        28.19
R-Sq(adj)   25.72
```

Stepwise Regression: Serogroup 6 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero6 on 35 predictors, with N = 21
N(cases with missing observations) = 31 N(all cases) = 52

No variables entered or removed
```

Figure 26. Minitab Output for 241-20F/1 Cooling Tower Evaluation

Table 13. Significant Variables for 241-20F/1 Cooling Tower

	Significant Variables	Adjusted R2
Total	Temp*Br	11.97
Sero 1	Temp*Cond, pH*Br, $Temp^2$	22.94
Sero 2	None	NA
Sero 3	Temp*Cond, DO*pH	15.89
Sero 4	pH^2	25.72
Sero 6	None	NA

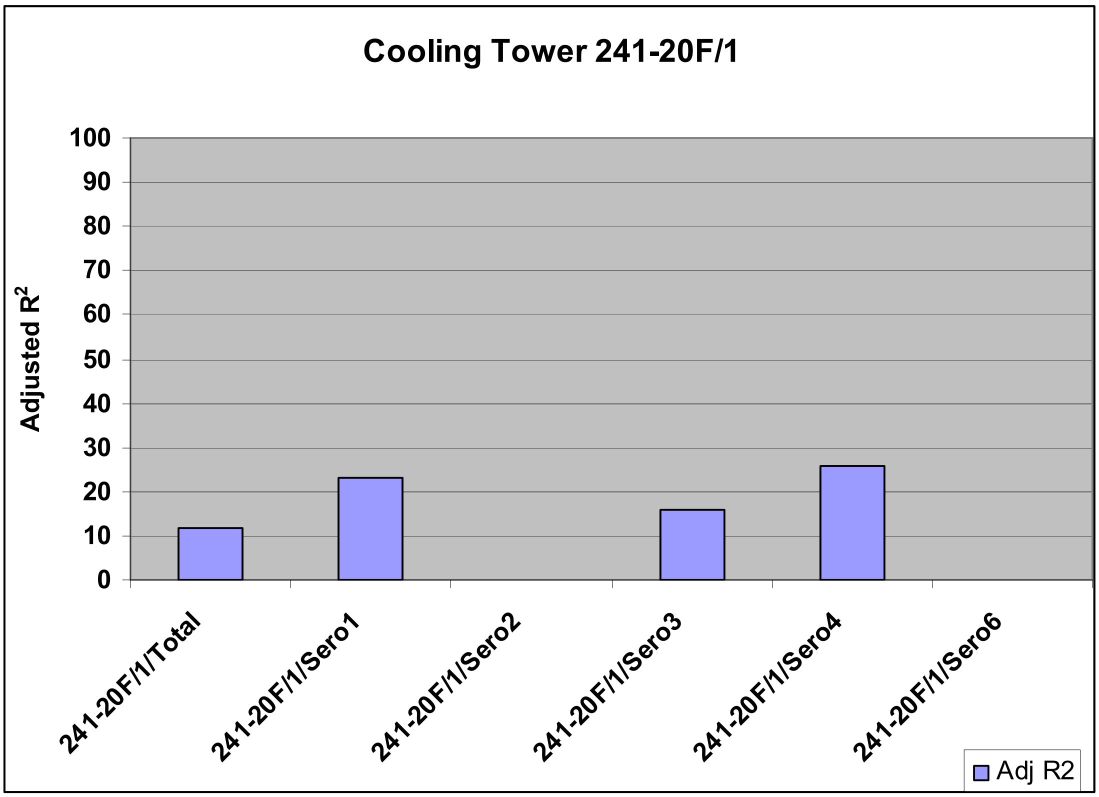

Figure 27. 241-20F/1 Cooling Tower R^2 Graph

None of these evaluations showed a significant relationship between *L. pneumophila* concentrations and any of the analyzed water chemistry data.

4.18 COOLING TOWER 241-20F/3

4.18.1 Operation

Cooling tower 241-20F/3 consists of a two cell galvanized cooling tower with plastic drift eliminators and fill, put into service in 1997. It is fed with domestic water (chlorinated and pH adjusted) and includes a continuous feed system which includes Valugard 250D corrosion inhibitor and Chemtreat CL-49 biocide system. The capacity is 1400 gpm.

4.18.2 Data

Cooling tower 241-20F/3 had data available from 10/31/2005 to 9/2/2008 for twenty-three (23) chemical and *L. pneumophila* level data points after duplicate or incomplete data was eliminated.

A step wise linear regression was run using all of the available data. Minitab's default value of 0.15 was used for the alpha to enter and alpha to remove values.

The regression was run for total *L. pneumophila* and the five serogroups with main effects, squares, and first order interactions with number for number of filters (a measure of solids in the water), chlorine, dissolved oxygen, conductivity, temperature, pH, and bromine levels included as shown in Figure 28.

Stepwise Regression: Total versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Total on 27 predictors, with N = 23

Step             1      2
Constant   -96.044  3.645

F*Temp         9.6   10.1
T-Value       3.65   4.48
P-Value      0.001  0.000

Temp*Cl              -3.4
T-Value             -2.97
P-Value             0.007

S              223    191
R-Sq         38.87  57.62
R-Sq(adj)    35.96  53.38
```

Stepwise Regression: Serogroup 1 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero1 on 27 predictors, with N = 23

Step             1       2       3        4
Constant   -40.376  43.111  -5.026  357.149

Temp2         0.30    0.56    0.80     0.53
T-Value       2.47    4.24    4.68     2.97
P-Value      0.022   0.000   0.000    0.008

Temp*Cond            -26.0   -45.3    -24.4
T-Value              -3.10   -3.70    -1.87
P-Value              0.006   0.002    0.077

Cond 2                         528     2487
T-Value                       2.04     3.30
P-Value                      0.055    0.004

Cond*pH                                -227
T-Value                               -2.73
P-Value                               0.014

S              123     103    95.9     82.9
R-Sq         22.48   47.69   57.10    69.63
R-Sq(adj)    18.79   42.46   50.33    62.88
```

Stepwise Regression: Serogroup 2 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero2 on 27 predictors, with N = 23

Step           1      2
Constant   22.00  30.42

pH*Cl      -0.71  -2.52
T-Value    -2.19  -2.28
P-Value    0.040  0.034

Cl2                 3.3
T-Value            1.71
P-Value           0.104

S           22.4   21.4
R-Sq       18.61  28.94
R-Sq(adj)  14.73  21.83
```

Stepwise Regression: Serogroup 3 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero3 on 27 predictors, with N = 18

Step            1      2       3       4       5       6
Constant    41.66  89.51  168.22  222.27  336.80  337.34

DO*Cl        -2.6   -3.3    -2.3    -7.7    -0.2
T-Value     -1.75  -2.28   -1.55   -2.72   -0.06
P-Value     0.100  0.038   0.144   0.018   0.950

Cond*pH            -13.9   -75.4  -101.6  -164.8  -165.3
T-Value            -1.73   -2.01   -2.85   -5.91   -6.42
P-Value            0.104   0.064   0.014   0.000   0.000

Cond 2                       654     837    1325    1330
T-Value                     1.67    2.34    5.03    5.48
P-Value                    0.116   0.036   0.000   0.000

Cond*Cl                               94     305     306
T-Value                             2.15    5.29    5.74
P-Value                            0.051   0.000   0.000

CL.                                         -109    -110
T-Value                                    -4.22   -6.13
P-Value                                    0.001   0.000

S            44.8   42.2    39.9    35.6    23.5    22.6
R-Sq        15.99  29.95   41.63   56.93   82.66   82.66
R-Sq(adj)   10.74  20.61   29.12   43.68   75.44   77.32
```

Stepwise Regression: Serogroup 4 versus Filters, TEMP., ...

```
  Alpha-to-Enter: 0.15  Alpha-to-Remove: 0.15

Response is Sero4 on 27 predictors, with N = 23

Step             1      2        3       4
Constant    -82.15  14.51  -101.73  -69.56

F2              59     52       41      50
T-Value       3.05   2.84     2.25    3.11
P-Value      0.006  0.010    0.037   0.006

DO*Cl                -5.7     -7.2    -7.9
T-Value             -1.95    -2.54   -3.21
P-Value             0.065    0.020   0.005

Cond*pH                         52     397
T-Value                       1.96    3.13
P-Value                      0.065   0.006

COND.                                -3045
T-Value                              -2.76
P-Value                              0.013

S              173    163      152     131
R-Sq         30.76  41.82    51.58   65.99
R-Sq(adj)    27.46  36.01    43.93   58.43
```

Figure 28. Minitab Output for 241-20F/3 Cooling Tower Evaluation

Table 14. Significant Variables for 241-20F/3 Cooling Tower

	Significant Variables	Adjusted R^2
Total	Filters*Temp, Temp*Cl	53.38
Sero 1	$Temp^2$, Temp*Cond, $Cond^2$, Cond*pH	62.88
Sero 2	pH*Cl, Cl^2	21.83
Sero 3	DO*Cl, Cond*pH, $Cond^2$, Cond*Cl, Cl	77.32
Sero 4	$Filters^2$, DO*Cl, Cond*pH, Cond	58.43

All serogroups in this cooling tower had evaluations with significant variables. The R^2's for them was insignificant for one (Serogroup 2) and had moderate coefficients of determination for the other three serogroups and the total. Serogroup 6 was not part of this evaluation because of the time the data was generated. The most common significant variables for this cooling tower were conductivity and chlorine levels, which might indicate a correlation between water quality (particulate/impurities) and *L pneumophila* in this cooling tower.

