BURNING IRRIGATION DITCHES

John Derek Scasta, Catherine Elizabeth Estep, Timothy Thomas Barrett, Caleb Gray, Jonathan Lautenbach, Liana Alane Boggs Lynch, Cory William Ott, Jordan Lee Skovgard, Ryan Wilbur, Landon Hoffer

INTRODUCTION

Burning irrigation ditches is a common practice and this document is intended for private landowners and irrigation districts. This is helpful for both beginners and long-time burners by introducing concepts and considerations to either get started or improve. Safe and effect ditch burns are the goal and we hope the ideas and considerations offered in this document help you keep burning safely and effectively.

UW College of Agriculture and Natural Resources Extension

UW College of Agriculture and Natural Resources Wyoming Agricultural Experiment Station

Wyoming Prescribed fire Council

B-1351 | September 2019

PURPOSE OF BURNING IRRIGATION DITCHES

Burning irrigation ditches and canals is an agricultural practice that dates back centuries and continues today (Hodge 1893). The delivery of water is a critical component for many types of agriculture. A major challenge to effectively deliver water down natural irrigation ditches is the seasonal vegetation growth that fills ditches with grasses, weeds, dead plant material and other debris (Figure 1). The accumulated vegetation slows the flow of water and ultimately can reduce the total capacity of the ditch. In addition, this vegetation can also harbor insects and disease (Canal Operation and Maintenance: Vegetation 2017). Uncleared irrigation ditches can clog gates and grates and cause flooding, such as a blowout, in unintended locations (Irrigation Ditches 2013) – problems that burning can alleviate (Figure 2). In the long-term, unmanaged vegetation ditches, gates and other infrastructure can become unusable.

Fire is one tool that can be used to effectively clear and maintain fully functional irrigation ditches. Other tools for maintaining irrigation ditches include mowing, dredging and chemical weeding (Dollinger et al. 2015). Arguably, burning irrigation ditches can be more efficient and less expensive to remove the accumulations of vegetation as compared to other tools. Burning of irrigation ditches can also reduce bank erosion, reduce water seepage and help control unwanted pests and disease (Irrigation Ditch FAQs 2013; Levavasseur et al. 2014). From a bank erosion and water seepage perspective, this is possible because it does not physically disrupt the soil as other practices do. Mowing and chemical weeding do not actually remove the accumulated vegetation and dredging causes a physical disturbance to the soil that increases the risk of erosion. Erosion is a major concern for ditch maintenance because if it escalates the irrigation ditch could gradually fill in due to sedimentation (Levavasseur et al. 2014). Chemical weeding is also a concern from a contamination perspective. Burning irrigation ditches also uniquely improves crop yields because the fire can reduce pests and disease. One study showed an 84 percent reduction in diseased sugar beets and a 91 percent reduction in aphids after nearby ditches were burned (Walis & Turner 1969). Other studies have reported reductions in mosquitos (Scasta 2015).

Figure 1. Irrigation ditches can become overgrown with vegetation and plant litter that can physically slow the rate of flow of irrigation water, clog gates and grates and harbor weeds, insects and disease. Long-term lack of maintenance can also render these unusable.

Figure 2. Burning ditches removes standing and accumulated vegetation material to improve the flow of water while also reducing weeds, insects and disease. In this picture, this irrigation ditch was burned in early May 2019 with water delivered down the ditch within weeks of the burn.

INTRODUCTION TO FIRE AS A MANAGEMENT TOOL

Historically fire has been an integral and essential phenomenon that shapes our ecosystems and humans have a long history of using fire for many purposes. Many systems require frequent to periodic fire to maintain natural plant communities and their functions. There are two types of fire, the first is wildfire. Wildfires are high intensity fires that burn large amounts of fuel and can be hard to control. The second type of fire is prescribed fire and this is the type of fire that would be used for burning irrigation ditches. Prescribed fires burn at a lower intensity than wildfires under specific criteria for weather, climatic variables and site factors. These burns are done in a more controlled fashion by using established fire breaks, water resources on standby, and milder weather conditions.

Prescribed fire can be utilized to alleviate fuel loads and debris in a variety of sites that are the result of the absence of fire. For irrigation ditches specifically, some studies have found that winter burning of the ditches effectively removes litter cover within and around the ditch as well as decreasing living cover in the surrounding area (Figure 3). Fire can also impact the chemical structure of soil, but it is often similar to traditional mechanical treatment methods with only slight increases in pH and calcium carbonates (Levavasseur et al. 2014 and Martin et al. 2018). Chemical, mechanical and burning can all have an impact on the biodiversity and the pH of the soil. By utilizing multiple techniques, desired objectives can be achieved. For example, Dollinger et al. (2017) found that burning in the winter can help the soil retain chemicals applied and therefore prevent contamination due to flooding and other runoff events (Dollinger et al. 2017). However, integrated management is not the only option to reach a management goal. Fire can be utilized to target specific species by altering the timing of the prescribed burn. Smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) can be targeted as the plants send tillers up, generally in late spring or early summer (Ditomaso et al. 2006).

