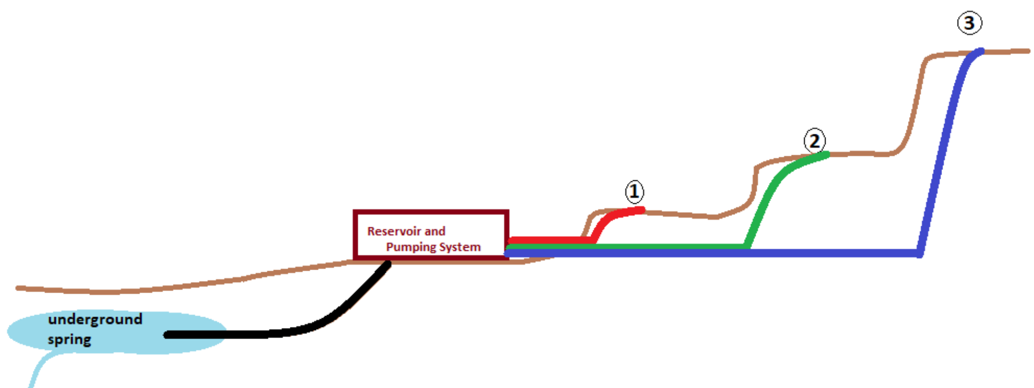
ECE-298 Embedded Project: Water Reservoir System

F2025

Project Background:

A terraced vineyard, near a community is undertaking a development that will require an **Embedded System Controller** for its irrigation system. It is to operate with energy efficiency.

A diagram below, shows the system that is already installed and what is needed is a Controller function for the system. There is a central water reservoir that is refilled with water from an INLET PIPE connected to an underground spring. A Water Depth Sensor in the reservoir is installed to sense water depth in the reservoir. When the irrigation activities occur, a single pump is used to move the water from the reservoir. A valve system is used to direct the water to each specific zone. The reservoir, pumps, pump motor and piping are already installed on the site.



The basic sequence of operation for the system is that the water reservoir is filled up with water from the underground spring. Then, the system distributes the water from the reservoir to each of the zones being irrigated.

A primary thing to keep in mind is that the 3 zones needing irrigation, are located at 3 different vertical elevations. This situation will require different water pressures to be applied from a pump running with different pump speeds.

EMBEDDED PROJECT DELIVERABLES:

The work to be done for the Embedded project consists of two parts. These are:

1) Team Final Feasibility Model Demo in Lab B4
2) Team Project Prototype Schematic and PCB Design in Lab B5

The Team Final Feasibility Model **Demo** in Lab B4 will consist of:

1) Develop a "Final Feasibility Model" design. There are Hardware and Software aspects for this project. The demo will be directed by a TA or the Lab Instructor for just testing for general functionality over a 24 hour span with:
   - I) Wall Clock Time always **starts at midnight**,
   - II) Scaled clock rate that is 300 times faster than regular wall clock rate,
   - III) Regular clock rate is used for RPM calculations,
   - IV) Start and Stop Pumping times for each pipeline connection,
   - V) Pump motor speed for each pipeline connection.
2) Present some performance calculations after the end of the demo (explained later). A Spreadsheet with calculations for Total DC Motor Energy Used and Motor Energy Cost per 24 hours.

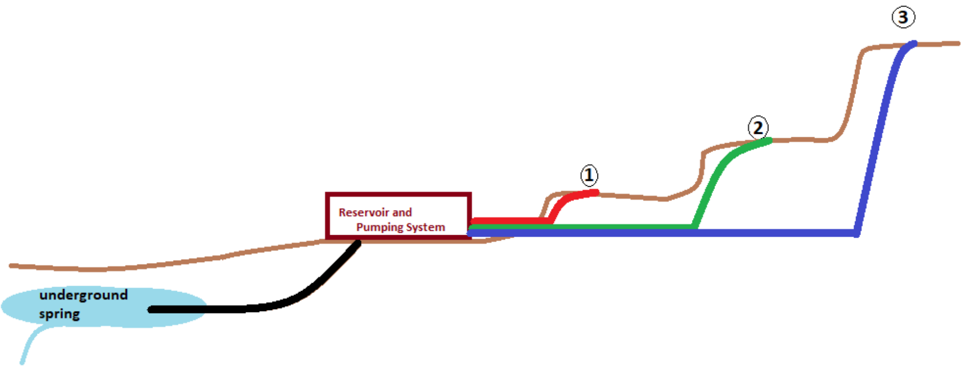
The Team Project Prototype Schematic and PCB Design in Lab B5 will consist of:

1) A Final Prototype Schematic;
2) A Final Prototype PCB Design and some associated files

The Team Project Prototype Design items will be reviewed and evaluated during the Lab B5 Session.

OPERATING TERMS AND DEFINITIONS:

You will be required to demonstrate your team's embedded system which includes hardware and software.



