

# Who to Call after the Storm?

## The Challenge of Flooding due to Climate Change for Fruit and Vegetable Growers in the Northeast United States

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■ **ABSTRACT:** Precipitation has increased across most of the United States over the last century. The Northeast region has seen the largest increase of ~15 percent, predominantly from an increase in the frequency of extreme events, and these trends will continue. Commercial diversified fruit and vegetable (F&V) growers in the Northeast are among the most vulnerable to the flooding that can result from this trend. These growers, as part of broader social networks, can also be part of the process of adaptation and transformation of the regional landscape. Here, I review literature on expected precipitation changes, farmer experimentation and decision-making, the effects of flooding on agriculture and F&V systems, and the adaptation options available to and in use by growers. I draw on two case studies and highlight how these growers' experiences complement the literature, and add context on advising needs, the challenge of prioritization, and the emotions that accompany changing rainfall patterns.

■ **KEYWORDS:** adaptation, agriculture, climate change, decision-making, fruit, rainfall, transformation, vegetables

### Review of Literature

#### *Climate Change Impacts to Northeast Fruit and Vegetable Growers*

The fact that our changing climate will impact food production is well established (Hatfield et al. 2020; Howden et al. 2007; Rosenzweig and Parry 1994). However, some geographic areas and production systems have been covered in more depth and with greater certainty. Within the United States, for example, literature on agricultural climate impacts is limited for the Northeast region<sup>1</sup> compared to regions with bigger agricultural economies such as the Midwest, Great Plains, and California (Ahn and Steinschneider 2019; Gowda et al. 2018). Works by Wolfe et al. and the USDA are among the few publications that focus specifically on the impacts and adaptation options for agriculture in the Northeast (NE) (Janowiak et al. 2016; Wolfe, Ziska et al. 2008; Wolfe, DeGaetano et al. 2018). National-scale assessments on climate change provide some coverage of the NE and agriculture, including the National Climate Assessments in the United States (USGCRP 2018; 2023), Laura Lengnick's *Resilient Agriculture* (2022), and a small number of reviews in journals (Hatfield et al. 2020; Lengnick 2015; Ortiz-Bobea et al. 2018). Other researchers have focused on singular climate challenges to NE agriculture, such as drought or irrigation demand (Krakauer et al. 2019; McDonald and Girvetz 2013; Sweet et al.



2017) or the impacts to specific products in the NE region such as maize (Hunter et al. 2021), maple syrup (Rapp et al. 2019) or livestock (Hristov et al. 2018).

The impact of climate change to fruit and vegetable growers in the NE has not to date been thoroughly studied or documented. There are some studies which begin to shed light on the issue, including Ranjan Parajuli, Greg Thoma, and Marty D. Matlock (2019) who discuss implications for global fruit and vegetable (F&V) production supply chains; and for the NE work by Rachel Schattman and colleagues focusing on both risks to growers as well as their perceptions (Schattman, Conner et al. 2016; Schattman, Méndez et al. 2018), as well a survey report on farmer responses (White et al. 2018). The projected impacts of climate change to large-scale grain crop production are featured in significantly more studies, such as in Kaur and colleagues (2020), Gabrielle Roesch-McNally, J. G. Arbuckle, and John Charles Tyndall (2017) and Ajay Singh, Francis Eanes, and Linda S. Prokopy (2020).

Fruit and vegetable growers are an important component of the NE's agricultural economy. The sector includes both large wholesale grower-shippers selling both nationally and internationally, as well as tens of thousands of small operations that sell through community supported agriculture (CSAs) or farmers markets (Wolfe, DeGaetano et al. 2018). The region generated approximately \$2.4 billion of sales value annually from vegetable, fruit, and nut crops in 2019. There is another ~\$7 billion from direct sales of frozen and processed F&V products and wine, and the NE ranks high nationally for several F&V crops including apples, sweet corn, and snap beans (USDA 2017, 2019). Individual states produce high-value crops such as low-bush blueberries in Maine and peaches in Pennsylvania. Beyond economic impact, a thriving local F&V industry in the NE delivers value through agricultural tourism, cultural identity, community connectedness and the environmental benefits that come from consuming produce grown locally (Dupigny-Giroux et al. 2018; Stone et al. 2021).

Changes in precipitation patterns and water availability are only one part of the spectrum of climate impacts facing farmers in the NE. Problems arise from both not enough and too much water. Perhaps because of the potentially severe consequences of drought, in particular on unirrigated land, drought has received more attention than flooding in the research and extension literature. There is little information available on the management options available to mitigate production losses due to waterlogging and flooding (Kaur et al. 2020). This gap is confounded by the fact that the consequences of heavy rain vary considerably based on topography, size of operation, and the type of crop(s), as will be discussed later in this article.

### ***The Farmer Decision-Making Process***

To adapt to new climate challenges, farm managers need to evaluate available information, interpret it, and weigh the best options for their business. This interpretation is just as crucial as the information itself. To that end, there exists a rich and growing body of research on farmer perception and adoption of recommended practices. Research in this area has spanned across categories of agricultural practice, from practices to increase production, often called Best Management Practices (BMPs) (Baumgart-Getz et al. 2012; Kuehne et al. 2017; Tjernström et al. 2021), to environmental conservation practices (Church et al. 2020; Ingram 2008; Pannell et al. 2006), and more recently climate adaptation or mitigation practices (Jemison et al. 2014; Roesch-McNally et al. 2017; Schattman, Conner et al. 2016; Schattman, Méndez et al. 2018; Takahashi et al. 2016). One basic premise remains the same: adoption of a new practice at the farm-level is based on the subjective perception of the farmer or management team (Pannell et al. 2006). I will use the framework laid out by D. J. Pannell and colleagues (2006) in their article on adoption of conservation practices to add context to the choices explained below that F&V

growers must make. The authors argue that perception is shaped by: (1) the process of learning and experience, (2) the characteristics and circumstances of the landholder within their social environment, and (3) the characteristics of the practice.

