Opportunities for Natural Infrastructure to Mitigate Flood Risk in Mississippi River Basin Watersheds: Prairie Creek Watershed Final Report

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ACRONYMS AND ABBREVIATIONS

Acronyms/Abbreviations	Definition
BLE	Base Level Engineering
CMIP	Coupled Model Intercomparison Project
CREP	Conservation Reserve Enhancement Program
DEM	Digital Elevation Map
DNR	Department of Natural Resources
EDF	Environmental Defense Fund
FEMA	Federal Emergency Management Agency
Hazus	Hazards of the US
HUC	Hydrologic Unit Code
IGS	Iowa Geological Survey
MRB	Mississippi River Basin
NI	Natural Infrastructure
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
PCW	Prairie Creek Watershed
RCP	Representative Concentration Pathway
SVI	Social Vulnerability Index
USACE	US Army Corps of Engineers
USGS	US Geological Survey
USDA NRCS	US Department of Agricultural Natural Resources Conservation Service
WASCOB	Water and Sediment Control Basin

1.0 EXECUTIVE SUMMARY

The overall goal of the *Opportunities for Natural Infrastructure to Mitigate Flood Risk in Mississippi River Basin Watersheds* project was to combine hydrology model capabilities with economic analysis to explore the impacts of NI implementation on flood risk under projected future rainfall conditions. To meet this goal, Tetra Tech collaborated with Environmental Defense Fund (EDF) and Iowa Geological Survey (IGS) to first identify the Prairie Creek Watershed (PCW) near Cedar Rapids, Iowa as the case study watershed within the Mississippi River Basin and then develop potential siting locations for natural infrastructure (NI) within the watershed.

Second, Tetra Tech leveraged publicly available, calibrated, baseline hydrology model (i.e., HEC-RAS 2D) from the Iowa Department of Natural Resources (DNR) and National Oceanographic and Atmospheric Administration (NOAA) Atlas 14 gridded rainfall datasets to model flood depths for five 24-hr design storms (i.e., 10-, 25-, 50-, 100-, and 500-yr) under present and future rainfall conditions. These model runs without NI included were referred to as baseline model runs. To incorporate NI into the HEC-RAS model, Tetra Tech modified the terrain, roughness, and curve number values of the baseline model inputs according to US Department of Agricultural Natural Resources Conservation Service (USDA NRCS) design standards and then re-ran the HEC-RAS models for a total of 32 model runs. Tetra Tech modified HEC-RAS inputs to create several NI scenarios: 2.5, 5, 10, and 17.2% of the watershed area implemented with NI, which corresponded to 14, 28, 56, and 100% of potential NI implementation for the PCW.

Third, Tetra Tech used a publicly available economic flood damage estimation tool called Hazus developed by the Federal Emergency Management Agency (FEMA). From Hazus outputs, Tetra Tech summarized loss for each model run and computed the net present value of avoided losses, net present value of the cost of implementing NI practices, and net benefits. Given the limited time duration of the project, Tetra Tech was only able to calculate net benefits for the 17.2% NI scenario, but results of the remaining NI scenarios are presented for the 10-yr and 50-yar design storms.

Future rainfall scenarios result in increased flood depths and expanded inundation areas across all design storms, with the largest change in flood inundation area for smaller rainfall design storms (i.e., 11.2% for 10-yr design storm). The modeled NI solutions, which include land cover changes and natural storage features, exhibit effectiveness in reducing flood depth and inundation extent. While NI implementation resulted in appreciable reductions in flood magnitudes across all design storms, their effectiveness was most pronounced for flooding associated with small-to-moderate recurrence interval design storms (i.e., 10-, 25-, and 50-yr design storms). Among the specific NI implemented, CREP wetlands stood out for their potential to store substantial flood waters.

Economic analysis results indicate the opportunity for 31-32% reductions in average annual losses when 17.2% of the watershed area is implemented with NI. This results in a net present value of $1.7 billion USD in avoided losses. When the cost of NI implementation and farmland loss are considered the overall benefit of implementing infrastructure on 17.2% of the watershed area is $884 million USD. Looking across the NI scenarios, NI implementation reduced total economic losses on average about 25% from the baseline condition for a range of NI implementation percentages under present and future 10-yr and 50-yr design storm conditions. On a per-acre basis, the lowest NI implementation simulated (2.5% of the watershed area, equivalent to 14% adoption) achieved nearly twice the economic benefit of other implementation levels.

Social vulnerability results indicated that vulnerable communities were still bearing the burden of flooding even with NI implementation. Notably, results also indicate that the increased frequency and intensity of future rainfall events may impact all communities regardless of their socio-economic status.

These coupled hydrologic modeling, economic analysis, and social vulnerability analysis results highlight an opportunity for NI implementation to reduce flood risk in the PCW for present and future rainfall conditions.

2.0 BACKGROUND

Flooding presents a complex and shifting challenge to humans, leading to infrastructure damage, social disruptions, economic losses, and environmental challenges. These challenges are exacerbated by land use and infrastructure decisions that increase flood vulnerability and severity. Natural infrastructure (NI) solutions—such as wetland restoration, land cover changes (e.g., row crop conversion to native grassland), or riparian buffers—offer a promising approach to mitigating these challenges by enhancing flood storage and reducing runoff while improving overall watershed resilience and ecosystem health in ways not mirrored by traditional flood control infrastructure. However, widespread implementation of NI at watershed scale requires substantial financial investment, long planning timelines, and coordination among multiple stakeholders. These requirements make it difficult to evaluate the effectiveness of NI at scale through direct implementation alone. Hydrologic or hydraulic models are critical tools for assessing flood risk and assessing mitigation strategies as they relate to use of NI solutions. Consequently, the work herein couples hydrologic models with spatial economic analysis methods to systematically assess whether and how distributed implementation of NI mitigates flood risk impacts such as building damage, building content loss, etc. Furthermore, this work also evaluates the relationship between the avoided economic losses from implementing NI and the financial cost of implementing NI at the watershed scale.

As part of the overall project *Opportunities for Natural Infrastructure to Mitigate Flood Risk in Mississippi River Basin Watersheds*, Tetra Tech and the Environmental Defense Fund (EDF) completed a series of hydrologic modeling scenarios to assess the effectiveness of NI. These modeling scenarios simulated flood inundation and flood depth under a variety of rainfall design storms, current and projected future rainfall conditions, and with and without implementation of NI. Tetra Tech used the 2-D Base Level Engineering (BLE) framework developed by the Iowa Department of Natural Resources (DNR). This model integrates high-resolution terrain, land cover, and precipitation data to simulate watershed hydrology using HEC-RAS 6.0. By incorporating present and future rainfall conditions, the analysis provides insights into the anticipated in flood extent and depth due to climate-driven increases in rainfall depth and intensity. Additionally, the study compares baseline (i.e., no NI modifications) and NI-enhanced scenarios under all the aforementioned rainfall conditions to address the effectiveness of NI interventions in reducing flood impacts.

In addition to completing the hydrological modeling scenarios, Tetra Tech assessed the economic impacts of NI implementation under a variety of precipitation design storms, current and future climate conditions, and NI adoption percentages in partnership with the Environmental Defense Fund (EDF). Tetra Tech then used flood depth raster grids generated from the hydrologic modeling work in the Prairie Creek Watershed (PCW) near Cedar Rapids, Iowa, USA as inputs into the Hazus v7.0 model. Hazus is a spatial economic risk assessment tool developed by the Federal Emergency Management Agency (FEMA) to quantify the physical, economic, and social impacts of floods and other natural disasters. Tetra Tech used Hazus because it offers a nationally-recognized, standardized methodology for quantifying economic losses for specific 24-hr design storm events. Furthermore, Hazus outputs can be used to calculate the average annualized loss and net present value of implementing NI as well as the overall net benefit of implementing NI compared to baseline conditions without NI. The latter of which accounts for the cost of installing and maintaining NI.

