

# TECHNICAL ARTICLE

## Case Study – New Control System and HMI Screens for a Municipal Ground Water Well

By Graham Nasby, City of Guelph Water Services

In 2018, Guelph Water Services embarked on a project to upgrade one its key groundwater wells. Located within city limits, the Emma Well provides approximately 35 liters/sec (550 us-gal/min) of reliable drinking water to the residents of Guelph. This article provides an overview of how a new SCADA (supervisory control and data acquisition) control system and HMI (human machine interface) was implemented as part of an overall facility upgrade.

### About Guelph Water Services

Guelph Water Services is a publicly owned/operated drinking water utility located in Guelph, Ontario, Canada. In operation since 1879, Guelph Water Services provides drinking water and fire protection water for a population of 140,000 people in the City of Guelph and the adjacent Gazer-Mooney Subdivision in Puslinch Township. The Guelph system consists of approximately 49,000 service connections, 2,900 fire hydrants, 21 groundwater wells, 3 water towers, and several pumping/monitoring stations. In all the system has approx. 600 km of water mains ranging from 4" to 30" serving three pressure zones. It also includes an 8km (5 mile) piped gravity aqueduct from the Arkell Spring Grounds wellfield. Guelph Water Services is one of the largest groundwater based drinking water systems in North America.

The Guelph Water SCADA system consists of 35 facilities linked together using a private MPLS fiber-optic network. This is supplemented with secondary private MPLS 3G/LTE wireless links, which are setup to restore connectivity within 45 seconds in the case of a fiber cable break. The control system uses a PLC+HMI architecture that consists of approximately 55 PLCs, 2 SCADA datacenters, and 15 view nodes located throughout the city. In each SCADA datacenter, the servers are fully virtualized using multiple physical hosts running VMs and multiple storage array networks (SANs). An automated back-up system backs up server images four times a day. Three redundant store/forward datalogging systems record process data from the field. After-hours call-out alarms are handed by two redundant call-out servers. In all, the Guelph Water SCADA system has approx. 750 instruments, 75 large pumps, 65 motorized valves, and a network of flow/pressure sensors in the distribution system. The system is staffed Mon-Fri 8am-4pm with an after-hours on-call operator.

### Motivation for the Upgrade

First drilled in 1931, the Emma Street Well has been in continuous use for almost 90 years. Coming from a bedrock aquifer, the well delivers water of very high quality that has historically required minimal treatment. To comply with regulatory requirements, the site has used both free chlorine (via sodium hypochlorite addition) and UV (via a packaged UV system) for primary disinfection. For secondary

disinfection, the free chlorine addition is also used to satisfy Ontario's O.Reg. 170 regulatory requirements with respect to ensuring that a sufficient amount of secondary chlorine residual is maintained throughout the distribution system.

In 2017, the facility's existing UV treatment system – due to the type of control system technology used in the UV vendor panel – had reached end-of-life and needed to be replaced.

A study was undertaken to do a cost-benefit analysis of two options: (a) replacing the existing UV treatment system with a new UV system, or (b) removing the existing UV system and replacing it with a new underground contact chamber (to increase the free chlorine contact time). Due to the cost of electricity in Ontario and the characteristics of the well, it was determined that it would be more cost effective in the long term to remove the UV and install a new underground contact chamber. This became the Emma Well Upgrade project.

In addition to removing the UV system and adding a new underground contact chamber, the project was also used as an opportunity to upgrade the site's automatic control system and HMI (human machine interface) operator control screens.

### Post-Upgrade Process Block Diagram

A block diagram of the newly upgraded treatment process for the Emma Well can be seen in Figure 1. The well itself uses a 60 HP submersible well pump to provide approximately 35 L/s of raw water. Upon leaving the pump, the water passes through a pilot-operated backpressure valve which functions as a one-way check valve.

The well is equipped with a well level transmitter, pump discharge pressure transmitter, and a flow transmitter to track pump performance over time. The well flowmeter is also used to ensure the well is operating within its Ontario Permit to Take Water (PTTW) in terms of maximum flow rate (L/s) and maximum allowed daily water taking (in cubic meters).

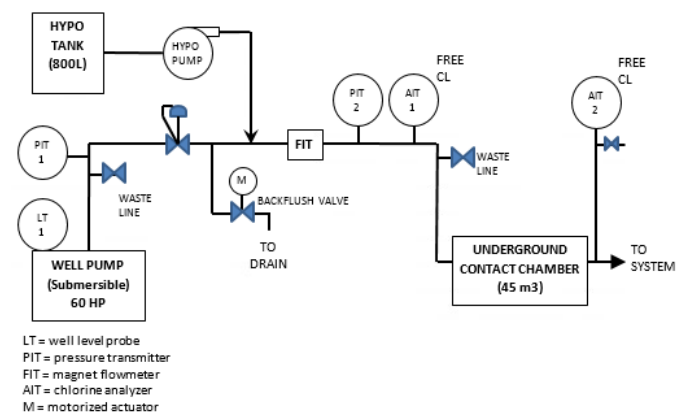


Figure 1 – Emma Well Process Block Diagram (post-upgrade)

After the water passes through the backpressure valve, the "hypo" (a 12% sodium hypochlorite solution) is injected as a source of free chlorine. The hypo is used for both primary disinfection and to maintain a secondary residual chlorine

concentration leaving the station. The hypo dosing rate is controlled by the PLC using flow-pacing, based on the well's flow rate and a target chlorine dose setpoint.

A baffled underground contact chamber provides the contact time needed to satisfy a regulatory requirement of a 2-log virus reduction. Sizing of the contact chamber was done per the Procedure for Disinfection of Drinking Water in Ontario from the Ontario Ministry of the Environment Conservation and Parks (MECP) to ensure an adequate contact time (CT) could be achieved even under worst case conditions. The underground contact chamber is actually sized so that it can achieve up to a 6-log virus reduction to allow for potential future capacity increases and/or increased regulatory treatment requirements in the future.

To aid in starting up the station, a motorized backflush valve is used as part of an automated start-up sequence to flush out any stagnant water from the contact chamber (which may have a degraded chlorine residual) before the well pump is started. The station's pilot-operated backpressure valve is used to ensure that flow from the well pump only flows from the well, and not back into the well. The pilot-operated backpressure valve and the motorized backflush valve were re-used from the site's previous UV disinfection system.

At the station outlet, also known as the point-of-entry (POE) into the water distribution system, the site is equipped with a free chlorine analyzer and a system pressure transmitter. The POE chlorine analyzer serves multiple purposes. It enables the free chlorine residual leaving the station to be monitored and logged. It enables for the control system to implement both a high-chlorine and low-chlorine shutdown interlocks. And it also enables the SCADA system to do real-time CT calculations to prove the 2-log virus disinfection requirement is being met whenever water is being produced.

### Verified As-Found Electrical Drawings as a Design Tool

To assist with planning/executing both the design and construction phases, the project scope was purposely defined to include creating full sets of both verified "as-found" and "as-built" electrical drawings. This was to fully document the before and after details of all electrical aspects of the station, including: power distribution, electrical layout/elevations, lighting panel schedules, lighting/receptacle locations, emergency lighting locations, motor starter wiring / connections, motorized valve wiring/connections, and PLC panel details. Also included were a full set of ISA-5.4 style connection/loop drawings for all devices and instrumentation.

Taking the time to create a set of verified "as found" drawings --- before the main station upgrade design work was undertaken -- greatly simplified the electrical design process and significantly reduced the amount of risk during the construction phase. Looking back on the project, it was well worth the time investment to create a good set of "as-found" drawings to feed into the station upgrade design work. Guelph Water has since implemented the step of creating as-found

electrical, P&ID and facility layout drawings as a design prerequisite for all capital projects moving forward.

It goes without saying that having high-quality/accurate as-built drawings at the end of a project makes operating, maintaining, and troubleshooting a facility much easier. Verification of both the as-found and later as-built drawings was done by yellow-lining. Yellow-lining is a technique in which the drawings are printed and each wire is highlighted with a yellow highlighter on the drawing as it is checked on site; any updates are noted on the drawing using a red pen.

### SCADA Coordination with the Design Team

One of the main reasons for the success of the Emma Well project was that the SCADA team was able to be involved with the design of the station all the way from project charter development, writing of the consultant terms of reference, to preliminary design and detailed design, as well as during the shop drawing review, construction and commissioning phases. Like any successful project, it was important the various project stakeholders and project disciplines worked as a team.

### Construction Phase

Physical construction work at Emma Well began in the spring of 2018 and was completed by the fall. This involved taking the facility offline, replacing the UV reactor with a straight-through piece of piping, installing a prefabricated underground steel contact tank, adding a new post-contact chamber chlorine analyzer, and reconfiguring yard piping for the facility. Figure 2 shows the construction crew setting the new epoxy-coated steel underground contact chamber into place.

The construction work also included correcting a number of existing control wiring inconsistencies in the well pump starter, adding in missing "status monitoring" I/O, and labelling previously undocumented wiring. The site's existing point-of-entry (POE) chlorine analyzer was also repurposed to measure the pre-contact chamber free chlorine residual, and the additional new free chlorine analyzer was installed with a sample line to measure the post-contact chamber / POE value.



Figure 2 – Installation of the underground contact chamber

## SCADA Software Development

During the preliminary design phase of the project, the decision was made to retain the existing PLC and PLC panel. The existing PLC was of high quality and still had many years of useful life left in it. (Under the facility's asset management plan, the PLC was not scheduled to be replaced for another 10 years.) The existing field wiring was also in good condition, so it was retained as well. By not trying to do a full PLC hardware/panel replacement project at the same time as a full software reprogramming effort, the project team was able to considerably reduce the amount of risk / complexity / unknowns associated with the project. Thus, it was possible to limit to the controls scope of the project to only include a rewrite of both the PLC and HMI code, correcting known deficiencies with the existing I/O wiring, and installing new I/O wiring as needed for new equipment.

Software development began in July 2018, so that the new PLC/HMI code would be ready by the time physical construction work had been completed in late-September. A decision was made to do all the PLC/HMI software development "in-house" at Guelph Water Services, with a summer SCADA co-op student doing the bulk of the work. This ensured that any issues with the then newly-released Guelph Water SCADA programming standards could be quickly identified and resolved on a same-day basis. Having the programming work done in-house also meant that daily checks could be done on the new PLC code and HMI screens as they took shape.

## New City of Guelph Water SCADA Standards

As a precursor to the Emma Well Upgrade project, the SCADA group at Guelph Water undertook a project to develop a new set of Guelph-Water-specific SCADA Design and Programming Standards. These standards, developed in-house, have the goal of taking best practices from utilities across North America, as well as best practices from other industries, and putting them into an implementation that best fits Guelph Water's needs for reliability, functionality, and ease of troubleshooting. There was also a strong desire to reduce the amount of "custom-code", which is both time-consuming to write and difficult to maintain.

Another major source of input into the new Guelph Water SCADA standards was the preliminary work by the recently formed ISA112 SCADA Systems Standards Committee, as well as other published ISA standards such as ISA101 (HMI Design), ISA18 (Alarm Management), ISA62443 (Cyber Security) and ISA95 (Enterprise Integration). Best practices and lessons-learned from other process industries were also incorporated into the new Guelph Water SCADA Standards.

Work to develop the new Guelph Water SCADA standards took place from Jan-July 2018. From an asset management point of view, developing a new set of SCADA standards was long overdue, as the previous version of the Guelph Water SCADA standards had not been updated in over 15 years. A

lot had changed with respect to available technology and industry best practices since 2002!

