GUAYULE – IRRIGATION MANAGEMENT

by

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As members of the Master's Committee, we certify that we have read the thesis prepared by Varshaa Punitharaj, titled *Guayule – Irrigation Management* and recommend that it be accepted as fulfilling the dissertation requirement for the Master's Degree.

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Units

m - meters

mm - millimeter

μm - micrometer

GPM – Gallons per minute

GPH or g/h – Gallons per hour

GPD – Gallons per day

sq.ft – Square feet

gps – Gallons per second

cm – centimeter

hrs – hours

min – minute

l - litre

l/h – litre per hour

l/min – litre /minute

cu.m/hr or m^3/hr – cubic meter per hour

cu.m/sec or m^3/sec – cubic meter per second

cu.m or m^3 - cubic meters

l/min – litre/minute

m/s – meter per second

psi – pound per square inch

in – inch

ft – feet

no.s – Numbers

mg/L – milligrapm per litre

g – gram

mL – milli Litre

ppm – parts per millions

kg/m^3 - kilogram /meter cube

eq/L – equivalents per litre

Bv//h – Bed Volume / hour

meq/L – milli equivalents per litre

ha – hectare

Acre- acre

lbs – pounds

TDH – Total Dynamic Head in ft

Abstract

Guayule (*Parthenium argentatum*) is a drought-tolerant shrub recognized for its potential as a sustainable source of natural rubber. Efficient water and nutrient management are crucial for maximizing guayule productivity for Bridgestone this be broader to include state growers in Arizona, particularly in arid and semi-arid regions. This study investigates the implementation of a drip irrigation system for guayule cultivation, incorporating clogging prevention methods and UAN32 (urea-ammonium nitrate) fertigation.

The drip irrigation system design, including emitter selection, lateral spacing, and operating pressures, is optimized for guayule cultivation. Various clogging prevention strategies are evaluated, such as proper water filtration, periodic flushing, and the use of chemical treatments like acid injections. Additionally, the study explores the integration of UAN32 fertilizer through the drip irrigation system, allowing for targeted and efficient nutrient delivery.

The results demonstrate that a well-designed drip irrigation system, coupled with effective clogging prevention techniques and UAN32 fertigation, can significantly improve water and nutrient use efficiency, leading to enhanced guayule growth and rubber yield. Specific clogging prevention methods, such as ion exchange process and acid injection, and physical methods like automated flushing valves, are found to be effective in maintaining system performance and longevity but are cost prohibitive for growers. The initial goal was to design a gravity fed system, however, given the water quality in the region, pressurized drip systems are required. The water in central Arizona has 500 to 760 ppm of TDS whereas the MCL is 500ppm.This study provides valuable insights for guayule growers and researchers, enabling them to implement sustainable and efficient irrigation and fertigation practices. It contributes to the successful cultivation of guayule as a viable alternative source of natural rubber while promoting water and nutrient conservation in arid and semi-arid regions.

Chapter 1 Introduction

In the arid regions of the southwestern United States, agriculture heavily relies on irrigation to overcome water shortages. However, ongoing drought conditions and the increasing allocation of water supplies for industrial and municipal purposes have posed significant challenges to irrigated agriculture in this region. Poor water quality can have significant negative impacts on drip irrigation systems such as emitter clogging due to high levels of minerals, sediment, or organic matter (9). Furthermore, the longevity and effectiveness of the irrigation equipment decreases, necessitating more frequent replacements. Fluctuations in pressure and flow rate can result in inconsistent water application and salinity issues. Poor water quality can create a favorable environment for the growth of pathogens and pests. To address poor water quality, water treatment or filtration systems are implemented (8). Filtration methods such as sand filters, screen filters, or media filters can remove sediments and debris from the water. Additionally, chemical treatments or technologies like reverse osmosis or ultrafiltration can help remove impurities and improve water quality. Regular water testing can provide insights into specific water quality parameters, to take appropriate measures for treatment or mitigation.

There is a pressing need for the implementation of efficient crop water management practices and the introduction of alternative agricultural crops that are both low water-use and drought-tolerant while offering economic viability. Among these alternative crops, guayule *(Parthenium argentatum,* A. Gray) has emerged as a promising solution for farmers in Arizona. This perennial shrub, native to the Chihuahuan Desert, not only thrives in low water conditions but also produces high-quality natural rubber, making it ideal for manufacturing commercial-grade tires.

Additionally, guayule yields resin with numerous potential applications and bagasse that can be converted into biofuel or high-density composite boards. By integrating guayule into the crop mix, Arizona farmers aim to alleviate the strain of water shortages and create a sustainable and resilient agricultural industry (1). However, successful guayule cultivation requires careful water management during the initial growth period and the adaptation of irrigation techniques in response to the southwestern U.S. desert's challenging environment. Moreover, ongoing research aims to develop drought-tolerant guayule varieties that could further reduce water requirements and guarantee its economic potential in the face of ongoing water scarcity (1).

Studies have shown that guayule has the remarkable ability to achieve rubber yields with as little as 500 mm of applied water per year (2). It has been found that the plant can survive on just a few irrigation schedules per year. However, recent research suggests that rubber productivity can be further optimized with annual water applications in the range of 700 mm (1, 2). By utilizing irrigation simulation models, farmers can accurately determine the water requirements of guayule crops at different stages of growth. This knowledge allows for precise irrigation scheduling, ensuring that water is applied when the plant needs it the most, thereby maximizing rubber productivity while minimizing water usage(4). The use of these models also helps in avoiding over-irrigation, which can lead to water wastage, nutrient leaching, and increased production costs. By adopting an optimized irrigation strategy based on these simulation models, farmers can not only conserve precious water resources but also enhance the economic feasibility of guayule cultivation in the desert (6, 7).

Numerous growers in Arizona use flood irrigation. The goal is to encourage them to switch to drip systems, either gravity fed or pressure driven systems depending on the quality of the irrigation water. However, for all types of drip irrigation systems, clogging is a typical problem. Mineral deposits, silt, debris, and algae can readily block the drippers' small channels, which control the flow of water. This may result in an uneven distribution of water and disturbance of the flow rate, which could lower crop health and irrigation efficiency (8). Regular system flushing or back-flushing methods can aid in clearing out any collected sediments or particles. Maintenance strategies for farmers are important to avoid irrigation problems.

In this thesis, we will explore the significance of guayule as an alternative crop in the southwestern U.S. desert. The water management practices necessary for its successful cultivation, including clogging prevention strategies in the drip irrigation systems and providing sufficient nutrients for rubber biosynthesis and yield formation, will be examined. Additionally, the potential benefits guayule offers to farmers and the region's overall agricultural industry will be discussed. The evaluation will also include a comparison of gravity-fed drip systems versus pressure-fed drip systems.

Chapter 2 Background

1. Guayule irrigation strategies

In direct seed cultivation, to facilitate the germination and establishment of the guayule crop, irrigation is a must for the initial two weeks following planting. The field is planned to be wetted each day, ensuring the necessary moisture for successful germination. The total amount of water applied during this period was measured at 284 millimeters especially for summers (2). After germination the spray system is removed and flood irrigation is used. The alternative is to install drip irrigation immediately, decreasing the amount of water loss during this critical period prior to germination and then use the drip throughout the growth period. Drip irrigation systems provide a controlled and consistent supply of water to agricultural fields, allowing plants to receive the necessary moisture throughout their growth cycle. In case of ratooned guayule, the irrigation cycle can be started with a direct drip system.

There have been three recent studies regarding the irrigation optimization of guayule. Time zero for these studies was after establishment. The research paper by Elshikha et al (1) focused on calibrating the WINDS model to simulate evapotranspiration and water content in the soil profile for guayule crops under furrow irrigation. Utilizing data from a furrow irrigated two-season guayule experiment in Arizona, the study developed segmented curves for guayule basal crop coefficient, canopy cover, crop height, and root growth. The calibrated model simulated soil moisture content in seven soil layers, demonstrating the effectiveness of the WINDS model in accurately representing guayule growth under furrow irrigation conditions. This research provided valuable insights into optimizing water use and irrigation strategies for guayule cultivation, highlighting the importance of tailored irrigation practices for the growth and development of guayule crops utilizing furrow irrigation techniques.

Another study focused on evaluating the response of guayule, with ratoon-cropping potential, to different irrigation treatments (2). This research aimed to assess dry biomass, rubber and resin contents, rubber and resin yields, and water productivity of guayule under varying irrigation levels. Irrigation treatments for this paper included subsurface drip irrigation at 50%, 75%, and 100% replacement of crop evapotranspiration (ETc) and furrow irrigation at 100% ETc replacement. Results indicated that dry biomass increased with total water applied, but rubber and resin content decreased with higher water levels. The study found that subsurface drip irrigation at 75% ETc replacement was most effective in maximizing rubber and resin yields and water productivity for both locations and soil types. Ratooned guayule required less water and yielded higher biomass, rubber, and resin compared to directly seeded crops (2).

The latest study evaluated different deficit irrigation strategies on two guayule cultivars (AZ2 and AZ6) grown for 22.5 months in Arizona, with total water applied ranging from 2780 mm (full irrigation) to 1084 mm (highest deficit) (41). Dry biomass, rubber yield, and resin yield generally increased linearly with increasing irrigation, but a treatment applying every other irrigation of the control resulted in statistically equivalent yields to the control with 36% less water applied. Plant height and cover fraction were greater at higher irrigation levels and for AZ6 compared to AZ2. While percent rubber generally decreased with more irrigation, percent resin did not change significantly. However, AZ2 had higher percent rubber, percent resin, rubber yield, resin yield, and water productivity than AZ6. Among the deficit treatments evaluated, applying every other irrigation maximized water productivity without yield penalties, offering the best strategy to increase guayule water productivity (41).

2. Drip Irrigation Systems.

While there are many other irrigation methods used worldwide, drip irrigation is becoming more and more common for crop irrigation. The main advantage of drip irrigation is its high efficiency in water use. By delivering water directly to the roots, it minimizes losses due to evaporation or deep percolation, resulting in a significant reduction in water consumption compared to traditional irrigation methods. In addition to water savings, drip irrigation also promotes high irrigation uniformity (10). The system is designed to deliver water uniformly across the field, ensuring that all plants receive an equal amount of water. This helps to prevent overwatering in some areas and under watering in others, improving crop health and yield.

Flow through the pipes is designed to have turbulence. The purpose of turbulent flow emitters is to create vortices in the flow channel. Since energy dissipates in turbulent eddies rather than in tiny diameter tubes or orifices, turbulent flow emitters have the advantage of having a greater diameter flow route. Consequently, they are less prone to plug than emitters with laminar flow or orifices.

To design a drip irrigation system, the analysis is carried out using the Darcy-Weisbach equation. The Darcy-Weisbach analysis provides information regarding the friction loss (h_f). It allows calculating the pressure drops that will occur due to frictional effects as water flows through the pipe network, including the main lines, submains, and lateral lines leading to the emitters (40). By accurately quantifying these friction losses, the analysis guides crucial decisions such as proper pipe sizing, emitter selection, and overall system hydraulics to ensure the design can deliver the targeted flow rates and pressures throughout the drip system using only the available head. Accounting for realistic friction losses is vital for optimizing the energy efficiency and uniform water distribution across the field (40, 25). Equation 1 is the Darcy- Weisbach equation,

$$h_f = \frac{KCLQ^m}{D^{2m+n}} \qquad (1)$$

where, K = Friction factor that depends on pipe material and that computed using K = 0.811(f/g)

f= friction factor (for turbulent flow), $f = 0.32\ N_R^{-0.25}$ and

g is gravitational acceleration (9.81 m/s^2)

L = Length of the pipe, m

Q = Discharge, l/min

D = Diameter of pipe, mm and

C, m and n = Constants

The values for the constants C, m, and n are 1.235, 2, and 1 respectively (25) for turbulent flow in the pipes for drip systems

Gravity-driven drip irrigation systems, as the name suggests, rely solely on the force of gravity to transport water from an elevated water source to the crop fields. These systems are typically simpler in design and require minimal energy input, making them cost-effective and environmentally friendly (25). The capital estimate for an N-Drip system in 2022 was $15,000 per acre. The water source, such as a reservoir or a water storage tank, is positioned at a higher elevation than the fields, allowing the water to flow downward through a network of pipes and emitters.

Accurately quantifying the slope or gradient of the field's surface is crucial for properly designing a gravity-fed drip irrigation system. The slope influences the water pressure and flow rates that can be achieved through the drip lines. By calculating distinct slope parameters for the topsoil layer specifically, the irrigation setup can be optimized to account for potential variations in soil properties and topography near the surface.

For drip irrigation systems to operate efficiently, excellent emitter uniformity is a must. The evenness of water output from each dripper or emitter in the system is referred to as emitter uniformity. When operating under the same pressure, ideal emitter uniformity means that every emitter gives the same flow rate per unit of time (9). In actuality, partial blockage and manufacturing flaws cause some variations. Crop yields are lowered by inconsistent irrigation due to low emitter uniformity. The main causes of non-uniformity include particulate matter clogging, chemical precipitation or algae development, pressure variations caused by friction losses along laterals, inadequate system design, and non-uniform emitter manufacturing(2). For high-efficiency drip irrigation to continue, outstanding emitter uniformity must be maintained through careful monitoring, maintenance, and system design. The emitter uniformity is checked using the equation,

$$EU = 100\left(1 - \frac{1.27}{\sqrt{Ne}}\,(Cv)\right) Qmin/Qavg \qquad (2)$$

Where EU = design emission uniformity, %

N_e = Number of point source emitters per emission point

Cv = manufacturer's coefficient of variation from the figure.

Q_{min} = Minimum emitter discharge rate in the system, l/h

Q_{avg} = Average or design emitter discharge rate, l/h. Then to get to know about the pressure variation along the pipeline use,

$$Pd = Pu - K\,(h1 \pm \Delta Z) \qquad (3)$$

Where, P_d, P_u = Pressure at downstream and upstream positions, kPa

h1 = Energy loss in the pipe, m

Where h1 = FH1+M1

F = Constant, f (number of outlets and method used to estimate H1)

H1 = Friction loss, m

M1 = Minor losses through fitting (generally assumed as 0)

ΔZ = Elevation difference, m

K = 9.81

However, the effectiveness of gravity-driven systems is limited by the elevation difference between the water source and the crop fields, as well as the distance over which the water needs to be transported. Additionally, some spots in these systems may struggle to maintain consistent water pressure, particularly in larger or sloping fields, potentially leading to uneven water distribution (25).

