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A Review on Analytical and Optimal Design of Main Line for Centre Pivot Sprinkler System

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ABSTRACT

The efficiency aspects of surface irrigation, particularly in minimizing waterlogging and drainage losses. Proper design is essential to ensure that irrigation systems achieve high application efficiencies while also reducing the risk of negative impacts like waterlogging and excessive deep drainage. This can lead to increased irrigation water use. For example, on self-mulching clay soils, excessive deep drainage caused by prolonged ponding resulted in a 1.2 ML/ha increase in irrigation water use. This highlights the importance of carefully managing the irrigation timing and ponding to avoid unnecessary water loss. Waterlogging, particularly on heavy clays or soils with low permeability, can stunt crop growth and reduce tiller numbers, which affects overall yield. This issue is most significant during winter and early spring when water retention in the soil is higher, and soil permeability may be low due to sodality or compacted layers. Soil health management to maintain good permeability and prevent sodality issues.

Key Words:- surface irrigation, deep drainage, Waterlogging, Soil health management, unnecessary water loss

Introduction

That's a great observation about the increasing adoption of center pivot irrigation systems worldwide. The combination of climate change-induced droughts and technological advancements is making these systems more attractive, even beyond their traditional large-scale farming applications.

Some key factors contributing to this trend include:

Water Efficiency – Modern center pivot systems incorporate precision irrigation, variable rate application, and remote monitoring to optimize water use and reduce waste.

Energy Savings – Advances in solar-powered and low-pressure systems help cut down energy costs, making them viable in regions with limited electricity access.

Affordability & Accessibility – Smallholder farmers, particularly in Africa, are benefiting from cooperative and shared-use models that reduce individual investment costs.

Adaptability – These systems are now designed to work even in challenging terrains and with alternative water sources like treated wastewater.

Literature Review

Nicolini and Zovatto (2009) studied in order to solve the issue of ideal pressure management in water distribution systems. Pressure-reducing valves were controlled in this study. Reduced pressure was intended to control water leaks, which were currently one of the main issues for water utilities because they could often represent a significant portion of the total volume provided. Multi-objective evolutionary algorithms addressed the two-criteria optimization issue of choosing these valves' quantity, position and setting. The first need was clearly expressed by minimizing the number of valves and the second was by minimizing the overall leakage in the system when maintaining the appropriate pressure at each node. The main advantage of the multi-objective approach was that it identifies several trade-off alternatives in a single run. That provided the best solutions with various levels of compromise between the conflicting objectives. At the same time, the information needed to choose and operate pressure reduction valves practically might be ascertained.

Daccache *et al.* (2010) derived that the hydrant pressure head may impact the performance of on-farm irrigation systems in an on-demand water distribution system which might be susceptible to significant changes depending on the discharge running through the pipes. A computer model was built, calibrated and used to compare the onfarm network with the hydrant characteristic curve at a certain operational condition to evaluate the efficacy of a drip irrigation system. The flow regulator inside the hydrant was essential for stabilizing the network's performance at hydrant pressures more significant than 27 m. When pressured on-demand systems gave water, the strategies discussed here were useful for ensuring proper irrigation management.

Delirhasannia *et al.* (2010) designed a single fixed spray sprinkler exposed to the wind was used to imitate the water application pattern on a field watered using a centre pivot. The model described a dynamic square grid of cells for applying water and a static square grid for collecting it. The dynamic grid recorded information on the water application pattern of a single spray sprinkler and followed the movement of the centre pivot lateral. The dynamic grid periodically gave water to the static grid which represented the whole field. The model's outputs included the applied water distribution plan and irrigation uniformity measurements (radial, travelling path and global). Simultaneously, several tests were carried out utilizing pivoting and single spray sprinklers. The model's findings and field observations have good agreement.

Afterwards, the average applied water depth and the Heermann and Hein uniformity coefficient had a root mean square errors of 0.02% and 0.08 mm, respectively. To demonstrate how wind affects irrigation uniformity model simulations were run.

Díaz *et al.* (2011) presented pressurized irrigation networks and a method for assessing water and energy utilization was created. During the 2006–2007 irrigation season, performance indicators created by the International Program for Technology and Research in Irrigation and Drainage (IPTRID) and the Institute for Diversification and Energy Savings (IDAE) in Spain were applied to ten representative irrigation districts with on-demand pressurized networks. The results confirm that modern irrigation systems require much energy to operate. The energy needed to apply an average depth of 2,589 m^3/ha was calculated to be 1,000 KWh/ha. The pumping energy (P.E.) efficiency was 58% and the required power per irrigated hectare was 1.56 KW/ha.