Starting with the characteristics of the practice itself, those highlighted as most influential to farmer adoption include (a) relative advantage, which encompasses advantages related to finance, management complexity, beliefs and values, risk reduction, and lifestyle and (b) trialability, or the ability for the farmer to try the practice out, gradually increasing scale in order to reduce uncertainty related to adoption (Pannell et al. 2006). It is important to note that any given practice will score differently on these metrics for every farm, which makes it challenging for advisors to issue recommendations at a regional or even local level and can also make it impractical for farmers to directly imitate a neighboring farm's practices (Tjernström et al. 2021). This points to the need to appreciate that "landholders have legitimate reasons for non-adoption," even of recommended or best management practices (Vanclay 2004: 217).

A farmer's process of learning and experience for any given practice can be viewed as a sequence of steps. As described by D. J. Pannell and colleagues (2006), this typically proceeds through (a) awareness of the problem or opportunity, and that it might be relevant to them, (b) non-trial evaluation, or collecting information; (c) trial evaluation; and depending on these results, possibly (d) adoption, or incremental scaling-up from the initial trial; (e) review and modification; and potentially (f) non-adoption or dis-adoption. Research around adult learning has shown that farmers prefer to seek information rather than be trained and to accept or reject information based on their personal context (Franz et al. 2010; Kilpatrick and Rosenblatt 1998; McKenzie 2013). Farmers do not typically make a decision instantaneously after learning something new. They make decisions in stages, and information, people, and events influence them at each stage of reflection (Kilpatrick and Rosenblatt 1998; Rogers 2003). At any stage of this dynamic process, the idea being tested may be modified or dropped all together. As Frank Vanclay, states, "adoption, itself, represents a form of scientific inquiry by farmers" (2004: 216).

Next, the characteristics and circumstances of the farmer within their social environment are worth exploring further. This starts with the decision-maker(s) themselves and can then be expanded outward to their family and business, and finally to their broader social network. The farmer is first a person, whose age, education, and personality may factor into their perceptions (Baumgart-Getz et al. 2012; Pannell et al. 2006). They necessarily view any communication through their unique worldview, which has been shaped by accumulated social experience (Box and Dusseldorp 1992; Kloppenburg 1991; Long 2003). This comes into play even before the learning process described above can begin, a farmer's move to the awareness stage is influenced by who or what they choose to listen to, and, how they interpret new ideas as relevant or irrelevant to their own goals. The decision-maker is also considering factors such as the range of priorities of both the family and the business at that particular point in time. Similar to other business owners, farmers are required to constantly make both small and large adjustments based on unexpected events, losses or fluctuations in market demand (Katchova and Dinterman 2018). All of this is occurring within what Vanclay calls their "social infrastructure," which will include other farmers, advisors, family and friends, selected media, and oftentimes also customers, neighbors, and the general public (Oreszczyn et al. 2010; Parks 2022; Rogers 2003; Vanclay 2004).

This social infrastructure is vitally important in shaping what a farmer views as "good farm management," or "doing the right thing" (Vanclay 2004: 214), or, more academically, the descriptive and injunctive norms that apply within their particular social group (Lapinski and Rimal 2005). As noted by Vanclay (2004), discussed in-depth in the book *The Good Farmer* (Burton et al. 2021), and confirmed in case studies in NZ (Wood et al. 2014) and the UK (Skaalsveen et al.

2020), norms around good farm management are determined through interaction within these social networks and are subject to continuous updating and change. The degree to which each farmer is also sharing their ideas with others, and discussing and questioning as a way to test, validate, or modify their perceptions varies and is an important area for further research.

One particularly important aspect of farmer characteristics is the way in which each land manager perceives and acts on risk. The intersection of climate change, agriculture, risk management and adoption of practices has been explored extensively. Key aspects include the farmer's beliefs around climate change, beliefs around how severe a risk the changing climate poses to their farm, what causes beliefs to change over time, and how the farmer responds through either short-term coping measures or longer-range transformative actions (Baumgart-Getz et al. 2012; Niles et al. 2016; Schattman, Conner et al. and 2016; Schattman, Méndez et al. 2018; Takahashi et al. 2016).

In order to analyze the ways these factors come together to influence farmer decision-making, many have drawn on the Theory of Planned Behavior (TPB) from the field of psychology, which considers the variables of attitude, subjective norms, and perceived behavioral control as drivers of behavior (Doran et al. 2020; Linder and Campbell-Arvai 2021; Niles et al. 2016; Roesch-McNally et al. 2017). This framework is helpful for examining the weight given to these variables by farmers (Doran et al. 2020). However, findings using this approach in the adoption literature have so far not pointed to any constants in the relative impact of these variables on farmer intention or actual behavior. Given the discussion above, this may be expected. Every farm, and farmer, is unique and therefore the attractiveness of any specific practice, at any given time, varies. In addition, pinpointing which social norms to probe in an analysis may be challenging given the fluid, complex, and often hidden nature of a farmer's peer group. And, the way in which perceived control interacts with risk for each individual is complicated by broader climate change conversations and each farm's ever-increasing physical vulnerability to climate extremes. These challenges may be partly addressed through more longitudinal studies which follow the sequential nature of farmer decision-making (Teodoro et al. 2023).

