LIFT, WRF, WEF
Intelligent Water Systems Challenge 2021
Solution Submission

# Intelligent Influent Flow Management

## The Team

The team consists of members from Clean Water Services, a public utility operating as a special service district providing waste water and storm water collection and treatment and watershed management for Washington County, Oregon.


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**The Opportunity**

As part of the inaugural Intelligent Water Systems Challenge in 2018, a team from Clean Water Services executed a project at the Rock Creek Advanced Waste Water Treatment Facility (AWWTF) to use available conveyance system volume to raise the water surface elevation in the influent pump station (IPS), thus reducing the total dynamic head (TDH) of the system to save pumping energy. Since that time a concept has been developed to use that storage capacity in a flow equalization (FEQ) mode that could provide benefits to the treatment process beyond energy efficiency. This idea forms the basis of the challenge presented to the team and the solution described in this submission.

Intelligent influent flow management (IIFM) can effect multiple benefits in the Water Resource Recovery Facility (WRRF). Flow equalization can provide process and control stability and reduce lag unit equipment runtime. Operating the IPS at lower TDH can provide significant energy savings. Flow equalization processes can be designed, constructed and incorporated into the IPS, but they may also be developed from available head, elevation and capacity for storage in the conveyance system, as is the case here. Risk is incurred when using existing conveyance systems and comes in the form of corrosion, solids deposition and retention, odors, and overflows. Ideally the advantages of IIFM can be balanced, maximized, and customized, and the risks minimized; this can be achieved by morphing data into information, knowledge, and action. In designing or advancing an Intelligent Water System (IWS), it is often best to start with the desired action or outcome and work backwards towards the data needed to inform that action:

- Action
    - Operate an existing IPS and conveyance system in FEQ mode for energy and equipment efficiency and process stability.
- Knowledge
    - What is the pumping efficiency of the IPS?
    - How do you quantify process stability?
    - What degree of equalization is achieved?
    - How can I know the risks to the conveyance system?

These questions help to identify the information and data needed to solve the Challenge.

**The Challenge**

Find, acquire, and leverage data to inform the operation of the IPS to maximize process and system efficiency, and inform risk knowledge when operating in a FEQ mode.

**The Solution**

The team accomplished the majority of tasks that they set forth in the Challenge plan. These accomplishments can be thought of in categories of efficiency measures, predictive parameters, and interface development.

*The Intelligent Water System*

The existing IWS consisted of separate and disparate data sources, programs, and user interfaces. IPS operational data were supplied through SCADA Historian, daily statistics and calculations from Hach WIMS, Telog (flow monitoring) data from conveyance, and receiving stream flow through the Oregon Water Science Center (USGS). Throughout the Challenge the Team leveraged new and existing data sources in creative ways. The new raw data incorporated into the IWS consists of data collection of existing power monitoring of two influent pumps and the receiving stream flow and gauge height forecast provided by the Northwest River Forecast Center (NWRFC). No new devices were installed in the course of the Challenge.

*Efficiency Measures*

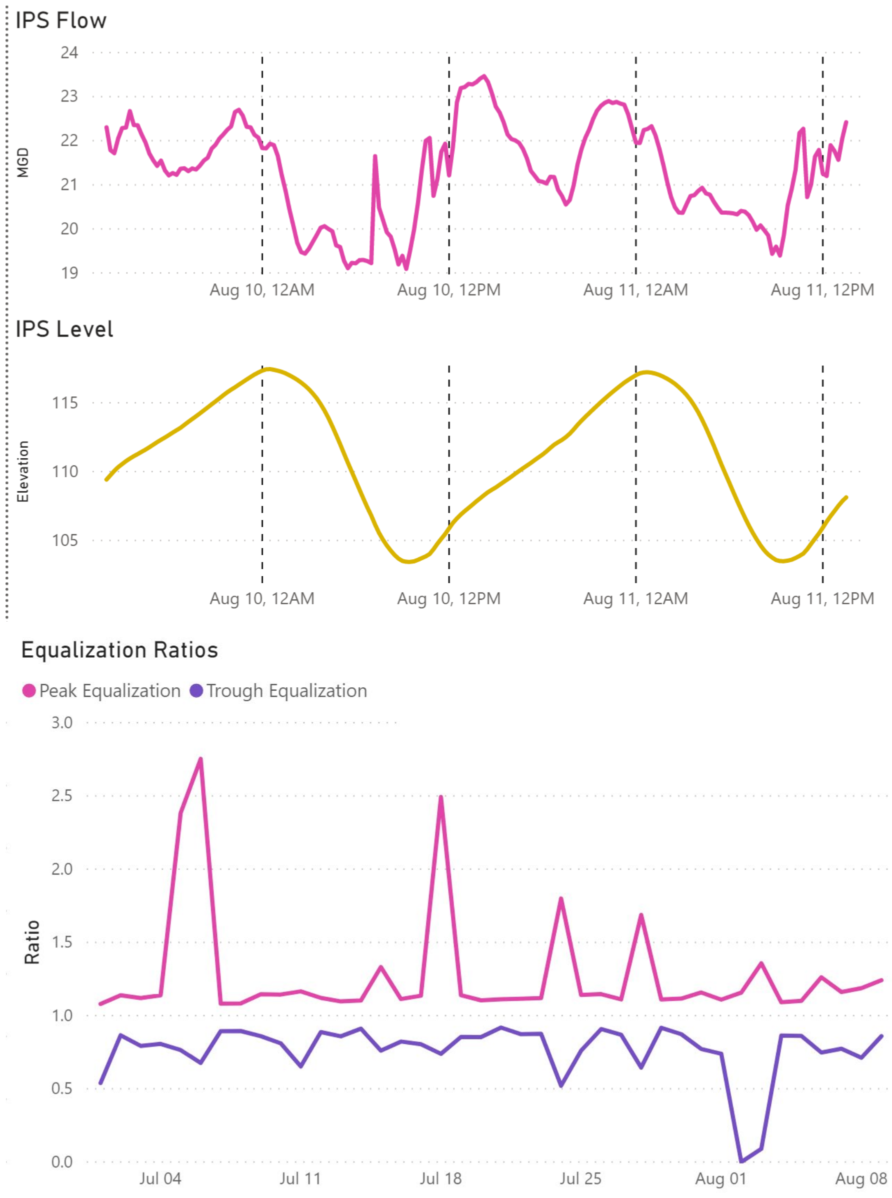
Before implementing a FEQ mode the Team had to consider how to program the IPS for safe and reliable operation. During work completed in anticipation of the 2020 IWS Challenge, six years of 15 minute IPS flow data was extracted from SCADA Historian and analyzed in Excel for daily flow patterns. The data captured high and low spikes in flow that originated in automatic lead-lag pump transfer sequences and manual operation. Data QA/QC was done by determining a rate of change in flow rate, filtering data that exceeded 0.09 MGD difference in 15 minutes, and using a previous one hour average in place of filtered data. The data was iteratively integrated at the 15 minute intervals to find the area between the diurnal curve and the daily average flow line. The area above and below the curve are equal and represent the volume of storage needed to achieve 100% equalization. Considering IPS operation, the simple concept is that when the diurnal flow curve crosses the average flow line on the way up the fill cycle should begin and maximum storage should be available. When the lines again intersect with flow decreasing, the drain cycle should begin so that low level is achieved by the next fill cycle. The data was further transformed to determine the time of day for the fill and drain cycles and if it was suitably regular to use in IPS controls. The Team determined these times to be 10:00 AM for the fill cycle and 1:00 AM for the drain cycle, and reliably at that. Acceptable high and low levels in the IPS had been determined during the previous challenge to be 102 to 118 feet in elevation.