A BASIC PUMP SYSTEM PARAMETER TERM --- HEAD:

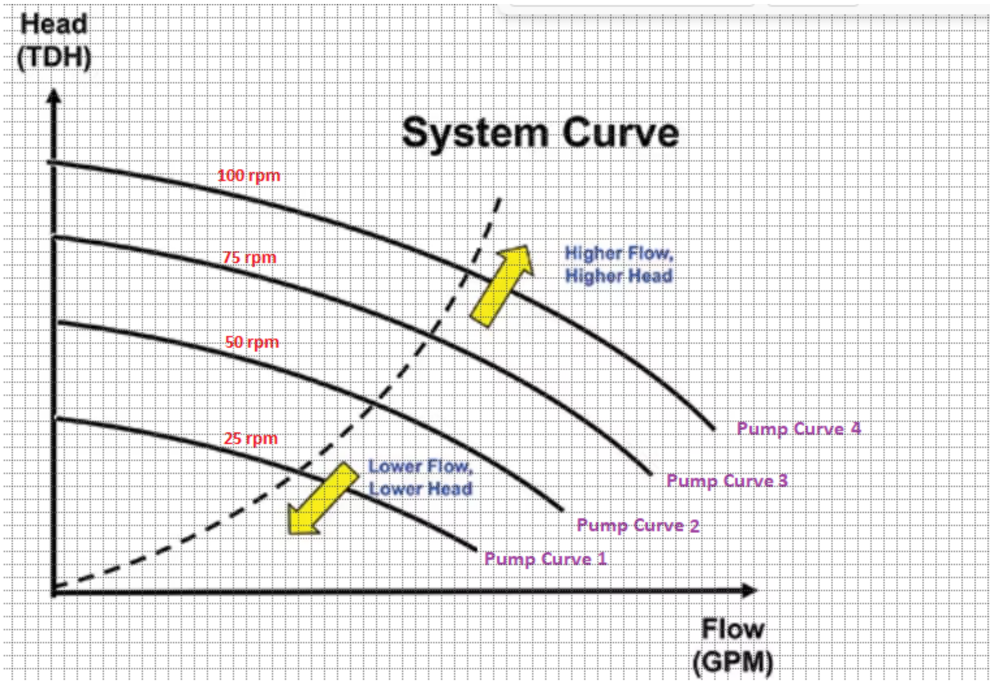
A parameter that is used in pumping system design is a term known as HEAD. It's unit of measure is based on vertical distance. This parameter is a much "handier" unit for general performance requirements since it conveys the capabilities of a water system design in general terms. It is proportional to a pump's ability to create water PRESSURE.

The height to which a pump can move a fluid, is generally given in HEAD terms (feet, metres etc.) because it is more intuitive for determining if a pump can perform sufficiently for a specific application. With everything then being in HEAD units (feet, meters etc.), one can use simple arithmetic calculations to develop the system design.

For example, if a pump has a Total Dynamic Head value (TDH) of 30 feet, then that means that the pump can lift, by the pump's water pressure, a fluid by 30 feet when operating at a specific rpm. But this parameter is usually specified for a water flow of ZERO. So, if your water pumping application requires a Head of 40 feet, then right away, one can know if the pump must be made to run faster to provide water flow at that height. Typically, the pump performance curves (pump curves) for a particular pump are provided by the pump manufacturer. They show a pump's TDH vs FLOW.

The PUMP CURVES and SYSTEM CURVE:

