A joint presentation from Nelson Irrigation and Senninger Irrigation
at the 2019 Irrigation Show & Education Conference, Dec. 2-6, 2019, Las Vegas, Nevada, USA

UNDERSTANDING PRESSURE REGULATION

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ABSTRACT

Irrigation systems are designed to distribute a predetermined amount of water over a specific area. Applicators operate within a specific range of flows and pressures. Because pressure affects flow, pressure regulators are used, so applicators run at the designed operating pressure to help assure delivery of the designed application rate.

All systems experience pressure fluctuations. Some of the causes include elevation changes within the irrigated area; pressure loss through pipes and fittings; fluctuations when zones cycle on or off; system demand change on large projects with multiple wells providing water; and activation of end guns and corner arms on mechanized systems.

Pressure regulators control excessive and varying inlet pressures to a constant outlet pressure and significantly improve overall irrigation system efficiency. They can help lower energy costs and save water by reducing wind drift, evaporation, and runoff.

This presentation provides the basics of pressure regulators, how to install pressure regulators in different types of irrigation systems, how to recommend the correct model for different installations, and how to identify problems and troubleshoot issues that can occur.

INTRODUCTION

Pressure regulation can be a topic of dispute. Some industry experts and growers will tell you that it is the best way to save water and energy, while others will claim it is not necessary unless you have uneven land to irrigate or significant changes in pipeline pressures caused by end guns or corner arms.

This joint presentation to the industry is to emphasize Nelson's and Senninger's commitment as irrigation component manufacturers of the importance of pressure regulation. Over our years in the industry, both companies have seen the benefits of pressure regulators and the problems encountered if they are not used when they should be.

The truth is that all irrigation systems experience pressure fluctuations. Proper use of pressure regulators helps maintain the overall efficiency of an irrigation system.

WHAT IS THE RELATIONSHIP BETWEEN PRESSURE AND FLOW?

Irrigation systems are designed to apply a specific amount of water to achieve a specific application rate tailored for the soil and crop.

Sprinkler flow "is related to the square root of the pressure" (Martin, Kranz, Smith, Irmak, Burr, & Yoder, 2017, p. 15). It follows that the operating pressure of an irrigation system always affects the flow rate.

Higher pressures increase flow along pipes. As that flow increases, water velocity increases as well. When water is rushing through a pipe at high velocities, the interior walls of the pipe create friction against it, which causes pressure loss. This results in pressure decreasing downstream due to friction loss.

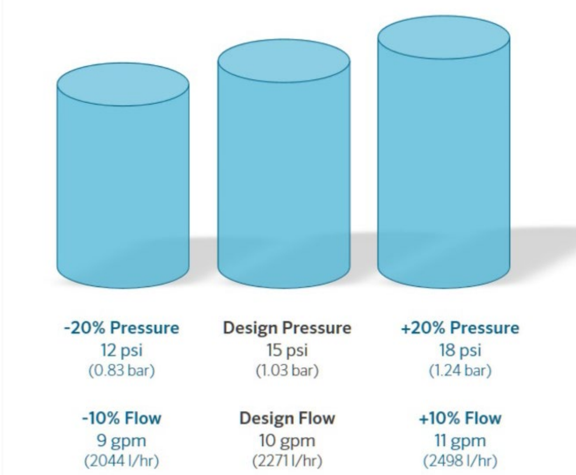

Figure 1. A system is designed to operate at 15 psi (1.03 bar). If this same system experiences a 20% pressure variation, that will result in a 10% flow variation. That small flow variation can negatively impact sprinkler performance and affect your yields.

Pressure Variations				
DESIGN PRESSURE	1 PSI *0.07 BAR*	2 PSI *0.14 BAR*	3 PSI *0.21 BAR*	4 PSI *0.28 BAR*
10 PSI *(0.69 BAR)*	**5.0%**	**10.0%**	**15.0%**	**20.0%**
20 PSI *(1.38 BAR)*	**2.5%**	**5.0%**	**7.5%**	**10.0%**
30 PSI *(2.06 BAR)*	**1.7%**	**3.3%**	**5.0%**	**6.7%**
40 PSI *(2.76 BAR)*	**1.3%**	**2.5%**	**3.8%**	**5.0%**
% Flow Variation				

Table 1. (Senninger Irrigation, 2018) Pressure regulators are recommended if there is a 10% pressure and/or a 5% flow variation. The lower a system's design pressure, the more critical it is to accurately control its pressure.