This report summarizes the coupled hydrologic modeling and economic analysis methodology. It presents hydrologic modeling results for each scenario in the form of flood inundation and depth maps, flood depth change maps, and summary statistics and distributions of the model outputs in the Prairie Creek Watershed (PCW) near Cedar Rapids, Iowa. It also describes (1) the methodology used to calculate average annual losses and net present value of avoided losses for a range of design storms and NI implementation scenarios under present and future rainfall conditions, (2) the methodology used to quantify the cost of implementing NI across the PCW, and (3) summarizes the results of these analyses for the PCW. The findings presented in this report highlight the potential for NI to serve as a complement to traditional flood management approaches, particularly in agricultural and mixed-use watersheds like PCW, which are typical of the Mississippi River Basin (MRB). Further, these results form the foundation of economic and social vulnerability analyses which comprise the latter part of the project with EDF.

3.0 METHODS

3.1 2-D Base Level Engineering Model

The 2-D Base Level Engineering (BLE) models developed by the Iowa DNR aim to enhance flood risk awareness and provide a comprehensive understanding of flood hazards across the state (Iowa DNR, 2025). These models were initiated as part of efforts to update outdated flood risk data, much of which was either unavailable or based on obsolete methodologies. The need for these updates became apparent following the devastating floods of 2008, which highlighted the limitations of existing data for emergency response and planning. The BLE models use advanced two-dimensional hydraulic modeling to provide foundational data for floodplain mapping, emergency management, and mitigation planning. Unlike traditional one-dimensional methods, these models account for fluvial and pluvial flooding, offering a more dynamic and spatially detailed understanding of water flow across entire landscapes.

The BLE models rely on a variety of inputs to ensure accuracy and functionality. Key datasets include high-resolution LiDAR-derived Digital Elevation Models (DEMs), National Land Cover Database (NLCD) land use information, rainfall data from the National Oceanographic and Atmospheric Administration (NOAA) Atlas 14, and soil properties from the SSURGO dataset. The models were built by AECOM for Iowa DNR using HEC-RAS 6.0 and incorporate boundary conditions, mesh refinements, and detailed breaklines to simulate water movement under various scenarios. According to documentation provided by Iowa DNR (Iowa DNR, 2021), 2-D BLE model calibration was performed by AECOM using historic high-water marks, USGS gage data, and observed flows to ensure model accuracy. According to detailed calibration results for the PCW, AECOM used USGS StreamStats data to calibrate the model for the 100-yr discharge because there was no USGS gage within the watershed (Iowa DNR, 2025). Specifically, AECOM did the calibration at nine locations along the river channel, including the watershed outlet and modified the model nine times to reach an adequate calibration. The model calibration was considered final when the estimated discharges fell within the -22.3% to +22.3% confidence interval of the StreamStats discharges. Hydrologic and hydraulic parameters, including Manning's roughness coefficients, were adjusted during the calibration process to match observed flood behaviors. The outputs include water surface elevation grids, velocity grids, and flood hazard maps, which undergo extensive quality assurance and are periodically refined based on stakeholder feedback. Model outputs and the underlying model files are available across the state of Iowa in spatial units corresponding to sub-watersheds at approximately the HUC 10 scale; although, some BLE model boundaries do not align with HUC 10 boundaries in the National Hydrography Dataset (Iowa DNR, 2021; 2025).

3.2 Study Area

This study focused on the Prairie Creek Watershed (PCW; HUC 10 0708020514) in Iowa, USA. The PCW has an area of 136,912 acres and is located within Linn and Benton Counties. The headwaters of PCW are primarily rural, while the outlet passes through the southwestern corner of Cedar Rapids, Iowa, USA. PCW is a tributary to the Cedar River, which ultimately joins the Mississippi River. The land cover in the PCW is primarily agricultural (84.7%), followed by developed (13.3%), wetlands (1.3%), forest (0.51%), barren lands (0.15%), scrub/grassland (0.08%), and open water (0.04%; USGS, 2023). The minimum and maximum elevations of the watershed are 501.5-feet and 993.2-feet, respectively (Iowa DNR, 2025). Historic vegetation prior to European settlement (circa 1832 – 1859) was primarily tallgrass prairie throughout the PCW (GDC, 2017). Forested areas were present in the riparian zone of the downstream reaches of Prairie Creek while many other historic vegetation types existed in small pockets throughout the watershed (GDC, 2017). The PCW is primarily located in the United States Department of Agriculture National Resource Conservation Service (USDA NRCS) Major Land Resource Area (MLRA) defined as “Eastern Iowa and Minnesota Till Prairies” (MLRA id 104), with a small fraction of the southwestern edge overlapping with the MLRA defined as “Illinois and Iowa Deep Loess and Drift” (MLRA id 108; NRCS, 2022b). For MLRA 104, the annual precipitation ranged from 31-39 inches and average annual temperatures ranged from 44-50 degrees F for the period from 1981 to 2000 (NRCS, 2022b). For MLRA 108, the annual precipitation ranged from 34-47 inches and annual temperature ranges from 47-58 degrees F for the period from 1981 to 2000 (NRCS, 2022b).

The HEC-RAS 2-D BLE model boundary, along with the main waterways and computational grid for the PCW, is shown in **Figure 3-1**. The PCW BLE computational grid consists of more than 511,260 cells with a base resolution of 200 ft. To enhance the representation of flow dynamics, breaklines and smaller cell sizes (ranging from 50-100 ft) were applied around main waterways, roads, and buildings (Iowa DNR, 2021). As described in Section 3.1, the model was configured using land use and soil data to simulate flooding caused by rainfall and stormflow for five design storms (i.e., 10-, 25-, 50-, 100-, and 500-yr). For this study, all five design storms have a 24-hour duration. The model employs the diffusion wave equation with a variable computational timestep, which adjusts dynamically based on maximum (1.5) and minimum (0.45) Courant numbers. The model calculates watershed outflow using a normal depth boundary condition. As mentioned in Section 3.1, model calibration of the model primarily involves adjusting the Manning’s roughness coefficients for channel areas to achieve accurate flow representation.

The PCW was chosen as a case study HUC10 watershed by EDF and Tetra Tech for several reasons. First, the PCW headwaters are primarily rural while the outlet region passes through the more developed city of Cedar Rapids. Consequently, there are many potential locations to implement NI practices that store water in the headwaters. Second, the Iowa hydrologic model for the PCW does not depend on routing from upstream contributing watersheds; therefore, it represents a good case study watershed because it is self-contained and does not require consideration of upstream model run outputs. Third, PCW has experienced flooding issues in the past (i.e., in and around Fairfax, Iowa), but has not received as much flood mitigation attention compared to nearby watersheds. While there are no active United States Geological Survey streamflow gages in the PCW, there are stream and water quality measurements from the mid-1970s – mid-1980s (i.e., USGS gage number 05464650). There are several active USGS streamflow gages nearby on the West Fork of the Cedar River (north of PCW), Salt Creek (west of PCW), and Iowa River (south of PCW).

