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Managing Climate Risks and Extreme Weather in Agriculture

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Agricultural production has always been sensitive to weather. Extreme weather events, like droughts and floods, cause billions of dollars in losses to crops and livestock in the United States every year (Motha 2011). These events not only cause damage directly but can also increase losses from disease and pests. To avoid this damage, agricultural communities should consider preparing for weather conditions that can reduce crop yields, increase livestock mortality, and damage infrastructure.

Even though it is not possible to control the weather, it is possible to drastically decrease its impact. In recent years, climate data availability and forecasts have tremendously improved, leading to the development of tools designed to help producers use this data to reduce weather-related losses. These resources, when combined with traditional programs like crop and livestock insurance, can be useful in minimizing the impacts of climate variability and extreme weather.

This bulletin summarizes weather-related risks to agricultural production and offers resources to help producers, as well as extension and conservation personnel who work with them, manage these risks. The first part of this bulletin provides information on different types of climatic risks that may be encountered in agricultural production. The second section describes general principles of risk management and how they apply to climatic risks. The final section describes tools and resources that can help put these principles into practice. These include financial programs, such as crop insurance, as well as technical resources and tools. Links to these resources are included in the "Additional Resources" section at the end of this document. A glossary of terms is also included at the end of the document. This information should help producers identify the weather-related risks that could impact their operations and design strategies to minimize the impact of those events.

Climate Variability and Its Impact on Agriculture

Climate conditions can affect agricultural production in many different ways. One type of climate risk is irregular or extreme temperatures that are significantly different from the historical average for that season. This includes many different types of events, such as an unusually warm winter, a cool summer, heat waves, or freeze/thaw periods that occur earlier or later than usual. While these circumstances may not seem too extreme, they can have consequences for agricultural production. Late frosts in the spring can harm young plants and slow growth, and early fall frosts can damage harvests for certain crops, such as corn. Some plants require a cold winter period to flower in the spring, a process that can be negatively impacted by warm winters. Heat waves decrease soil moisture, increasing the need for irrigation and making crops vulnerable to dry periods when irrigation is not available. Even when sufficient water is available, extreme heat on its own can damage crops. For instance, during the 2010 heat wave, one Virginia producer was quoted as saying, "The last few weeks I've been watering constantly, but I can't water my way out of the heat" (quoted in Virginia Farm Bureau Membership@Work 2010). A prolonged heat wave can also cause heat stress in livestock, which can lead to stunted growth, a decrease in dairy production, or even animal death.

Variability in rainfall also has dramatic impacts on agricultural production, particularly prolonged periods with little or no rainfall. During droughts, crops may grow more slowly, or even die, without access to irrigation. While irrigation can help supply water during droughts, it often requires large upfront installation costs along with operational costs associated with fuel, labor, and water. Droughts also decrease the amount of moisture in the soil and the amount of grass available for livestock grazing, forcing agricultural producers to

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purchase more feed. A drought can decrease the water level in groundwater wells, ponds, streams, and rivers. This reduces the amount of water available for irrigation and means that even producers with irrigation might not have water available when it's needed the most. Droughts can result in massive financial losses. For example, the 2007 drought devastated most of the Mid-Atlantic, including Virginia. In North Carolina alone it caused an estimated $573 million in agricultural losses (Davis 2015; NCDEQ 2008).

Heavy, intense rainfall can also result in serious agricultural damage and can be particularly problematic in temperate-humid regions, including Virginia. Excess rainfall can waterlog soils, leading to stunted crop growth, reduced yields, or plant death, and is often associated with a higher risk of disease occurrence and pest pressure. Excess rainfall can also cause land degradation from eroding top soil and leaching of nutrients from the root zone. If rainfall exceeds the land's drainage capacity, flooding can occur and damage roadways, buildings, and other infrastructure. Flooding can also result in rot and mold damage to buildings, which is a health hazard to people and livestock. Floodwaters also present dangerous drowning risks to both people and livestock. Floods can lead to serious environmental problems when agricultural runoff, chemicals, and wastes flow into rivers and streams.