The IPS at Rock Creek is deceptively complex, with seven pumps in two sizes and two flow meters, and now a dynamic discharge head. However, operation must remain simple. The pump station operates in level mode with variable frequency drive (VFD) driven pumps ramping and cycling to maintain the level set point. This is the safest control strategy and the desire was to maintain level control. The IPS was programmed to automatically adjust the level set point to begin the fill cycle by linearly adjusting level up to 118 feet by 1:00 AM. In the drain cycle the level is adjusted with a variable slope to achieve the low level set point of 102 feet by 10:00 AM.

The metrics developed to inform the degree of equalization achieved were a peak and trough equalization ratio. A ratio approaching 1 approaches complete equalization.

$$Peak\ EQ = \frac{Max\ Q}{Avg\ Q}\ \ and\ Trough\ EQ = \frac{Min\ Q}{Avg\ Q}$$

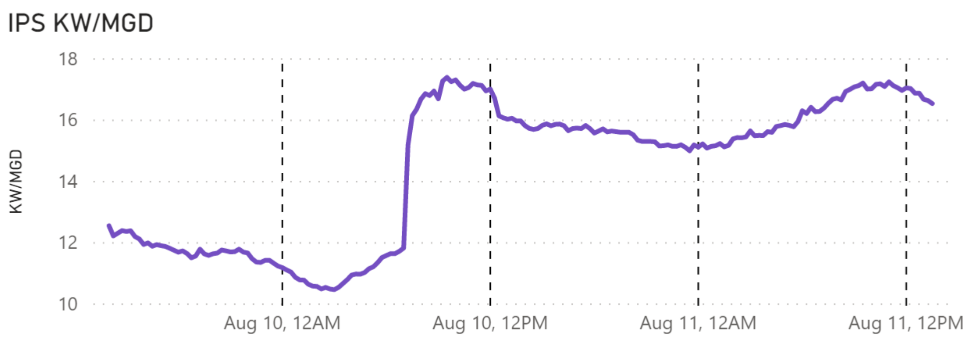
The diurnal flow and level pattern as well as the equalization ratios are shown in the figure below.




*Diurnal IPS flow and level trends in FEQ mode, and equalization ratios. Spikes in equalization ratios are due to the use of raw data which captures pump sequencing and manual operations. A filtered data set has been created to eliminate unrepresentative flow data and give a more accurate picture of minimum and maximum flows and equalization ratios.*

Evident in the figure above are the spikes in the ratios with no corresponding spikes in the flow trend. The flow trend is done with 15 minute average SCADA data while the ratios are calculated from daily raw flow data. The raw data captures values from pump sequencing and manual pump flushing operations. To address this QA/QC problem a new SCADA tag was created to make a filtered flow data set that holds the last flow value static during lag pump start up and manual operations. Data collection has just begun on this tag.

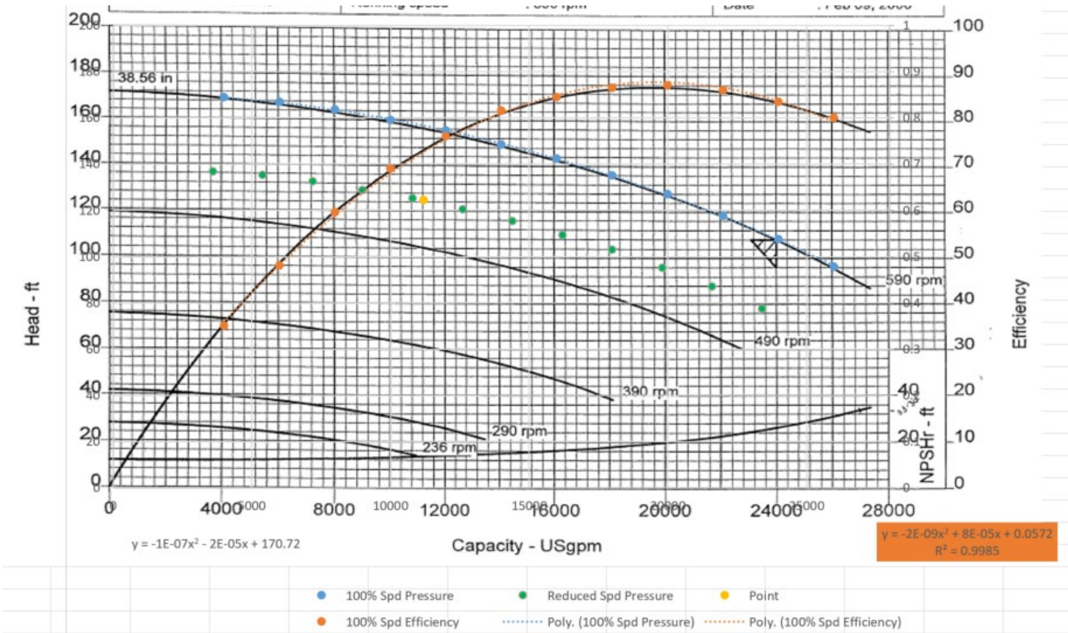
The data existed to truly maximize the energy efficiency of the IPS, the Team only needed to produce the right information to know the true energy consumption. Kilowatt data was already recorded in SCADA Historian for the 5 large IPS pumps and collection was begun on the two small pumps. With a total picture of energy, SCADA tags were made for the total IPS pump kilowatts and the ultimate metric, kW/MGD. The figure below shows the trend of the efficiency metric and also illustrates the value that this IWS has already produced. The substantial step increase in kW/MGD corresponds to switching pumps (pump 5 to pump 4, both small pumps). Pump 4 had just been rebuilt. The increase could indicate a problem with the rebuild, however the first step will be to confirm the power data.




*Power to pump ratio is the ultimate metric developed to evaluate IPS efficiency between operating modes.*

In addition to the overall IPS efficiency, an individual pump performance indicator was created. Eventually the data collected can further maximize efficiency by identifying the most efficient pumps and pumping conditions. A real time pump performance chart was created in Power BI.