WHY ARE PRESSURE REGULATORS NEEDED?

All sprinklers are designed to operate within a specific range of flows and pressures. This assures they deliver the intended distribution pattern and application rate. The overall irrigation system design is based on that performance. Without regulators, the radius of throw is reduced, application rates are not consistent, and uniformity numbers are drastically affected (Senninger Irrigation, 2018). This may also impact the application of fertilizers, chemicals, and nutrients through the irrigation system.

Sprinkler rotational speed changes when operated outside of the recommended pressure, producing over or under-watered areas and uneven crop growth. Higher pressures produce small droplets which are prone to wind drift and evaporation and increase wear on irrigation components.

Without pressure regulators, the sprinklers' radius of throw may be reduced, application rates will not be consistent, and uniformity numbers will be drastically affected (Senninger Irrigation, 2018). This may also impact the application of fertilizers, chemicals, and nutrients through the irrigation system.

WHAT CAUSES PRESSURE VARIATIONS?

All irrigation system experience pressure fluctuations, and there are several reasons why.

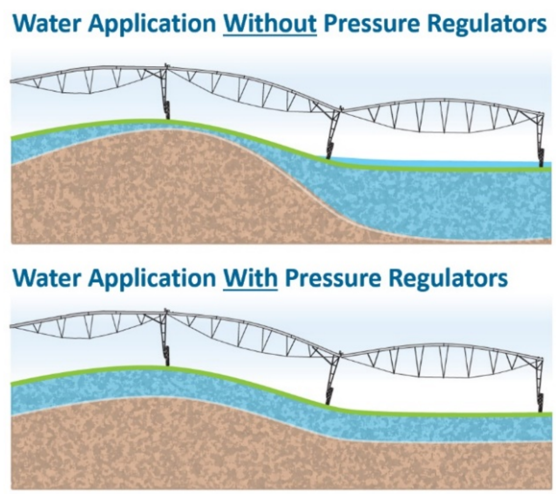

Figure 2. Graphic showing flow without and with pressure regulators in relation to elevation.

Elevation changes within the irrigated area (Kranz, Irmak, Martin, & Yonts, 2007) – Pressure is related to gravity. More pressure is needed to move water uphill. When water moves downhill, more pressure is available. Every 2.31 ft or 0.7 m of elevation change will result in 1 psi or 0.07 bar (Martin, Kranz, Smith, Irmak, Burr, & Yoder, 2017). pressure change. Elevation difference on the outer spans involves a greater amount of water and a greater irrigated area than near the pivot point. Lower design pressure allows less elevation change before pressure regulators are needed.

Hydraulic conditions – There is pressure loss through pipes and fittings. Fluctuations occur when end guns or corner arms cycle on and off or irrigation zones in non-mechanized systems cycle on and off.

Pumping scenarios – System demands change with multiple water sources. Additionally, pump efficiencies play a role.

WHAT ARE PRESSURE REGULATORS? WHAT DO THEY DO?

Pressure regulators control excessive and varying inlet pressures to a constant outlet pressure. Pressure regulators do not produce or store energy, so the outlet pressure will never exceed the inlet pressure. Manufacturers offer several models of pressure regulators to meet various irrigation needs: flow ranges, operating pressure rating, maximum inlet pressure, inlet and outlet connection size, inlet and outlet connection type - NPT, BSPT, and hose connection threads.

HOW DO PRESSURE REGULATORS WORK?

A pressure regulator is comprised of a hollow, generally cylindrical housing. It has a stationary seat near its inlet end and an inner axially moveable tubular stem (throttling stem) in the middle. The throttling stem has a spring around its outer diameter and a diaphragm attached to its outer, downstream end. Two O-rings and the diaphragm isolate the spring in a dry chamber.

Figure 3. Cutaway of a pressure regulator.

Water flows through the inlet end, around the seat, and through the throttling stem (Senninger, 2014). Water pressure acting on the diaphragm forces the spring to compress and push the throttling stem back toward the seat. This closing of the distance between the seat and throttling stem reduces the water pressure on the diaphragm. A balance is quickly reached between the force on the diaphragm and the resistance of the spring. A steady outlet pressure is then established as determined by the compressive load of the spring. Different springs are used for the different pressure models.