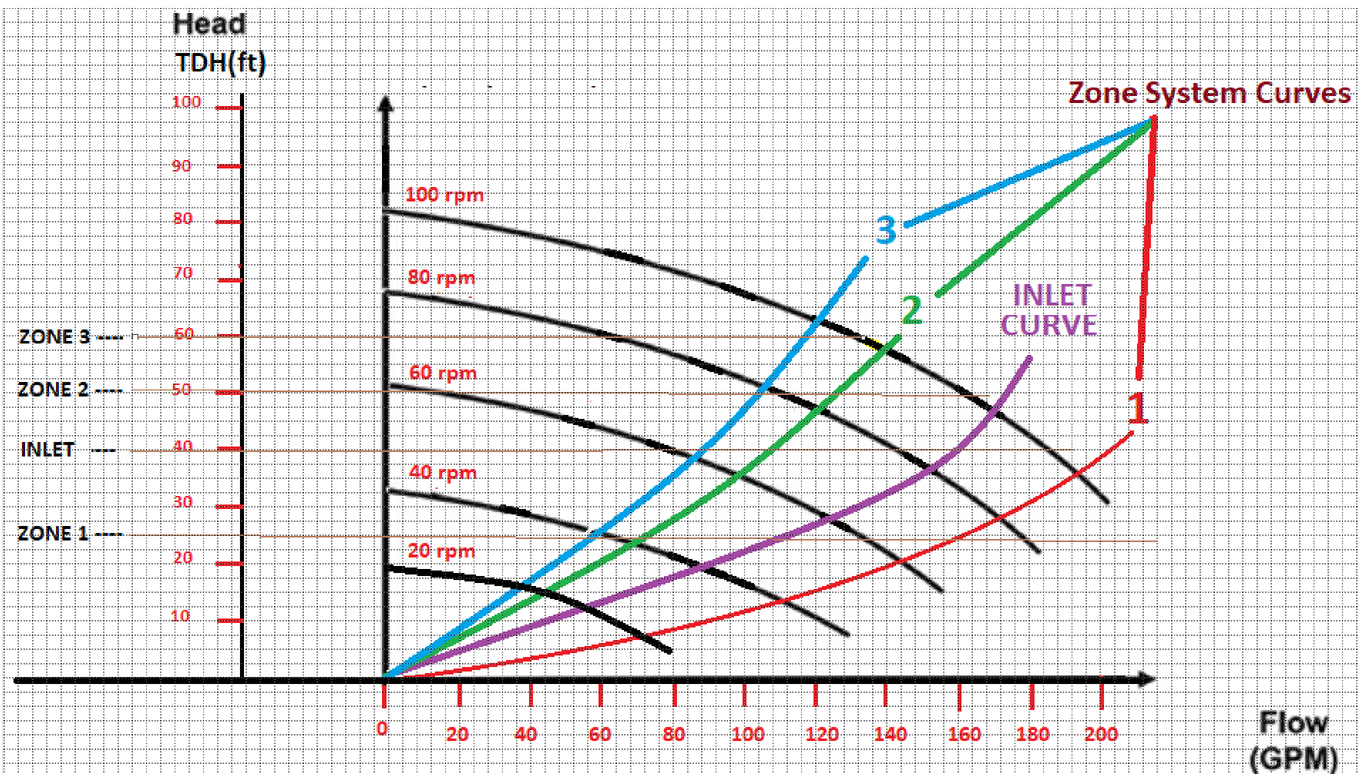
Another characteristic of a Pumping System is the System Curve. This is established by the **piping system design and pipeline layout at the customer site**. The System Curve is used as an overlay over the Pump Curves to establish how a pump will perform at the customer site for various pump parameters such as revolutions per minute (RPM).



For any known System Curve, a pump's RPM value will affect the operating point of a system along its System Curve.

CUSTOMER SITE SYSTEM CURVES FOR THE PROJECT:

At the customer site for this project, there are four, already installed pipeline. For these, there are three system curves for the zones and one inlet system curve for drawing water to fill the water reservoir to consider. Each system curve is based on different tubing pipe diameters and/or routing on the property.



Each system curve above shows the operating points of the system for each zone or inlet pipeline connection.

For example: Zone 1 is at an elevation of 25 feet above the elevation of the water reservoir.

The system curve for the pipeline to **Zone 1** shows that the pump will provide water to zone 1 when it is running with **at least a TDH that is sufficient** for zone 1. This requires a minimum rpm of 70 rpm (with a resulting flow of 160 GPM) and up to a maximum of 100 rpm (with about 193 GPM).

The system curves for the remaining two zones can be determined from the graph using the minimum TDH value to reach the zone and the range of rpm values. Intermediate values of rpm between the pump curves can be estimated.

IRRIGATION REQUIREMENTS

The Reservoir capacity is 94000 gallons in total. All the water in the reservoir is consumed with irrigation all 3 zones every 24 hours.

INLET Water Source (Underground Spring) is used as a resource to fill the reservoir.

The HEAD from the spring to the reservoir is 40 feet 94000 gallons must be pumped to the reservoir.

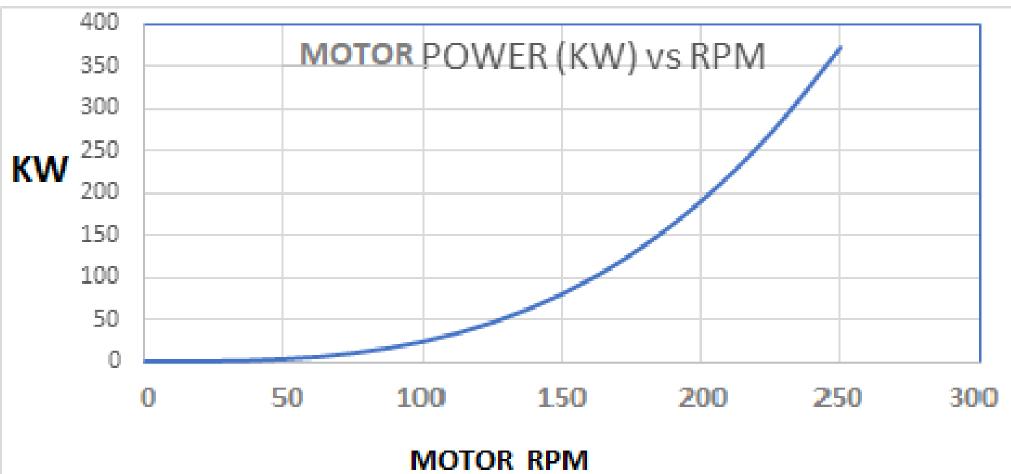
HEAD to zone 3 is 60 feet; 14000 gallons must be pumped to zone 3