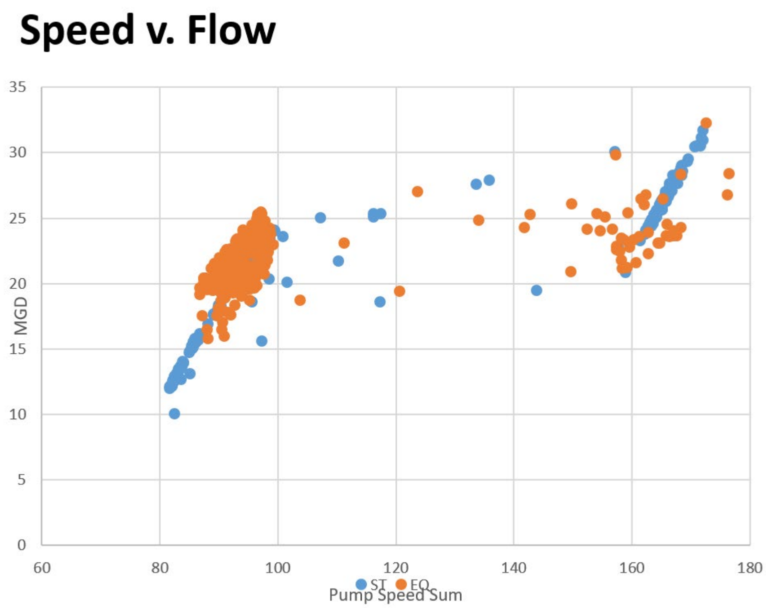
The first step in making this tool was to “reverse engineer” the pump curve from the manufacturer’s literature. Most often the pump curve is provided in static format, as a PDF, or a page in a paper manual. A creative and attainable method was developed and used to convert the curve to data and equations. An object image of the curve is pasted into an Excel sheet. The image can be flipped or rotated to get the desired dependent variable on the y-axis. A transparent graph is overlaid on the image and the axes and scale are adjusted to match the pump curve. To model the curve, a data set of x and y variables is created to match points on the curve. The curve is then modeled with a trinomial equation to represent the 100% speed curve. From this information the pump affinity laws are employed to determine the pump curves at other speeds. The culmination of this method is shown below.




*Development of data sets to plot pump curves was done in Excel. A transparent graph has been overlaid on the pump curve image and axes adjusted to match the pump curve. The axes values of both the chart and image are visible in the figure.*

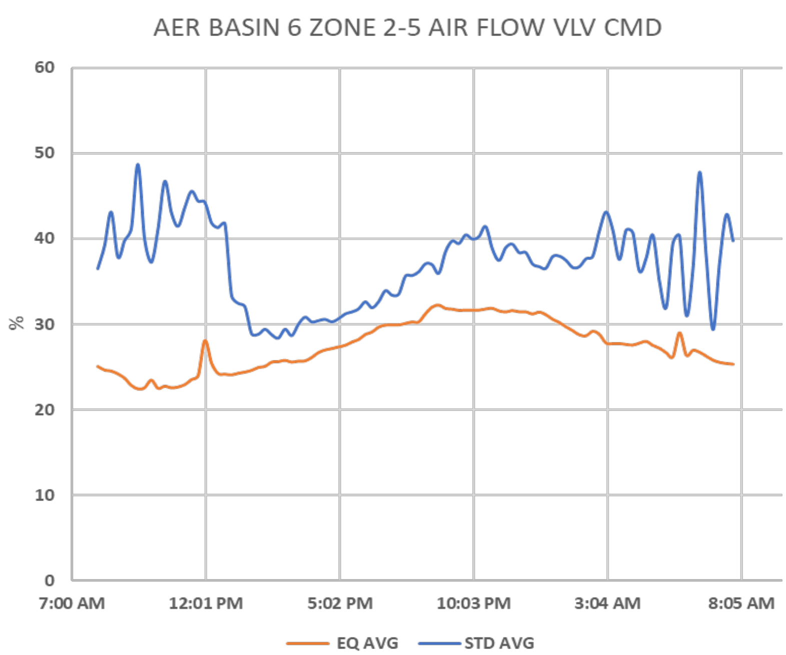
Pump flow and speed are known so the last piece of data needed to complete the puzzle was the pump head. The variable TDH was calculated in SCADA assuming a constant discharge elevation at the screenings channel. The tool is currently only a visualization but the future envisioned for this information is to automatically display the pump curve at current speed, calculate expected flow, and record and trend a pump efficiency.

In addressing the gains of FEQ in equipment efficiency, comparisons were made between successive two-week periods of FEQ operation and standard operation at a static level set point of 102 feet. At the IPS the pump speed sum was plotted against flow and the number of hours with a lag pump running were tabulated. The result was a 78% reduction in lag pump runtime from peak flow attenuation, plus the pumps were more efficient at lower TDH. Primary effluent is pumped to secondary treatment through two primary effluent pump stations (PEPS) and those stations saw 53% and 94% reductions in lag unit runtime.




*Hourly IPS total pump speed and flow data for operation in FEQ mode and standard low-level mode to quantify lag unit run time as number of hours with total pump speed greater than 100%.*

Process stability and reliability is difficult to define and measure, but generally is a function of stable controls. This was examined visually by looking at the cycling of valve position on an air flow control valve operated to control to a dissolved oxygen set point in the aeration basin. There was a reduction in cycling during low flow and load periods and it is indeed felt that the greatest benefit to process stability comes from mitigating the overnight trough flow.