WHY IS ADDITIONAL INLET PRESSURE NEEDED?

<u>Friction loss</u> - As water moves through a pipe, it creates friction resulting in pressure loss. Friction loss within a pressure regulator is caused by springs, seals, and the internal wall surface. Pressure regulators do not function until the inlet pressure exceeds the rated operating pressure by at least 5 psi or 0.34 bar to compensate for that friction loss.

<u>Hysteresis</u> - When a regulator has very low hysteresis it can maintain similar performance while the system pressure increases compared to decreasing pressure. When the irrigation system starts,

pressure begins to build but is still below the regulator's preset pressure. The regulator is not regulating at this point – *Figure 4 angled line.*

When the inlet pressure increases above the regulator's set pressure, it functions as designed and reduces the outlet pressure maintaining it at the desired set point – *Figure 4 top line.* As the inlet pressure of the system decreases, the regulator will be able to maintain a similar behavior. However, due to internal friction losses, the outlet pressure will be below the set point – *Figure 4 lower lines.* The difference in the regulator performance while increasing versus decreasing pressure is called hysteresis (von Bernuth & Baird, 1990) – *Figure 4 distance between the horizontal lines*.

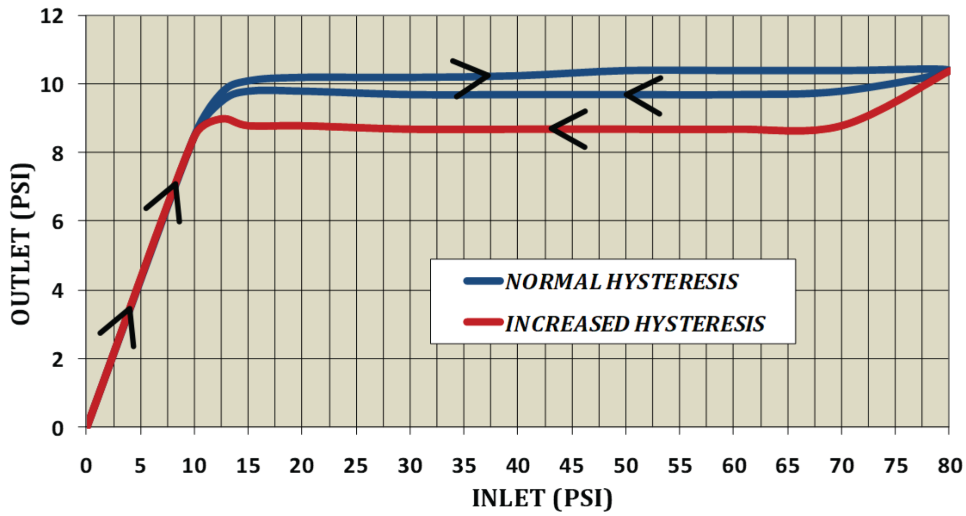

Figure 4. Hysteresis curve

<u>Why is accuracy important?</u> No pressure regulator is perfect, but those with the highest accuracy are better at maintaining the desired outlet pressure. The left set of red lines in *Figure 5* show a range that is 6% higher and lower than the desired outlet pressure indicated by the blue line. The right set of red lines in *Figure 5* show a range that is 12% higher and lower.

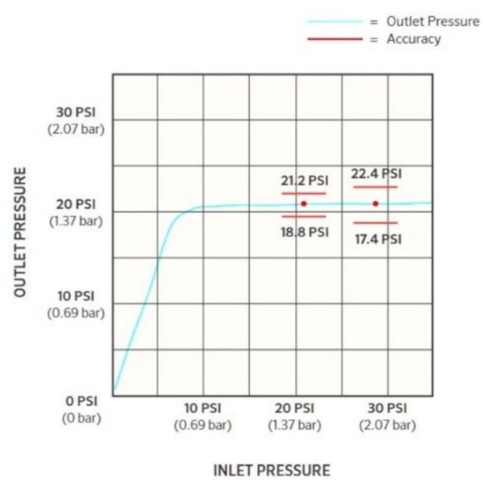

Figure 5. Variation of accuracy

<u>What is a performance curve?</u> **-** Every pressure regulator is designed to operate at a minimum and maximum inlet pressure and a predetermined flow range. A regulator performance curve illustrates how the pressure regulator will perform at this range of inlet pressure and flows. Each model will have a different performance curve. The Y-axis shows outlet pressure, and the X-axis shows inlet pressure.