Moreno *et al.* (2012) provided that one industry where energy use was rising the irrigation because of updated techniques created to conserve water by using pressurized water delivery. One of the main expenses in irrigation was energy. This work used a novel technique to determine the least overall water application cost (investment + operating expenses) for centre pivot systems that used healthy water. The recommended approach enhanced the pump's effectiveness, characteristic curves, pipe types, widths for distribution and pumping. The technique also considers economic factors, hydraulic factors (head losses in pipes, flow demand) and soil variables (infiltration parameters, surface storage capacity, and impermeability). Dynamic water table level and temporal fluctuation were examples of hydrological variables (energy costs, pump and pipe costs). In order to aid managers and technicians in transferring technology, free software (DOP, Optimal Pivot Design) was developed using MATLAB. The lowest water application cost was reached in all case studies for centre pivot systems irrigating 75 ha utilizing lateral pipes of 254 mm.

Valín *et al.* (2012) described that Centre-pivot sprinkler irrigation gained much traction. As a result, the simulation model DEPIVOT was created to design new systems or alter existing systems. It was aimed at providing advice to farmers. The programme consists of a Visual Basic simulation suite and an Access database. For the following reasons, the model was broken into five basic sub-models: (a) calculating the total irrigation needs; (b) estimating the lateral pipe spans using hydraulic calculations of friction losses and corresponding operational simulations, accounting for topographic impacts and the probable necessity for an end gun; (c) selecting a sprinkler system which entails figuring out the pressure and discharges at each outlet and accounting for pressure regulators; (d) confirming the sprinkler system by figuring out the potential runoff by comparing application and infiltration rates at particular points along the lateral; and (e) figuring out the anticipated uniformity performance indicators when the system was in use. Until the ideal circumstances were met. The user determines if performance was within the initial goal values and may design various sprinkler packages. Indicators of performance were calculated utilizing information from farmer fields to assess the present systems in use. The model may change the present systems and improve management in response to farmer demands. This section explained the idea with examples of how it might be applied to picking a sprinkler system and figuring out each runoff potential.

Lai *et al.* (2013) presented a new approach since the reverse seawater osmosis (SWRO) sector used much energy. In SWRO facilities, pressure exchanger and booster pump-equipped energy recovery systems were frequently employed. The challenge of constructing booster pumps, a crucial component of an energy recovery system comes from their high inlet pressure, medium causticity and high flow rates. Significant flow rates and high-efficiency requirements strain hydraulic design significantly, while high inlet pressure complicates seal design. This study presented the design and optimization of a 625 m^3/h booster pump using the output of a CFD (Computational Fluid Dynamics) simulation. A novel high-pressure mechanical seal was used to the impeller where volute was carefully constructed and the axial force was evenly distributed. The efficiency of the pump was increased following optimization based on blade redesign. According to the CFD simulation results, the best efficiency at the design point was greater than 85 %.

Mahar and Singh (2013) presented a model for the total cost of a pumped water delivery system, which includes the capital costs of the pipeline and pumping units. The replacement costs of the different components and the energy costs related to system operation. Energy and pipeline capital costs were nonlinear factors of pipe diameter. Additionally, the nonlinear nature of the pump characteristics, component replacement costs and rising energy expenditures were considered. This work proposed a nonlinear optimization model to construct a pumping main for the required discharge, static head, pump characteristics and economic factors. The optimization model satisfies the equations about the pump characteristic curve while optimizing the yearly cost of the pump and pumping main. How the proposed model may be used was demonstrated through a design example. The ideal discharge range with pump efficiency for an available diameter or the optimal pumping primary diameter with pump efficiency for a required discharge were determined using the optimization model. The optimization model showed how growing components and energy prices impact the size of the pumping main. The ideal operating parameters for a new pumping system may be determined using the model which can also be used to examined an existing pumping system.