Furthermore, to determine the feasibility of implementing gravity-fed drip irrigation systems, it is crucial to assess the water quality that will be utilized. This involves conducting various water quality tests, such as total solids test, ion chromatography, and total organic carbon tests, to identify the composition of the water and any potential contaminants present. Based on the results of these tests, it will be possible to determine if supplemental equipment is needed to remove specific components from the water before it is used for irrigation. Additionally, understanding the water quality will also inform the type of maintenance required for the system and the frequency at which it should be performed to ensure optimal performance and longevity. By conducting thorough water quality assessments and taking appropriate measures based on the findings, the gravity-fed drip irrigation system can be effectively designed and maintained for efficient and sustainable water use in agricultural practices.

In water, total solids consist of suspended and settle able solids in addition to dissolved solids. All of the dissolved and suspended organic and inorganic particles found in water are referred to as total solids (TS). Arizona is known for its arid climate and scarce water resources, which can significantly impact the quality of available water supplies. According to the water quality report published by the state, one of the major concerns is the high levels of total dissolved solids (TDS) present in many water sources across Arizona (19). TDS refers to the combined content of inorganic salts and small amounts of organic matter dissolved in water. These dissolved solids can originate from natural sources, such as the weathering of rocks and soil, or from human activities like agricultural runoff, industrial effluents, and wastewater discharges (19, 20). The particles of calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions that pass through a filter with holes that are about 2 microns (0.002 cm) in size make up the dissolved solids in stream water. The presence of high TDS levels in water can have various implications. Elevated TDS concentrations can cause scaling and clogging in household plumbing systems and appliances, leading to increased maintenance costs and reduced lifespan of equipment (20). Thus, it's critical to monitor and manage TS to ensure that treatment is effective and effluent discharge limitations are met. In both natural water bodies and water treatment facilities, TS is a crucial water quality indicator that is routinely assessed.

The liquid chromatography method known as ion chromatography (IC) is used to separate and measure ions according to how they interact with a column that is loaded with resin. It has the ability to detect and quantify the amounts of anions (negatively charged ions) and cations (positively charged ions) in a liquid sample. A conductivity detector measures the concentrations of the separated ions as they come out of the column. An IC chromatogram produced by the detector has peaks that represent the various ions' retention periods (29). The ions can be recognized by comparing the retention durations to established standards. The quantitative analysis is made possible by the peak regions' proportionality to the ion concentrations.

As the water sample is irrigation water it might contain dissolved mineral salts, such as calcium, magnesium, iron, and carbonates, which can precipitate and form scale deposits inside the narrow pathways of drip emitters and tubing. Additionally, certain ions like iron and manganese can promote the growth of bacterial biofilms, further exacerbating the clogging problem (26).

TOC analyzers, such as the Shimadzu brand, employ the combustion catalytic oxidation method to determine the total organic carbon content in a sample. This method involves the complete oxidation of organic compounds present in the sample, converting them into carbon dioxide (CO_2). The resulting CO_2 is then measured using a highly sensitive non-dispersive infrared (NDIR) detector, which provides an accurate quantification of the organic carbon content (32). Secondly, the instrument acidifies the sample with a strong acid, such as phosphoric acid, to convert the inorganic carbon species (carbonates and bicarbonates) into carbon dioxide. This carbon dioxide is then measured using the NDIR detector, providing the inorganic carbon concentration. Then the inorganic carbon (IC) value is subtracted from the total carbon (TC) value to obtain the total organic carbon (TOC) concentration in the sample generally (33).

This TOC analyzer is used quantify the inorganic carbon present in water samples (32). Inorganic carbon refers to the carbon present in the form of carbonates, bicarbonates, and dissolved carbon dioxide. This measurement can help in understanding the presence of inorganic carbon that possibly reacts with other cations present in the water eventually leading to scale formation and corrosion issues.

Chapter 3 Materials and Methods

1. Irrigation Water Sample

The water sample was collected from the pump that fills water in the open channel. The main source of this water is a pond located near the farmland at the Bridgestone Eloy farm in Arizona. The open channel transports the pond water to the pumping station, where it is then pumped through the irrigation system for distribution across the farm's fields. By collecting the sample directly from the pump, it represents the water quality being applied for irrigation purposes after being drawn from the pond source through the open channel conveyance system.

2. Total Dissolved Solids

The Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) test for a water sample was conducted in the laboratory following a systematic procedure. The water sample was collected and filtered through pre-weighed filter papers of 2 μm pore size to separate the suspended solids for TSS analysis. The filter paper was dried and weighed to calculate the TSS concentration. The conductivity meter is used to measure the TDS in the water sample. The meter is calibrated using two calibration standards (concentrated and diluted) and the water sample is tested. The value obtained is 810.1 μS/cm, which is then converted to 518.465 mg/L of TDS. These results provide valuable information about the quality of the water sample in terms of its dissolved and suspended solid content, crucial for assessing water purity and potential sources of contamination (Table 1).

Total Suspended Solids	0.093333	mg/L
Total Dissolved Solids	518.465	mg/L

Table – 1 Total solids experiment output

3. Ion Chromatography

The IC was a capillary IC system (ICS-5000; Thermo Fisher Scientific) with two capillary pumps, a conductivity detector, a column heater, an AS-AP auto-sampler, two six-port valves, and a 50 L sample loop. The EGC-KOH eluent generator created the mobile phase. Using the ACES 300 suppressor, background conductivity was suppressed. Before the conductivity detector, a CRD 200 carbon dioxide removal device was placed. Software called Chrome Leon 6.80 was used to gather and process chromatographic data. To capture any potential contaminants, an anion trap column ATC-HC column (50 × 4 mm ID) was positioned on the water feeding line in this setup (29). The standards used are the anion seven standard and cation six standard. The fluoride, chloride, nitrite, bromide, nitrate, phosphate, and sulfate are quantified using the anion standard (Fig. 1.7). Whereas lithium, sodium, ammonium, potassium, magnesium, and calcium are done with cation standards (Fig 1.8). The standards are diluted in 5 serial fold using distilled water and the same goes for sample.

No.	Time min	Peak Name	Peak Type	Area µS * min	Height µS	Amount ppm
1	2.29	Fluoride	BMB	0.206	2.543	0.4803
3	2.99	Chloride	BM	30.513	318.984	96.3330
4	3.19	Nitrite	M	0.236	1.526	1.2923
6	4.10	Sulfate	M	36.392	272.764	157.5286
7	4.54	Nitrate	Mb	17.823	136.954	97.6420
TOTAL				85.17	732.77	353.28

Table 2 – IC anions concentrations

No.	Time min	Peak Name	Peak Type	Area µS * min	Height µS	Amount ppm
3	4.15	K	M	34.253	176.944	51.9771
6	6.63	Mg	M	38.595	92. 529	43.1378
TOTAL				72.85	269.47	95.11

Table 3 – IC cations concentrations

4. Total Organic Carbon/Total Inorganic Carbon

The Shimadzu TOC and TIC analyzers are designed to accurately measure the total carbon content in organic and inorganic compounds, providing crucial information for a wide range of applications. These analyzers offer high sensitivity and accuracy, enabling users to obtain precise results for TOC and TIC analysis (33). TOC/TIC calibration curve on a Shimadzu analyzer is created, by preparing a series of calibration standards from stock solutions of organic (e.g., potassium hydrogen phthalate) or inorganic (e.g., sodium carbonate/bicarbonate) carbon compounds spanning the desired concentration range. Then analyze the standards from lowest to highest concentration, plotting the instrument response against the known concentrations. It is verified for better linearity with a correlation coefficient ≥0.995. This is used calibration curve to quantify unknown samples by interpolating their response (table 2).

System	TOC-TN
S/W Version	1
User	VARSHAA
Date/Time	########

[System]
Instrument
Options TOC/ASI/IC Unit/TN/

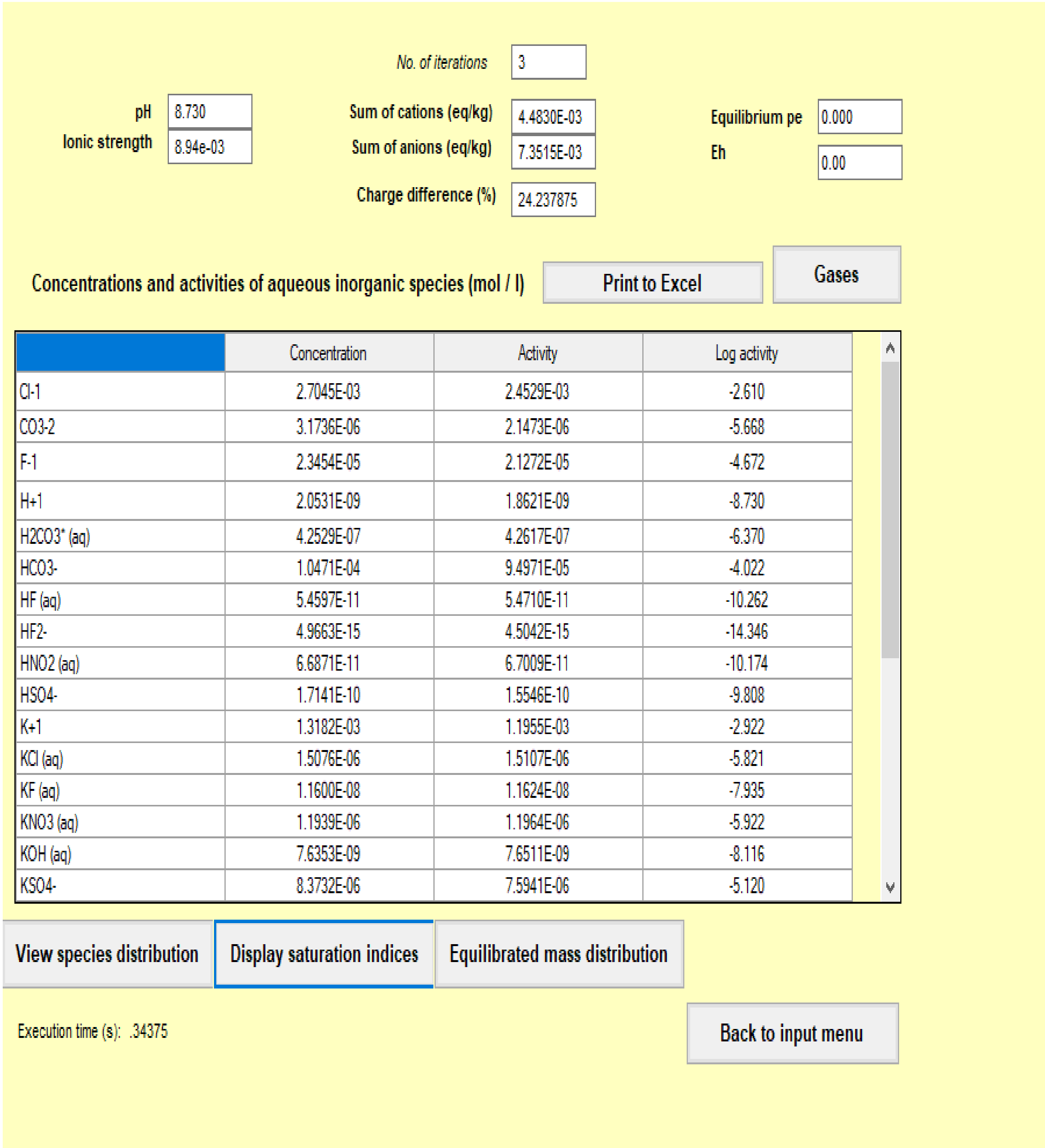
[Data]

Type	Anal.	Sample Name	Sample ID	Result(IC)	Unit	Vial		Date / Time
DI	IC	Untitled	Untitled	0	ppm	1		
DI	IC	Untitled	Untitled	0	ppm	1		
Standard	IC	Untitled	Untitled	50	ppm	2, 3, 3,3 ,3		
DI	IC	Untitled	Untitled	0.07352	ppm	6		
W1	IC	w1	Untitled	6.673	ppm	4		
W2	IC	w2	Untitled	5.187	ppm	5		

Table 4 - Results obtained from Shimadzu instrument for Inorganic carbon

5.Visual MinTEQ

It is a chemical equilibrium modeling software used to calculate the distribution of chemical species in aqueous systems. This software is used to obtain the charge balance and saturation index for the species present in the water sample. The ions and their concentrations along with water pH and temperature values are input in the software to run the analysis. The output values obtained from the analysis include the total cations and anions present (Fig 3.1, 3.2 and table 5) in the sample including their charge difference. Also this saturation index denotes that the species are under saturated (Fig 3.3).



