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Irrigation Design in Montana: Accommodating varying water accessibility across the continental divide.

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Project Summary

The design work performed in this project was conducted over two summers (2018, 2019) of internship experience with the Natural Resources Conservation Service (NRCS) across the state of Montana. The first summer's design work was based out of Glendive, MT, in Dawson County, approximately 50 kilometers from the North Dakota border. The second summer was in Missoula, MT, in Missoula County, near the Idaho border. The two areas differ significantly in topography, weather, and water availability with the main separating geographic influence being the Rocky Mountains.

This paper focuses on the design process and requirements for two farms located outside Glendive, MT and outside Stevensville, MT. The locations will be referred to in this document by their county locations, Dawson County and Ravalli County, respectively. Dawson County is on the far east side of Montana, and Ravalli County is on Montana's western border.

With both locations in the same state, they follow the same NRCS design standards. However, the design requirements, systems implemented, and crops grown can differ significantly between the two regions. In Dawson County, on the east side of Montana, many farmers with fields greater than 20 hectares have converted their irrigation systems to center pivots for irrigation. This transition is largely a result of the center pivot's ability to tightly control the application rate of water, resulting in a higher yield per gallon applied. Additionally, the cost of installation for a center pivot is significantly cheaper per hectare on the large fields compared to fields smaller than 10 hectares. In contrast, farmers in Ravalli County operate in smaller fields of around 4 hectares. These farmers historically use severely inefficient irrigation systems such as wild flood irrigation and are switching to more efficient systems such as hand and wheel line. At their relatively small operational scales, it would typically be financially inadvisable to install a center pivot on the land.

The NRCS is not able to directly reach out to farmers and propose or require implementations for land management practices. The NRCS is a non-regulatory agency, as such it offers assistance to those who ask for help, rather than mandating changes to the farms. At this point, the NRCS can begin helping the farmers improve their land management. The NRCS will work with farmers so that they can become better land stewards. A large part of the NRCS's engineering design work is in irrigation systems. The NRCS works to minimize water usage to meet the needs of the crops as well as minimize soil erosion. These designs were the primary responsibility of the author during his internship. The design for a farmer in Dawson County was replacing his old tow line irrigation system with a center pivot irrigation system. Upgrading this system resulted in a projected water use reduction, decreased labor, and increased the irrigable season (NRCS New Mexico, 2012). The design in Ravalli County provided an upgrade from a wild flood system to a wheel line system, increasing the farm's irrigation efficiency from 30% to 65%.

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1. Introduction

The Natural Resource Conservation Service, NRCS, is a federal organization under the U.S. Department of Agriculture. The NRCS serves to provide technical and financial assistance to farmers voluntarily “wanting to make improvements to their land” (NRCS, 2015). They want to “[help] producers prepare for what’s ahead;” with projects stating that farmers will need “to produce as much food in the next 40 years as they have in the last 500,” it is incredibly important to maximize the use of the available agricultural land (NRCS, 2015). While the NRCS is a national organization, its structure, goals, and management are controlled on a state level. While the structure in each state is similar, the states can vary significantly regarding priorities and resource concerns. In Montana, the farmers submit a proposal for the improvements they would like to make to their farm to their county NRCS office, referred to as field offices. The staff then creates a preliminary design plan for the project with rough cost estimates and materials needed. With this information, they rank all the proposed projects. At this point, they accept the projects going down the list until all the available budget is exhausted. The NRCS field offices can then begin the design and planning work for the farmers, as well as create a final summary of expenses that the NRCS will pay, leaving the remaining portion for the farmer to cover.

The primary financial assistance program used by the engineering office of NRCS is the Environmental Quality Incentives Program (EQIP). This program works to develop a conservation plan with the farmer that meets their needs as well as provide technical and financial assistance for implementing the conservation practice (NRCS, 2018). The conservation practices that are covered most often are irrigation, cover crops, prescribed grazing, and forest stand improvement (NRCS, 2018). In addition to the general EQIP funding, certain locations qualify for special initiatives that receive additional funding. In much of Eastern Montana, the Sage Grouse Initiative provides additional funding for many of the projects developed in that portion of the state (NRCS, 2018).

In determining if an irrigation system is to be funded by the NRCS, in Montana, an irrigation efficiency improvement must be greater than 10%. Both discussed designs meet this requirement. The farm in Dawson County is moving from tow line irrigation at 65% efficiency, to center pivot irrigation with 75% efficiency. The Ravalli County farm moves from a wild flood irrigation system at 30% efficiency to wheel line irrigation with 65% efficiency (Kohl et al., 1974). Potential designs are evaluated through the Montana Farm Irrigation Rating Tool program that assesses management factors, system design factors, and water quantity to determine the effectiveness of proposed changes.

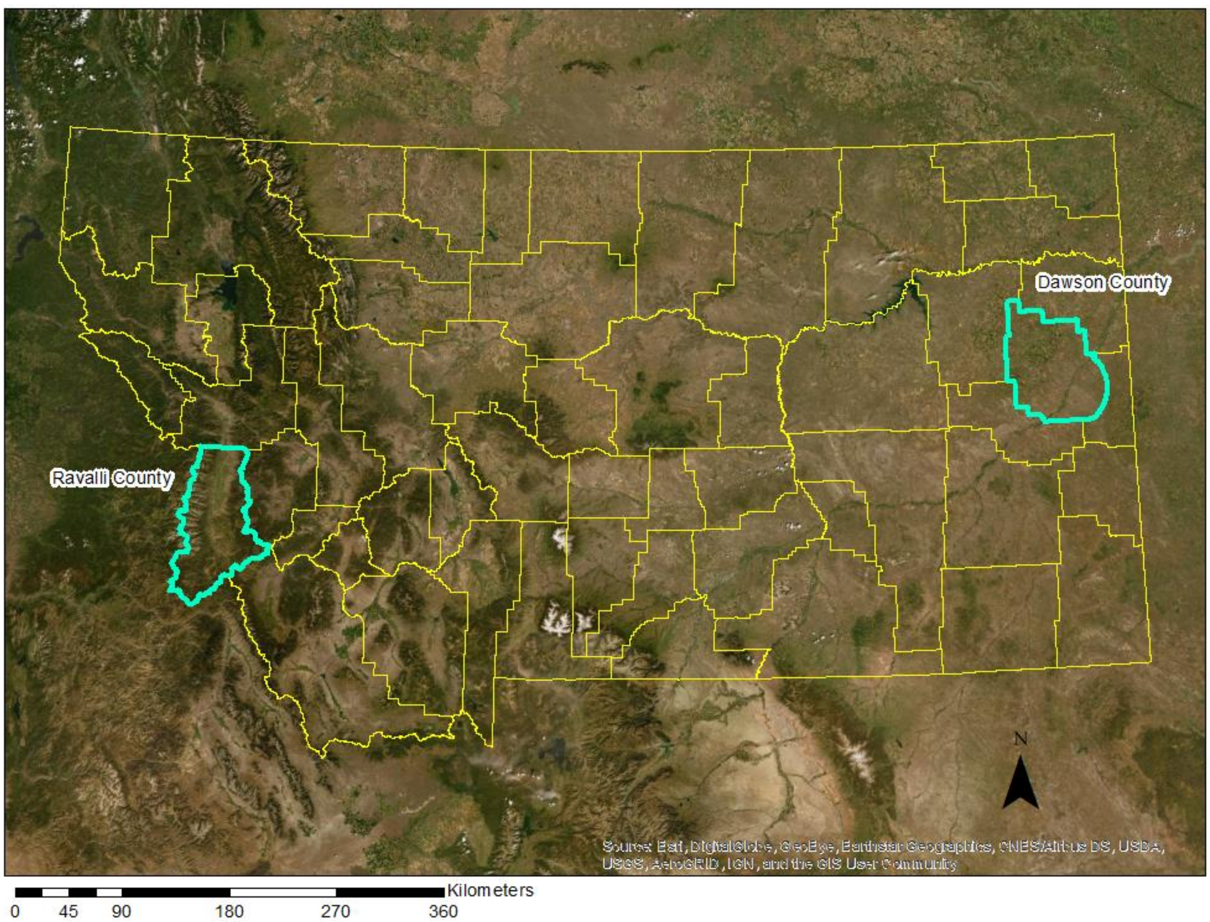

Figure 1: Map of Montana showing the location of Dawson and Ravalli Counties. Image Source: ArcGIS Base Map with County information from http://geoinfo.msl.mt.gov/ (Montana State Library, 2019).

Dawson County and Ravalli County are separated by a 965-kilometer, 9-hour car drive across a highly diverse landscape (Figure 1). The terrain changes from badlands and wide grass prairies on the east to mountainous rolling terrain on the west side of the divide. The wide diversity in topography has a significant impact on rainfall across the region and when it is available. Dawson and Ravalli County both receive about the same amount of precipitation annually, 31.8 and 35.4 centimeters respectively (WRCC, 2005, 2016). The main difference comes in when the water arrives. Dawson County gets 77% of its rainfall between April and September, while Ravalli County gets 55% (WRCC, 2005, 2016). When operating in Montana's dry climate, the 10-centimeter difference in rainfall received during the primary growing season has a drastic effect on what crops can be grown and what irrigation management techniques need to be followed. In addition, the soils in Eastern Montana generally have higher available water content and a deeper soil profile, meaning more of the rainwater is captured and made available to the plants. Water withdrawals from irrigation districts on the east side of the state are also much more reliable throughout the year. These differences help explain why the crops grown in Eastern and Western Montana, as well as their yields, are so different. Western Montana primarily grows grass and hay crops with some farmers growing small scale commodity crops, while in Eastern Montana it is much more common to grow wheat, barley, and pulse crops in addition to the standard hay crops (NASS, 2019).

Much of Dawson County receives its water from the Buffalo Rapids Irrigation District. This district supplies water for approximately 11,000 hectares of farmland (PBS&J, 2009). The Lower Yellowstone Irrigation District located in Richland County, northeast of Dawson, supplies water from the river to 22,300 hectares of farmland (PBS&J, 2009). On the other side of the state, irrigators pull most of their water from creeks fed primarily by snowmelt.

2. Literature Review and Project Background

2.1 Legal challenges with modern irrigation

The idea of converting all farms to more efficient irrigation systems to help solve the water crisis is not as straightforward as it would appear at first glance. A legal case between Montana and Wyoming helps to illustrate some of the less often discussed issues that could present themselves as a result of widespread irrigation practice modifications. In 2007, Montana sued Wyoming over violations of the Yellowstone River Compact where they claimed that “there was inadequate water available for Montana appropriators in the Tongue River and Powder River sub-basins” after the extreme droughts Montana faced in 2000 and 2006 (MacDonnell, 2012). The complaint focused on “irrigation of new acreage in Wyoming; new and expanded storage facilities; new groundwater pumping, especially associated with coalbed methane development; and increased consumption of water due to improved irrigation efficiency on existing irrigated acreage” (MacDonnell, 2012). “Montana requested that Wyoming regulate its post-1950 water rights so that Montana's pre-1950 water rights holders could receive water” (MacDonnell, 2012). The Supreme Court sided with Wyoming in its decision, but MacDonnell argues the ruling is “inconsistent with the fundamental law of prior appropriation and fails to adequately reflect hydrologic realities that bind together users of water” (MacDonnell, 2012).

There are two primary focuses raised in the case of Montana v. Wyoming: water rights and irrigation efficiency improvements. Water rights are a highly complex issue encompassing water use across the western United States. With water rights, the process works through “first in time, first in right” where a water user claims access to a specified flow rate at a certain point from a water source. The person with the oldest claim has the highest priority to the water source and can restrict the flow of those with later rights to ensure they receive their allotted flow rate. The lawsuit brings up the claim that conversion to more efficient irrigation systems increases overall water consumption. The argument focuses on the idea that "water 'saved' in irrigation use can then be made available for other, non-irrigation uses" rather than the excess water being collected and reused by downslope irrigators (MacDonnell, 2012).

The fears presented by the state of Montana in the lawsuit regarding additional water usage were not an issue discussed or considered in project selection and design by the NRCS. Instead, the focus was placed primarily on improvements in irrigation efficiency, thereby lengthening the farmer's available growing season. In post-build visits with farmers, there were no mentions of using additional water once the volume used for irrigation was reduced. Dawson County has a plentiful water source in the Yellowstone River, with water usage rates of so little concern that irrigation costs were based on a per-acre basis rather than the volume of water consumed. Ravalli County has the opposite problem whereby water supply limits prevent maximum production from the fields. Conversion of irrigation systems to more efficient technologies allowed the farmers to access water later in the growing season than they could previously. There is no excess water available for other uses as suggested in the Montana v. Wyoming case.

2.2 Irrigation in a global context

While the information written in this thesis focuses on irrigation practices within the state of Montana, the practices can be applied elsewhere. The Dawson County location is close to the North Dakota border and has very similar geographic features. In addition to sharing similarities to North Dakota, eastern Montana is very similar to the province of Alberta in Canada. The southern region of Alberta is a continuation of the Great Plains of the US, with a similar climate to that seen in eastern Montana. The irrigation systems are very similar, but there are differences in land management strategies that play a contributing factor in the overall soil health and fertility.

The location in Ravalli County is not as representative of the surrounding farms given the varied terrain of the area, but this project can still inform decisions in other areas. The site is in a valley and can have similar conditions to farms to the west in Idaho. The farms in this area vary in size from small plots of 4 hectares to ones considerably larger, more similar to the areas seen in Eastern Montana. Many of the smaller farms are operated primarily by hobbyists, with the larger farms run as multigenerational operations.