Figure 3. Fire removes the dead plants and plant litter. Perennial grasses in the irrigation in the ditch in this photo rapidly re-grow after fire in the spring.

EQUIPMENT NEEDS AND OPERATIONAL CONSIDERATIONS

Much of the same equipment generally used for prescribed burns in range and forest ecosystems are used for burning irrigation ditches (Figure 4). This includes a variety of hand tools, safety gear, fire suppression tools and water supply devices (Figure 4). Hand tools such as rakes and flappers are commonly used for tending to prescribed fires and have great utility for burning irrigation ditches (Figure 5). There are a variety of hand tools commonly used for fire suppression (Randall and Harr 2012) (Figure 5), these include:

- Rakes – for debris removal and spreading debris out
- Shovels - to break up smoldering patches or put soil on embers to smother them
- Flapper/swatters - for smothering burning embers by limiting oxygen
- Leaf blowers – for extinguishing backing fires
- People – to maximize the number of eyes and hands watching and managing the fire (e.g., the more people = more eyes on the fire = more response available).

Figure 4. Ten common fire tools that can be important for burning irrigation ditches.

Figure 5. Hand tools such as rakes, shovels and flappers are also important for managing fire when burning irrigation ditches.

Figure 6. Propane gas burner with extended nozzle mounted on a truck [Image from Wallis et al. 1969. Burning weeds in drainage ditches to suppress population of green peach aphids and incidence of beet western yellows disease in sugar beets. Economic Entomology 62:307-309].

Propane torches are the most common ignition sources for irrigation burning and have a long history, particularly for ditches that are deep and steep (Figure 6). For example, in the figure below a propane gas burner with three burner heads on a 15 foot boom is mounted to a 2-ton truck (Wallis & Turner 1969). Drip torches that use a mixture of diesel and gasoline (typically 50:50 mix but in hot weather mixes of 60:40 or 70:30 are used to minimize flashiness of flare up from the gasoline are also commonly used for burning ditches (Figure 7) in addition to small hand held propane burners (http://bit.ly/FuelMixtures).

A reliable and readily available water source is critical for suppressing fire if needed or to strategically manage a burn. A portable water backpack sprayer can be used for spot spraying (Figure 4). It has a hand pump which makes controlling small fires easy (Randall and Harr 2012). More water in larger tanks on trucks and tractors also enhance the ability to burn safely (Figure 8). When vegetation along an irrigation ditch is high, fire breaks should be established by raking, mowing or plowing around the area. Water lines, or spraying water in a line directly on the vegetation, can be useful when vegetation is low but they can be slow to install and fire can still creep across so they must be used cautiously.

Communication with local dispatchers and your crew is essential to maintaining a safe ditch burn. A phone call to local dispatch before ignition is recommended, so they are aware and fire crews are not dispatched unnecessarily. Always check local burn regulations and possible burn bans before starting.

It is generally suggested to begin burning areas that reduce the risk for control and establish fire breaks by back burning (Figure 9). This starting point is often referred to as the “anchor point” and is generally on the downwind side of the ditch and has good fire guards (also known as fire lines or fire breaks where the fuel has been removed with plowing, mowing or was already removed like on a road) in place such as a two-track road (Figure 10). It can be helpful on larger ditches to use an

ignition team of two people (Figure 11). Always start with a small test fire and always check the weather on-site. Burning into the wind is recommended and often slows the rate of spread and makes the fire easier to control. If burning a large stretch of irrigation ditch, radios for direct communication with crew members are helpful. It is also important to be cautious when placing personnel around deep ditches with steep slopes as the slope can accelerate fire behavior because heat rises according to the thermodynamics. Specifically, slope accelerates fire behavior by (1) escalating the drying/pre-heating of fuels up-slope, (2) facilitating more rapid rates of spread up-slope, (3) having faster wind speeds up-slope (Figure 12). When fuels are heavier or conditions are more extreme, the person lighting the fire should work in close coordination and proximity with someone that can help suppress the fire (Figure 13). Some ditch burning scenarios present ignition hazards such as snow fences or other infrastructures that may require milder conditions, specific wind directions or other suppression tactics (Figure 14). If a fire gets out of hand call 911 and have clear and explicit directions to your location ready.

Figure 7. Use of a drip torch with a mix of diesel and gasoline for a ditch burn.

Figure 8. Adequate equipment for both ignition and suppression are needed for safe and effective ditch burning. In this picture, the tractor has a spray tank with boomless nozzles and a hose, the truck has a spray tank with a hose and other hand tools, and proper signage is displayed due to the proximity of the road.