HEAD to zone 2 is 50 feet; 39000 gallons must be pumped to zone 2

HEAD to zone 1 is 25 feet; 41000 gallons must be pumped to zone 1

Some additional metrics for the system operations are shown on the next page. These are for some calculations.

MOTOR POWER CONSUMPTION:

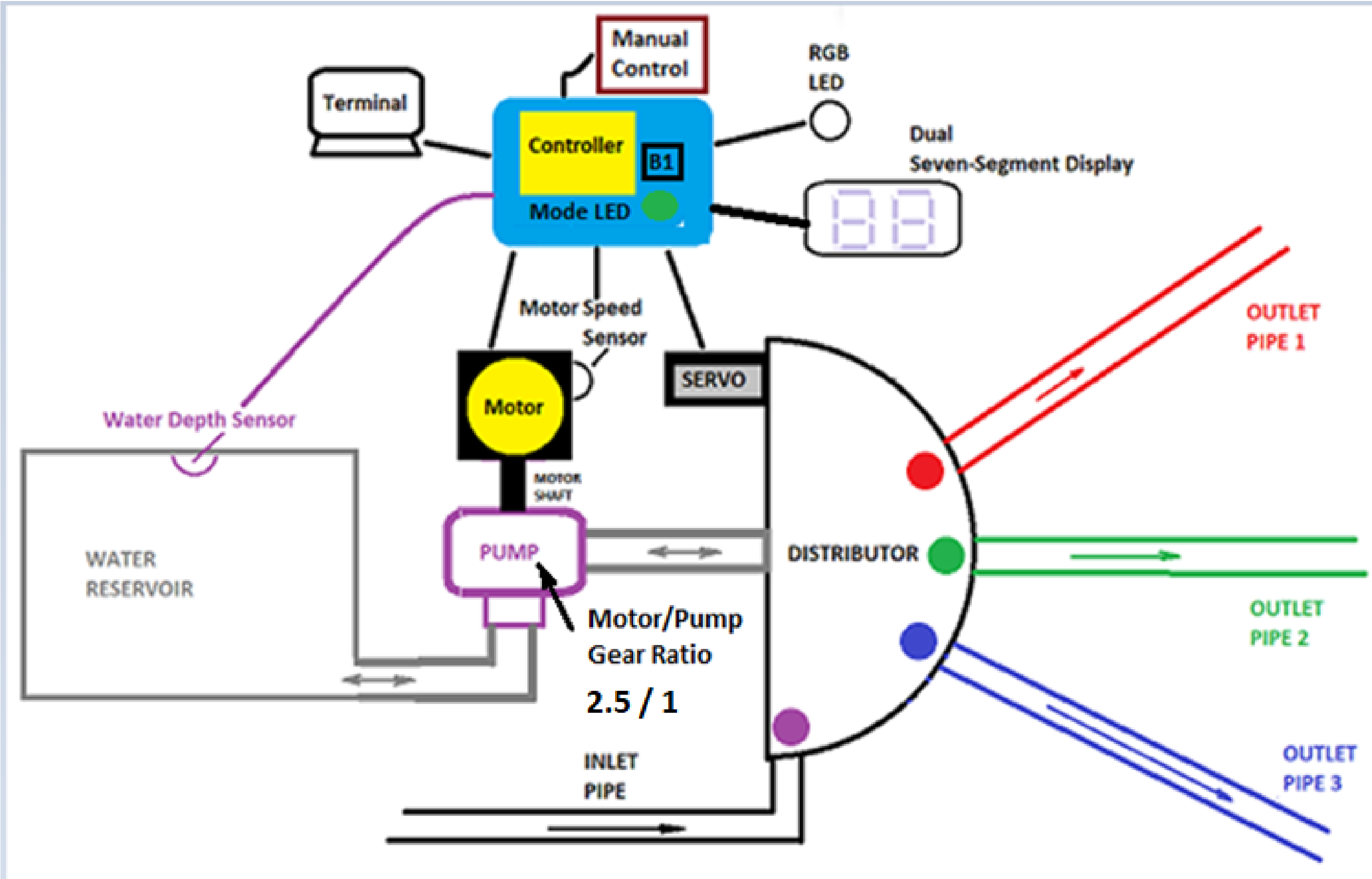


The pump motor that is installed at the customer site, has a gearbox for use with the pump. The Motor RPM is 2.5 times higher than the pump RPM.