Perhaps the most devastating extreme weather events that impact the Mid-Atlantic are tropical cyclones, including hurricanes. Tropical cyclones are storms that originate over warm water in the southern Atlantic, most often between June and November, and result in high winds and heavy rain. A tropical cyclone is classified as a hurricane if it results in wind speeds of at least 72 miles per hour. While hurricanes are defined by high wind speeds, they generally result in extremely high rainfall as well. For instance, Hurricane Irene resulted in 5 to 10 inches of rainfall over two days in eastern Virginia and North Carolina in 2011 (PRISM Climate Group, 2017). This combination of high rain and wind can cause extensive damage to buildings, land, and crops. Furthermore, hurricanes can also damage critical infrastructures like roads, power grids, and water systems. When these systems are damaged, it becomes more difficult to respond to on-farm impacts and recover. In 2016, Hurricane Matthew caused over a billion dollars in damage in North Carolina alone (North Carolina General Assembly 2016). This included an estimated $400 million in field crops, $20 million in landscape and nursery crops, 2,800 swine lost, and 1.8 million poultry lost (Stewart and Ballard 2016).

It is important to recognize the interaction that climatic risks have with other agricultural stresses, such as diseases and insects. In the United States, the annual cost of pest-related crop loss is estimated to be $32 billion from weeds, $34.7 billion from insects, and $33 billion from plant diseases (Pimentel et al. 2000). Pest damage is often closely related to weather conditions. For instance, warmer weather increases the growth and reproduction rate of many species of insect pests (Jackson et al. 2012), and many plant diseases infect and spread most quickly in wet, humid conditions (Glen and Mathews 2013). More pests over a wider area also have the potential to increase the frequency of vector-borne diseases in humans and livestock. Higher temperatures associated with climate change allow pests to migrate north to areas where it was previously too cold for them to survive. This would lead to pests of all kinds appearing in new places for the first time, forcing agricultural producers to adopt new pest-management strategies.

Whereas climate change and climate variability are not the same things, they are related. Climate variability refers to differences in weather that occur over seasonal, annual, and decadal timescales. Climate change refers

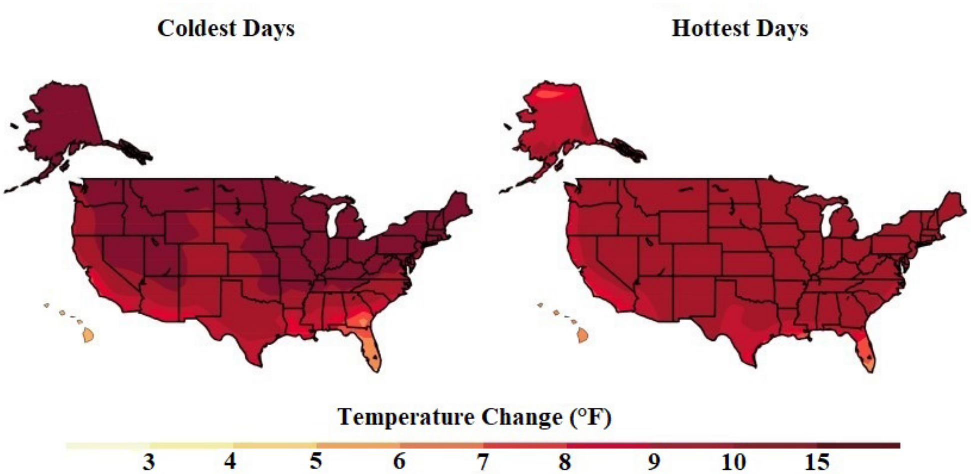

Figure 1: Projections for coldest (left) and hottest (right) days by the end of the century (source: Melilo et al., 2014)

to long-term changes in the climate associated with increased greenhouse gases in the atmosphere. For example, the average temperature in coastal Virginia is about 1.5 degrees F higher now than it was in the early 1900s (Melillo, Richmond, and Yohe 2014); this is the result of climate change. While a change of 1.5 degrees might not sound like much, it can influence the occurrence and severity of extreme weather events like heat waves and intense rainstorms. Heat waves are already occurring more often than they have historically (IPCC 2012), and in the southeastern United States, more rainfall occurs during extremely heavy storms now than it did in the early 1900s (Melillo, Richmond, and Yohe 2014). Higher temperatures can also intensify drought impacts; for instance, the 2012-2014 drought in California was especially severe because of higher temperatures from climate change (Williams et al. 2015). These trends are expected to continue into the future, and by the end of the century, the hottest days of the year could be, on average, about 10 degrees warmer than they are now (Figure 1). Thus, climate change makes it even more important that agricultural producers take measures to help manage risks related to climate variability and extreme weather.