The Koppen-Geiger Climate Classification system provides a quantitative system for classifying world climates through vegetation, precipitation, and air temperature (Kottek et al., 2006). Using this system (Fig. 2), Dawson County is given the code BSk giving it the classification of arid climate, steppe precipitation, and cold arid temperature (Kottek et al., 2006). Ravalli County is given the code Dfb, meaning it is a snowy climate with a fully humid precipitation zone and warm summer temperatures (Kottek et al., 2006). When expanding, one can compare the climatic zones of the two studied areas within Montana and determine their global counterparts. Dawson County has the same climate classification as parts of Argentina, South Africa, Kazakhstan, and Mongolia (Kottek et al., 2006). Ravalli County's climate is similar to most of Eastern Europe as well as the southern half of Canada (Kottek et al., 2006).

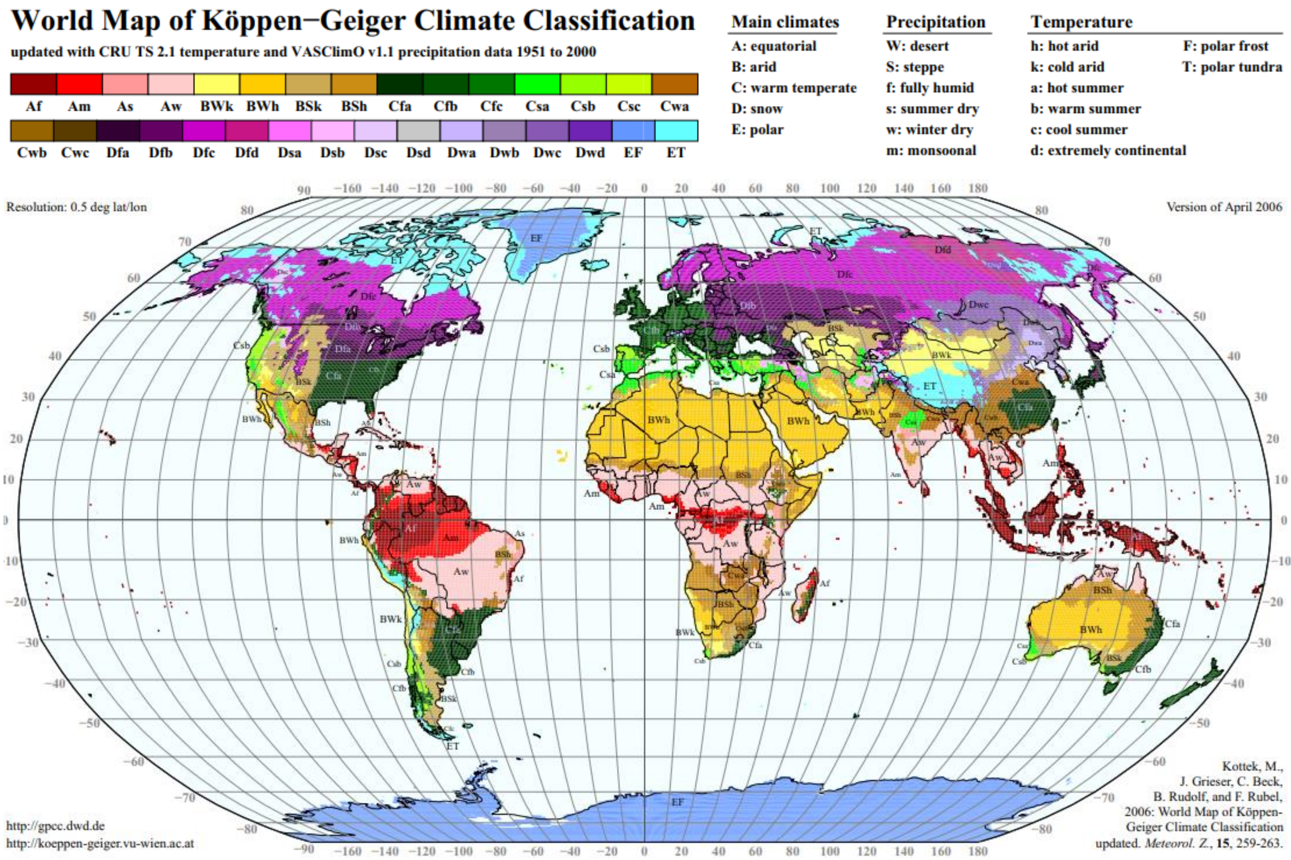

Figure 2: Koppen-Geiger Climate Classification world map (Kottek et al., 2006).

Climate change is expected to impact yield and farm income for farmers in Montana. A study conducted by Qiu and Prato (2012) on the Flathead Valley of Montana, located in the northwest corner of the state, projects farm yields, without adaptation, to drop between 7% and 48% compared to historical averages. The study found that with irrigation, yields can be maintained, but only with a continuously available supply of water (Qiu and Prato, 2012). Since Montana began recording snowpack levels in the 1930s, the state's snowpack has decreased, with a large uptick in decline beginning in the 1980s [high agreement, medium evidence] (Cross et al., 2017). Snowmelt now occurs earlier in the spring than historical trends with projections suggesting the "patterns are very likely to continue into the future as temperatures increase [high agreement, robust evidence]" (Cross et al., 2017). With much of western Montana's irrigation water supply dependent on snowmelt, late-season water availability will be further limited by the lack of late-season snowpack remaining to melt into the streams. Regardless of water availability, the study by Qiu and Prato determined that regardless of actions taken by farmers to combat the effects of climate change, net farm income will decrease compared to historical averages (Qiu and Prato, 2012). Additionally, they determined that the cost of installation and running a center pivot system is not financially beneficial compared to a more traditional style of irrigation (Qiu and Prato, 2012). However, these cost estimates do not take into consideration the funding that many farmers receive from the NRCS towards the purchase and installation of the more efficient center pivot irrigation systems. When this is taken into consideration, the financial benefit will likely become more apparent.

The USDA Agricultural Research Service (Evans, 2001) states that 29% of all irrigated land is under center pivot irrigation, accounting for 60% of all sprinkler irrigated land in the U.S. Thus, sprinkler irrigation provides 48% of all irrigation in the U.S. in 2001 (by land area). This document also reports an increase in center pivot usage of 50% from 1986 to 1996 (Evans, 2001). In 2016, a report from the Congressional Research Service stated that 58% to 65% of irrigation systems in the U.S. are under pressure-based systems (Stubbs, 2016). The rise in prevalence of pressure-based irrigation systems shows a general trend across the U.S. of powered irrigation as farmers aim to maximize yields and reduce their total labor input per acre as the average farm size expands (USDA, 2019).

The source document that the NRCS uses in calculating the expected efficiencies in their installed irrigation systems is the Agronomy Tech Note 76 published by the New Mexico branch of the NRCS. Tech Note 76 puts the typical efficiency of a center pivot system between 75% and 90% with NRCS field offices typically using an expected efficiency of 75% in their calculations (NRCS New Mexico, 2012). In contrast, the report generated by Hoffman and Willett places the expected efficiency of a center pivot at 70% (Hoffman and Willett, 1998). Tech Note 76 gives the irrigation efficiency range for a wheel line system as 60-75% with an application efficiency of 65% typically used in calculations (NRCS New Mexico, 2012). Wheel line's application efficiency is approximately 65% (Hoffman and Willett, 1998). While the NRCS publishes a wide range of potential efficiencies, likely to accommodate for climatic and land differences, the expected efficiencies typically used in calculations lines up well with the data published by other groups.

As mentioned in the 2017 climate report published by the state of Montana, “groundwater demand will likely increase as elevated temperatures and changing seasonal availability of traditional surface water sources force water users to seek alternatives [high agreement, medium evidence]” (Cross et al., 2017). Current NRCS practices do not involve looking at the long-term sustainability of groundwater stores when placing pumps. To be considered viable, a pump only needs to be able to meet the required discharge of the project design. Groundwater provides some of the baseflow to the streams that irrigators rely upon, so continued depletion of groundwater resources will have compounding effects on limited water availability for irrigators throughout the region (Cross et al., 2017).

3. Methods

3.1 The NRCS Planning Process

The NRCS planning process consists of three phases and nine steps. To fully incorporate designs, multiple people within the NRCS collaborate to develop a comprehensive land management strategy for the client. The engineering side focused on designing the irrigation and stock water systems for the land. Others would help the landowner develop a soil management or cattle grazing strategy. Through this collaborative effort, all the implemented strategies work together to maximize the effectiveness of each independent system. Improved soil management practices help the engineers to develop solutions for the soil to retain available water, as well as reduce erosion keeping a higher-yielding soil layer on the land. Together, the NRCS employees were able to complete the planning process for the client. The steps of the NRCS Planning process (NRCS, 2014) are copied here (Table 1):

Table 1: NRCS planning process. Taken from (NRCS, 2014) and applied in this project in two locations.

(1) Phase I – Collection and Analysis *(i) Step 1 – Identify Problems and Opportunities.—Identify existing resource problems and concerns and potential opportunities in the planning area.* *(ii) Step 2 – Determine Objectives.—Identify and document the client's objectives.* *(iii) Step 3 – Inventory Resources.—Inventory and document the natural resources and their current onsite and offsite conditions and effects, as well as the economic and social considerations related to the resources.* *(iv) Step 4 – Analyze Resource Data.—Analyze the resource information gathered in Step 3, "Inventory Resources," to clearly define the existing natural resource conditions, along with economic and social issues related to the resources. Information from this step will help to further define and clarify problems, concerns, and opportunities.* *(2) Phase II – Decision Support* *(i) Step 5 – Formulate Alternatives.—Formulate alternatives that will achieve the client's objectives, solve identified natural resource concerns, and take advantage of opportunities to improve or protect resource conditions, and demonstrate a variety of technical and economic implementation strategies.* *(ii) Step 6 – Evaluate Alternatives.—Evaluate the alternatives to determine their effects in addressing the client's objectives and the identified natural resource concerns and opportunities. Evaluate the projected effects on social, economic, and ecological concerns. Special attention must be given to those ecological values protected by law or Executive order.* *(iii) Step 7 – Make Decisions.—The client selects their preferred alternatives and works with the planner to schedule the conservation system and practice implementation.* *(3) Phase III – Application and Evaluation* *(i) Step 8 – Implement the Plan.—The client implements the selected alternatives. The planner or technical expert provides the land manager with detailed practice implementation information, including engineered designs. Conservation staff will also provide practice layout, construction inspection, and certification. Each land manager directs the implementation of each practice. The planner provides encouragement to the client for continued implementation.* *(ii) Step 9 – Evaluate the Plan.—Evaluate the effectiveness of the plan in solving the resource concerns as it is implemented and work with the client to make adjustments as needed.*

3.2 Utilizing the NRCS Planning Process

The NRCS planning process outlined above in Table 1, was used throughout the design process for the two sites discussed in the thesis. The following section walks through the steps used in the planning portion of the design process and discusses specific design considerations at each site. With the design process in Dawson County, the engineer walked me through the process, explaining the steps and decisions made in the design. From this, I was able to perform calculations, and create a preliminary construction design document and technical drawings using Autodesk's Civil 3d computer-aided design (CAD) program. The Ravalli County design was more independent, where I generated ideas and design work independently and then discussed the plans with my supervisor to further refine the process. Both locations required a survey, which I assisted on, of the land to be conducted in order to get proper elevations along the site.

Given the nature of summer internships, time was limited, and the full design was not completed in the available time frame. In both locations, the preliminary design work was finished near the end of the internship session. The design is then passed to the field engineer to finalize the design and approval. After approval, the client hires a contractor to build the design to the specifications laid out by the engineering plans. Upon completion, the engineer is then responsible for checking the built design, certifying the completion to the desired specifications, allowing the NRCS to pay out on the build.

(1) Phase I – Collection and Analysis

(i) Step 1 – Identify Problems and Opportunities.

With both locations, the primary engineering problem is an out of date and inefficient irrigation system. Both sites are next to existing water sources that are able to provide irrigation water. The farmer in Dawson County has an existing pipeline system in place that can be used in the new system.

The farmer in Ravalli county has its water cut off during the growing season as water availability decreases. The exact cutoff date fluctuates depending on seasonal water availability but can be expected in early to mid-July.

(ii) Step 2 – Determine Objectives.

The farmers at both sites wanted to upgrade their irrigation systems to increase yield and lengthen their growing seasons. For farmers in Ravalli County, converting to a more efficient water application system would give them higher priority access to the water flow regulated by the local irrigation district.

With the increased time of available irrigation water, the farmers can expect to get approximately one additional cutting of alfalfa or grass per year.

(iii) Step 3 – Inventory Resources.

As mentioned in step 1, the farmer in Dawson County has an existing pipeline system. The existing system splits from the route needed to reach the target field, but the beginning portion of the pipeline leading from the water source can be used. This farmer also already has a pumping system in place which has the potential to be used again for the new system.

The farmer in Ravalli County has fewer existing resources available for use. The current irrigation supply is provided by a small mountain stream controlled by an irrigation ditch and provides irrigation to many other irrigators along the line.

(iv) Step 4 – Analyze Resource Data.

With the pump in Dawson County already installed and running for the last few years, it was expected to have losses in performance. To further reduce costs, a complete pumping test was not done to recertify the pump. Instead, an adjustment was made to the original pump power provided by the manufacturer to determine a worst-case scenario power loss. The adjusted power information was compared to the standards set in the Nebraska

Pumping Plant Standard to determine if the pump met the efficiency requirements of the NRCS (NRCS Montana, 2019).

The site in Ravalli County is fed by a ditch running water managed by the Sunset Bench Irrigation District. This irrigation district allows for irrigators to pull up to 56 L min^{-1} hr^{-1} ac^{-1}. On small plots, like the irrigator in this study, the irrigation district allows for a greater flow rate to meet the crop's irrigation needs.

The potential viability of a pump location as a water source is determined through the analysis of geologic records of the area. The Montana Bureau of Mines and Geology (MBMG) records the location, depth, and discharge of all well and pump sites across the state (MBMG, 2018). Using an aggregation of the MBMG data with geologic records of the area, one can estimate the expected discharge before financially committing to digging a well.

(2) Phase II – Decision Support

(i) Step 5 – Formulate Alternatives.