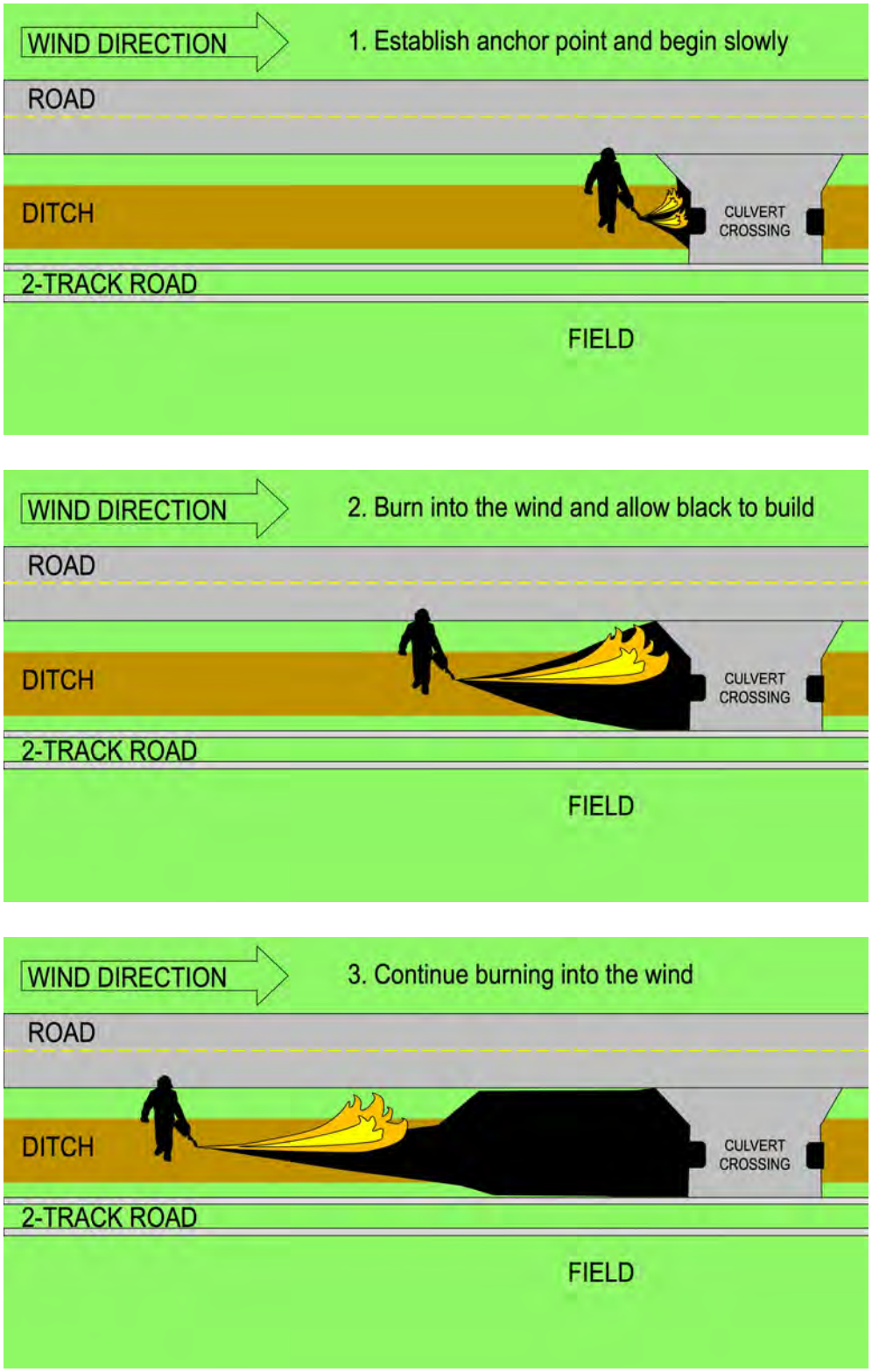

Figure 9. Begin burning areas that reduce the risk for control and establish fire breaks by back burning. In this image, this starting point (aka the "anchor point") is on the downwind side of the ditch and has good fire guards in place (in this case roads and culvert crossing; also known as fire lines or fire breaks where the fuel has been removed with plowing, mowing or was already removed like on a road). Always start with a small test fire, light into the wind, proceed slowly and allow the fire widen the fire guards as it burns out vegetation.

Figure 10. Use of an existing road as a fire break for burning vegetation near an irrigation ditch.

Figure 11. An ignition team can work both sides of a ditch in parallel to more efficiently light fires. Using a team can also reduce the need for people to jump across the ditch and minimize the risk of injury.