The newly developed Guelph Water SCADA design and programming standards now consist of the following parts:

- An overarching SCADA philosophy document
- Standardized workflows and milestones for undertaking SCADA projects, and workflows/milestones for project managers to use for capital projects that involve SCADA
- Approved standardized PLC hardware and HMI software
- Approved standardized equipment/instrumentation lists
- Standardized PLC panel design templates
- Standardized loop drawing/connection drawing templates
- I/O Design templates including standardized I/O for each type of starter/actuator/instrument
- PLC Programming guides and templates, for both the new standardized "modern technology" PLC hardware and for updating already-installed legacy PLC hardware
- HMI screen design guides and templates
- Standardized tagging for HMI data tags
- Alarm design guidelines and templates
- Example code (PLC/HMI) for fully programmed sample sites, one for each type of facility that Guelph Water uses
- Process Control Narrative (PCN) templates and examples.
- Templates for various documents, drawings, and check sheets that are used at the various stages of design, programming, testing and commissioning.

The entire package of standards has been developed to work together as a set. For example, the format and structure of the new standardized PCN format is tailored to line up the with new standardized code structure.

One feature that is unique to the Guelph Water SCADA standards is that they include design/programming guidelines for *both* how to use new modern PLC hardware, *and* for how to update legacy PLC hardware while it is still in service. The intent is the standards could be used both for complete PLC/HMI replacement projects and for projects where the existing PLC hardware is being re-programmed in conjunction with the development of new HMI screens.

The first version of the new Guelph Water SCADA design and programming standards was released in July 2018.

## Testing out the New Guelph Water SCADA Standards

Three capital projects were used to test out the newly-released Guelph Water SCADA Standards. Two existing well stations, Emma Well and Water St Well, were selected to test out using the standards for re-programming legacy PLC hardware. A new-build project, the Burkes Well Upgrade – which involved the complete replacement of all process equipment and the



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## Adapting High Performance HMI Design to Guelph Water

When it came to applying High Performance HMI design techniques, Guelph Water decided to use a modified approach.

To try to roll out all of HPHMI features/techniques all at once would have resulted in considerable changes to the existing HMI system that the operations team is familiar with, and could have resulted in significant push-back from operators.

Instead, a conscious decision was made to roll out the High Performance HMI design techniques gradually so the operations team had time to get familiar with the new screens, and the associated updated PLC Programming.

A fully integrated approach was also taken to HMI design, as many of the new HPHMI features are only possible to implement if the associated data tags to drive them are also implemented in the PLC code. Thus, as part of the Guelph Water SCADA Standards update, both the new HMI screen templates and PLC code templates were developed in parallel.

When selecting which High Performance HMI (HPHMI) techniques to use, the features Guelph Water decided to use were based on what would provide the most immediate benefits for the operations team, and what would make the best use of the built-in features of the current HMI software.

The following is a list of the HPHMI design decisions that were made by Guelph Water as part of developing its new SCADA design and programming standards:

- The Operations Team was used to having HMI screens with a certain look and feel. Trying to institute radical changes all at once would have resulted in significant resistance/confusion, so a gradual approach for updating the appearance and functionality was used.
- Rather than using the usual High Performance HMI grey background, a neutral light-blue color was selected. The light blue also tied in well with a “blue = water” theme.
- The existing use of the colors Green (running/open) and Red (stopped/closed) was retained, as the operations team was used to using a “traffic-light oriented” color scheme.
- At this time, there are no plans to move to the newer HPHMI scheme of white (running/open) and grey (stopped/closed). However, the Guelph Water SCADA standards do require that pump/valve status be shown with redundant coding of using both color and On/Off (Open/Closed) text.
- Site-specific overview screens for sites, such as Emma Well, will be created as Level 3 screens, and will look like a simplified version of Process Flow Diagrams.
- The more advanced HPHMI design techniques, such as presenting process data with sliders, radar charts, embedded charts, and normal operating envelopes/trip values, will be reserved for use on Level 1 and 2 overview screens. Level 1 and 2 screens, as well as task-specific

screens, are being developed as part of the overall HMI system and not as part of any site-specific upgrade. In the future, the plan is to implement Level 1 and 2 screens to use the HPHMI white/grey color schemes, rather than the red/green statuses used on Level 3 screens.

- Overall, current HPHMI design efforts will be concentrated on removing unnecessary graphical elements from screens and developing standardized toolkits using a muted grey color scheme, as much as possible.
- A clear distinction will be made between how status indicators, alarm indicators, faults, interlocks, and permissives are shown on screens.
- Status signals will be shown as raw status signals. Alarms will be shown as alarms. The old practice of using a single indicator to show both status/alarm will no longer be used, as alarms almost always have additional filtering, such as trigger delays, latching and state-based masking.
- The use of “alarms” for purposes other than notifying an operator of an abnormal situation requiring a timely response will no longer be permitted. Alarms will not to be used to show status or to act as interlocks.
- The concepts of “Control Scheme”, “Permissives” and “Interlocks” for controlling equipment will be built into the design of the HMI and clearly depicted as such.
- Each device in the system will be programmed so it will have its own collection of numbered permissives and interlocks for detailing with abnormal situations, plus a list of numbered alarms that are specific to that device.
- The Guelph Water Design/Programming standards will contain both written guidelines and programming templates, along with fully-functional programmed PLC+HMI examples for each type of facility. The intent is to make following the standards programmer-friendly.

A trade-off also had to be made between what graphic elements were “easy” to do in the existing HMI software package and which would require additional custom programming. Some of the more advanced HPHMI techniques, such as zoned analog sliders, radar plots, and auto-masked screen elements were used sparingly, and only on Level 1 & 2 overview screens, to reduce the amount of custom code. Fortunately, the current HMI software package made it possible to embed process trends on both screens and pop-ups. The current package also contained tag-substitution macro-files which made using standardized pop-up windows easier.

The main difference between a pure High Performance HMI design approach, and what is being used for Guelph Water’s design standards, is the color scheme.

Thus, for now, Guelph Water continues to use a traffic-light based color scheme:

- Red = Stopped/Closed
- Green = Running/Open.
- Yellow = Valve partially open/closed
- Magenta = error / fault / alarm indicator

In 5-10 years the color scheme will be re-evaluated. At that time there may be more interest in converting to the muted-grey HPHMI colors. In the meantime, operators continue to “obey traffic lights” – Red means stop and Green means go.

### Using the New Guelph Water HMI Design Standards

The design of the new Guelph Water HMI is structured around the concept of a station overview screens. Each station will have its own overview screen, which provides an overview of the station and various buttons/icons that can be clicked to view/access additional details. This is then accompanied by a set of overall system-level screens that provide system level overviews, trend screens and various other screens for troubleshooting purposes.

The new Level 3 overview screen for the Emma Well station can be seen in Figure 4.

### List of Screens & Pop-up Windows for Emma Well

The following new screens and pop-up windows were developed for the Emma Well upgrade project:

- Emma Overview Screen (Level 3 screen, full screen)
- Trend screen, selectable set of Emma pens (full screen)
- Device Pop-Up Windows (Pop-Ups)
  - Well Pump
  - Motorized Backflush Valve
  - Hypo Pump (12% NaOCl peristaltic feed pump)

- Analog Measurement/Alarm Windows (Pop-Ups)
  - Well Level
  - Well Pump Discharge Pressure
  - Well Pump Discharge Flow / POE Flow
  - Hypo Tank Level
  - Pre-Contact Free-Chlorine Analyzer
  - POE / Post-Contact Free-Chlorine Analyzer
  - POE / Distribution System Pressure
  - Building Temperature
- Control/Setpoint Pop-Up Windows (Pop-Ups)
  - Station Permissives & Interlocks
  - Flow and Runtime Data
  - List of Alarms (list of all configured alarms)
  - Station Setpoints
  - Hypo Dosing Setpoints
  - Interlock Setpoints
  - CT Calculator (real-time contact time calculator)

The Guelph Water SCADA standards make use of a set of Guelph-Water-specific re-useable pop-up window templates that are used throughout the SCADA system using easily-programmed tag-substitution scripts/macros. Tag-substitution scripts are a common feature in most modern HMI software packages, and they make deploying standardized pop-up window much easier to program and maintain.

Through the use of tag substitution scripts and macro files, Guelph Water has been able to customize the standardized pop-up windows at each site, while at the same time reducing the amount of custom code that needs to be written.

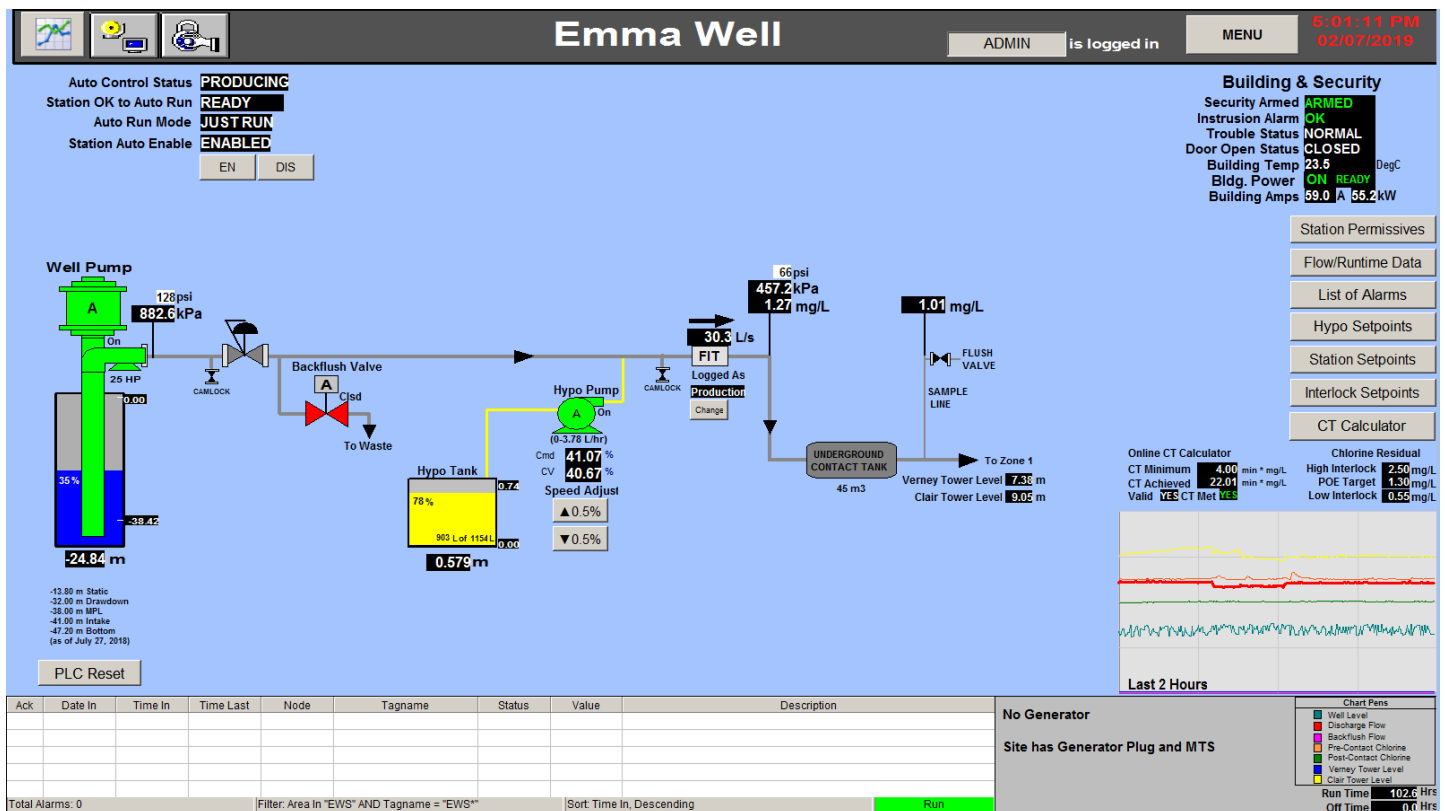


Figure 4 – Emma Well Overview Screen (Level 3 HMI Screen)

## Standardized HMI Data Tags

Within the Guelph Water SCADA system, a standardized tagging scheme is used for all of the HMI data points. In the HMI software that Guelph Water uses, a real-time database is used to define each tag, which PLC memory address it points to, and a polling frequency. For most tags, a polling frequency of 2000 milliseconds (syncing values every 2 seconds) is used as this provides a reasonable trade-off between screen updates / response-to-operator input vs. load on the system.