### ***Moving from Adoption to Transformation to Confront Climate Change***

With this mind, it may be more fruitful to investigate the adoption and use of strategies and mindsets rather than practices. With increasing pressures from climate hazards, all farmers will need to make changes. In order to attain resilience in this context, many farmers will need to more radically transform their operations. I draw on the definition of resilience presented by Carl Folke and colleagues as “the capacity of social-ecological systems to continually change and adapt yet remain within critical thresholds” (2010: 1). Adaptability in this case is a part of resilience—the ability to adjust one's responses to change. And then, “transformability is the capacity to cross thresholds into new development trajectories” (Folke et al. 2010: 1). Transformation may be “forced” by external changes, or it may be “deliberate,” driven by individuals or groups, and is often a combination of both (Folke et al. 2010). What is important is the shift from trying to control change and minimize variability, to “shaping change,” increasing flexibility, and taking advantage of disturbances to look for new opportunities (Folke 2006). Transformation may begin at an individual farm, however, these small-scale changes can enable larger-scale change when new meanings and norms are institutionalized and spread through a farmer's social networks (Gosnell et al. 2019; Oreszczyń et al. 2010; Skaalsveen et al. 2020; Šūmane et al. 2018; Wood et al. 2014). A number of examples of agricultural transformation have been documented, such as the shift to no-till systems by farmers dealing with land degradation in South America (Folke et al. 2010), a new mindset around home vegetable gardening among women in

Burundi (Delaney 2016), and the transition of sheep and beef farmers in Australia to regenerative agriculture (Gosnell et al. 2019). In this article, I will attempt to contribute to filling in part of the gap at the junction between increasing flood risk in the Northeast, adaptation options in F&V production systems, and farmer experience and response, and explore the idea that small changes could lead to broader transformation here as well.

## **Climate Changes in the Northeast**

Since the end of the last Ice Age, the region we call the Northeast of the US has seen considerable climate variability driven by natural processes (Jacobson et al. 2009). However, it is now widely understood that since the mid-twentieth century, we have made rapid additions of CO<sub>2</sub> to the atmosphere and, with it, seen rapidly rising global temperatures. In Maine, for example, the average annual temperature has increased by about 3°F (1.5°C) since 1890, and annual precipitation has increased by about 15 percent, or by 5.8 in (14 cm) (Fernandez et al. 2020). The NE region has had the largest increase in annual precipitation volume in the United States over the last ~100 years, with the biggest increase so far in summer and autumn. Some areas of the NE have seen summer and autumn precipitation volume increase by more than 15 percent (1986–2015 average compared to 1901–1960 average) (Easterling et al. 2017).

### ***Extreme Rainfall***

Trends of increasing temperature and precipitation mix and can produce additive effects. With a warmer climate, the increased heat and moisture in the atmosphere leads to changes in the jet stream, with steeper temperature gradients resulting in more powerful storms (Fernandez et al. 2020). Rising temperatures have been found to increase precipitation intensity by ~6 percent for each degree of Celsius temperature increase (Easterling et al. 2017). We can see this impact in rainfall patterns in the NE, with the increase in precipitation volume to date largely being driven by an increase in extreme rainfall events.<sup>2</sup> There has been a 55 percent increase in 99th percentile precipitation, for example, in the NE from 1958 to 2016 (Easterling et al. 2017), and most excess precipitation since 1900 is from increases in rainfall events that bring 1–4 inches in a single day (Fernandez et al. 2020).

The NE region has experienced the largest increase in extreme rainfall events in the United States and the most significant increase in extreme precipitation has been in the spring. This is in contrast to the bigger increase in overall annual rainfall attributed to changes in the summer and autumn (Easterling et al. 2017). The strongest trend in heavy (95th percentile) precipitation in the region has been observed in April. Wet persistence, or the average probability of a wet day following a wet day, has also increased since 1900, with the highest increase in probability of wet persistence occurring in June. The fact that both intense and persistent events are already increasing has significant flooding implications. With earlier spring thaws, and winter-spring streamflow volume moving earlier, spring and early summer precipitation is increasingly exceeding the rate of soil infiltration resulting in more frequent flooding (Guilbert et al. 2015).

### ***Future Climate Impacts***

The NE is projected to warm slightly faster than other regions in the United States; CMIP5 (Coupled Model Intercomparison Project)<sup>3</sup> simulations show the region warming by 5.4°F (3°C) at the same time as the rest of the world warms on average by 3.6°F (2°C) (by ~2050, high emis-

sions scenario) (Karmalkar and Bradley 2017). With this warming trend, the Earth's hydrological cycle will also continue to intensify. Greater evaporation from the ocean leads to increased water vapor in the atmosphere, which can turn into heavier precipitation events. There is high confidence that annual precipitation will continue to increase in the NE in response to increasing greenhouse gas concentrations, particularly during winter and spring (Easterling et al. 2017; Hicke et al. 2022: 1937).

There is also high confidence that extreme precipitation events will continue to increase in frequency (MCC STS 2020), and we continue to add to our evidence of water cycle intensification (IPCC 2021, 19). Work on modeling in the area of precipitation change is ongoing, including efforts to interpret relatively coarse global and regional climate models to the local-scale and to incorporate the discontinuous physical processes that create local intense rainstorms (Ahn and Steinschneider 2019; Bush and Lemmen 2019; Easterling et al. 2017).

### ***Implications of Rainfall Changes to Growers in the NE***

Farmers are in many ways uniquely vulnerable to heavy rainfall and flooding. On a farm, flooding is defined as any time that crops are fully or partially underwater or when there is waterlogging or ponding on the land. Waterlogging is the saturation of soil with water, and specifically when soil is saturated for long enough that anaerobic conditions exist (Kaur et al. 2020). Ponding is when runoff water collects in one or more depressed areas on a farm (Murphy 2012). Flooding presents issues for all crop plants, however most above-ground F&V plants are more sensitive to even short-lived plant submergence or waterlogging than grain plants or root crops. Waterlogged soils also lead to delays in planting and crop management, and for diversified growers, delays can lead to negative domino effects for their entire growing season (Schattman, Conner et al. 2016).