The farm in Dawson County has fewer options since it is on a much larger plot of land. The primary options that would be considered are wheel line and center pivot. Using some of the other options available in Ravalli County would be too labor-intensive to be viable in this scenario.

The Ravalli County location has multiple possibilities given its small size. The primary options used on small scale properties are K-Line, hand line, and wheel line. While not typically used on small acreage plots, center pivot is an option.

(ii) Step 6 – Evaluate Alternatives. Ecological values protected by law or Executive order.

The size of the field for the Dawson County location places some limitations on what irrigation methods will be suitable for the site as it needed to be ensured that the irrigation cycle time was less than the time it would take for the available water content (AWC) to fall below desired levels.

For the Ravalli County farmer, switching to a sprinkler-based irrigation system will give them higher priority in the irrigation district. The irrigation district regulates access to maximize the usage of available water through minimizing runoff as there is not enough water available from this creek to meet the needs of all irrigators within the district during the later summer months. This means that they will have access to water longer into the growing season.

(iii) Step 7 – Make Decisions. System and practice implementation.

The initial site analysis is typically performed by looking at satellite imagery, DEM maps, and topographic maps. Rough preliminary calculations are made, and a few potential alternatives are generated. This information is taken to the client for an in-person discussion. Here, the alternatives are discussed with the client to determine their preferences in design options to pursue. While at this site visit, measurements are taken with a survey grade Trimble GNSS system to have more precise information for further calculations.

Upon completing the site analysis, a design is created for the full irrigation system. The design includes all necessary parts for the construction, as well as full build instructions for the construction team to follow to meet NRCS specifications.

(3) Phase III – Application and Evaluation

(i) Step 8 – Implement the Plan.

The design is passed along to the landowner, who coordinates with a contractor to complete the design created by the NRCS engineer. The engineer confirms that the system has been built as specified in the design plan.

(ii) Step 9 – Evaluate the Plan.

Upon completion of the irrigation system, the engineer performs periodic checks with the landowner to confirm the system is operating as intended.

3.3 Site Descriptions and Considerations

3.3.1 Resource Availability

The site in Dawson County is over 55 km from the Yellowstone River, but a creek running along the field provides a water source. The creek is short in length at just under 9 km from the headwaters and feeds into the Redwater River. The creek feeds a 7.4 ha-m surface water storage pond where the farmer draws his irrigation water from. The irrigated land is relatively flat with a small gulley near the pivot point that the base is set upon. The soil was Attewan loam, a loam to clay loam soil, with good fertility.

The site in Ravalli County is surrounded by creeks that are all fed by snowmelt. This farmer’s water is managed by the Sunset Bench Irrigation District who regulates the ditch passing his land. The farmer operates on a significantly smaller, 4-hectare piece of land that slopes gently from east to west. The soil here is Brid-Woodchuck complex, a gravelly loam, reasonable for irrigation, but the gravel adds some problems to rooting of the vegetation.

3.3.2 Glendive, MT (Dawson County)

The system in western Dawson County was designed for a farmer looking to convert their tow line irrigation system to a center pivot. This client had an existing pipeline system they wanted to build from, so much of the design process involved examining the capabilities of their existing system and determining if they met current NRCS standards as well as the desired goals of the new design. The existing structure was based upon a storage pond that the client would draw irrigation water from. Pulling water from this pond was an old diesel pump leading onto an existing pipe system. This pipe led to an area that the client was no longer farming. Instead, they wanted to tee off of the existing mainline, and divert it into a new pipeline leading to a new field.

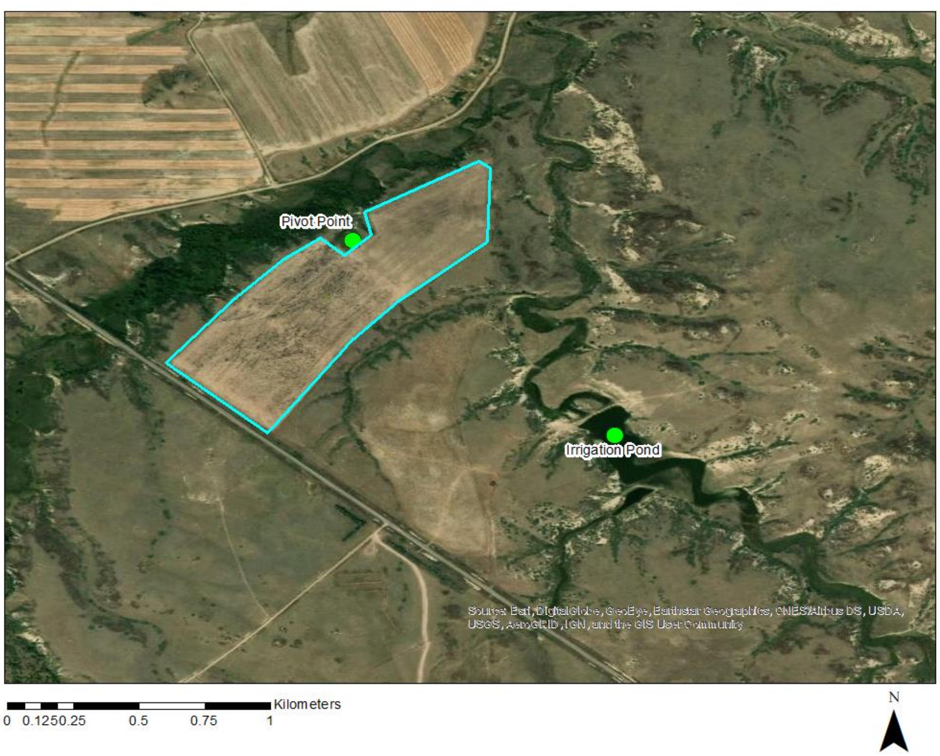

Figure 3: Map of the project area in Dawson County. The field boundary is outlined in blue, with attention drawn to the proposed pivot point and the irrigation pond. Image Source: ArcGIS Base Map.

The existing pond, shown in the SE corner of Figure 3, was originally constructed in the 1960s when the NRCS began working with the site. Due to its age, the pond had lost much of its depth to silting in overtime. Through looking at old design notes, as well as originally reported yields, we were able to determine an approximate depth of the original pond. To accommodate for potentially overestimated original numbers, the depth was raised a few feet when determining the water storage capacity. This change resulted in a predicted storage volume of 7.4 ha-m. The existing pump was compared to the Nebraska Pumping Plant Standards. According to these specifications, the pump had to meet an efficiency of 4.46 metric horsepower per hour per liter (NRCS Montana, 2019). Due to the cost and difficulties of measuring the fuel consumption of the pump and comparing those values to the power delivered by it, the manufacturer's information for the pump, a Deutz 912, was used with an error allowed for degradation of the pump over time. It was found that the pump should still meet Nebraska Pumping Plant standards and would not need to be replaced for the new project.

To ensure that the pond was an adequate size, the irrigation requirements for an alfalfa crop needed to be determined. Alfalfa was selected as the determining crop in sizing, as it has the highest peak consumptive use of the crops expected to be grown on the field. Examining the irrigation water requirements measured at weather stations surrounding the farm tells what the effective precipitation is in dry and normal years, daily average and peak evapotranspiration rates, growing season, as well as soil moisture carryover. Through this information, we can determine the irrigation rate for a field given how much water is consumed by the plants, and the available water content the soil can store. Through this work, one can create a water balance to compare the expected water volume yield against the crop water needs. Calculating the runoff volume filling the pond was done through looking at the average annual runoff, snowmelt fraction, 50% chance volume, and 80% chance volume. With the crop requirements and expected volume of the pond, it was determined that the farmer could expect to have access to water through the end of July.

This client had an existing pipeline system installed in the past that was used to irrigate a field on another section of their land. To help reduce costs, it was decided to install a tee off of the existing line, saving the client from purchasing an additional 850 meters of PVC piping. The primary concern with the existing line was its age as it had been installed over twenty years earlier. Typically, NRCS projects are implemented with an expected lifespan of the installed materials to be 15 years. In reusing the existing line's materials, the pipe section would be 35 years old by the end of the new project's expected lifespan. However, since this pipeline was buried, and the farmer was willing to take liability for the risk, we moved forward with connecting the new line to the existing designed system. At the tee, the pipe size was expanded from the existing 6" to an 8" (15 to 20 cm) nominal diameter 80 psi PIP PVC with the pressure checked using an NRCS spreadsheet calculating flow and pressure along stretches of pipe using Manning's equation and Hazen-Williams equation. The design change in pipe size was implemented since the pressures on the pipe were close to the allowable limit in the 6" pipe at static pressure. With the pivot at the downhill side of the line, if a sudden shutoff occurred, that end of the pipe would receive most of the force from the surge pressure.

3.3.3 Stevensville, MT (Ravalli County)

The farm in Ravalli County seen in Figure 4 is on a small 4-hectare plot (that size plot is relatively common in the area) and is planning on irrigating a field just over 2.5 hectares large on that land. The farmer's current method of irrigation is wild flooding, with a series of check dams diverting floodwater across their field from an irrigation ditch running next to it (Figure 5). The farmer plans on replacing their irrigation system with a wheel line system (Figure 7), moving the irrigation efficiency up from about 30% to 65% (NRCS New Mexico, 2012). In switching to a sprinkler system for irrigation, this farmer will be able to irrigate more consistently. Their irrigation district, Sunset Bench Irrigation District, gives priority access to irrigators running sprinkler systems, shutting down those using less efficient methods of irrigation during periods of low water, incentivizing irrigators to be more efficient. Additionally, since the water they can pull from the irrigation ditch is limited to 47-57 L min^{-1} ha^{-1} in this area, the more efficient irrigation system should allow the farmer to apply enough water to sufficiently supply the water needed to meet the peak consumptive use of their alfalfa crop. The inlet structure at this location will be placed about 61 meters west of the SW corner of the field along the primary irrigation ditch. A metal screen is placed along the bottom of the ditch, diverting some of the water into a sump directly next to the ditch. From here the water is pumped out and into the mainline running to the field. When running alongside the field, a series of risers are placed on the line at 18.3-meter spacings. The farmer can then tie the wheel line into these to run the irrigation water across the field.

Figure 4: Map of the project area in Ravalli County. The field boundary is outlined in light blue, with attention drawn to the existing irrigation ditch shown in dark blue, and the pump house location. Image Source: ArcGIS Base Map, base map updated February 2020.

Figure 5: Wild flood or cascade irrigation system in Ravalli County, separate from the one discussed in this thesis. Water flows down a ditch until it reaches the check dam shown above. Here it builds up until it flows over the bank on the downhill side flooding into the field below. Image taken July 18, 2019.

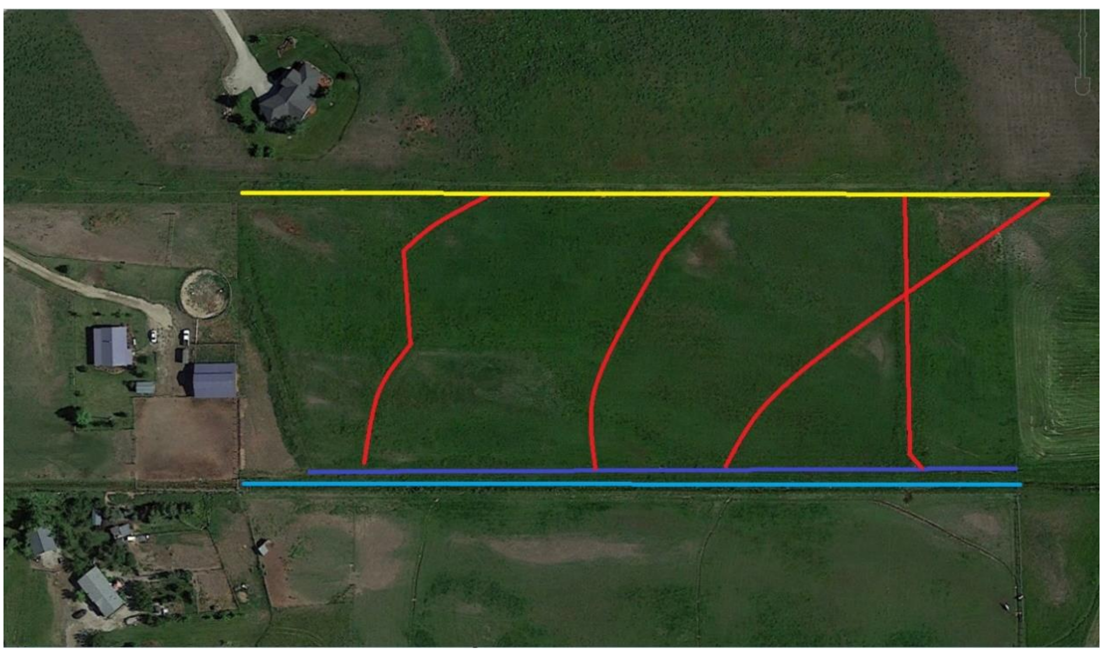

Figure 6: Ditch system across the field for flood irrigation on a farm in Stevensville, MT. The water flows northwest from the purple line to the yellow. The red lines correspond to the drainage ditches running through the field where a series of check dams moved to varying spots throughout to divert water onto the field. The purple line represents the farmer's ditch that he pulls water from, diverted from the main ditch in blue. The yellow line represents the overflow ditch for the excess water. Check dams are placed at the intersection of the purple line and red line to divert water onto the field. Additional dams are placed sporadically along the red line to divert water to the areas that have not yet been irrigated. Image Source: Google Earth Pro, accessed 7/29/19.

Figure 7: Wheel line or side roll irrigation system. This image serves as a reference for what the nomenclature is referring to as the system is not used universally across the country. Image source: OSU Ag.

Figure 8: Pump inlet structure from an irrigation ditch like the one planned for installation at the Ravalli County location. The water is collected below the grate and sucked out via a centrifugal pump through a sluice pipe. This allows water removal without air entering the system. The pump house is to be situated immediately behind the area shown in the photograph.