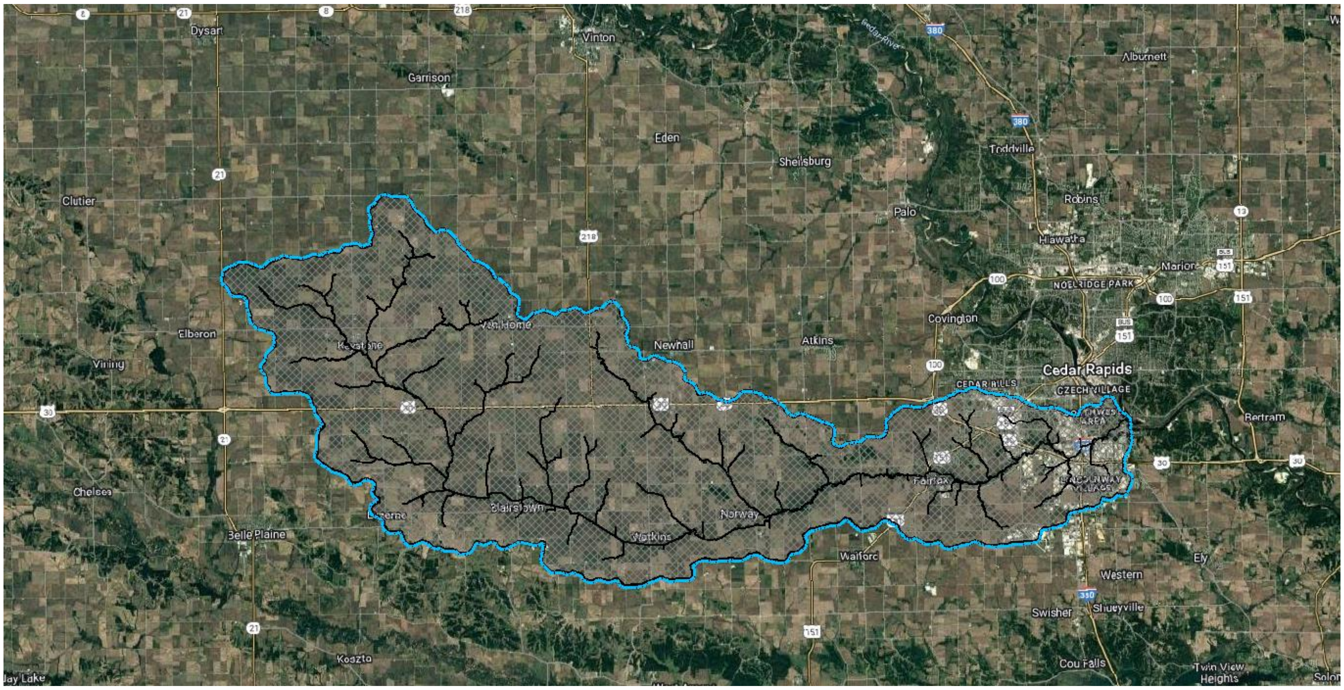

Figure 3-1. Prairie Creek Watershed 2-D BLE model boundary (blue), waterways (black), and computational grid cells (grey) near the city of Cedar Rapids, IA, USA.

3.3 Future Rainfall

The Iowa DNR BLE model uses spatially variable, gridded rainfall data for five design storms (i.e., 10-, 25-, 50-, 100-, and 500-yr) with a 6-minute temporal resolution stored in a HEC data storage system (HEC-DSS) file as an input for flood simulations. To ensure a fair comparison between present and future scenarios, it is critical that projected future rainfall data exhibits similar temporal and spatial distribution characteristics as the baseline model inputs. Iowa DNR provided documentation on how gridded rainfall data was generated for the baseline Iowa DNR BLE models. Specifically, Iowa DNR confirmed with Tetra Tech and EDF via email that they derived baseline rainfall inputs for design storms from the NOAA Atlas 14 datasets (NOAA, 2024; USACE, 2024).

Tetra Tech followed the outlined approach in the previous deliverable Natural Infrastructure for Flooding Risk Mitigation Study Design Memorandum (Task 1.1, Section 3.2) to generate seamless rainfall spatial datasets for future design storms. Tetra Tech used rainfall data derived from the localized constructed analogs (LOCA) downscaled Coupled Model Intercomparison Project 5 (CMIP5) climate models under the RCP 8.5 scenario for mid-century (2036–2065), as described by Butcher et al. (2023). While CMIP6 outputs are available, they have not been downscaled and holistically validated at this time. Additionally, NOAA is working to develop updated Atlas 14 raster datasets, which were not publicly available at the time this memorandum was drafted. This approach leverages the higher-emission RCP 8.5 pathway to account for more conservative future planning. Tetra Tech interpolated projected future intensity-duration-frequency (IDF) rainfall depths for storms of a specified frequency and duration using regression kriging, guided by NOAA Atlas 14 baseline datasets. Tetra Tech used this approach to maintain spatial coherence with historic rainfall records. Projected future rainfall patterns are shown and compared to present rainfall in **Figure 3-2**. Overall, future rainfall exhibited a similar spatial distribution to present rainfall, but with higher intensities. For both future and present scenarios, rainfall intensity increases from west to east. Differences were more pronounced for larger design storms. However, for the 500-yr design storm, the future storm intensity in the western portion of the PCW is slightly lower than present rainfall, measuring 8.98

inches compared to 9.39 inches (**Figure 3-2**). This highlights the impact of climate change on present rainfall distribution patterns.

Tetra Tech acknowledges the World Climate Research Programme's Working Group on Coupled Modeling, which is responsible for CMIP5, and thank these modeling groups for producing and making available their model output. For CMIP5, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

Tetra Tech extracted and analyzed the temporal distribution of rainfall in the PCW BLE model using a series of Python scripts. All rainfall design storms were assigned the same within-storm temporal distribution with peak rainfall occurring approximately 12 hours after the beginning of the simulation (**Figure 3-3**). Future, spatially distributed rainfall datasets (right column, **Figure 3-2**) were then disaggregated into 6-minute temporal intervals based on this distribution using standard methods (NRCS, 2004; **Figure 3-3**). The resulting gridded rainfall data were then stored in a grid format (NetCDF), ensuring compatibility with the Iowa DNR BLE model for flood simulations across multiple design storms.