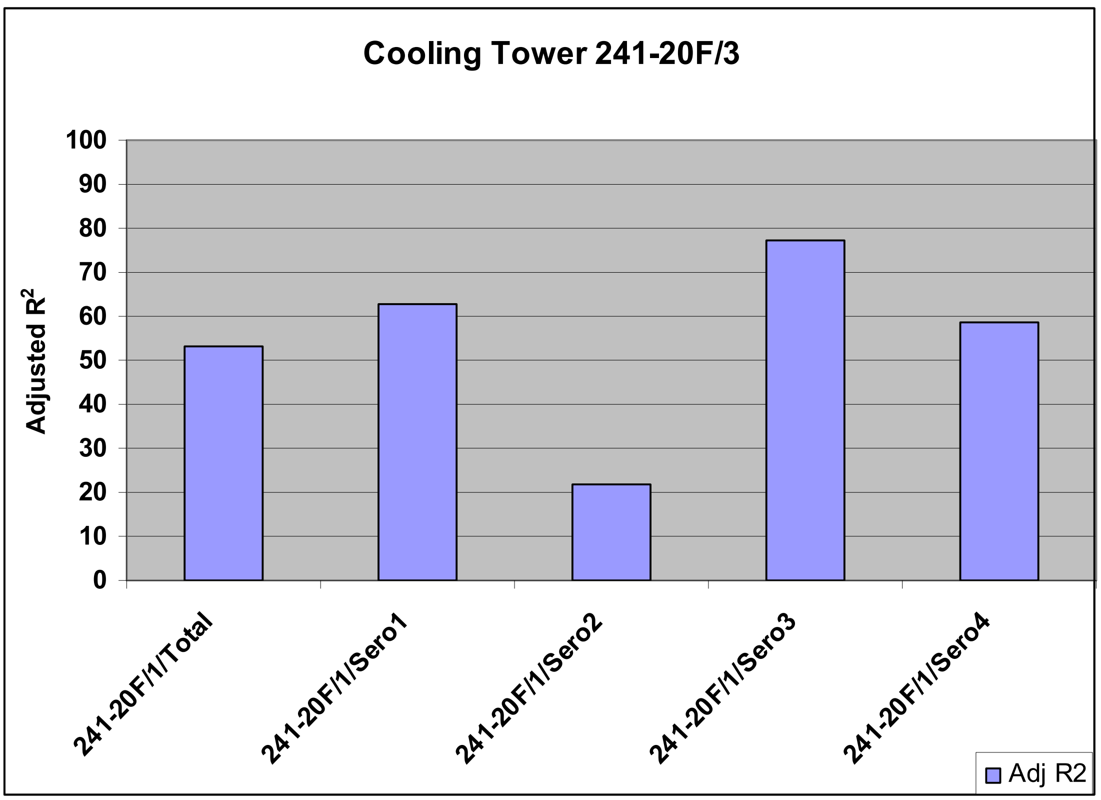

Figure 29. Cooling Tower241-20F/3 R^2 Graph

Figures 30-36 summarize the individual Cooling Tower adjusted R^2 water chemistry variables relative to *L. pneumophila* concentrations, both for individual serogroups and combined total concentrations. The top rows of these figures represent the seven individual water chemistry parameter interactions, the second seven rows represent the squared parameters, and the bottom 21 rows are the interactions between the combined chemical parameters. The blackened boxes represent where significant interactions occurred with the resultant adjusted R^2 at the top of the column. As summarized earlier there is no clear pattern in the results except an observed higher frequency of significant interactions with respect to the Filters or relative suspended solids.

	285-4F/Total	285-4F/Sero1	285-4F/Sero2	285-4F/Sero3	285-4F/Sero4	285-4F/Sero6	285-11F/Total	285-11F/Sero1	285-11F/Sero2	285-11F/Sero3	285-11F/Sero4	285-11F/Sero6
Adj R^2	34	94	95	50	53	34	NA	88	74	13	22	43
Filters					■							
Temperature										■		
Dissolved Oxygen												
Conductivity												■
pH		■	■						■			■
Chlorine												
Bromine												
F^2					■				■			■
T^2		■										
DO^2			■									
Co^2	■		■		■							
pH^2	■	■	■		■							
Cl^2												
Br^2												
F*T											■	
F*DO												
F*Co				■								
F*pH					■							
F*Cl												
F*Br										■		
T*DO												
T*Co												
T*pH				■		■						
T*Cl												■
T*Br												■
DO*CO		■							■			
DO*pH												
DO*Cl												
DO*Br						■						
Co*pH			■									
Co*Cl								■	■		■	
Co*Br								■	■			
pH*Cl												
pH*Br												
Br*Cl								■				

Figure 30. Significant Water Chemistry Variables and R^2 per Cooling Tower (1)

	285-11H/Total	285-11H/Sero1	285-11H/Sero2	285-11H/Sero3	285-11H/Sero4	285-11H/Sero6	264-3H/Total	2l64-3H/Sero1	264-3H/Sero2	264-3H/Sero3	264-3H/Sero4	264-3H/Sero6
Adj R^2	NA	76	70	35	NA	57	46	17	9	46	51	95
Filters												
Temperature		■	■									
Dissolved Oxygen				■				■				
Conductivity												
pH						■	■				■	■
Chlorine												
Bromine												
F^2												
T^2		■	■	■					■			
DO^2				■								
Co^2												
pH^2						■	■				■	
Cl^2												
Br^2												■
F*T												
F*DO												
F*Co												
F*pH												
F*Cl												
F*Br							■				■	
T*DO												
T*Co												
T*pH												
T*Cl												
T*Br							■				■	■
DO*CO												
DO*pH												
DO*Cl												
DO*Br												
Co*pH												
Co*Cl								■		■		
Co*Br												
pH*Cl												
pH*Br												
Br*Cl												■

Figure 31. Significant Water Chemistry Variables and R^2 per Cooling Tower (2)

	218-2H/Total	218-2H/Sero1	218-2H/Sero2	218-2H/Sero3	218-2H/Sero4	218-2H/Sero6	785-1/Total	785-A/Sero1	785-A/Sero2	785-A/Sero3	785-A/Sero4	785-A/Sero6
Adj R^2	19	49	56	10	34	23	18	NA	15	20	15	NA
Filters				■								
Temperature												
Dissolved Oxygen												
Conductivity		■										
pH					■	■						
Chlorine												
Bromine												
F^2		■							■	■		
T^2			■									
DO^2												
Co^2		■										
pH^2					■							
Cl^2												
Br^2	■											
F*T		■					■			■	■	
F*DO												
F*Co		■				■						
F*pH												
F*Cl												
F*Br	■											
T*DO												
T*Co		■										
T*pH												
T*Cl												
T*Br	■											
DO*CO									■			
DO*pH												
DO*Cl												
DO*Br												
Co*pH												
Co*Cl												
Co*Br												
pH*Cl												
pH*Br												
Br*Cl												

Figure 32. Significant Water Chemistry Variables and R^2 per Cooling Tower (3)

	785-B/Total	785-B/Sero1	785-B/Sero2	785-B/Sero3	785-B/Sero4	785-B/Sero6	285-9H 1&2/Total	285-9H 1&2/Sero1	285-9H 1&2/Sero2	285-9H 1&2/Sero3	285-9H 1&2/Sero4	285-9H 1&2/Sero6
Adj R^2	30	40	6	99	25	NA	37	90	NA	79	NA	91
Filters				■								
Temperature		■										
Dissolved Oxygen										■		■
Conductivity												
pH												
Chlorine												
Bromine												
F^2		■		■								
T^2								■		■		
DO^2								■				
Co^2												
pH^2												
Cl^2					■					■		■
Br^2												■
F*T												
F*DO				■								
F*Co		■								■		■
F*pH								■		■		■
F*Cl												
F*Br								■				
T*DO												
T*Co								■				■
T*pH			■									
T*Cl												
T*Br												
DO*CO	■	■			■		■	■		■		■
DO*pH								■				
DO*Cl	■											
DO*Br							■	■				
Co*pH								■				
Co*Cl				■						■		■
Co*Br												
pH*Cl												
pH*Br												
Br*Cl												

Figure 33. Significant Water Chemistry Variables and R^2 per Cooling Tower (4)

	785-2A/Total	785-2A/Sero1	785-2A/Sero2	785-2A/Sero3	785-2A/Sero4	785-2A/Sero6	785-1B2/Total	785-1B/Sero1	785-1B/Sero2	785-1B/Sero3	785-1B/Sero4	785-1B/Sero6
Adj R^2	72	94	15	89	16	NA	98	99	92	97	88	NO
Filters									■			
Temperature				■								
Dissolved Oxygen							■					
Conductivity							■				■	
pH												
Chlorine												
Bromine												
F^2									■	■		
T^2			■	■	■		■			■	■	
DO^2				■								
Co^2											■	
pH^2								■				
Cl^2	■	■										
Br^2												
F*T							■	■		■		
F*DO		■					■					
F*Co												
F*pH								■		■		
F*Cl	■											
F*Br												
T*DO												
T*Co							■				■	
T*pH												
T*Cl												
T*Br												
DO*CO												
DO*pH												
DO*Cl												
DO*Br												
Co*pH												
Co*Cl		■										
Co*Br		■										
pH*Cl												
pH*Br												
Br*Cl		■										