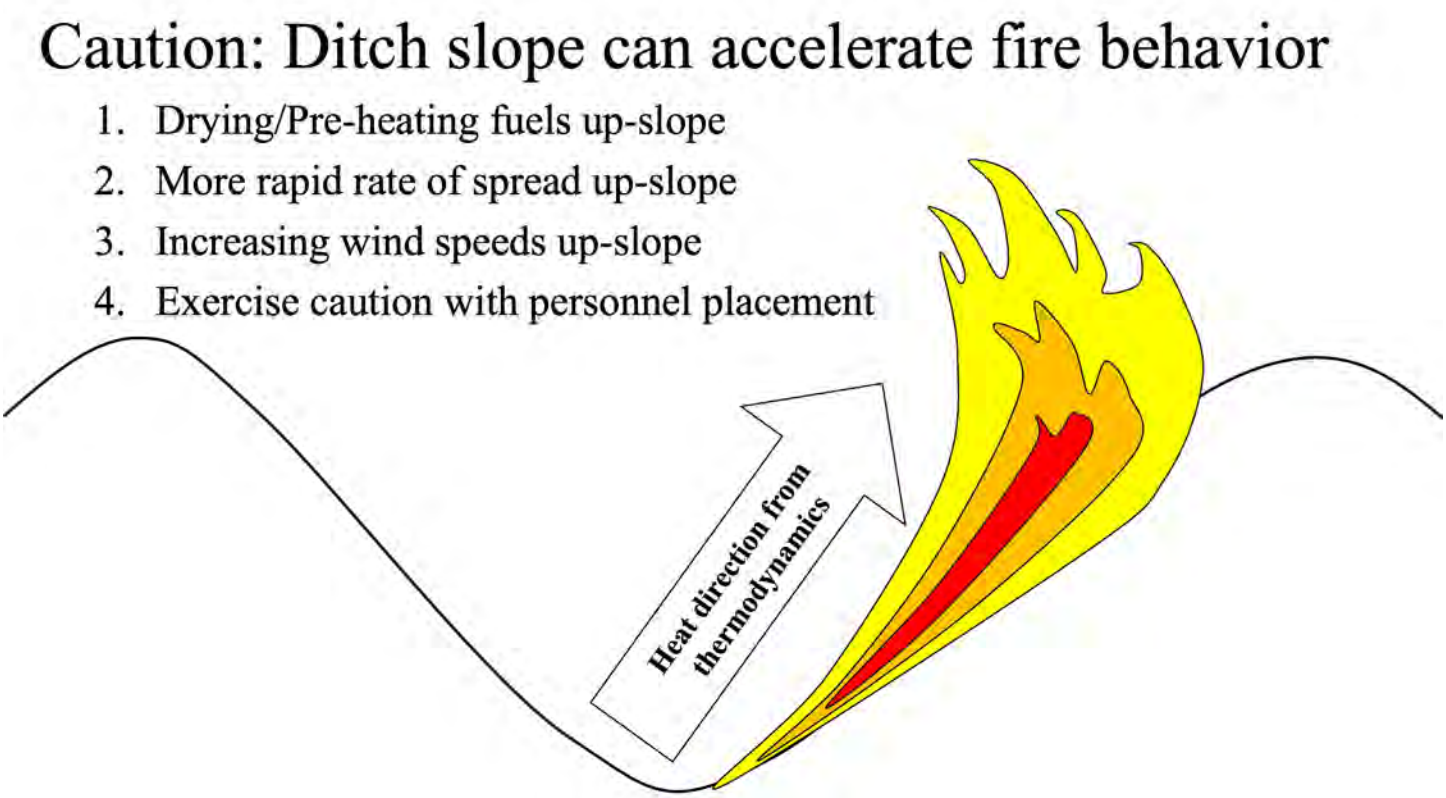

Figure 12. Slopes can alter fire behavior. For deeper ditches with steeper slopes, it is important to exercise caution with where personnel are placed relative to slope and ignition points.

SAFETY CONSIDERATIONS

When burning irrigation ditches, you should always prepare a burn plan, inform your community and get the proper protective gear (PPE or Personal Protective Equipment) needed to keep yourself safe. The burn plan should include details on the site, a description of the burn area, objectives of the burn, acceptable weather conditions, hazards within the burn unit, equipment and personnel needs, and contact information for local authorities (NRCS 2008; Randall and Underberg 2010; National Fire Fighter Wildland Corp 2017; Weir et al. 213). Prior to starting your burn, always check the ditches that you are burning to make sure that the fire cannot escape from the ditches and burn areas that you do not want to get burned.

In addition to making sure that the burned area is secure and having a plan, you need to inform your community about your burn. This might include neighbors with respiratory issues, smoke sensitive areas such as schools, hospitals or airports. You should also contact local authorities to inform them that you are conducting a burn (NRCS 2008) and generally a courtesy call to the County Sheriff dispatch is sufficient. When contacting them, give them your location, what you are burning, and when you expect to complete the burn. In addition you might consider contacting the local fire department and neighbors that are adjoining your land or are downwind of you so they know you intend to burn.