The first and most evident harm from a flood is the direct injury to plants from water flowing over the field, especially if it has picked up soil or other debris as it flows, or from submergence of the plant during ponding. The timing of the event in relation to the plant's growth is important. Crops will be most affected by flooding conditions at earlier growth stages. When it comes to ponding injury, the duration of submergence of a crop is key. A plant can adapt, but generally only for a short period of time, after which damage and toxicity increase. Higher temperatures in the soil also make it more difficult for crops to recover. Finally, crops that are stressed will become more susceptible to the onslaught of pests and diseases that come with wet conditions (Kaur et al. 2020).

Next, water can accumulate and persist in soils, leading to excessively wet field conditions. The texture (proportion of clay-silt-sand-gravel particles) and the structure (the aggregation of soil particles, amendments, and plant roots) come together to influence the amount of pore space available in a soil. This then determines the permeability of the soil and the infiltration rate of water hitting the soil surface. Small particles have higher water holding capacity and therefore lower permeability and slow drainage. Soil aggregates are important for maintaining space, however aggregates that obstruct the downward movement of water also reduce permeability. Infiltration rates in soils can range from as slow as 1.5 mm/hour to more than 500 mm/hour (Scherer et al. 2017). Soils may become compacted either at the surface or subsurface layers from walking, animal grazing, tilling, or farm machinery traffic. Compaction causes decreased pore space, increased bulk density, and changes the size and shape of existing soil aggregates. This alters how water and air move through the soil profile. Soil compaction can be prevented by improving the strength of soil aggregates, reducing traffic over the soil, and paying attention to soil wetness—the wetter or more saturated the soil is, the more susceptible it is to compaction (Hamza and Anderson 2005).

Waterlogging and compaction can introduce three challenging negative feedback cycles for farmers. First, compacted soils lead to less water infiltration and also inhibit healthy plant root growth, which therefore further reduces soil permeability. Second, soils that are less permeable will take longer to drain after heavy rain, and the likelihood of farmers needing to work the soil when it is still wet increases, therefore increasing the likelihood of further compaction. Growing seasons are particularly short in temperate climates such as the NE, and a flood event arriving anytime from April to August will coincide with critical crop management activities such as tillage, planting, weeding, monitoring, or harvesting. At its most inconvenient, a badly timed heavy rainfall can push back a crop planting so far that it is either completely or nearly impractical to still plant or can delay a harvest to the point of significant losses in quality. It is in these cases that farm managers are forced to choose between two negative results—delaying an important field activity or damaging their soils.

Third, when a soil is saturated with water, the chemistry of the soil changes. Without any empty pore space, oxygen is absent. Oxygen is the preferred electron acceptor in the soil redox reactions which are part of normal microbial decomposition. Without oxygen, the redox potential of the soil ( $E_h$ ) is lowered, which in turn changes the reactions of other chemicals in the soil such as nitrogen as well as the soil pH, which both have implications for plant growth and soil nutrient management. A waterlogged soil will cause plants to close their stomata, reducing photosynthesis and building up oxygen free radicals, which alter normal cell metabolism and damage plants. Furthermore, in the absence of oxygen, plants will undergo fermentation processes, leading to glycolysis and accumulation of lactate and ethanol, which are toxic to most crops. Roots are also not able to respire and will slow their growth and even decay, reduce nodulation, or try to grow up near the soil surface, all of which have negative effects on a plant's ability to take up nutrients (Kaur et al. 2020). Slower growing or decaying crops absorb less water and undermine soil health, therefore again augmenting the saturation challenge.

Crops have an impressive ability to adapt to waterlogged conditions, and some species and varieties have evolved, or been bred, to have higher tolerances to flooded conditions. For example, crops triggered by changes, such as elevated ethylene levels, may enlarge their stems, grow new or adventitious roots near the surface, form new air spaces in the root cortex, or create *aerenchyma*, which are enlarged gas spaces formed within plant tissue to provide a path for gas exchange between aerobic shoots and anaerobic roots. Crops can also produce antioxidants to protect against damaging reactive oxygen species or slow down their metabolism and therefore temporarily slow their growth (Kaur et al. 2020; Kozłowski 1984).

Adding to the challenges from wet soils, persistent wetness on plant leaves and fruits increases a wide array of insect pests and plant diseases, in particular fungal pathogens, which cause blight, leaf spot, and rot. *Botrytis cinerea*, for example, causes gray mold on shoots, leaves, and fruits of a huge variety of crops, especially grapes and berries, and can lead to plant death. Very heavy and persistent rain events are challenging for pest and disease management, since a farm team may want to wait for soils to dry before trafficking the field for spraying, leaves do not dry off, and insecticidal or fungicidal sprays may be washed off by the next rain before having the intended impact.

At the same time, issues arise from increased runoff, erosion, and water flux during and after rainfall events. Erosion causes loss of soil itself, and farmers can lose a portion of their most valuable asset. High runoff rates also cause soluble nutrients (e.g., nitrogen, phosphorous) to be washed out of soil. Nitrogen losses occur through a combination of surface runoff, denitrification, and nitrate leaching. Leaching is the movement of nitrate-nitrogen through the root zone, and depending on fertilizer application timing, 10–40 percent of applied nitrogen can be lost during a heavy rain (Kaur et al. 2020). Nitrogen contamination of both ground and surface

waters poses health and environmental problems, and growers therefore need to factor new rainfall patterns into their nutrient management strategies. Finally, growers in the United States must comply with the Food and Drug Association's standards for food safety; any edible portion of a crop exposed to flood waters may not be sold for consumption (FDA 2011). With many vegetable and berry crops growing close to the ground, these safety guidelines can be one final blow for a grower if the flood event results in high levels of runoff or ponding in fields.

## **Adaptation Options for Growers**

Fruit and vegetable growers are familiar with managing soil and water in fluctuating weather. Many practices that they are already doing help to mitigate the effects of a heavy rainfall event and resulting flooding. Also, some preferred practices have other benefits beyond water management (Schattman, Méndez et al. 2018), for example, practices that improve soil health such as cover cropping or practices that reduce erosion and sequester carbon like planting perennials. However, as discussed above, the region will experience a continued build in the precipitation intensity and persistence in the spring and summer seasons. This will bring what was previously an occasional challenge to the forefront of many growers' minds and require new practices and changes in strategy.