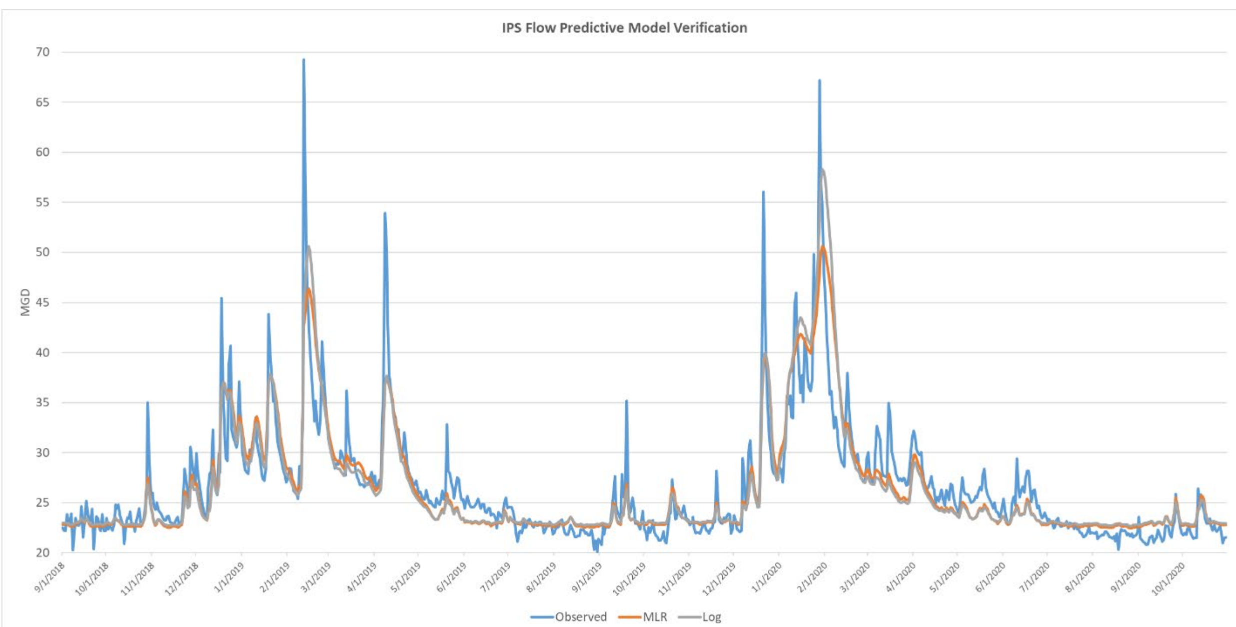



*Mitigating the overnight baseline period of low flow and load through FEQ perhaps provides the greatest benefit to process stability, as evidenced by better DO control in the aeration basin.*

*Predictive Parameters*

The greatest cause for concern in using the conveyance system as a FEQ basin is the increased risk for overflows. This risk is elevated in two ways; a wet weather event occurring at high FEQ level preventing the free flow of waste water to the IPS or a failure of the IPS at high flows and high FEQ level which decreases or eliminates the time available to respond to the failure. An influent flow prediction would inform this risk and the decision to switch out of FEQ mode and return to standard mode during an anticipated high flow event.

The National Oceanic and Atmospheric Administration (NOAA) operates 12 regional River Forecast Centers throughout the U.S. In Oregon, the NWRFC issues a ten day forecast for flow and gauge height for the receiving stream for the Rock Creek AWWTF, the Tualatin River. The Team sought to leverage this forecast into a predictive model for IPS flow, if a correlation could be found. Five years of daily river flow, gauge height, and IPS flow were used in model development with 3 years of data used to develop a model and 2 years of data used verify and tune the model. In Excel, a multiple linear regression (MLR) model was calculated and the model verification returned a root mean square error (RMSE) of 4.06. Coefficients were then applied to both the flow and gauge terms and the Solver function in Excel was utilized to find the coefficients that would minimize the RMSE. The result was that the gauge term was heavily weighted, while the flow term went to zero and the RMSE was reduced to 2.68. After finding the principal dependency of IPS flow on gauge height a second model was employed using a simple logarithmic data fit between flow and gauge height and the same method for minimizing RMSE. This model returned an RMSE of 2.91, but proved to be slightly better at predicting the highest flows. The model verification is shown in the chart below.




*Predictive flow models were developed in Excel and based solely on the NOAA NWRFC Tualatin River 10 day stage forecast at the Farmington gauge.*

The models, though simplistic, were thought to offer sufficiently useful flow predictions, especially considering that the flow predictions can go out the same ten days as the NWRFC forecast. Because of this the effort was made to automatically import the NWRFC forecast data into Clean Water Services databases through Power BI, and run production models.

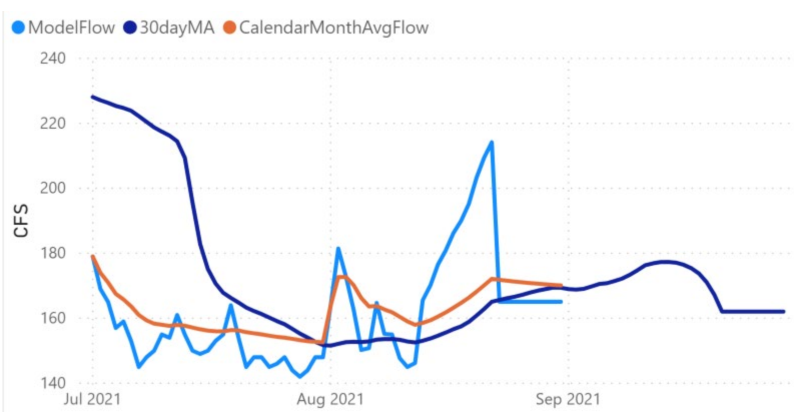
Once the Team had the forecast data available, another side benefit was found and pursued.

The Rock Creek AWWTF is subject to a year-round ammonia permit limit based on toxicity. The limits are structured in tiers dependent on the receiving stream flow, as shown in the table below.

| **Tualatin River Flow at Farmington, cfs** | **RC Ammonia Limits, mg/L N (Nov-Apr)** | |
|---|---|---|
| | **Daily Max** | **Monthly Average** |
| <500 | 11.5 | 4.8 |
| 500-1,000 | 23.2 | 11 |
| >1,000 | 38.6 | 16.2 |

*Daily maximum and monthly average effluent ammonia limits depend on the daily and monthly average river flows. Prediction of the monthly average river flow informs the efficient process control of nitrification for ammonia removal.*

The monthly average ammonia limit is dependent on the monthly average river flow, which is not known until the end of the month. Because of this the process control analysts must operate the treatment plant with extreme conservatism, often with nitrification rates far beyond what the monthly limit requires. Having the ten day river flow forecast enabled the Team to estimate the monthly average river flow in advance. To do this a model flow data set was created that agglomerates actual flow, forecast flow, and a 30 day running average flow that includes the forecast data. The database is automated such that each day the actual flow for the previous day is recorded, the forecast data is updated and the 30 day running average is recalculated. The 30 day running average fills in the data for the remainder of the month and the monthly average estimate is recalculated. Another 30 day running average is calculated to run out 30 days beyond the end of the forecast flow period. The concept is illustrated in the chart and table below.