It is important to wear non-flammable materials and leave little exposed skin when conducting a ditch burn. You and anyone on the burn should always wear the proper gear (Figure 4). When considering gear to wear on a fire you should have head gear, clothing, eye protection, gloves and footwear (NRCS 2008; Randall and Harr 2012; National Fire Fighter Wildland Corp 2017; Weir et al. 2016). Head gear should be fire resistant and ideally will

Figure 13. For heavier fuels or more extreme conditions, a person lighting the fire should work in close proximity with some operating suppression equipment.

include a helmet and goggles to prevent embers from falling on your head or getting in your eyes. The best clothing to wear is fire resistant (Randall and Harr 2012; Weir et al. 2016). Avoid wearing synthetic materials as it can melt when exposed to heat. Shirts and pants should be long-sleeved and cover your entire arm and leg. In addition to these safety clothes, you should also wear leather gloves and comfortable leather footwear.

WEATHER CONSIDERATIONS

Weather strongly influences fire behavior and therefore are the most important factors to consider when planning a ditch burn in terms of managing safety, risk and liability. Understanding how weather can influence fire is important for reducing the risk of escape and burning property unintentionally (Joshi et al. 2019). The weather factors to check include relative humidity, wind speed and temperature (Table 1). For ditch burning they all need to be considered as they will likely change through the day and season to ensure that the fire does not escape containment and become a potential risk to person and property, but also to ensure that all of the desired material is burned.

Table 1 presents prescription parameters for these three weather variables that are generally recommended for burning vegetation safely. Winds often increase and humidity often drops in the afternoon so be aware of the changes of these parameters through the day. Checking the weather forecast before you start and monitoring the weather as you burn is vital to conducting safe burns of irrigation ditches. Websites such as The National Weather Service (weather.gov) or your smartphone weather app are useful tools. On the day of burn it is recommended to monitor the weather prior to, during and after the fire with the use of a handheld weather meter to take temperature, wind speed and relative humidity. Calling the National Weather Service at

Figure 14. Ignition hazards should be managed with extra attention such as this snow fence. In this picture, the fence was wet with water in front of the igniter, relative humidity was moderate (45-55 percent), and the fire was ignited with the wind blowing away from the snow fence.

800-211-1448 prior to ignition can also help you avoid weather related issues (National Weather Service. N.D.). It is also not recommended to burn if a known front or change in the weather is predicted for that day.

Since winds are stronger in open areas, the tops of the ditch may be more strongly influenced by the wind. This could cause the fire to move more quickly at the tops of the ditch than the bottom of the ditch. If the wind is blowing parallel to the ditch, there may not be equal burning in all parts of the ditch (NWS 2019). If the fuel moisture is high then it may be hard to get the vegetation to ignite so more wind or lower humidity may be needed (Sow et al. 2013). In Wyoming, the accumulation of snow in the bottoms of ditches, and the micro-climate of this part of the ditch can make it difficult to burn ditch bottoms in the spring (Figure 15). Ditch vegetation are typically grasses which are one hour fine fuels, meaning they will typically lag only an hour or so behind changes in humidity through the day. Temperature also has an influence on relative humidity as generally with every 20 °F increase in temperature the relative humidity will be reduced by half. Therefore, the amount of time since the last moisture event, the relative humidity, and the temperature of the day will all need to be considered for safety and smoke production.

TIMING OF BURNING

Deciding when the best time of year to burn ditches can be a difficult task for landowners and fire officials throughout the state of Wyoming. This is primarily due to the exceptionally high and variable winds that the majority of the state experiences year-round. It is also important for the individuals planning the ditch burns to understand the number of "burnable days" available at the beginning of each season, as the timing of ditch burns can be strategically planned based upon the number of "burnable days" available in each season (Weir 2011) but must also coincide with snow melt and water delivery (Figure 15). Burnable days are considered days where the wind, humidity, and temperature are within ranges that allow for safe and effective burning (Table 1). Ideally, ditches are burned in the early spring time prior to the release of irrigation water for the upcoming growing season (Bureau of Reclamation, 2017). Following the burn, vegetation that was once existing within the ditch will need enough time to recover, as improving the root systems helps to minimize erosion of the soil and generally if perennial grasses are present this happens very quickly (Bureau of Reclamation, 2017). Ditch burns that are to be applied in Wyoming should be planned carefully, while taking great safety precautions no matter what season of the year it is due to the highly variable weather conditions that can occur across the state. Burning in the early spring months is the safest time of year for the individuals managing these burns (WGFD, 1999).

Table 1. Prescription parameters for three weather variables recommended for burning vegetation safely.