The motor power requirements (KW) are based on the RPM of the **motor**. The energy, in Kilo-Watthours (KWH), to run the motor at a given RPM value is the KW power times the runtime in hours to run the pump.

In the real-world situation, your design must be running as economically as possible with its operations.
In the real-world situation, you **must not waste energy or water** with your system design.

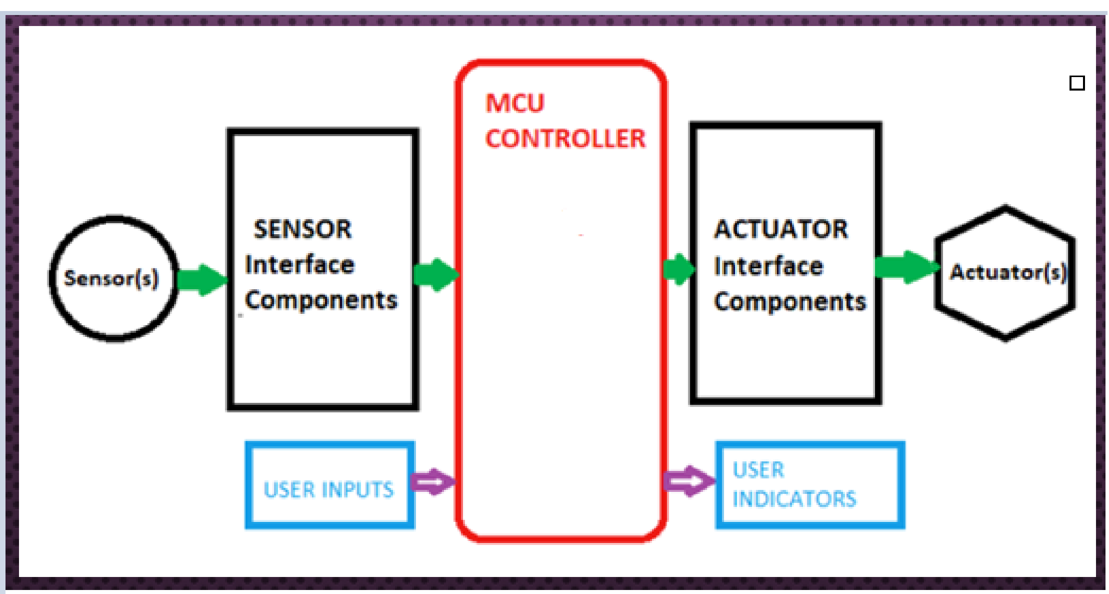
PUMPING SYSTEM DESIGN



Team Final Feasibility Model Demo

1) TEAM DEMO HARDWARE DESIGN:

The Team Final Feasibility Model Demo will include hardware components such as in the following sketch:



gdf

The Nucleo board will be the Embedded System Controller, and it will connect to various external devices with proper interfacing logic included in the Reservoir System Kit. Besides the kit components, a Lab A Timer Board will be used (in "LOAD MODE") to display numeric info. The Nucleo board interfaces required are listed below:

1) Computer Workstation Terminal (UART COMM link)
2) Potentiometer Analog Input (Manual Cntrl)
3) PWM signals to a motor controller(L9110) for Brushed DC Motor
4) PWM signals interface for SERVO Motor
5) Timer I/F to ultrasonic Distance Sensor
6) Interrupt interface from RPM Speed Sensor
7) GPIO interface to Timer Display
8) GPIO interface to RGB LEDs
9) GPIO interface for Mode LED (on the Nucleo board)
10) GPIO interface to B1 Push Button. (on the Nucleo board)

All interfaces must have the <u>appropriate</u> signal voltage translation buffers included for full marks. Refer to the information provided in the Lab Presentation slides, Lab Manuals, MCU Pin Planning spreadsheet and the device datasheets.

<u>Computer Workstation Terminal Interface (UART COMM Link)</u>
The Terminal is configured to run with a BI-DIRECTIONAL UART connection to the embedded system. It is used to enter SETUP Mode information or display RUN Mode information when the embedded project is operating in each of its operating modes (SETUP or RUN).

<u>MANUAL CONTROL (Analog Input)</u>
A Manual Control (Potentiometer) can be optionally used to manually set the speed of the motor for any zone or inlet connection, if the option is chosen with the terminal during the SETUP MODE of the embedded system. The Analog Voltage Level of the Potentiometer output can be converted to a digital value between 0 and 255 (decimal). The decimal value can be divided by 255 to geta Percentage of full scale. That percentage may then be applied to the PWM Pulse Width (Duty Cycle) for the DC Motor speed. Alternatively, from the Terminal keyboard, a Motor Speed (PWM OPTION) may be set for a zone or inlet pipeline connection in SETUP Mode.

