SDI Flush Line Design and Precision Flush Management

Dale H Allred, PE, MS
AES International, PLLC, 1203 E 700 N, American Fork, UT 84003, dale5790@gmail.com

Abstract. *A methodology is presented for designing SDI sub-units with Flush Manifolds using UDU (Ultimate Distribution Uniformity) and the CHLR (Cost Head-Loss Ratio). Using CHLR/UDU design protocols solves for the unknowns, qExtra, qHelped, the qNeutral location along the flush manifold, and the qZero array of distal lateral dead flow locations. Solving for these unknowns not only leads to optimal sub-unit design, it forms the basis for operational and flushing solutions in the field. Implementing CHLR/UDU design protocols for sub-unit SDI irrigation design and leveraging finesse to precision manage sub-unit flushing can dramatically reduce system cost, improve the efficacy of sub-unit flushing compared to traditional solutions, and more correctly assess DU in terms of defined risk.*

Keywords. SDI, Flush Manifolds, DU, Drip Irrigation Design, Submain Design, Manifold Design, Database Drip Irrigation Design Application, Drip Irrigation, Irrigation System Risk Assessment.

Introduction

The first time I ever saw a flush manifold was in 1984. It was of my own design and making. I had gone to Mexico in 1982 and was involved in the very first line source drip irrigation system ever installed in Central Mexico. By 1985 I had designed and installed thousands of acres of drip irrigation in vegetable crops in Central Mexico from Colima to San Luis Potosi to Sinaloa and beyond. These were surface drip tape systems or minimally buried tape systems with the lateral ends such that each dripline could be opened and individually flushed. Within a year of designing and installing that first flush manifold system in 1984, individual line flushing gave way to flush manifolds as the preference for nearly all my growers.

In those days we didn't have the computing power nor the understanding nor indeed the need to optimize flush manifold design. Tape systems were seasonal and if the flushing was not done optimally, it didn't matter so much provided it were done to some extent. The tape would be replaced for the coming season anyway, giving a fresh beginning. Flush line design ended up being really token hydraulic design with many assumptions because the hydraulics were dynamic and complicated. To hopefully insure that each line was properly flushed and avoid dead zones I always called for multiple flush manifolds having flush valves on the ends of each (2, 3, or 4 per each source manifold or submain depending on width). Though not optimally designed, overall flushing throughout the season was greatly improved using these flush manifolds.

Times have changed. Permanent subsurface drip irrigation (SDI) systems require operational viability for ten years or more. It is here that flush manifold design and precision management is critical to system longevity.

Traditional Flush Manifold Design

In 1996, Dr. Charles Burt, a classmate on mine at Utah State University in the mid 1970's, published an article titled "Sizing of Header and Flushing Manifolds for Row Crop Drip" in the May/June edition of Irrigation Journal. This was a call to designers to consider the implications in both header and flush manifold design to achieve tape flow-through velocities of at least 1 fps for tape flushing. Further, there was a call for an increased pressure at the field valve to bring more water and pressure to bear on the subunit to achieve proper drip line flushing. Figures 1 and 2 from that paper are shown here as Figure 1.

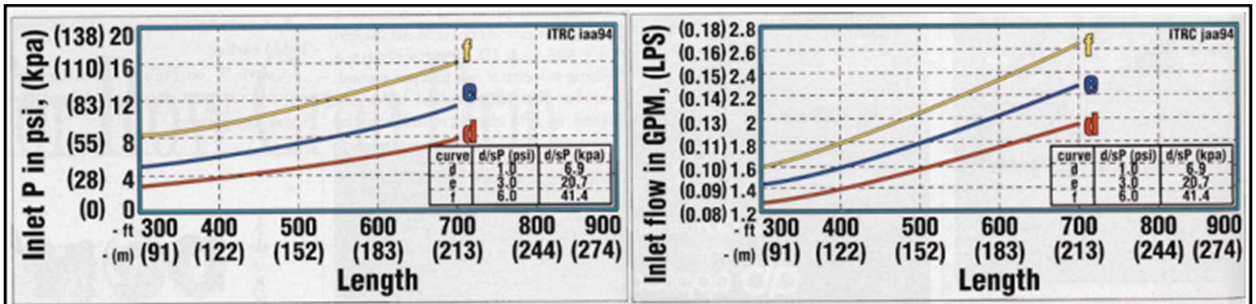

Figure 1. Inlet pressure vs. length for 0.625-inch ID drip tape. Q = 0.22 GPM/100 feet at eight psi (excluding c.v. consideration). Various downstream pressures and fixed flushing flow of one GPM, (0.063 LPS) x = 0.5, zero slope.