One of the benefits of the HMI software package that Guelph Water uses is that the update frequency of each tag can be explicitly defined/tuned for each tag. (Some systems do not provide this feature). Each tag also has both an alphanumeric tag identifier and text description field, along with a field for the tag's engineering units. Each tag can also do value scaling, in case this is not already handled within the PLC code.

Guelph Water data tags are either 12 or 16 characters long, depending on the complexity of the associated device/instrument/item. Data tags may be associated purely with a device/instrument, or may represent a setting, setpoint, status or condition within the control system itself. The 12 character tags are made up of 5 separate tag fragments, whereas the 16 character tags use 6 fragments. The tags are arranged so they are "big-endian", meaning that they can be easily sorted from general-to-specific when read from left-to-right. The tags also always start with a letter, contain no spaces or dashes, and are always the same length. Only letters, numbers and underscores are used. This makes it easier to sort/manage data tags in both the HMI software package and in other systems that use the HMI data tags to do reporting.

The 12-character data tags, consisting of five fragments, are used for simple equipment and are structured as follows:

- AAA = site code
- BBB = equipment type (e.g., RES = reservoir, G00 = well pump)
- x = equipment number, starting at 1 for the site, or 0 for all
- CC = aspect (e.g., 00 for device, FI = flow, LI = level, etc.)
- D = signal type (e.g. S = status, E = alarm, Q = analog, etc.)
- EE = signal meaning (e.g., RS = run status, 01 = value, etc.)

For example, for tag: EWSDL01AIQ01

- EWS = Emma Well
- DL01 Discharge Line 1
- AI = chlorine analyzer (on discharge line)
- Q = analog value
- 01 = scaled engineering value (0-5 mg/L)

For more complex equipment, the 16-character data tagging scheme is used, consisting of six fragments:

- AAA = site code
- BBB = equipment type (e.g., RES = reservoir, G00 = well pump)
- x = equipment number (e.g., starting at 1, or 0 for all of type)
- CCC = sub-equipment type (e.g., DV0 discharge valve)
- y = sub-equipment number (e.g., starting at 1)
- DD = aspect (e.g., 00 for device, FI = flow, LI = level, etc.)
- E = signal type (e.g. S = status, E = alarm, Q = analog, etc.)
- FF = signal meaning (e.g., RS = run status, 01=value, etc.)

For example, for tag: BKSFLT1MV01ZI01

- BKS = Burkes Well
- FLT1 = Filter 1
- MV01 = motorized valve 1 (on the filter)
- ZI = position feedback
- Q = analog value
- 01 = scaled engineering value (0-100% open)

To guide software developers using the Guelph Water SCADA Programming standards, both a Tagging Convention document (that defines the valid codes that can be used for each fragment) plus a Tagging Examples document (that provides examples of valid tags made from fragment combinations for a variety of applications) are provided. Used together, the two documents help avoid a lot of the ambiguity that is often present in SCADA data-tagging standards.

The above 12 character (5 fragment) and 16 character (6 fragment) tagging schemes were developed for backwards capability with existing tags in the system. Like ISA-5.1 based schemes, the Guelph Water scheme is based on the function of each instrument/device. However, unlike ISA5.1-based scheme is more easily alphabetically sorted by equipment.

## Features of the Emma Well Overview Screen

The Emma Well overview screen has been designed with several standard screen elements that appear on every Level 3 screen as part of the Guelph Water SCADA Standards. The idea is to provide a consistent Level 3 HMI screen interface that the operations team can get used to working with.

The parts of a Guelph Water Level 3 overview screen include:

1. Top Information Bar (top)
2. Station Status & Control (top left)
3. PLC Reset Button (bottom left)
4. Alarm Banner Area (bottom)
5. Building Security/Temperature/Power Status (Top Right)
6. Buttons to bring up site setpoint/status pop-ups (Right)
7. Real-time Online CT Calculator (Right)
8. Chlorine Residual Target, Hi/Lo Interlocks (Right)
9. Embedded Station KPI Trend (Bottom Right)
10. Generator/Power Status Information (Bottom Right)
11. Station Run Time vs. Off Time in Hours (Bottom Right)

**Top Information Bar:** The Top status bar provides navigation buttons to return the SCADA system's main menu screen, bring up the full-screen alarm summary display, bring up the full-screen trending tool, and for a user to login/logout. It also provides the title for the current screen, the username of the currently logged in user, and the current date/time. An example of the top status bar can be seen in Figure 5.



Figure 5 – Top Information Bar



**Station Status & Control:** On the top-left, station status indicators provide overview information as the status of how the station is working as a whole. The station's automatic control status gives a quick Producing / Idle status in terms of if the site is producing water. The "Station OK to Auto Run" provides a status if all the station permissives have been met to allow the station to run automatically (noting that Permissives only refer to prerequisites for the station to able run, and not the core automatic control scheme). The "Auto Run Mode" provides information as to what type of automatic-control mode the station is using, whether it be "Just Run", "Tower Level Mode" or "Pressure Transmitter Mode". Lastly, the "Station Auto Enable" setting allows an operator to quickly Enable/Disable the station, by clicking the EN/DIS buttons and then answering "Yes" to a confirmation dialog box that comes up. This can be seen in Figure 6.

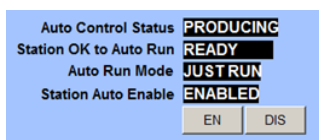


Figure 6 – Station Status Indicators

**The PLC Reset Button:** On the bottom left of the overview screen is a "PLC Reset" button. Each site has two master PLC reset buttons – the first is a physical reset button that is mounted the PLC panel and the second is the clickable "PLC Reset" button that on the overview screen. These buttons are used to reset any activated interlocks (which will latch into place if they have shut down a pump/valve) and to unlatch any latched alarms (if latched alarms are used as part of a site's programming.)

**Bottom Alarm Banner:** Each overview screen also has an alarm banner area at the bottom, which displays any alarms for the site. It has a filter applied so alarms from other sites are not shown. The banner features columns for the date/time of the alarm, the alarm tag, its current status, and the alarm tag's description. This can be seen in Figure 7.

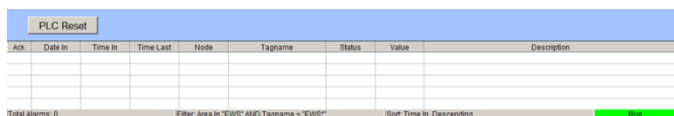


Figure 7 – PLC reset button and bottom alarm banner

**Building Status:** The top right corner of the overview screen is used to show the status of the station building itself. Reading from the top, this includes the site's security system (armed, intrusion alarm, trouble/low-battery, and door open). This is then followed by the building temperature.

During the past 5 years, Guelph Water has moved away from using Hi/Lo temperature switches. Instead, all buildings are now equipped with a low-cost building temperature transmitter, with a local LCD readout. This allows building

temperatures to be monitored over time, and adjustable alarms to be configured to alert operators to overheating in the summer (exhaust fan failures) and winter freezing (heating failures). Having real-time building temperatures has also made it easier to avoid overly heating buildings in the winter.

The building status screen also displays the building's real-time electricity usage in Amps and Watts from the building's digital power monitor. If a station's smoke detector, flood switch, and/or hatch switches are activated, indications would appear in this area as well.

There are also two indicators with respect of current status of power at the station: The ON/OFF indicator shows if building power is currently available on site; whereas the Ready/Not-Ready indicator shows if the building power has been on and stable for at least 2 minutes. The station's PLC programming will not attempt to auto-restart any equipment until the power has been stable for a minimum of 2 minutes. The determination of the building power status is done via a *PLC panel power feed status relay* that is located inside the PLC panel. A close-up screenshot of the Building Status indicators can be seen in Figure 8.

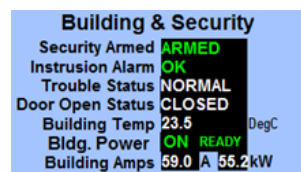


Figure 8 – Building Status Indicators

**Navigation Buttons:** Buttons to bring up pop-up windows for the stations' pop-up windows, not associated with specific devices or analog measurements, are located on the right side of the screen. A standardized ordering and labelling of these buttons is used. User-based security is used to ensure that certain buttons only work when a user with appropriate permissions has logged into the HMI. See Figure 9.

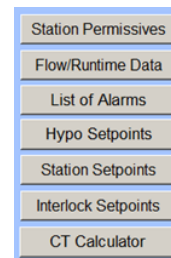


Figure 9 – Right-hand side Navigation Buttons

Each device and analog measurement has its own pop-up window which is accessed by clicking on the associated icon.

The top information Menu bar, also contains buttons to navigate to the SCADA system's main menu screen, trend screen, and full-screen alarm display.



**Real-Time Online CT Calculator:** The right-hand side of the site overview screen contains summary information from the online CT Calculator. This consists of displaying real-time key performance indicators (KPIs) for the disinfection process. This includes the Required CT, Achieved CT, and an indicator if the Required CT is currently being met or not. A Calculation Valid/Invalid indicator is also shown to remind the user that the CT numbers are only valid once the well pump has been running for several minutes and all of the various analyzers/transmitters have had a chance to achieve steady state after start-up. This is shown in Figure 10.

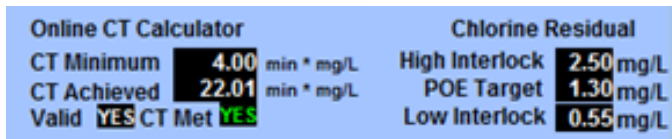


Figure 10– Online CT Caculator and Chlorine Residual KPIs

**Chlorine Residual Target & Interlocks:** In addition to the Online CT Calculator, the current Hypo dosing target setpoint (in terms of mg/L of free chloride), and the worst case Hi and Lo chlorine shutdown interlocks are shown. This provides a handy on-screen reference for the operator while they are operating the station.

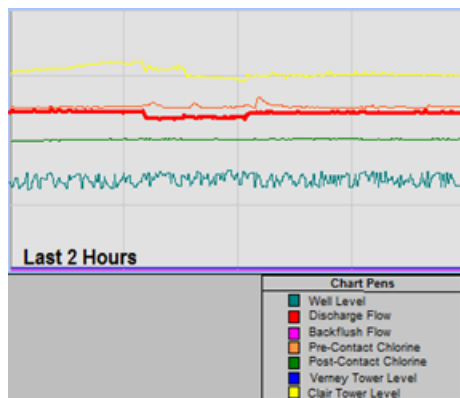


Figure 11 – Embedded Summary Trend of KPIs

**Embedded Summary Trend:** On the bottom right of the screen is an embedded summary trend that contains the key performance indicators (KPIs) for the site. This includes: well level, discharge flow, backflush flow (used during start-up), pre-contact-chamber chlorine and post-contact-chamber chlorine. The display also contains the level of two water towers in the distribution system that the well pumps into.

By default, the summary trend displays a 2 hour time period but the user can click on the time scale text to toggle between the last 2 hours, 12 hours, 24 hours, 48 hours, and 7 days. The intent of this graph is for the operator to quickly be able to scan for anomalies by looking at the “shape” of the lines. If needed, a more detailed analysis of trends can be undertaken using the full-screen trend screen (accessible by the Trend button on the top-left of the site overview screen).

**Generator Status:** Also on the bottom right part of the screen is a grey-backgrounded information area for the site’s back-up power generation. If a site has a manual transfer switch (MTS) and a generator hookup, like Emma Well does, this standby power information will be shown here. This can be seen in Figure 12. As Guelph Water has 35 different facilities, having this information readily available on the HMI overview screen for each facility is a helpful reminder for operators.