	Concentration	Activity	Log activity
Cl-1	2.7045E-03	2.4529E-03	-2.610
CO3-2	3.1736E-06	2.1473E-06	-5.668
F-1	2.3454E-05	2.1272E-05	-4.672
H+1	2.0531E-09	1.8621E-09	-8.730
H2CO3* (aq)	4.2529E-07	4.2617E-07	-6.370
HCO3-	1.0471E-04	9.4971E-05	-4.022
HF (aq)	5.4597E-11	5.4710E-11	-10.262
HF2-	4.9663E-15	4.5042E-15	-14.346
HNO2 (aq)	6.6871E-11	6.7009E-11	-10.174
HSO4-	1.7141E-10	1.5546E-10	-9.808
K+1	1.3182E-03	1.1955E-03	-2.922
KCl (aq)	1.5076E-06	1.5107E-06	-5.821
KF (aq)	1.1600E-08	1.1624E-08	-7.935
KNO3 (aq)	1.1939E-06	1.1964E-06	-5.922
KOH (aq)	7.6353E-09	7.6511E-09	-8.116
KSO4-	8.3732E-06	7.5941E-06	-5.120

Fig 3.1 Output from Visual MinTEQ

A	B	C
Componen	% of total concentratio	Species name
CO3-2	2.854	CO3-2
	1.581	MgCO3 (aq)
	1	MgHCO3+
	0.013	Mg2CO3+2
	94.169	HCO3-
	0.382	H2CO3* (aq)
F-1	92.775	F-1
	7.179	MgF+
	0.046	KF (aq)
Cl-1	99.534	Cl-1
	0.411	MgCl+
	0.055	KCl (aq)
NO2-1	100	NO2-1
SO4-2	88.374	SO4-2
	11.116	MgSO4 (aq)
	0.511	KSO4-
NO3-1	99.924	NO3-1
	0.076	KNO3 (aq)
K+1	99.165	K+1
	0.113	KCl (aq)
	0.63	KSO4-
	0.09	KNO3 (aq)
Mg+2	88.745	Mg+2
	0.099	MgCO3 (aq)
	0.063	MgHCO3+
	0.087	MgOH+
	0.102	MgF+
	0.629	MgCl+
	10.273	MgSO4 (aq)

Table 5 Various Speciation distribution

Distribution of components between dissolved, sorbed and precipitated phases

(Concentrations in molal)

Component	Total dissolved	% dissolved	Total sorbed	% sorbed	Total precipitated	% precipitated
Cl-1	2.7172E-03	100.000	0	0.000	0	0.000
CO3-2	1.1120E-04	100.000	0	0.000	0	0.000
F-1	2.5281E-05	100.000	0	0.000	0	0.000
H+1	1.0106E-04	100.000	0	0.000	0	0.000
K+1	1.3293E-03	100.000	0	0.000	0	0.000
Mg+2	1.7743E-03	100.000	0	0.000	0	0.000
NO2-1	2.8090E-05	100.000	0	0.000	0	0.000
NO3-1	1.5747E-03	100.000	0	0.000	0	0.000
SO4-2	1.6398E-03	100.000	0	0.000	0	0.000

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Fig 3.2 Mass distribution table

Mineral	log IAP	Sat. Index (=log IAP - log Ks)	Stoichiometry and mineral components							
Artinite	5.846	-4.113	-2	H+1	2	Mg+2	1	CO3-2	5	H2O
Brucite	14.487	-2.953	1	Mg+2	2	H2O	-2	H+1		
Epsomite	-5.982	-3.821	1	Mg+2	1	SO4-2	7	H2O		
Hydromagnesite	-20.076	-11.962	5	Mg+2	4	CO3-2	-2	H+1	6	H2O
KCl(s)	-5.533	-6.433	1	K+1	1	Cl-1				
Magnesite	-8.641	-1.121	1	Mg+2	1	CO3-2				
Mg(OH)2 (active)	14.487	-4.307	1	Mg+2	2	H2O	-2	H+1		
Mg2(OH)3Cl:4H2O(s)	17.634	-8.366	2	Mg+2	1	Cl-1	-3	H+1	7	H2O
MgCO3:5H2O(s)	-8.641	-4.101	1	Mg+2	1	CO3-2	5	H2O		
MgF2(s)	-12.317	-4.231	1	Mg+2	2	F-1				
Nesquehonite	-8.641	-4.043	1	Mg+2	1	CO3-2	3	H2O		
Periclase	14.487	-7.549	-2	H+1	1	Mg+2	1	H2O		

Red text - oversaturation   Blue text - undersaturation   Back to main output menu   Print to Excel

Green - apparent equilibrium

Fig 3.3 Saturation Index

6. EPANET Software

EPANET is a software tool developed by the United States Environmental Protection Agency (EPA) for modeling and simulating water distribution systems. It is widely used by water utilities, engineers, researchers, and students to analyze the behavior and performance of water distribution networks under various conditions (15). https://epanet22.readthedocs.io/en/latest/

The primary purpose of EPANET is to assist in the design and operation of water distribution systems by allowing users to simulate and evaluate different scenarios. It can model the flow of water through pipes, pumps, valves, and storage facilities, taking into account factors such as pipe roughness, minor losses, and system controls (15).

EPANET is widely recognized for its user-friendly interface, comprehensive modeling capabilities, and the ability to integrate with other software tools. It is available as a free software package and has been adopted by water utilities and engineering firms worldwide, making it a valuable tool for the efficient and sustainable management of water distribution systems (15).

The EPA Net component of the WINDS computer simulation is used to model an automated flushing valve system specifically designed for flushing drip irrigation systems to remove clogs. This automated flushing valve system combines an emitter and a throttle control valve within the EPA Net simulation environment. The emitter represents the inflow of water into the drip system, while the throttle control valve allows for precise regulation of the flow rate and pressure during the flushing process.

By integrating these components into the EPA Net simulation, helps in modeling and analyzing the performance of the automated flushing valve in terms of its effectiveness in removing clogs from the drip irrigation system. This involved simulating different flushing scenarios, such as varying the flow rate, pressure, and duration of the flushing cycle, as well as accounting for factors like the layout and configuration of the drip system itself.

Chapter 4 Results and Discussion

The first step to designing and evaluating a gravity drip irrigation system was to use the WINDS software to design a hypothetical 1-hectare irrigation system for the Bridgestone farm in Eloy, Arizona. After the basic system layout was completed, EPANET was used to design a maintenance or flushing system for the irrigation unit. The water quality was also determined, and acid injection and ion exchange pretreatment systems were evaluated. Finally a fertigation plan was incorporated into the irrigation system.

1.WINDS Irrigation Design

The gravity driven system design consists of eighty 12 mm laterals from a 30 mm main will cover the irrigation for a 1 -hectare farm area. The main line has an estimated total head of 15 m. When empty, 45 mil (a mil is one-thousandth of an inch) thick wall tubing keeps its cylindrical shape. While it comes in a variety of diameters, the 12, 16, and 22 mm ID sizes are commonly used for drip laterals in landscaping and agriculture. Emitter flow rates of 0.3 GPH and spacing of up to 0.5 m are possible using thick wall inline drip tubing. Common interior sizes for thick wall tubing and drip tape with built-in emitters are 10 mm. The source of water is a pond from where the water is drawn through a canal. The water is then pumped to a tank after the water is treated with one of the feasible ways to prevent the clogging agents and gravity-fed to the crop roots (Appendix E a. Gravity Fed – Drip Irrigation System Design).

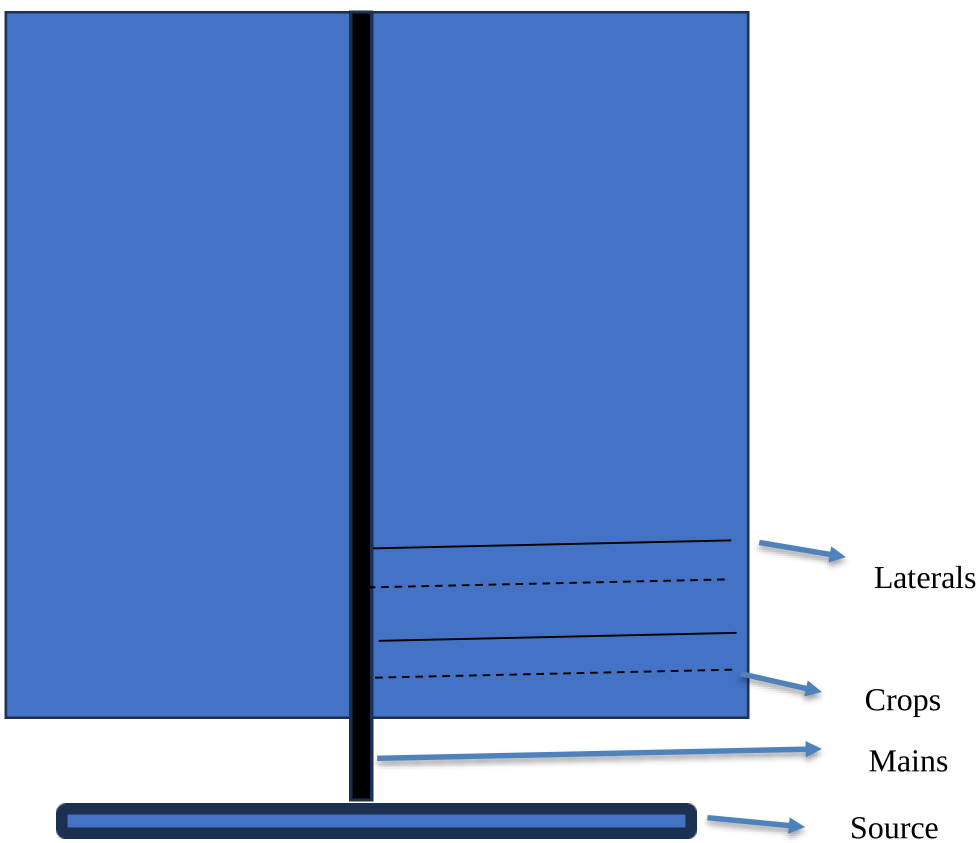


Fig 4.1 Schematic Diagram of the drip system

2. Irrigation Maintenance

Water must be consistently and reliably delivered to crops via emitters, pipelines, and tubing systems for irrigation to be effective. Over time, debris, sediment, and mineral deposits can accumulate inside irrigation networks, clogging emitters and distributing water unevenly (14,15). Crop yields and irrigation efficiency are lowered as a result. By periodically cleansing the system, automated flushing valves offer a vital answer to this issue.

Specially constructed valves known as automated flushing valves (AFVs) are strategically placed throughout the irrigation piping network (15). The AFV builds pressure by momentarily stopping the main water flow and then rerouting it into a flush line at predetermined intervals, here designed using EPANET. The system is cleaned by this pressure, which flushes out accumulated silt and debris. The AFV resets itself after a brief period, restoring regular water flow.

The pressure should be sufficient to clear all the clogging along the pipe. To check the efficiency the AFV is attached at three different positions to detect the optimum design to meet the pressure. Scheduled, unsupervised flushing during irrigation is made possible by AFVs. They optimize system efficiency and lifetime while drastically reducing labor needs when compared to manual flushing. Modifiable flush duration and frequency parameters maximize flushing for particular water conditions and network architecture. The AFV design considerations, selection variables, and performance benefits are discussed here.

Working Mechanism

The input pipe that is attached to the drip lines allows water to enter the AFV (Fig 4.2). Water enters the upper compartment of the AFV through a tiny ascending route. The remaining amount goes directly through to the output. Water presses against a flexible rubber diaphragm on top as it fills the upper space. After a predetermined period, the diaphragm stretches until it reaches the exit and seals it off, technically called flushing duration (FD). Pressure increases within the valve as a result of sealing the outlet. This pushes water through the drain hole to flush out any debris or obstructions. The flushing volume (FV) is the volume of water released during this flush (14, 15). The flushing volume divided by the amount of time needed to close off the outlet (FV/FD) yields the flushing rate (FR). In conclusion, the AFV briefly blocks the outflow and generates enough pressure to flush the system using the flexible diaphragm. By doing this, any debris or obstructions that can harm the drip irrigation drip lines are removed.

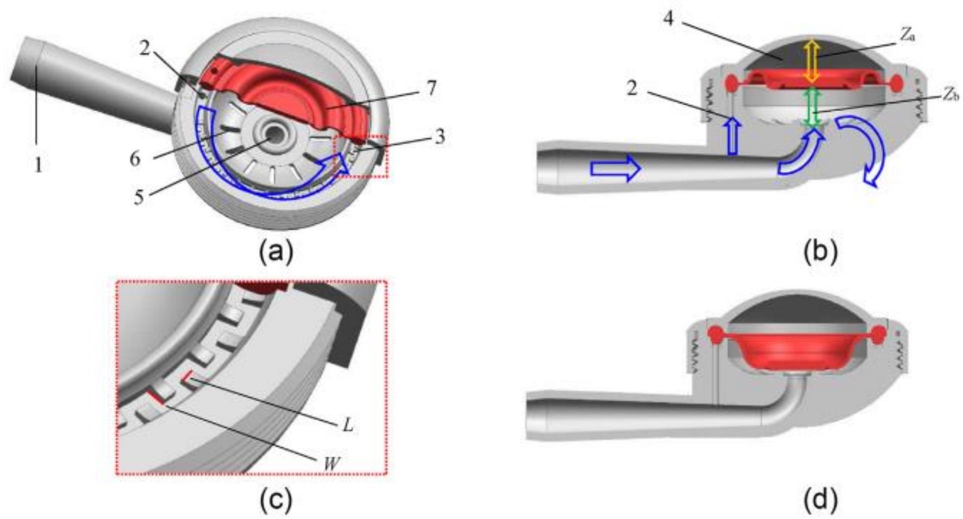


Fig. 1 – Schematic diagram of the working principle of the automatic flushing valve (AFV). Z_a is the height of the upper cavity of the AFV, mm; Z_b is the height of the lower cavity of the AFV, mm; *L* is the dentation length of the delay channel, mm; *W* is the dentation width of the delay channel, mm. The blue arrow is the direction of water movement. To visualize the internal structure of the AFV, Fig. 1(a) shows the cover and elastic diaphragm split open. 1, Water inlet; 2, Ascending channel; 3, Delay channel; 4, Upper cavity; 5, Outlet; 6, Drain hole; 7, Elastic diaphragm. (a) Positive triaxial side view of the AFV when it starts flushing. (b) Front section view of the AFV when it starts flushing. (c) Enlarged view of the size of the delay channel structure in the red dash box in Fig. 1(a). (d) Front sectional view of the AFV when the elastic diaphragm comes into close contact with the outlet, namely, the flushing is stopped.

Fig 4.2 Automated Flushing Valve Model (Picture credit - North China University of Water Resources and Electric Power)

The automatic flushing valve design technique (AFDM) determines the flushing duration (FD) as follows:

The kind of soil, crop water requirements, and other factors determine the kind of emitters used in drip lines and their flow parameters. The amount of flushing required to clean the emitters is dependent on the water quality (sediment levels). Leaky water requires longer flushing times (14).

Based on the emitters used and the quality of the water, experiments calculate the flushing time required per unit length of drip line (T), the length of a single drip line (l), and (m) the number of drip lines flushing concurrently, are used to compute FD.

Hence, if T, l, or m increase, FD also does. More flushing time is required for longer, filthy drip lines

$$FD = T\ x\ l\ x\ m \qquad (8)$$

The valve opening time (Ha) is correlated with FD. Therefore, the valve can be sized according to the intended flushing parameters using the equation that joins FD and Ha (15). In conclusion, the AFDM conducts studies to ascertain the amount of time required for flushing given emitters and water.