Figure 3. Inlet flow vs. length for 0.625-inch ID drip tape. Q = 0.22 GPM/100 feet at eight psi (excluding c.v. consideration). Various downstream pressures and fixed flushing flow of one GPM (0.063 LPS), x = 0.5, zero slope.

Figure 1. Figures 1 & 3 from Charles Burt, “Sizing of Header and Flushing Manifolds for Row Crop Drip”

As can be seen in these figures, required flush flows can easily reach double the operating flows and the corresponding pressures to achieve those flows can easily triple or quadruple depending on the emitter exponent. Logical conclusions would be bigger manifolds, adjustable pressure regulators, and thicker walled tape to withstand high flush mode pressures. Because of the “tremendous variability of design” as noted by Dr. Burt and due to the shear complexity of analysis of the interactive hydraulics of an irrigation subunit in flushing mode, it is difficult to give a single or even multiple rules for header and flush manifold sizing.

Dr. Burt concludes, “Hopefully this article will encourage designers to plan for larger flushing lines as well as larger valves and adjustable pressure regulators at the inlet to the blocks.” These qualitative recommendations have evolved into traditional flush manifold design criteria.

In a day where SDI is proliferating in many crops and extending deep into nearly every clime, it is time for a new more quantitative look at how we design and manage SDI systems, particularly sub-unit flushing.

The Flush and Source Manifold System

The dynamic complexity of sub-unit hydraulics is modeled to find strategic elements that define system operation. AES International, PLLC has developed a database software application to solve for the unknowns, qExtra, qHelped, the qNeutral location along the flush manifold, and the qZero array of distal lateral dead flow locations as shown in Figure 2. Solving for these unknowns not only leads to optimal sub-unit design, it forms the basis for operational and flushing solutions in the field.

In taking a more digital approach to sub-unit design wherein every emission point within the sub-unit is evaluated, two new logical design parameters became apparent. These duo sub-unit design parameters are UDU (Ultimate Distribution Uniformity) and CHLR (the Cost Head-Loss Ratio). CHLR/UDU sub-unit design more logically elucidates design results and more properly defines risk compared to traditional design. CHRL/UDU sub-unit design delivers the most economical field solution for a given risk for both operational and flushing modes.