Figure 34. Significant Water Chemistry Variables and R^2 per Cooling Tower (5)

	CT-460M/Total	CT-460M/Sero1	CT-460M/Sero2	CT-460M/Sero3	CT-460M/Sero4	CT-460M/Sero6	981-S/Total	981-S/Sero1	981-S/Sero2	981-S/Sero3	981-S/Sero4	981-S/Sero6
Adj R^2	28	64	NA	11	18	53	17	73	NA	10	61	NA
Filters					■			■			■	
Temperature												
Dissolved Oxygen												
Conductivity												
pH	■	■										
Chlorine					■							
Bromine												
F^2							■	■			■	
T^2								■		■		
DO^2												
Co^2												
pH^2	■	■										
Cl^2						■						
Br^2												
F*T								■				
F*DO												
F*Co				■								
F*pH												
F*Cl												
F*Br						■						
T*DO												
T*Co												
T*pH											■	
T*Cl												
T*Br												
DO*CO												
DO*pH												
DO*Cl						■						
DO*Br												
Co*pH												
Co*Cl												
Co*Br												
pH*Cl												
pH*Br						■						
Br*Cl												

Figure 35. Significant Water Chemistry Variables and R^2 per Cooling Tower (6)

	241-20F/1/Total	241-20F/1/Sero1	241-20F/1/Sero2	241-20F/1/Sero3	241-20F/1/Sero4	241-20F/1/Sero6	241-20F/3/Total	241-20F/3/Sero1	241-20F/3/Sero2	241-20F/3/Sero3	241-20F/3/Sero4
Adj R^2	12	23	NA	16	26	NA	53	63	22	77	58
Filters											
Temperature											
Dissolved Oxygen											
Conductivity											■
pH											
Chlorine										■	
Bromine											
F^2											■
T^2		■						■			
DO^2											
Co^2								■		■	
pH^2					■						
Cl^2									■		
Br^2											
F*T							■				
F*DO											
F*Co											
F*pH											
F*Cl											
F*Br											
T*DO											
T*Co		■		■				■			
T*pH											
T*Cl							■				
T*Br	■										
DO*CO											
DO*pH				■							
DO*Cl										■	■
DO*Br											
Co*pH								■		■	■
Co*Cl										■	
Co*Br											
pH*Cl									■		
pH*Br		■									
Br*Cl											

Figure 36. Significant Water Chemistry Variables and R^2 per Cooling Tower (7)

Figures 37-42 summarize the individual Cooling Tower water adjusted R^2 water chemistry variables relative to total *L. pneumophila* (Figure 37), serogroup 1 (Figure 38), serogroup 2 (Figure 39), serogroup 3 (Figure 40), serogroup 4 (Figure 41), and serogroup 6 (Figure 42) cell concentrations . Again the top rows of these figures represent the seven individual water chemistry parameter interactions, the second seven rows represent the squared parameters, and the bottom 21 rows are the interactions between the combined chemical parameters. The column labels are the individual tower designations. The blackened boxes still represent where significant interactions occurred with the adjusted R^2 at the top of the column. As summarized earlier there is no clear pattern in the results except an observed higher frequency of significant interactions with respect to the number of filters or relative suspended solids.

	285-4F/Total	285-11F/Total	285-11H/Total	264-3H/Total	218-2H/Total	785-1A/Total	785-B/Total	285-9H 1&2/Total	785-2A/Total	785-1B/Total	CT-460M/Total	981-S/Total	241-20F/1/Total	241-20F/3/Total
Adj R^2	34	NA	NA	46	19	18	30	37	72	98	28	17	12	53
Filters														
Temperature														
Dissolved Oxygen										■				
Conductivity										■				
pH				■							■			
Chlorine														
Bromine														
F^2												■		
T^2										■				
DO^2														
Co^2	■													
pH^2	■			■							■			
Cl^2									■					
Br^2					■									
F*T						■				■				■
F*DO										■				
F*Co														
F*pH														
F*Cl									■					
F*Br				■	■									
T*DO														
T*Co										■				
T*pH														
T*Cl														■
T*Br				■	■								■	
DO*CO							■	■						
DO*pH														
DO*Cl							■							
DO*Br								■						
Co*pH														
Co*Cl														
Co*Br														
pH*Cl														
pH*Br														
Br*Cl														

Figure 37. Significant Water Chemistry Variables and R^2 per Total *L. pneumophila*

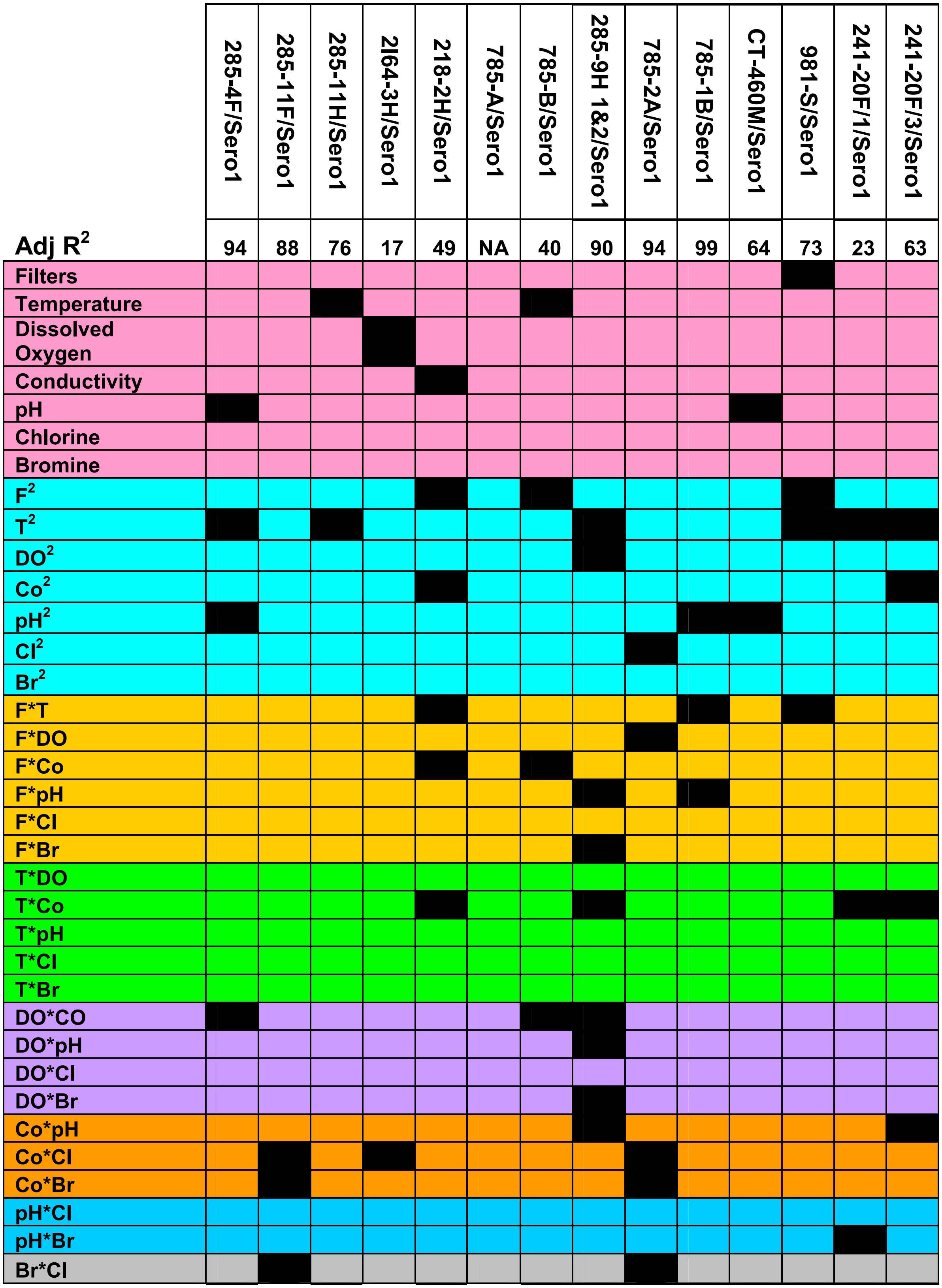

Figure 38. Significant Water Chemistry Variables and R^2 per Serogroup (1)

	285-4F/Sero2	285-11F/Sero2	285-11H/Sero2	264-3H/Sero2	218-2H/Sero2	785-A/Sero2	785-B/Sero2	285-9H 1&2/Sero2	785-2A/Sero2	785-1B/Sero2	CT-460M/Sero2	981-S/Sero2	241-20F/1/Sero2	241-20F/3/Sero2
Adj R^2	95	74	70	9	56	15	6	NA	15	92	NA	NA	NA	22
Filters										■				
Temperature			■											
Dissolved Oxygen														
Conductivity														
pH	■	■												
Chlorine														
Bromine														
F^2		■				■				■				
T^2			■	■	■				■					
DO^2	■													
Co^2	■													
pH^2	■													
Cl^2														■
Br^2														
F*T														
F*DO														
F*Co														
F*pH														
F*Cl														
F*Br														
T*DO														
T*Co														
T*pH							■							
T*Cl														
T*Br														
DO*CO		■				■								
DO*pH														
DO*Cl														
DO*Br														
Co*pH	■													
Co*Cl		■												
Co*Br		■												
pH*Cl														■
pH*Br														
Br*Cl														