Managing Climate Risks

Typically, risks are characterized by two things: likelihood and consequences. Likelihood, also known as probability, specifies the chances of an event occurring. Some damaging weather events occur relatively frequently in certain areas, meaning that they have a high likelihood. For example, at high elevations, frosts in the early spring or late fall are events producers might experience once every few years. Other events occur far less frequently and thus have a much lower likelihood. Extreme rainfall and flooding are often defined by its likelihood of occurring. A 100-year flood is expected to occur approximately once every 100 years, and a 500-year flood is expected to occur once every 500 years. This means, in any given year, the probability of a 500-year flood occurring is 1/500, or 0.2 percent. This doesn't mean that it's impossible for a 500-year flood to occur more often than that, or even multiple times in just a few years. However, it is unlikely.

Consequences refer to the damage that results from an event. Often, events that have a high likelihood have relatively low consequences, whereas events that result in very severe consequences have a lower likelihood of occurring. However, there may be an instance where an event has both a high likelihood of occurring and high consequences if it does occur; these events should be a priority in risk management.

Although it is not possible to control the weather, there are steps that can be used in agricultural production to manage weather-related risks and reduce the impacts that they have on operations. The four components of risk management (Figure 2) can help producers prepare for climate variability and extreme weather. These components are identifying risks, making a plan, reducing the likelihood of a risk, and reducing consequences of a risk. While taking these steps cannot guarantee that weather-related damages will never occur, they can reduce the chances that bad weather will lead to extensive crop, livestock, or financial losses, and speed recovery of farm operations following a weather-related disaster.

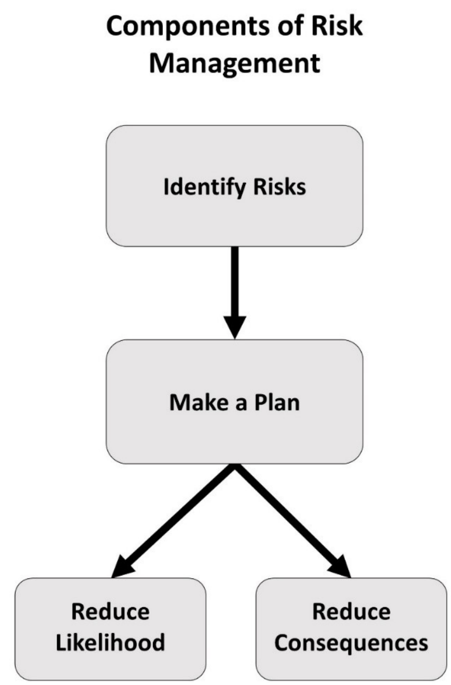

Figure 2: Components of Risk Management

Step 1: Identify risks

The first component is to identify the risks that could affect farm operations. Not all climatic disasters are likely to occur in every area; therefore, it is only necessary to consider relevant ones. Droughts and excess rainfall can occur almost anywhere, but certain risks are location-specific. For instance, flooding generally occurs near water bodies or in areas of low elevation. Wildfires tend to occur in areas with extensive forest or grassland. However, it is important to note that just because a certain event *has not yet* occurred in a geographic area does not mean that it *cannot* occur. Hurricane Harvey hit the southern United States in

August 2017 and caused at least 60 deaths and an excess of $125 billion in damages (Blake and Zelinksy, 2018). One Federal Emergency Management Agency (FEMA) official stated, "We have not seen an event like this. You could not draw this forecast up. You could not dream this forecast up" (Sullivan and Berman 2017). This example demonstrates that extreme weather that exceeds what has happened historically can occur at any time. When identifying risks, people often have a short memory and focus on damaging events that have occurred recently. This can lead people to ignore the risk of events that have not occurred in a long time. For this reason, it is important to prepare for all types of possible extreme weather events and not just those that are fresh in memory. Producers need to try to identify risks that perhaps occurred many years ago, or even those that have never affected their property but have occurred in nearby, similar locations.