Weather variable	Recommendation for safety
Relative Humidity*	Greater than 20%
Wind speed	Less than 15 miles per hour
Air temperature	The cooler the better

*As relative humidity drops, the risk or a spotfire (an ember leaving the intended burn area and igniting somewhere else) increases with the probability increasing at less than 40 percent; For those with limited experience consider the 60:40 rule or burn with a temperature below 60 °F, relative humidity above 40 percent, and wind speeds from 5 to 15 miles per hour (Weir et al. 2009).

Spring burns are also generally easier to control because relative humidity is higher, in contrast to controlling fall burns, which can be more difficult due to lower relative humidity and fuel moisture levels (Weir 2007). When planning ditch burning treatments for the upcoming grow season, landowners and fire managers need to also strongly consider the cascading ecological effects that will result from burning vegetation at a certain point in time. With concern to various bird species that use these ditches to brood their young (e.g. Greater Sage-grouse, White Faced Ibis, Northern Pintail, etc.), ditch burns may need to be completed before chicks have begun to hatch so that a more desirable green-up of vegetation will be available to benefit their survival (USFWS, 2017; McPeake, n.d.). When planning edge treatments, it is best to avoid the nesting and rearing seasons (until late-July) for most species in order to minimize stress to wildlife with habitat near the ditches (Bureau of Reclamation, 2017; McPeake, n.d.). Fall burns can also be conducted in conjunction with spring burns, as a rotational plan, and can allow for the successful management of various wildlife and vegetative species. In the state of Wyoming, burning ditches in the early spring months can be the

most beneficial time of year to obtain favorable results concerning wildlife, vegetation and the safety of those applying the burns.

POLICIES AND REGULATIONS

A private landowner must consider several policy and regulation requirements before they can legally burn an irrigation ditch, many of which pertain to smoke management (Figure 16). Smoke management is an important part of planning and managing a ditch burn because smoke is a public health concern. It is important to avoid putting smoke onto smoke sensitive features (roads, homes, hospitals, airports, etc.) and understanding Wyoming emissions regulations.

The Wyoming Department of Environmental Quality (DEQ) sets the guidelines for conducting burns as it relates to smoke with specific parameters and guidelines for burning of vegetative materials (http://bit.ly/DEQBurning). When reviewing DEQ guidelines it is important to note the specific regulations for refuse burning (trade wastes, salvage operations, fire hazards, fire fighter training), wood waste and vegetative burning. The policy and guidelines have implications for permission, notification and inspection and if you are unsure contact DEQ before you burn. If the irrigation ditch burn has a small amount of vegetation volume being burned per day (<0.25 tons/day PM_{10}*), it

Figure 15. In Wyoming, the bottoms of ditches can create a micro-climate where snow accumulates, wind is minimized, and moisture is held and waiting until the fuel moisture in the bottom dries out is ideal for more effective and complete burning. In this picture taken May 7, 2019 near Laramie, Wyoming, patches of snow persisted in the bottom of the ditch but the timing of water coming down the canal dictated that burning needed to be done as soon as possible.

Figure 16. Smoke management is an important aspect of fire management that includes avoiding putting smoke onto smoke sensitive features (roads, homes, hospitals, airports, etc.) and understanding Wyoming emissions regulations.

Figure 17. Burning irrigation ditches is an important tool to manage irrigation water in Wyoming. In this picture, the ditch was burned on Monday and water was run on Friday (May 6 and May 10).

would fall under Open Burn standards, but if it is larger (>0.25 tons/day PM_{10}), then it would fall under Smoke Management Program (SMP) standards (DEQ 2005). The acronym PM indicates coarse Particulate Matter in the air such as solids or liquids that are generally 10 micrometers and smaller (EPA 2014). Standard values for different vegetation types are provided by Wyoming DEQ and approximately 12 acres of ditches is equivalent to 0.25 tons PM_{10} emissions (Table 2). However, this can also vary by the width, length and depth of the ditch burn and if you know the width then you can identify the corresponding length of ditch burning that releases the equivalent emissions (Table 3).

Table 2. State of Wyoming, Department of Environmental Quality – Air Quality Division acreage and pile volume/ emissions equivalency conversion (http://bit.ly/DEQAirQuality)

Vegetation Type	0.25 tons PM_{10} Emissions
Field crops	16 acres
Shrub land	8 acres
Forest	6 acres
Grass	25 acres
Weeds (ditches, fence lines)	**12 acres**
Shrub/Forest piles	1,250 feet

Table 3. State of Wyoming, Department of Environmental Quality – Air Quality Division ditch and fence line burn width and length/emissions equivalency conversions to 0.25 tons PM10 Emissions (12 acres Weeds) (http://bit.ly/DEQAirQuality).