There are a range of options available for adapting to increased flooding risk. A clear starting point is to improve soil health and structure in order to increase water infiltration capacity. This can be achieved through practices such as adding organic matter, reducing tillage, or adding permeable cover to the land. Tilling stimulates decomposition of crop nutrients and soil organic matter, therefore reducing tillage can conserve these resources. Tilling, however, has traditionally been the most common method of preparing a field for planting, and to control weeds. Therefore, to reduce tillage, a grower needs to revise multiple aspects of crop management strategy and may need to invest in machinery and tools to plant in un-tilled soil.

Cover can be added in a few different ways. One common option is to plant a cover crop, a crop planted for the primary purpose of covering the soil and slowing erosion. Cover crops can also reduce weed growth as well as increase biodiversity in a field, providing habitat for beneficial insects, pollinators, and birds (Clark 2015). Cover crops can be planted on a field for a full growing season to establish soil health, structure, and infiltration, however, unless the crop is of equal economic value to other options this results in reduced income from that area in the short term. Cover crops can also be grown in the winter when other cash crops would typically not be growing and can have the added benefit of drying out the soil for the spring as the winter crop uses available soil water (Clark 2015). However, timing within the short growing season in the NE is challenging. Winter cover crops need to be planted by late August, which is before many cash crops are harvested. Other options include interseeding cover crops into mature cash crops (Schattman, Lilley, et al. 2022), or intercropping, where the grower plants the cover crop together with another crop in the same field, and they overlap for most or all of their growing season (Clark 2015). Additional options for adding land cover include mulching with leaves, bark, wood chips, or straw around crops or between rows, and adding permanent mulch to laneways and farm roads with rubber or gravel.

To target water drainage in a farm landscape, farmers can create drainage systems. This can include surface drainage such as trenches and drains, or subsurface tile drainage that consists of buried perforated pipes that direct excess water below the surface to an outlet. Drainage can be highly effective at preventing waterlogging but is expensive to install and comes with environmental costs due to potential increased and concentrated nitrogen and phosphorus runoff.



Water quality impacts can be partially mitigated through attention to fertilizer dosing or linking drainage to irrigation systems such as through “controlled drainage and subirrigation” (CDSI) or linking subsurface drainage to farm irrigation reservoirs (Kaur et al. 2020).

Crops can be raised out of the wettest area of soil through the creation of raised beds, which can be helpful in providing just enough aeration for seedlings to survive in a heavy rainfall event. This practice is very common among vegetable growers as it also makes plants more accessible and helps soil to warm faster in the spring. A farmer may also choose to move certain crops into low tunnels, high tunnels/hoop houses, or greenhouses to provide protection against excess precipitation, as well as control temperature. This is becoming a more common investment for growers in the NE but can require significant financial outlay depending on material and size.

A further investment is moving into farm landscape modifications. Rainwater can be controlled through berms, contours, and terracing across the farm area, including on non-planted sections. Farmers can also add plants to slow down runoff, decrease erosion, and protect soil. Conservation buffer strips make use of permanent vegetation such as grasses, and perennial shrubs and trees. Larger areas of tree cover can be planted or conserved through orchards, forested areas, or by interspersing trees in the cropped area using agroforestry techniques (Asbjornsen et al. 2014). Broader strategic changes in landscape design can also be considered: for example, keyline design, which uses topography to create a hydrology design (Carmen Ponce-Rodríguez et al. 2021; Yeomans 2008), or the permaculture approach, in which a farm is designed to mimic patterns in nature (Ferguson and Lovell 2014). More intentional farm mapping can inform decisions on what crops can be planted in different areas of the farm, how to rotate from year to year, and what may need to be modified as rainfall patterns change.

Crop choice, planting schedules and investment decisions can be better supported with forecasting services and tools that provide land managers with predictions for their region. The more localized the information is, the more usable it is for individual farmers. Advances in modeling over the last few decades continue to bring down the scale of forecasting and current models use a grid resolution of 30–100km (Birkel n.d.; Schär et al. 2020). For small-scale producers, the information may still feel too broad, especially if they are in a micro-climate influenced by mountains or coastline. Several decision support tools are also in development. However, many are focused on temperature or drought rather than on excess rainfall. Some options for F&V growers in the NE include Cornell University’s “Climate Smart Farming Tools” (CICSS 2021), and the USDA’s statistics service crop reports (USDA-NASS 2021). The translation and testing of these types of tools is an area of active effort that extends to the other climate challenges such as drought and temperature change.

F&V growers may choose to make modifications to their overall business strategy. These can include increasing on-farm crop diversity to spread out risk, diversifying income through new markets, adding new value-added products, or adding off-farm income. Adding insurance may also be an option, depending on what is available in the state for the crops being grown and what it covers—options for diversified growers have historically been limited due to coverage being based on single crops. However, the USDA’s Risk Management Agency has recently added a “whole-farm revenue protection plan (WFRP)” that aims to serve diversified farms and those selling to local and regional markets (USDA-RMA 2022).