In *Figure 6*, the 30-psi band covers the 30-psi or 2.07 bar band and extends above and below that line. A 30-psi regulator may not always regulate precisely 30-psi. At the lowest flow, the regulator will maintain an actual outlet pressure that is slightly higher than 30-psi. At the highest flow, the actual outlet pressure is slightly lower than 30-psi (Rogers, Shaw, Pragada, & Alam, 2010).

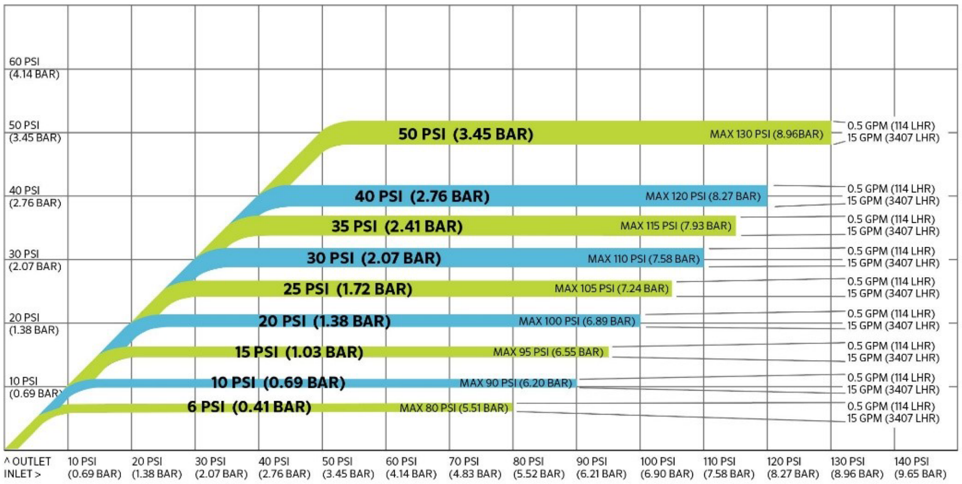

Figure 6. Regulator performance curve.

HOW DO YOU SPECIFY REGULATORS?

Irrigation design software will provide the necessary parameters for pressure regulator selection. Overall system pressure is used to calculate available pressure to sprinklers or irrigation zones. Important considerations include:

"Operating pressure ranges for the inlet and outlet" (Beswick, n.d., "The Basics of Pressure Regulators," para. 2). – Select the psi model based on available system pressure, sprinkler type selected, desired application rate, and droplet size. Assure inlet pressure is at least five psi above regulator model's preset outlet pressure (Martin, Kranz, Smith, Irmak, Burr, & Yoder, 2017).

Modern sprinklers are designed to operate within a narrow range of operating pressures to assure optimum performance. That window varies only by 5 to 10 psi or 0.34 to 0.69 bar. However, most installations will have more pressure differential than that in the system. Verify maximum inlet pressure does not exceed the regulator model's recommendations.

Flow requirements for the inlet and outlet – Assure the flow matches the regulator model's recommendations.

Material of the internal components – The seals, springs, diaphragms are a consideration for possible chemical compatibility.

Size and weight constraints (Beswick, n.d.).

HOW LONG DO PRESSURE REGULATORS LAST?

Like sprinklers, pressure regulators do not last forever. The conditions under which pressure regulators operate influence their lifespan. Irrigators are encouraged to check their pressure regulators at least every three to five years. Factors that contribute to pressure regulator wear vary.

<u>Poor water quality</u> – Surface water may contain grit and fibrous matter. Over time, suspended abrasive materials cause wear on the seat and the end of the throttling stem which alters regulator performance. These installations should employ filtration to help assure proper performance of the regulators and the sprinklers. Some water sources contain chemicals from runoff, including petroleum, which can cause damage to internal regulator components. Systems using well water with high iron content often see rust buildup on and in the components.

Figure 7. Inlet and outlet of worn pressure regulators.

Figure 8. Scarred throttling stem from a worn pressure regulator.