Figure 39. Significant Water Chemistry Variables and R^2 per Serogroup (2)

	285-4F/Sero3	285-11F/Sero3	285-11H/Sero3	264-3H/Sero3	218-2H/Sero3	785-A/Sero3	785-B/Sero3	285-9H 1&2/Sero3	785-2A/Sero3	785-1B/Sero3	CT-460M/Sero3	981-S/Sero3	241-20F/1/Sero3	241-20F/3/Sero3
Adj R^2	50	13	35	46	10	20	99	79	89	97	11	10	16	77
Filters					■		■							
Temperature		■							■					
Dissolved Oxygen			■					■						
Conductivity														
pH														
Chlorine														■
Bromine														
F^2						■	■			■				
T^2			■					■	■	■		■		
DO^2			■						■					
Co^2														■
pH^2														
Cl^2								■						
Br^2														
F*T						■				■				
F*DO							■							
F*Co	■							■			■			
F*pH								■		■				
F*Cl														
F*Br		■												
T*DO														
T*Co													■	
T*pH	■													
T*Cl														
T*Br														
DO*CO								■						
DO*pH													■	
DO*Cl														■
DO*Br														
Co*pH														■
Co*Cl				■			■	■						■
Co*Br														
pH*Cl														
pH*Br														
Br*Cl														

Figure 40. Significant Water Chemistry Variables and R^2 per Serogroup (3)

	285-4F/Sero4	285-11F/Sero4	285-11H/Sero4	264-3H/Sero4	218-2H/Sero4	785-A/Sero4	785-B/Sero4	285-9H 1&2/Sero4	785-2A/Sero4	785-1B/Sero4	CT-460M/Sero4	981-S/Sero4	241-20F/1/Sero4	241-20F/3/Sero4
Adj R^2	53	22	NA	51	34	15	25	NA	16	88	18	61	26	58
Filters	■										■	■		
Temperature														
Dissolved Oxygen														
Conductivity										■				■
pH				■	■									
Chlorine											■			
Bromine														
F^2	■											■		■
T^2									■	■				
DO^2														
Co^2	■									■				
pH^2	■			■	■								■	
Cl^2							■							
Br^2														
F*T		■				■								
F*DO														
F*Co														
F*pH	■													
F*Cl														
F*Br				■										
T*DO														
T*Co										■				
T*pH												■		
T*Cl														
T*Br				■										
DO*CO							■							
DO*pH														
DO*Cl														■
DO*Br														
Co*pH														■
Co*Cl		■												
Co*Br														
pH*Cl														
pH*Br														
Br*Cl														

Figure 41. Significant Water Chemistry Variables and R^2 per Serogroup (4)

	285-4F/Sero6	285-11F/Sero6	285-11H/Sero6	264-3H/Sero6	218-2H/Sero6	785-A/Sero6	785-B/Sero6	285-9H 1&2/Sero6	785-2A/Sero6	785-1B/Sero6	CT-460M/Sero6	981-S/Sero6	241-20F/1/Sero6
Adj R^2	34	43	57	95	23	NA	NA	91	NA	NO	53	NA	NA
Filters													
Temperature													
Dissolved Oxygen								■					
Conductivity		■											
pH		■	■	■	■								
Chlorine													
Bromine													
F^2		■											
T^2													
DO^2													
Co^2													
pH^2			■										
Cl^2								■			■		
Br^2				■				■					
F*T													
F*DO													
F*Co					■			■					
F*pH								■					
F*Cl													
F*Br											■		
T*DO													
T*Co								■					
T*pH	■												
T*Cl		■											
T*Br		■		■									
DO*CO								■					
DO*pH													
DO*Cl											■		
DO*Br	■												
Co*pH													
Co*Cl								■					
Co*Br													
pH*Cl													
pH*Br											■		
Br*Cl				■									

Figure 42. Significant Water Chemistry Variables and R^2 per Serogroup (6)

The data from Figure 37 on total L. pneumophila concentrations relative R2 by Cooling Tower is summarized graphically in. The correlations ranged from highly correlated with an 98<R2 for Tower 785-1B to no predictable relationship with 285-11F and 285-11H.