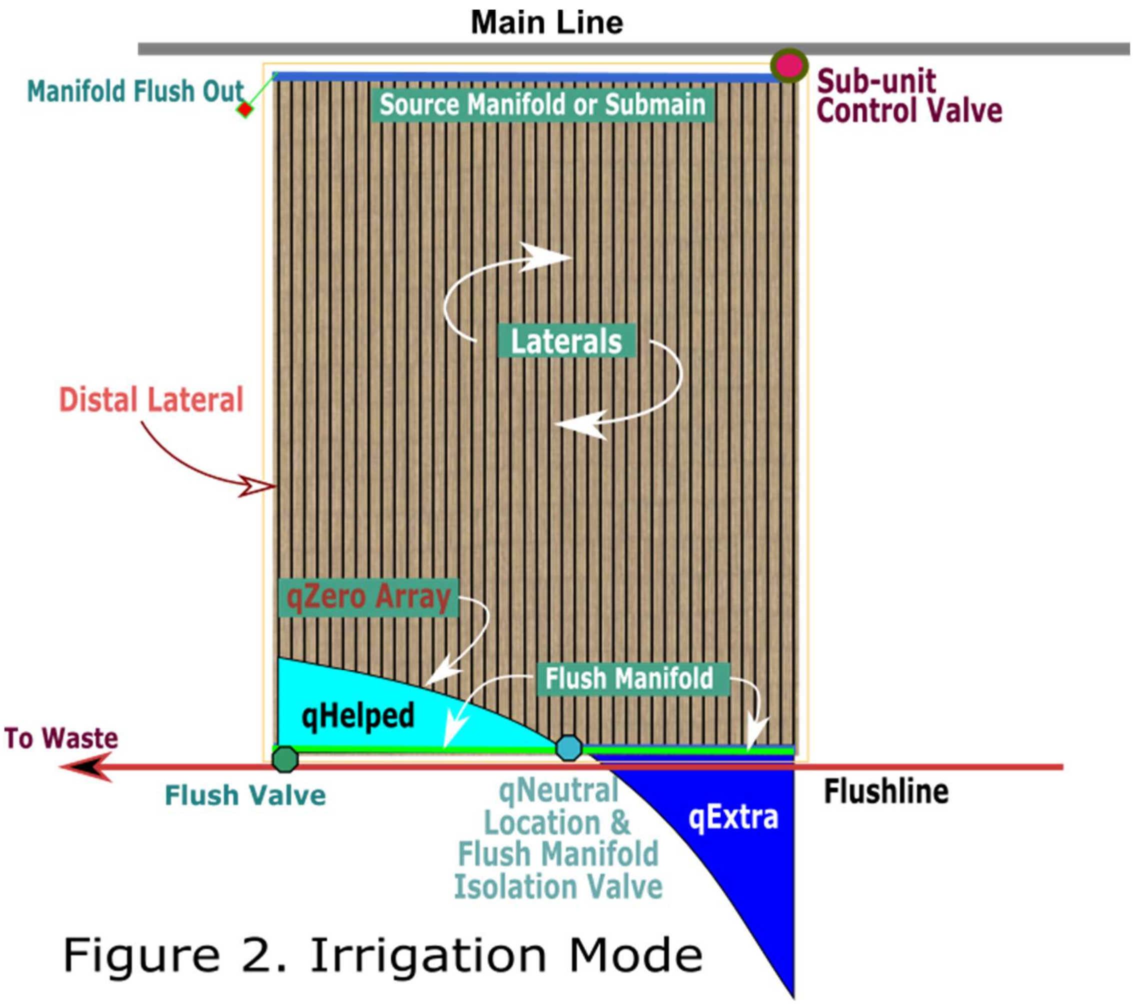

Figure 2. Irrigation Mode

UDU – Ultimate Distribution Uniformity or Ultimate DU

In 1986, standards for structural design changed from ASD (Allowable Stress Design) to USD (Ultimate Strength Design). USD gives the ultimate strength capacity of a structure at no risk. USD is a direct function of a structural configuration with design loads at zero risk. In final design, risk factors are evaluated and applied to define maximum safe loads for the structure. UDU (ultimate DU) in drip irrigation sub-unit design is the equivalent of USD for structural design.

UDU does not include emitter variability risk. Also, as with USD, UDU is a direct function of sub-unit configuration and entrance pressure along with the pressure vs discharge relationship of the emitter to be used. UDU is obtained by evaluating and tabulating the discharge of each emission point in the sub-unit for a given sub-unit configuration and entrance pressure. The sub-unit submain or manifold piping configuration is determined by the value of the CHLR.

For a given value of the CHLR, the corresponding UDU is the ratio of the average of the low ¼ of the sub-unit emission point discharges to the overall average emission point discharge. UDU is a stable measure which is completely reliable to the extent design inputs are reliable. This is the logical design measure to which risk factors can be applied.

This follows the long-standing use of the average discharge of the low ¼ as the practical value for minimum discharge. This was the methodology recommended by the old U.S. Soil Conservation Service (now the NRCS) for field evaluation of irrigation systems.

Jack Keller & David Karmeli also utilized the concept of the average discharge of the low ¼ in their epic development of the expression for the drip irrigation sub-unit design EU (design emission uniformity). EU was the precursor to DU. As part of that development, they came up with is an emitter variability risk factor called the AMDR (Adjusted Manufacturers' Discharge Ratio)

$$\text{AMDR} = \left(1.0 - \frac{1.27}{\sqrt{e}}\ v\right) \qquad \text{Equation 1.}$$

in which

e is 1.0 or the number of emission points per plant
σ is the standard deviation for the emission device at the average emission pressure
qa is the emission flowrate for the emission devise at the average emission pressure
v is the manufacturers' coefficient of variation which is (σ/qa)

A discharge of 1.27σ below qa is precisely the average discharge of the low ¼ based on the standard curve. The AMDR is the ratio of the average discharge of the low ¼ to the overall average discharge at the average emission pressure for an emission device with a manufacturers' coefficient of variation of *v*.