In designing the pump and inlet structure, it was important to install a sluice pipe at the bottom of the sump (Figure 8). This pipe would be run the length of the ditch and daylight when it reaches a point in the ditch with an elevation below that of the sump. This sluice pipe can be opened occasionally to prevent sediment accumulation in the pump.

4. Results

The information discussed in Section 3 is primarily done before any on-site visit and more in-depth discussions with the farmer. Section 4 will focus upon the development of the design after doing on-site analysis, speaking with the farmer fully about their intentions with the project, and the completion and building of the design. This section summarizes the design work completed over the course of the two summers.

(1) Phase I – Collection and Analysis

(i) Step 1 – Identify Problems and Opportunities.

In conducting an on-site visit of the field in Dawson County, a rugged valley, a small area with slopes around 20% slopes (Figure 3), in the north-central portion of the field was discovered. That portion of the field is where the pivot point would be located if the center pivot option was pursued. In discussing with the pivot manufacturer, it was determined that the slopes presented in this situation are still manageable for the center pivot system, so it would not raise problems. The storage pond next to the field, if cleaned can provide a steady supply of irrigation water through July.

The Ravalli County location has no significant geographic challenges, maintaining a gently sloping terrain across the field. Also, it has an existing irrigation ditch running parallel to the field that can easily be tied onto.

(ii) Step 2 – Determine Objectives.

The overreaching objective of the farmers at both the Dawson County and Ravalli County locations is to increase their yield and lengthen the time they can irrigate during the growing season.

In the Dawson County location, the farmer is wanting to expand their fields under irrigation through branching off an already installed pipe network on their property. In this situation, the farmer is wanting to maximize the use of existing equipment to minimize costs while still fully meeting the requirements to successfully operate the newly installed irrigation system.

The Ravalli County farmer is looking at reducing overall labor inputs and wants to install a more efficient irrigation system to give them higher priority access to the water provided by Sunset Bench.

(iii) Step 3 – Inventory Resources.

As discussed in Section 3.2, the farmer had an existing pump on site that they wished to continue using to reduce the total cost. To meet the desired application rate the pump needed to produce 1560 L min^{-1} and produce a TDH of 40 meters, resulting in a needed power of 25 hp. The nozzle package for the center pivot was designed off these values.

The site in Ravalli County had an existing ditch network from the Sunset Bench irrigation district that could be tied to in order to reduce the overall construction and modification needed. Building off the existing system ensures a consistent grade and predictable water flow rate.

(iv) Step 4 – Analyze Resource Data.

The on-site pump in Dawson County was found to meet the standards set by the NRCS so no upgrades needed to be made. The pond was determined to provide 7.4 ha-m of water on an average year allowing the farmer to irrigate through July.

To meet the expected irrigation needs, it was determined that the farmer would need to withdraw at a rate greater than the allotted 56 L min^{-1} hr^{-1} ac^{-1}. As a result, the farmer would need to pull at an additional rate, which is allowed by the irrigation district for smaller plots due to situations such as this.

(2) Phase II – Decision Support

(i) Step 5 – Formulate Alternatives.

In examining the site in Dawson County, the shape of the field lends itself to either a half circle pivot or a long wheel line irrigation system. A rugged valley in the north-central portion of the field is still navigable by a center pivot system, so it does not eliminate that option. The site in Ravalli County in comparison has more options. As mentioned in Section 3.2, K-line, wheel line, and center pivot are all viable systems.

(ii) Step 6 – Evaluate Alternatives. Ecological values protected by law or Executive order.

As discussed in Section 3.2, the primary alternatives for the Dawson County site were wheel line and center pivot irrigation systems. The shape of the farmer's field would be good for wheel line irrigation, and would irrigate a higher percent of the acreage, but would be labor-intensive. Additionally, given the length of the field, the cycle time necessary to maintain the AWC of the soil above the permanent wilting point would require near constant running of a wheel line system. The center pivot would be relatively hands-off in comparison, as the irrigation schedule could be programmed into the machine. With the information presented, the farmer selected a center pivot irrigation system for their project.

The primary alternatives in the Ravalli County site were hand line, K-line, and wheel line. The farmer at this site has retired and bought this land as a hobby farm. For the farmer, labor contributions were a factor in the decision-making process. Moving a handline multiple times a week, as is needed for the irrigation system, would be impractical for this farmer. The farmer decided that a wheel line irrigation system would best suit their needs for the final design project.

The farmer has the end say in which irrigation system they choose to use for their farm. If the irrigation efficiency improvements meet the requirements set by the NRCS, they will go forward with providing financial and design assistance for the project.

(iii) Step 7 – Make Decisions. System and practice implementation.

After installation of the center pivot, the farm in Dawson County will have an irrigated area of 20.5 ha with a small 1 ha section around the pivot center that is left unirrigated due to the unsuitable terrain mentioned in Section 4. With the wheel line system in place, the farm in Ravalli County will irrigate 4 hectares of crops. Both farmers are expected to primarily grow alfalfa crops. With the expected length of the irrigation season ending at the end of July, the alfalfa crops will have time to “rest” before the first freeze around mid-October, allowing for a successful crop reestablishment in the following year (Lackman, 2020).

With a decision made on the irrigation system, the final design process can be begun. This includes pipe sizing, pump sizing, determining thrust block sizing, and placing appurtenances. The calculated information is laid out into a design report, shown in Appendix A and B, that conveys to the builder all necessary information for building the system to NRCS standards and specifications. More information on the design report is listed in section 5.

5. Expected Results

Section 5 discusses the final steps of completing the engineering design, building the irrigation system, inspection and evaluation of the completed build, and maintaining positive relationships with the community. Given the nature of summer internships and the timeframe associated with NRCS projects, typically on the time scale of two to three years, none of the projects designed in this thesis were seen to completion. Section 5 covers the final steps of the NRCS design process that would be used in completing the design. It discusses the process upon completion of the design documents moving forward with construction and follow up to determine the success of the project.

(3) Phase III – Application and Evaluation

(i) Step 8 – Implement the Plan.

To convey the design plans to the construction crew, a full design document is created on AutoCAD. These documents include location maps, estimated material requirements, and build specifications. The documents for the projects in Dawson and Ravalli County are located in Appendix A and B respectively with landowner information removed.

These design documents follow a regimented format with a title page, plan map, materials page, profiles, and miscellaneous details. This format ensures consistency between documents and allows people looking at the projects later to easily find information on the design. Depending on the scope of the project and experience level of the engineer, the completed design documents are sent to another engineer for a check of calculations and clarity.

(ii) Step 9 – Evaluate the Plan.

NRCS projects often take place over the course of multiple years. The designs discussed in this thesis were not built over the two summers of work. After completion of the build by the contractor, the engineer goes out to the site and examines what has been built. They mark the actual build specifications and modify the design report to create an as-built document for the NRCS records as well as let the farmer know if anything needs to be changed to receive full NRCS funding. NRCS employees will continue to check with the landowner for multiple years to understand their satisfaction with the design, see how things are holding up, and importantly, maintain the relationship with the farmer. This helps build community trust of the NRCS and encourages more farmers to participate in environmental stewardship programs and continue to follow them.

6. Discussion and Future Opportunities

6.1 Site Replicability

NRCS funding is highly beneficial for farmers, with funding covering significant portions of the associated costs. Specific percentages paid to the farmer depend on a multitude of factors including amount purchased, size, and if the landowner is considered historically underserved. With the advantage of offering significant financial assistance, the NRCS can encourage farmers to adopt more environmentally friendly practices, such as wetland conservation, not farming or grazing vulnerable lands, and conversion to more efficient irrigation methods.

The farm in Dawson County studied is relatively indicative of the area. Since it is not near the Yellowstone River, it does not have a constantly available supply of water like many other farms do, but the farmer is still able to collect adequate runoff to supply irrigation water for a majority of the growing season. However, the method of irrigation water storage used by this farmer, collection of water in a storage pond, is used by many farmers in southeastern Montana if the soil conditions allow for it. The farm in Ravalli County is more indicative of the surrounding area. With the topography being much more extreme than on the eastern side of the state, farms are often smaller in size with most irrigators on plots of 10-20 acres. There are larger farms in western Montana, but they are less common and more likely to be in larger valleys. For an irrigator to get sufficient water to a larger farm west of the divide, they either need to be located near a river or have an early water rights claim.

6.2 Irrigation Systems

Center pivot irrigation systems are easily scalable, but they do have a limit on how large they can be. The limiting factor is the speed at which they rotate. If the pivot rotates too fast, the water will be applied too quickly and not have time to infiltrate; instead, it will run off the surface away from where it was applied (Rogers et al., 2017). If the pivot moves too slow, it may not circle around to the point it was irrigating before the soil has reached the wilting point of the crop. To prevent this, a middle ground must be reached that balances the intensity of water application with maintaining the desired available water content in the soil (Rogers et al., 2017). In the same fashion as center pivots, wheel line irrigation system lengths are limited by the cycle time to reirrigate a point. With the wheel line typically moved in 12-hour bursts, lengths of over 14 risers are uncommon for most of these systems.

Most of the irrigation methods discussed in this thesis are standard across the United States. Currently, 58% to 65% of irrigation systems in the U.S. are pressure-based systems (Stubbs, 2016). Most of these systems are wheel line and center pivot. These two irrigation systems are very common in irrigated areas. With these designs being so ubiquitous across the country, there is likely a standard approach with little need for extreme variation in design approaches.

K-Line is a less common method but is popular in some areas in Montana where they have mixed field uses with livestock sharing the ground. This irrigation method works well in all sizes of irrigated land where grass or forage is the crop. K-Lines can be easily moved behind a ATV, are durable, and can be arranged in all shapes to accommodate odd field shapes. They also have wide range of application intensity rates accommodating even very low intake rate soils. Because they are never in exactly the same location, they don't have the distribution uniformity issues commonly associated with nozzle throw, common with other sprinkler systems. With this irrigation method, farmers can allow cattle to graze while irrigating a field without worry of the cattle damaging the system through stepping on the sprinklers.

An irrigation method that is growing in adoption rate is sub-surface drip irrigation (SDI)irrigation. Currently, it is used most heavily with small scale farming operations but is gaining traction in highly water-scarce areas. The NRCS in Texas and New Mexico is moving into trickle irrigation systems steadily as the available water declines. In these areas, the higher costs associated with trickle irrigation are justifiable as they typically grow higher-value crops, and there is no viable alternative if they wish to continue farming (Porter, 2004). In Montana, trickle irrigation is not financially viable to be adopted on most irrigated land. Some farmers have requested to use trickle irrigation in their systems in parts of Montana, but after seeing the differences in costs, determined it was not economically justifiable. While trickle irrigation is not viable in Montana now, it is likely to grow in popularity on non-grass crops as climate change begins to have a greater effect on when and how much water is available (Frisvold and Bai, 2016).

6.3 Climate Change

As in many other areas, climate change is impacting Montana and is expected to continue affecting the state. A study of climatic data for Montana over the past 100 years found that “extremely cold days (≤ −17.8°C) terminate on average 20 days earlier and decline in number, whereas extremely hot days (≥32°C) show a three-fold increase in number and a 24-day increase in seasonal window during which they occur” (Pederson et al., 2010).

6.3.1 Availability of snowmelt

With the trend towards warmer days and shorter, less intense winters, there are likely to be significant effects on the availability of water for irrigation supply. An analysis of the St. Mary River, originating in Glacier National Park, suggests that “an earlier spring and associated earlier onset of snowmelt and probable declines in maximum annual snow water equivalent” (MacDonald et al., 2010). For a historical period studied by MacDonald et al. (2010), it was determined that 70% of the annual precipitation was snow, and “as temperatures increase, the proportion of snow to total annual precipitation [decreased] from the historical period in every scenario.” With a decreasing snowpack, late-season availability of water will decrease (Figure 9a). All 3 models run by MacDonald et al. (2010) predict earlier snowmelts removing a large portion of the snowpack.

