Chapter

2

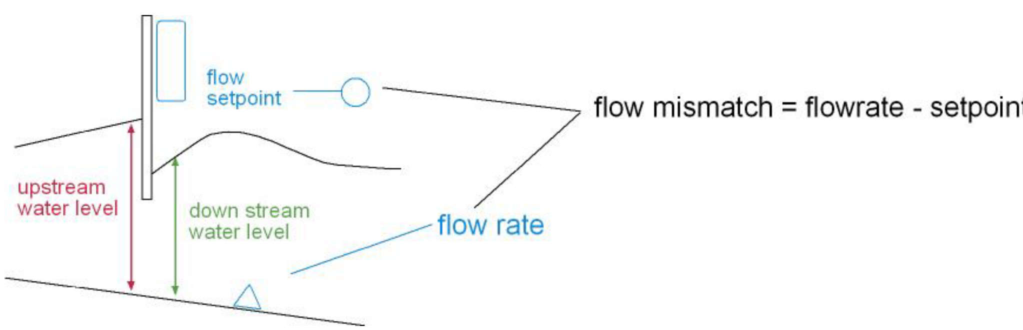
Chapter 2 : Understanding the Theory

This chapter provides a detailed examination of the control theory involved in canal automation. Specifically, it breaks down the two major control theories used: Feedforward and Feedback.

Understanding the concept of Feedback.

Flow Control

Flow control attempts to match the measured flow rate with a flow rate setpoint.[1] The difference between the flow rate and the setpoint, in the case of flow control, is called flow mismatch.



If flow mismatch is positive, meaning there is more flow under the gate than desired, the gate is closed to reduce the current rate of flow. If flow mismatch is negative, meaning there is less flow under the gate than desired, then the gate in opened to increase the current rate of flow.

[1] Water can flow over the site's gate as well as spill out over the weirs. However, this flow is exclusive of the flow in local flow control because it cannot be adjusted or managed by the site.

Local Flow Control Flow Mismatch and Results

Flow Mismatch	Result
Positive	Gate moves down
Negative	Gate moves up

In general, flow control cannot be performed without level control. However, a single site cannot simultaneously perform local flow control and local level control. Therefore, in order for a site's flow and level to be controlled, local flow control should be accompanied by some form of level control at a downstream site (either by central level control or local level control at the downstream site). In the case of a headgate, that site's upstream level is assumed static, so it may have local flow control without central level control. In the case of a tailgate (the last centrally level controlled site in a control vector), it is possible to have local flow control because that site's level is centrally controlled.

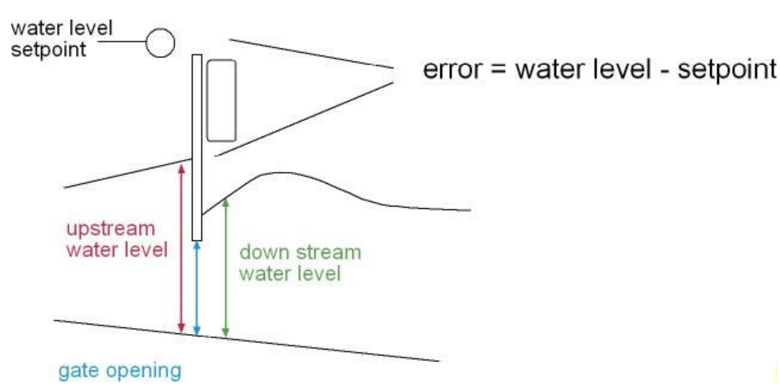
Control Strategies

Manual Control

Under Manual Control, the operator, not the computer, provides the feedback.

Local Level Control

Local level control attempts to match the upstream water level at a site with its water level setpoint. The difference between the water level and the setpoint is called error.