<u>DC MOTOR AND PUMP (Dual PWM Controls)</u>
The Pump is driven by the DC MOTOR. The DC Motor direction and speed are controlled via a PWM signals from the MCU. **Note that there is a gearbox that has a gearing ratio of 2.5 to 1. This means that PUMP MOTOR runs 2.5 times FASTER than the PUMP in terms of RPM**.

Note that the direction of water by the pump **<u>with the INLET is</u> <u>OPPOSITE</u>** to the water flow to the ZONES.

<u>WATER DISTRIBUTION SELECTOR (PWM Interface Controlled Servo)</u>
For general operation, the Reservoir must ALWAYS be filled first before any irrigation to the zones can begin.
After the water reservoir is filled, the Controller can direct water from the water reservoir to any one of the three zones for irrigation at a time.

The selection of the zone pipe connection is done by controlling the SERVO.

<u>RESERVOIR WATER DEPTH SENSING (Timer Peripheral Interface)</u>:
The depth of water in the water RESERVOIR may be determined at any time by using the Ultrasonic Distance Sensor. You should set in code, your determined limits for minimum and maximum Water Level distance values. Then your code should calculate the percentages for distance values between those limits. Note that the distance Sensor is mounted at the <u>CEILING of the Reservoir</u>. So, as the water level rises, the distance to the sensor decreases. The Water depth must be seen on the Dual Seven-segment display on the Timer Board and on the Terminal.

<u>RPM SPEED Sensor</u>

The RPM Speed sensor is used to sense the motor speed by employing an optical sensor with a slotted encoder wheel on the DC Motor shaft. Pulses from the sensor are counted over a fixed time interval by the MCU to determine the DC Motor RPM speed. Please note that the Time Interval must be based on Real Time (not Scaled Time).

<u>TIMER BOARD NUMERIC DISPLAY</u>

The water depth will be shown in percentage terms (0% to 99%) on this display. Keep in mind that when the water level is HIGHER in the reservoir, the distance measurement by the Distance Sensor will be LOWER in value. The Reservoir water level can be represented by some sort of movable barrier (such as a piece of cardboard etc.) in front of the Distance Sensor.

<u>RGB LED</u>

When the SERVO has been configured for a new selection, the RGB LED is Driven to the specified colour. Note that for the INLET Pipe, the RGB colour is set for PURPLE.

<u>NUCLEO LD2 GREEN LED</u>

The Nucleo Board has a Green LED that will be used to indicate the System Mode.

<u>NUCLEO B1 BLUE USER Push-Button</u>

The Nucleo Board has a Blue Push-Button that will be used to change the System Mode.

<u>NUCLEO BLACK RESET Push-Button</u>

The Nucleo Board has a BLACK Push-Button that will be used to RESET the System Mode.

2) TEAM DEMO SOFTWARE DESIGN:

The DEMO will just use a constrained set of input option values (for simplicity).

The Embedded System is to be designed to run all pumping operations within a 24-hour time period.

Your system is to run in both a **SETUP** Mode and a **RUN** Mode. **For The DEMO, the RUN Mode operations must ALWAYS START at Clock Hour = 00 and then STOP WHEN Hour 24 is reached.**

For specific hours of scaled time, a number between 00 and 23, inclusively speaking, may be entered at the keyboard in SETUP Mode for the following requests by the system.

1) SETUP MODE:

This MODE is entered by Resetting the NUCLEO MCU (Black Reset Button). **The GREEN LED on the Nucleo board is to be OFF while in SETUP MODE. NOTE: PUMP MOTOR MUST BE OFF in SETUP MODE.**

The Terminal displays "SETUP MODE and then displays the messages in **Part A** below to cover all the choices for pipeline operations. The entries in Part A are to be made for the DEMO.

A) IINLET PIPELINE PUMP MOTOR PWM (chosen by TA to SET to option 0 for Manual Control for the Demo):

FIRST ZONE CHOICE FOR IRRIGATION (option 1-3): chosen by TA
FIRST ZONE CHOICE FOR PUMP MOTOR PWM OPTION (1,2,3): chosen by TA

SECOND ZONE CHOICE FOR IRRIGATION (option 1-3): chosen by TA
SECOND ZONE CHOICE FOR PUMP MOTOR PWM OPTION (1,2,3): chosen by TA

THIRD ZONE CHOICE FOR IRRIGATION (option 1-3): chosen by TA
THIRD ZONE CHOICE FOR PUMP MOTOR PWM OPTION (1,2,3): chosen by TA

Use the following list for entering the PWM option for the PUMP MOTOR SPEED for a ZONE or INLET:

0) **Manual Control (the Potentiometer setting in Run Mode for the Inlet connection only);**
1) **PWM OPTION 1; PWM Duty Cycle = 70%;**
2) **PWM OPTION 2; PWM Duty Cycle = 85%;**
3) **PWM OPTION 3. PWM Duty Cycle = 99%;**

For simplicity, this DEMO WILL HAVE ONLY ONE ZONE OR INLET CONNECTED TO THE PUMP IN EACH HOUR, THERE WILL BE NO OVERLAP OF WALL-CLOCK ENTRIES TESTED (so save yourself some development time) .