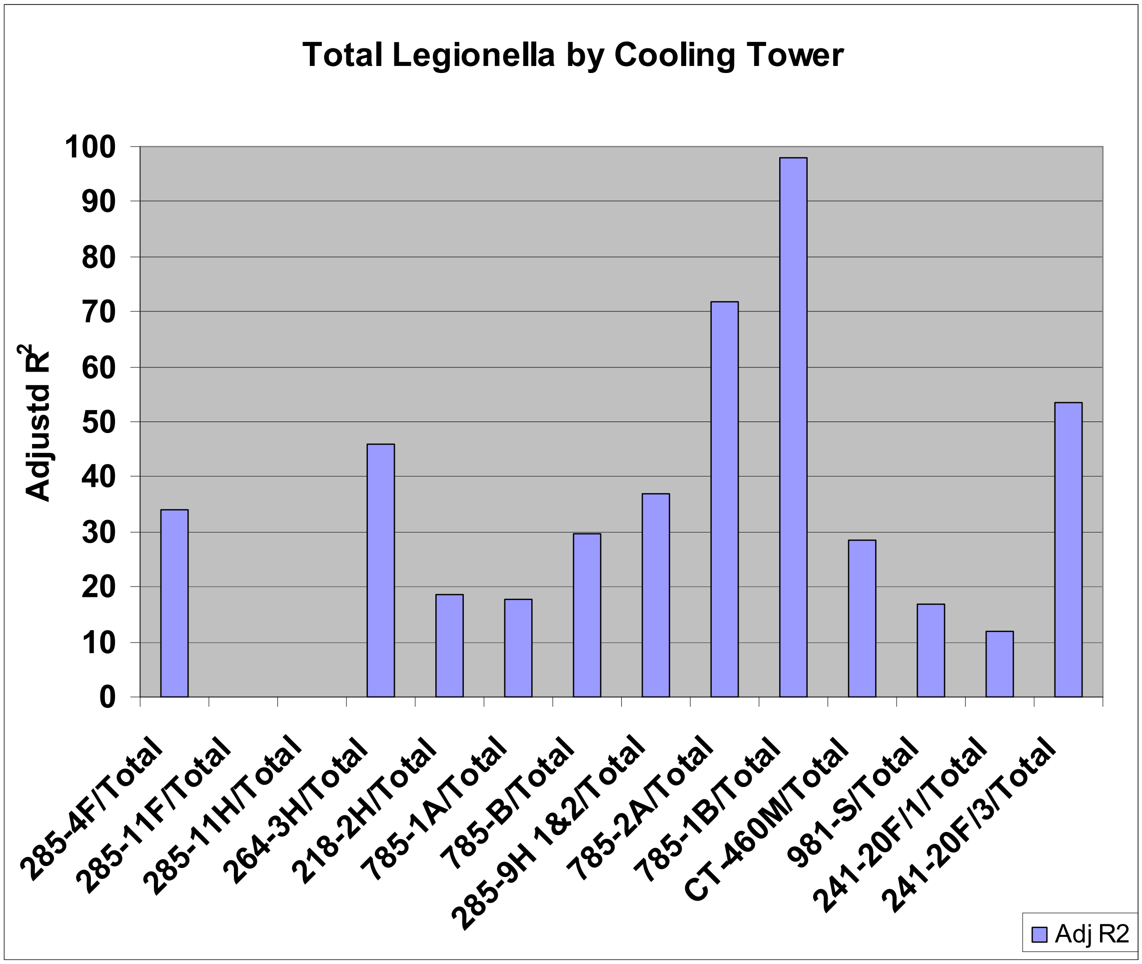

Figure 43. Total *L. pneumophila* concentrations R^2 by Cooling Tower

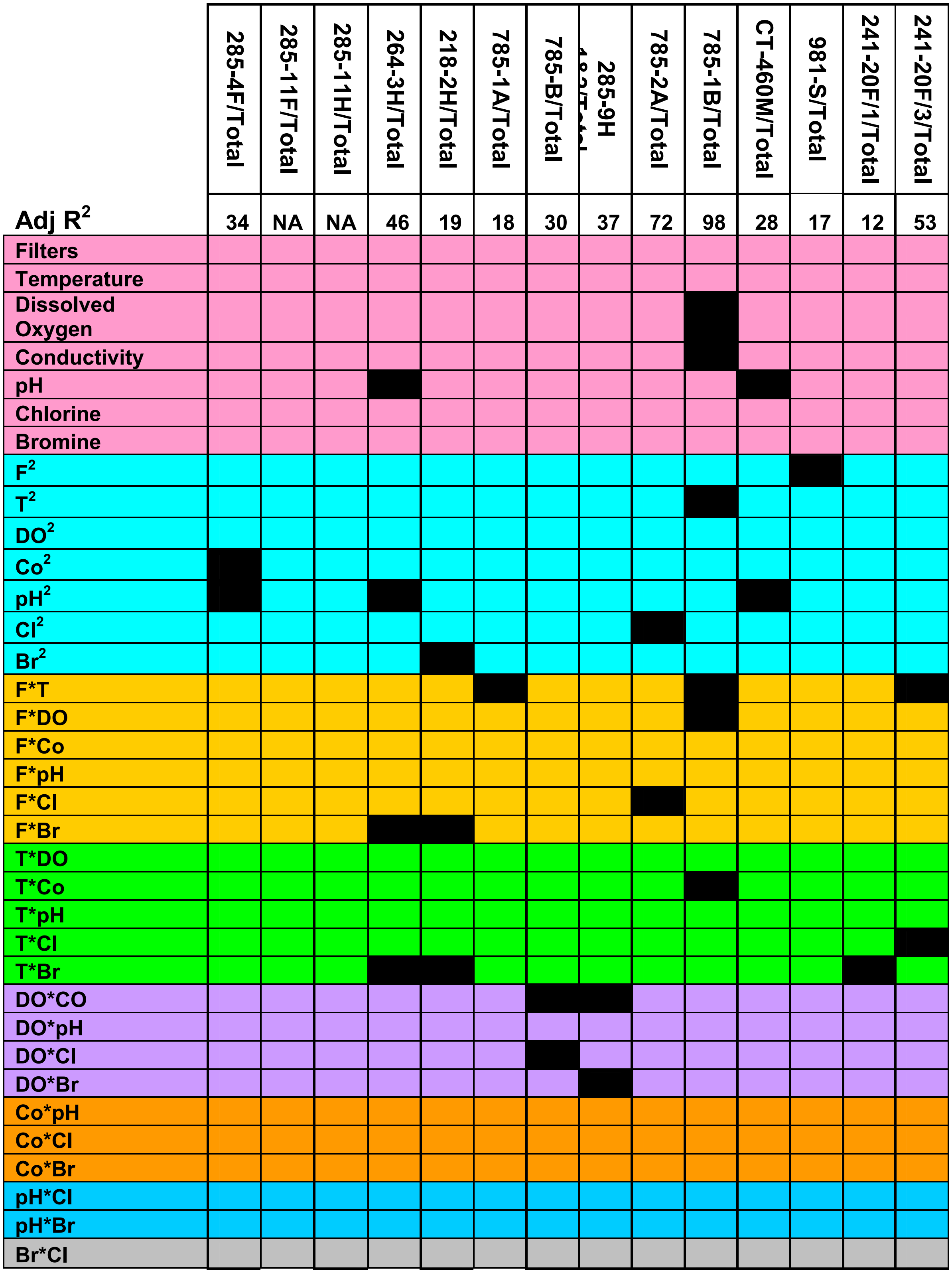

Figure 44. Significant Variables by Serogroup (Total)

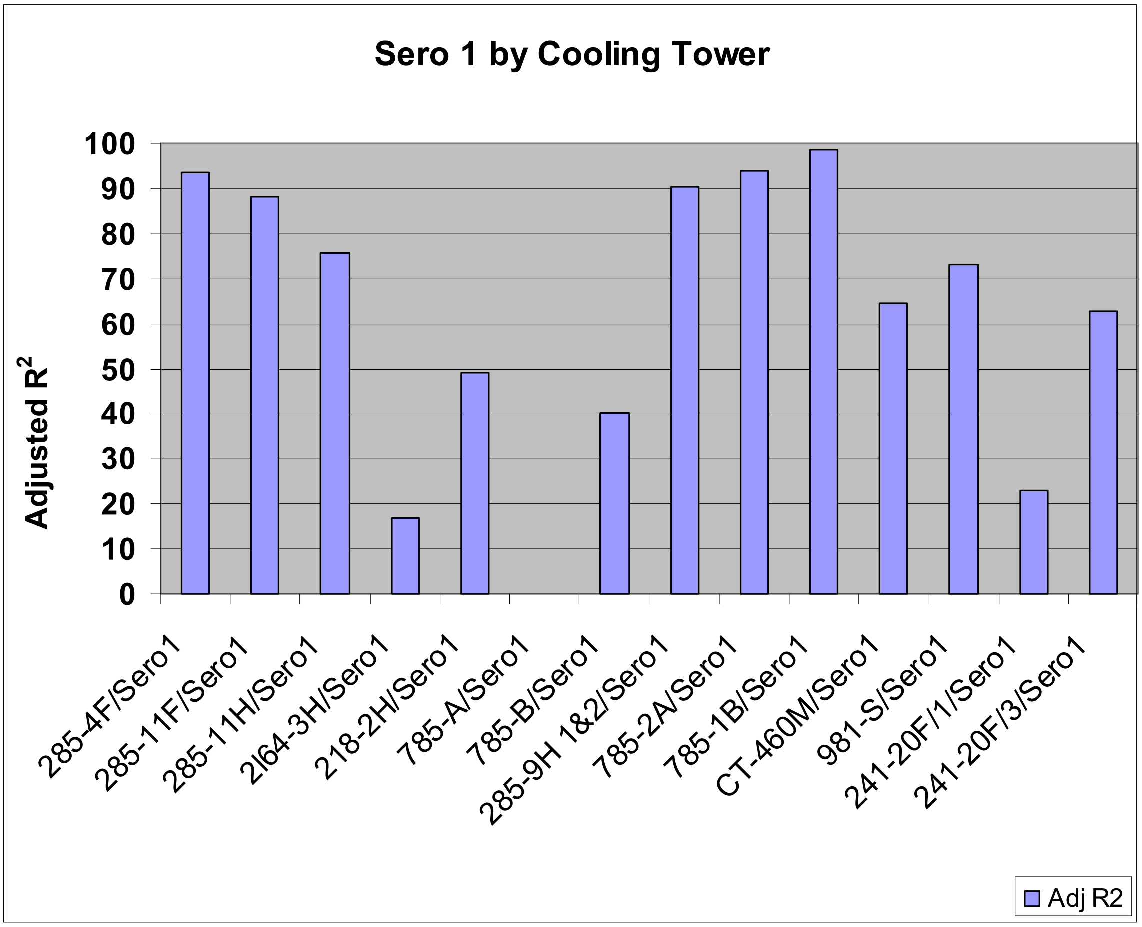

Figure 45. Serogroup R^2 by Cooling Tower

	285-4F/Sero1	285-11F/Sero1	285-11H/Sero1	2I64-3H/Sero1	218-2H/Sero1	785-A/Sero1	785-B/Sero1	285-9H	785-2A/Sero1	785-1B/Sero1	CT-460M/Sero1	981-S/Sero1	241-20F/1/Sero1	241-20F/3/Sero1
Adj R^2	94	88	76	17	49	NA	40	90	94	99	64	73	23	63
Filters												■		
Temperature			■				■							
Dissolved Oxygen				■										
Conductivity					■									
pH	■										■			
Chlorine														
Bromine														
F^2					■		■					■		
T^2	■		■					■				■	■	■
DO^2								■						
Co^2					■									■
pH^2	■									■	■			
Cl^2									■					
Br^2														
F*T					■					■		■		
F*DO									■					
F*Co					■		■							
F*pH								■		■				
F*Cl														
F*Br								■						
T*DO														
T*Co					■			■					■	■
T*pH														
T*Cl														
T*Br														
DO*CO	■						■	■						
DO*pH								■						
DO*Cl														
DO*Br								■						
Co*pH								■						■
Co*Cl		■		■					■					
Co*Br		■							■					
pH*Cl														
pH*Br													■	
Br*Cl		■							■					

Figure 46. Significant Variables by Serogroup (Serogroup 1)