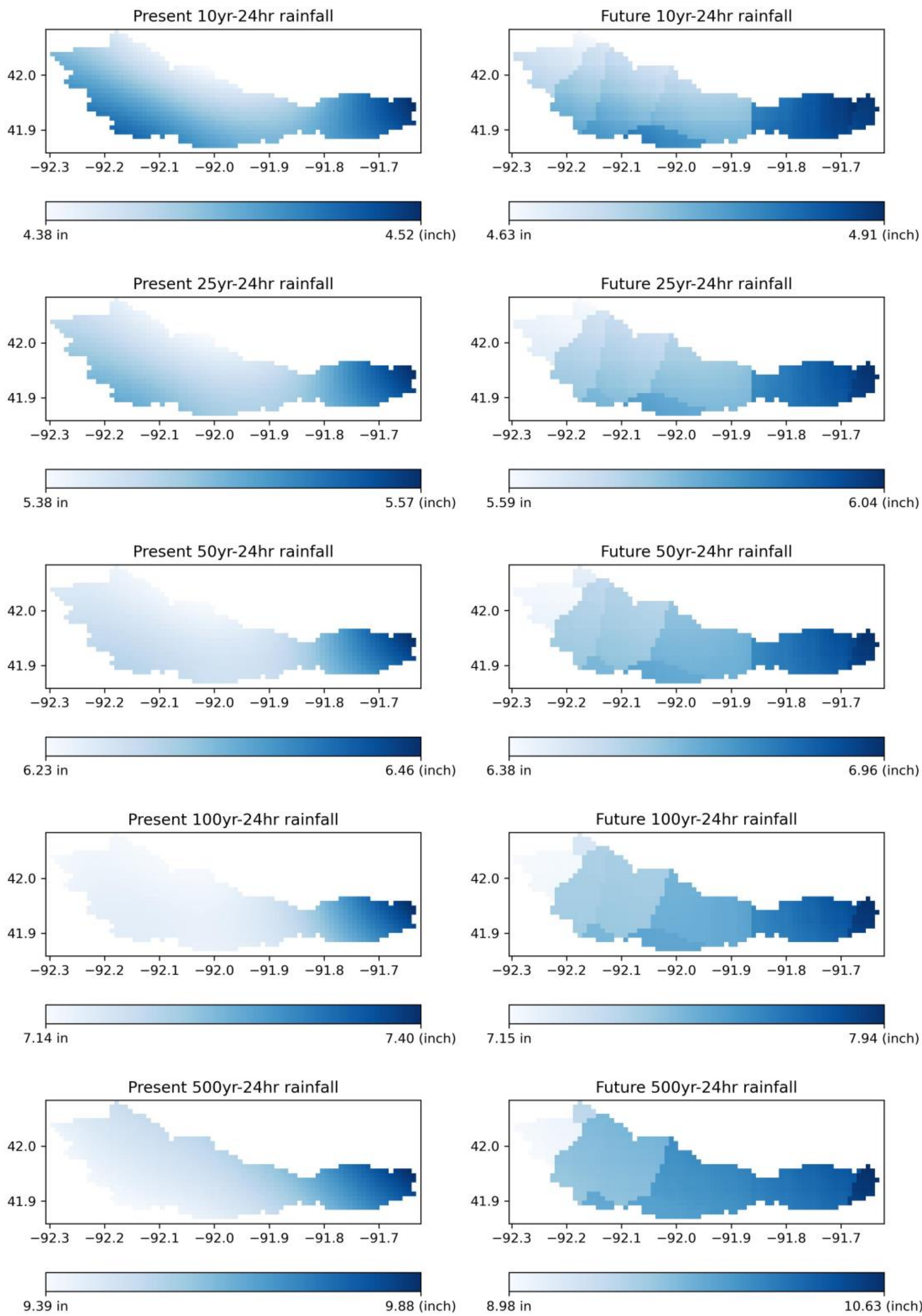

Figure 3-2. Present and future (mid-century) rainfall depths for the 10 through 500-yr 24-hr design storms. Note that scales vary between model runs. The x axis is represented in degrees longitude and the y axis is represented in degrees latitude.

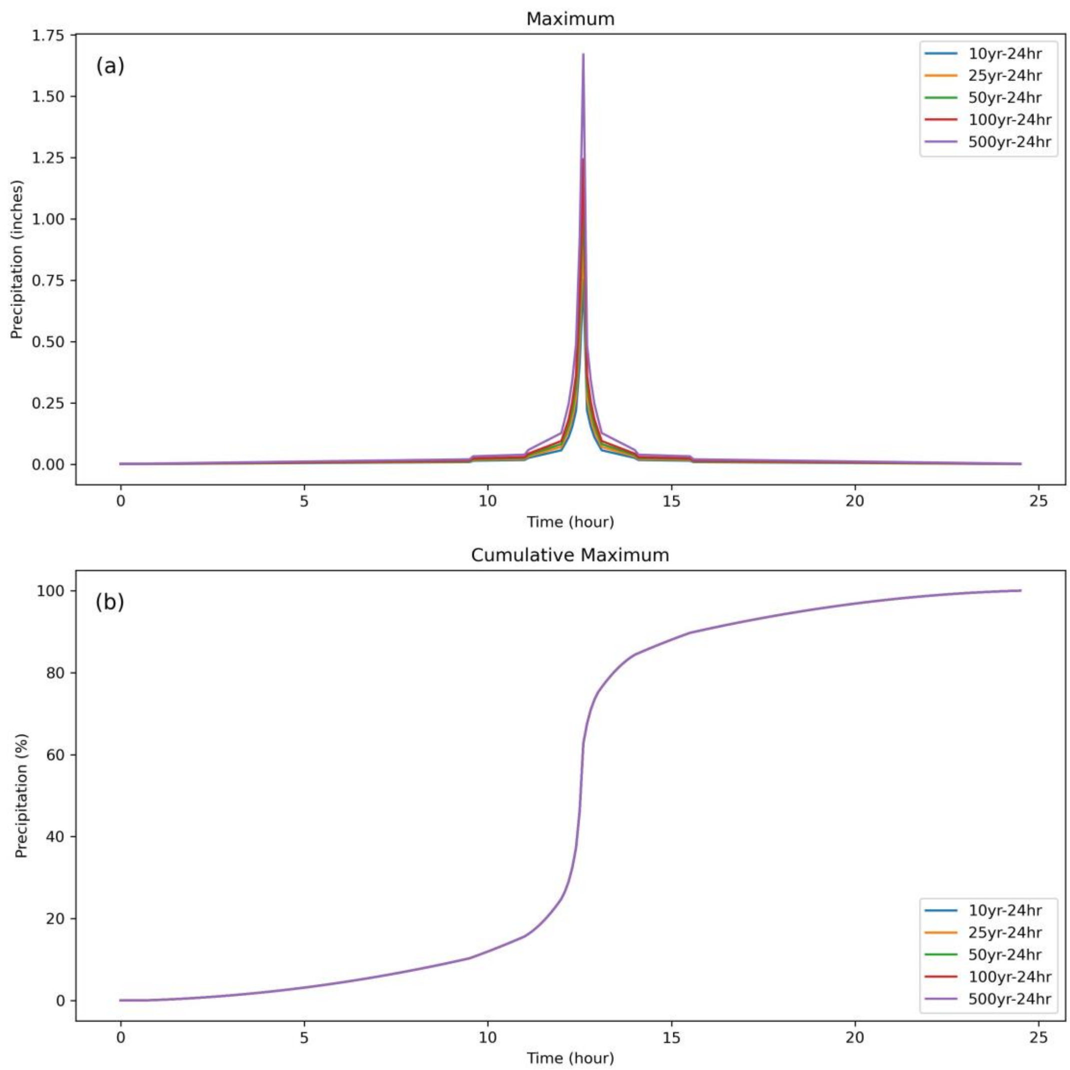

Figure 3-3. Temporal patterns of precipitation (rainfall only) in Iowa BLE models. (a) Temporal distribution of maximum rainfall and (b) Cumulative percentage of rainfall. Note that only the 500-yr cumulative distribution is visible (purple line) because each design storm uses the same temporal distribution; the results are stacked on top of one another.

3.4 Natural Infrastructure

The focus of this study is to assess the ability of NI to mitigate flood risks. The methods for incorporating potential NI in the BLE HEC-RAS model are discussed in detail below. Tetra Tech's implementation of NI in the model was comprised of three steps: (1) conducting a literature review to determine appropriate parameters for NI implementation, (2) spatial data processing to align all necessary geospatial data and create derivative geospatial products necessary for the analysis, and (3) modifying HEC-RAS modeling files using these geospatial files to incorporate NI practices into the model.