Step 2: Make a Plan

Once risks have been identified, the second component of risk management is to make a plan. It is critical to develop a plan to determine specifically what will be done if an extreme weather event occurs. Planning for extreme weather can be as simple as determining when to begin irrigation in a drought to something as complex as dealing with the aftermath of a hurricane. Each plan will differ depending on the identified risks and the goals of managing them. Determining the best course of action is not always readily apparent, but there are several resources and programs designed to help agricultural producers plan for extreme weather. These are discussed in the Resources and Tools section.

Step 3: Reduce the Likelihood of Risks

Since humans cannot control the weather, it is generally not possible to reduce the likelihood of an extreme weather event. Moving a farm from a commonly flooded region to somewhere at a higher elevation would reduce the likelihood of flooding; however, this is an extreme action that would probably be out of reach or undesirable for most people. Therefore, it is important to focus on reducing the consequences of extreme weather when they occur.

Step 4: Reduce Consequences of Risks

Even though weather extremes are inevitable, excessive damages from extreme weather are not. Producers can take several actions to reduce the negative impact of extreme weather; these can include measures like keeping extra feed for livestock, maintaining access to adequate water supplies, and using drought-resistant varieties of crops. In many cases, conservation practices can be effective in reducing the impact of droughts and extreme precipitation. Insurance programs are aimed at reducing the financial consequences of an extreme weather event that leads to crop loss. Finally, some technical tools have been developed recently to help producers understand and manage the extreme weather risks that could affect their operations. These strategies and programs are discussed in the following sections.

Resources and Tools

Resources, programs, and tools are available to help put the four steps to risk management described above into practice. These resources are described in the following sections, and links to each are provided in the "Additional Resources" list at the end of this document.

Identifying Risks and Planning

Virginia, like many other states, has an emergency management division that maintains a website with information on planning, prevention, and relief information for extreme weather. These websites are a useful way to identify weather-related risks associated with a given location. The web address for the Virginia Department of Emergency Management is included in the "Additional Resources" section at the end of this document. Other potentially useful resources for identifying climate risks are the United States Department of Agriculture (USDA) climate hubs. The USDA operates ten regional climate hubs aimed at providing agricultural producers and natural resource managers with information on risks related to climate variability and change in their region. The Southeast regional climate hub website includes factsheets, webinars, and educational modules aimed at addressing different types of climate risks. The hubs also include alert systems that will send notices when certain types of climate-related risks, such as drought and cattle heat stress, are likely to occur.

Another resource that can be useful in planning for extreme weather is the Adaptation Workbook developed by the USDA and Cornell University's Climate Smart Farming program. The Adaptation Workbook is a customizable workbook designed to help agricultural managers define their goals and create a plan to accomplish them. This workbook takes into account extreme weather and helps plan mitigation strategies based on geographic location. Users input the location, size, and production characteristics of their farm, along with their management goals and objectives. The workbook then prompts users to identify climatic risks associated with their area. The Adaptation Workbook even suggests potential issues and possible mitigation strategies based on location. The next step is to evaluate how management goals and objectives might be impacted by climate conditions. Certain extreme weather presents obstacles to goals and others present opportunity. It is important to consider both of these before creating a plan of action. Next, the workbook will suggest tactics to achieve the user's goals. Tactics can be anything from decreasing runoff to changing management strategies. Lastly, the Adaptation Workbook allows users to export and print their plan for easy implementation. Users also have the option of sharing their plan and viewing the plans of other agricultural producers.

Climate Resilient Conservation Practices

Conservation practices are designed to conserve natural resources, protect against extreme weather, and increase crop yield. One such practice is conservation tillage. Conservation tillage is the practice of reducing soil disturbance from tillage and leaving the majority of the field covered in the previous year's crop residue. By employing conservation tillage, leftover plant matter will degrade into the soil, increasing carbon content and improving overall soil health. It also reduces soil runoff and erosion while allowing water to infiltrate further into the soil, increasing resilience to droughts (Easton and Faulkner 2014).