Emitter variability risk as defined by Keller and Karmeli, AMDR, is applied to UDU to get a more logical and precise system design efficiency, DU.

$$\text{DU} = \text{UDU x AMDR} \qquad \text{Equation 2.}$$

in which

DU is Distribution Uniformity
UDU is Ultimate Distribution Uniformity
AMDR is the Adjusted Manufacturers' Discharge Ratio

All other risk factors such as mapping and elevation irregularities, ET miscalculations, potential water source failures, and cyclical extended heat waves are handled within the number of extra daily operational hours build into the system.

CHLR – Cost to Head-Loss Ratio

The Cost to Head-Loss Ratio (CHLR) is made up of a specific measure for the Numerator and a different specific measure for the Denominator as follows:

CHLR Numerator: The CHLR numerator is the cost of increasing the size of a pipe segment to the next larger pipe size versus continuing with the pipe size of the previous pipe segment.

CHLR Denominator: The CHLR denominator is the decrease in the pipe segment head loss from changing to the next larger segment pipe size versus continuing with the previous segment pipe size.

Each pipe segment between laterals making up a source manifold or submain has a different flowrate. The maximum flowrate occurs immediately downstream of the sub-unit control valve. The flowrate diminishes as water leaves, feeding the laterals along the manifold. The minimum flowrate occurs in the last pipe segment feeding the distal lateral.

CHLR/UDU design protocol is an iterative process starting with the distal pipe segment diameter and an initial CHLR target value. A unique UDU sub-unit value will result from a given CHLR target value. The design protocol begins at that distal pipe segment of the manifold with an initial diameter carrying only the distal lateral flowrate. Due to this low distal pipe segment flowrate, the CHRL value will be many multiples above the target value at the start.

Moving along pipe segments from the distal pipe segment toward the control valve, the manifold flowrate increases while the CHLR numerator remains constant. A constant CHLR numerator combined with an increasing CHLR denominator due to escalating manifold flowrates lowers the CHLR toward the target value with each passing pipe segment. When the CHLR target is reached the process calls for a pipe size increase. After the pipe diameter increase the CHLR numerator moves to a new constant value. The CHLR denominator also changes. These changes again result in the CHLR value spiking upward many multiples above the target value for that first increased diameter pipe segment. The process is repeated through all the pipe segments until the control valve is reached.

The optimal economic design solution is where a chosen CHLR delivers the desired UDU. The first design pass results in an initial UDU which is unique to the initial CHLR and sub-unit configuration. If UDU is at the proper level for the project circumstances, design is complete. If UDU is too low, then the CHLR target is increased and the design protocol is repeated. If the UDU is too high, then the CHLR target is reduced and again, the design protocol is repeated.

Sub-unit Flushing Dynamics

The flushing manifold serves a dual function. In flush mode it carries flush water out away from the sub-unit to waste. In irrigation mode, it carries lateral flow-through water from the laterals closest to the sub-unit control valve to the bottom reaches of the laterals furthest from the control valve.

As can be seen in Figure 2, there is a qNeutral location along the flush manifold in which sub-unit hydraulics are such that lateral flow-through water is neutral. All laterals upstream from the neutral location are constantly being flushed during normal irrigation operations. This natural flushing increases to a maximum for the lateral starting closest to the control valve. Conversely, there is a dead flow point for each lateral, defined by the qZero array, from the distal lateral all the way to the qNeutral location along the flush manifold.

For effective sub-unit flushing when opening a valve from the flush manifold to atmosphere, sub-unit hydraulics must be such that flushing occurs on all laterals. The desirable lateral flushing flowrate should be at a maximum on the distal lateral decreasing to a minimum at the qNeutral location.

Contrary to common thought and practice, the worst thing to do for sub-unit flushing hydraulics is to increase the inlet pressure to the sub-unit. That action sends more flow-through water down the rows nearest the sub-unit control valve. It also pushes higher flows through the manifold pipe sections closest to the control valve, burning up manifold pressure needed at the distal end of the manifold. This action exacerbates the problem. Maintaining the control valve outlet pressure the same in flush mode as in irrigation mode, or even reducing the pressure, would provide better flushing hydraulics.