As described in the previous deliverable, *Natural Infrastructure for Flooding Risk Mitigation Study Design Memorandum*, Tetra Tech leveraged previous work conducted by EDF and the Iowa Geological Survey to identify six potential NI that would be best suited for implementation in the PCW. These six types of NI included depressional wetlands, Conservation Reserve Enhancement Program (CREP) wetlands, water and sediment control basins (WASCOBs), row crop conversion in the floodplain, row crop conversion on highly erodible soils (in the highlands), and riparian buffers. These six NI practices are briefly described below. Further details on how these NI were incorporated into the various model runs is described in Sections 3.4.2 and 3.4.3.

1. Depressional wetlands inside and outside the floodplain – Restored wetlands located in natural topographic depressions found inside the 100-yr floodplain (e.g., swamp) or on land outside the 100-yr floodplain (e.g., prairie potholes). Depressional wetland opportunities are relatively scarce in the PCW and frequently overlap potential CREP wetland sites.
2. CREP wetlands – Wetlands constructed via the Conservation Reserve Enhancement Program are primarily located in agricultural areas to remove chemicals associated with croplands activities.
3. WASCOBs - Small earth embankments on agricultural land that collect and store runoff from concentrated flow paths.
4. Row crop conversion within the floodplain – Conversion of land used for conventional row crop production located within the 100-yr floodplain to native grassland/prairie.
5. Row crop conversion on highly erodible land – Conversion of highly erodible row crop land (i.e., on slopes greater than 7%) to native grassland/prairie. High slopes are not found in the floodplain and therefore the footprint of conversion of row crops within the floodplain and on highly erodible land do not overlap each other.
6. Riparian buffers - Vegetated areas adjacent to a waterbody that intercept pollutants in runoff originating from nearby land uses. Multiple types of vegetation were historically present in the PCW (Iowa GDC, 2017). However, grassland/prairie dominated most of the watershed area and is, therefore, the most likely land use that riparian buffers be restored to.

While not a focus of this work, levee reconnection includes the reconnection of lands to the 100-yr floodplain that are previously separated by a levee. Tetra Tech did not include levee reconnection in this analysis because previously conducted Iowa Geological Survey spatial analysis work indicated no opportunities for implementation of this NI in the PWC. Spatial data revealed that this NI practice is not present in the PCW. As such, no further action was taken to incorporate this NI in the hydrologic modeling analysis. Levee reconnection may also be referred to as “floodplain reconnection”, but Tetra Tech uses the term levee reconnection here to be consistent with information provided by Iowa Geological Survey staff.

3.4.1 Literature Review

The NI practices were represented in the HEC models by their ability to retain and infiltrate water (summarized by the runoff curve number), the speed at which water flows overland (summarized by the Manning’s roughness coefficient (N), and any modifications to the topography. Tetra Tech conducted a literature review to determine acceptable ways to modify these three model parameters (terrain, Manning’s n, curve number) to represent NI practices. Further rationale for these modifications is provided for each NI practice below and summarized in **Table 3-1**. Tetra Tech focused on modifying these three variables in HEC-RAS because, while modifying the outlet flow is possible, outlet flow modification cannot be automated for each of the hundreds of implemented NI (i.e., WASCOBs, depressional wetlands, and CREP wetlands) sited at the HUC 10 scale.

Modifications to the HEC-RAS terrain by NI practice were as follows:

- Depressional wetlands – By definition, depressional wetlands are already located in areas with natural lower elevations (e.g., swamps and prairie potholes). Therefore, no modifications were made to the HEC-RAS terrain for these NI.
- CREP wetlands – CREP wetlands are designed to maintain a 1-foot minimum buffer between normal pool elevations and any incoming tile drain outlets (CREP, 2016). The depth of tile drains in Iowa are recommended to be 3-5-ft below grade (CTRE, 2005). Assuming a water depth of CREP wetlands of 2 ft, a minimum required depth of excavation to construct CREP wetlands would therefore be 6 ft. It should be noted that CREP wetlands may not only exist where tile drains are present. However, tile drain depth was still used to assume a consistent terrain modification of 6 ft in the HEC-RAS model to represent CREPs. In reality, CREP depth and presence of tile drains will be highly variable. The BLE models developed by Iowa DNR and used in this study do not include tile drainage.
- WASCOBs – Tetra Tech leveraged GIS data from EDF and Iowa Geological Survey staff to site these locations; however, the ideal depth varies based on the area of the NI and design standards. Iowa specific design standards do not provide a typical embankment height for WASCOBs, but a maximum height of 15 ft is given (NRCS, 2024). Additionally, any basin designed to impound water at a depth of 3 ft or greater must include additional foundation and seepage control considerations (NRCS, 2024). Other models that simulate impacts of best management practices (i.e., Agricultural Conservation Planning Framework; ACPF) use 1.5-meters (4.9 ft) as the default WASCOB embankment height (Porter et al., 2024). In England, Quinn et al., 2013 describe runoff attenuation features that function like WASCOBs and recommend that embankment heights do not exceed one meter (3.3 ft). In practice, the local terrain, drainageway width, and other site-specific considerations determine WASCOB embankment height. However, simulating WASCOBs at the PCW HUC 10 scale in HEC-RAS requires a degree of simplification such that these NI can be readily simulated. As such, Tetra Tech decreased the WASCOB footprint by an elevation of 3.5 ft in the HEC-RAS terrain. This terrain modification of 3.5 ft was substantiated by the three sources listed above that describe WASCOB embankment heights of 3-, 4.9, and 3.3 ft respectively. This simplified terrain modification does not account for the drawdown time for which the WASCOB was designed. This level of detail is possible to model in HEC-RAS but is not feasible for the number of WASCOBs present at the HUC 10 scale. Additionally, the drawdown time will likely not impact the degree that each WASCOB attenuates peak flows, which is the primary goal of this study. Therefore, the simplified terrain modification to simulate WASCOBs is appropriate in this case.
- Row crop conversion in floodplain – Converting row crops to native grassland/prairie does not change the elevation of the terrain. Therefore, no modifications were made to the HEC-RAS terrain for this NI.
- Row crop conversion on highly erodible land – Converting row crops to native grassland/prairie does not change the elevation of the terrain. Therefore, no modifications were made to the HEC-RAS terrain for this NI.
- Riparian buffers – Establishing vegetated areas (grassland/prairie) in the riparian area does not change the elevation of the terrain. Therefore, no modifications were made to the HEC-RAS terrain for this NI.