Another common conservation practice is using cover crops and crop rotations. Planting cover crops rather than keeping a field fallow will increase overall soil health and fertility of a field, while simultaneously increasing resilience to droughts and floods (Easton and Faulkner 2014). Cover crops, especially those nitrogen-fixing types that can put nitrogen back into the soil, increase the level of nutrients that would otherwise have been lost to the atmosphere. Having cover crops present also helps reduce soil erosion. During heavy rainfall events, having roots in place helps absorb rainfall and prevent nutrient runoff. During dry periods, the roots also hold soil in place and help to prevent erosion from wind (Easton and Faulkner 2014). Crop rotations work in much the same way as for cover crops, but with a few additional benefits. They allow for diverse nutrient requirements and fixation, decreasing the chances that soil will be depleted of any one nutrient (Easton and Faulkner 2014). Using crop rotations also reduces the impact of pests and diseases that are specific to a certain species or family of crops.

Insurance Programs

The U.S. Department of Agriculture authorizes private companies to provide crop insurance to agricultural producers. The USDA regulates the premiums and coverage options for these companies as well. These companies ensure agricultural production in the event of both extreme weather and loss of revenue due to a drop in price. In Virginia alone, insurance companies paid more than $501 million in liability in 2016 (National Crop Insurance Services 2017). However, private insurance companies are not required to cover every crop in every area. Crop coverage varies from county to county, but generally covers the major agricultural crops associated with that region. The USDA maintains a coverage and cost estimate tool on its website so agricultural producers can see if they are eligible for coverage (see "Additional Resources"). The USDA's Risk Management Agency also provides several livestock insurance policies, but these are primarily geared toward managing declines in market prices. Private livestock insurance policies are available that may be better suited to managing weather-related livestock losses.

The USDA's Noninsured Crop Disaster Assistance Program (NAP) insures some crops not covered by private insurance. Generally, crops covered by the NAP are specialty crops not grown in large enough quantities to support a private insurance program. However, not every crop is eligible for a NAP. The USDA maintains an online tool to view which crops are covered and provides an estimate for payout if a crop is covered by the NAP. In order to receive compensation from a NAP, agricultural producers are required to register and buy coverage the same way they would for traditional insurance.

Seasonal Forecasts

The National Oceanic and Atmospheric Administration (NOAA) prepares seasonal forecasts that can provide producers with information on expected weather conditions over the growing season. These forecasts do not have specific weather predictions but rather a general trend in precipitation and temperature for up to one year in the future. This can help agricultural producers to see whether they should expect the coming months to be cooler, hotter, wetter, or drier than average. For instance, Figure 3 shows a seasonal forecast created in March 2018 for summer (June-August) of 2018. It shows the probability that temperatures will be warmer than average for different regions of the country. The forecast suggests that there is a 50 percent chance that temperatures will be higher than average in the Southwest. In the Southeast and Mid-Atlantic, including Virginia, there is a 40 percent chance they will be higher than average. These seasonal forecasts also allow users access to more specific temperature and precipitation predictions. For instance, NOAA provides graphs that show the chances of a certain amount of precipitation or extreme temperatures occurring. It should be noted that neither of these forecasts predicts specific events like a heat wave or intense storm, but they provide general insights. These can be useful in seasonal planning; for instance, if dry conditions are expected, it might be useful to plant drought-resistant crop varieties. Conversely, if the spring was forecast to be cooler than average, producers could plant later than they normally would to avoid the chances of a late frost damaging young plants.

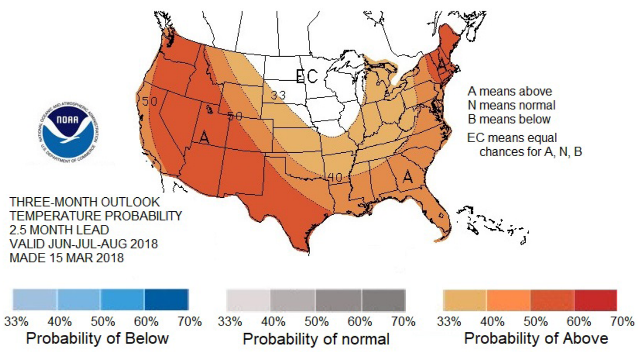

Figure 3: Sample 5.5-month seasonal forecast for the United States (source: NOAA National Weather Service Climate Prediction Center 2018)