Modeling of an AFV system in EPANET:

An automated flushing valve could be modeled by combining an emitter and throttle control valve in EPANET (Fig 4.3).

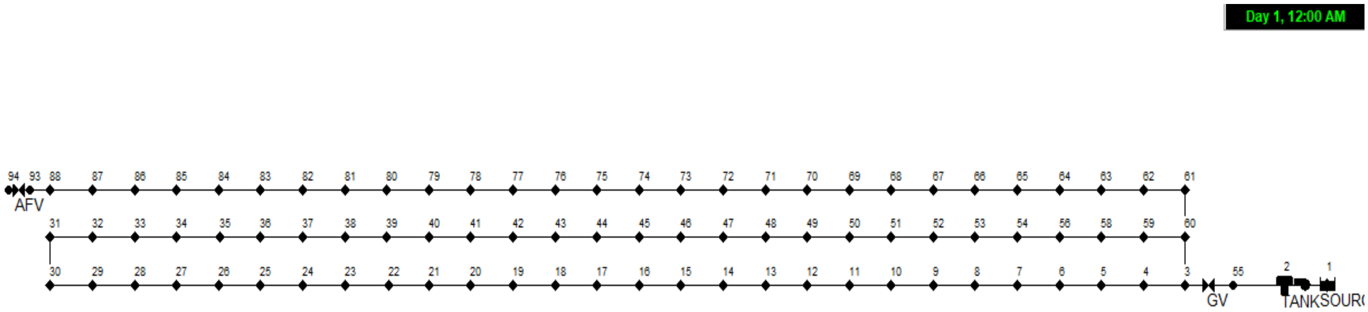


Fig. 4.3 EPANET AFV Model -1 - AFV at every third line

The emitter are used to model the flow rate of water released during a flushing event. The discharge coefficient and pressure exponent could be adjusted to get the desired flow rate (14). The throttle control valve could be set up with a control (rule-based) to open and allow flow through the emitter on a set flushing schedule (e.g. open every 24 hours for 5 minutes).

The rule-based control is attached (fig 4.4 and 4.8). The valve and emitter could be placed on a small diameter piping branch connected to the main water system piping (15). Additional logic could be added to the control rule to flush based on water quality sensors if desired.

However, this layout analysis wasn't successful because the design pressure to flush the system only reached half the flushing path. So the layout is revised to check the working of the valve fixed at each drip line. Then to get an optimized model layout, the valves are connected at every alternative line and analyzed. The analysis output is for the optimized layout where AFV is attached at every alternative drip line (fig 4.6). The analysis run status and output values are obtained (tables 3, 4)

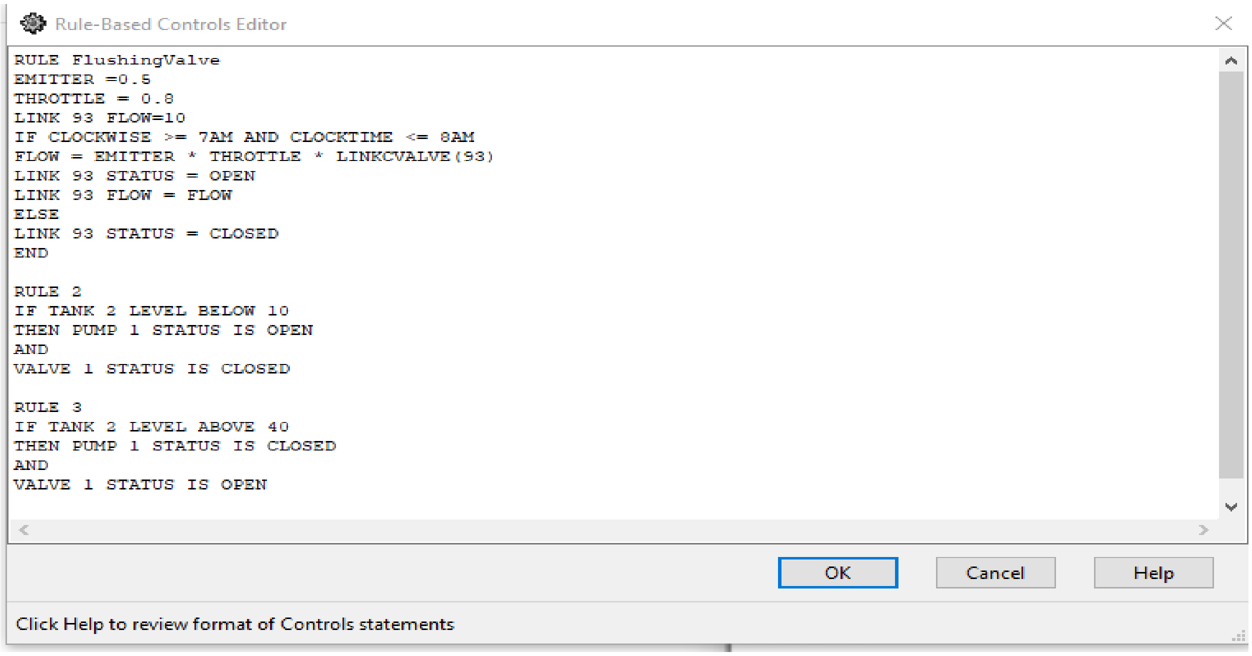


Fig. 4.4 Code used to create an Automated Flushing Valve from an emitter and Throttle control valve

Fig. 4.5 EPANET Model - 2 - AFV at every line

Fig 4.6 EPANET Model - 3 - AFV at alternative lines

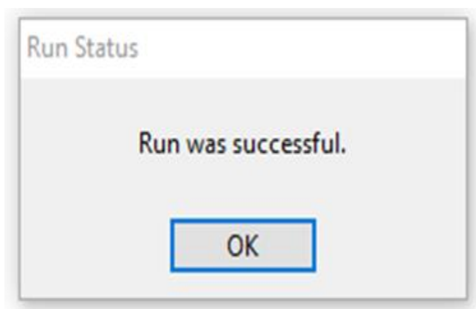


Fig 4.7 EPANET analysis status

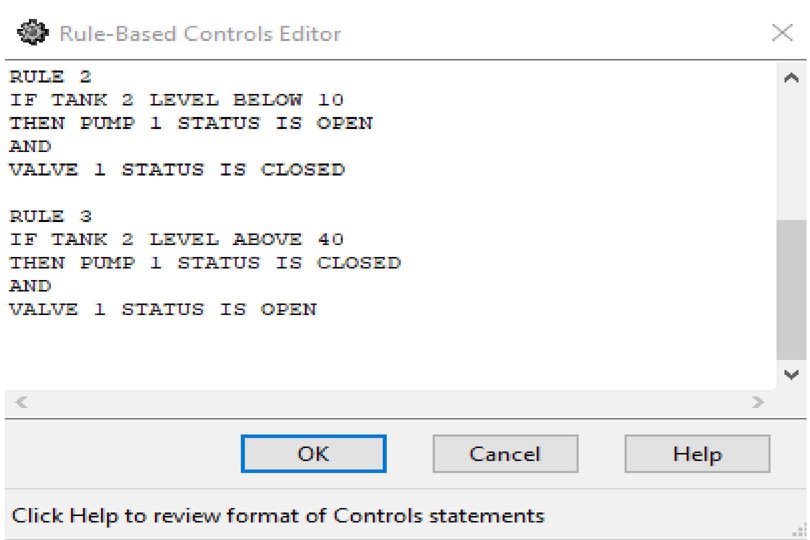


Fig. 4.8 EPANET rule-based controls feed for AFV at all lines

Node ID	Demand	Head	Pressure	Quality
	GPM	ft	psi	
Junc 4	0.01	6699.09	8.59	0
Junc 5	0.01	6699.09	8.59	0
Junc 6	0.01	6699.09	8.59	0
Junc 7	0.01	6699.08	8.59	0
Junc 8	0.01	6699.08	8.59	0
Junc 9	0.01	6699.08	8.59	0
Junc 10	0.01	6699.08	8.59	0
Junc 11	0.01	6699.08	8.59	0
Junc 12	0.01	6699.07	8.59	0
Junc 13	0.01	6699.07	8.59	0
Junc 14	0.01	6699.07	8.59	0
Junc 15	0.01	6699.07	8.59	0
Junc 16	0.01	6699.07	8.59	0
Junc 17	0.01	6699.07	8.59	0
Junc 18	0.01	6699.06	8.58	0
Junc 19	0.01	6699.06	8.58	0
Junc 20	0.01	6699.06	8.58	0
Junc 21	0.01	6699.06	8.58	0
Junc 22	0.01	6699.06	8.58	0
Junc 23	0.01	6699.06	8.58	0
Junc 24	0.01	6699.06	8.58	0
Junc 25	0.01	6699.06	8.58	0
Junc 26	0.01	6699.06	8.58	0
Junc 27	0.01	6699.06	8.58	0
Junc 28	0.01	6699.06	8.58	0
Junc 29	0.01	6699.06	8.58	0
Junc 30	0.01	6699.06	8.58	0
Junc 31	0.01	6699.05	8.55	0
Junc 32	0.01	6699.05	8.55	0
Junc 33	0.01	6699.05	8.55	0
Junc 34	0.01	6699.05	8.55	0
Junc 35	0.01	6699.05	8.55	0
Junc 36	0.01	6699.05	8.5	0
Junc 37	0.01	6699.05	8.5	0
Junc 38	0.01	6699.05	8.5	0
Junc 39	0.01	6699.06	8.5	0
Junc 40	0.01	6699.06	8.48	0
Junc 41	0.01	6699.06	8.48	0

Junc 42	0.01	6699.06	8.48	0
Junc 43	0.01	6699.06	8.48	0
Junc 44	0.01	6699.06	8.48	0
Junc 45	0.01	6699.06	8.48	0
Junc 46	0.01	6699.06	8.48	0
Junc 47	0.01	6699.06	8.48	0
Junc 48	0.01	6699.06	8.48	0
Junc 49	0.01	6699.07	8.48	0
Junc 50	0.01	6699.07	8.48	0
Junc 51	0.01	6699.07	8.48	0
Junc 52	0.01	6699.07	8.48	0
Junc 53	0.01	6699.07	8.47	0
Junc 54	0.01	6699.08	8.47	0
Junc 56	0.01	6699.08	8.47	0
Junc 58	0.01	6699.08	8.47	0
Junc 59	0.01	6699.08	8.47	0
Junc 60	0.2	6699.08	8.42	0
Junc 61	0.01	6699.08	8.42	0
Junc 62	0.01	6699.08	8.42	0
Junc 63	0.01	6699.08	8.42	0
Junc 64	0.01	6699.07	8.42	0
Junc 65	0.01	6699.07	8.42	0
Junc 66	0.01	6699.07	8.42	0
Junc 67	0.01	6699.07	8.42	0
Junc 68	0.01	6699.07	8.42	0
Junc 69	0.01	6699.07	8.4	0
Junc 70	0.01	6699.06	8.4	0
Junc 71	0.01	6699.06	8.4	0
Junc 72	0.01	6699.06	8.4	0
Junc 73	0.01	6699.06	8.4	0
Junc 74	0.01	6699.06	8.4	0
Junc 75	0.01	6699.06	8.4	0
Junc 76	0.01	6699.06	8.4	0
Junc 77	0.01	6699.05	8.4	0
Junc 78	0.01	6699.05	8.4	0
Junc 79	0.01	6699.05	8.4	0
Junc 80	0.01	6699.05	8.4	0
Junc 81	0.01	6699.05	8.39	0
Junc 82	0.01	6699.05	8.39	0

Junc 83	0.01	6699.05	8.39	0
Junc 84	0.01	6699.05	8.39	0
Junc 85	0.01	6699.05	8.39	0
Junc 86	0.01	6699.05	8.39	0
Junc 87	0.01	6699.05	8.39	0
Junc 88	0.01	6699.05	8.39	0
Junc 3	0.2	6699.05	8.39	0
Junc 93	0.01	6699.05	8.39	0
Junc 94	0.01	6699.05	8.39	0
Junc 55	0.01	6699.05	8.39	0
Junc 90	0.01	6699.05	11.23	0
Junc 91	0.01	6699.05	11.23	0
Resvr 1	100	10	0	0
Tank 2	20	6800	12	0

Table 6 - The nodes output extracted from EPANET software

Link ID	Flow	Velocity	Unit headloss	Friction Factor	Quality	Status
	gpm	fps	ft/Kft			
Pipe 4	0.2	0.8	0.12	0.114	0	Open
Pipe 5	0.19	0.7	0.1	0.098	0	Open
Pipe 6	0.19	0.7	0.12	0.132	0	Open
Pipe 7	0.19	0.7	0.1	0.115	0	Open
Pipe 8	0.18	0.6	0.12	0.156	0	Open
Pipe 9	0.18	0.6	0.1	0.136	0	Open
Pipe 10	0.18	0.6	0.07	0.111	0	Open
Pipe 11	0.18	0.6	0.1	0.163	0	Open
Pipe 12	0.18	0.6	0.1	0.18	0	Open
Pipe 13	0.16	0.6	0.7	0.15	0	Open
Pipe 14	0.16	0.6	0.7	0.167	0	Open
Pipe 15	0.16	0.6	0.7	0.188	0	Open
Pipe 16	0.16	0.5	0.7	0.213	0	Open
Pipe 17	0.16	0.5	0.7	0.162	0	Open
Pipe 18	0.16	0.5	0.6	0.279	0	Open
Pipe 19	0.16	0.5	0.7	0.217	0	Open
Pipe 20	0.13	0.5	0.7	0.256	0	Open
Pipe 21	0.13	0.5	0.7	0.319	0	Open