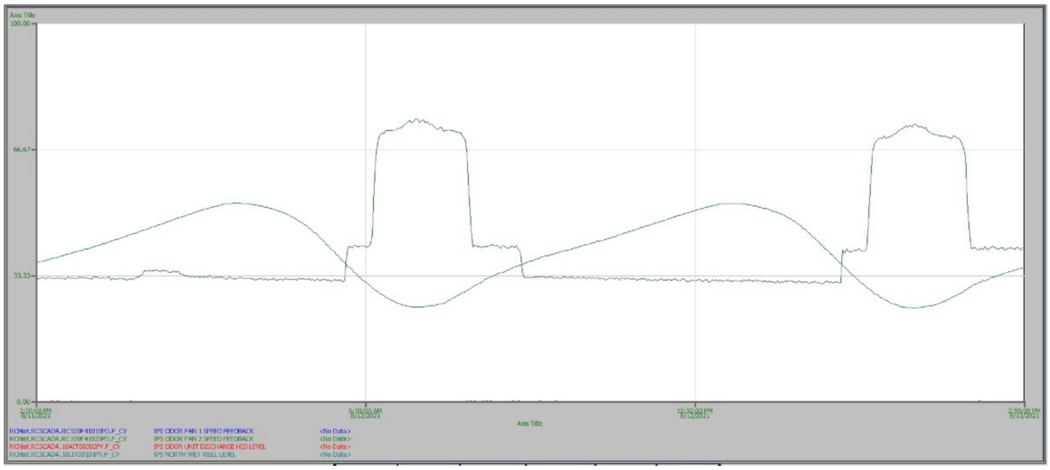

*Tualatin River flow predictions based on NWRFC 10 day forecast.*

| CalendarDate | ActualFlow | ForecastFlow | ModelFlow | CalendarMonthAvgFlow | 30dayMA |
|---|---|---|---|---|---|
| 08/11/21 | 145.00 | 162.47 | 145.00 | 159.04 | 152.85 |
| 08/12/21 | 146.21 | 162.52 | 146.21 | 157.97 | 152.55 |
| 08/13/21 | | 165.55 | 165.55 | 158.55 | 153.07 |
| 08/14/21 | | 170.13 | 170.13 | 159.38 | 153.78 |
| 08/15/21 | | 176.61 | 176.61 | 160.53 | 154.66 |
| 08/16/21 | | 180.89 | 180.89 | 161.80 | 155.59 |
| 08/17/21 | | 186.23 | 186.23 | 163.24 | 156.63 |
| 08/18/21 | | 190.00 | 190.00 | 164.72 | 157.50 |
| 08/19/21 | | 195.17 | 195.17 | 166.33 | 158.87 |
| 08/20/21 | | 203.18 | 203.18 | 168.17 | 160.81 |
| 08/21/21 | | 209.43 | 209.43 | 170.13 | 162.86 |
| 08/22/21 | | 214.17 | 214.17 | 172.14 | 165.07 |
| 08/23/21 | | | 165.07 | 171.83 | 165.63 |
| 08/24/21 | | | 165.07 | 171.55 | 166.17 |
| 08/25/21 | | | 165.07 | 171.29 | 166.64 |
| 08/26/21 | | | 165.07 | 171.05 | 167.24 |
| 08/27/21 | | | 165.07 | 170.83 | 167.91 |
| 08/28/21 | | | 165.07 | 170.62 | 168.51 |
| 08/29/21 | | | 165.07 | 170.43 | 168.98 |
| 08/30/21 | | | 165.07 | 170.25 | 169.45 |
| 08/31/21 | | | 165.07 | 170.08 | 169.39 |
| 09/01/21 | | | | | 168.97 |
| 09/02/21 | | | | | 168.83 |
| 09/03/21 | | | | | 169.06 |
| 09/04/21 | | | | | 169.79 |
| 09/05/21 | | | | | 170.55 |
| 09/06/21 | | | | | 170.79 |
| 09/07/21 | | | | | 171.47 |
| 09/08/21 | | | | | 172.22 |
| 09/09/21 | | | | | 173.38 |
| 09/10/21 | | | | | 174.80 |
| 09/11/21 | | | | | 176.31 |
| 09/12/21 | | | | | 176.91 |
| 09/13/21 | | | | | 177.30 |
| 09/14/21 | | | | | 177.35 |
| 09/15/21 | | | | | 177.11 |
| 09/16/21 | | | | | 176.46 |
| 09/17/21 | | | | | 175.42 |
| 09/18/21 | | | | | 173.77 |
| 09/19/21 | | | | | 171.10 |
| 09/20/21 | | | | | 167.27 |
| 09/21/21 | | | | | 162.05 |
| 09/22/21 | | | | | 162.05 |

*Actual and forecast Tualatin River flows are aggregated into a single data set for prediction of 30 day moving average and calendar month average flow.*

Other concerns about conditions in the conveyance system are addressed through monitoring SCADA parameters and communicating through the new Power BI interfaces. Those concerns and the relevant data and information are:

- Corrosion and Odors
    - IPS Odor Control
        - Fan speed
        - Discharge $H_2S$
    - At FEQ low level the IPS Odor Control system is open to the conveyance system and partially evacuates the head space in the main interceptor. The fan speed increases at these conditions (~70%), and decreases (~30%), when the interceptor is submerged, which effects an additional energy savings. Monitoring the SCADA trend shows the periods of submergence and evacuation. Serendipitously the system is open to conveyance during the daytime hours, reducing the likelihood of nuisance odors.




*During daytime hours the IPS level is sufficiently low that the IPS odor control unit evacuates the headspace in the collection system, which helps to minimize nuisance odors from storing wastewater in the interceptor. The figure shows the odor control fan speed in green and the IPS level in blue.*

- Grit and Trash Accumulation
  - Grit
    - Hourly Grit Production
    - Grit Hopper Weight
    - Daily Grit Production
    - Grit Dumpster Haul Weight
  - Trash
    - Bar Screen Cycles per Hour
    - Screenings Dumpster Haul Weight
    - Sludge Screenings Dumpster Haul Weight

Hourly data is calculated for grit and trash removal to understand the diurnal trends of deposition and scouring. The grit production is monitored from the weigh cells on the grit hoppers. The bar screen operates in level control mode, so the cycles per hour indicate the removal rate. Daily production data and dumpster haul weights provide long term trends. The trends can be seen in the interface development section. The next step in advancing data analytics in these systems will be to check correlations that may allow for predicting the headworks production, predict the time to haul and use the knowledge to maximize haul weight and minimize hauls.