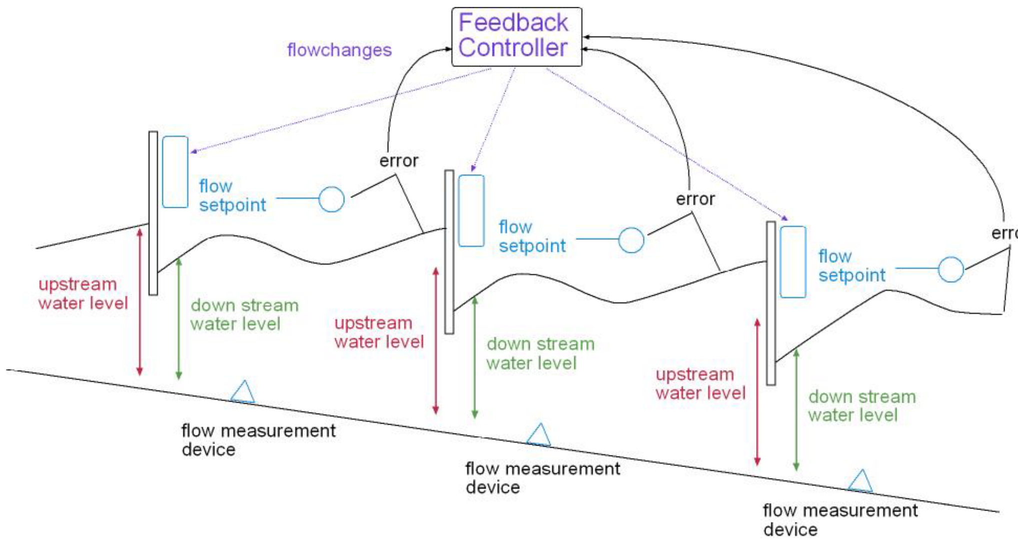
During local level control, if the error is positive, meaning the water level is higher than the setpoint, the gate is opened to allow more water to flow under the gate and thus reduce the upstream water level. If the error is negative, meaning the water level is below the setpoint, then the gate is lowered to reduce the flow under the gate and increase the upstream water level.

Local Level Control Error and Results

Error	Result
Positive	Gate moves up
Negative	Gate moves down

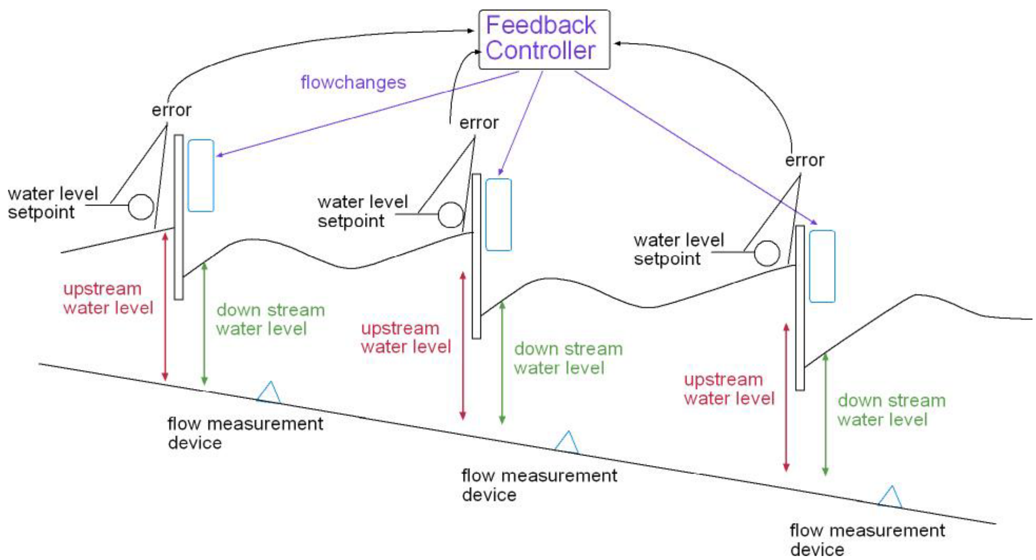
Centralized Level Control

Essentially, centralized level control is a Master/Slave approach where water level errors serve as input to the "master" feedback controller, which dictates changes to flow rate setpoints, used by the "slave" flow controllers.



Master Slave Control Figure 1

The error calculated at each site is fed into the Feedback Controller, which then calculates the necessary flow changes that are processed by the flow controllers when adjusting the gates to balance the water levels in the system. Centralized level control considers the flow rate when suggesting flow changes and likely is moving gates upstream of the site where the level needs to be corrected. This is contrary to local level control, which does not consider the flow rate locally when attempting to correct the local water level error and moves the local gate as opposed to any gates upstream.



Central Level Control Figure 1

Interrelation of Control Components

	Local Flow	Local Level	Central Flow	Central Level
Local Flow	Compatible	Incompatible	Compatible	Compatible
Local Level	Incompatible	Compatible	Incompatible	Incompatible
Central Flow	Required	Incompatible	Compatible	Compatible
Central Level	Compatible	Incompatible	Compatible	Compatible

What is a state space feedback configuration?

The SacMan state space feedback configuration model is primarily comprised of a state vector, a control vector and a gain matrix.

What is the state vector?

The state vector is a column vector containing values that represent the current state of a system. The state vector contains all the errors in the canal. Errors are differences in the target flow set point from the actual flow set point in the canal. The state vector may contain changes in error, prior flow changes or prior errors. The height (number of rows) of the state vector matches the width (or number of columns) in the gain matrix. The state vector actually determines the gain matrix. The state vector contains the following types of entries, change in error, prior flow change and prior error.