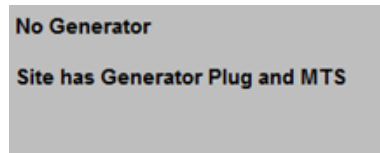


Figure 12 – Emma Well Standby Power information

If a site had permanently installed standby generator and automatic transfer switch (ATS), these details will be shown on the bottom right of the site’s HMI overview screen. How the generator plus ATS info would appear is shown on Figure 13, which is a screenshot from the Burkes Well facility.

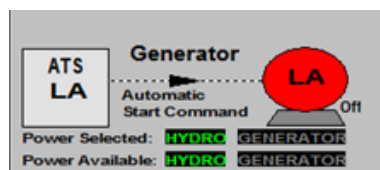


Figure 13 – ATS and Generator status indicators from another Guelph Water site (Burkes Well)

In the Burkes Well example, notice how the status indicator “LA” (instead of “L”) is used to show that both the ATS and Generator are in a “local auto” mode, in that they are automatically controlled by a local controller (and not the site PLC, and not using locally mounted hand switches). One of the interesting quirks about Canada is that the term “Hydro” is used to mean utility power, since most electricity in Canada traditionally comes from hydroelectric power stations.

**Station Run Time vs. Off Time:** On the extreme bottom right of all screens there is are hours counters that shows how long a site has been producing water continuously or how many hours the site has been shut down for. These two hour counters, which are driven by the PLC, give operators a quick view of how long the station has been operating or offline. For some stations, there are special sampling and/or flushing requirements as part of a restart procedure if the station has been offline for more than a certain period of time. These two counters make it easier for operations staff to determine if these additional station re-start steps are needed or not.

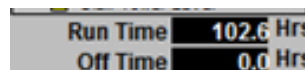


Figure 14 –Station Run Time vs. Off Time Display

**Process Overview Area:** In the centre of the Emma Well Overview screen, the process details are shown using a simplified right-to-left and top-down process flow diagram. Visual cues are put on the screen to remind operators of the piping configuration on the site, such the pilot-operated backpressure control valve and camlock connections with hand valves. Each one of Guelph Water's 35 facilities is slightly different from each other, so it is not reasonable to expect the human operator to memorize all the piping details at each site. Thus, the visual cues are provided on the HMI screens to remind operators of major piping details, with printed copies of each site's Process Flow Diagram being readily available if further investigation is ever needed.

### Well Pump Icon on the Overview Screen

The main piece of process equipment at the Emma Well is the well pump itself. Though the pump is a submersible pump, it is shown as a motor-on-top pump to make it easier for the operators to visualize. The pump is colored to show its status: Green for running and Red for stopped. The pump also has the status text "On" and "Off" to make its status even more clear.

The size of pump motor in horsepower is noted in static text ("25 HP"). The use of kW for motor size is avoided, since kW can be easily confused with the actual electric power usage.

The pump has a letter on it to show its current control mode (A= SCADA automatic control, M = SCADA manual control, or L = local control via the hand-off-auto switch at the pump starter). The use of A, M, L are the standardized control modes used throughout the Guelph Water SCADA system. (As noted earlier, a different set of modes, LA = local auto and L= local, are used to show statuses of generators and ATS's.)

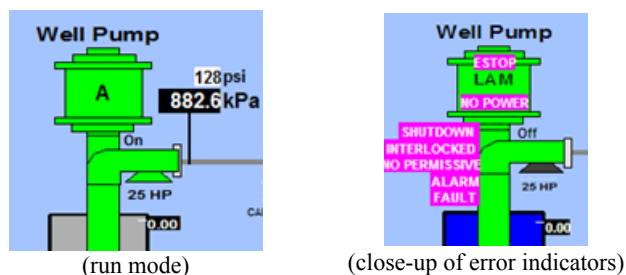


Figure 14 – Well Pump Icon with Status Indicators

Under the pump discharge icon there is a small triangle shape, with just its base showing, that is used to show the current command being sent to the pump by the PLC (Green = pump is being commanded to run, Red = pump is not being commanded to run). For all Guelph Water pumps, 2-wire control is used – that is, pumps are always sent a maintained run command. Separate start and stop commands are not used. This ensures that if a PLC were to fault or lose power, the run commands to pumps will drop out instantly. Thus, three-wire control, consisting of start and stop commands, is not used.

The well is equipped with a water level transmitter. The level transmitter consists of a submersible hydrostatic pressure transmitter that has its 4-20mA signal in the PLC scaled according to the insertion depth of the transmitter down from the well's baseplate. Guelph water uses a standardized 0.39" diameter 0-100 psi hydrostatic probe, that is has a raw scaling of -70.39 to 0.00 mH<sub>2</sub>O, with an offset applied in the PLC according to the probe's insertion depth. By using a standardized 0-100 psi probe for all of Guelph Water's 22 production wells, it has allowed for a single type of probe to be used regardless of the well's individual depth. This has made spare parts management for well level probes considerably easier (and cheaper) for Guelph Water.

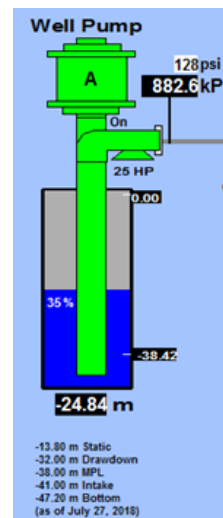


Figure 15 – Well Water Level and Discharge Pressure Transmitters

On the right-side of the well graphic, the insertion depth of the probe is shown, along with a reminder that the "zero reading" of the probe is at the well base plate. Well level measurements are negative, in meters below the well base plate. The percentage readout of the usable span of the probe is also shown, along with a "fill animation" in the well itself. Lastly, the actual well level reading is shown, along with a visual reminder that the well level probe does not go down as far as the pump's intake. Below the pump are the construction details of the well, along with the maximum pumping level, and static/drawdown levels from the last pumping test that was carried out. This information is updated annually.

All Guelph Water well pumps are equipped with discharge pressure transmitters. These transmitters, which are a low-cost 0-300 psi pressure transmitter, are installed directly on the pump discharge before any isolation valves or check valves, in order to get the true discharge pressure of the pump. In the SCADA system, since Canada is a metric country, the pressure is shown in kPa; however, an additional readout in PSI is also provided for those operators more familiar with the older Imperial pressure units. Clicking on the kPa pressure

readout will bring up an analog value pop-up window with more information about the instrument and user-adjustable LoLo/Lo/Hi/HiHi alarms which can be set to provide alarm notifications if needed for operational reasons.

### Standardized Analog Pop-up Windows

As part of the new Guelph Water SCADA standards, a new standardized analog measurement alarm/diagnostic window was developed. This is shown in Figure 16.

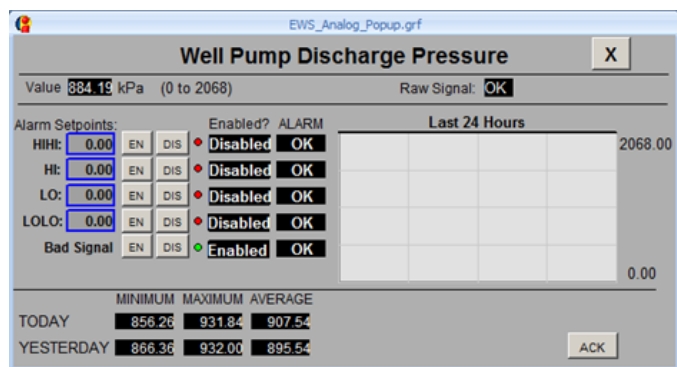


Figure 16 – Analog Measurement Pop-up Window Example

The analog measurement pop-up window provides a standardized way for operators to enable/disable and adjust the Lo, LoLo, Hi and Hi-Hi alarms as needed. The setpoint and enabled/disabled status of each alarm is clearly shown. The in-place trend display makes it possible for the operator to view the analog value trend without having to go another screen. The “Last 24 hours” text can also be clicked with a mouse to toggle between showing a 2 hour, 6 hour, 12 hour, 24 hour, 7 day, or 30 day time period.

It must be emphasized that as part of the Guelph Water programming standards, alarms are no longer used to implement shut-down interlocks or permissives for any process equipment. Instead each piece of equipment will have its own device-specific numbered permissives and interlocks that are specific to that device.

### Station Control vs. Sequencer Control vs. Device Control

As part of the Guelph Water SCADA standards, control of a station is broken down into several hierarchical levels, which are as follows:

- **Station Control** – controls when a station is called upon to produce water. For a groundwater well this can include several modes including: “Off,” “Just Run,” “Tower Level Control,” and “Pressure Control”. The “Just Run” mode is exactly what it says: the station just runs.
- **Station Sequencer** – controls how the station automatically starts-up, shuts-down, and automatically restarts after a power outage or loss of station-level

permissive. The sequencer receives a call to run command from the Station Control module. The Station Sequencer module will typically have programmed states like: Off, Waiting-for-Permissive, Backflushing, UV Warming-Up, Starting-Up, Producing, Idle, Restart-wait-on-Permissive, and Shutdown-on-Interlock. The station sequencer will also have of Station-level Permissives that inform it when it is safe to attempt to automatically start the station.

- **Unit Control Module (only sometimes used)** – controls an individual unit process within a station, consisting of several devices working together under a control scheme. For example, a pressure filter at a large treatment site would have its own dedicated control module in the PLC, which will receive commands from the station sequencer. For a small facility like a groundwater well, a Unit Control Module would not be used.
- **Device Level Control** – control of an individual device, which the device being under SCADA-Auto, SCADA-Manual or Local control, as outlined in the next section.

### Device Control Modes

In the Guelph Water SCADA system, three control modes are used for controlling devices such as pumps and motorized valves. They are as follows:

- **A = SCADA Auto**, the Hand-Off-Auto switch (or Local-Remote switch) on the device has been set to Auto, so the PLC is in control. The PLC is controlling it automatically with using the PLC’s automatic control program.
- **M = SCADA Manual**, the Hand-Off-Auto switch on the device has been set to Auto, so the PLC is in control. The PLC is controlling the device based on a fixed command setting in the PLC, entered in by an operator via the HMI.
- **L = Local**, the Hand-Off-Auto switch on the device has been set to Off or Hand. Any commands from the PLC to the device will be ignored by the device. The device is being operated locally using the device’s local switches.

For equipment that has its own local controllers (and is not controlled by the SCADA PLC), they are depicted as being in “Local” or “Local Auto” mode. In “Local”, the device is being controlled using its local switches. In “Local Auto”, the device is being controlled based on a standalone local controller. Examples of this type of control would be a Generator-ATS system, or motorized discharge valves on large pumps that are typically controlled by the motor starters.

In fact, it is a requirement at Guelph Water that any control devices, such as a motor starters or motorized valves, must be equipped with physical local Hand-Off-Auto (HOA) switches.



The installation of devices without HOA switches (or Remote/Local switches) is not permitted. At Guelph Water, there must always be an option to run equipment “in hand” using switches, without relying on the SCADA system, so in the case of a SCADA failure the station be run in hand.

### Control Schemes and Abnormal Condition Handling

One of the central tenants of the Guelph Water SCADA standardization strategy was to standardize how normal and abnormal operating conditions are handled as part of the overall control strategy.

In the Guelph Water SCADA system, automatic control is modular in nature and broken down into two sets of programmed rules: The first is the “control scheme”, which is how the automatic control is to work under normal conditions. The second is the “exception handling”, which takes the form of a set of numbered permissives and interlocks that are specific to the device.

The following terminology is used:

- **Control Scheme** – A control scheme is the basic control for a device (pump or valve) when under automatic control, such as level-based control for emptying or filling. A control scheme may involve one or more devices under automatic control.
- **Permissive** – A permissive is a condition that must be true in order for a device to run and/or start. If a permissive is lost when a pump is not running, no action is taken other than that the device is prevented from starting. However, if a permissive is lost while a device is running, the device will stop. Once all of its permissive condition becomes true again, the device will auto-restart according its control scheme. Each device has its own set of device-specific numbered permissives.
- **Interlock** – An interlock is an abnormal condition that prevents a device from running (or a valve opening). If an interlock occurs while a device is not running, no action is taken other than preventing the device from starting. However, if an interlock is tripped while the device is running, the device will stop and remain stopped until the interlock is reset by an operator. (The interlock reset must be done via the PLC Panel Reset button on site or via the HMI “PLC reset” button on the site’s overview screen.) Each device will have its own set of numbered interlocks.