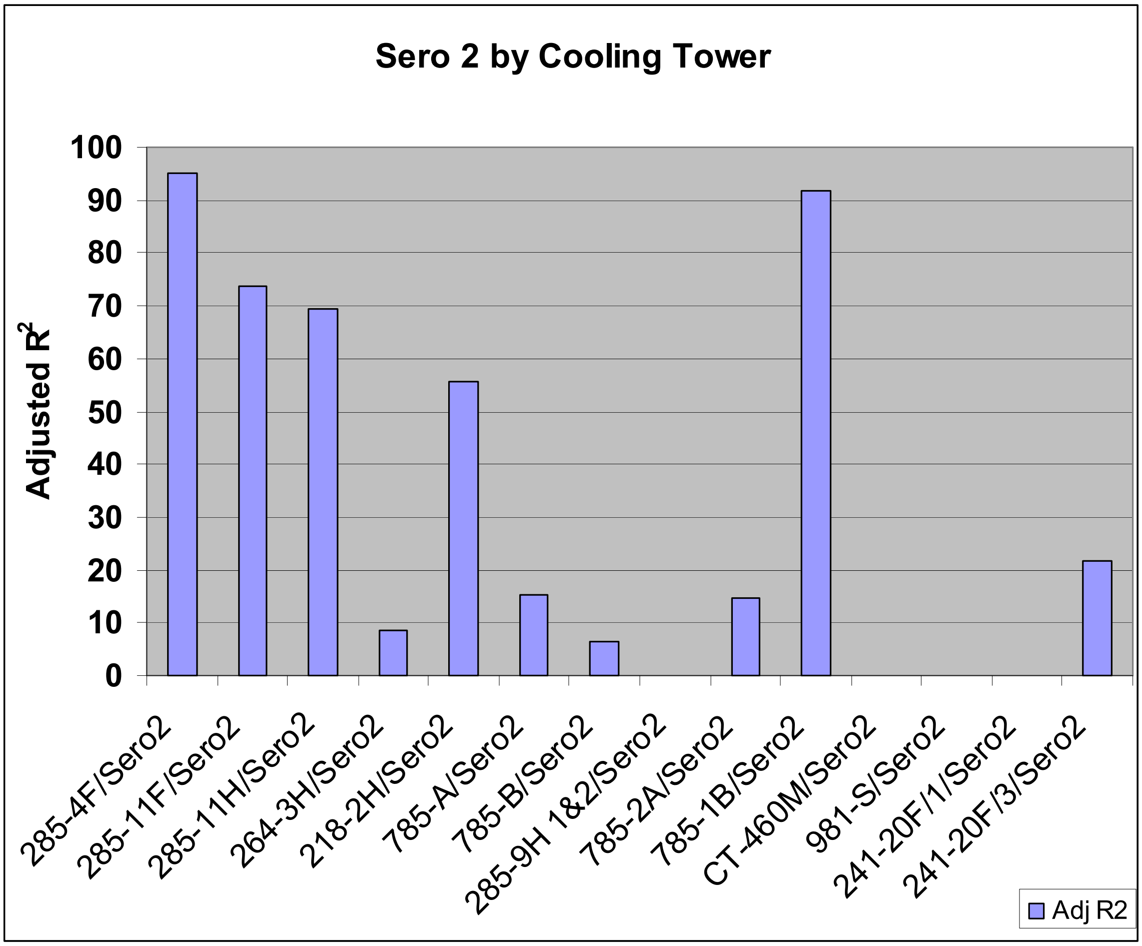

Figure 47. Serogroup 2 R^2 by Cooling Tower

	285-4F/Sero2	285-11F/Sero2	285-11H/Sero2	264-3H/Sero2	218-2H/Sero2	785-A/Sero2	785-B/Sero2	285-9H 1&2/Sero2	785-2A/Sero2	785-1B/Sero2	CT-460M/Sero2	981-S/Sero2	241-20F/1/Sero2	241-20F/3/Sero2
Adj R^2	95	74	70	9	56	15	6	NA	15	92	NA	NA	NA	22
Filters										■				
Temperature			■											
Dissolved Oxygen														
Conductivity														
pH	■	■												
Chlorine														
Bromine														
F^2		■				■				■				
T^2			■	■	■				■					
DO^2	■													
Co^2	■													
pH^2	■													
Cl^2														■
Br^2														
F*T														
F*DO														
F*Co														
F*pH														
F*Cl														
F*Br														
T*DO														
T*Co														
T*pH							■							
T*Cl														
T*Br														
DO*CO		■				■								
DO*pH														
DO*Cl														
DO*Br														
Co*pH	■													
Co*Cl		■												
Co*Br		■												
pH*Cl														■
pH*Br														
Br*Cl														

Figure 48. Significant Variables by Serogroup (Serogroup 2)

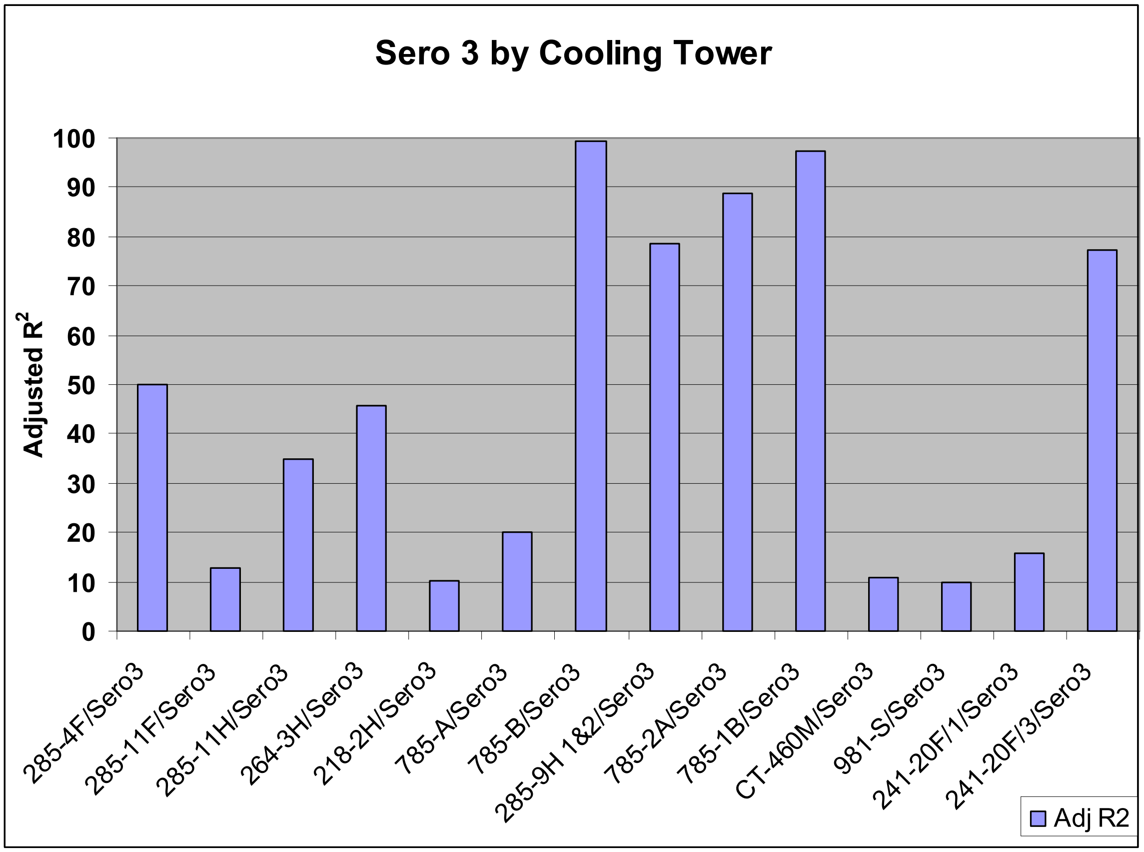

Figure 49. Serogroup 3 R^2 by Cooling Tower

	285-4F/Sero3	285-11F/Sero3	285-11H/Sero3	264-3H/Sero3	218-2H/Sero3	785-A/Sero3	785-B/Sero3	285-9H 1&2/Sero3	785-2A/Sero3	785-1B/Sero3	CT-460M/Sero3	981-S/Sero3	241-20F/1/Sero3	241-20F/3/Sero3
Adj R^2	50	13	35	46	10	20	99	79	89	97	11	10	16	77
Filters					■		■							
Temperature		■							■					
Dissolved Oxygen			■					■						
Conductivity														
pH														
Chlorine														■
Bromine														
F^2						■	■			■				
T^2			■					■	■	■		■		
DO^2			■						■					
Co^2														■
pH^2														
Cl^2								■						
Br^2														
F*T						■				■				
F*DO							■							
F*Co	■							■			■			
F*pH								■		■				
F*Cl														
F*Br		■												
T*DO														
T*Co													■	
T*pH	■													
T*Cl														
T*Br														
DO*CO								■						
DO*pH													■	
DO*Cl														■
DO*Br														
Co*pH														■
Co*Cl				■			■	■						■
Co*Br														
pH*Cl														
pH*Br														
Br*Cl														

Figure 50. Significant Variables by Serogroup (Serogroup 3)