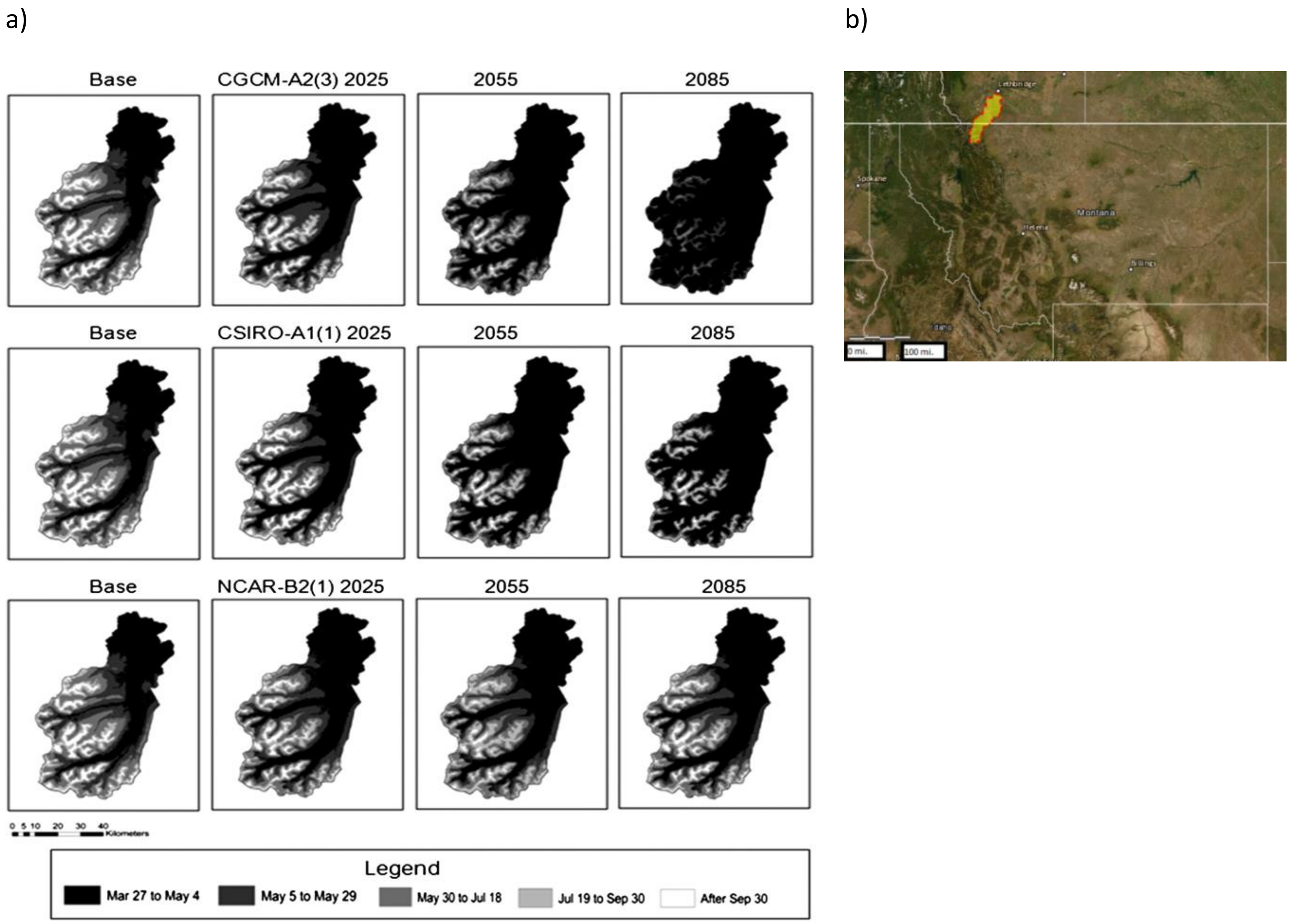

Figure 9: a) Predicted melt date of snowpack within the St. Mary watershed (MT). The models demonstrate snowmelt given predicted temperatures from multiple models developed around expected climatic conditions for 30-year periods comparing the historical conditions of 1961-1980, 2025, 2055, and 2085. Data and figure adapted from (MacDonald et al., 2010).
b) Location map of the St. Mary's River watershed. The snowpack in Figure 9a is located on a mountain peak within the St. Mary watershed. Map sourced and modified from mslservices.mt.gov

6.3.2 Public opinion regarding climate change

Farmers in Montana are already beginning to experience the effects of climate change through severe droughts. Ranchers describe the recent droughts experienced as "unprecedented" and "they viewed adaptation as critical and employed a wide range of responses to drought, but lack of financial resources, risks associated with change, local social norms, and optimism about future moisture created barriers to change" (Yung et al., 2015). Despite facing severe droughts, "most ranchers attributed drought to natural cycles and were skeptical about anthropogenic climate change" (Yung et al., 2015). Yung et al. (2015) were not able to determine an absolute relationship between a farmer's belief in climate change, and their willingness to take adaptative action “since the handful of ranchers adapting in anticipation of long-term drought were skeptical or uncertain about anthropogenic climate change.”

The study by Yung et al. (2015) suggests that a different approach may need to be taken to help the farmers prepare for the predicted upcoming effects of climate change. In addition, Yung et al. found that many of the farmers held strong anti-governmental sentiments. The findings suggest that farmers would not be willing to accept help from agencies, such as the NRCS, that aid with farm adaptations to mitigate the risks of climate change. For an effective solution, the argument for the updating of farm management technologies and strategies should not discuss the ability to minimize the effects of climate change. Instead, approaches should, as Yung et al. (2015) suggests, “build on local norms and ideologies.” This effort could include highlighting the financial benefits of a more efficient system, as many farmers across the region are currently experiencing financial hardship.

6.3.3 Direct effects on irrigators

The expected trend of earlier snow melts will impact farmer’s abilities to irrigate through the growing season. The early snowmelt will precede historically dry summers. Many of the ranchers describe the drought conditions of the last decade as ‘prolonged’ and ‘continual’, with less snow in the winter, earlier snowmelt, reservoirs not filling, springs drying up, and less rain in the summer” (Yung et al., 2015). The lack of readily available water is financially hurting the ranchers, as they are “forced to reduce their herd size, purchase hay at high prices, and lease additional rangelands” to accommodate the diminishing yields and availability throughout the state (Yung et al., 2015).

At the beginning of the growing season, farmers are inundated with an excess of water as the snowmelt begins. In that period, there are no restrictions on water use as every farmer easily has their needs met. As the growing season progresses into late June and early July water availability drops significantly. With the projected declines, farmers will need to compete for water earlier in the season as the water supply melts away too quickly to be used by the irrigators. Decreasing yields will economically challenge many of the irrigators across the state and will likely force some to sell their farms as they lose their economic viability. The analysis published by Willingham and Green (2019) states that more than 40% of midsize farms operate on a profit margin less than 10%, “placing them at high risk of financial problems.”

7. Conclusion

While the NRCS is a national organization, much of the operational issues are decided on the state level, and then broken down into the areas within the state. This reasoning largely comes from the highly diverse landscapes and conditions specific to each state. The variability allows the NRCS to apply a much more targeted approach in modifying designs to meet the specific needs of the irrigators in their area. The Dawson County site's water availability was completely different than that of the one in Ravalli County. Both sites also had highly differing landscapes, scales, and irrigator needs. In evaluating the conditions and after speaking with the irrigators, it was determined that the Dawson County site's best solution would be to install a center pivot system on a spur off their existing pipe network, resulting in a projected irrigation efficiency increase of 65% to 75%. The Ravalli County site had a new sump pump installed to feed the planned wheel line system for a projected irrigation efficiency increase from 30% to 65%. The improvements in irrigation efficiency are necessary to meet the rise in total yield needed to make a profit farming. Snowbanks are expected to melt earlier in the year as a result of climate change. Through minimizing wasted water, the farmers can maximize the available water, lengthening their growing season compared to their previous systems.

The design work performed with the NRCS required systems to be designed so that they meet the requirements of the irrigator while maintaining feasibility in the specific site landscape. Analysis of soil properties, typical seasonal rainfall, and crop consumptive use allowed for the sizing of the irrigation systems to meet the expected uses laid out by the irrigator. In performing this work, I learned a significant amount about the American farming industry, irrigation systems, and the difficulties faced in the western half of the US in accessing water through the growing season. The work also heavily utilized the biological engineering coursework taught at the University of Arkansas through pump and pipe sizing, fuel consumption and efficiency, and well drawdown among other subjects.

Acknowledgments

I would like to thank the NRCS staff across the state of Montana. Extra thanks to Ann Ross, area engineer in Miles City, Sam Greenwalt, field engineer in Glendive, Mark Zuber, area engineer in Missoula, and Kristine Handley, field engineer in Missoula.

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References

Cross, W. F., LaFave, J., Leone, A., Lonsdale, W., Royem, A., Patton, T., McGinnis, S. (2017). 2017 Montana Climate Assessment - Water and climate change in Montana. Bozeman, MT and Missoula, MT: Montana State University and University of Montana. Retrieved from https://montanaclimate.org/sites/default/files/thumbnails/image/2017-MCA-Water-Chapter-lr.pdf

esri. (2010, April 28). ArcGIS Online Basemaps. Retrieved from https://www.arcgis.com/home/group.html?id=702026e41f6641fb85da88efe79dc166#overview

Evans, R. G. (2001, July). Center Pivot Irrigation. USDA ARS. Retrieved from https://www.ars.usda.gov/ARSUserFiles/21563/center%20pivot%20design%202.pdf

Frisvold, G., Bai, T. (2016). Irrigation Technology Choice as Adaptation to Climate Change in the Western United States. Journal of Contemporary Water Research & Education, 158(1). Retrieved from https://doi.org/10.1111/j.1936-704X.2016.03219.x

Kohl, R. A., Pair, C. H., Larsen, D. C. (1974). Tow Line Sprinkler Systems. University of Idaho. Agricultural Extension Service, 6.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, *15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Lackman, S. (Accessed 2020, February). Alfalfa Establishment. Montana State University Extension. Retrieved from http://agresearch.montana.edu/wtarc/producerinfo/agronomy-nutrient-management/Alfalfa/AlfalfaEstablishment.pdf

MacDonald, R. J., Byrne, J. M., Kienzle, S. W., Larson, R. P. (2010). Assessing the Potential Impacts of Climate Change on Mountain Snowpack in the St. Mary River Watershed, Montana. Journal of Hydrometeorology, 12(2), 262–273. https://doi.org/10.1175/2010JHM1294.1

MacDonnell, L. J. (2012, March 22). Montana v. Wyoming: sprinklers, irrigation water use efficiency and the doctrine of recapture. Retrieved January 8, 2020, from https://0-link-galegroup-com.library.uark.edu/apps/doc/A290733658/LT?sid=lms

Montana State Library. (2019, February). Administrative Boundaries. Retrieved November 3, 2019, from http://geoinfo.msl.mt.gov/msdi/administrative_boundaries

Montana State Library. (2003). Watershed Subbasin Maps. Retrieved from https://mslservices.mt.gov/geographic_information/maps/watershed/

NASS. (2019, March 11). *2017 State and County Profiles - Montana*. Retrieved from Census of Agriculture: https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Montana/

NRCS. (2014, November). Part 600 – National Planning Procedures Handbook.

NRCS. (2015). *NRCS General Factsheet.* Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/about/

NRCS. (2018, October). *Environmental Quality Incentives Program*. Retrieved from Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

NRCS New Mexico. (2012). *Agronomy Tech Note 76.* Natural Resources Conservation Service.

PBS&J. (2009). Irrigation in Montana: A Preliminary Investigation of Irrigation Infrastructure. Retrieved from http://dnrc.mt.gov/divisions/cardd/docs/publications/InventoryofIrrigationInfrastructureinMontana.pdf

Pederson, G. T., Graumlich, L. J., Fagre, D. B., Kipfer, T., Muhlfeld, C. C. (2010). A century of climate and ecosystem change in Western Montana: what do temperature trends portend? Climatic Change, 98(1), 133–154. https://doi.org/10.1007/s10584-009-9642-y

Porter, D. (2004). Irrigation for Small Farms. Texas Water Development Board. Retrieved from https://www.twdb.texas.gov/conservation/resources/doc/Irrigation_Manual.pdf

Qiu, Z., Prato, T. (2012). Economic feasibility of adapting crop enterprises to future climate change: a case study of flexible scheduling and irrigation for representative farms in Flathead Valley, Montana, USA. Mitigation and Adaptation Strategies for Global Change; Dordrecht, 17(3), 223–242. http://0-dx.doi.org.library.uark.edu/10.1007/s11027-011-9322-x

Rogers, D. H., Aguilar, J., Kisekka, I., Lamm, F. R. (2017). Center Pivot Irrigation System Losses and Efficiency. Presented at the Central Plains Irrigation Conference, Burlington, CO: Kansas State Research and Extension. Retrieved from https://www.ksre.k-state.edu/irrigate/oow/p17/Rogers17.pdf

Stubbs, M. (2016, October 17). Irrigation in U.S. Agriculture: On-Farm Technologies and Best Management Practices. Congressional Research Service. Retrieved from https://fas.org/sgp/crs/misc/R44158.pdf

USDA. (2019). *Farms and Land in Farms 2018 Summary* (No. ISSN: 1995-2004). Retrieved from https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnlo0419.pdf

Willingham, Z., Green, A. (2019, May 7). A Fair Deal for Farmers. Retrieved from https://www.americanprogress.org/issues/economy/reports/2019/05/07/469385/fair-deal-farmers/

WRCC. (2016, June). Glendive, Montana: Period of Record Monthly Climate Summary. Retrieved October 8, 2019, from https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt3581

WRCC. (2005, December). Stevensville, MT: Period of Record Monthly Climate Survey. Retrieved October 21, 2019, from https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?mtstev

Yung, L., Phear, N., DuPont, A., Montag, J., Murphy, D. (2015). Drought Adaptation and Climate Change Beliefs among Working Ranchers in Montana. Weather, Climate and Society. https://doi.org/10.1175/WCAS-D-14-00039.1

Appendix A: Dawson County

PLANS FOR THE CONSTRUCTION OF

CENTER-PIVOT IRRIGATION SYSTEM

[redacted] - EQIP 2018

PREPARED BY

U.S. DEPARTMENT OF AGRICULTURE

NATURAL RESOURCES CONSERVATION SERVICE

MONTANA

LOCATION MAP

[redacted]

2000 0 2000 4000

Scale in Feet

INDEX OF DRAWINGS

SHT NO.	TITLE
1	Index of Drawings
2	Plan Map
3	Materials & Quantities
4	Pipeline Profile
5	Miscellaneous Details
6	Miscellaneous Details (Cont.)

SPECIFICATIONS

MT-100	General Requirements
MT-102	Pollution Control
MT-104	Excavation
MT-105	Earth Fill
MT-106B	Reinforced Concrete-Minor Structures
MT-111	Plastic Pipe-Pressure Conduits
MT-116	Valves and Meters
MT-442	Sprinkler System
MT-533	Pumping Plant

GENERAL NOTES

1. System design consists of a pumped irrigation pipeline (approx. 4672' total with 1834' new installation) with a design flow rate of 412 gpm. Pipeline serves a single center pivot sprinkler with approx. 50.6 acres of coverage.
2. Individual sprinkler flow rate is based on 0.35"/day peak consumptive use for alfalfa hay.
3. Land Owner is responsible for obtaining necessary permits and easements and for notifying all utilities affected by this project.
4. All work will be completed in accordance with plans and specifications. Proposed changes must be approved by NRCS prior to construction.
5. Land Owner or Contractor shall notify NRCS a minimum of TWO days prior to initiating construction.