A low-pressure swing check valve is installed in the line between the Flush Manifold and the Flushline near the distal end. See Figure 3. This allows for multiple sub-units to be flushed using a single Flushline and a single Flush Valve hydraulic closing/opening line. A hydraulically operated valve which is either opened or close is placed in the flush manifold precisely at the qNueutral location. This is the Flush Manifold Isolation Valve shown in Figure 3. A second hydraulically operated valve is placed right after the check valve. This is the Flush Valve shown in Figure 3. With the Flush Valve opened, flush water can flow from the flush manifold into the Flushline and then on to atmosphere. Both the Flush Manifold Isolation Valve and the Flush Valve can be operated remotely via a ½" Sch 40 PVC hydraulic line.

Sub-unit Flushing Procedures

The two hydraulically operated valves can be opened and closed multiple times to create localized surge flushing to take further advantage of momentary elevated local pressure differentials across the sub-unit set up by using CHLR/UDU design protocols.

1. Close the Flush Manifold Isolation Valve. See Figure 3, 1st Flushing Mode
    a. The source manifold pressure will initially increase down the line toward the distal end. This will cause a surge in lateral flow-through just downstream of the Isolation Valve giving a good flushing to the laterals in that section.

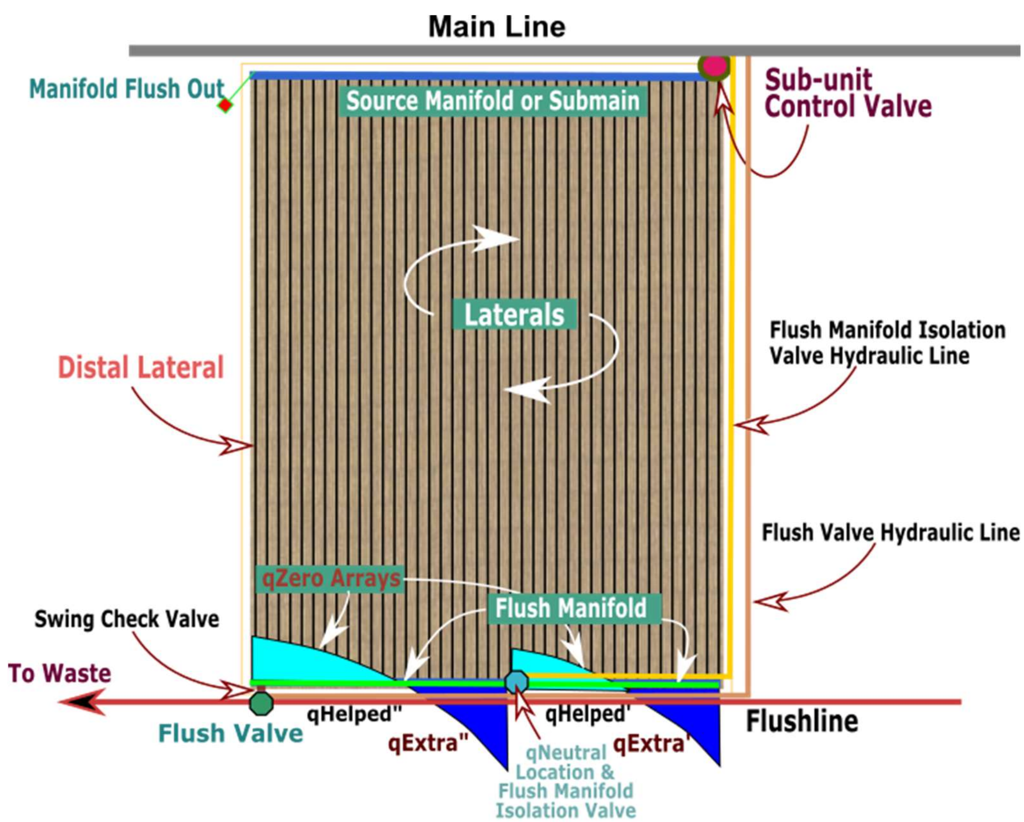

Figure 3. 1st Flushing Mode

b. New dual gExtra and qHelped equilibrium hydraulics will emerge.
c. Leave this configuration until after the system comes to equilibrium.