Modifications to the HEC-RAS Manning's n by NI practice were as follows:

- Depressional wetlands – Worley et al. (2023) used a 2-D HEC-RAS model to simulate the potential enhancement of flood resiliency in response to wetland restoration, among other practices. Originally cultivated cropland, the Manning's n values were set to 0.12 to mimic a wetland land cover type in this study. Also informed by land cover types, the HEC-RAS 2-D User Manual (USACE, 2024) provides a range of Manning's n values from 0.045 to 0.15 for woody wetlands and emergent herbaceous wetlands. Through this literature review, Tetra Tech determined that 0.12 is an appropriate Manning's n value to use for depressional wetlands in the HEC-RAS model because it falls within the acceptable range of values provided by the 2-D HEC-RAS User Manual for this land use and aligns with other recently published studies (Worley et al., 2023).
- CREP wetlands – The same Manning's n modifications made for depressional wetlands described above were used for CREP wetlands.
- WASCOBs – The earthen embankments constructed during WASCOB installation are specified to be at slopes suitable for agricultural machinery such that the embankment itself can remain in cultivated cropland production (NRCS, 2017). Additionally, the temporary nature of the stored water within WASCOBs does not typically harm crop health. Therefore, the land cover and subsequent Manning's n values were kept identical to those in the existing baseline model.
- Row crop conversion in floodplain - The nomenclature provided for row crop conversion in the floodplain specifies that these NI practices are to convert row crops to native grassland/prairie. Chow, 1959 provides Manning's n values for a variety of channel and floodplain characteristics. For the NLCD land cover type of grassland/herbaceous, Chow (1959) specifies Manning's n values may range from 0.04 to 0.06 for the floodplain. The BLE models assigned 0.06 to row crops in the PCW, which is the upper range of the spectrum found in the literature. As a conservative estimate and to stay within the range supported in the literature, Tetra Tech used a Manning's n of 0.05 to represent native grassland/prairie. Chow (1959) does not specify "uplands" or "highly erodible land"—only "within channel" or "outside of channel". Here, row crop conversion is considered outside of the channel.
- Row crop conversion on highly erodible land – Modification of Manning's n for row crop conversion on highly erodible land were treated the same as row crop conversion in the floodplain.
- Riparian buffers – The nomenclature provided for riparian buffers only specifies that these NI practices are to establish a "vegetated area" adjacent to waterbodies. The NRCS provides conservation practice standards for riparian buffers of both forested and herbaceous types (NRCS, 2020; NRCS 2022a). However, because grassland/prairie is historically the dominant vegetation type throughout the PCW, this land cover was used for riparian buffer establishment. As stated above, the BLE models assigned 0.06 to row crops in the PCW, which is the upper range of the spectrum found in the literature. As a conservative estimate and to stay within the range supported in the literature, Tetra Tech used a Manning's n of 0.05 to represent grassed riparian buffers.

Modifications to the HEC-RAS curve number by NI practice are as follows:

- Depressional wetlands – Curve numbers vary based on the hydrologic soil group (HSG) of the underlaying soils. The National Engineering Handbook provides representative curve numbers for unique land use – HSG combinations. For NLCD land uses of woody wetlands and emergent herbaceous wetlands the curve numbers range from 72 for HSG A to 93 for HSG D (NRCS, 2004).
- CREP wetlands – The same curve number modifications made for depressional wetlands described above were used for CREP wetlands.
- WASCOBs – The earthen embankments constructed during WASCOB installation are specified to be at slopes suitable for agricultural machinery such that the embankment itself can remain in cultivated cropland production (NRCS, 2017). Additionally, the temporary nature of the stored water within WASCOBs does not typically harm crop health. Therefore, the land cover, soils, and subsequent curve number values remained identical to those in the existing baseline model.
- Row crop conversion in floodplain - Curve numbers vary based on the hydrologic soil group (HSG) of the underlaying soils. The National Engineering Handbook provides representative curve numbers for unique land use – HSG combinations. Like Manning's n, the BLE models assigned curve numbers to row crops that are at the upper range of the spectrum found in the literature. As a conservative estimate and to stay within the range supported in the literature, Tetra Tech used the grassland/herbaceous NLCD land use to represent native grassland/prairie which corresponds to a curve numbers range from 55 for HSG A to 89 for HSG D (NRCS, 2004).
- Row crop conversion on highly erodible land – Modification of the curve number for row crop conversion on highly erodible land were treated the same as row crop conversion in the floodplain.
- Riparian buffers - The nomenclature provided for riparian buffers only specifies that these NI practices are to establish a "vegetated area" adjacent to waterbodies. The NRCS provides conservation practice standards for riparian buffers of both forested and herbaceous types (NRCS, 2020; NRCS 2022a). However, because grassland/prairie is historically the dominant vegetation type throughout the PCW (Iowa GDC, 2017), this land cover was used for riparian buffer establishment. As such, riparian buffers were represented in the HEC-RAS model by an NLCD land cover type of grassland/herbaceous. Like row crop conversion in the floodplain, curve numbers ranged from 55 for HSG A to 89 for HSG B (NRCS, 2004).

Table 3-1. Natural infrastructure practices and how they are incorporated into the Iowa DNR BLE HEC-RAS models.

Natural Infrastructure Practice	HEC-RAS Layer Modification		
	Terrain	Manning's n	Curve Number
Depressional Wetlands	N/A	0.12	Varies by hydrologic soil group: A = 72 B = 80 C = 87 D, A/D, B/D, C/D = 93
CREP Wetlands	Decrease existing terrain by 6 ft	0.12	Varies by hydrologic soil group: A = 72 B = 80 C = 87 D, A/D, B/D, C/D = 93
WASCOBs	Decrease existing terrain by 3.5 ft	N/A	N/A
Row Crop Conversion in Floodplain	N/A	0.05	Varies by hydrologic soil group: A = 55 B = 71 C = 81 D, A/D, B/D, C/D = 89
Row Crop Conversion on Highly Erodible Land	N/A	0.05	Varies by hydrologic soil group: A = 55 B = 71 C = 81 D, A/D, B/D, C/D = 89
Riparian Buffers	N/A	0.05	Varies by hydrologic soil group: A = 55 B = 71 C = 81 D, A/D, B/D, C/D = 89

3.4.2 Spatial Data Processing

The spatial extents of all potential NI opportunities in the PCW were provided to Tetra Tech by EDF and Iowa Geological Survey (IGS) via a geodatabase. The location and extent of potential NI were established by Schilling et al. (2023). Spatial datasets used to define seven unique NI practices include but are not limited to the Cropland Data Layer (CDL), National Hydrography Dataset (NHD), Soil Survey Geographic Database (SSURGO), agricultural tile drained lands, watershed boundaries of various HUC sizes, and 100-yr floodplain extents. A detailed description of the NI practice, key assumptions, input datasets, and GIS processing steps are provided in Appendix A of Schilling et al. (2023).

First, Tetra Tech removed infeasible NI locations from consideration. Opportunities were considered infeasible when they overlapped with existing infrastructure (i.e., buildings and roads) or had a limited area (i.e., a single raster cell). Feasibility of NI practices at the locations provided by EDF and IGS depend on many other factors (e.g., pipelines, wind turbines, landowner acceptance, etc.), all of which are highly site-specific and were therefore not able to be included in the spatial data processing of NI for use in the HEC-RAS model.

Second, Tetra Tech conducted additional geoprocessing as necessary for specific NI practices. Namely WASCOBs and row crop conversion on highly erodible land were defined by the same criteria and therefore a single raster file provided by EDF and Iowa Geological Survey included both NI practices, often overlapping in spatial extent. Per communication between Tetra Tech and EDF, Tetra Tech conducted a literature review to inform which footprints could be assigned to each NI practice. Specifically, Quinn et al., 2023 described the maximum practical size of WASCOBs to be 2.5-acres while NRCS, 2024 specified the maximum uncontrolled drainage area to a WASCOB should not exceed 50-acres.

An initial geospatial assessment of the data revealed that 2,258 of the potential 2,272 (99.4%) WASCOB locations had direct drainage areas under the 50-acre threshold specified in the NRCS National Standard documentation. Of the 14 WASCOBs that had drainage areas greater than 50-acres, all but one of them was over the 2.5-acre footprint threshold specified by Quinn et al., 2023 and would, therefore, be removed from WASCOB consideration. Furthermore, the single WASCOB location that was over the 50-acre direct drainage area threshold yet under the 2.5-acre footprint threshold had a drainage area of 52.9-acres, which is within reasonable error of drainage area delineation. As such, Tetra Tech implemented only the 2.5-acre maximum footprint size threshold; the 50-acre direct drainage area threshold was not used in this study. Because the delineation of drainage basins is a computationally expensive process that scales exponentially with area of interest, it will be important to consider the applicability and relevance of the previously mentioned thresholds for watersheds at larger spatial scales.