Mutikanga *et al.* (2013) discussed that water issues and revenue losses were global problems the water business faces. Tools and techniques have been developed over time to lower these losses and increase the effectiveness of water distribution systems. This study examined the methods and techniques currently used to measured track and reduce losses in water distribution systems. The goal was to pinpoint the tools and techniques used, knowledge gaps and areas that required additional investigation in the future. The review's conclusions showed numerous technologies and techniques for managing water loss had been created and used. They ranged from straight forward management tools like performance indicators to extremely complex optimization techniques like evolutionary algorithms. However, it had been discovered that their general applicability to existing water distribution systems was somewhat constrained. The gap between theory and applications could be closed by strong cooperation between research institutes and water service companies. Despite not being thorough, this review could be a valuable source of information for professionals and researchers working on water loss management in water distribution systems.

Kurek *et al.* (2014) devised a methodology to operate water distribution networks and this paper offers a multi-objective model for balancing pumping costs and water quality. There were restrictions placed on flows, pressures, routine tank operations and tank storage. Under extended period simulation settings and fluctuating energy tariffs. The methodology was applied to two example applications of increasing complexity and integrates the multi-objective SPEA2 algorithm and EPANET. The suggested method enables decision-makers to fully utilize the gathered data on a multiobjective scale for cost, water quality and storage reliability criteria. By engineering judgement verifying the model outcomes on all runs for both sample applications. The model's appropriateness as a decision tool was established. The use of variable speed pumps to mimic the whole pumping station operation with an assumed constant efficiency. The storage reliability constraint as a u-priori set parameter and the computational work required to discover solutions for real-sized systems were the fundamental limitations of the model.

Ghorbanian *et al.* (2015) created many standards specify the essential minimum pressure at which water must be delivered to customers by a water distribution system (WDS). Thus, it was noteworthy to note that while water delivered under the same pressure in some countries was deemed unacceptable. The pressure delivered to a client in other countries may be deemed high enough to fulfil standards. This study described the effects and ramifications of modifications to the minimum pressure criterion (MPC) for WDS design. Lowering the MPC may decrease pressurebased demands like a faucet, shower, and lawn watering by using less energy reducing leakage and reducing the frequency of pipe breaks. It may also improve system performance. Lowering this requirement nevertheless, can increase the system's susceptibility to low-pressure failures, whether hydraulic (such as an inability to provide the necessary flow) or safety-related (e.g., increasing the risk of an intrusion event associated with hydraulic transients). Therefore, before making modifications to the MPC, it was essential to grasp the implications and difficulties fully. The importance of the minimum pressure standard and the problem of how the MPC was enforced/ensured. The WDSs were rarely linked in plans to manage and prevent lowpressure incidents.

Izquiel *et al.* (2015) derived that the centre pivot was one of the most widely used irrigation methods worldwide. The goal was to create a tool that would help water distribution, centre pivot systems be designed and managed in such a way as to minimize the cost of water application per unit area which included investment, operation, and maintenance costs. Two alternatives were considered to achieve this goal: directly from an aquifer or by employing a regulating reservoir to supply the centre pivot. The study area simulated the minor CT was 70 ha for direct pumping from the borehole and 100 ha for using an intermediary reservoir. Incorporating a regulation reservoir resulted in fewer CT than direct delivery from the borehole for S > 100 ha for any DWL. CT rose linearly with the DWL due to a significant increase in Ce, which predominantly impacts the cost of water extraction from the aquifer and has a less significant influence on the application cost of the irrigation system.

Mostafa *et al.* (2015) introduced a centre pivot system that were on the market from the manufacturers allowed users to adjust irrigation water application rates by adjusting speed. However, these systems often cannot alter the application rate along the pivot boom's length. The entire process can speed up to apply more water or slow down to apply less. When a pivot crosses dry (sandy) and wet (drainage region) terrain, a conventional irrigation system would have to deal with the issue of over- or underirrigating one particular area. On the other hand, a variable-rate pivot might simultaneously apply more water to the dry region and less water to the wet area. The system being studied at the moment is a fundamental variable rate centre pivot. The system was created and put through a two-year test period where the amount of water saved and sugar beet yield were assessed. The contrasts were easier to see than they would have been during a high wet year during another season since one season was mostly dry. The results showed water savings in the second season (102 mm) but no difference in the first season's water usage (36 mm). For the two seasons, sugar beet and sugar yield were equivalent under full irrigation (100% of water balance) and VRI (80% of water balance) on loamy soil (medium quality), proving that it can produce the same product while using less water.