Pipe 22	0.13	0.4	0.7	0.357	0	Open
Pipe 23	0.13	0.4	0.7	0.231	0	Open
Pipe 24	0.13	0.4	0.7	0.295	0	Open
Pipe 25	0.13	0.4	0.7	0.78	0	Open
Pipe 26	0.13	0.3	0.5	0.539	0	Open
Pipe 27	0.13	0.3	0.6	0.794	0	Open
Pipe 28	0.13	0.3	0.6	0.51	0	Open
Pipe 29	0.13	0.3	0.7	0.241	0	Open
Pipe 31	0.11	0.3	0.6	0.251	0	Open
Pipe 32	0.11	0.3	0.5	0.107	0	Open
Pipe 33	0.11	0.3	0.7	0.315	0	Open
Pipe 34	0.11	0.3	0.7	0.115	0	Open
Pipe 35	0.11	0.3	0.7	0.772	0	Open
Pipe 36	0.11	0.3	0.7	0.513	0	Open
Pipe 37	0.11	0.3	0.7	0.374	0	Open
Pipe 38	0.11	0.4	0.7	0.569	0	Open
Pipe 39	0.9	0.4	0.8	0.224	0	Open
Pipe 40	0.9	0.4	0.7	0.361	0	Open
Pipe 41	0.9	0.4	0.7	0.298	0	Open
Pipe 42	0.9	0.4	0.7	0.249	0	Open
Pipe 43	0.9	0.4	0.7	0.212	0	Open
Pipe 44	0.9	0.4	0.7	0.274	0	Open
Pipe 45	0.9	0.5	0.7	0.159	0	Open
Pipe 46	0.9	0.5	0.5	0.209	0	Open
Pipe 47	0.7	0.5	0.7	0.185	0	Open
Pipe 48	0.7	0.5	0.7	0.165	0	Open
Pipe 49	0.7	0.5	0.7	0.148	0	Open
Pipe 50	0.7	0.5	0.7	0.178	0	Open
Pipe 51	0.7	0.5	0.6	0.161	0	Open
Pipe 52	0.7	0.5	0.6	0.11	0	Open
Pipe 53	0.7	0.6	0.6	0.134	0	Open
Pipe 56	0.7	0.6	0.7	0.131	0	Open
Pipe 57	0.7	0.6	0.6	0.121	0	Open
Pipe 58	0.7	0.6	0.6	0.133	0	Open
Pipe 59	0.7	0.6	0.7	0.119	0	Open
Pipe 60	0.9	0.8	0.7	0.102	0	Open
Pipe 61	0.9	0.8	0.7	0.138	0	Open
Pipe 62	0.9	0.8	0.7	0.12	0	Open
Pipe 63	0.9	0.8	0.5	0.131	0	Open

Pipe 64	0.9	0.8	0.5	0.143	0	Open
Pipe 65	0.9	0.8	0.5	0.157	0	Open
Pipe 66	0.9	0.7	0.6	0.129	0	Open
Pipe 67	0.9	0.7	0.7	0.191	0	Open
Pipe 68	0.9	0.7	0.7	0.16	0	Open
Pipe 69	0.11	0.7	0.7	0.179	0	Open
Pipe 70	0.11	0.7	0.7	0.202	0	Open
Pipe 71	0.11	0.7	0.7	0.153	0	Open
Pipe 72	0.11	0.6	0.7	0.263	0	Open
Pipe 73	0.11	0.6	0.7	0.203	0	Open
Pipe 74	0.11	0.6	0.6	0.238	0	Open
Pipe 75	0.11	0.6	0.6	0.282	0	Open
Pipe 76	0.11	0.6	0.6	0.341	0	Open
Pipe 77	0.11	0.6	0.6	0.42	0	Open
Pipe 78	0.7	0.6	0.6	0.265	0	Open
Pipe 79	0.7	0.6	0.6	0.345	0	Open
Pipe 80	0.7	0.5	0.5	0.466	0	Open
Pipe 81	0.7	0.5	0.5	0.666	0	Open
Pipe 82	0.7	0.5	0.5	0.102	0	Open
Pipe 83	0.7	0.5	0.5	0.179	0	Open
Pipe 84	0.7	0.5	0.5	0.311	0	Open
Pipe 85	0.7	0.5	0.5	0.321	0	Open
Pipe 86	0.7	0.5	0.6	0.154	0	Open
Pipe 87	0.7	0.5	0.6	0.106	0	Open
Pipe 88	0.7	0.5	0.6	0.038	0	Open
Pipe 89	0.5	0.6	0.6	0.344	0	Open
Pipe 90	0.12	0.6	0.6	0.132	0	Open
Pipe 93	0.12	0.5	0.6	0.393	0	Open
Pipe 94	0.12	0.5	0.6	0.386	0	Open
Pipe 95	0.12	0.5	0.7	0.343	0	Open
Pump 1	20	1.5	0.9	0.75	0	Open
Valve 2	0.5	0.8	0.2	0.06	0	Active
Valve 54	0.99	1.2	0.1	0.15	0	Active
Valve 92	0.99	1.2	0.2	0.19	0	Active

Table 7 – Link (pipes) output from EPANET software

3. Impact of Water Quality

A summary of the important water quality measurements is found in Table 7. The ion chromatography results indicate a significant presence of total dissolved solids (TDS) in the forms of chloride, sulfate, and nitrate in the water sample. Additionally, a noticeable concentration of potassium and magnesium was observed, potentially posing a hindrance to the efficiency of the drip irrigation system. The concentration of carbonates in the water is 6.673 ppm.

Parameter	Value	Desired values based on USDA and WHO regulations for irrigation water
pH	8.72	6.5 – 8.0
TDS (mg/L)	0.12	<500
TSS (mg/L)	0.0933	-
TIC	6.673	-
Hardness mg/L as CaCO3)	59.7	<150
Alkalinity (mg/L as CaCO3)	2317.952	-
Fluoride, ppm	0.4803	1.5
Chloride, ppm	96.330	<100
Nitrite, ppm	1.2923	No MCL
Sulfate, ppm	157. 5286	<100
Nitrate, ppm	97.6420	<5
Potassium, ppm	51.9771	No MCL
Magnesium, ppm	43.1378	No MCL

Table 8 - Analysis values

The treatments were conducted to assess the effectiveness of different methods in reducing or eliminating clogging agents in the water before it reaches the drippers. The initial water sample being analyzed had a pH of 8.72, with concentrations of inorganic carbon (IC) at 6.673 ppm and magnesium (Mg) at 43.137 ppm Sulfates at 157.53ppm, as previously determined. Calculations based on these parameters indicated a high total alkalinity of 2317.952 mg/L as CaCO3 for the 7570 L sample volume. Effective removal of these ions was achieved through the use of chemical methods such as ion exchange or acid injection.

4. Acid Injection

Acid injection is a proactive method employed to mitigate clogging in drip irrigation systems by dissolving and eliminating mineral deposits formed by calcium or magnesium carbonates. This process involves injecting diluted acid solutions, typically composed of water and sulfuric or hydrochloric acid, into the irrigation lines. The acid solution lowers the pH within the lines, preventing carbonate. To inhibit carbonate precipitation in the water sample, the target pH is typically lowered to 6.5 (Fig 4.9) by adding sulfuric acid with a normality of 1.

However, in the present case, the computed volume of acid required to achieve the desired pH adjustment was a mere 780 mL (Appendix E b. Acid Injection), an exceptionally small quantity that seems implausible for the large water volume involved. Such a minute acid volume would necessitate extensive monitoring and precise control, rendering the process impractical and challenging to implement effectively.

Considering the minimal carbonate concentration in the water, implementing an expensive treatment method like acid injection solely for the purpose of removing carbonate to make the water suitable for the drip irrigation system would be unwise and economically unjustified. The substantial investment in equipment, operational costs, and potential environmental concerns associated with handling and disposing of acidic waste streams outweigh the benefits of this approach for the given water chemistry.

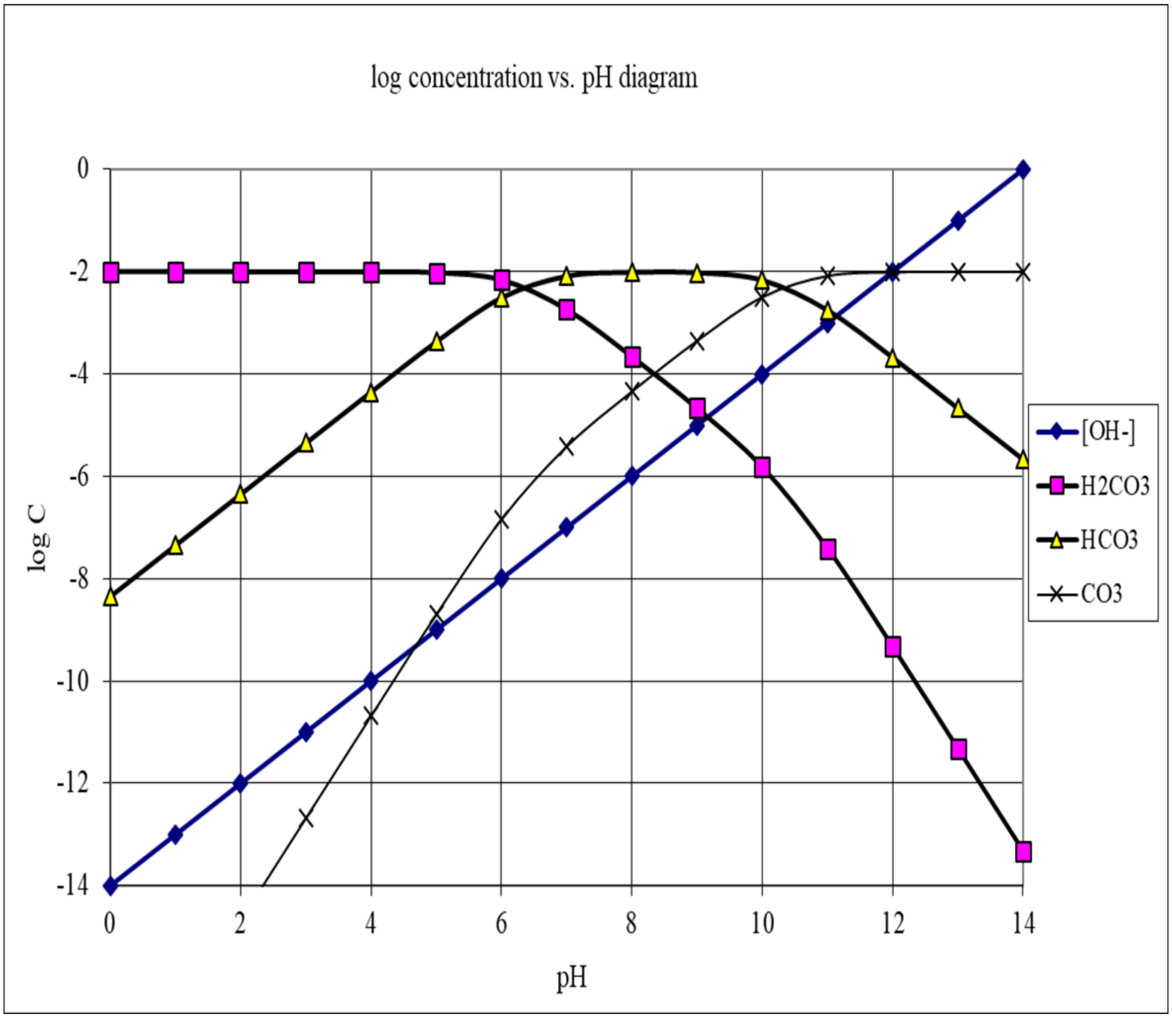


Fig 4.9 Carbonate speciation Graph

5. Ion Exchange

Ion exchange is another water treatment process that selectively removes specific dissolved ions from water by exchanging it with other ions of the same charge. This process offers a potential solution for addressing issues related to the deposition of ions such as sulfates, chlorides, magnesium, and others within the emitters of drip irrigation systems, which can cause clogging and operational problems.

The selection of ions to be removed is a critical step in the ion exchange process and is guided by the selectivity factor or coefficient of the particular ion (Figure 4.10). The selectivity factor represents the affinity of the ion exchange resin for a specific ion compared to other ions present in the water. This factor plays a vital role in ensuring efficient separation and optimizing the resin's service life and regeneration process.

Based on the selectivity factors, the maximum useful capacity of the resin type can be computed, allowing for an optimized selection of the most appropriate resin for the targeted ions. In this way, a cation exchange resin in used to remove 43.17 ppm of Mg. DOWEX 50W-X8 (Fig 4.11 and 4.12) exchanges its positively charged ions from a solution with hydrogen ions (H+) attached to its sulfonic acid functional groups. Generally represented as R-SO3-H. The ion exchange reaction is shown by the following equation:

$$2(R - SO_3{}^{-}H^{+}) + MgCl_2 \rightarrow (R - SO_3{}^{-})_2Mg^{2+} + 2HCl \_\_\_\_\_\_ (4)$$

where:

$R\text{-}SO_3{}^{-}H^{+}$ represents the resin in its hydrogen form, with the sulfonic acid functional groups bearing hydrogen ions.

$MgCl_2$ is the magnesium chloride salt present in the water.

$(R\text{-}SO_3{}^{-})_2\ Mg^{2+}$ represents the resin with magnesium ions bound to its sulfonic acid groups after the ion exchange process.

HCl is the hydrochloric acid produced as a byproduct of the reaction.

Once the service of the column is complete, the resins can be regenerated using Hydrochloric acid to replace the Mg^2+ ions in the resin with the H+ ions. The chemical reaction involved in the regeneration process is represented as follows:

$$R - SO_3 - Mg^{2+} + HCL \rightarrow R - SO_3 - H+ + MgCl_2 \_\_\_\_\_\_ (5)$$

where:

$R - SO_3 - Mg^{2+}$ Represents the resin with bound cations ($Mg\ ^2+$)

HCl is the hydrochloric acid regenerant solution

$R\text{-}SO_3\text{-}H^+$ represents the regenerated resin with hydrogen ions attached to the sulfonic acid groups

$MgCl_2$ is the chloride salt formed by the displaced cations

According to the design configuration, the process removes a total of 987458.28 eq/day of MgCl2 from the water. The column setup consists of 5 columns including the standby, each with a diameter of 1.5m and a volume of 2.65m^3. The service flow rate is 5 Bv/h, and the service time is 0.4 hours (Appendix E. c. Ion exchange – Cation removal).

During the regeneration process, each column requires 15.707 kg (1.45 lbs) of regenerant and 0.75 hours for regeneration. In the backwash stage, the flow rate is 15m/hr, and the duration is 10 minutes. The rinse stage has a flow rate of 35 Bv/h and a duration of 35 minutes.