Location-Specific and Interactive Tools

Resources are available that provide location-specific data on historic weather risks and interactive tools that can help producers manage these risks. For instance, the University of Florida maintains a website called AgroClimate that contains tools such as a degree-day calculator, crop yield calculator, and others. While many of these tools are designed for the Gulf States (e.g. Florida, Georgia, and Alabama), some are also available as far north as Virginia. One useful tool on AgroClimate is the growing degree-day monitor. This tool provides an interactive map of the Southeast that displays heat accumulation over a user-specified period. As seen in Figure 4, it also provides a side-by-side comparison of the deviation in heat accumulation from the historical average. By seeing a deviation from the historical average, agricultural producers can more accurately estimate the rate of development of both crops and pests. An unusually hot season may justify irrigation or other preventive measures to ensure that crops do not suffer from heat or water stress. Warmer weather also could indicate a higher than average pest pressure and a need for additional pest monitoring.

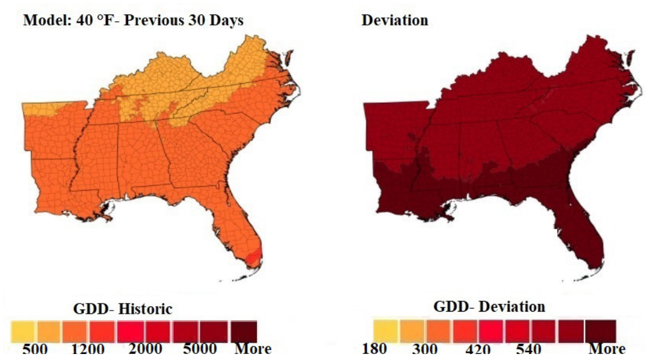

Figure 4: Growing degree-day monitor tool (source: AgroClimate 2017)

Cornell University maintains a similar set of resources within the Climate Smart Farming program. Climate Smart Farming has tools to help monitor drought, water deficit, and even nitrogen usage. One particularly useful tool is the water deficit calculator, shown in Figure 5. This tool allows users to input the location of their farm, soil type, and crop type. It then gathers weather data from the inputted location along with crop and soil information to produce a graph displaying whether or not crops are experiencing a water deficit. It also uses historical weather data to estimate the chances that a water deficit will occur in the next 30 days, and if the deficit will be significant enough to cause stress in the crops. By using this tool to monitor water stresses in

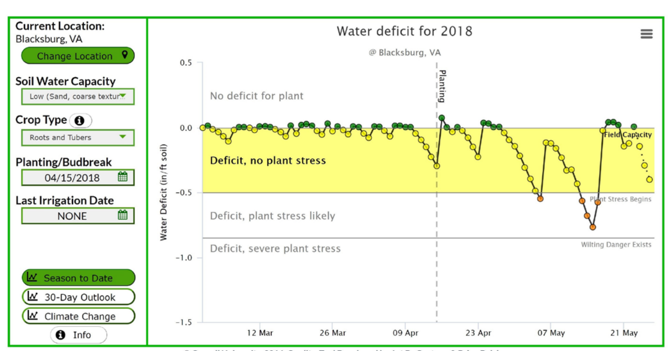

Figure 5: Water deficit tool (source: Climate Smart Farming 2017)

crops, agricultural producers can make sure to irrigate before water stress occurs, while maximizing water-use efficiency and avoiding the costs of unnecessary irrigation.

Another tool that can be useful in farm management is a crop simulation model called CROPWAT from the Food and Agricultural Organization (FAO). CROPWAT is a free program designed to help optimize crop output. Users input agricultural information such as local climate, crop data, irrigation amount, and soil type, and CROPWAT will output pertinent information such as nutrient and water deficiencies. It then calculates their effect on crop growth and production. Alternatively, if an agricultural producer does not have access to the necessary agricultural information, CROPWAT has preloaded information about most crops, soil types, and locations that can provide a good estimate. CROPWAT can also help agricultural producers create an irrigation schedule based on climate information. It will output the recommended amount of irrigation to apply per day (or per week) and will adjust the growth of crops accordingly. This program allows producers to evaluate the effect of water deficits on their production and gives them the necessary tools to adjust their managerial habits to achieve maximum production.