## **Adaptation Advising for Farmers**

Farmers in the US can seek out advice from different types of advisors for the various aspects of their business. While Cooperative Extension educators remain among farmers’ most highly

trusted sources, the role of private advisors has increased over the last few decades (Prokopy, Carlton, et al. 2015). At the same time, federal funding for Extension has been decreasing, requiring states to make up funding differences, or decrease staff (Wang 2014). The type of content offered as well as the methods used for communicating naturally varies by state, however, each of the states in the NE have fruit and vegetable programs for commercial growers at the Cooperative Extension organization of their state university. While agricultural advising has historically been criticized for relying too heavily on lecture-based methods, the advising community, observing the interpersonal dynamics in farmer decision-making, has in many locations partly shifted away from purely linear training models to more decentralized and participatory services (Bourne et al. 2017). New considerations to farmer support services include a more attentive approach to the relationship between advisor and farmer and the role of trust (Franz et al. 2010; McKenzie 2013), and the addition of more interactive and participatory sessions (Kilpatrick and Johns 2003; Schattman, Kaplan et al. 2019; Strong et al. 2010). Other programs have ventured further and experimented with programs facilitating farmer-to-farmer knowledge exchange through discussion groups and communities of practice, and research is ongoing to uncover best practices in this area (CAF 2022; Dolinska and d'Aquino 2016; Morgan 2011; Prager and Creaney 2017; Skaalsveen et al. 2020).

Our changing climate has added a new layer on to this already complex system of farmer support. The science of climate change, climate modeling, and climate forecasting is continuously evolving and improving, and these are not areas that agricultural professionals have typically received training. Efforts to add material for agricultural advisors have been building, and there now exists a growing body of materials educators can draw from (Schattman, Kaplan et al. 2019). However, even if a good start has been made, curricula will need to be continuously updated due to the rapidly evolving nature of this field (Schattman, Kaplan et al. 2019). Educators also have the daunting task of learning this new information, applying it to their areas of practice, and then again translating it for their farmer clients, paying attention to language, specificity of content, and relevance to the audience (Diehl et al. 2018; Eanes et al. 2019; Prokopy, Carlton, et al. 2015; Prokopy, Haigh et al. 2013; Schattman, Kaplan et al. 2019). Agricultural advisors also approach the topic of climate adaptation through the lens of their own beliefs and risk-management preferences, and these perceptions inevitably come together with farmers' perceptions during advising visits or trainings (Prokopy, Morton, et al. 2015; Schattman, Méndez et al. 2018).

## **How Fruit and Vegetable Growers Are Responding**

It is useful to look at what F&V growers in the region have been doing to cope with the challenge of extreme rain and flooding. While much of the information on farmers' response is anecdotal or tacit knowledge held by farmers and agricultural advisors, one recent study provides documentation. A survey of 193 F&V growers in New England carried out in 2017–18 asked about their use of adaptive management practices and their perceived capacity to adapt to expected weather extremes. The survey included a question specifically about the strategies growers are using for “heavy precipitation and flooding” (White et al. 2018). Looking at the results, the most common changes so far taken by this group of growers were around building soil health, specifically through cover crops (74 percent), organic fertilizers (66 percent), and green manures (crops grown and then tilled into the soil to improve quality) (56 percent). Respondents were also using some reduced tillage (37 percent) to cope with flooding. Other strategies in common use included increasing crop rotation (65 percent) and crop diversity (54 percent) and adding

protective measures such as raised beds (54 percent) and hoop houses (47 percent). Options such as changing varieties or changing planting schedules were less common, although 40 percent of farmers had planted late to cope with flooding (White et al. 2018).

Respondents were also asked what changes they planned to make or thought to be innovative and promising. While the above shows that growers are making changes that are smaller in scope and investing more heavily in practices they may already do for other reasons, a select few are planning more intensive investments such as using perennials (6 percent), terracing (2 percent), and other landscape modification (2 percent). Tellingly, the practices farmers called promising or innovative, but are not yet using or planning, lean toward revisions in the farm system such as permaculture (3 percent) or using agroforestry (3 percent) or earthworks (2 percent) (White et al. 2018). The survey also asked about the use of business-related strategies to adapt to increased heavy precipitation. Market diversification was the most used (24 percent). Only 9 percent of growers reported using insurance to respond to flooding (White et al. 2018). One prevailing challenge to proactively changing business operations for small growers in the NE is financial capital. In the survey, 76 percent of farmers agreed with the statement “I do *not* feel like I have the financial capacity to deal with any weather-related threats to the viability of my farm operation” (White et al. 2018). The primary goal of the survey project was to document information that could be shared with other farmers, and beyond grouping adaptive practices by site characteristics (i.e., clay soils, steep slope), the authors did not venture into further discussion around why particular strategies are currently more common, or what may lead to increased interest in the more transformative options farmers cited as promising.

## Individual Farmer Experiences with Spring Flooding

Here I will present two case studies, each with a diversified vegetable grower in the NE who experienced a flooding event. These two growers were both taking part in a 12-month fellowship program called the Climate Adaptation Fellowship (CAF 2022) and responded to a request to participate in semi-structured interviews on the topic of flooding to support this review. The interviews took place in October 2021 were not part of a larger research study. These case studies are therefore not meant to provide generalizable results, but instead to add individual narratives to complement the literature reviewed. One farmer is in Vermont and the second in New Hampshire, and they will be referred to as farmerVT and farmerNH. Their cases are highlighted in Box 1 and Box 2.

### **Box 1: A cloudburst hits in a wet month, washing out years of work in Vermont**

FarmerVT manages a small, diversified farm, producing vegetables, fruits, and nuts, and also raises animals for meat and keeps horses. He has been farming the land since 1999, and he has spent much of that time building up his soil health, adding organic matter through cover crops, composting, mulching, and minimizing tillage.

The farmer grew up in a floodplain in the NE, studied agronomy as an undergraduate, and spent time working at a university research farm on drainage trials. These experiences gave him a unique perspective on the importance of soil conversation and drainage. He has put this to use and had been managing his farm landscape to reduce flooding issues. He plants his rows across slopes, and has added drainage tile, ditches and culverts and built up the pathways for the animals to keep them out of any mud.

In July of 2021, his farm received two extreme rainfall events in a four-day period, with 2.7 inches falling in 18 hours and then three days later 1.8 inches in fifteen minutes, which he called a “cloudburst.” These events came after an already persistently wet month. After the cloudburst event the farm had 2–6 inches of water running across it, and the culverts overflowed.