NOTE: WALL-CLOCK TIME is expressed in a simple 24-hour (HH:MM) format.
The entry options are: 00 – midnight, 01 – 1:00am, 02- 2:00am, ….,, 12 – noon, 13- 1:00pm…. 23 – 11:00pm

After all INLET and ZONE INFO is entered in Part A, the Terminal displays the messages in Part B below. The wall clock times are next to be entered.

The order of wall clock time entry options is listed below:

B) INLET WALL CLOCK START TIME (chosen by TA to SET to 00 for the Demo):
INLET WALL CLOCK STOP TIME (chosen by TA to SET to 07 only for the Demo):
The above settings allow for Manual Control Testing in scaled time operation. An object must be placed in front of the distance sensor (to represent an Inlet water fill level) before hour 07 is reached.

<u>FIRST ZONE</u> WALL CLOCK <u>START</u> TIME (08-23): chosen by TA
<u>FIRST ZONE</u> WALL CLOCK <u>STOP</u> TIME (09-23): chosen by TA

<u>SECOND ZONE</u> WALL CLOCK <u>START</u> TIME (08-23): chosen by TA
<u>SECOND ZONE</u> WALL CLOCK <u>STOP</u> TIME (09-23): chosen by TA

<u>THIRD ZONE</u> WALL CLOCK <u>START</u> TIME (08-23): chosen by TA
<u>THIRD ZONE</u> WALL CLOCK <u>STOP</u> TIME (09-23): chosen by TA

<u>NOTE:</u> WALL-CLOCK TIME is expressed in a simple 24-hour (HH:MM) format.
<u>The entry options are:</u> 00 – midnight, 01 – 1:00am, 02- 2:00am… 12 – noon, 13- 1:00pm…. 23 – 11:00pm

After all WALL-CLOCK entries are completed in the SETUP MODE, the system then displays all SETUP Mode parameters entered (with Parameter Descriptions added) and then the system **<u>flashes</u>** the GREEN LED on the Nucleo board continuously on the Nucleo board. This indicates that the Setup Mode entries are completed. The system remains **<u>waiting</u>** at the end of **SETUP MODE**. The MCU is waiting for the activation of the **BLUE B1 button** before it brings the embedded system into **RUN Mode**. When the BLUE B1 Button is pressed and released, the system leaves **SETUP MODE and goes to RUN MODE**. **<u>The GREEN LED stays ON continually during RUN MODE</u>**.

<u>RUN MODE</u>:

<u>Because we don't have 24 hours to test each team design, we will be running the DEMO with "scaled time" operation.</u>

An internal MCU Timer should be used to drive variables for the SCALED WALL CLOCK time values for scaled hours and scaled minutes. If we let the 24-hour cycle of WALL-CLOCK TIME be represented as 4.8 minutes in SCALED TIME. So, for example, a scaled running time of 1 hour, the duration in REAL TIME becomes 0.2 minutes (or 12 seconds of real time)**.** This means that the Timer must run 300 times faster than real time.

<u>Status Reports to the Terminal</u>:
The Status reports to the terminal are to be "historical" rather than "live". This means that the system sends results to the Terminal for the **<u>PAST</u>** hour while the system is working on the **<u>NEXT</u>** hour.

During RUN Mode, the Terminal displays the system STATUS by using a set of Column headings as shown below:

Wall-Clock Hour, Minutes optional| Zone/Inlet | Motor Speed %PWM | Motor RPM | Reservoir Water Depth |

The <u>Timer Board</u> must also show the Water Depth Percentage with each hourly measurement.

Updates about the system status information should be displayed with ONE line of info per update on the terminal display. There can be multiple reports per hour if you wish, but then you must include the minutes value as well.

The display gets updated on a new row of info **<u>at least once every WALL CLOCK hour</u>**. The info shown should reflect the operations of the system during that hour (typical RPM measurements have +/- 5% RPM values for any given motor speed). If a Wall Clock Hour has no Zone or Motor operation being used the Zone/Inlet and Motor Speed %PWM MUST BE BLANK.

The RPM values must be based on revolutions per **<u>REAL TIME MINUTE</u>** (<u>not scaled time</u> intervals).
<u>IMPORTANT:</u> Because of motor inertia, it is suggested that the RPM value calculation not use RPM tick counts near the beginning of each hour when a change in motor speed is being made (typical RPM measurements will have about +/- 5% RPM values for any given motor speed).
Motor RPM's must be reported even when the Motor is OFF.