Additional tools aimed at helping producers manage climate risks can be found at the USDA's Climate Hub Tool Shed database. These resources focus on education and prevention of common agricultural problems that result from extreme weather and climate change. The Climate Hub Tool Shed can be filtered by area, agriculture type, or issue type so agricultural producers can quickly find the information they are looking for. The database includes tools developed by a wide range of organizations, including federal agencies, universities, and the private sector. These include forecasts for extreme weather as well as related risks (such as pests or diseases) and interactive tools aimed at improved management of these risks.

Conclusion

Even though we cannot control the weather, there are many actions that producers can take to manage the risks that extreme weather poses to their operations. A number of new tools have been developed to help producers manage these risks in addition to longstanding resources like the USDA's crop insurance programs. Multiple resources exist that can help producers identify the most pressing risks for their operations and develop plans to help manage these risks. Additionally, numerous technical tools and resources aimed at providing information on extreme weather risks and management strategies are freely available online. These resources can help producers avoid the most devastating consequences the next time extreme weather occurs.

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Glossary

Climate: The generally prevailing weather conditions of a region, throughout the year, averaged over a series of years. For instance, "the average high temperature in Blacksburg on January 1 is 41 degrees F" is a statement about climate.

Climate change: A nonrandom change in climate that is measured over several decades or longer. Even though the earth's climate is always changing, in this document climate change refers to the warming trend that has occurred over the past century.

Climate variability: The range of climate conditions that occur on time scales from a few weeks to a few decades. For instance, "the high temperature in Blacksburg on January 1 ranged from 23 to 78 degrees F over the past 100 years" is a statement about climate variability.

Consequences: The impacts of a risk occurring. These impacts can be related to finances, farm operations and production, general health and well-being, or other issues. For instance, the consequences of a flood could be loss of livestock and crops, damage to farm buildings and infrastructure, and increased disease pressure on crops.

Drought: A period of below-average rainfall that results in adverse impacts on people, animals, or vegetation over a sizable area.

Extreme weather: Weather conditions that are unexpected, unusual, severe, unseasonable, or fall well outside the range of typical weather for a location and time of year.

Likelihood: The chances of an event occurring, typically estimated as a percentage (e.g., "there is an 80 percent chance of rain tomorrow"), fraction ("there is a 1/20 chance that someone will experience a car accident in a given year") or odds ("the odds of winning are 2:1").

Probability: See likelihood

Risk: In this document, risk refers to an event that may or may not occur (and is therefore uncertain), but will have negative consequences if it does occur. We describe a risk by its likelihood (what are the chances that it will happen?) and its consequences (what will the impact be if it happens?).

Seasonal forecast: An estimate of how climate in next few months or year will compare to typical conditions. Seasonal forecasts do not provide specific weather information (e.g., "Will it rain in Blacksburg on July 1, 2018?"), but instead a general estimate of how climate conditions will compare to long-term averages (e.g., "Will the summer of 2018 be drier or wetter than average?")

Weather: The condition of the atmosphere, in terms of temperature, cloudiness, moisture, etc., at a specific point in time and location. For instance, today's high temperature is an example of weather, whereas climate refers to average weather conditions over a long time (e.g., the average high temperature for today's date). For instance, "the high temperature in Blacksburg on January 1, 2018, was 19 degrees F" is a statement about weather.

Additional Resources

Identifying Risks and Planning

1. Virginia Department of Emergency Management: http://www.vaemergency.gov

2. USDA Climate Hubs: https://www.climatehubs.oce.usda.gov

3. Adaptation Workbook: https://www.adaptationworkbook.org

Insurance Programs

1. USDA Coverage and cost estimate tool for crop insurance: https://webapp.rma.usda.gov/apps/actuarialinformationbrowser/

2. USDA Noninsured Crop Disaster Assistance Program: http://fsa.usapas.com/NAP.aspx

Technical Tools

1. NOAA Seasonal Forecasts: http://www.cpc.ncep.noaa.gov/products/predictions/90day/

2. University of Florida AgroClimate: http://agroclimate.org

3. Cornell University Climate Smart Farming: http://climatesmartfarming.org/

4. FAO CROPWAT: http://www.fao.org/land-water/databases-and-software/cropwat/en/

5. USDA Climate Hub Tool Shed: https://tools.serch.us/tbl_tools_list.php

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