- An *error* is the water level minus the set-point
- A *change in error* by definition is the current error minus the prior error.
- A *prior error* is the error from the last control interval.
- A *prior flow change* is the output into the control vector from the last control interval.

What is a gain matrix?

The gain matrix is a matrix that acts as a de-amplifier to the values in the state vector. Columns in the gain matrix are multiplied by the values in the state vector[2]. The result is stored in the control vector. The gain matrix is what allows the sites in the system to be controlled.

How to read the gain matrix. Every gain matrix is at least twice as wide as it is tall. In other words, there are at least twice as many columns as there are rows. Under this control theory there can be multiple types of gain matrices. The most basic gain matrix is a proportional integral (PI) controller. If the matrix is divided into two halves the right portion which is the integral portion is square.

Proportional: The proportional part of the gain matrix, responds to changes in error. If initially there is no error at a site then an error of 5 is detected, your change in error is five and the proportional part of the gain matrix affects the output to the control vector.

In the case of the PI controller the left portion is also square. When you add "lag," or delays to a PI controller, making it a "PIL" controller, then the left portion of the matrix is rectangular and reflects the number of "delays" in the sites of the state vector.

Delays (Lag): Control theory divides time into equal intervals; however, the physical characteristics of pools often differ. Delays compensate for the mismatch between the theory and the real world constraints. Lag occurs when more than

[2] See discussion of matrix operations and matrix multiplication.

one control cycle is needed for a flow-change upstream to correct a water level error downstream. Lags appear as prior flow changes in the state vector and as extra columns of numbers in the proportional section of the gain matrix.

Integral: The integral portion of the gain matrix responds to prior errors. Initially there are no prior errors in the state vector, so this part of the gain matrix does not affect the output. If an error of five is placed into the state vector, your prior error was zero and the integral portion of the gain matrix is not having any effect on the output. If another error of five is placed into the state vector, your change in error is zero but your prior error is five. This means that only the integral part of the gain matrix is used.

What is a control vector?

The control vector is a column vector that contains the results of the multiplication of the state vector and the gain matrix. Under this theory, the values in the control vector represent flow changes. In the situation where lags are used, these flow changes become prior flow changes when they are inserted into the state vector as input during the next control interval.