The other ion that is considered to be removed by the ion exchange process is sulfates present at a concentration of 157.52 ppm. The removal involves anion exchange resin selected by the selection factor. The resin used is Amberlite IRA67 (Fig. 4.13 and 4.14). It is a weak base anion exchange resin. It is a macroporous styrene resin with tertiary amine functional groups (-N (CH3)2) that can exchange anions from the water (27).

The service cycle reaction:

$$2R - N(CH_3)_2 + SO_4{}^2 - \rightleftharpoons \ (R - N(CH_3)_2)2SO_4 \_\_\_\_\_\_\_\_ \ (6)$$

where:

$R\text{-}N\ (CH_3)_2$ represents the free base form of the resin with tertiary amine functional groups.

SO_4^{2}- represents the sulfate ions present in the water.

$(R\text{-}N\ (CH_3)_2)2SO_4$ represents the resin-sulfate complex formed after the ion exchange process.

Regeneration Cycle:

$$(R - N(CH_3)_2)2SO_4 \ + \ 2NaOH \ \rightleftharpoons \ 2R - N(CH_3)_2 \ + \ Na_2SO_4 \ + \ 2H_2O \_\_\_\_ \ (7)$$

where:

$(R\text{-}N\ (CH_3)_2)2SO_4$ represents the resin-sulfate complex before regeneration.

NaOH is the sodium hydroxide regenerant solution.

$R\text{-}N\ (CH_3)_2$ represents the resin being restored to its free base form after regeneration.

Na_2SO_4 is the sodium sulfate released in the regenerant solution after the exchange. The ion exchange process eliminates a total of 2451129.97 eq/day of sulfate from the water. The setup comprises of 9 columns, one serving as standby, with a 2 m diameter and a volume of 6.28 m^3 each. The service flow rate is 6 Bv/h, with a service duration of 12 hours. During regeneration, each column necessitates 17.18 kg (37.87 lbs) of regenerant and 0.75 hours for the process. The backwash phase operates at a flow rate of 15m/hr for 20 minutes, while the rinse stage runs at 5 Bv/h for 25 minutes (Appendix E. d. Ion exchange – Anion removal).

While effective in ion removal, the ion exchange process is not recommended for a drip irrigation system due to its uneconomical nature. The large footprint required for the setup of multiple columns makes it impractical for the agricultural field. Additionally, the long service time, regeneration time, and high flow rates during the backwash and rinse stages contribute to increased operational costs adding up with the regenerant costs.

Moreover, the environmental impacts of such a system, including high water consumption and chemical usage for regeneration, can be detrimental. The process may not align with sustainable practices required for drip irrigation systems, which aim to conserve water and minimize environmental harm.

Separation factors of ions for resins[a]

Strong acid cation resins[b]		Strong base anion resins[c]	
Cation, i	α_{i/Na^+}	Anion, i	α_{i/Cl^-}[d]
Ra^{2+}	13.0	$UO_2(CO_3)_3^{4-}$	3200
Ba^{2+}	5.8	ClO_4^-[e]	150
Pb^{2+}	5.0	CrO_4^{2-}	100
Sr^{2+}	4.8	SeO_4^{2-}	17
Cu^{2+}	2.6	SO_4^{2-}	9.1
Ca^{2+}	1.9	$HAsO_4^{2-}$	4.5
Zn^{2+}	1.8	HSO_4^-	4.1
Fe^{2+}	1.7	NO_3^-	3.2
Mg^{2+}	1.67	Br^-	2.3
K^+	1.67	SeO_3^{2-}	1.3
Mn^{2+}	1.6	HSO_3^-	1.2
NH_4^+	1.3	NO_2^-	1.1
Na^+	1.0	Cl^-	1.0
H^+	0.67	BrO_3^-	0.9
		HCO_3^-	0.27
		CH_3COO^-	0.14
		F^-	0.07

Fig. 4.10 Separation factor Tabulation from Mackenzie L. Davis - Water and Wastewater Engineering (2010)

Fig. 4.11 The selected cation exchange resin - Dowex 50W-X8

Fig. 4.12 Dowex 50W-X8 Resin beads

Fig. 4.13 The selected anion exchange resin - Amberlite IRA67

Fig. 4.14 Amberlite IRA67 Resin beads

6. Fertigation

Fertigation, a combination of fertilization and irrigation, is a modern agricultural practice that has gained significant importance in the cultivation of the Guayule plant. The cultivation of Guayule involves a two-year cycle until harvest, during which a well-designed fertigation program is implemented. The fertilizer suitable for the Guayule fertigation program to supply nitrogen forms of nutrients is UAN32, a liquid fertilizer solution containing 32% nitrogen in the form of urea and ammonium nitrate.

The use of UAN32 offers several advantages for Guayule growth. The urea component provides a readily available source of nitrogen, ensuring immediate plant uptake and supporting rapid growth. Simultaneously, the ammonium nitrate component acts as a slow-release nitrogen source, ensuring a prolonged and consistent supply of nitrogen to the plants throughout their growth cycle.

The fertigation program involves the application of 30 gallons of UAN32 per acre, repeated eight times over a two-year period (Appendix E f. Fertigation). These applications are primarily carried out during the summer months, coinciding with the irrigation schedule to facilitate efficient nutrient delivery. Moreover, fertigation will enable growers to exercise precise control over the timing and quantity of fertilizer application, allowing them to adjust the nutrient supply according to the specific growth stages and requirements of the Guayule crop.

7. WINDS Irrigation - Pressure Driven System

The gravity-fed system did not meet the standard to deliver water precisely in the field and requires expensive pretreatment process to prevent the emitters from clogging. This leads to design a pressurized drip system ensuring efficient water distribution, allowing for precise control over water delivery to each crop. This is less prone to clogging due to the force of the water that helps to flush out any potential blockages in the system.

Pressure-driven drip irrigation systems can accommodate uneven farm terrain and layout in Eloy. It is easily integrated with fertigation systems, allowing for the precise application of fertilizers (23). Also, operations are carried out flawlessly using automated controllers and timers, allowing for accurate scheduling and management of irrigation cycles (21).

The pressure driven drip system designed for 1 hectare land is proposed to have 4485 emitters and 820 for each 55 numbers of laterals running for a span of 820 ft. With an emitter uniformity 0.86 greater than 0.80 the requirement from the manufacturer specification. The manifold pipe line connects the laterals in numbers of 11 to the main line. The length of the manifold is calculated to be 1100 ft. carrying 993 GPH in a 2” diameter pipe (Appendix E g. Pressure Fed – Drip Irrigation System Design).

The main line has a flow rate of 1985 GPH through a 4” diameter pipe running for 820 ft. from the filtration tank is the only pretreatment step required to remove particulate matters. The water from the open channel is pumped at a rate of 1750 GPM @ 160 ft TDH using DV 200c Pump. Other miscellaneous pipe fittings like pressure regulators, air vents at high points, flow meters, pressure gauges and black preventers are needed as per requirement.

The filtration tank is made of sand media 14” x 48”.This provides a physical barrier against particulate matter, effectively removing silt, and other debris from the water before it enters the drip lines. This mechanical filtration process is highly effective and does not rely on chemical treatments, making it a more environmentally friendly option.

These filters portray a vast supremacy over any other treatment methods discussed. These advantages include effective physical filtration, minimal maintenance requirements, operational simplicity, versatility, and comprehensive protection against various clogging agents.

For flushing, it is recommended to flush the whole system before and after every fertigation process. During other irrigation schedules, it is important to clean the system at 4- 6 weeks intervals.

Chapter 5 Future Scope

The project will look forward in integrating sensors, controllers, and remote monitoring systems to optimize irrigation scheduling based on real-time weather conditions, and crop water requirements. Additionally, cost-benefit analysis will be conducted and environmental impact assessment will evaluate the long-term sustainability and scalability of the pressure-driven drip irrigation system. Furthermore, exploring the feasibility of powering the system with renewable energy sources like solar or wind power might also fall under this vision.

Appendix A – Bridgestone farm, Eloy

A 1.1 Guayule Drip Irrigation setup

Appendix B – Study References

ARIZONA METEOROLOGICAL NETWORK MONTHLY SUMMARY

Maricopa
June 2023

Jun	AIR TEMP MX	AIR TEMP MN	AIR TEMP AV	DEW PT	REL HUM MX	REL HUM MN	REL HUM AV	SOIL T 4	SOIL T 20	WIND AV	WIND MX	SOL	RAIN	ETo AZ	ETo STD	HEAT UNITS 55	HEAT UNITS 50	HEAT UNITS 45
1	91	60	77	37	46	10	24	84	82	4.3	15	723	0.00	.33	.28	20	25	30
2	93	65	80	39	42	10	25	79	81	3.8	14	715	0.00	.32	.28	22	27	32
3	99	67	85	41	47	10	23	78	79	4.7	13	718	0.00	.34	.32	24	29	34
4	103	71	88	36	30	8	17	83	79	5.1	13	724	0.00	.37	.34	26	31	36
5	104	64	87	28	42	4	14	86	80	6.5	24	709	0.00	.40	.38	24	29	34
6	99	60	82	27	42	5	15	84	80	7.4	24	728	0.00	.42	.38	21	26	31
7	96	54	80	28	60	5	16	85	80	5.1	23	734	0.00	.37	.32	18	23	28
8	95	55	79	28	50	5	17	85	81	4.5	14	693	0.00	.33	.29	18	23	28
9	96	62	80	32	38	8	19	85	81	4.3	16	706	0.00	.33	.30	22	27	32
10	100	57	82	31	58	4	19	86	81	4.7	17	707	0.00	.35	.32	20	25	30
11	92	59	79	38	52	11	23	85	81	7.8	31	726	0.00	.39	.35	19	24	29
12	91	62	77	43	48	15	31	85	81	4.5	16	722	0.00	.31	.28	21	26	31
13	95	67	81	44	51	12	28	87	82	4.3	15	724	0.00	.33	.29	24	29	34
14	98	63	83	41	57	12	25	88	82	4.5	15	724	0.00	.34	.31	22	27	32
15	98	68	83	41	41	11	24	86	83	4.3	13	710	0.00	.33	.30	24	29	34
16	100	66	85	35	47	6	19	80	82	4.9	16	735	0.00	.37	.33	24	29	34
17	102	68	87	37	38	8	18	82	81	4.0	12	732	0.00	.36	.31	25	30	35
18	106	69	89	34	41	6	16	86	81	6.5	24	727	0.00	.41	.39	26	31	36
19	105	68	88	32	34	5	15	87	82	4.9	22	680	0.00	.36	.34	25	30	35
20	102	69	87	37	39	8	18	89	82	5.1	22	739	0.00	.39	.34	25	30	35
21	104	67	88	34	39	7	16	89	83	4.7	17	713	0.00	.37	.33	25	30	35
22	103	66	87	29	42	4	13	89	83	5.4	15	734	0.00	.36	.35	24	29	34
23	98	65	83	24	41	4	13	89	84	4.5	13	753	0.00	.36	.32	23	28	33
24	104	57	82	24	47	2	14	88	83	3.1	11	756	0.00	.35	.29	21	26	31
25	108	70	89	31	33	4	13	90	84	3.8	12	716	0.00	.36	.32	27	32	37
26	109	71	91	30	30	4	13	91	84	3.4	13	659	0.00	.34	.29	27	32	37
27	107	69	90	34	40	4	15	91	84	4.9	17	726	0.00	.38	.35	26	31	36
28	105	68	88	42	49	7	21	92	85	4.7	18	719	0.00	.37	.34	25	30	35
29	104	65	86	33	42	5	16	88	85	3.8	14	736	0.00	.36	.31	24	29	34
30	107	70	89	36	30	5	16	83	85	3.6	14	729	0.00	.36	.31	26	31	36
AVG	100	65	84	34	43	7	19	86	82	4.8	17	721						
TOT													0.00	10.8	9.7	698	848	998

B 1.2 AZMET – June month - Summary

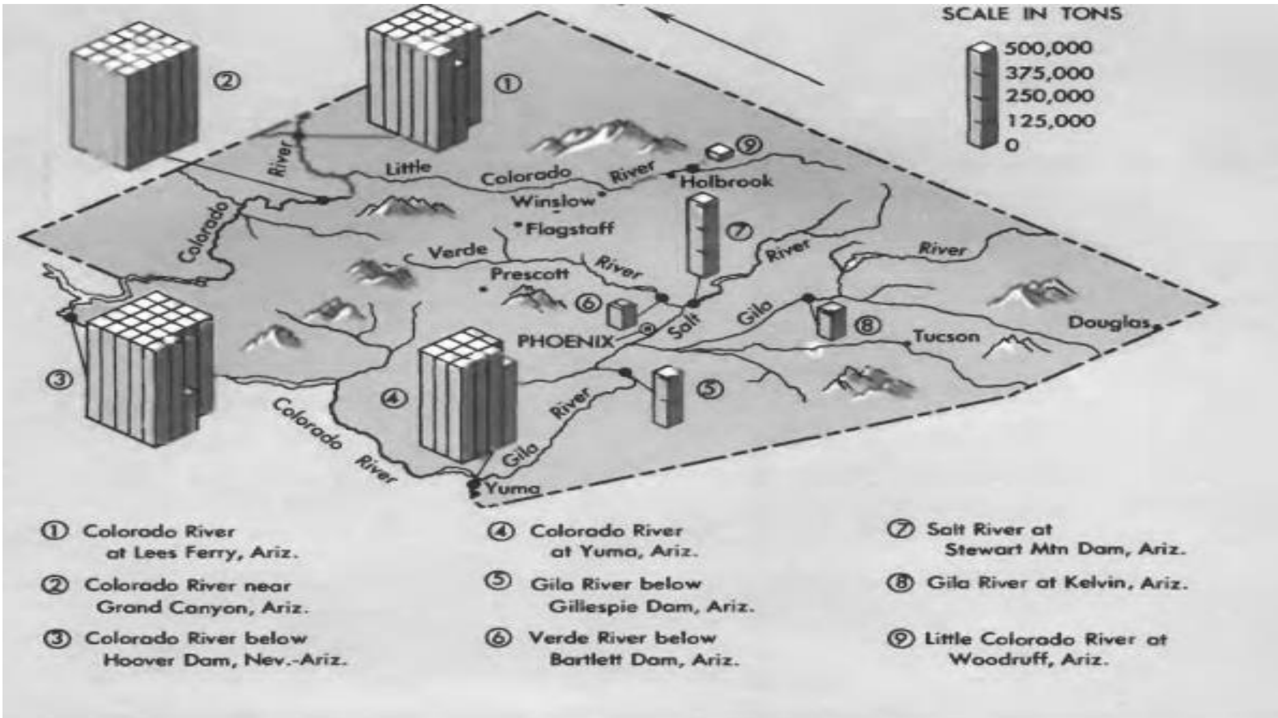


Figure 11. Average loads of dissolved salts in Arizona streams.