This approach resulted in 338 and 1,934 potential locations for row crop conversion on highly erodible land and WASCOBs, respectively. This approach follows the preference of EDF that NI practices that store water on the landscape (i.e., WASCOBs count = 1,934) are to be prioritized over land conversion practices (i.e., row crop conversion count = 338), while also simulating a more realistic implementation of NI practices on upland locations than a 100% allocation to WASCOBs.

The final geoprocessing step required prior to incorporating NI data into the HEC-RAS model was accounting for NI that was co-located within the PCW. Where NI practices overlap one another, an order of supersedence was developed with input from EDF and is provided below. For example, if a riparian buffer overlaps a CREP wetland, then the CREP wetland was preferentially sited at that location. See the introduction of Section **Error! Reference source not found.**, for specific d efinitions of each NI practice.

The order of NI supersedence is as follows:

1. <u>Depressional wetlands inside and outside the floodplain</u> –Since depressional wetland opportunities are relatively scarce in the PCW and frequently overlap with CREP wetland sites, depressional wetlands superseded CREP wetlands so as to not remove all opportunities for depressional wetland implementation.
2. <u>CREP wetlands</u>
3. <u>WASCOBs</u>
4. <u>Row crop conversion within the floodplain</u> – These NI are located within the 100-yr floodplain.
5. <u>Row crop conversion on highly erodible land</u> – Since these NI are typically located in the highlands (also referred to as the uplands) of the PCW (**Figure 3-5**). As such, the order of supersedence between this NI practice and row crop conversion within the floodplain did not impact the final NI simulated in the HEC-RAS model.
6. <u>Riparian buffers</u>

3.4.3 HEC-RAS Modifications

The six different types of natural infrastructure were incorporated into the HEC-RAS model by modifying the terrain and land use as discussed above (**Figure 3-4** and **Figure 3-5**). New land cover types were defined for each NI and the Manning's n and CN modifications were made via the HEC-RAS data tables (**Figure 3-6**).

After removal of infeasible areas (Section 3.4.2) and incorporating the order of supersedence to co-located NI, the PCW has the potential to host 133-acres of depressional wetlands (0.1% PCW area), 12,423-acres of CREP wetlands (9.1% PCW area), 1,151-acres of WASCOBs (0.8% PCW area), 4,469-acres of row crop conversion within the floodplain (3.3% PCW area), 3,061-acres of row crop conversion on highly erodible land (2.2% PCW area), and 2,390-acres of riparian buffers (1.7% PCW area).

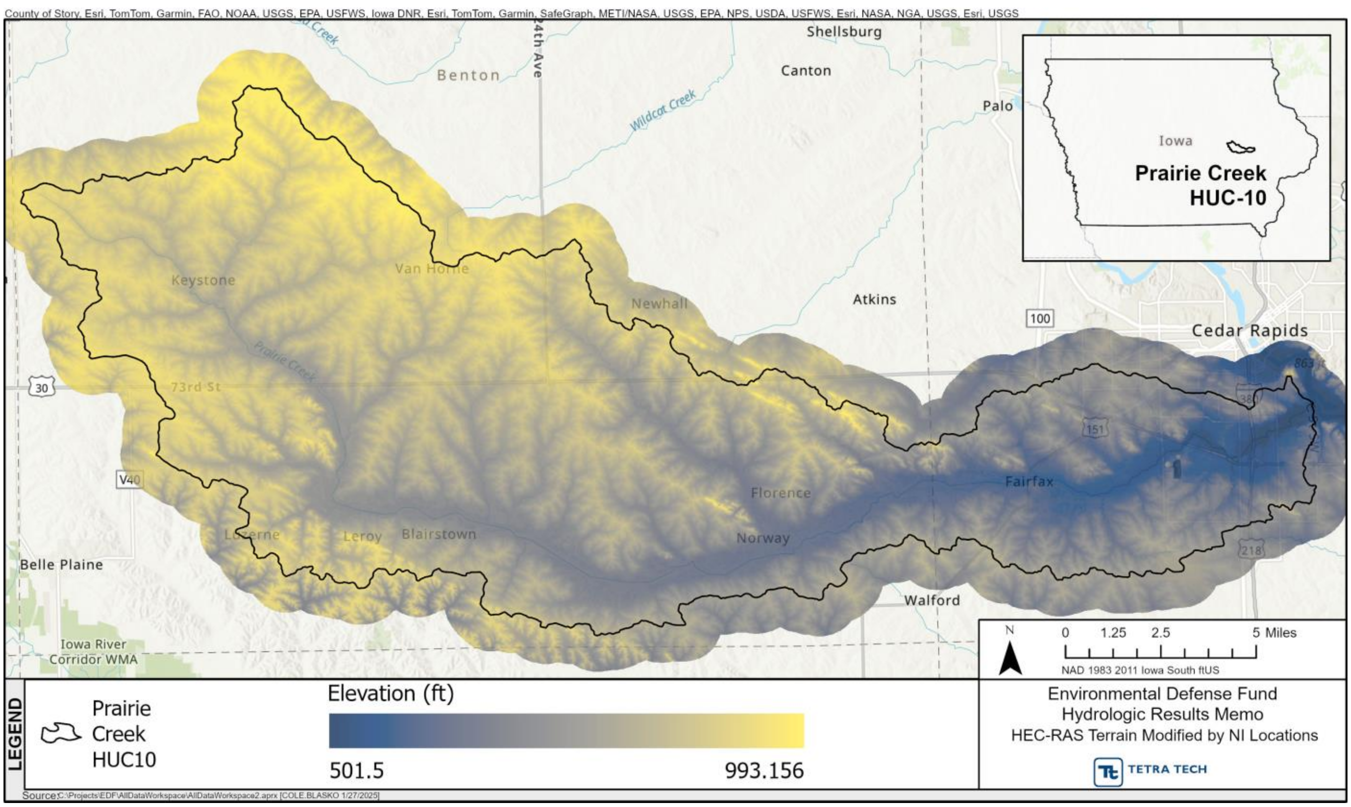

Figure 3-4. Natural Infrastructure incorporated in the elevation data used as the HEC-RAS terrain input data. Elevation data extends past the PCW boundary in the BLE model provided by Iowa DNR; therefore, Tetra Tech retained this extent.