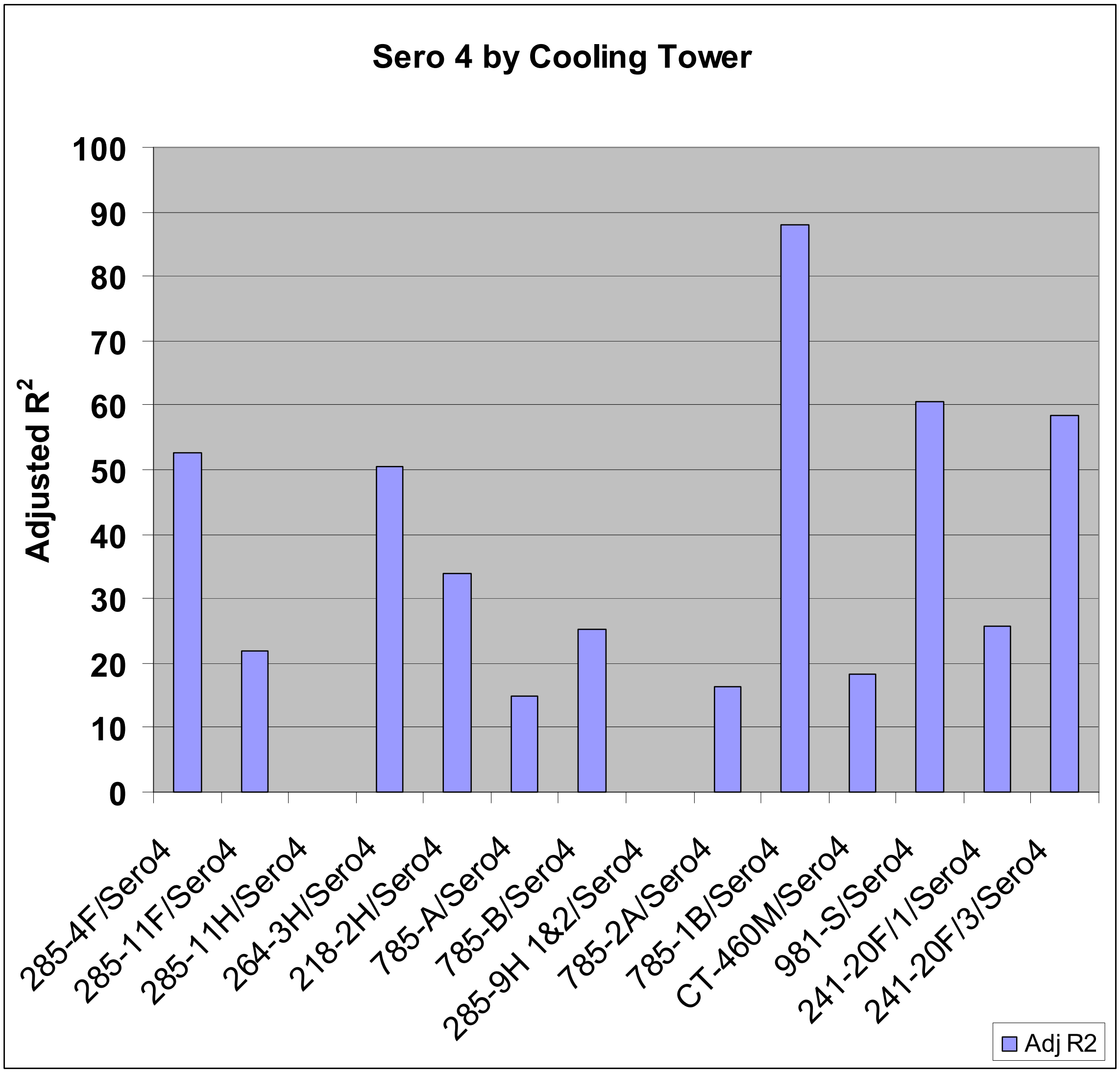

Figure 51. Serogroup 4 R^2 by Cooling Tower

	285-4F/Sero4	285-11F/Sero4	285-11H/Sero4	264-3H/Sero4	218-2H/Sero4	785-A/Sero4	785-B/Sero4	285-9H 1&2/Sero4	785-2A/Sero4	785-1B/Sero4	CT-460M/Sero4	981-S/Sero4	241-20F/1/Sero4	241-20F/3/Sero4
Adj R^2	53	22	NA	51	34	15	25	NA	16	88	18	61	26	58
Filters	■										■	■		
Temperature														
Dissolved Oxygen														
Conductivity										■				■
pH				■	■									
Chlorine											■			
Bromine														
F^2	■											■		■
T^2									■	■				
DO^2														
Co^2	■									■				
pH^2	■			■	■								■	
Cl^2							■							
Br^2														
F*T		■				■								
F*DO														
F*Co														
F*pH	■													
F*Cl														
F*Br				■										
T*DO														
T*Co										■				
T*pH												■		
T*Cl														
T*Br				■										
DO*CO							■							
DO*pH														
DO*Cl														■
DO*Br														
Co*pH														■
Co*Cl		■												
Co*Br														
pH*Cl														
pH*Br														
Br*Cl														

Figure 52. Significant Variables by Serogroup (Serogroup 4)

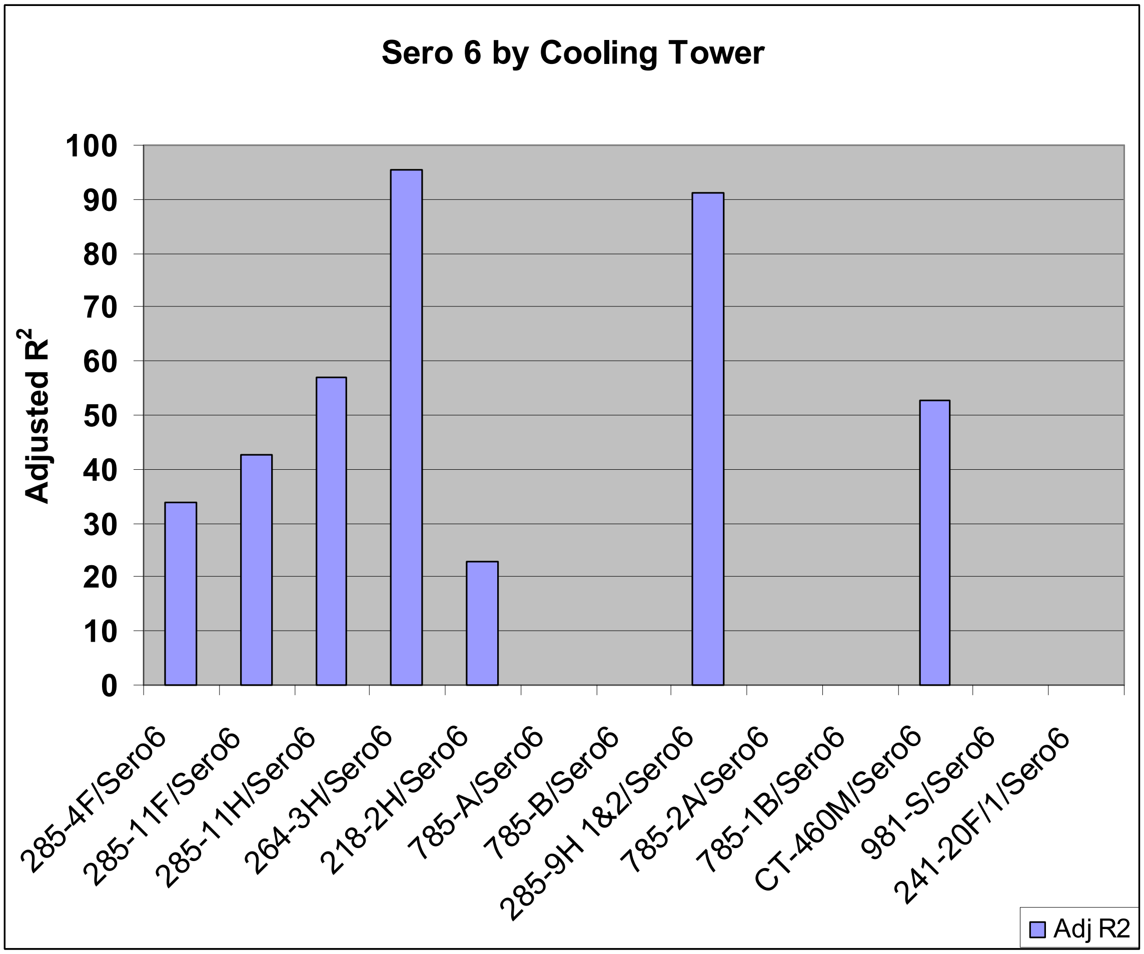

Figure 53. Serogroup 6 R^2 by Cooling Tower

	285-4F/Sero6	285-11F/Sero6	285-11H/Sero6	264-3H/Sero6	218-2H/Sero6	785-A/Sero6	785-B/Sero6	285-9H 1&2/Sero6	785-2A/Sero6	785-1B/Sero6	CT-460M/Sero6	981-S/Sero6	241-20F/1/Sero6
Adj R^2	34	43	57	95	23	NA	NA	91	NA	NO	53	NA	NA
Filters													
Temperature													
Dissolved Oxygen								■					
Conductivity		■											
pH		■	■	■	■								
Chlorine													
Bromine													
F^2		■											
T^2													
DO^2													
Co^2													
pH^2			■										
Cl^2								■			■		
Br^2				■				■					
F*T													
F*DO													
F*Co					■			■					
F*pH								■					
F*Cl													
F*Br											■		
T*DO													
T*Co								■					
T*pH	■												
T*Cl		■											
T*Br		■		■									
DO*CO								■					
DO*pH													
DO*Cl											■		
DO*Br	■												
Co*pH													
Co*Cl								■					
Co*Br													
pH*Cl													
pH*Br											■		
Br*Cl				■									

Figure 54. Significant Variables by Serogroup (Serogroup 6)

The frequency of significant findings by total *Legionella pneumophila* and serogroups are summarized in **Table 15**.

Table 15. Frequency of Significance by Serogroup (Individual Factors)

	Total	Sero1	Sero2	Sreo3	Sreo4	Sero6	Total
Significant Adj R^2	12	13	10	14	12	7	68
R^2>50	3	9	5	6	5	4	32
R^2>70	2	7	4	5	1	2	21
Filters		1	1	2	3		7
Temperature		2	1	2			5
Dissolved Oxygen	1	1		2		1	5
Conductivity	1	1		2	2	1	7
pH	**2**	**2**	**2**		**2**	**4**	**12**
Chlorine					1		1
Bromine				1			1
F^2	**1**	**3**	**3**	**3**	**3**	**1**	**14**
T^2	**1**	**6**	**4**	**5**	**2**		**18**
DO^2	1	1	1	2			5
Co^2	1	2	1	1	2		7
pH^2	**3**	**3**	**1**		**4**	**1**	**12**
Cl^2	1	1	1	1	1	2	7
Br^2	1					2	3
F*T	3	3		2	2		10
F*DO	1	1		1			3
F*Co		2		3		2	7
F*pH		2		2	1	1	6
F*Cl	1						1
F*Br	2	1		1	1	1	6
T*DO							0
T*Co	1	4		1	1	1	8
T*pH			1	1	1	1	4
T*Cl	1					1	2
T*Br	3				1	2	6
DO*CO	2	3	2	1	1	1	10
DO*pH		1		1	1		3
DO*Cl	1			1		1	3
DO*Br	1	1			1	1	4
Co*pH		2	1	1			4
Co*Cl		3	1	4	1	1	10
Co*Br		2	1				3
pH*Cl			1				1
pH*Br		1				1	2
Br*Cl		2				1	3

The frequency of significant findings by total *Legionella pneumophila*, serogroups, individual factors and square interactions are summarized in Table 16.