*Interface Development*

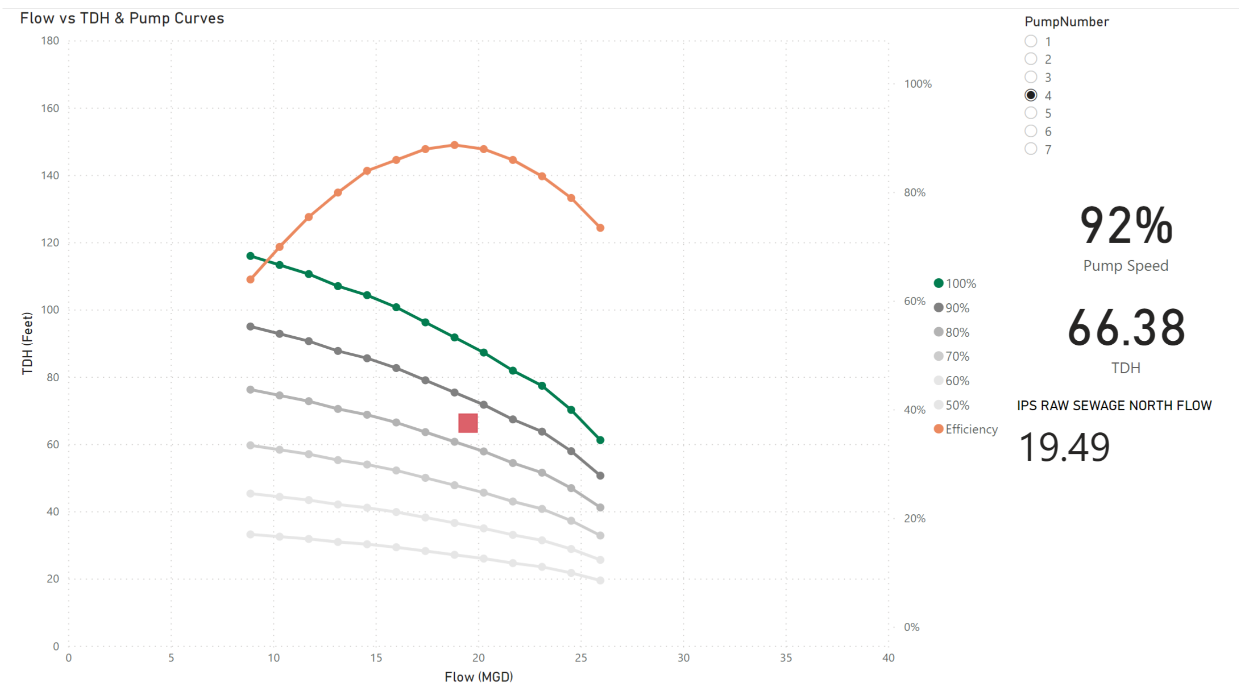
Three distinct visual interfaces were developed to convey information to the variety of anticipated users. These interfaces address Pump Efficiency, FEQ Operations, and Flow Forecasting.

Clean Water Services has made a push to better utilize Power BI to gather disparate data sources for information access across all departments. Existing integration processes were leveraged to retrieve information from the SCADA Historian and Hach WIMS and place it in a format suitable for display in Power BI. Information from the SCADA historian is retrieved every 15 minutes, while Hach WIMS information is updated daily. A Python process was created to retrieve river stage and discharge forecasts from the Northwest River Forecast Center and add to a staging database in SQL Server. From the staging table, information is transformed by applying the model described above for influent flow; results are stored in a table suitable for display in Power BI. Transact-SQL is used for this portion of the process. The process runs 4 times daily.

Power BI is used to display visuals, drawing mainly from SQL Server tables populated by the data integration processes described above. For data that is relatively static, such as pump efficiency curves, the Power BI data model will be updated as needed. Update of this information may be automated in the future if there is business need.

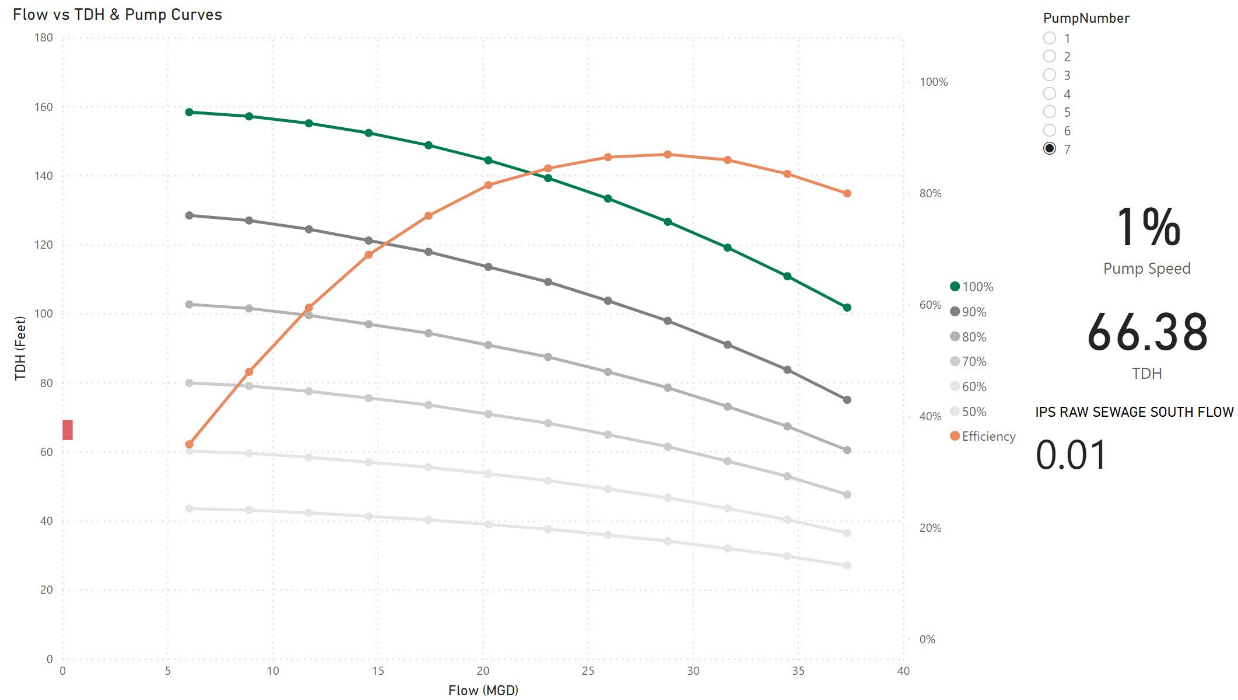
*Pump Efficiency*

Two screens comprise the pump efficiency interface. The first displays a column chart of the pump speed of all the IPS pumps so the user knows which pumps are running. From there they proceed to the pump efficiency page, displayed below.




*Real time pump efficiency plot for small pump on north flow meter.*

The pump curve chart was created from static data within Power BI and overlaid with a scatter plot of the current operating point of the pump from the TDH and flow. Because there are seven pumps in two sizes and two flow meters, two pump curves were needed. Pump number selection in the upper right of the interface was created so the user can change the display to change the pump curve, the flow display between north or south, or both. The interface below shows a large pump on the south flow meter for reference.