2. Open the Flush Valve. See Figure 4.
   a. This will reverse the previous hydraulics causing an initial surge of flow-through flushing through the distal laterals, which will decrease to a minimum just downstream of the Isolation Valve where before Flush Valve opening the highest lateral flow-through occurred. This creates localized cycle flushing.
   b. The sub-unit hydraulics will gradually come to equilibrium and approach the steady state flush designed for the manifold/flushing manifold sub-unit configuration together with the flush line configuration from the distal end flush valve to where the Flushline flow outlets to atmospheric pressure.
   c. In this configuration a pressure differential will reach a maximum across the Flush Manifold Isolation Valve.

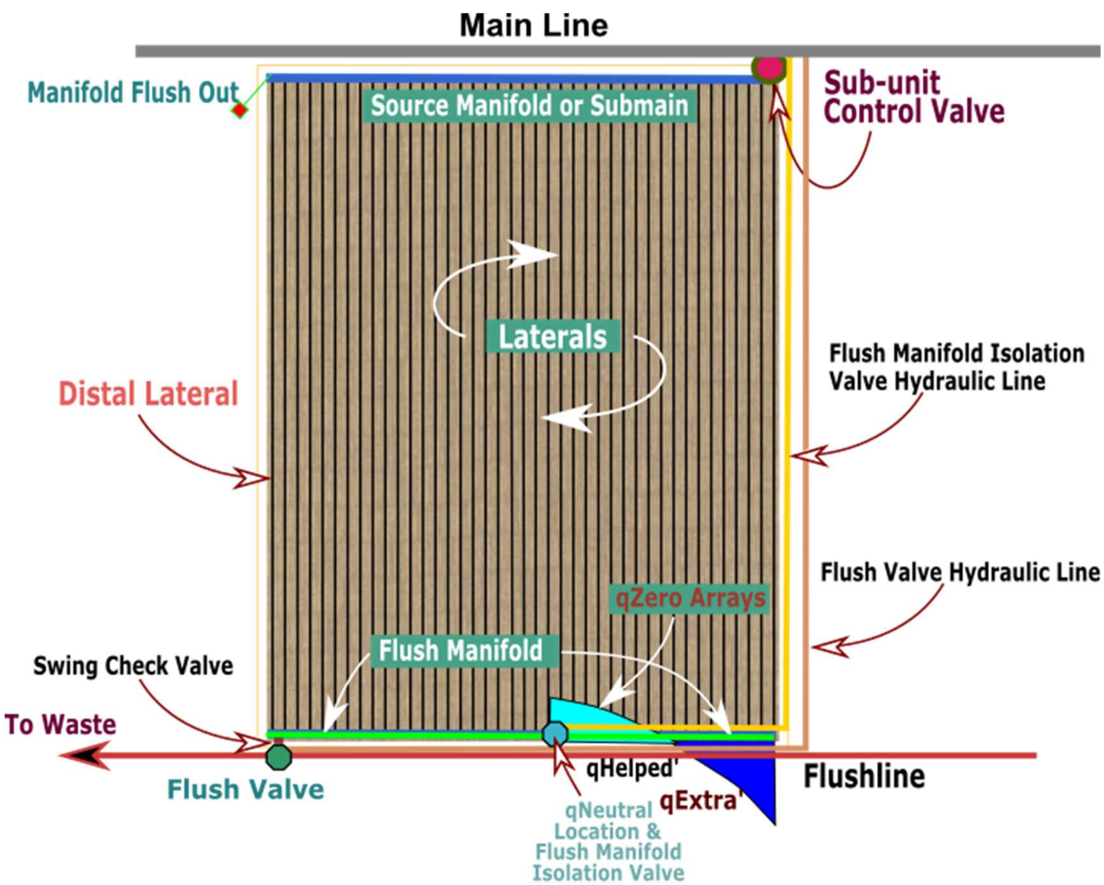

Figure 4. 2nd Flushing Mode

3. Open the Flush Manifold Isolation Valve. See Figure 5.

a. This will cause an initial surge of flow-through flushing from the laterals just upstream from the isolation valve in response to the elevated pressure differential.
b. This flushes the irrigation mode qExtra section laterals that have the least lateral flow-through during normal irrigation operation.