Interlocks do not generate alarms – instead there is a special device-specific latching alarm for each device called the “device shutdown on interlock” that is triggered when a device has been shutdown due to an interlock eing tripped while the device was running.

- **Alarm** – An alarm is a notification of an abnormal condition that requires a timely Operator Response, so that the Operator’s actions can avoid a likely negative outcome (if the operator did not respond). Each device will have its own set of numbered device-specific alarms. In the Guelph Water SCADA standards, alarms are only used for operator notification – they are not used to implement interlocks, permissives or control schemes.

For motorized pumps, the first five numbered device alarms are standardized as: fail-to-start, fail-to-stop, uncommanded-start, uncommanded-stop, and shutdown-due-to-interlock. Likewise, for motorized valves, the first five numbered device alarms are standardized as: fail-to-open, fail-to-close, uncommanded-open, uncommanded-close, and closed-due-to-interlock. Additional numbered alarms for a device are implemented as needed. Commonly implemented additional numbered alarms for a device are “device power off”, “device e-stop activated”, “valve position feedback bad signal”, etc..

For each set of permissives, interlocks and alarms, arrays of numbered tags are used, thus avoiding the need for “custom tags”. For example, for the Emma well pump device, the tags used are: EWSG001\_PERMxx, EWSG001\_ILOCKxx, and EWSG001\_ALRMxx, with xx being the number. The “description” field of each tag is then used define what the numbered permissive, interlock, and/or alarm is for. Permissives, Interlocks and Alarms are also implemented as numbered arrays within the PLC code.

If there is a genuine need for an “Inhibit” (that is, a condition to prevent a device from starting but not to stop a device that is already running), this is implemented as a specially programmed permissive. For example, at Guelph Water Booster Pumping stations each booster pump will have a permissive to prevent it from starting if another pump at the station has already started or stopped within the last 10 minutes – this is to prevent transient pressure waves.

### Standardized Device Pop-Up Windows

As part of the Guelph Water SCADA programming templates, a set of standardized pop-up templates has been developed to support the overall control strategy of: control schemes, permissives, interlocks, and alarms when it comes to devices. This can be seen in the default view “rolled-up version” of the well pump device pop-up window in Figure 17.

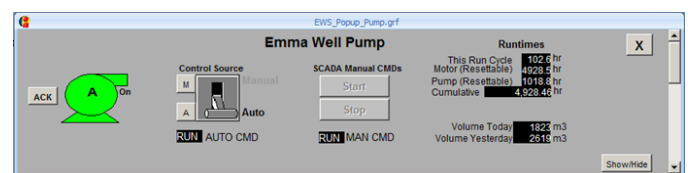


Figure 17 – Well Pump Pop-Up Device Control Window  
(shown in the default “details rolled up” view)

When a pump device pop-up is called up by a user by clicking on a pump icon on the overview screen, the pop-up will appear in its default rolled-up form. Most operators will only use the pop-up this way. However, a “Show/Hide” button is provided so the details of the device’s permissives, interlocks and alarms can also be shown in “rolled-down” view. In this view, the pump pop-up becomes a powerful troubleshooting tool. However, let us first go over the screen elements of the normally-viewed top part of the pop-up window.

### Pump Device Pop-Up Window – Top Part

The top part of the pump device pop-up window has been designed to give the operator a quick way to view key status information and be able to remotely control the pump via the HMI. The features of this top part of the device pop-up are, from left to right, as follows:

**Ack Button:** On the far left of the top part of the screen is a device-specific “Ack” button that is used for acknowledging pump-specific alarms and resetting pump-specific interlocks. (This is an alternative to using the station-wide “PLC Reset” button that is on the station’s overview screen.)

**Pump Icon:** This is followed by a Pump Icon that colored to show its status (Green = running, Red = stopped) and has pump status text “On” and “Off” beside it. Colors and text are used to provide redundant coding/display to the operator. The error condition indicators, namely: NO POWER, ESTOP,

SHUTDOWN, INTERLOCKED, NO PERMISSIVE, ALARM, and FAULT, which also appear on the associated pump icon on the overview screen, are also replicated here.

**Error Indicators:** The error indicators, which are standardized and appear as white text on a bright pink/magenta background, are defined as follows:

- E-STOP = e-stop has been pressed
- NO POWER = motor starter has not power
- SHUTDOWN = pump was shutdown on an interlock
- INTERLOCKED = an numbered interlock is active
- NO PERMISSIVE = a numbered permissive is not met
- FAULT = overload/fault status from the starter
- ALARM = one of the pump’s numbered alarms is active

**Mode Indicator:** Just like on the overview screen, the pump icon has a mode letter inside of it, which can be A = Auto, M = Manual, and L = local. In Local Mode, the pump is being controlled locally via the HOA switch on the motor starter.

**Command Status:** The base of the pump icon (the triangle that the main pump icon sits on) is colored to show the current command being sent to the pump from the PLC’s digital output card. Green Base = pump run command being sent, Red Base = no run command being sent to the pump.

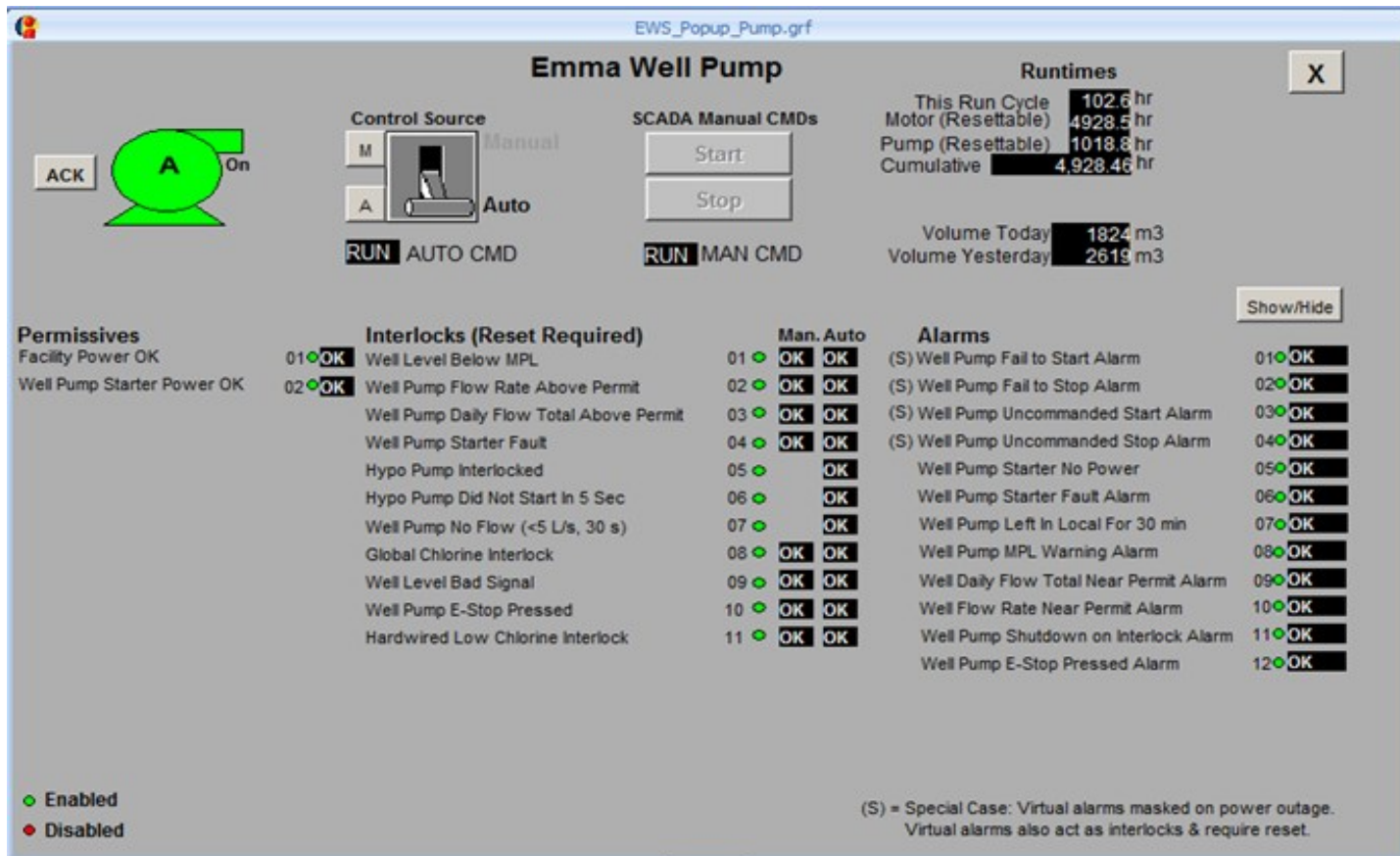


Figure 18 – Well Pump Pop-Up showing numbered device Permissives, Interlocks and Alarms (un-rolled-up view)

**Mode Selection:** The large toggle switch icon displays the PLC control mode for the pump, namely if it is in to ‘SCADA-Auto’ or ‘SCADA-Manual’ mode, per the setting in the PLC. The Toggle Switch icon and the text “Auto” and “Man” are used to provide redundant coding/display to the operator.

Buttons, with labels “A” and “M”, are provided to set the device remote control mode in the PLC. When either of the A or M buttons is clicked, a confirmation dialog window comes up for the operator to confirm they want to make the change.

The reason for providing separate A and M buttons for changing the mode, rather than the traditional approach of clicking on the toggle switch, is to avoid the problem of an impatient operator rapidly cycling the remote control mode by repeatedly clicking on the toggle switch.

Note that the Auto/Manual selection indicators and A/M buttons are always visible, even when the pump is in local mode. This allows the operator to set what mode (Auto or Man) the pump will return to after it leaves local mode. When the pump is in Local, a large text indicator “LOCAL” is shown, in addition to an “L” in the center of the pump icon.

**SCADA Manual Start/Stop Buttons:** When the pump is in SCADA-Manual mode, “Start” and “Stop” buttons are made available for the operator to manually start and stop the pump. They too have confirmation dialog boxes. When the pump is in Auto or Local mode, the Start/Stop buttons are greyed out. In figures 17 and 18, the start and stop buttons are shown as greyed-out because the pump is in SCADA-Auto mode.

One of the great mysteries that operators have in many SCADA systems, is knowing what a device will do when it goes into SCADA-Auto or SCADA-Manual mode. This problem is avoided in the Guelph Water SCADA system by providing the “AUTO CMD” and “MAN CMD” indicators on the pump pop-up window. On the pump pop-up, the AUTO-CMD and MAN-CMD indicators show the operator, exactly what command would be sent to the pump if the pump was put into “Auto” mode or “Manual” mode, prior to the operator putting the pump into those modes.

The PLC has also been programmed, so that when the pump is in SCADA-Auto, the SCADA-Manual command will automatically follow whatever the SCADA-Auto command is doing. This allows the operator to seamlessly switch the pump from Auto-to-Manual mode, without the pump suddenly starting or stopping.

(A similar approach for “bumpless” speed control is used for the SCADA-Auto and SCADA-Manual speed commands on the VFD-version of the pump device pop-up window).

**Runtimes & Flow Totals:** The indicators on the far right side of the top part of the pump pop-up are purely for displaying status information. The first are the pump’s runtime indicators, which are calculated by the PLC based on the pump’s running status signal. See Figure 19.