B 1.3 Geological water survey Report

Table 1. Public drinking water quality standards and guidelines

Primary Maximum Contaminant Levels (Health-based Standards)		
Constituent	Number of Wells Exceeding Standards	Percentage of Wells Exceeding Standards
Nitrate	21	27%
Arsenic	18	23%
Fluoride	17	22%
Uranium	3	4%
Secondary Maximum Contaminant Levels (Health-based Standards)		
Constituent	Number of Wells Exceeding Standards	Percentage of Wells Exceeding Standards
TDS	77	100%
Chloride	77	100%
Fluoride	44	57%
Sulfate	41	53%
pH-field	2	3%
Aluminum	2	3%

Table 2. Groundwater characteristics of Gila Bend basin samples

pH-field	
Slightly Acidic (< 7 su)	5
Slightly Alkaline (7 – 8 su)	56
Moderately Alkaline (> 8 su)	16
TDS	
Fresh (< 1,000 mg/L)	2
Slightly Saline (1,000 – 3,000 mg/L)	56
Moderately Saline (3,001 – 10,000 mg/L)	19
Hardness	
Soft (<75 mg/L)	1
Moderately Hard (75 – 150 mg/L)	11
Hard (151 - 300 mg/L)	14
Very Hard (301 - 600 mg/L)	13
Extremely Hard (> 600 mg/L)	38
Water Chemistry	
Sodium-Chloride	59
Mixed-Chloride	8
Could not be determined because of lab error	10
Nitrate	
Natural Background (<0.2 mg/L)	1
May or May Not be from Human Influence (0.2-3.0 mg/L)	22
May Result from Human Influence (3.0 - 10 mg/L)	33
Probably Results from Human Influence (> 10 mg/L)	21
Trace Elements	
Detected at less than 50 percent of sites	aluminum, antimony, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, thallium, and zinc
Detected at more than 50 percent of sites	arsenic, barium, boron, fluoride, selenium, and strontium

B 1.4 Gila Bend - Water quality test report

B 1.5 Line source drip lines

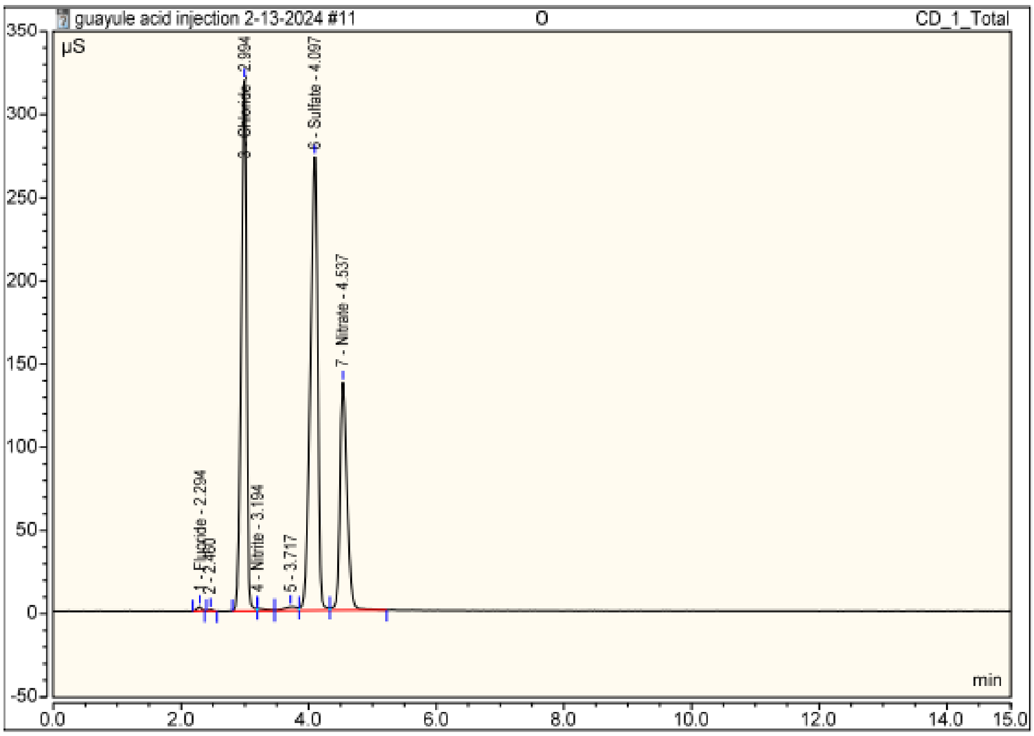
B 1.6 Emitter

Appendix – C – Analysis Report

Peak Integration Report

Sample Name:	**0**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Program:	**AD-checkout-doublesystem-060120**	*Operator:*	**University of Arizon**
Inj. Date / Time:	**13-Feb-2024 / 14:45**	*Run Time:*	**15.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount ppm
1	2.29	Fluoride	BMB	0.206	2.543	0.4803
3	2.99	Chloride	BM	30.513	318.984	96.3330
4	3.19	Nitrite	M	0.236	1.526	1.2923
6	4.10	Sulfate	M	36.392	272.764	157.5286
7	4.54	Nitrate	MB	17.823	136.954	97.6420
TOTAL:				85.17	732.77	353.28

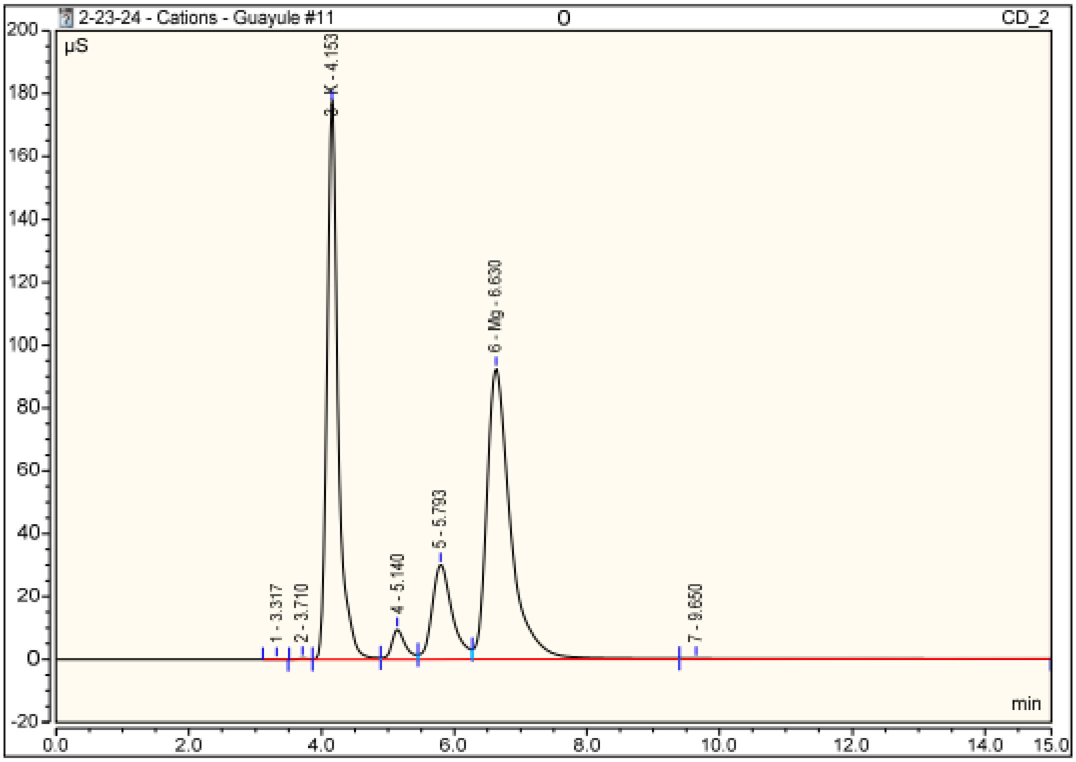


C 1.7 IC anion peak Integration graph for the water sample

Peak Integration Report

Sample Name:	**0**	*Inj. Vol.:*	**100.00**
Injection Type:	**Unknown**	*Dilution Factor:*	**1.0000**
Program:	**AD-checkout-doublesystem-060120**	*Operator:*	**University of Arizon**
Inj. Date / Time:	**23-Feb-2024 / 16:58**	*Run Time:*	**15.00**

No.	Time min	Peak Name	Peak Type	Area µS*min	Height µS	Amount mg/L
3	4.15	K	M	34.253	176.944	51.9771
6	6.63	Mg	M	38.595	92.529	43.1378
		TOTAL:		72.85	269.47	95.11



C 1.8 IC cation peak Integration graph for the water sample

Appendix D – Manufacturer Specifications

D 1.9 Inline Emitters

EMITTER TYPE	SOIL TOPOGRAPHY	EU RANGE FOR ARID AREA
Point source on permanent crops	Uniform Steep or undulating	90 to 95 85 to 90
Point source on permanent or semi-permanent crops	Uniform Steep or undulating	85 to 90 85 to 90
Line source on annual row crops	Uniform Steep or undulating	80 to 90 70 to 85

D 1.10 Emitter Uniformity Tabulation from Manufacturer's Specification

EMITTER TYPE	CV RANGE	CLASSIFICATION
Line Source	<0.10	Good
	0.10 to 0.120	Average
	>0.20	Marginal to unacceptable
Point Source	<0.05	Good
	0.05 to 0.10	Average
	0.10 to 0.15	Marginal
	>0.150	Unacceptable

D 1.11 Coefficient of Variation of inline emitter pipe from Manufacturer's specification

Product Data Sheet

Simplot

UAN-32
Urea Ammonium Nitrate Solution
32-0-0

GUARANTEED ANALYSIS

TOTAL NITROGEN (N)..32.00%
- 7.75% Ammoniacal Nitrogen
- 7.75% Nitrate Nitrogen
- 16.50% Urea Nitrogen

Derived from Ammonium Nitrate and Urea.

KEEP OUT OF REACH OF CHILDREN

WARNING

CAUSES EYE IRRITATION.
PRECAUTIONARY STATEMENTS: Wash thoroughly after handling.
FIRST AID: IF IN EYES Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists get medical attention.

PHYSICAL CHARACTERISTICS

Specific Gravity @ 68°F:	1.327
Weight (lbs. per gal.) @ 68°F:	11.06
Total Nitrogen (lbs. per gal.):	3.54
Ammonic Nitrogen	0.86
Nitrate Nitrogen	0.86
Urea Nitrogen	1.82
Salting Out Temperature:	32°F
Solution pH:	6.8
Free Ammonia:	0.01%

CONSTRUCTION OF STORAGE & TRANSFER EQUIPMENT

1. Mild steel, stainless steel, aluminum and certain fiberglass materials are suitable. Copper and alloys containing copper (brass) should not be used.

COMPATIBILITY

1. Compatible with ammonium phosphate solutions such as 10-34-0, 11-37-0, 9-30-0, etc.
2. Compatible with potash solutions and combinations of potash and ammonium phosphate solutions.
3. Compatible with many herbicides. NOTE: Consult pesticide label or manufacturer before mixing Simplot UAN-32 Urea Ammonium Nitrate Solution 32-0-0 with pesticide chemicals.

USES

1. A nonpressure solution– is well adapted for a wide range of application practices. Direct application in preplant plow-down programs, injecting or banding in the soil, or applied through various irrigation systems– sprinkler, drip, flood or furrow.
2. Is the preferred source of nitrogen in liquid blending plants and in combination with herbicides for "weed and feed" programs.

ADVANTAGES

1. Provides both fast acting and long lasting plant food from its three forms of nitrogen. Quick response from nitrate, longer lasting from ammonic and sustained feeding from the water soluble organic nitrogen in urea.
2. Enjoys great compatibility with other fertilizers and many chemicals. Makes possible two or more jobs in one trip over the field. Saves time, labor and money.
3. Is easy to store, handle and calibrate for accurate application in the field.
4. Is safe– being a nonpressure neutral solution, eliminates safety hazards associated with corrosive materials and high pressure systems.

PRECAUTIONS

1. Do NOT spray Simplot UAN-32 Urea Ammonium Nitrate Solution 32-0-0 full strength on crops other than pastures.
2. Do NOT mix with aqua ammonia as the blend is very corrosive.

Warning: [illegible]

Information regarding the contents and levels of metals in this product is available on the internet at [illegible]

DISCLAIMER OF WARRANTIES J.R. Simplot Company [illegible]

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GUARANTOR
J.R. SIMPLOT COMPANY • P.O. Box 198, Lathrop, CA 95330

[illegible]

D 1.12 UAN 32 fertilizer product data sheet

Appendix E – Design Outputs

a. Gravity Fed - Drip Irrigation System Design

Crop	Guayule						
Spacing		0.75	x	0.5	m		
Area	1 ha	107600		sq.ft		100	x 100 m
Slope	0.35	%					(Roughly)
Water source		Pond					
Static Head		15	m		0.075		
ET crop		12	mm/day		From WINDS Models emulation of Guayule Irrigation		

Assuming Soil Characteristics

Clay Soil				
Field Capacity	48	%		
Wilting point	25	%		
Bulk density	1.3	g/cm^3		
Effective root Zone Depth			60	cm
				3.6
Wetted area	10	%		
Max. Pump Discharge			0.75	gps

Volume of water to be applied

Volume		Area	x	Depth
	0.45	m^3		

Number of Emitters per plant

No. of emitters per plant is to be selected based on the layout

Say, one emitter per plant (0.1 g/h)

Irrigation Time

Irrigation Time Volume/Discharge rate

4.50	hrs.	270	min

Number of Emitters per lateral

Length of the field 100 m

Assuming the submain is laid at the center of layout, hence later length 50 m

Emitter spacing on lateral Plant spacing 0.5 m

No. emitters per lateral 100 no's

Discharge through one lateral

Q lateral	10	g/h	0.166666667	gpm	37.8541	l/h

Number of lateral per manifold

Pump Discharge	0.6	gps	
2160	g/hr	36	gpm

No. of lateral that can be operated

216	say	220	nos of lateral will have the required pressure after all the frictionloss.