(CONTINUED ON SHEET 3)

[redacted]

CALL BEFORE YOU DIG

State law and NRCS policy require that the excavator contact the Utility Notification Center at 811 or 1-800-424-5555 for underground utility locations at least two (2) full business days prior to the start of excavation work.

JOB CLASS II

		Date
Designed	J. Lampson/S. Greenwalt	7/2018
Drawn	J. Lampson	7/2018
Checked		
Approved		

INDEX OF DRAWINGS
CENTER-PIVOT IRRIGATION SYSTEM
[redacted] - EQIP 2018

DAWSON COUNTY MONTANA

USDA United States Department of Agriculture
Natural Resources Conservation Service

[redacted]

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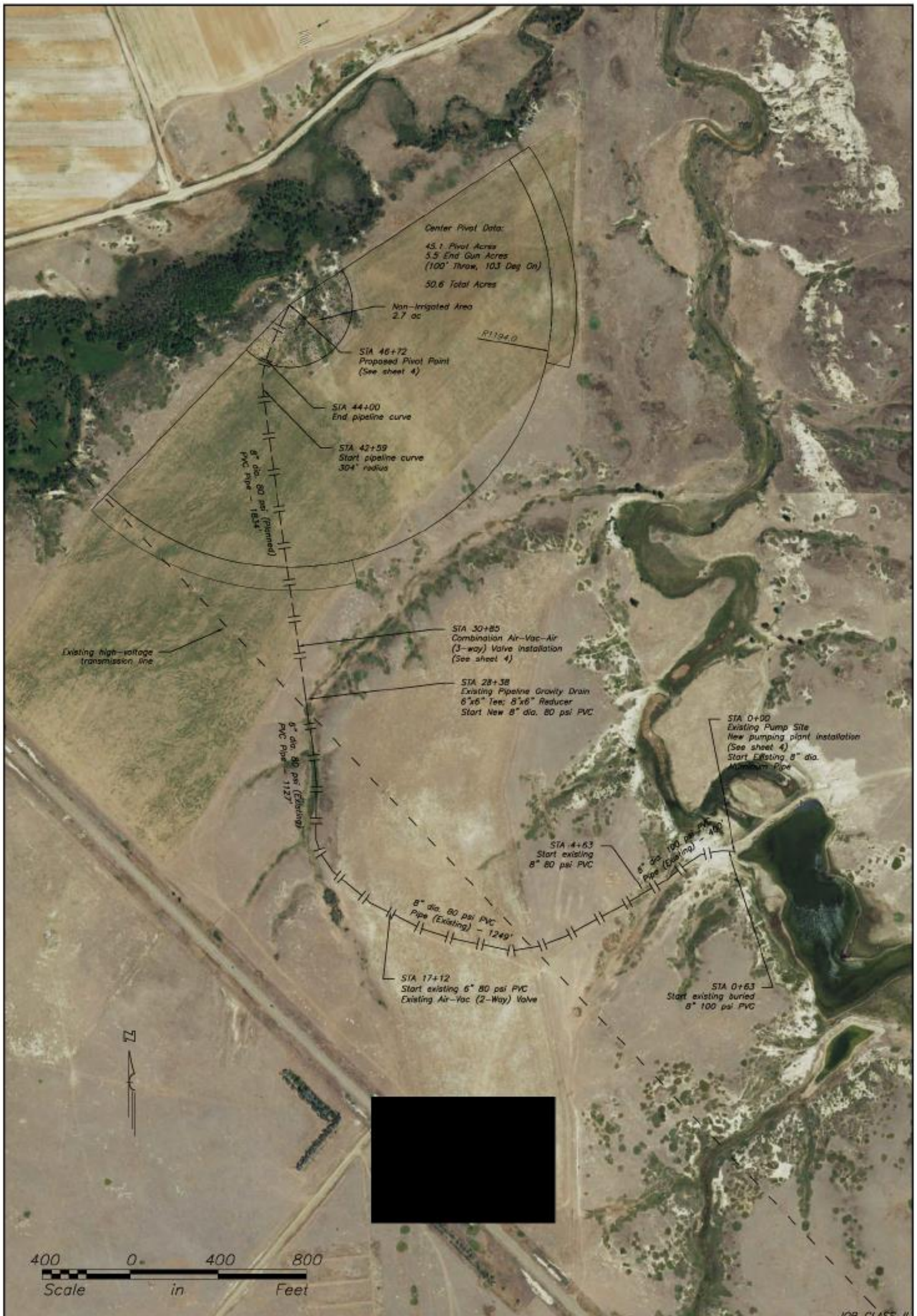
Sheet 1 of 6



Sheet 2 of 6 8/22/18 1:39 PM [redacted]

USDA United States Department of Agriculture
Natural Resources Conservation Service

PLAN MAP
CENTER-PIVOT IRRIGATION SYSTEM
[redacted] - EQIP 2018

DAWSON COUNTY MONTANA

		Date
Designed	J. Lampson/S. Greenwalt	7/2018
Drawn	J. Lampson	7/2018
Checked		
Approved		

ESTIMATED MATERIALS LIST

ITEM	UNIT	DESIGN	AS-BUILT
PIPE			
8" DIA. 80 PSI PIP W/ TRENCHING & INSTALLATION	FT	1834	
4" DIA. SCH 40 PVC RISER	FT	2.5	
MISC. STEEL PIPE		JOB	
PIPE FITTINGS			
6" x 6" x 6" 80 PSI PVC TEE	EA	1	
8" x 90 deg. 80 PSI PVC ELBOW	EA	1	
8" x 90 deg. 14 GA. STEEL ELBOW	EA	1	
8" X 6" 80 PSI PVC REDUCER	EA	1	
8" VAN STONE FLANGE	EA	1	
MISC PIP/IPS PVC FITTINGS		JOB	
MAINLINE CONNECTION FITTINGS		JOB	
PIVOT POINT FITTINGS		JOB	
VALVES & GAUGES			
1" AIR-VAC-AIR (3-WAY) VALVE	EA	2	
1" AIR-VAC (2-WAY) VALVE	EA	1	
8" GEAR OPERATED BUTTERFLY VALVE	EA	1	
8" SPRING-ACTUATED CHECK VALVE	EA	1	
PRESSURE GAUGE	EA	2	
VACUUM PRESSURE GAUGE	EA	1	
CONCRETE			
THRUSTBLOCKS	CY	1	
PUMP PAD		JOB	
CENTER PIVOT PAD		JOB	

ESTIMATED MATERIALS LIST (CONT.)

ITEM	UNIT	DESIGN	AS-BUILT
CENTER PIVOT SPRINKLER SYSTEM			
1194' LOW PRESSURE PIVOT W/ END GUN SERVING APPROX. 50.6 AC. (INCLUDES NRCS-APPROVED SPRINKLER PACKAGE)	EA	1	
PUMP			
CENTRIFUGAL PUMP W/ DIESEL MOTOR OPERATING POINT: 412 GPM W/ 160 FT TDH	EA	1	
FOOT VALVE W/ SCREEN	EA	1	
WIRELESS PUMP CONTROLLER	EA	1	
FLOWMETERS			
8" DIAMETER MECHANICAL FLOWMETER	EA	1	
CLEAN SAND/PEA GRAVEL			
AIR VALVE	CY	0.5	
OTHER			
18" COATED STEEL CULVERT 16 GA. W/ LID (3' LONG)	EA	1	
7/8" GALVANIZED THREADED ROD	FT	10	
MISC. HARDWARE		JOB	

GENERAL NOTES

(con't from Sheet 1)

7. NRCS is required to provide owners/operators with a Cultural Resource Inventory on all ground disturbing practices that have the potential to yield significant archaeological or cultural resource sites. This is done to help preserve any significant sites which may be of historic value. The inventory must be completed before this practice is begun. If a significant site is found in the area to be disturbed and you choose to proceed with the practice without protecting the site, then NRCS is instructed to withdraw all assistance to you on this project. If cultural resources are encountered while implementing the ground disturbing practice, all activity in the immediate area must cease and NRCS must be notified so that it's significance can be determined. If the site is deemed significant, it will be left undisturbed by relocating the construction site, changing the route of the pipeline, or excluding the site from the practice being installed.
8. When raising alfalfa hay, reservoir volume will likely only support operation of the pivot through July. Lower consumptive use crops under the pivot may facilitate irrigation later into the growing season and/or permit operation of the existing tow lines without exhausting reservoir volume.

JOB CLASS II

Designed J. Lampson/S. Greenwalt Date 7/2018
Drawn J. Lampson 7/2018
Checked
Approved

MATERIALS & QUANTITIES
CENTER-PIVOT IRRIGATION SYSTEM
[redacted] – EQIP 2018
DAWSON COUNTY MONTANA

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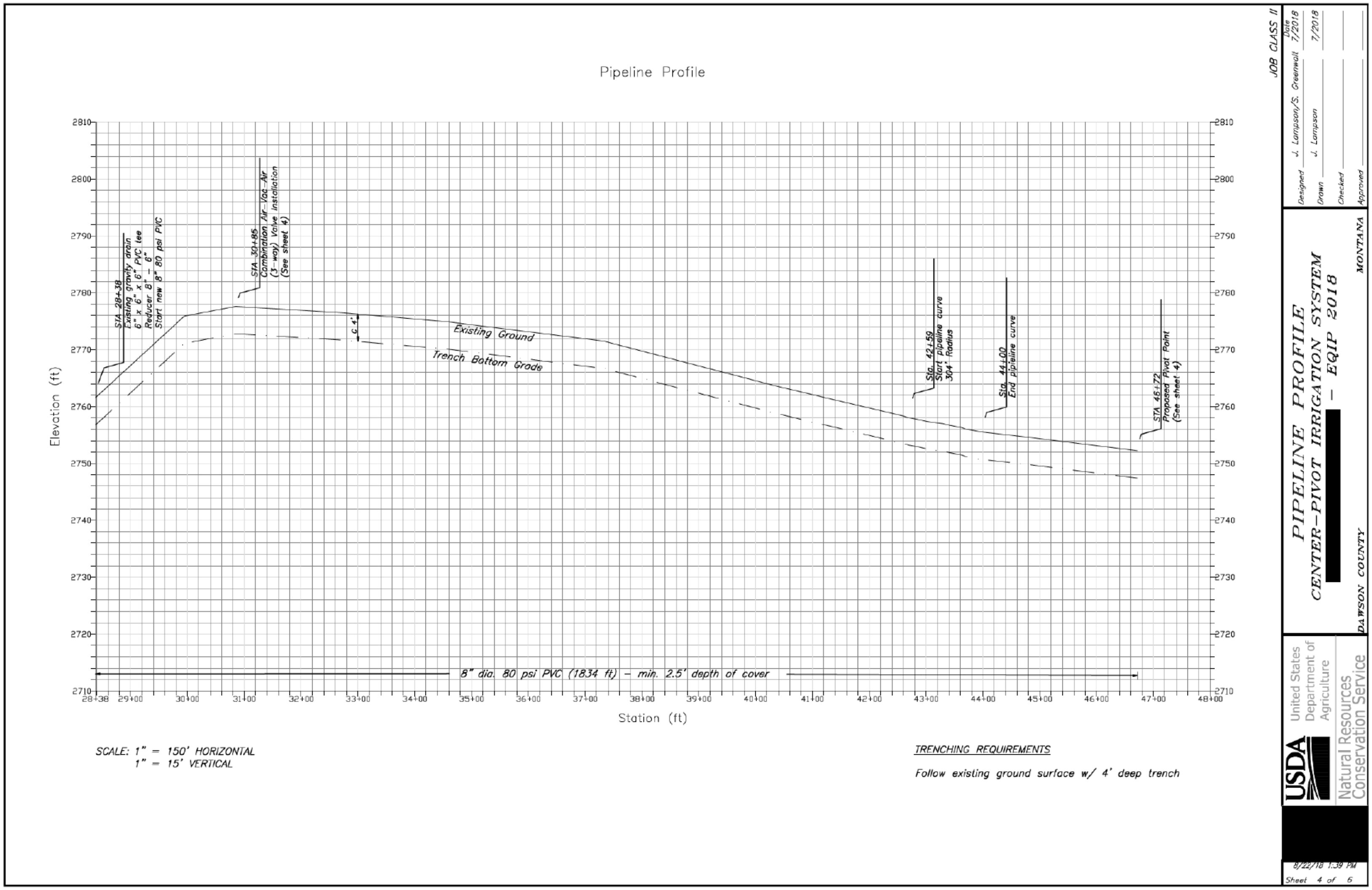
File Name
[redacted]
8/22/18 1:39 PM
Sheet 3 of 6