The farmer was surprised by the intensity of the rain and the damage to his land because he had previously felt able to manage heavy rainfall. He described the situation during and immediately after the flooding as “totally insane” and reported feeling helpless at the time of the storm. Once he could get out on the field to assess, he could see that many of his vegetables had significant damage—submerged beets, bent corn stalks and washed-out potatoes. There were 6-inch gullies running down his fields and the “thin layer of loose crumbling soil that is in contact with the mulch . . . where all the action happens” had washed away. He shared that it had taken him eight years to build up that layer, and “you can’t replace that.”

### **Box 2: An extremely wet July in New Hampshire makes pest management impossible**

The farmer in NH grew up in a city in the Midwest, but he always knew he wanted to farm. He studied agriculture and has spent the last 21 years farming. When he met his wife, also a farmer, they began trying out different types and scales of farm enterprises. The farm they have now is an intensive organic vegetable farm linked to a CSA that they manage together. It also includes laying hens and an apiary. They started the farm in 2012 and have been slowly building up the business.

FarmerNH experienced a dry spring in 2021, followed by a wet summer similar to that described by farmerVT. He reported receiving more than triple the historical average rainfall for July and August. And, along with this steady high rainfall, the area saw some extreme rainfall events, such as just under 10 inches of rain falling in one day mid-month with half of that falling in just a few hours overnight. FarmerNH felt surprised, and at first helpless, and shared that it was hard not being able to do anything until the field dried out. He immediately checked for what they could harvest, reached out to other farmers in the area, and notified their customers. He said that it was “sad, tough and stressful.”

FarmerNH shared a long list of damages to his operations from the flood, which included erosion and crops being washed downhill, some vegetables being submerged, runoff from tarps onto crops, and soil moving even under their high tunnels. This was despite the fact that the farm had been investing in building soil organic matter, and cover cropping and interseeding as much as possible. However, they had been more focused on mitigating drought risk than on flood risk and so had not invested heavily in drainage strategies.

Some of the damage to crops was only aesthetic, but they did have reductions in yield. After the flooding, the challenges related to the excessive water continued, with the farm experiencing extreme increases in weeds, insect pests, and fungal diseases, and the soil being too wet for timely fall planting.

The farmer shared that he had to essentially give up on fighting pests for the remainder of the summer, “Particularly because it would rain the next day and just wash off so at one point, I just said, ‘I’m done, I can’t.’”

In many ways, the stories in these case studies showcase a selection of the impacts outlined above. The two farmers mention plant injury, soil erosion, waterlogged soils, and increases in weeds, insects, and disease. What the case studies also reveal are new contextual elements to what was previously a factual list of challenges. The extreme rainfall they experienced came as a surprise. And it brought to the forefront the need to make difficult decisions for their farms' future, as will be discussed more below. Their emotional reactions to the flooding are relevant in an occupation that can strain mental health (Fraser et al. 2005; Hagen et al. 2019). The need to "give-up" on things like insect control and the fact that a single event can wash out years of work building up soils on a farm places new gravity on these issues. Emotional response is notably absent from the literature reviewed, with the exception of a discussion on how farmer emotions contribute to mental models and management decisions as reported by Hannah Gosnell, Nicholas Gill, and Michelle Voyer (2019).

While each of these two experiences were in some ways unique, there were further common themes that came from the conversations.

### ***Gap in Assistance: Access, Neutrality, and Awareness***

The first common theme from these interviews was the identification of a gap in the type of assistance required to support farmers with flooding. The gap described includes several components, with the most discussed being technical assistance for adapting to flood risk. Both farmerVT and farmerNH feel that they do not have sufficient access to the type of technical advice and support that would help them better prepare. They shared that they need more access to advisors with expertise in soil conservation, soil health, and farm landscape planning from a perspective of limiting erosion and flood damage. FarmerNH also sees a clear need for what he called "climate risk planning" or "contingency planning." From his perspective, the support for this is not there yet, and he shared, "I feel that's a really big need as well as an opportunity."

Second, where advisory services are available, the affiliation of the advisor can be important. Many advisors who are available do not provide neutral advice; they may be biased toward directing a farmer into one of their government or private programs, focused on ensuring the farmer complies with regulations, or the advisors have a product to sell. This means that a farmer must find an advisor who is tasked to help with their needs to avoid frustration on both sides. FarmerVT shared how he has seen a marked decline in the continuity of agricultural agency personnel in his area, and how he personally feels that the coming and going of staff has limited the ability of advisors to build relationships with farmers. Both farmers talked about the strong personalities of their peers in the farming community, describing them as "self-motivated," "curmudgeons," and mistrusting of government assistance. This makes the relationship-building piece not only trickier, but also more important, so that an advisor can get to know the idiosyncrasies of their clients. As farmerVT put it, advisors need to identify the "agricultural cultural baggage" of each farmer and try to style their advising approach. FarmerVT drew a clear link between farmer success in soil management under the approaching extreme climate conditions, and advisor-farmer relationship building, stating "to keep soil in place we need to have agronomists and soil conservationists that have a positive relationship with farmers."

The third piece mentioned was awareness of who to call. FarmerNH described how many farmers in his area were not clear about which agency to call for either long-term support or post-disaster assistance, saying that "there's a gigantic gap within the farming community." This problem has been exacerbated recently by some closures or reductions in government offices after the start of the Covid pandemic.

### ***Reevaluation: Prioritizing Flooding Risk and Making New Plans***

These two farmers have been thinking about both annual weather and longer-term climate trends for years. In both cases, however, they had been focusing more effort on drought and had previously felt relatively well prepared for heavy rainfall. As farmerVT said, “It didn’t cross my mind to think about flooding before, since it hadn’t happened. It hasn’t been an issue.” Both had soil conservation and landscape management practices in place, and both reported that some of their neighboring farmer contacts suffered worse damage from the events we spoke about. However, the combination of persistent wetness and one or more extreme rain events overwhelmed their systems.