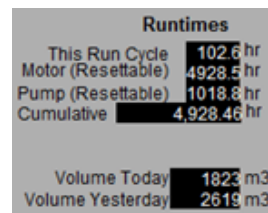


Figure 19 – Well Pump runtime and flow statistics

One of the common problems with resettable runtime counters in most SCADA systems is that operators can never remember when (date-wise) when they last reset the runtime. To counter this problem, the Guelph Water SCADA standards use a cumulative runtime counter, which is only set to zero when the station was commissioned. After that, it is never reset. The cumulative runtime counter, in hours, is also stored as a floating point number in the PLC so there is no risk of it overflowing. (In older SCADA systems, if a traditional signed 16-bit integer number was used as a runtime calculator, it would overflow at approximately 32767 hrs, which translates to just over 3.75 years runtime.) Lastly, the runtime is calculated in 6 minute increments so an operator can easily see the runtime counter advancing as the pump is running.

With that said, two resettable runtime hour counters are provided so the maintenance team can use them for calculating maintenance intervals for the pump’s electrical motor and mechanical pump parts if they wish.

Overall, the following runtime readouts are provided:

- **This Run Cycle** = how long the pump has been running for; this is automatically set to zero when the pump stops
- **Motor (Resettable)** = resettable runtime counter for the pump’s electric motor
- **Pump (Resettable)** = resettable runtime counter for the pump’s mechanical pump part
- **Cumulative** = cumulative runtime since the station was commissioned; this value is never reset.

If the pump has a flowmeter on its outlet, daily flow totals for the current day and previous day are also provided. If there is no flowmeter (or not a dedicated flowmeter for the pump), this part of the device pop-up is blanked out.

One of the design decisions in the Guelph Water SCADA standards was not to create the code and tags to calculate the number of pump starts/stops inside the PLC. Instead, this information can be readily determined from analyzing logged data in the historian, without having to spend the effort to write/maintain extra code the PLC and HMI for this.

### Pump Device Pop-Up Window – Bottom Part

On the bottom part of the device pop-up window, see Figure 18, the details of each of the device’s various numbered permissives, interlocks and alarms are shown. Each is numbered, so it can be easily communicated over the phone to other operators and/or a support person (E.g., An operator can report that a certain pump is stuck on Interlock 5).



Beside each of the device-specific numbered permissive, there is a status indicator. When a permissive has been satisfied, a white-on-black “OK” indicator is shown. When a permissive has not been satisfied, a white-on-bright-pink/magenta “BAD” indicator is shown. Permissives, due to their programming in the PLC, will automatically switch between the OK and BAD status based on their satisfied/non-satisfied condition.

For each device-specific numbered interlock, a similar OK/BAD indicator is shown. However, if an interlock is tripped (goes BAD) while a device is running, the BAD status will latch in PLC as part of the PLC programming. As noted earlier, this must then be reset but the operator by clicking the Ack/PLC-Reset button the HMI or by pushing the “PLC Reset” button on the station’s physical PLC Panel. Have the latched Interlock, provides information to the operator as to what interlock it was the stopped the pump.

Similarly, for each device-specific numbered alarm, the status indicators will show on either the white-on-black OK status, or a white-on-bright-pink/magenta ALARM status. Depending on the alarm, some alarms may require resetting by an operator using the Ack/PLC-reset button.

Beside each Permissives, Interlock and Alarm is a little circle that is colored either Green or Red. For Permissives and Interlocks, a Green circle beside it indicates that the permissive/interlock has been enabled; a Red circle indicates it has been bypassed PLC. Likewise, a green circle beside a numbered alarm indicates that it is enabled, whereas a red circle indicates that it has been disabled in the PLC. (The setting of permissive/interlock bypasses and device alarm disables is set in the PLC code itself, and is managed by the SCADA group using a change control process.)

The use of preconfigured bits/tags in the PLC/HMI for implementing bypasses makes the process of commissioning and troubleshooting stations much easier and much less error prone. The red/green indicators also ensure that if bypass has been activated or a device alarm has been disabled, it is clearly shown on the pop-up window so it is not forgotten.

### Why numbered permissives, interlocks and alarms?

As noted earlier there are several benefits of using numbered permissives, interlocks and alarms. These include:

- It eliminates the need for custom data tags for each type of interlock/permissive. Simple numbered tags can be used, instead of having to create custom interlock and permissive specific alphanumeric tags for each condition.
- It allows for simple numbered arrays to be used when programming the PLC data structures.
- It also, most importantly, makes writing Process Control Narratives much, much easier to write and understand. Tables with numbered entries to describe permissive, interlocks and alarms can now be used. Figures 20, 21, and 22 show the PCN tables for the well pump at the Emma Well. Note how the use of tables makes the PCN much more compact, precise and easier to understand.

Permissives – Required to Run, Auto Restart Possible			Applies to			Other
#	Name	Description, Logic, Setpoints, Timers	SCADA Manual	SCADA Auto	Local	
1	Facility Power OK	- Facility Power must be online	X	X	X	
2	Well Pump Starter Power OK	- Well Pump starter power OK signal	X	X	--	
Plus	No Interlock Conditions are True	- None of the interlocks in the following table can be active	X	X	--	

Figure 20 – Example Numbered Permissives Table for Well Pump

Interlocks – Stops the Pump, Manual Reset Necessary			Applies to			Reset Type		Other
#	Name	Description, Logic, Setpoints, Timers	SCADA Manual	SCADA Auto	Local	Via HMI button	at PLC Panel	
1	Well Level MPL Interlock	- Well Level dropped below 37.00m for 30 seconds	X	X	--	X	X	
2	Well Daily Flow Total Max Exceeded	- Daily Well Flow Total Reaches 3100 m3 for day	X	X	--	X	X	Totalizer resets at midnight
3	Well Max Instant Flow Exceeded	- Max Instantaneous flow is above limit of 35.8L/s for 60 seconds	X	X	--	X	X	
4	Well Pump Starter Fault	- Fault signal from Well Pump Starter	X	X	X	X	X	
5	Hypo Pump Interlocked	- Hypo Pump interlocked	--	X	--	X	X	
6	Hypo Pump did not run	- Hypo Pump did not start within 5 seconds, after Well Pump Started	--	X	--	X	X	
7	Well Pump No Flow	- Less than 5 L/s of flow for 30 Seconds	X	X	--	X	X	
8	Global Chlorine Interlock active	- Encompass all interlocks related to both chlorine analyzers. HI LO Cut out, Analyzer Fault and Analyzer Bad Signal for both Pre and Post Chlorine Analyzers.	X	X	--	X	X	
9	Well Level Bad Signal	- Feedback signal outside of 4-20mA Range	X	X	--	X	X	
10	E-Stop Pressed	- Well Pump or Building Hardwired E-Stop Pressed	X	X	X	X	X	
11	Hardwired Chlorine Interlock	- Hardwired interlock from pre contact Chlorine Analyzer active	X	X	X			
Plus	Well pump Virtual alarms	- Well pump fail to start, fail to stop, uncommanded start, uncommanded stop	X	X	--	X	X	Masked if power outage

Figure 21 – Example Numbered Interlocks Table for Well Pump

#	Alarm Description	Alarm Logic	Purpose	Consequence if Ignored	Operator Action	Time to Respond
1	Fail to Start	Standard alarm	Acts as interlock	Loss of production	Investigate	2 hours
2	Fail to Stop	Standard alarm	Acts as interlock	Loss of production	Investigate	2 hours
3	Uncommanded Start	Standard alarm	Acts as interlock	Loss of production	Investigate	2 hours
4	Uncommanded Stop	Standard alarm	Acts as interlock	Loss of production	Investigate	2 hours
5	Starter No Power	Status from starter, mask if no station power	Notify that site cannot run	Loss of production	Investigate, if sustained	4 hours
6	Left in Local for 30 min	HOA not in Auto for 30min	Notify operator	Not available for auto-control	Investigate on site	4 hours
7	Starter Fault Alarm			Loss of production	Investigate to re-start	2 hours
8	Well Level near MPL	Level below - 35.00m for 5min	Pre-trip warning	Loss of production	Adjust flow rate on site	4 hours
9	Daily Flow Total Near Permit Warning	Daily flow total above 3500 m3 since midnight	Pre-trip warning	Loss of production soon if it hits interlock value	Adjust flow rate on site	2 hours
10	Daily Flow Rate Near Permit Warning	Flow rate above 40 L/s for 60 seconds, pump on for 5min	Pre-trip warning	Loss of production soon if it hits interlock value	Adjust flow rate on site	2 hours
11	Well Pump Shutdown on Interlock Alarm	Well pump shutdown due to interlock	Notification site shut down	Loss of production	Investigate to re-start	1 hour
12	Well Pump E-Stop Pressed Alarm	e-stop button status	Notify that e-stop activated	Onsite assistance needed	Call field operator	5min

Figure 22 – Example Numbered Alarms Table for Well Pump

## Other Standardized Device Pop-Up windows

The Guelph Water SCADA system standards also provide a set of pre-built device pop-up window templates for a wide variety of device types. For example, the standardized pop-up window for a motorized valve device pop-up can be seen in figures 23 and 24.

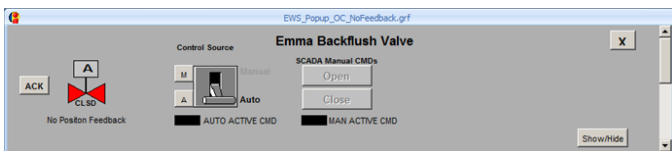


Figure 23 – Motorized Valve Device Pop-Up (default view)

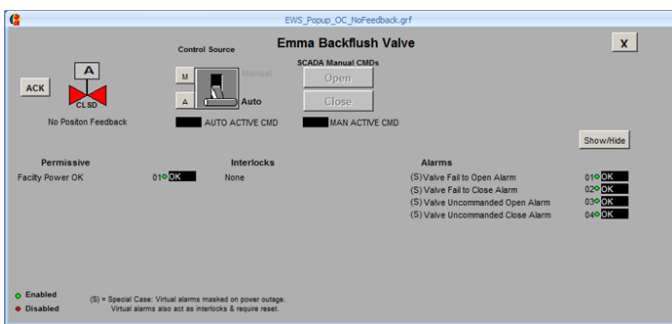


Figure 24 – Motorized Valve Device Pop-up (rolled-down view)

A similar standardized device pop-up window is used for a chemical feed pump. For hypo pumps, Guelph Water uses a standardized speed-controlled peristaltic pump, which has provides both speed feedback and a number of status contacts, including its mode, running status, general fault and tube-leak fault. The Hypo pump device pop-up window from Emma well can be seen in Figure 25 and 26.

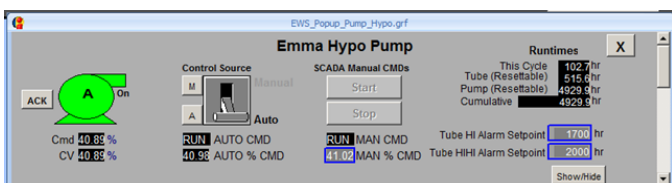


Figure 25 – Hypo Pump Pop-up (default view)

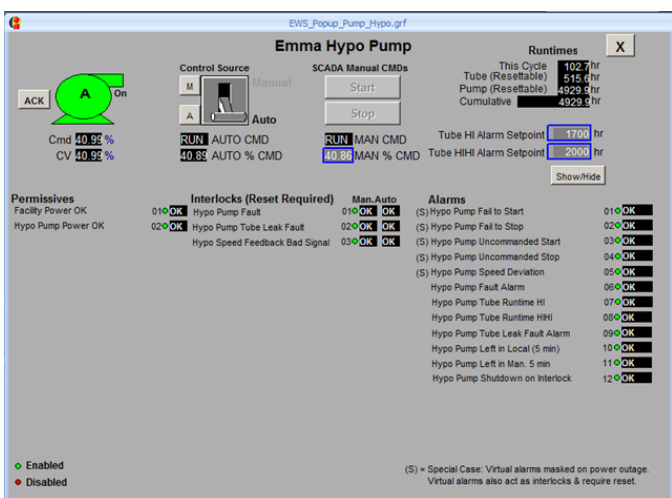


Figure 26 – Hypo Pump Device Pop-up (rolled-down view)

## Show Tank and Reservoir Level & Storage Status

One of the features of the Guelph Water SCADA standards is to pack a lot of detail into a screen in such a way that is visible but avoids making the screen seem cluttered. In Figure 27 the Hypo storage tank for 12% NaOCl solution is shown. The level of the tank is shown in meters, the percent full is shown, the tank is animated to show the fill level in yellow, and both the tank total volume and volume remaining are shown. On the right side of the tank, the min-max limits of the 4-20mA signal for the level transmitter are also explicitly shown.