Pipeline Profile
Elevation (ft)
Station (ft)
2810
2800
2790
2780
2770
2760
2750
2740
2730
2720
2710
28+38
29+00
30+00
31+00
32+00
33+00
34+00
35+00
36+00
37+00
38+00
39+00
40+00
41+00
42+00
43+00
44+00
45+00
46+00
47+00
48+00
STA 28+38
Existing gravity drain
6" x 6" x 6" PVC tee
Reducer 8" - 6"
Start new 8" 80 psi PVC
STA 30+85
Combination Air-Vac-Air
(3-way) Valve installation
(See sheet 4)
4'
Existing Ground
Trench Bottom Grade
Sta. 42+59
Start pipeline curve
304' Radius
Sta. 44+00
End pipeline curve
STA 46+72
Proposed Pivot Point
(See sheet 4)
8" dia. 80 psi PVC (1834 ft) - min. 2.5' depth of cover
SCALE: 1" = 150' HORIZONTAL
1" = 15' VERTICAL
TRENCHING REQUIREMENTS
Follow existing ground surface w/ 4' deep trench
JOB CLASS II
Designed J. Lampson/S. Greenwalt Date 7/2018
Drawn J. Lampson 7/2018
Checked
Approved
PIPELINE PROFILE
CENTER-PIVOT IRRIGATION SYSTEM
[redacted] - EQIP 2018
DAWSON COUNTY
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[redacted]
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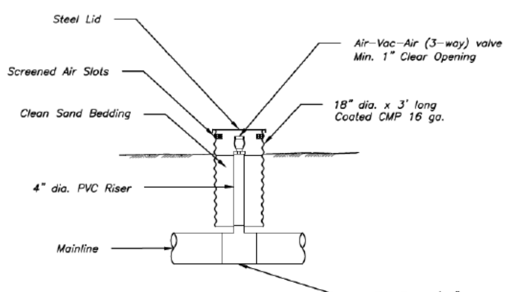
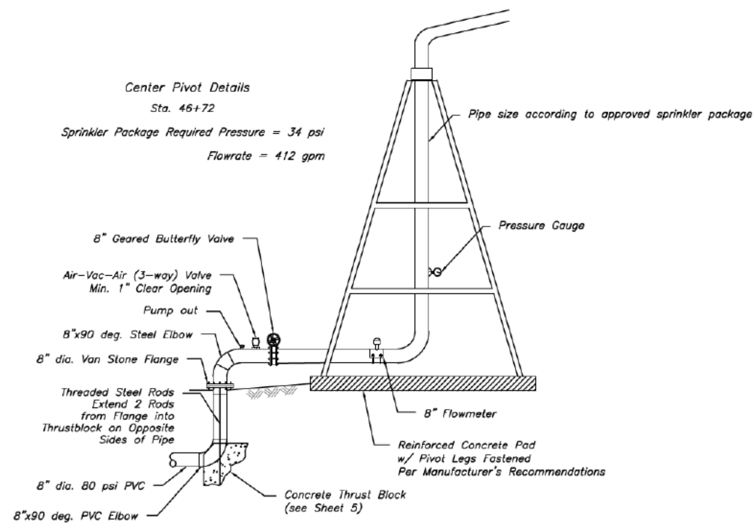
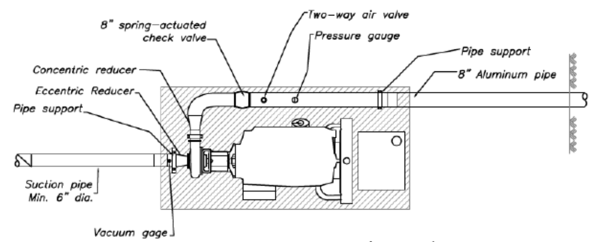
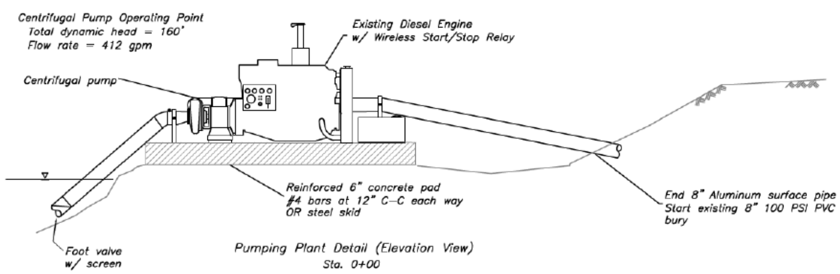


Air Valve Details
Sta. 30+85





Pumping Plant Detail (Plan View)
Sta. 0+00



Pumping Plant Detail (Elevation View)
Sta. 0+00

PIVOT POINT NOTES

Sprinkler nozzle heights shall be uniform throughout the field and as specified in the NRCS-approved sprinkler package.

Center pivot control panel shall include an integrated wireless sending unit for pump ON/OFF control.

Gear-operated butterfly valve closure time shall exceed 13 seconds to prevent development of harmful surge pressures within the pipeline.

Manufacturer requirements for straight run upstream and downstream of flowmeter shall be met.

Flowmeter shall display both gpm and ac-ft.

Actual set-up may vary. However, changes to what is shown must be approved by NRCS prior to construction.

PUMP NOTES

Pumping plant will be subject to 50% payment rate reduction for used materials if existing diesel engine is used.

An equivalent sized propane generator and electric pump may be substituted in lieu of the diesel engine and direct drive pump combination.

-DRAWINGS NOT TO SCALE-

JOB CLASS II

		Date
Designed	J. Lampson/S. Greenwalt	7/2018
Drawn	J. Lampson	7/2018
Checked		
Approved		

MISCELLANEOUS DETAILS
CENTER-PIVOT IRRIGATION SYSTEM [redacted] — EQIP 2018

DAWSON COUNTY MONTANA

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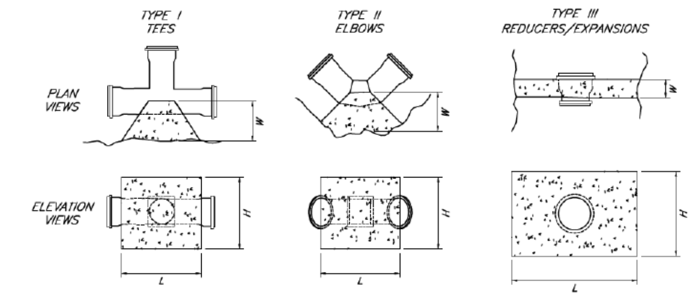
[redacted]

8/22/18 1:39 PM

Sheet 5 of 6



STATION	DESCRIPTION	TYPE	DIMENSIONS LxHxW (FT)	COMMENTS
28+38	6" x 6" x 6" Tee	I	4 x 1 x 1.5	PVC Tee
28+38	8"–6" Reducer	III	2 x 1.5 x 1	PVC Expansion
46+72	8" x 90 deg. Elbow	II	2.25 x 2 x 1.5	PVC Elbow up to Pivot
AS NEEDED		JOB		

CONCRETE THRUST BLOCK NOTES

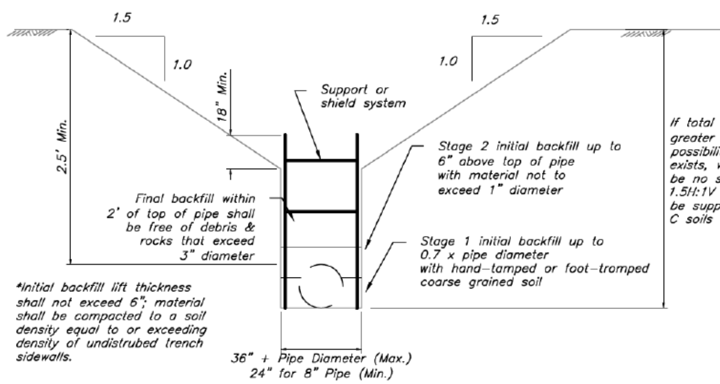
Actual thrust block dimensions may need to be adjusted based on site–specific conditions. However, thrust block bearing area (perpendicular to the direction of thrust) must equal to or exceed what is specified in the adjacent table.

Thrust block bearing area shall not be in contact with elastic clays or silts. If encountered at thrust block locations, these soils must be excavated and replaced by compacted granular material suitable for thrust block support.

Thrust blocks may be required at locations not listed in the table. See MT–111 Plastic Pipe–Pressure Conduits Construction Specifications for guidance when additional thrust blocks are needed.

Concrete Thrust Block Details

–NOT TO SCALE–



Typical Trench Details

–NOT TO SCALE–

TRENCH NOTES

Trench details have been developed in accordance with 29 CFR 1926 Subpart P OSHA Requirements for Excavations. Site soils are assumed to be Type C as defined in the OSHA requirements and no site specific soil investigations have been performed by NRCS. Support or shield systems must comply with 29 CFR 1926.652(c). The top of the support or shield system must extend 18" above top of vertical walls.

Excavated side slopes not protected by an approved support or shield system must be no steeper than 1.5H:1V. If a support or shield system is not used, excavated side slopes must be no steeper than 1.5H:1V from trench bottom to surrounding grade.

The above may be modified per OSHA Requirements if a site specific soils analysis is performed in accordance with 29 CFR 1926 Subpart P Appendix A.

These requirements do not apply in locations where excavations are less than 5 feet in depth and examination of the ground by a competent person provides no indication of a potential cave–in.

JOB CLASS II

Designed J. Lampson/S. Greenwalt Date 7/2018
Drawn J. Lampson 7/2018
Checked
Approved

MISCELLANEOUS DETAILS CONT.
CENTER–PIVOT IRRIGATION SYSTEM
[redacted] – EQIP 2018
DAWSON COUNTY MONTANA

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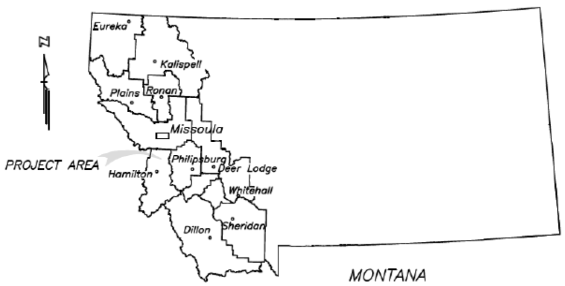
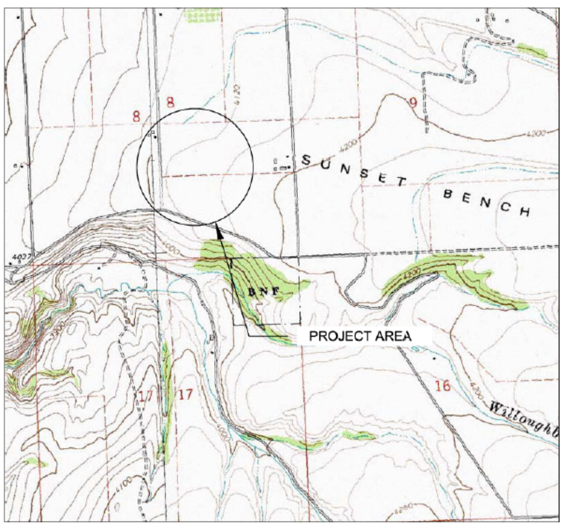
Sheet 6 of 6

Appendix B: Ravalli County





2000 0 2000
Scale in Feet

[redacted]

[redacted]

2019 EQIP APP - IRRIGATION SYSTEM

PREPARED BY

USDA United States Department of Agriculture

Natural Resources Conservation Service

ESTIMATED QUANTITIES			
ITEM	UNIT	PLANNED	AS-BUILT
INLET BOX	EA.	1	
PUMP SUMP	EA.	1	
CENTRIFUGAL PUMP FLOW=110 GPM TDH=165 FT	EA.	1	
PIPELINE TRENCHING	FT.	643	
6" DIA 100 PSI IPS	FT.	20	
4" DIA 100 PSI IPS	FT.	493	
3" DIA 100 PSI IPS	FT.	130	
Concrete	CF.	1	
3-Way Air Valve	EA.	1	

See plans and detail sheets for fittings, valves, etc.

LIST OF SPECIFICATIONS		
SPEC #	SPECIFICATION TITLE	DATE
MT-100	GENERAL REQUIREMENTS	3-14
MT-104	EXCAVATION	2-14
MT-106C	REINFORCED CONCRETE FOR MINOR STRUCTURES	11-14
MT-109	CORRUGATED METAL PIPE	3-14
MT-110	STEEL PIPE	6-11
MT-111	PLASTIC PIPE - PRESSURE CONDUITS	4-13
MT-113	METAL FABRICATION AND INSTALLATION	3-14
MT-533	PUMPING PLANT	10-12

INDEX OF DRAWING	
SHEET #	DRAWING TITLE
1	COVER SHEET
2	PROJECT PLANVIEW
3	SUCTION LINE PROFILE
4	MAINLINE PROFILE
5	INLET BOX DETAILS
6	PUMP SUMP DETAILS
7	PIPELINE DETAILS

GENERAL NOTES

1. All elevations are in feet. All stationing is based on preliminary survey line data and is measured horizontal unless otherwise noted.
2. This system shall be installed according to plans and specifications. Any changes shall be approved by the respective design individual PRIOR to installation.
3. The NRCS may not be obligated to pay for as-built quantities that exceed those quantities shown on the contract.
4. It shall be the landowner's responsibility to obtain all necessary permits and easements as well as any other agreements necessary for the construction and operation of this project.
5. These plans and specifications do not indicate the existence or non-existence of utilities. It shall be the landowner's responsibility to locate all private utilities that may be impacted by the project.

OWNER/OPERATOR REVIEW

1. I have reviewed the drawings, special provisions and construction specifications and agree to construct this project in accordance with them. Any modifications to the final drawings, specifications, or special provisions will require approval from the NRCS design individual before changes are made.
2. I agree to obtain all necessary permits, easements and water rights. I will inform NRCS of all conditions pertaining to the construction of the project as stated in the acquired permits. I also agree to comply with all Federal, State, and local laws pertaining to this construction.
3. I agree to notify NRCS at least 2 weeks before construction begins.
4. State law and NRCS policy require that the excavator contact the Utility Notification Center at 811 (1-800-551-8344 for Flathead and Lincoln Counties) prior to the start of the excavation work. The contractor/excavator will provide NRCS a copy of the locate ticket number before any excavation begins.

OWNER/OPERATOR DATE

Engineering Job Class I

Designed J Lampson/ M Zuber Date 7-17
Drawn J Lampson/ M Zuber 7-17
Checked
Approved

MONTANA

COVER SHEET
[redacted]
2019 EQIP

RAVALLI COUNTY

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Sheet 1 of 6

Project Survey Datum:

Trimbles:
UTM Zone 11N
Horizontal Datum: NAD83
Vertical Datum: NAVD88
Horizontal Distance: US Feet
Vertical Distance: US Survey Feet
Geiod Model: Geoid 03
Cogo Setting: GROUND

Instrument point coordinates are Known with no OPUS correction.

TBM–JL:
Top of concrete base for winter waterer along fence. Painted pink.

ELEV = 4123.45

NOTES:

1) System was designed for a 6-day irrigation frequency in order to allow for future expansion of hand-lines/pods on small section of land at the NW corner of the primary field.
Flow was based on the July average water use for Alfalfa of 0.23" per day and an irrigation efficiency of 65%.