<u>Unflushed chemicals in the system</u> – Irrigation systems are frequently used for chemical applications. Chemicals like nitrogen, fertilizers, and solutions used to combat insects and weeds can cause damage to internal regulator components. It is best to flush the system after chemical application to help prevent residue from accumulating inside the regulator.

<u>Extended operating hours</u> – Anything with moving parts wears out over time. Though regulators last for years, the degree of regulation will change over time as internal parts begin to wear.

WHAT ARE THE MAIN SIGNS OF WEAR OR PROBLEMS?

Malfunctioning pressure regulators can be difficult to identify visually; however, some emit water through the sides of the regulator when they fail structurally. Sometimes they also produce a high-pitched squealing. A malfunctioning regulator can result in a sprinkler pressure that will be too high. A sprinkler emitting a finer spray or exhibit a faster rotation speed relative to adjacent sprinklers may indicate a regulator that is operating above its nominal rating. If operating below its nominal rating, sprinklers will produce larger droplets and slower rotation speed, as well as reduced wetted diameter.

During the irrigation season, the operator should intermittently observe sprinkler performance. This is best done either early or late in the day when the sun is low as differences between sprinklers are easier to identify in this light. On mechanized systems, the number of acres affected is greater if worn regulators are located on the outer spans of the machine.

TESTING PRESSURE REGULATORS

It is best to test regulators from a few different locations, including those that see the highest flow. In mechanized systems, these are on the outer spans.

One method of testing pressure regulators is to install a high-quality "pressure gauge on each side of the regulator" (Senninger Irrigation, 2015, "How to Identify a Bad Regulator, para. 6). The gauge on the inlet side assures there is enough pressure for the regulator to operate. The gauge after the regulator should match the preset pressure on the gauge allowing for slight variation due to flow. If your irrigation dealer has a regulating testing device, check the readings on a new pressure regulator matching the model you are testing.

If your irrigation dealer has a regulating testing device, check the readings on a new pressure regulator matching the model being tested. Use this unit as a witness. For example, if the new unit regulates in the apparatus two percent higher than the preset outlet pressure, then the unit being tested should also regulate two percent higher. Substantial variations are a concern.

Another method employs a pitot tube inserted into the flow of the applicator and matching it to a printed nozzle flow chart. Care should be used to be sure the pitot tube is in the center of the flow stream (Senninger Irrigation, 2015).

A flowmeter can be a valuable tool and can ensure that the flow output of sprinklers, regulators, and end guns matches the sprinkler chart. Pressures and flow rates that change during the irrigation season could indicate problems with a sprinkler package.

Yield maps and overhead imaging can also be utilized to identify poor sprinkler performance.

PRESSURE REGULATOR INSTALLATION RECOMMENDATIONS

<u>Direction of flow</u> - Each pressure regulator is marked to indicate the direction of the flow. If installed improperly, pressure regulators will behave more like a check valve, allowing little to no downstream pressure. This improper installation will also damage internal components.

<u>Flow range</u> – Each pressure regulator is designed to handle a specific flow range printed on the outside. Flows that greatly exceed this range could shorten the life of the pressure regulator. Flows

that fall beneath that range will prevent the regulator from functioning properly and can produce a high-pitched squealing sound.

Maximum pressures – Each pressure regulator is designed with a maximum pressure rating, typically 80 psi or 5.51 bar above the designed pressure rating for that model. Operating outside these recommendations will damage the regulator and may cause vibration that manifests itself in a loud chattering sound. Check the manufacturer's specifications.

Shut-off valves - Pressure regulators should be installed after the shut-off valve to avoid damaging the regulator from prolonged exposure to back pressure.

Water hammer - If systems fill with water quickly at start-up, it can create high pressure shock waves or a water hammer which can damage system components. If this hammer exceeds the regulators maximum inlet pressure, it can damage regulators. This damage is often evidenced by leaking between the upper and lower housings.