For water storage at reservoirs and water tower sites, a similar approach is used to show the current level, percent full, total and filled volume, the overflow level, and the min/max range of the level transmitter, plus the status of any float switches.

(HPHMI design purists will notice that the tank icons do not include a trend line to show how the level has changed over time. Due to constraints in the current HMI software package, it was decided it was not worth the programming effort to add a trend line inside the tank. Instead operators can navigate to another screen to see hypo tank level trends.)

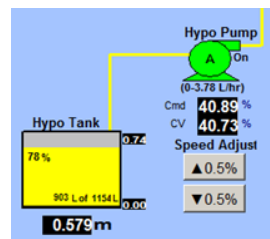


Figure 27 - Hypo Storage Tank with level, % level and volumes

Figure 27 also shows the standardized way of showing a speed controlled device, which consists of the device icon plus the Speed Command ("Cmd") signal being sent to the pump, the Speed Feedback ("CV") signal coming back from the pump, and informative text showing the normal flow range for the pump. It should be noted the "Speed Adjust" buttons are not part of the pump icon, but instead part of the automatic control scheme for the pump when it is in SCADA-Auto mode.

## Speed Units: Hz for Water Pumps and % for Hypo Pumps

For the control of VFD (variable frequency drive) water pumps, Guelph Water has adopted a policy of using Hz units for pump speed, and not percentage. In practice, it has been found that percentage speed is too vague and leads many communication problems during the design, construction, commissioning and operation of water facilities. The problem with using percentage for speed is that is unclear if it refers to (a) percentage of the full 0-60Hz range, (b) percentage of a 30-60Hz speed range, (c) percentage of a usable pump speed range, e.g., 40-60Hz, or (d) some other arbitrary speed range. By standardizing on using Hz for the water pump speed units, using 4-20mA = 30-60Hz for all speed reference signals, and using 4-20mA=0-60Hz for all speed feedback signals, Guelph Water has been able to avoid many of the common problems associated with commissioning and operating VFDs.

## Station-Level Permissives and Interlocks

At the station level, the Emma Well has a set of station-level auto-control permissives and interlocks that are used to ensure the Station Sequencer module does not attempt to start-up the station in automatic mode unless all the equipment is ready for an automated start-up. For the particular Emma Well overall automatic control scheme, a “global chlorine interlock” was implemented to ensure station would not attempt to run automatically if there was an issue with either of the chlorine analyzers. The station permissives and global interlocks had to all satisfied in order for the station to be able to start-up and run automatically. A listing can be seen in Figure 28.

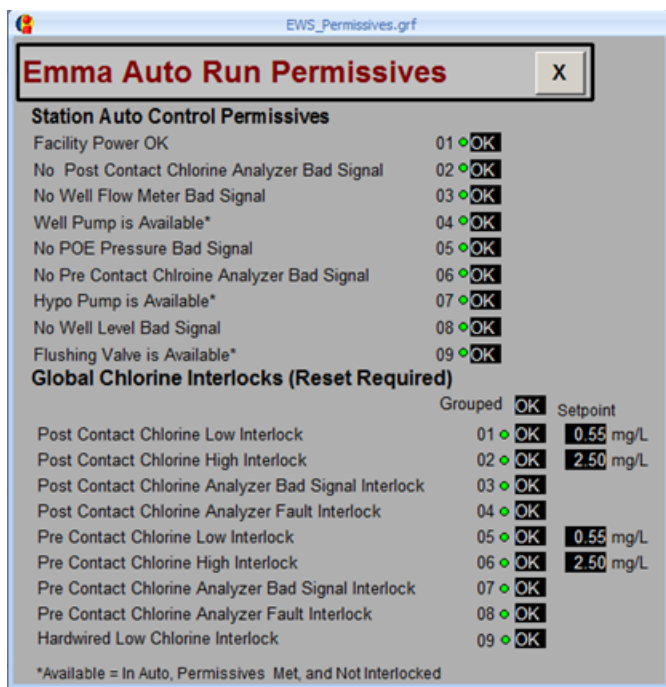


Figure 28 – Station-level permissives and interlocks

One of the automatic control system goals for the reprogrammed Emma Well site was to enable it to be able to automatically re-start without operator assistance after a minor issue, such as a brief power outage. The station-level permissives (auto-restart is possible) and station-level interlocks (automatic re-start not possible) are used by the Station Sequencer Module for managing station re-starts.

## Station Control Module & Station Sequencer Module

Apart from the overview screen, analog measurement pop-ups, device pop-ups, and station permissives/interlocks, two major parts of the Emma Well’s automatic control system are the Station Control Module and the Station Sequencer Module.

As mentioned earlier, the Station Control Module looks after when the station is called to produce water, while the Station Sequencer Module manages the start-up, shut-down, and automatic re-start of the station. The setpoints associated with these two modules can be seen in Figure 29.

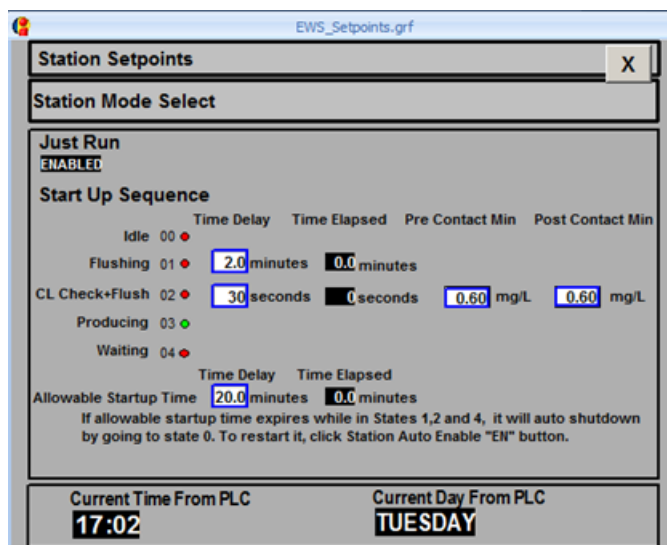


Figure 29 – Station Control & Station Sequencer pop-up

Because the control scheme for Emma Well is relatively straight-forward, and the well is only used in the “Just Run” mode, a single pop-up window is used by operators for entering in the setpoints for both the Station Control Module and the Station Sequencer Module.

The pop-up window in Figure 29 shows the various numbered steps that the Station Sequencer uses to start-up the station. The station shutdown sequence is fairly simple, the well pump is shutoff, the hypo pump shut off, and the PLC ensures the backflush valve is also closed.

From Figure 28 it can be seen there are a number of process conditions, including loss of power, which can cause the Emma Well to auto-shutdown. In the case of an auto-shutdown, the Station Sequencer Module will then attempt for the next 20 minutes to auto-restart the station by continually checking the status of the various station-level permissives and interlocks. If the sequencer is not able to re-start the station within 20 minutes, a “failed to auto-restart” call-out alarm will be triggered, so an operator can come investigate as to what the issue is and take corrective action.

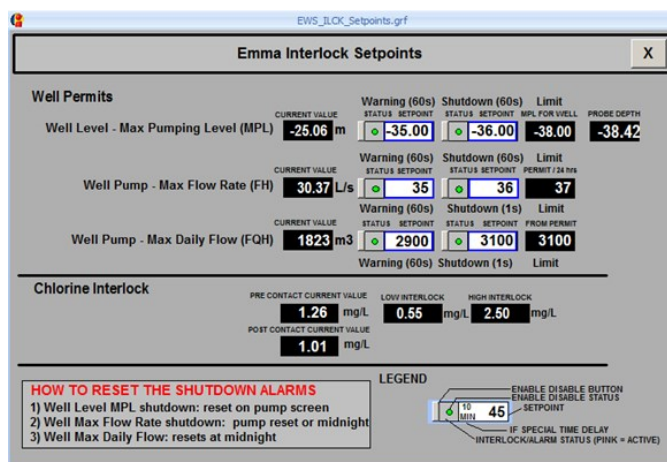


Figure 30 – Well Pump Interlock Settings pop-up



## Well Pump Interlocks and Hypo Pump Automatic Control

As the control of the well pump is very straight-forward, in that it is simply commanded to run once the start-up sequence is complete, there are no well-pump specific control setpoints. The well pump does, however, have several interlock setpoints associated with the well's PTTW (permit to take water), operational well level draw down limits, and regulatory limits for high/low chlorine. This is shown in a pop-up shown in Figure 30.

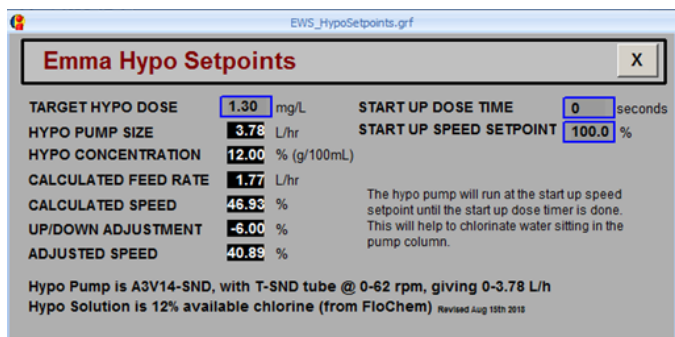


Figure 31 – Hypo Pump Automatic Control Setpoints Window

For the automatic control of the Hypo pump, a dedicated setpoints pop-up window is used to contain its various setpoints, including the target hypo dose setpoint, the calculated feed rate, and the current operator initiated up/down speed adjustment. There is also a setting to give the system a brief shot of extra hypo solution on startup, though in practice, this setting is rarely needed. The Hypo Pump automatic control settings pop-up can be shown in Figure 31.

## Better Flow Total, Flow Accounting and Runtimes

Providing better and more standardized flow totalizations and runtime calculations were two goals of the new Guelph Water SCADA programming standards. A standardized pop-up window design is now used for all sites to show both daily flow totals and runtime calculations, as shown in Figure 32. To avoid floating point math errors, flow totalization is only done on a daily basis. Other software tools, as part of the SCADA system's reporting software, are used to add up the daily flow totals. The "yesterday flow total" is generally used in calculations as it always reflects all the flow for the day before, rather than the "today flow total" which accumulates as the day progresses.

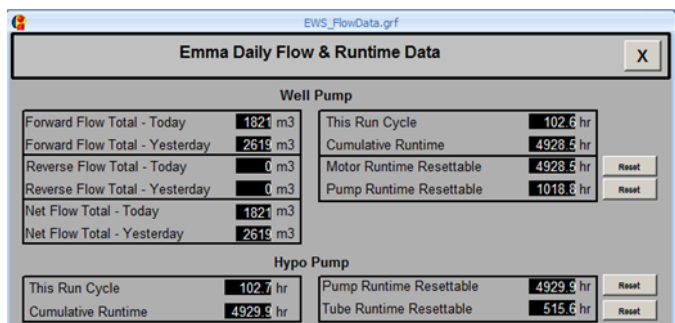


Figure 32 – Daily Flow totalization and runtime calculations

As an extension to the daily flow totalization, a second set of flow totalizers is also used to track how much well water is sent "to production" vs. how much is sent "to waste" due to well flushing activities. The "to production" and "to waste" daily totals have proved to be very useful for when doing end-of-year water balance flow total accounting for revenue vs. non-revenue water for the utility. The flow-accounting pop-up window can be seen in Figure 33.