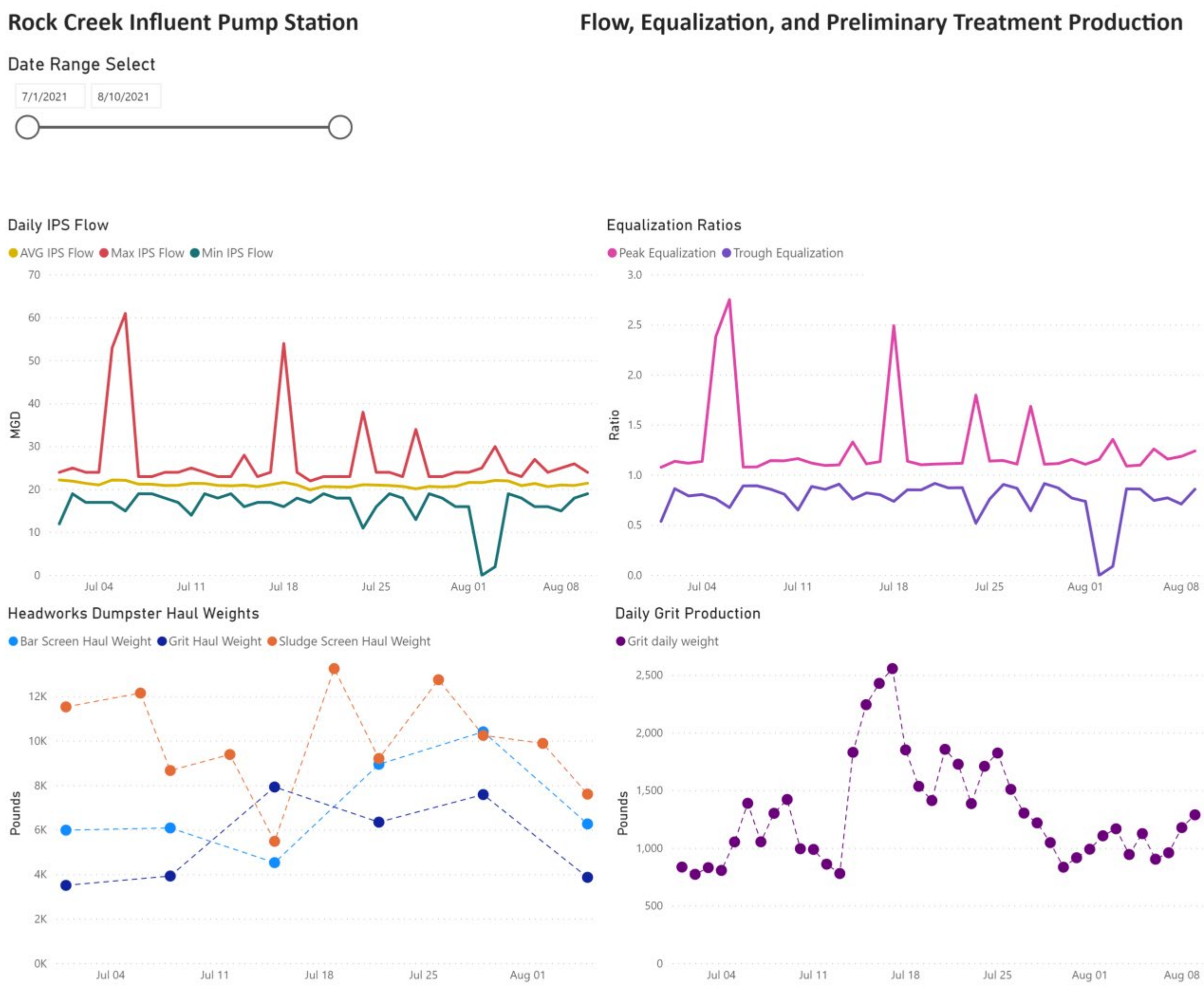



*Real time pump efficiency plot for large pump on south flow meter.*

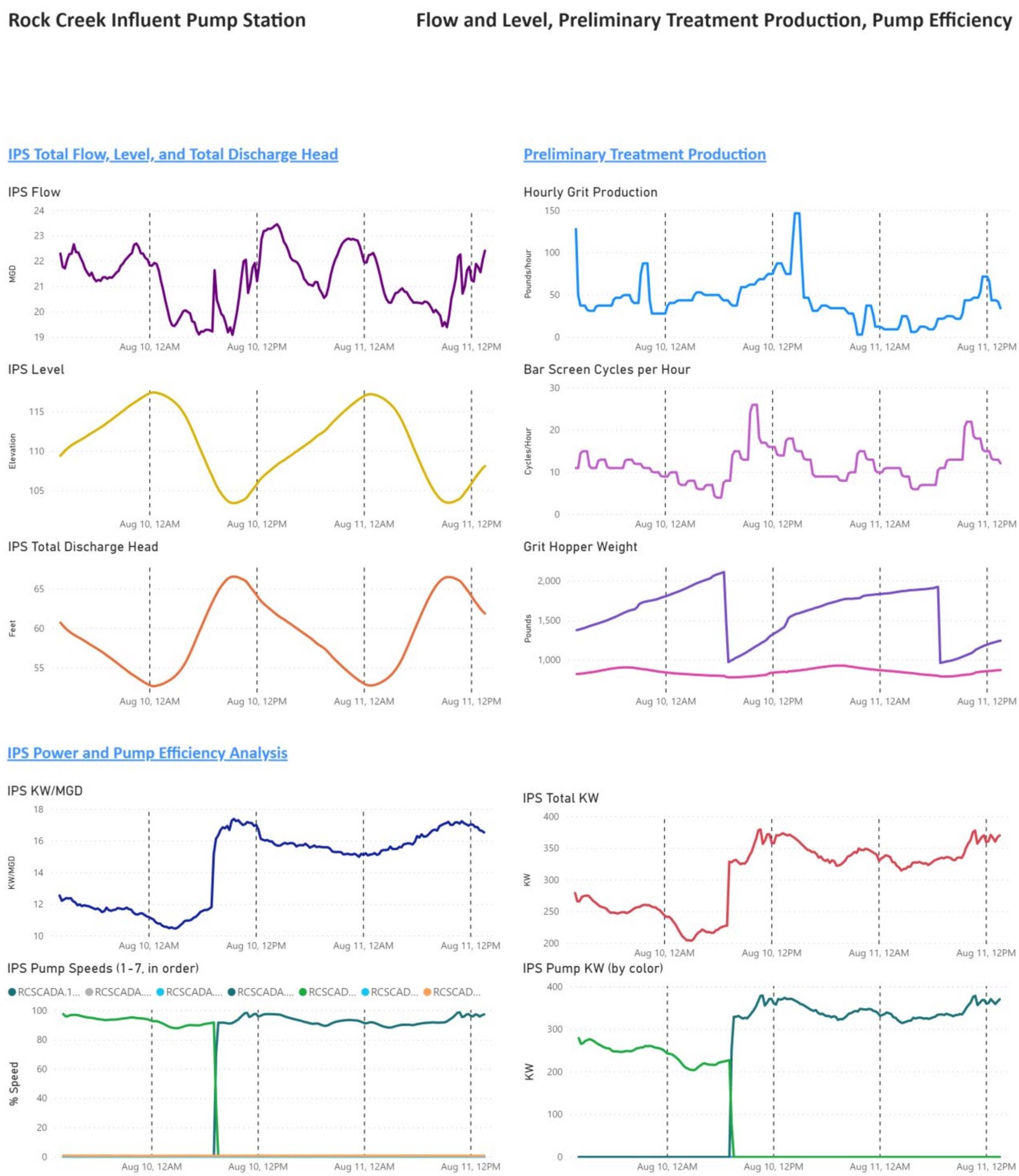
Information on pump efficiency is conveyed by noting the pump speed, approximating position from the family of curves, estimating expected flow at that position and visualizing efficiency and condition. Creative IIFM modes may be enabled by tracking this data, and operating pumps and the pump station increasingly at peak efficiency

*FEQ Operations*

Both plant and collections operators and process control analysts can find relevant operational data on this interface. Many of the elements have been seen or described previously in the submission. The overall interface is displayed below, consisting of two screens, one for daily data and one for 48 hours of 15 minute SCADA data.