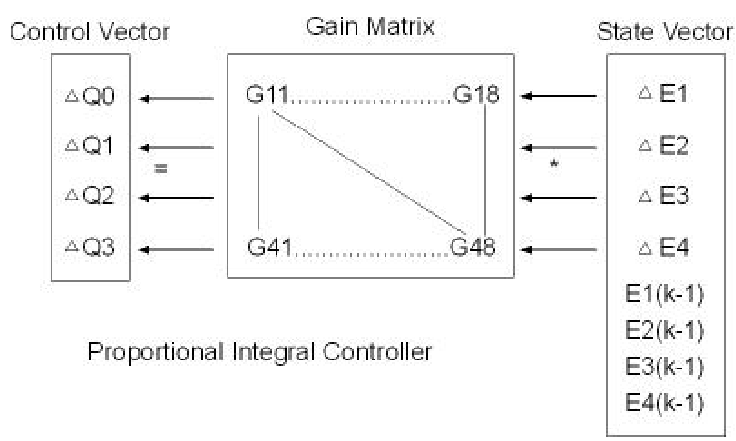


Figure 1: State Space Feedback Configuration using a PI Controller

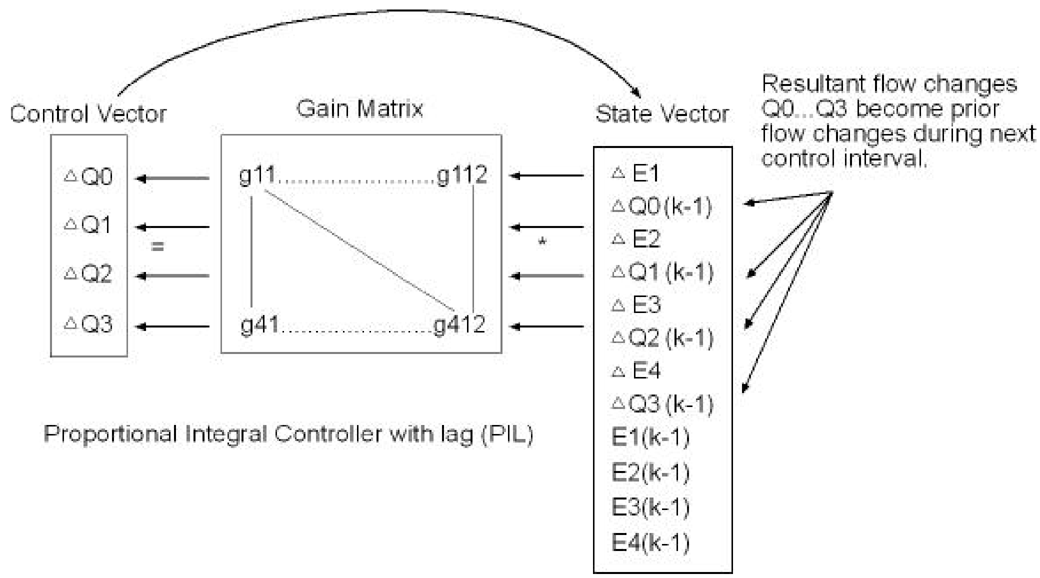


Figure 2: State Space Feedback Configuration using PIL controller.

0.2828	0.4881	0.2963	0.3442	0.0482	0.4097	0.1413	0.4492	0.2073	0.2802
-0.0883	0.5267	0.3198	0.3588	0.0503	0.4226	0.1457	0.4617	0.2131	0.2879
-0.0204	-0.2021	-0.1227	0.3541	0.0496	0.3504	0.1208	0.3449	0.1684	0.2258
-0.0124	-0.0991	-0.0602	-0.1788	-0.0251	0.4344	0.1499	0.4100	0.1892	0.2517
-0.0061	-0.0452	-0.0274	-0.0639	-0.0090	-0.1845	-0.0636	0.4929	0.2275	0.2921
-0.0021	-0.0153	-0.0093	-0.0202	-0.0028	-0.0475	-0.0144	-0.2130	-0.0983	-0.1120
-0.0007	-0.0049	-0.0030	-0.0062	-0.0009	-0.0134	-0.0044	-0.0380	-0.0175	-0.0215

Negative value
Positive value
Change in error
Prior flow change

Figure 3: A partial look at the "propotional" part of a gain matrix.

0.2828	0.4881	0.2963	0.3442	0.0482	0.4097	0.1413	0.4492	0.2073	0.2802
-0.0883	0.5267	0.3198	0.3588	0.0503	0.4226	0.1457	0.4617	0.2131	0.2879
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-0.0007	-0.0049	-0.0030	-0.0062	-0.0009	-0.0134	-0.0044	-0.0380	-0.0175	-0.0215

Each value is used to control the site represented by each row

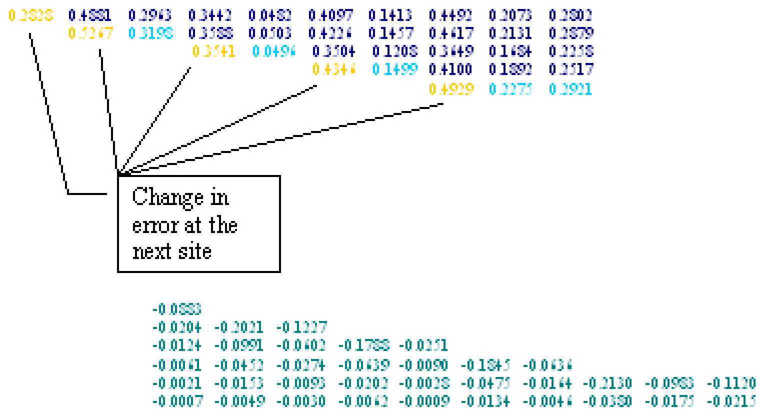
Gain Matrix Illustration 1

0.2828	0.4881	0.2963	0.3442	0.0482	0.4097	0.1413	0.4492	0.2073	0.2802
	0.5267	0.3198	0.3588	0.0503	0.4226	0.1457	0.4617	0.2131	0.2879
			0.3541	0.0496	0.3504	0.1208	0.3449	0.1684	0.2258
					0.4344	0.1499	0.4100	0.1892	0.2517
							0.4929	0.2275	0.2921

Prior Flow change

-0.0883									
-0.0204	-0.2021	-0.1227							
-0.0124	-0.0991	-0.0602	-0.1788	-0.0251					
-0.0061	-0.0452	-0.0274	-0.0639	-0.0090	-0.1845	-0.0636			
-0.0021	-0.0153	-0.0093	-0.0202	-0.0028	-0.0475	-0.0144	-0.2130	-0.0983	-0.1120
-0.0007	-0.0049	-0.0030	-0.0062	-0.0009	-0.0134	-0.0044	-0.0380	-0.0175	-0.0215

Gain Matrix Illustration 2



Gain Matrix Illustration 3