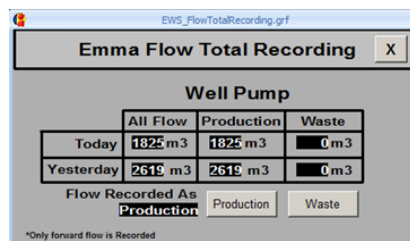


Figure 33 – Production vs. Waste flow accounting pop-up

The flow accounting programming works as follows: By having a flowmeter mounted on the discharge of the well pump, prior to the two valves for "to system" vs. "to waste", the flowmeter can record all flows from the well. As part of standard operating procedures, the operator on site can then use the buttons to tell the SCADA system where the water is being sent to. The flow accounting buttons are available on all the SCADA View nodes, as well as the touchscreen displays mounted on the PLC panel at each Guelph Water facility.

## Automatic Online CT Calculator

Part of the new Guelph Water programming standards is to include an online CT Calculator at all sites that use chlorine for primary disinfection/treatment. The calculator provides a number of key numbers that are needed to demonstrate the required CT is being met. The CT Required is calculated based on Ontario Procedure for the Disinfection of Drinking Water. The CT Achieved is calculated based on the current process conditions. The CT is considered met as long as the CT Achieved number is higher than the CT Required. The "CT Calculation Valid" will show Yes once the well pump has finished starting up and the process has settled down into steady state before the online CT calculation is ready for use.

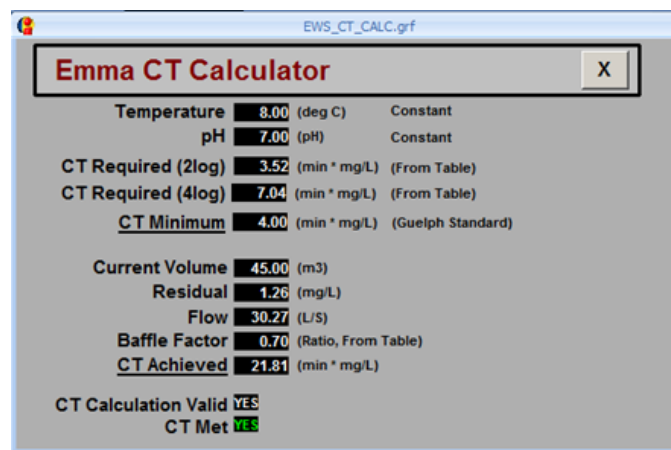
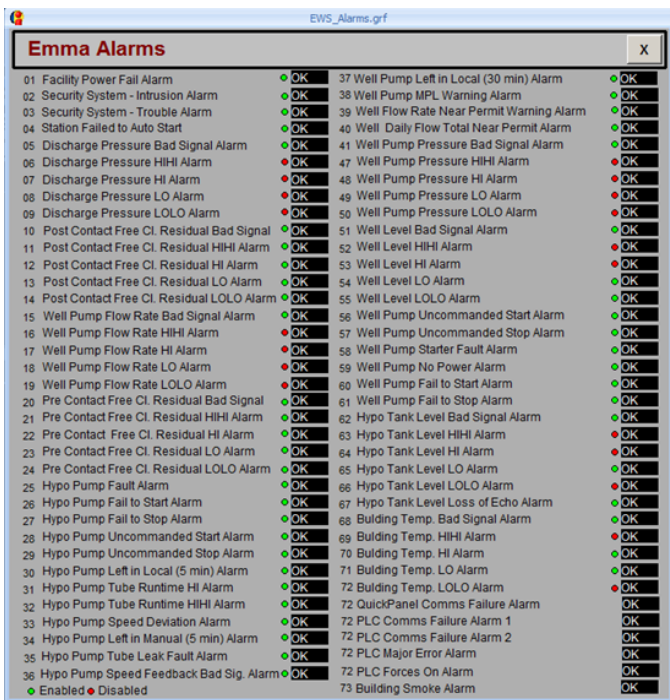


Figure 34 – Online CT Calculator

## List of All Alarms (and their Enabled/Disabled Status)

Lastly, as part of the Guelph Water SCADA Standards, a dedicated pop-up window is provided for each site that lists all of the configured alarms for the site, along with their enabled/disabled status. This screen allows for an operator to quickly see what alarms a site has configured, to check that the enabled/disabled status reflects what should be set for the station's current operating conditions. An example from the Emma Well can be seen in Figure 35.

One of the major benefits of having a pop-up window with a listing of all of the station's alarms readily available is that it makes it very straight-forward for an operator to find out what alarms are configured for a particular station. This is especially helpful as each of Guelph Water's facilities has a different set of configured alarms based on the facility's age, scope of automation, and nature of its specific process.



Emma Alarms		
01 Facility Power Fail Alarm	OK	
02 Security System - Intrusion Alarm	OK	
03 Security System - Trouble Alarm	OK	
04 Station Failed to Auto Start	OK	
05 Discharge Pressure Bad Signal Alarm	OK	
06 Discharge Pressure HI/Hi Alarm	OK	
07 Discharge Pressure HI Alarm	OK	
08 Discharge Pressure LO Alarm	OK	
09 Discharge Pressure LO/LO Alarm	OK	
10 Post Contact Free CI. Residual Bad Signal	OK	
11 Post Contact Free CI. Residual HI/Hi Alarm	OK	
12 Post Contact Free CI. Residual HI Alarm	OK	
13 Post Contact Free CI. Residual LO Alarm	OK	
14 Post Contact Free CI. Residual LO/LO Alarm	OK	
15 Well Pump Flow Rate Bad Signal Alarm	OK	
16 Well Pump Flow Rate HI/Hi Alarm	OK	
17 Well Pump Flow Rate HI Alarm	OK	
18 Well Pump Flow Rate LO Alarm	OK	
19 Well Pump Flow Rate LO/LO Alarm	OK	
20 Pre Contact Free CI. Residual Bad Signal	OK	
21 Pre Contact Free CI. Residual HI/Hi Alarm	OK	
22 Pre Contact Free CI. Residual HI Alarm	OK	
23 Pre Contact Free CI. Residual LO Alarm	OK	
24 Pre Contact Free CI. Residual LO/LO Alarm	OK	
25 Hypo Pump Fault Alarm	OK	
26 Hypo Pump Fail to Start Alarm	OK	
27 Hypo Pump Fail to Stop Alarm	OK	
28 Hypo Pump Uncommanded Start Alarm	OK	
29 Hypo Pump Uncommanded Stop Alarm	OK	
30 Hypo Pump Left in Local (5 min) Alarm	OK	
31 Hypo Pump Tube Runtime HI Alarm	OK	
32 Hypo Pump Tube Runtime HI/Hi Alarm	OK	
33 Hypo Pump Speed Deviation Alarm	OK	
34 Hypo Pump Left in Manual (5 min) Alarm	OK	
35 Hypo Pump Tube Leak Fault Alarm	OK	
36 Hypo Pump Speed Feedback Bad Sig. Alarm	OK	
37 Well Pump Left in Local (30 min) Alarm	OK	
38 Well Pump MPL Warning Alarm	OK	
39 Well Flow Rate Near Permit Warning Alarm	OK	
40 Well Daily Flow Total Near Permit Alarm	OK	
41 Well Pump Pressure Bad Signal Alarm	OK	
42 Well Pump Pressure HI/Hi Alarm	OK	
43 Well Pump Pressure HI Alarm	OK	
44 Well Pump Pressure LO Alarm	OK	
45 Well Pump Pressure LO/LO Alarm	OK	
46 Well Level Bad Signal Alarm	OK	
47 Well Level HI/Hi Alarm	OK	
48 Well Level HI Alarm	OK	
49 Well Level LO Alarm	OK	
50 Well Level LO/LO Alarm	OK	
51 Well Pump Uncommanded Start Alarm	OK	
52 Well Pump Uncommanded Stop Alarm	OK	
53 Well Pump Starter Fault Alarm	OK	
54 Well Pump No Power Alarm	OK	
55 Well Pump Fail to Start Alarm	OK	
56 Well Pump Fail to Stop Alarm	OK	
57 Hypo Tank Level HI/Hi Alarm	OK	
58 Hypo Tank Level HI Alarm	OK	
59 Hypo Tank Level LO Alarm	OK	
60 Hypo Tank Level LO/LO Alarm	OK	
61 Hypo Tank Level Loss of Echo Alarm	OK	
62 Building Temp. Bad Signal Alarm	OK	
63 Building Temp. HI/Hi Alarm	OK	
64 Building Temp. HI Alarm	OK	
65 Building Temp. LO Alarm	OK	
66 Building Temp. LO/LO Alarm	OK	
67 QuickPanel Comms Failure Alarm	OK	
68 PLC Comms Failure Alarm 1	OK	
69 PLC Comms Failure Alarm 2	OK	
70 PLC Major Error Alarm	OK	
71 PLC Forces On Alarm	OK	
72 Building Smoke Alarm	OK	

Figure 35 – List of All Station Alarms Pop-Up

An astute reader will notice that the Emma Well seems to still have quite a few alarms for a newly-programmed station. This is because the station's alarms are still in the process of being rationalized, but that can be subject of another article about the challenges of applying alarm management to water facilities.

## Summary

You've made it to the end! Congratulations! I hope you have found this article informative, as it has provided an in-depth tour of what the new automatic control system and HMI screens can look like for a recently modernized/re-programmed SCADA system for a municipal well.

Do the Guelph Water SCADA standards represent a true High Performance HMI (HPHMI) implementation? I will be the

first person to say that they do not. But what they do demonstrate is that they show how a municipal water utility can use key concepts from HPHMI design theory to develop a much improved set of SCADA design and programming standards, in order to provide a SCADA system that offers much improved functionality while also striving to reduce the "shock" to operators who are more familiar with traditional SCADA system designs. As a plus, Guelph Water was also able to leverage its existing investments in SCADA software.

As the Guelph Water SCADA standards continue to develop, it is anticipated that additional HPHMI concepts will be incorporated over time. In the meantime, the focus is to implement the newly developed standards across the current roster of 35 existing water facilities. By the time the new programming has been fully deployed, each of these sites will be much easier to monitor, control, operate and troubleshoot than they were with the old code.

The Emma Well Upgrade project was wrapped up in early 2019. The HMI screenshots for this article were taken in July 2019, after the newly upgraded station had been running for several months. Since then, the Guelph Water SCADA standards have undergone several iterative revisions and have been used to develop new PLC+HMI SCADA code for 10 more facilities. Work continues to deploy this new control system programming onsite, and to rewrite the programming code for the remaining Guelph Water facilities. Several nearby water utilities have also started using the Guelph Water SCADA standards to update their SCADA systems as well.

I would like to thank the members of the ISA112 SCADA Systems standards committee for providing me with a wealth of ideas and suggestions that have now made their way into the Guelph Water SCADA standards. Not heard about ISA112 yet? Take a look at [www.isa.org/isa112](http://www.isa.org/isa112) to find out more.

In practice, I have found that end-user SCADA standards are very much application, use-case, and organization specific. One size does not fit all. In this article, I have attempted to show how the new Guelph Water SCADA standards have been built around our specific needs. For all the end-users out there, I hope you have found this article helpful. The design concepts presented here are also not software specific, so they can be adapted to almost any SCADA platform out there. Feel free to adapt (or reject) the ideas contained here. That's the beauty of end-user-developed SCADA standards – you have the flexibility to tailor them to your needs. That's what we did, and I encourage you to do the same.

## About the Author



**Graham Nasby, P.Eng, PMP, CAP** holds the position of Water SCADA & Security Specialist at City of Guelph Water Services, a publicly-owned/operated water utility located in Guelph, Ontario, Canada. Prior to joining Guelph Water, he spent 10 years in the engineering consulting community after completing his B.Sc.(Eng.) at the University of Guelph. He is senior member of the International Society of Automation (ISA) and co-chair of the ISA112 SCADA System Standards Committee. Contact: [graham.nasby@guelph.ca](mailto:graham.nasby@guelph.ca)