*Power BI display for daily data for FEQ operations.*

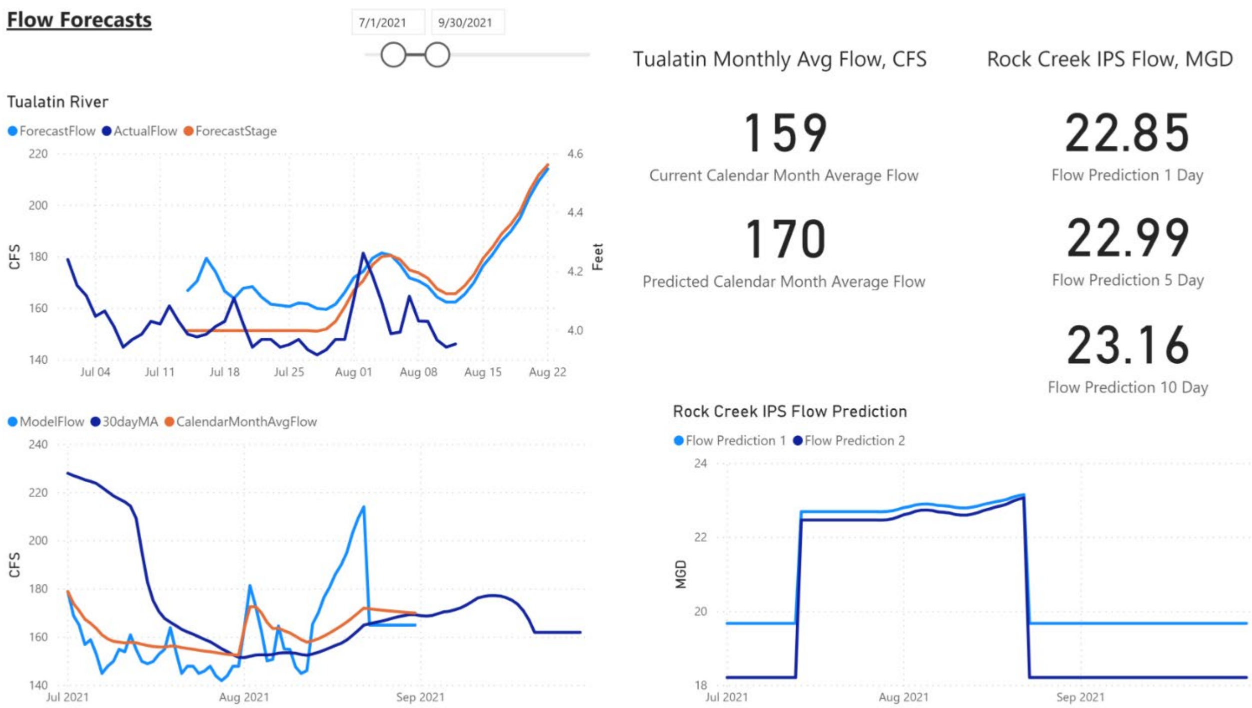



*Power BI interface is used to communicate real-time SCADA data across the organization, to personnel without SCADA access.*

*Flow Forecasting*

Again, facility operations staff and conveyance personnel can get information from the flow forecasting interface. Manipulation of river flow to produce the model flow, prediction, and moving averages is done in the database, while the influent flow prediction models are calculated as columns inside Power

BI. Quick visual interpretation of the charts may be slightly more difficult in this interface, so more succinct information is conveyed through the cards in the upper right of the display that show the current values for predicted flows.




*Flow Forecasts dashboard developed in Power BI to inform IPS operation and ammonia toxicity permit limit requirements.*

**The Conclusions**

Propelled by the Challenge, the Team has advanced the analysis of data and the transformation of data into information to enable more knowledgeable decisions and actions. In summary, the solution implemented by the Team has:

- Informed the operation of the IPS in FEQ mode through system and pump efficiency measures and influent flow prediction.
- Informed the condition of individual IPS pumps through real time pump curve analysis.
- Informed the effect on the conveyance system through better monitoring of preliminary treatment production.
- Informed the process control of the nitrification process through monthly average river flow prediction.
- Informed the benefit and degree of equalization attained by the facility.

Operation in FEQ mode, enabled by the IWS, has been demonstrated to have high value through:

- Lower specific pumping energy in the IPS.
- Reduction in lag unit run time in the IPS and PEPS.

- Reduction in equipment cycling through low flow attenuation.

Although the specific opportunity of FEQ is a special case, the methods employed in the course of the Challenge offer attainability by other utilities. The Team creatively leveraged existing data using available tools like Excel and Power BI. The opportunity for FEQ, and to apply a similar IWS, is scalable both up and down to small and large facilities as well as remote pump stations. The NWRFC alone provides forecasts at over 1000 gauges across the Pacific Northwest, so the applicability of the influent flow model presented here would seem to have ubiquitous potential.

The IWS created through the Challenge is but a first iteration, hinting at the potential created by bringing together data streams from sources and departments across Clean Water Services. In the near future the tools developed here will be documented with user instructions, training developed and administered, and feedback gathered from the various user groups. Ease of use of the interfaces is also key and one-click access needs to be established for each user group from the most used programs. For example, a link on SCADA for plant operators or a link in Hach WIMS for process control analysts. The long term benefit of collecting and analyzing the IPS and pump efficiency data would ideally be innovation in IIFM modes. Hybrid modes can be imagined that utilize differential fill rates, spending more time at high level for energy efficiency, and still reaping the stability benefits of trough equalization. The Rock Creek AWWTF pumps water three times (seasonally dependent) to move it through the treatment process. Influent FEQ provides equalization for the rest of the pump systems and throws open the door to creative flow management throughout the plant for efficiency and process stability. The IWS should be expanded to import conveyance flow data and rainfall data and forecast.

The common pitfall in developing an IWS is failing to recognize that an asset has been acquired. Even the simple interfaces that have been fabricated in the solution to this challenge are digital assets and require an asset management plan. Maintaining these assets could be assigned to and accomplished by information technology staff, but Clean Water Services is striving to push the Power BI skills needed to improve and maintain these interfaces to engineering and analyst staff. The skills learned by Team members through the arc of the Challenge was an enormous unforeseen value addition. Regardless, digital asset management adds workload, and the primary need in maintaining these systems is skilled and knowledgeable personnel.

The Intelligent Water System advanced by the Team has creatively leveraged existing data sources into great potential for energy and process efficiency gains through targeted information that allows staff to make more knowledgeable decisions and take action with more confidence, innovation, and consequence.