Width of Burn (feet)	Length of Burn (miles)
1	103
2	52
3	34
4	26
5	21
6	17
7	15
8	13
9	11
10	10
15	7
20	5
30	3
40	3
50	2

Depending on the size of the burn, proximity to populated areas and planned burning of weed growth in and along ditch banks incident to clearing ditches for irrigation purposes is not subject to certain subsections of the DEQ Chapter 10 Smoke Management standards, including 4(e)(ii), 4(f)(i), 4(f)(ii)(B), and 4(f)(v) of Chapter 10, Section 4 which deal with inspection of property, notification, and post-fire report (refer to http://bit.ly/DEQBurning Chapter 10, Section 2 (page 10-13).

For ditch burns that do exceed 0.25 tons/day PM_{10}, SMP is categorized as SPM-I (0.25-2.0 tons/day PM_{10}) or SPM-II (>2.0 tons/day PM_{10}). Similar to Open Burn standards, SMP-I notifies Administrator of the Division and the jurisdictional fire authority within the geographic area and the burner must monitor the burn behavior. When there is a population within 0.5 mile radius the burner must contact the public no sooner than 30 days before the burn and no later than two days of ignition. Furthermore, the burner must conduct the burn during the daylight hours and when there is only a slight breeze. The burner must submit a report of the burn within six week post burn (DEQ 2005). SMP-II is different than SMP-I in several ways. The burner must submit their planned project at a minimum two weeks before the burn, they must attend a smoke management training course, must consider alternatives to the burn and implement one emission technique for the burn (DEQ 2005). DEQ may waive all requirements for conducting a burn if the area is considered an emergency, or if the burner provides sufficient reason to burn within the required standards (DEQ 2205).

Landowners should also consider the potential risks associated with the escape of an irrigation ditch burn. In the state of Wyoming there are criminal penalties for leaving a fire unattended or having a negligent fire (Yoder et al. 2003). Taking precautions (burn plans, getting trained in prescribed burning, etc.) and considering alternatives to prescribed burns can potentially reduce the possibility for escape. Moreover, the criminal

penalties that burners can be charged with can curtail burners from burning irrigation ditches regardless of the potential ecological benefits (Yoder et al. 2004). For more information, go to http://deq.wyoming.gov/aqd/.

CONCLUSION

Burning irrigation ditches is important for water delivery to agricultural operations in Wyoming (Figure 17). It is one of the most effective tools for irrigation ditch management but does require some planning and forethought. Careful consideration and application of fire in ditches will ensure the ability to continue to use this tool into the future. While this document is not intended to be a legal guide to all aspects of burning, it is a starting point. If you have questions, always contact the appropriate local and state authorities before you begin.

REFERENCES

Bugwood (2018) The Bugwork Network. [Online] https://www.bugwood.org/pfire/weather.cfm

DOI BR (2017) Canal Operation and Maintenance: Vegetation. U.S. Department of the Interior, Bureau of Reclamation. [Online] https://www.usbr.gov/assetmanagement/docs/Canal_Vegetation.pdf.

WY DEQ (2005) Wyoming Department of Environmental Quality: air quality division standards and regulations Chapter 10 smoke management. https://www.epa.gov/sites/production/files/2018-06/documents/chapter_10_smoke_management.pdf

Ditomaso et al. (2006) Control of invasive weeds with prescribed burning. *Weed Technology* 20:535-548.

Dollinger et al. (2015) Managing ditches for agroecological engineering of landscape. A review. *Agronomy for Sustainable Development* 35:999-1020.

Dollinger et al. (2017) Impact of maintenance operations on the seasonal evolution of ditch properties and functions. *Agricultural Water Management* 193:191-204.

EPA (2018) Particulate Matter (PM) pollution. Environmental Protection Agency [Online]. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

Hodge (1893). Prehistoric irrigation in Arizona. *American Anthropologist* 6:323-330.

CFC (2013) Irrigation Ditches. City of Fort Collins Utilities. [Online] https://www.fcgov.com/utilities/img/site_specific/uploads/Irrigation_Ditches_Brochure.pdf

CG (2016) Irrigation Ditch Frequently Asked Questions. Water Resources, City of Boulder, [Online] www.static.bouldercolorado.gov/docs/2016-11-09_Ditch_FAQ-1-201611091612.pdf

Joshi et al. (2019) Determinants of perceived risk and liability concerns associated with T prescribed burning in the United States. *Journal of Environmental Management* 230:379–385

Levavasseur et al. (2014) Time-varying impacts of different management regimes on vegetation cover in agricultural ditches. *Agricultural Water Management* 140:14-19.

Martín et al. (2018) Effects of vegetation management on plant diversity in traditional irrigation systems. *Journal of Environmental Management* 223:396-402.