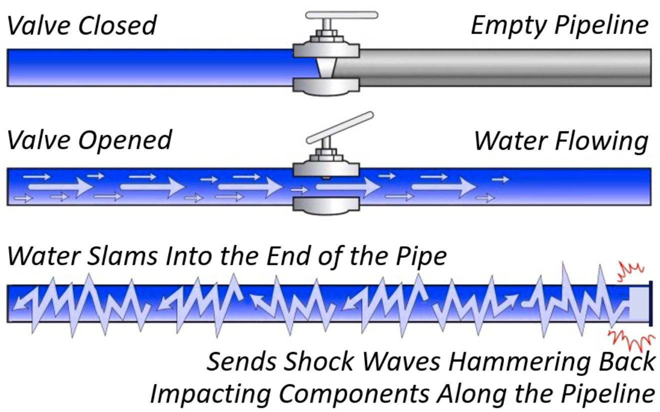

Figure 9. (Water hammer, 2018) illustration of what happens inside pipes including water hammer

Mechanized systems –

- Pressure regulators are usually installed immediately preceding the sprinkler.
- Some prefer to install the pressure regulator on the outlet or inlet side of the gooseneck. Increased pressure or head between the regulator and the sprinkler should be a design consideration.

Solid Set field installations –

- Regulators are usually installed at the beginning of the lateral.
- Although, based on the design, one regulator can be used to manage pressure for several laterals.
- Certain installations may require a pressure regulator for each sprinkler.
- In high flow scenarios, a high flow model should be used. Although, multiple regulators in manifold can be used to handle the specific flow requirements.
- Timer-control installations employ regulators after the control valve, whether for multiple units or inside a valve box.

WHAT IS THE DIFFERENCE BETWEEN A PRESSURE REGULATOR AND A PRESSURE REGULATING LIMIT VALVE?

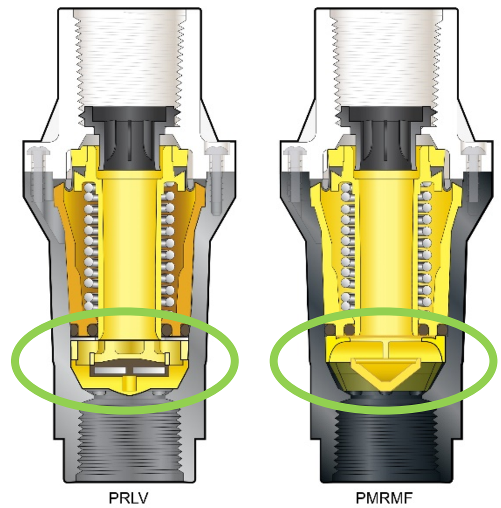

Figure 10. Comparing the seats of a limit valve versus a pressure regulator

"Pressure regulating limit valves are used where there is a shut-off valve downstream. When this shut-off valve is closed, the limit valve's [throttling] stem flow-passage closes and seals to limit the outlet pressure to only 10 to 15 psi or 0.69 to 1.03 bar above its normal regulating pressure. This helps protect downstream components from potential damage due to high static upstream water pressure.

With a standard regulator, when the downstream shut-off valve is closed, the [throttling] stem is unable to seal completely against the harder seat.

The high inlet pressure eventually equalizes across the regulator and up to the valve. Upon opening the shut-off valve, a high-pressure surge could damage downstream meters, sprinklers, or other plumbing components" (Senninger Irrigation, 2018, p. 15).

WHAT IS THE DIFFERENCE BETWEEN A PRESSURE REGULATOR AND A PRESSURE REGULATING DRAIN CHECK VALVE?

Regulating drain check valves combine pressure regulation with a check or shut-off feature. They are used to help "eliminate sprinkler drizzle during shut-down and start-up" (Nelson Irrigation, 2014, para. 2). Pressure regulating drain check valves do not allow water to pass through them until the preset outlet pressure is achieved. This eliminates washout and erosion damage caused by partially pressurized sprinklers.

Standard pressure regulators allow water to pass through them and begin regulating only when inlet pressure is five psi above the preset outlet pressure is reached. Sprinklers will discharge water as the pressure increases. However, they do not distribute water properly without the required minimum pressure.

WHAT IS THE DIFFERENCE BETWEEN A PRESSURE REGULATOR AND A PRESSURE CONTROL VALVE?

Pressure control valves are sized by flow rate to control pressure in large higher flow piping systems. Most open and close slowly to help prevent water hammer and surge (Nelson Irrigation, 2019). Pressure control valves react through a pressure control regulator. Depending on the needed functionality, you can choose pressure reducing valves, pressure sustaining valves, or both, with many models available with manual or electric closing control.

WHAT ABOUT FLOW CONTROL NOZZLES?