Vicente *et al.* (2015) presented a Water Distribution Systems (WDSs) frequently employ pressure management (PM). It has been a strategic objective in the sector for the past ten years to develop new scientific and technical approaches. Progress has not always been reflected in actual activities though because there has not been a thorough study of the outcomes of practical situations. This paper provided a comprehensive analysis of the most recent developments in PM-related areas to address this problem. The technique proposed was based on a case-study comparison of qualitative thoughts utilizing published information from 140 sources. The findings included a qualitative investigation of four areas: (1) the goals achieved by PM; (2) different regulatory measures, such as sophisticated control systems via electronic controllers; (3) fresh approaches to district planning; and (4) the creation of optimization models related to PM. The four aspects above' development were examined and talked about. Conclusions on the current state of each factor were made and suggestions for additional research provided.

Darko *et al.* (2017) derived a water was the most limited resource. Thus, it was unnecessary to emphasize how crucial it was to utilize it wisely in the agricultural sector to support agricultural expansion and slow environmental damage. Future land reclamation initiatives will play a far more significant part due to the accomplishments of employing sprinkler irrigation to produce new areas. To increase on-farm productivity, it was crucial to optimize water consumption through the adequate improvement of water management practices and other production aspects. This study identified several variables that impact sprinkler irrigation's uniformity and water usage effectiveness, suggesting potential strategies to enhance such crucial crop production metrics. The emphasis of the study was on an irrigation system that applies water effectively such that it remained in the root zone and it was always accessible in quantities large enough to fulfil crop water requirements. It offered workable suggestions for controlling irrigation systems within acceptable bounds while keeping in mind the impact of wind, which was a significant cause of sprinkler irrigation inconsistency.

Musriyadi and Naifah (2017) derived dredgers were a type of watercraft used to transport goods from below the water's surface to an area above it. Dredgers can be classified as Suction, Bucket, Backhoe and water injection dredgers among others. A revolving cutter head on the Cutter Suction Dredger (CSD) was used to cut and break up stubborn soils. Dredge pumps were used to pump the soil up and it was dumped into a deposit location via a floating pipeline and pipelines on land. The material may occasionally be deposited into split hopper barges that were docked next to the cutter suction dredger. At the deposit place, these split hopper barges discharge the soil. The pump unit was the most crucial component of the dredger. NPSH was required to calculate the pump's performance capability and efficiency rating. Booster pump performance analysts were required to maintain the pump's effectiveness and performance. This study described the drawing process and computerized simulation of pump performance using 3 different fluid types and five impeller rotation scenarios. The pumps utilized in this study were more effective when used with fluids that tend to condense from liquids and less effectively used with pure water fluid.

Muller *et al.* (2020) developed a new methodology using mathematical optimization techniques. In the design and operation of water delivery systems that offer the potential to improve energy efficiency while also lowering investment costs significantly. It provided a systematic methodology utilizing mixed-integer nonlinear and mixed-integer linear modelling approaches for optimal design and operation of pumping systems in actual high-rise structures. It also takes into account different booster station topologies such as central booster stations that are decentralized, parallel and seriesparallel. In order to confirm the accuracy of the underlying optimization models with actual system behaviour present validation results based on tests utilizing a modularly constructed pumping test rig. It can be used the models to incorporate layout and control decisions for various load scenarios producing a deterministic analogue of a two-stage stochastic optimization process. By piecewise linearizing and relaxing the properties of the pumps, it generated mixed-integer linear models. In order to save calculation time, it can provide a problem-specific precise solutions method in addition to the commercial solver-based solution. In order to efficiently explore the solution space, it divided the issue into smaller subproblems that can be partially cut off throughout the solution process. The effectiveness and suitability of the proposed solutions for actual structures were also examined. Engineers assessed the technical aspects of the solutions while keeping in mind the critical economic trade-off between capital expenditures and operational expenses.

Sutrisno *et* al. (2020) discussed that using equipment and tools to aid production could cause loud sounds. A business that manages the local water supply and processes drinking water was called PDAM Tirtanadi. However, the company's equipment and products had the potential to produce noise. In order to assess the association between communications disruption, psychology and physiology, the article first measured the noise intensity in booster pumps at five different locations. The sound level metre was used as a study tool and the sound pressure level measurement method was based on the Indonesian Minister of the Environment Decree Number 48 the Year 1996. The outcome demonstrated that the noise level increased by 5 points and exceeded the threshold limit value (TLV) by 96.40 dB - 96.75 dB. The disruption of communications, psychology and physiology was further significantly impacted by noise intensity with an R-value of multiple correlations of 0.884.