As discussed above, the likelihood of this combination occurring in the spring or summer in the NE is predicted to increase. Both interviewees had already begun to reevaluate their priorities and think about shifting time and financial resources to flood mitigation at the time of our conversations in autumn of the same year. FarmerNH said, “I didn’t think it (flood mitigation) needed to happen overnight, but now . . .” It was evident in these conversations that in cases where tradeoffs would need to be made, decisions on where to put resources were far from simple. In the case of farmerVT, the need to invest in renting heavy machinery prevented him from pushing forward faster with bigger landscape modifications. On the NH farm, the husband-wife business team will need to reconcile two sets of values, priorities, and perceptions of multiple climate risks.

Despite these obstacles, each of the farmers was able to share a long list of the changes they were planning to make in the coming seasons to address this challenge, and those are combined into four broad categories and listed in Table 1.

This case study material, while very limited in scope, does add to what is currently available in the literature at the intersection of excess precipitation and food production, particularly in the NE regional context. First, it provides two storylines to accompany the farmer learning and decision-making process that was presented in this article’s introduction. They affirm the uniqueness of each farm context, the subjective nature of this type of decision-making, and the way each farmer must place investments in an area like flood mitigation into a broader range of personal and business priorities. The accounts also add elements of emotion, including both surprise and despair, that was previously missing. Because these interviews do not capture these

**Table 1:** New strategies being planned by case study farmers to mitigate flooding risk

<i>Soil management</i>	<i>Crop planning and strategy</i>	<i>Drainage</i>	<i>Whole farm and landscape management</i>
Reduce tillage	Increase crop diversification	Ensure right-sized culverts	Add and more deliberately maintain raised beds
Add more cover crops	Add crop rotations	Dig drainage ditches deeper	Change raised bed direction
Enhance mulching	Enhance interseeding and intercropping	More intentionally keep drainage ditches clean	Change wood chips to grass/shrubs
Build up tools to be able to reduce tillage and manage cover crops	Add hoop houses and other covered areas	Add new drainage such as shallow wells, drainage tile, pond drainage	Add contour strips, permanent sod strips or buffers
			Add grass waterways

farmers' actions in subsequent seasons, it is unfortunately not possible to track later aspects of the decision-making process, such as trialing, evaluation, review, or adoption.

The cases also affirm the shortfall in farmer advising services that has been documented, as well as the importance of farmer-advisor relationships and trust. The stories seem to emphasize the personal element even more so than the literature and pinpoint this as something that is a requirement for success. The reevaluation of the risk that extreme precipitation poses is not yet well documented, likely in part because the frequency and severity of these events is presently increasing. The survey data above showed that farmers are thinking about flooding issues, and work in particular by Rachel Schattman reveals how growers in the region perceive climate risk. However, this type of change in mindset, to see flooding as a risk equal to if not more serious than drought, is important and could be investigated further.

## Conclusion

Persistent and heavy precipitation can lead to flooding and waterlogged conditions on agricultural land. Soil saturation changes the chemistry of soil, and prolonged waterlogging leads to both plant stress and increased likelihood of soil compaction. The NE region will continue to see an increase in rainfall volume as well as frequency of extreme rainfall events in the spring and summer seasons, more so than any other US region. F&V farms are an important piece of the regional agricultural economy, culture and food system, and these operations are at particular risk to these climatic changes. F&V growers in the NE are working with a short growing season, often managing complex puzzle-like planting and harvesting calendars, and delays from extreme rainfall can cause detrimental knock-on effects for their operations. Adaptation options are available, and include improving soil infiltration, protecting plants in raised beds or covered areas, adding drainage, investing in larger-scale landscape modifications and de-risking business through insurance or diversification.

Growers in the region are aware of the predictions and are starting to respond to these challenges on their farms. However, most are so far only making smaller changes, or putting an increased focus on measures such as soil conservation that they would already want to invest in (White et al. 2018). The farmers featured in this article's case studies voiced that they are personally starting to reevaluate their priorities and make plans for more intentional flood mitigation and whole-farm landscape modifications. However, these two farmers were participants in a climate adaptation program and had recently experienced a flooding event, so they may be more inclined than the average grower to make these types of plans. They both felt unprepared and surprised by extreme rain events and pointed to a need for a greater availability of support for growers in the region that is technically proficient, neutral, and delivered in a way that the strong-willed farmers of the region will respond to.

The ways in which growers in the NE, and elsewhere, will respond to the increasing challenges from extreme rainfall and flooding are still to be seen. All farmers will need to adapt incrementally. New outlooks on flooding risk may also push some to make more transformative shifts on their farms. All growers are part of the larger social infrastructure of farming in their region, and their experiences, responses and questions will inevitably spread and impact others. Over time this will create new ideas around what constitute "good" ways to manage excess rainfall in "changing environments where the future is unpredictable, and surprise is likely" (Folke 2006: 254). Farmers will choose who to call—to better plan for the storms that are coming, to help work through emotions, and to find a way forward after a storm has cleared.

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## ■ NOTES

1. For this article, the USDA's definition of the Northeast region is used. This includes the New England states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont and the Middle Atlantic states of New Jersey, New York, and Pennsylvania.
2. Defined either as daily precipitation that exceeds the 99th percentile amount or the number of two-day events that exceed the largest two-day event that is expected to occur in a five-year period.
3. The climate model simulation used for the IPCC reports, coupled model intercomparison project phase 5. The most recent climate model simulation, CMIP6, used for the IPCC 2022 report, considers higher climate sensitivity from amplifying cloud feedback, and assesses higher levels of risk from lower global warming levels than the previous simulation (CMIP5).

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