PIPELINES:

1) INLET:

The WALL CLOCK will begin running from “00” hour when the system is placed in RUN Mode.
The FIRST pipeline connection to be made with the pump is the **INLET** pipeline. The system configures this pipeline connection by setting the Servo to the pointer position for that connection (say 0 degrees). The system sets the RGB LED to indicate the **INLET** connection colour. The system requests a measurement for the Water Level in the Reservoir. If the Reservoir is **NOT FULL** (say less than 90% full), the system enables the motor to use the Manual Control with the **INLE**T connection for the DEMO to set the motor speed. While running with the **INLET** connection, the system makes RPM measurements of the motor speed during each hour. The system also makes Water Level measurements during this time. At the end of the **INLET** operation (WALL CLOCK STOP TIME for a pipeline connection) shut down the motor.

2) ZONE PIPELINES:

The RUN Mode sequencing proceeds through the irrigation process for each ZONE (like the above steps for the INLET connection) in their selected order specified in the SETUP Mode, and with each one using its respective motor speed PWM setting, SERVO and RGB LED settings. After the Wall Clock reaches 24 hours, THE GREEN LED on the Nucleo board is Turned OFF. The system should stop and then should wait for a RESET
KEEP IN MIND THAT THE DEPTH OF THE RESERVOIR MUST BE MONITORED AT LEAST ONCE PER WALL CLOCK HOUR (SEE SPECIAL EVENT BELOW).

SPECIAL EVENT

A special Event is detected if the Water Reservoir (after being filled) ever reaches **ZERO depth %** during its 24-hour operation. The embedded system then immediately turns OFF the MOTOR. The Terminal display indicates that the RESERVOIR IS EMPTY and the RGB LED sequentially displays a FLASHING WHITE COLOUR. THE GREEN LED on the Nucleo board is Turned OFF. The system should stop and then should wait for a RESET.

Team PROTOTYPE Model Presentation of Project Operating Plan Spreadsheet

Besides the Prototype design for the Schematic and PCB Layout to be presented in the last lab session, you will have to present your team plan for running your Prototype System at the customer site. A Spreadsheet is required to develop your plan.

Determine the necessary **Pump RPM** from the System Curves above to pump the required water to each zone or inlet into the reservoir over a 24-hour period.

Calculate the required **MOTOR RPM** (2.5 x Pump RPM) for each Zone or Inlet connection.

Calculate the Zone/Inlet **Pump Running Time** (in Hours) necessary (based on the GPM data from the System Curve graphs) for the pump to send the **required amount of water** to each zone or the Reservoir.

From the Motor Power vs RPM graph, determine the **Motor Power** (in KW) required for each Zone or Inlet.

Calculate the TOTAL **Motor Energy** Consumed (in KWH) for all irrigation.

Calculate the TOTAL **Energy Cost** for a 24-hour operation using the Time of Use table below.

SMALL BUSINESS PRICING:

TOU Price Periods	Summer (May 1 – October 31)	TOU Prices (¢/kWh)
Off-Peak	Weekdays 7pm – 7am Weekends and holidays all day	7.4
Mid-Peak	Weekdays 7am – 11am and 5pm – 7pm	10.2
On-Peak	Weekdays 11am – 5pm	15.1

For your spreadsheet you may start your 24-hour operations at ANY hour you wish. It does not have to start at midnight like was done for the Demo.

An example spreadsheet is shown below. The Orange column cells require graph data input for the System Curves or from the Motor Power vs RPM curve.

The Spreadsheet is downloadable from Learn.

	INLET	ZONE1	ZONE2	ZONE3
Minimum PUMP	85	70	85	97
Maximum PUMP	100	100	100	100
WATER REQUIRED PER 24 HOURS	94000	41000	39000	14000

FIRST CLOCK HOUR	LAST CLOCK HOUR	PUMP RUN TIME (HR)	INLET / ZONE	PUMP RPM	GPM (from System Curves)	ZONE or INLET GALLONS INCREMENT	ZONE or INLET CUMULATIVE GALLONS	MOTOR RPM (PUMP RPM x 2.5)	MOTOR POWER in KW (MOTOR RPM vs KW graph)	MOTOR ENERGY (KWH) KW X RUN TIME	ENERGY COST per KWH	ENERGY COST $CDN
12am	1am											
1am	2am											
2am	3am											
3am	4am											
4am	5am											
5am	6am											
6am	7am											
7am	8am											
8am	9am											
9am	10am											
10am	11am											
11am	12pm											
12pm	1pm											
1pm	2pm											
2pm	3pm											
3pm	4pm											
4pm	5pm											
5pm	6pm											
6pm	7pm											
7pm	8pm											
8pm	9pm											
9pm	10pm											
10pm	11pm											
11pm	12am											
										TOTAL ENERGY (KWH) 0	TOTAL 24 HOUR COST 0	

Have your Spreadsheet data ready during your Prototype Schematic/PCB Design Presentation in the Last lab.