McPeake (2010) Best Management Practices for Waterbirds on Agricultural Lands. University of Arkansas Division of Agriculture: Agriculture and Natural Resources [Online] https://www.uaex.edu/publications/pdf/FSA-9098.pdf

FFFWC (2017) Tools and tactics for conducting prescribed fires. National Fire Fighter Wildland Corp. [Online] http://www.nationalfirefighter.com/blog/Top-Tools-Tactics-for-Conducting-Prescribed-Fires

NWS (2019) Spring Burning – Learn Before You Burn. National Weather Service. [Online] https://www.weather.gov/riw/agburning

NRCS (2008) Conducting a successful prescribed burn. Prescribed Burning: conservation practice information sheet. IS-MO338 [Online] https://efotg.sc.egov.usda.gov/references/public/MO/PrescribedBurn_InfoSheet_4_08.pdf

Randall & Harr (2012) Considerations for prescribed burning: tools & safety gear. Iowa State University Extension. PM 2088B. [Online] https://store.extension.iastate.edu/product/Considerations-for-Prescribed-Burning-Tools-Safety-Gear

Randall & Underberg (2010) Developing a prescribed fire burn plan: elements and considerations. Iowa State University Extension. PM 2088A [Online] https://store.extension.iastate.edu/product/Developing-a-Prescribed-Fire-Burn-Plan-Elements-Considerations

Ryan et al. (2013) Prescribed fire in North American forests and woodlands: History, current practice, and challenges. *Frontiers in Ecology and the Environment* 11:e15-e24.

Scasta (2015a) B-1271 Wildland fire in Wyoming: patterns, influences, and effects. University of Wyoming Extension, Laramie, WY, USA. [Online] http://www.wyoextension.org/publications/Search_Details.php?pubid=1882&pub=B-1271

Scasta (2015b) Fire and parasites: an under-recognized form of anthropogenic land use change and mechanism of disease exposure. *EcoHealth* 12:398-403.

Sow et al. (2013) Fuel and fire behavior analysis for early-season prescribed fire planning in Sudanian and Sahelian savannas. *Journal of Arid Environments* 89:84-93

University of Wyoming: Wyoming State Climate Office. 2008. Humidity. Wyoming State Climate Atlas. http://www.wrds.uwyo.edu/sco/climateatlas/humidity.html. Chapter 9.

US DOI: Bureau of Reclamation. 2017. Canal Operation & Maintenance: Vegetation. Reclamation: Managing Water in the West. [Online] https://www.usbr.gov/assetmanagement/docs/Canal_Vegetation.pdf

US Fish & Wildlife Service: Wyoming. 2017. PFW Program Mountain-Prairie Region Strategic Plan. [Online] https://www.fws.gov/mountain-prairie/refuges/partnersPDFs/WYPFW%20SP2017-2021.pdf .Pp. 251-292.

Wallis & Turner 1969. Burning weeds in drainage ditches to suppress population of green peach aphids and incidence of beet western yellows disease in sugarbeets. Economic Entomology. 62:307-309

Weather Spark. 2016. Average Weather in Laramie. https://weatherspark.com/y/3574/Average-Weather-in-Laramie-Wyoming-United-States-Year-Round .

Weir 2007. Using Relative Humidity to Predict Spotfire Probability on Prescribed Burns. USFS Proceedings: Shrubland Dynamics—Fire and Water. [Online] https://www.fs.fed.us/rm/pubs/rmrs_p047.pdf#page=76

Weir et al. 2009. Oklahoma Prescribed Burning Handbook. Oklahoma Cooperative Extension Service. E-1010. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-6613/E-1010%20Prescribed%20Fire.pdf

Weir 2011. The Best Time of Year to Conduct Prescribed Burns. Oklahoma Cooperative Extension Service; Oklahoma State Division of Agricultural & Natural Sciences. Pp. 1-4.

Weir et al. 2013. E-2893 Burn plan for prescribed burning. Oklahoma Cooperative Extension Service Factsheet. http://www.forestry.ok.gov/Websites/forestry/images/NREM-2893,_Burn_Plan_for_Rx_Fire.pdf

Weir et al. 2016. Prescribed Burn Equipment. Oklahoma Cooperative Extension Service. NREM-2899

Wyoming Game and Fish Department. 1999. Fire Management and Wildlife. Habitat Extension Bulletin. [Online] https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Extension%20Bulletins/B49-Fire-Management-and-Wildlife.pdf

Yoder et al. (2003). Economics and prescribed fire law in the United States. Review of Agricultural Economics, 25(1), 218-233.

Yoder et al. (2004). Liability, incentives, and prescribed fire for ecosystem management. Frontiers in Ecology and the Environment, 2(7), 361-366.

B-1351 • September 2019

Editor: Katie Shockley. Graphic design: Tanya Engel.

Issued in furtherance of extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Kelly Crane, director, University of Wyoming Extension, University of Wyoming, Laramie, Wyoming 82071.