Flow control nozzles can sometimes eliminate the need for pressure regulators. In some cases, they may pass debris more easily than conventional nozzles and provide a more economical system. Operating pressure alters the nozzle orifice to change the flow rate. The flow remains "nearly constant" (Kranz, Irmak, Martin, & Yonts, 2007). Be sure your system has pressure sufficient to activate flow control nozzles and yet not so high as to negatively affect sprinkler performance.

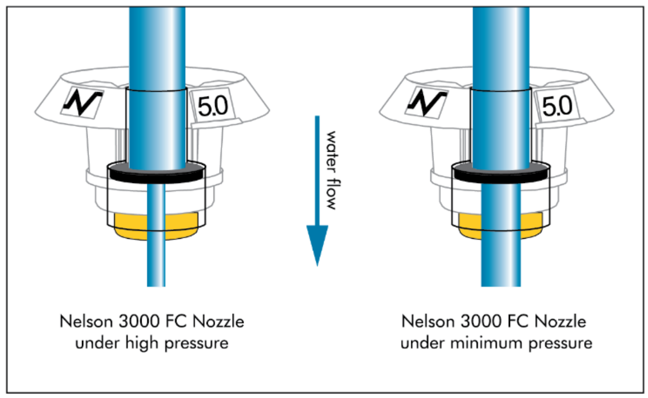

Figure 11. Comparing outlet flow under high and minimum pressure.

SUMMARY

Investing in new pressure regulators is worth the investment when compared with the time and money lost in wasted input costs and potential yield loss. Pressure regulators help make the most of the water applied to improve crop yield. They are an important tool to help provide food, fiber, and fuel for a growing population.

REFERENCES

Beswick Engineering Co., Inc. (n.d.). *The basics of pressure regulators* [PDF file]. Retrieved from https://www.beswick.com/wp-content/uploads/2018/12/Basics-of-Pressure-Regulator.pdf

Kranz, W.L., Irmak, S., Martin, D.L., & Yonts, C.D. (2007). Flow control devices for center pivot. G88-888 [PDF file]. *University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources.* Retrieved from http://extensionpublications.unl.edu/assets/pdf/g888.pdf

Martin, D., Kranz, W., Smith, T., Irmak, S., Burr, C., & Yoder, R. (2017, February). Center pivot irrigation handbook [PDF file]. *Nebraska Extension Publications, EC3017.* 53-54. Retrieved from http://extensionpublications.unl.edu/assets/pdf/ec3017.pdf

Nelson Irrigation (2014, June). *Mini regulator, mini regulator drain check & mini drain check* [PDF file]. Retrieved from http://nelsonirrigation.com/media/resources/REG_MR_MRDC_MDC.pdf

Nelson Irrigation. (2019, July). 1000 series valves & twig wireless controls [PDF file]. Retrieved from http://nelsonirrigation.com/media/resources/1000V_CATALOG_0719_2.pdf

Rogers, D.H., Shaw, L.K., Pragada, S.R., & Alam, M. (2010, February). Evaluation of pressure regulators from center pivot nozzle packages [PDF file]. *Kansas State University, Department of Biological and Agricultural Engineering.* Retrieved from https://pdfs.semanticscholar.org/74cc/04dd4b3f05daecd08a0fa3e398bea725fe8e.pdf

Senninger Irrigation (2018, Feb March). Connecting pressure flow and system efficiency. *SABI Magazine*, 14-15. Retrieved from https://issuu.com/sabimagazine/docs/2018-february-march-email

Senninger Irrigation. (2014, April). *How does a pressure regulator work* [Web blog post]. Retrieved from https://www.senninger.com/news/2017/09/28/how-does-pressure-regulator-work

Senninger Irrigation. (2015, August). *How to identify a bad pressure regulator* [Web blog post]. Retrieved from https://www.senninger.com/news/2017/09/28/how-identify-bad-pressure-regulator

von Bernuth R. D., Baird D. (1990). Characterizing pressure regulator performance. *American Society of Agricultural and Biological Engineers.* ASAE. 33(1): 0145-0150. doi: 10.13031/2013.31308

Water hammer - How to prevent water hammer. (2018, September). The Plumbing Blog [image]. Retrieved from http://www.plumbingblog.co.uk/water-hammer-how-to-prevent-water-hammer/