Breadth of the field 100 m

No. of laterals along the breadth depend on row spacing

Distance between two laterals 1 m

Say 1.25 m to give enough space for the crop

Number of lateral on one side 80 no's

Total number of laterals (both sides) 160

Number of Sub mains 0.727272727 Say 2 for uniformity in layout

Number of laterals per manifold 80 no.s Say 80

Size of lateral

Let us assume a lateral of 12mm diameter

V	Q/A			
A	113.0973355	mm^2	0.000113097	m^2
Q	37854.1	cu.m/hr	630901.6667	l/min

V 92973.2582 m/s

Nr $\rho vD/\mu$

1115679098 > 4000

Flow is turbulent

Compute f

f	0.001750915							
K	0.000144749							

Take corrected L		50	m					
H1	18.617007	m						
h1	FH1+M1							
	0.032596804	Less than 0.5% of static head					7.5	m

Size of Submains

Q submain	Q lateral	x	No. of lateral per submain			
	800	g/hr	3028.328	l/hr	50.47213333	l/min
	13.33333333	gpm	3.028328		m3/hr	

Manifold Design

Assume Manifold Diameter		28	mm	0.028	m

V	Q/A			
V	1.366137671	m/s		
A	0.000615752	sq.m		
Nr	38251.8548	>	4000	

Flow Turbulent Flow

f	0.022881624
k	0.001891641

L	50	m				
H1	6.17491E-07	m				
h1	2.08712E-07	m	Less than 0.5% of static head		7.5	m

Head at inlet of manifold H emitter +H lateral+H slope+ H manifold

0.207597012 m

Size of Main

Length of main 100 m from well location

Q main	1600	g/hr	6056.656	l/hr	100.9442667	l/min
			6.056656	m3/hr	6.056656	m^3/sec

Assume main diameter 30 mm 0.03 m

V	Q/A			
V	2.38011541	m/s		
A	0.000706858	sq.m		
Nr	71403.4623	>	4000	Turbulent
f	0.019575829			
K	0.001618348			

H1	8.381E-05	m				
h1	2.83278E-05	m	Less than 0.5% of static head		7.5	m

Total Head

Total Head	Head manifold inlet+ H main+ H static + H local

15.00002854 m

The pipe will in the line source with in-line orifice

Material Polyethylene

Manufacturer's coefficient of variation Cv is maintained below 0.1 for better usage of the pipe lines. As per ASAE recommendation

Emitter Uniformity

Q	0.1	g/h	0.378541	l/hr	1.3627476	m3/s
Cv	0.1					
Q min - field	0.075	g/hr	0.28390575	l/hr		

EU	74.0475	%	okay

Pressure Variation along the pipeline

K	9.81		
Δz	0.35	m	0.35
h1	18.62	m	
Pu	45	psi	
Pd	-134.20	psi	
	Gravity fed		

b. Acid Injection

pH of water	8.72

Total Alkalinity

IC	6.673	ppm
Mg	43.137	ppm

TA	333.65 +	1984.302
2317.952	mg/L of CaCO3	

Acid required (mL) TA (mg/L as CaCO3) x Volume of Water (L) x (10^-pH t - 10^-pH 0)/ Acid Normality x 50000

pH 0	8.72		
pH t	6.5		
Volume of water	7570	L	water distributed per hour
Acid Normality	1	N	Sulfuric Acid

Acid Required	0.000110308	mL

c. Ion Exchange – Cation Exchange

Desired softness of water		100	mg/L	CaCO3
Q	44.815914	m^3/sec		
Temperature	20	C		
Softening	100	mg/L		
Column Diameter		1.5	m	bases on manufacturer spec.
Regeneration	HCl			
Resin type	SAC	Dowex 50W-X8		

Manufacturer's data about the resin

Softening Capacity		250	Kg/m3
Capacity	1.5	eq/L	
Leakage	1	%	of untreated water hardness
Maximum Diameter		1.5	m
Bed Depth	1	m	
Backwash bad Expansion		>50%	

Recommended Operating Conditions

Operation	Rate	Solution	Time in min.
Service Flow rate	1- 6 Bv/h	Water	
Backwash		Water	5 to 15
Regenation	1- 10 Bv/h	4 - 8% HCl	45 to 75
Rinse	8 - 40 Bv/h	Water	10 to 40

Convert Mg to meq/L

Concentration 357.7709451 mg/L CaCO3

Co 7.155418902 meq/L

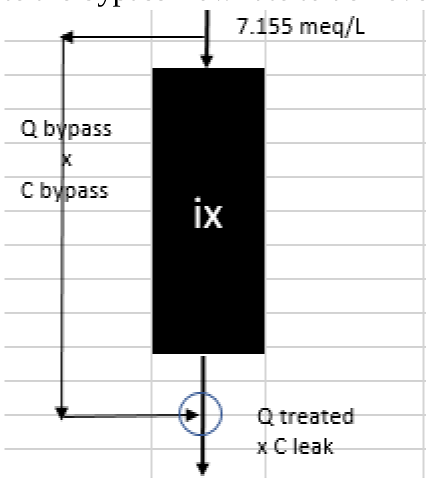
Ceff. 2 meq/L

Compute the Mg in the effluent from the ion exchange column due to leakage

C leakage 0.071554189 meq/L

C desired 2 meq/L

Compute the bypass flow rate to achieve the desired hardness level



Assumptions at the connection of the Q bypass and Q treated

1. CSTR
2. No reaction occurs
3. Steady state

Q total = Q treat + Q bypass

Q treat x C leakage + Q bypass x C bypass = Q total x C desired

Q bypass = f(Q total)

Q treat = (1 -f) Q total

f = 0.964 96.4 %

Q Bypass = 43.2025411 m^3/sec

Q treat = 1.613372904 m^3/sec

Total Mg to be removed each day

= 987458289 meq/day of hardness

987458.2892 eq/day of hardness

Total Resin capacity = 1.5 eq/L

Reduce by 15 % for nonideality

Operating Resin Capacity = 1.275 eq/L

Bed Depth

As per specification not < 0.75m

Service flow rate

= 5 Bv/h m^3/m^3.h

Cross Sectional Area per column

= 1.767145868 m^2

Maximum Diameter 1.5 m

Volume of column

= 2.650718801 m^3

Total volume required

Total flowrate = 1161.628491 m

Loading Rate

No. of Columns Required

Volume required = 4.382315054

Volume of 1 column

Say 5 with 1 standby

Exchange capacity of each column

= 3379.666472 eq

3379666 meq

Service time of the column

Column Capacity X No. of columns

Total Hardness to remove per day

= 0.017112958 day

0.410710995 hr

Total weight of Regenerant required per column					From Man. Specs
=	0.6626797	kg	=	1.45 lbs	

Total weight of solution

Assume 10 % HCl solution

=	6.626797004	kg	=	14.607 lbs

Volume of the salt required '

Sp. Gravity of the salt		1.18	
=	0.00561593	m^3	Salt Solution

Regenartion time		atleast 0.5 hr		So take0.75	hr
Starting Q	4	Bv/h	0.003721563	h	
Reduced Q	3	Bv/h	0.004962083	h	

Backwash flow rate

Temperature		20	C
=	15	m/h	

Backwash Duration

=	10	min

Rinse rate and time

From Table

At	35	Bv/h	for	35	min

Total Time

Operation time + Regenration time + Rinse Time +Backwashing time (in hr)

0.410710995 + 0.75 + 0.583333333 + 0.166666667

= 1.910710995 hr

d. Ion Exchange – Anion Exchange

Desired softness of water	100	mg/L	CaCO3	
Q	44.815914	m^3/sec		2 SETUPS
Temperature	20	C		
Softening	100	mg/L		
Column Diameter	2	m	bases on manufacturer spec.	
Regeneration	NaOH			
Resin type	WBA	Amberlite IRA-67		

Manufacturer's data about the resin

Softening Capacity	250	Kg/m3	
capacity	1.25	eq/L	
Leakage	0.1	%	of untreated water hardness
Maximum Diameter	1.5	m	
Bed Depth	1.25	m	
Backwash bad Expansion	>50%		

Recommended Operating Conditions

Operation	Rate	Solution	Time in min.
Service Flow rate	2-8 Bv/h	Water	
Backwash		Water	10 to 30
Regenation	0.5 -2 Bv/h	4 - 8% NaOH	45 to 75
Rinse	2-5 Bv/h	Water	10 to 30

Convert sulfate to meq/L

Concentration 164.15 mg/L CaCO3

Co 3.283 meq/L

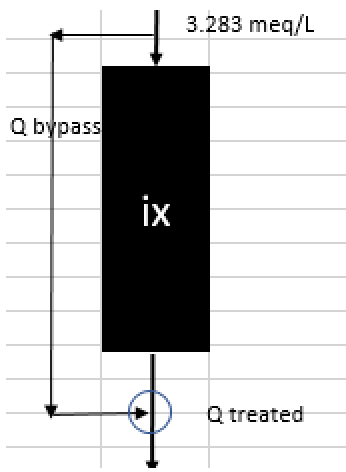
Ceff. 2 meq/L

Compute the SO42 in the effluent from the ion exchange column due to leakage

C leakage 0.003283 meq/L

C desired 2 meq/L

Compute the bypass flow rate to achieve the desired hardness level



Assumptions at the connection of the Q bypass and Q treated

1. CSTR
2. No reaction occurs
3. Steady state

Q total = Q treat + Q bypass

Q treat x C leakage + Q bypass x C bypass = Q total x C desired

Q bypass = f(Q total)

Q treat = (1 -f) Q total

f = 0.135 13.5 %

Q Bypass = 13.5 mg/L

Q treat = 86.5 mg/L

Total Sulfate to be removed each day

= 24511292971.20 meq/day of hardness

24511292.97 eq/day of hardness

Total Resin capacity = 250 Kg/m3

Reduce by 15 % for nonideality

Operating Resin Capacity = 212.5 Kg/m3

Bed Depth

As per specification not < 0.75m

Service flow rate

= 6 Bv/h m^3/m^3.h

Cross Sectional Area per column

= 3.141592654 m^2

Maximum Diameter 2 m

Volume of column

= 6.283185307 m^3

Total volume required

Total flowrate = 51.9 m

Loading Rate

No. of Columns Required

Volume required = 8.260141546

Volume of 1 column

Say 9 1 is standby

Exchange capacity of each column

= 1335176.878 eq

1335176878 meq

Service time of the column

Column Capacity X No. of columns

Total Hardness to remove per day

= 0.490247165 day

11.76593197 hr

Total weight of Regenerant required per column								From Man. Specs	
	=	17.0796327		kg	=	37.87	lbs		

Volume of the salt required '				
Sp. Gravity of the salt			1.18	
	=	0.133118333		m^3

Regenartion time		atleast 0.5 hr		So take0.75	hr	
Starting Q	2	Bv/h	0.418203576	h		
Reduced Q	1.5	Bv/h	0.557604768	h		

Backwash flow rate			
Temperature		20	C
	=	15	m/h
Backwash Duration			
	=	20	min

Rinse rate and time						
	From Table					
	At	5	Bv/h	for	25	min

Total Time

Operation time + Regenration time + Rinse Time +Backwashing time (in hr)

11.76593197	+	0.75	+	0.416666667	+	0.333333333

= 13.26593197 hr

e. Fertigation

Area to irrigate	1	ha		
	2.469135802	acre		Conversion
UAN 32 supplied for each stage			30 gallons/acre	1 acre=0.405hec
Total UAN 32	74.07407407	gallons		
	UAN 32			1 hec =2.469135802ac

Stages (Months)	Nitrogen Required (gallons/acre)
April	30
May	30
June	30
July	30
April	30
May	30
June	30
July	30

f. Pressure Driven Drip Irrigation System

Area to be irrigated	1	Hectare	107640	sq. ft		
Crop Water Requirement		0.11	GPD			
Minimum allowable pressure variation				20	%	Assumed

Minimum operating pressure for drip emitters

7.5 psi

maximum operating pressure for drip emitters 10 psi

Emitter flow rate	0.11	GPH		
Emitter spacing	12	in	1	ft
Emitter device type	Inline non- pressure compensating			
Target distribution uniformity			>0.80	
Tubing inner diameter	0.875	in		
Tubing wall thickness	13	mil	0.013	in
Tubing outer diameter	0.901	in		
Control Valve pressure setting		12	psi	

Row Spacing 40 in

Calculate the total water requirement

Total Water requirement Area x Crop water requirement

= 11840.4 gallons per day

LATERAL LINE DESIGN:

Emitter flow variation = 20% of 7.5 psi operating pressure

Flow variation 1.5 psi

From Manufacturer Data

Lateral Length available		820	ft	9840	in

Use 820 ft lateral lines with emitters at 12 in spacing

Number of lateral Total emitters/ emitters per lateral

Total emitters	4485	emitters		
Emitters/lateral		820	no.s	
No. of laterals	54.69512195	Say	55	

Emission uniformity

Emitter flow rate 0.11 GPH

Flow variation along 820 ft lateral with 0.11 GPH emitters is 15%

EU 1 - (1.27 * Q var/ Q avg) X Cv

0.861454545

EU 0.861454545 >0.80 requirement

MANIFOLD DESIGN

55 laterals divided into 5 of 11 laterals each

Manifold pipe length 1100 ft

Flow 992.2 GPH

Manifold pipe diameter for 993 GPH 2 in

MAIN LINE DESIGN

Flow rate	1984.4	GPH
Main line diameter	4	in
Main pipeline length	820	ft

Miscellaneous Informations:

Filter type	Sand Media	14 x 48	in high
Filter GPM/ tank		237	
Pump Flow (GPM)		1750	
Pump Total Dynamic Head (FT)			
	106		
Pump Horsepower		60	

Others Components

1. Pressure regulators / Sustaining Valves
2. Air Vents at High points
3. Flow meters, pressure gauges, backflow preventers if needed

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