Al-agele *et al.* (2021) presented that large fields were irrigated with centre pivot irrigation systems. They were more efficient in applying water than sprinklers or surface irrigation methods. However, dynamic elevation spray application (DESA) may be even more effective, responding to plant growth and canopy heterogeneities by dynamically altering the nozzle height. The plant canopy height was a crucial piece of information needed to achieve DESA but it was difficult to measure in real-time due to canopy heterogeneity and the possibility of active water spray interference. For this, an ultrasonic sensor was examined. Evaluations in the lab and on the ground were also done. For maize, clover and potato lab studies employed view angles ranging from 0 to 35 at increments of 5° and heights ranging from 0.5 m to 1.75 m. Field assessments were conducted using green beans, green peppers, eggplants, grass and the ground at heights ranging from 0.5 m to 1.25 m with views of 0° and 5°. Results from the lab indicated that with each unit increase in angle's degree. DESA sensor accuracy droped by roughly 0.5 %, regardless of plant or height. The sensor accuracy decreased by about 9% when maize was utilized. According to the field results, the green beans with a 1.25 height had the lowest accuracy (92 %). Field experiments with active water spray produced considerably different measurements from those without water spray, although they still had accuracy levels over 97 %. These results showed that employing ultrasonic sensors for DESA was feasible.

Alsayim (2021) discussed that the research was carried out on the eastern bank of the Atbara River during the winter of 2019–2020 under desert-high terrace soil. The increasing usage of modern irrigation systems, particularly centre pivot irrigation systems necessitate understanding how effectively they can be used. Thus, defining the characteristics of water distribution under these systems. The four centre pivot sprinkler irrigation systems make up the trial units. Warm winters and a semi-arid environment were the norms. Penman-Monteith results for evapotranspiration varied from 5.69 to 6.26 mm/day for November and December and from 6.14 to 6.89 mm/day for alfalfa crop (Medicago sativa) consumptive usage, respectively. The results revealed that diverse management practices impacted the hydraulic performance of uniformity coefficients C.U., distribution uniformity D.U. and potential efficiency of low quarter PELQ for the centre pivot systems. This indicated a lack of adherence to the design requirements for sprinkler placement and distribution an undesirable irrigation schedule.

Rakibuzzaman *et al.* (2021) found that connecting a booster pump system (BPS), which consists of two or more vertical or horizontal centrifugal pumps connected in series. This may control the number of revolutions using an inverter. The most appealing features of booster pump systems, efficiency and energy savings can be increased by regulating individual pumps' operating parameters and evaluating their flow rates. A system for booster pumps that used a flow sensor to detect various flow rate levels and a control system to regulate the number of revolutions per minute for each pump with low and high flow rates was essential for better functioning. Computational fluid dynamics was first used to build the turbine-type flow sensor. Testing proved the accuracy of the flow sensor after it was improved using computational fluid dynamics techniques with a measurement error of 0.4 %. The intended flow sensor's final flow measurement accuracy was within 4 %. Additionally, a testing pump facility was constructed and used to evaluate the booster pump system's effectiveness and determine the amount of energy saved. The flow and frequency control operation techniques were then employed after running a single pump with a modest flow rate operating at a control valve. This technique raised the drive pump's permitted output by raising the inverter's frequency. Power savings improved because of the low-flow rate pump's long driving range when the frequency corresponding to the permitted output was obtained rather than the high flow rate pump. Investigations into the energy consumption of the new system revealed that depending on the system under consideration, energy savings were on average 6.2 % when compared to the traditional system. A booster pump system with a flow sensor has been designed and it had been tried or proved successful.

Methodology

The Center Pivot Sprinkler System is a highly efficient irrigation method used in large-scale agriculture. It consists of a rotating sprinkler arm mounted on wheeled towers that move in a circular pattern around a central pivot point, distributing water uniformly over the field.

Site Selection and Preparation

- Choose a flat or gently sloping field to ensure even water distribution.
- Conduct a soil and water analysis to determine water needs and irrigation capacity.
- Clear obstacles from the field that could hinder the system's movement.