Table 16. Frequency of Significance by Serogroup (Individual Factors, Squares, Interactions)

	Total	Sero1	Sero2	Sreo3	Sreo4	Sero6	Sum
Significant Adj R^2	12	13	10	14	12	7	68
R^2>50	3	9	5	6	5	4	32
R^2>70	2	7	4	5	1	2	21
R^2>90	1	5	2	2	0	2	12
Filters		1	1	2	3		7
Temperature		2	1	2			5
Dissolved Oxygen	1	1		2		1	5
Conductivity	1	1		2	2	1	7
pH	**2**	**2**	**2**		**2**	**4**	**12**
Chlorine					1		1
Bromine				1			1
F^2	1	3	3	3	3	1	14
T^2	**1**	**6**	**4**	**5**	**2**		**18**
DO^2	1	1	1	2			5
Co^2	1	2	1	1	2		7
pH^2	3	3	1		4	1	12
Cl^2	1	1	1	1	1	2	7
Br^2	1					2	3
F Interactions	7	9	0	9	4	4	33
T Interactions	**8**	7	1	4	**5**	**5**	30
DO Interactions	5	6	2	4	3	3	23
Cond Interactions	**1**	**16**	**5**	**10**	**3**	**5**	**40**
pH Interactions	0	6	3	5	3	3	20
Cl Interactions	3	2	2	5	1	**5**	18
Br Interactions	6	6	1	1	3	**5**	22

As seen in the data analyses, some of the associated correlations were found to be positive with respect to water chemistry and *L. pneumophila* concentrations and others were negative. Table 17 summarizes significance of these individual factors based on positive (P) or negative (N) correlations.

Table 17. Significance of Individual Factors based on Positive (P) or Negative(N) Correlations (Composite)

	P	N
Filters	2	5
Temperature	1	6
Dissolved Oxygen	1	2
Conductivity	2	3
pH	**1**	**10**
Chlorine	0	2
Bromine		
F^2	**12**	**2**
T^2	**14**	**2**
DO^2	3	0
Co^2	**7**	**0**
pH^2	**11**	**1**
Cl^2	5	1
Br^2	3	0
F*T	5	4
F*DO	1	3
F*Co	5	3
F*pH	0	4
F*Cl	0	1
F*Br	2	4
T*DO		
T*Co	4	5
T*pH	1	3
T*Cl	1	1
T*Br	3	3
DO*CO	2	7
DO*pH	0	2
DO*Cl	1	3
DO*Br	0	2
Co*pH	2	4
Co*Cl	6	4
Co*Br	1	2
pH*Cl		
pH*Br	0	3
Br*Cl	0	3

Table 18 summarizes significance of all factors (Main effects, Squares, and interactions) based on positive (P) or negative (N) correlations. From these associated correlations for water chemistry and *L. pneumophila* concentrations, conductivity (Co) is the most predominant factor followed by filters (F) (a measure of dissolved solids), followed by dissolved oxygen (DO), pH, with chlorine (Cl) and bromine (Br) being equal.

Table 18. Significance of All Factors (Main Effects, Squares, Interactions)

	P	**N**
F	13	19
T	14	16
DO	**4**	**17**
Co	21	25
pH	**3**	**16**
Cl	8	12
Br	6	14

5.0 CONCLUSIONS

5.1 EVALUATION

All SRS Cooling towers analyzed here were found to be different in multiple ways with regard to water chemistry and *L. pneumophila* concentrations. Figures 30 through 41 are representations of various combinations of cooling towers and serogroups, as noted, in an attempt to discover a common thread. A summary of all factors analyzed is shown in Table 15.

The frequency of significant findings by total *Legionella pneumophila*, serogroups, individual factors, and square interactions are summarized in Table 16. As seen in the data analyses, some of the associated correlations were found to be positive with respect to water chemistry and *L. pneumophila* concentrations, and others were negative. Table 15 summarizes significance of these individual factors based on positive (P) or negative (N) correlations.

No common factors are obvious for all towers in the evaluation significant individual factors based on positive (P) or negative (N) correlations (Table 17 and Table 18). Interestingly Table 15 demonstrates that the most frequently identified significant factors are the pH and squares of temperature, number of filters, and pH. The squared factors are a statistical method to anticipate the effects of a particular factor on specific response.

Table 16 looks at the same data but combines all interactions into a single factor. This double-counts the interactions but identifies those that show up most frequently. It can be seen the most common interaction includes conductivity, with the number of filters being the second most-common interaction. There are 21 R^2's greater than 70, with 12 of them being greater than 90, a very strong indication that the model explains most of the variation in the response data.

As seen in the data analyses, some of the associated correlations were found to be positive with respect to water chemistry and *Legionella pneumophila* concentrations and others were negative. Table 17 summarizes significance of these individual factors based on positive (P) or negative (N) correlations.

Table 17 shows the sign of the variable in each of the regressions. From this analysis, if the sign is positive, an increase in that factor will predict an increase in *L. pneumophila,* if negative, an associated decrease will be observed. Therefore, if pH rises, the expected reaction is to reduce the level of *L. pneumophila* in the cooling tower.

Applying a sign test to the data shown in Table 17 shows that pH, square of filters, square of temperature, square of pH, and square of conductivity are all significant in that they are consistently predicting the direction of change of *L. pneumophila* levels when the variable changes at $p = 0.05$. None of the interactions were significant with this test.

Table 18 totals the impact of each factor, whether it shows a main effect, square, or interaction. This allows each interaction to be double-counted but is intended to identify those factors which are significant in any combination. Applying the same sign test to the data shown in Table 18 shows that dissolved oxygen and pH are the only factors which are significant in predicting the direction of change in *L. pneumophila* levels.

5.2 PREDICTION

The prediction equation for a specific serogroup /tower combination can be used to predict the expected *L. pneumophila* level by using the appropriate water chemistry data in the equation. Therefore, for example, the predictive equation for cooling tower 285-4F, Sero 1 is *Legionella* counts = $5816.7 - 1320 * pH + 74.5 * pH^2 + 3.3 * DO * Cond + 0.026 * Temp^2$. Substituting typical values (pH = 8.5, temp = 20, DO = 5, Cond = 0.6) would produce the following: $5816.7 - 1320 * 8.5 + 74.5 * 8.5 * 8.5 + 3.3 * 5 * 0.6 + 0.26 * 20 * 20 = 93$. This result seems reasonable considering the data values.

One caution on using a prediction equation is not to use it outside the range of the data used to develop the equation. Therefore the same equation developed from one tower's monitoring data analysis could not be necessarily used for a different tower. The equation cannot be extrapolated beyond the range evaluated because it isn't known how the system behaves outside its evaluated range. The individual towers construction, system management, biocide system, water source, and other parameters make each tower unique in terms of response.

6.0 RECOMMENDATIONS

Evaluation of fourteen cooling towers shows that each cooling tower has different significant factors in predicting *L. pneumophila* levels. Furthermore, each serogroup has different factors in the same cooling tower. A thorough evaluation of all towers, however, shows that some factors including conductivity, dissolved solids (Filter number), and pH are significant more frequently than others. Other factors not taken into consideration here including cooling tower water metal and cation concentrations, have also been found to influence *L. pneumophila* growth. Certain older SRS Cooing Towers in fact have had problems with copper (Cu) and zinc (Zn) in their aquatic discharges after blowdowns due to deterioration of older materials. Specifically iron (Fe) and cations such as phosphate (PO_4) and nitrates (NO_3) can also impact *L. pneumophila* in cooling tower water as these key nutrients are required for microbial growth. It is recommended that future water analyses are needed to look at the impact of these metals and cations on SRS Cooling Tower *L. pneumophila* densities.

The most frequently occurring significant factors are squares of number of filters, squares of temperature, squares of conductivity, squares of pH, and pH. Other frequently occurring factors include the conductivity, number of filters, and temperature interactions. It is interesting to note, however, that chlorine does not show up a significant factor, despite the fact that chlorine is normally the biocide added to control *L. pneumophila.* However, chlorine and bromine interactions, combined, are also frequently occurring. They do not appear to be significant by the sign test, however. It should be noted that some of the biocides utilize a biocide that contains both Br and Cl in a stabilized form. Certain towers are limited as to the amount of biocide that can be added to do to discharge permits.

Further evaluation of SRS likely Legionella control factors should proceed, and additional characterization is needed on the *L. pneumophila* data from the additional 14 Cooling Towers currently monitored at SRS not included in this work. Recommendations based on the findings presented here include 1) monitoring and maintaining Cooling Tower water pH @ 8.5; 2) checking and maintaining cooling tower water conductivity below (0.25 S/m); 3) strictly adhere to manufacturers guidelines on biocide applications; and 4) evaluating conditions on individual towers leading to increased dissolved solids in cooling tower water that can decrease biocide effectiveness.

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