2) Design flow is 110 gpm, TDH is 165 feet.

3) Install mainline about 15 feet past last wheel line riser at STA 4+78 and install 3-way vent and thrust block.

4) Contractor will provide pump curve to NRCS and will also submit a completed pumping plant certification form MT-ENG-533.

125 0 125 250
Scale in Feet

Designed	J Lampson/ M Zuber	Date 7-17
Drawn	J Lampson/ M Zuber	7-17
Checked		
Approved		

PROJECT PLANVIEW
[redacted]
2019 EQIP
RAVALLI COUNTY MONTANA

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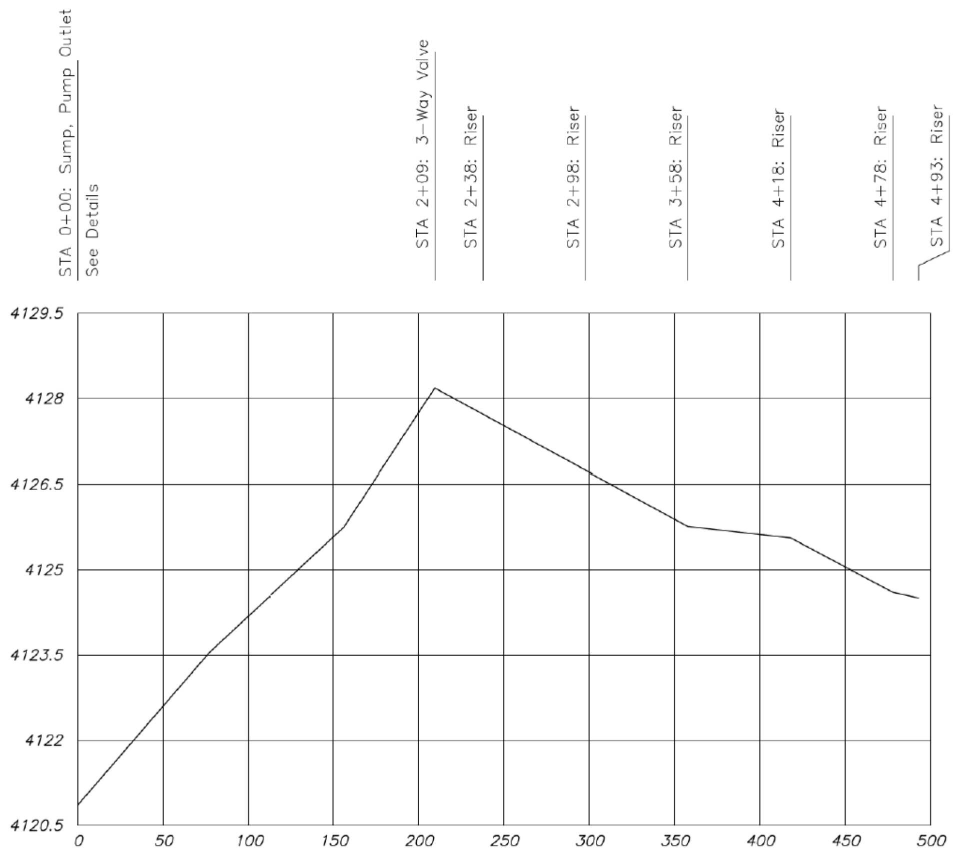
[redacted]

Sheet 2 of 6



NOTES:

1) Use clean sand for initial backfill around pipe and hand-tamp across county road.

2) No thrust blocks are required on the suction line bends.

Designed	J Lampson/ M Zuber	Date 7-17
Drawn	J Lampson/ M Zuber	7-17
Checked		
Approved		

SUCTION LINE PROFILE

[redacted]

2019 EQIP

RAVALLI COUNTY MONTANA

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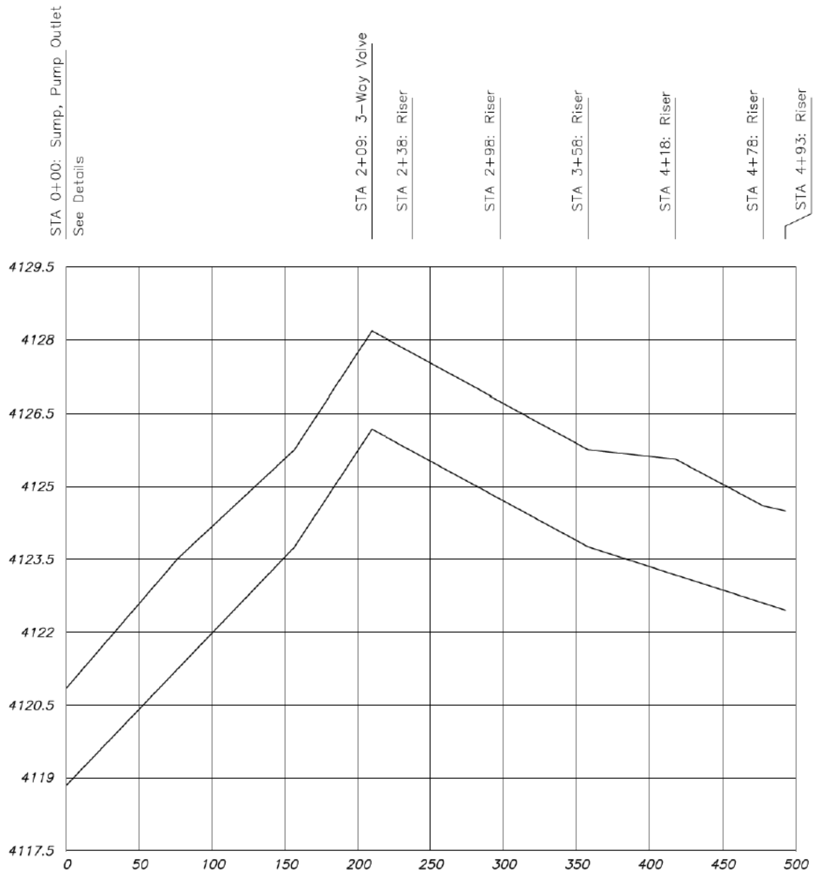
Sheet 3 of 6



STATION	APPROX. TRENCH GRADE
0+50	4120.4
1+56	4123.8
2+09	4126.2
3+58	4123.8
4+78	4122.6
4+93	4122.5

NOTES:

1) The main line servicing the wheel line system goes through STA 4+78. An additional 15 feet of pipe was included to allow for the possibility of tying a hand line on to an additional riser for irrigation of the west field via hand line.

2) Pipeline will be drained using a pump-out drain at STA 0+25.

Designed	J Lampson/ M Zuber	7-17
Drawn	J Lampson/ M Zuber	7-17
Checked		
Approved		

MAINLINE PROFILE

[redacted] 2019 EQIP

RAVALLI COUNTY MONTANA

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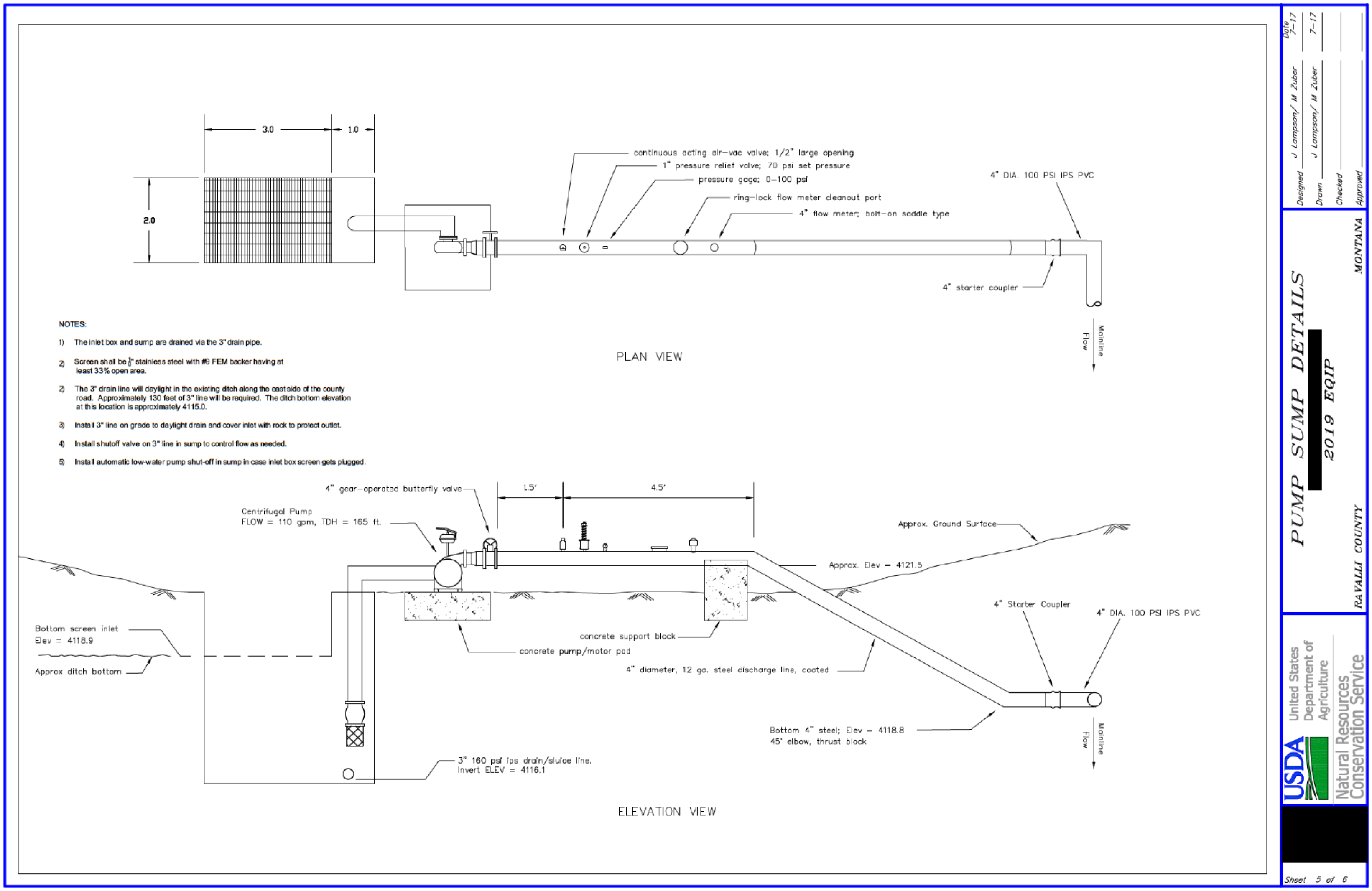
Natural Resources Conservation Service

[redacted]

Sheet 4 of 6


3.0
1.0
2.0
continuous acting air-vac valve; 1/2" large opening
1" pressure relief valve; 70 psi set pressure
pressure gage; 0-100 psi
ring-lock flow meter cleanout port
4" flow meter; bolt-on saddle type
4" DIA. 100 PSI IPS PVC
4" starter coupler
Mainline Flow
PLAN VIEW
NOTES:
1) The inlet box and sump are drained via the 3" drain pipe.
2) Screen shall be 1/8" stainless steel with #9 FEM backer having at least 33% open area.
2) The 3" drain line will daylight in the existing ditch along the east side of the county road. Approximately 130 feet of 3" line will be required. The ditch bottom elevation at this location is approximately 4115.0.
3) Install 3" line on grade to daylight drain and cover inlet with rock to protect outlet.
4) Install shutoff valve on 3" line in sump to control flow as needed.
5) Install automatic low-water pump shut-off in sump in case inlet box screen gets plugged.
4" gear-operated butterfly valve
1.5'
4.5'
Centrifugal Pump
FLOW = 110 gpm, TDH = 165 ft.
Approx. Ground Surface
Approx. Elev = 4121.5
Bottom screen inlet
Elev = 4118.9
Approx ditch bottom
concrete support block
concrete pump/motor pad
4" Starter Coupler
4" DIA. 100 PSI IPS PVC
4" diameter, 12 ga. steel discharge line, coated
Bottom 4" steel; Elev = 4118.8
45° elbow, thrust block
Mainline Flow
3" 160 psi Ips drain/sluice line.
Invert ELEV = 4116.1
ELEVATION VIEW
Designed J Lampson/ M Zuber Date 7-17
Drawn J Lampson/ M Zuber 7-17
Checked
Approved
PUMP SUMP DETAILS
[redacted]
2019 EQIP
RAVALLI COUNTY MONTANA
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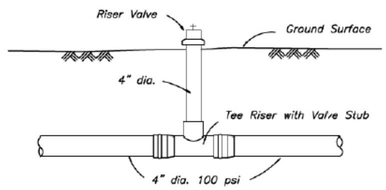
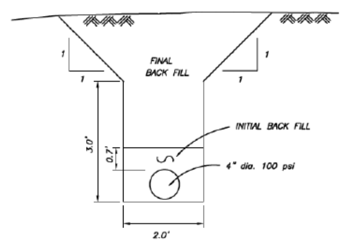
Sheet 5 of 6

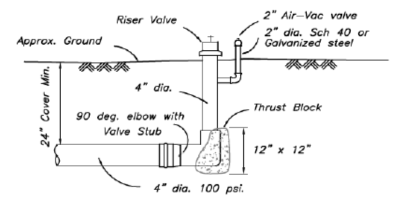


TYPICAL FIELD & PUMPOUT RISER

NOTE: T – RISER AND VALVE CAN ALSO BE INSTALLED WHERE DRAINS ARE NEEDED.



TYPICAL TRENCH DETAILS



END RISER
WITH AIR VAC RELIEF VALVE

End of Pipe line Sta. 4+93

Drawing not to Scale

Designed J Lampson/ M Zuber 7-17
Drawn J Lampson/ M Zuber 7-17
Checked
Approved

PIPELINE DETAILS
2019 EQIP

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