System Installation

- **Central Pivot Point:** Install a water supply line and pivot stand at the center of the field.
- **Pipeline and Towers:** Assemble galvanized steel or aluminum pipes supported by truss structures and wheeled towers.
- **Sprinkler Heads:** Attach high-efficiency sprinkler nozzles at specific intervals along the pipeline.
- **Control System:** Install automated controls, pressure regulators, and flow meters for water efficiency.

Water Source and Pumping System

- Connect the pivot to a reliable water source (well, reservoir, or canal).
- Install a pump and filtration system to maintain proper water pressure and prevent clogging.

Operation & Irrigation Scheduling

- **Rotation & Movement:** The system moves in a circular motion at a controlled speed to ensure uniform coverage.
- **Irrigation Scheduling:** Set schedules based on crop requirements, soil moisture levels, and climate conditions.
- **Pressure and Flow Control:** Maintain consistent water pressure to optimize efficiency and minimize water loss.

Maintenance & Troubleshooting

- **Regular Inspection:** Check sprinkler nozzles, pipes, and pivot joints for leaks or clogs.
- **Lubrication & Alignment:** Keep moving parts well-lubricated and ensure the system is aligned for smooth rotation.
- **Electrical & Control Systems:** Monitor automation controls and sensors for proper functioning.

Efficiency & Water Conservation

- Use **low-pressure sprinkler heads** to reduce water loss from evaporation and wind drift.
- Consider **variable rate irrigation (VRI)** to adjust water application based on field variability.
- Incorporate **soil moisture sensors** to optimize irrigation timing and prevent overwatering.

Conclusion

Investing in automation or autonomous systems takes this efficiency to the next level by reducing manual intervention and enabling consistent, precise control over irrigation events. Have you been looking into integrating more advanced technologies for irrigation regular audits and maintenance are key to keeping systems running optimally, especially with overhead or drip systems checking for application uniformity and ensuring system capacity through routine audits can help prevent water wastage and improve crop productivity. Proper timing of irrigation events, monitoring the supply head height, and checking siphon placement can go a long way in ensuring even water distribution. It's also essential to avoid crop stress caused by over or under-watering. Tools like soil moisture monitors, water advance systems, and channel level sensors make these tasks much easier by providing real-time data.

References

1. Delirhasannia, R., Sadraddini, A.A., Nazemi, A.H., Farsadizadeh, D. and Playan, E. 2010. Dynamic model for water application using centre pivot irrigation. Biosyst. Engg.,105:476-485.
2. Diaz, J.A.R., Poyato, E.C. and Perez, M.B. 2011. Evaluation of Water and Energy Use in Pressurized Irrigation Networks in Southern Spain. J. Irrig. Drain. Eng., 137(10):644-650. Evans, G.R. 2001. Center pivot irrigation. pp-4-6.
3. Ghorbanian, V., Karney, B.W. and Guo, Y. 2015. Minimum pressure criterion in water distribution systems: challenges and consequences. World environment and water resources congress. 777:791.
4. Goulter, I.C. 1992. Systems analysis in water-distribution network design: from theory to practice. J. Water. Resour. Plann. Manage. 118:238-248.
5. Izquiel, A., Carrion, P., Tarjuelo, J.M. and Moreno, M.A. 2015. Optimal reservoir capacity for centre pivot irrigation water supply: Maize cultivation in Spain. Biosyst. Eng., 135:61-72.
6. Kale, R.V., Singh, R.P. and Mahar, P.S. 2008. Optimal design of pressurized irrigation subunit. J. Irrig. Drain. Eng., 134(2):137-146.
7. Kang, Y., Yuan. B.Z. and Nishiyama, S. 1997. Design of micro-irrigation laterals at minimum cost. Irrig. Sci. 18:125-133.
8. Karmeli, D., Gadish, Y. and Meyers, S. 1968. Design of optimal water distribution networks. J. Pipeline Div., 94(1): 1-10.
9. King, B.A. and Wall, R.W. 2000. Distributed instrumentation for optimum control of variable speed electric pumping plants with centre pivots. Appl. Eng. Agric., vol.16(1):45-50.
10. Kurek, W., and Ostfeld, A. 2014. Multiobjective Water Distribution Systems Control of Pumping Cost, Water Quality, and Storage-Reliability Constraints. J. Water Resour. Plan. Manag., 140(2):184-193.