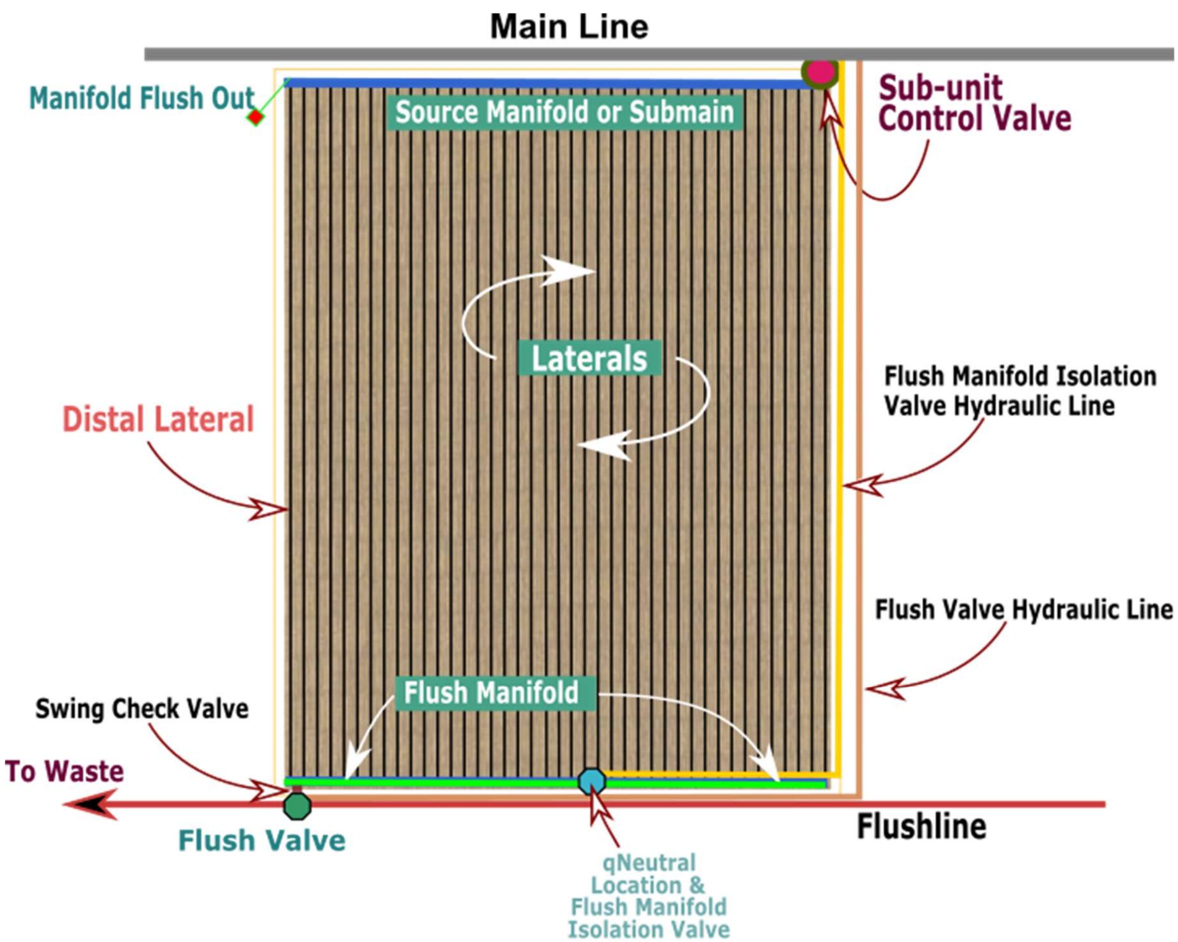

Figure 5. 3rd Flushing Mode

4. Close the Flush Valve to return system to irrigation mode.
5. The flushing system can also be configured and carried out for multiple sub-units.

Conclusion

Implementing CHLR/UDU design protocols for sub-unit SDI irrigation design and leveraging system operation finesse enabled by the design protocols can dramatically reduce system cost, improve the efficacy of sub-unit flushing compared to traditional solutions, and more correctly assess DU in terms of defined risk.

References

Burt, CM. 1996. Sizing of Header and Flushing Manifolds for Row Crop Drip. Irrigation Journal. May/June p 24-27.

Keller, J and Karmeli, D. 1975. Trickle Irrigation Design. Chapter 4 in
Selection and Efficiency of Emitters, Rain Bird Sprinkler Manufacturing Corporation