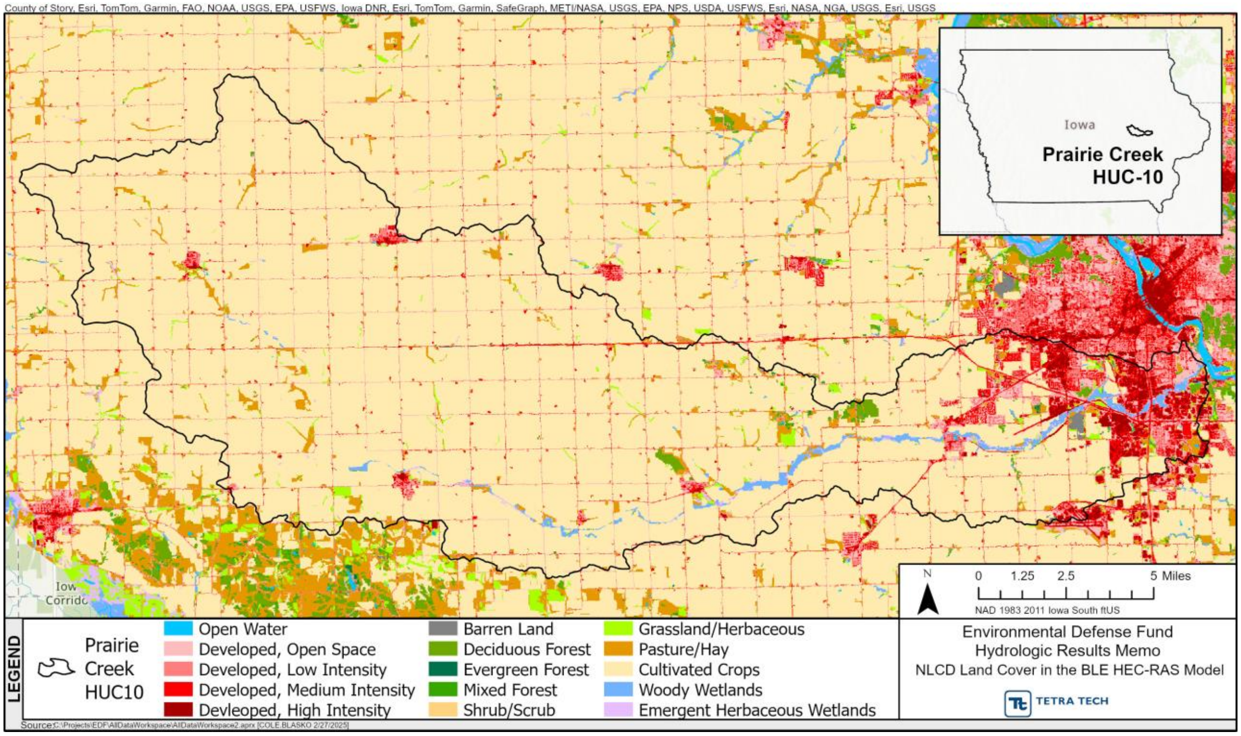

Figure 3-5. 2023 National Land Cover Dataset (NLCD) used as the HEC-RAS land cover input data. Land cover data extends past the PCW boundary in the BLE model provided by Iowa DNR; therefore, Tetra Tech retained this extent.

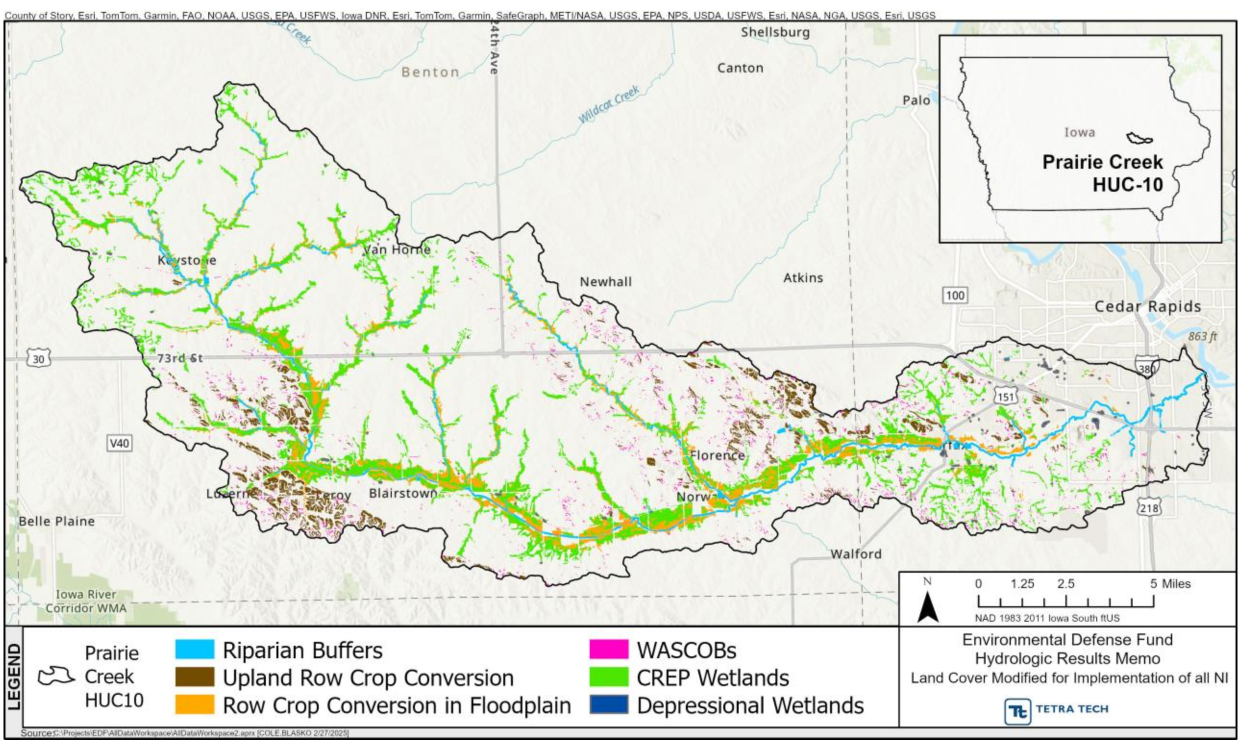

Figure 3-6. Location and extent of all potential natural infrastructure in the PCW after removal of the infeasible areas and incorporating the order of supersedence to co-located NI.

Implementation of all potential NI corresponds to a PCW coverage of approximately 17.2% (**Figure 3-6**). Through discussions with EDF, it was decided that the additional HEC-RAS model scenarios would have natural infrastructure implemented on 10%, 5%, and 2.5% of the PCW. Implementation of NI on 2.5% of the PCW corresponds to implementation of approximately 15% of all potential NI. This rate of NI implementation is believed to be a realistic and upper-end goal in terms of buy-in from local stakeholders. Likewise, the 5% and 10% PCW coverage scenarios represent NI implementation rates of 29% and 58%, respectively. These scenarios represent a range of NI implementation and coverage within the PCW. HEC-RAS results over this range will give insight as to whether the relationship between NI area and flood mitigation is linear.

Spatial distribution and extent of NI under the 10%, 5%, and 2.5% scenarios are shown in **Figure 3-7**, **Figure 3-8**, and **Figure 3-9**, respectively. Implementation of NI under these scenarios was chosen randomly spatially and in terms of the footprint size of each opportunity. While this randomization process was automated, a visual check to ensure each NI category was distributed throughout the watershed. While outside the scope of this study, to determine uncertainty of spatial distribution of randomly chosen NI herein, Tetra Tech recommends running at least 10-20 randomizations of each NI percentage to determine how the spatial uncertainty impacts hydrology and economic results.

The footprint of potential NI opportunities were not modified to achieve the exact acreage required to meet the 10%, 5%, and 2.5% scenario areas. Therefore, the areas and percentages listed in **Table 3-3** represent NI opportunities rounded to the whole practice and is the closest area achievable without going over the 10%, 5%, and 2.5% goals. The ratio of areas between all NI practices was maintained throughout all scenarios. Finally, practices in the 2.5% scenario were carried through into all increasing NI percentage model runs while the same was done for the 5% and 10% scenarios. This ensures the results are directly comparable.

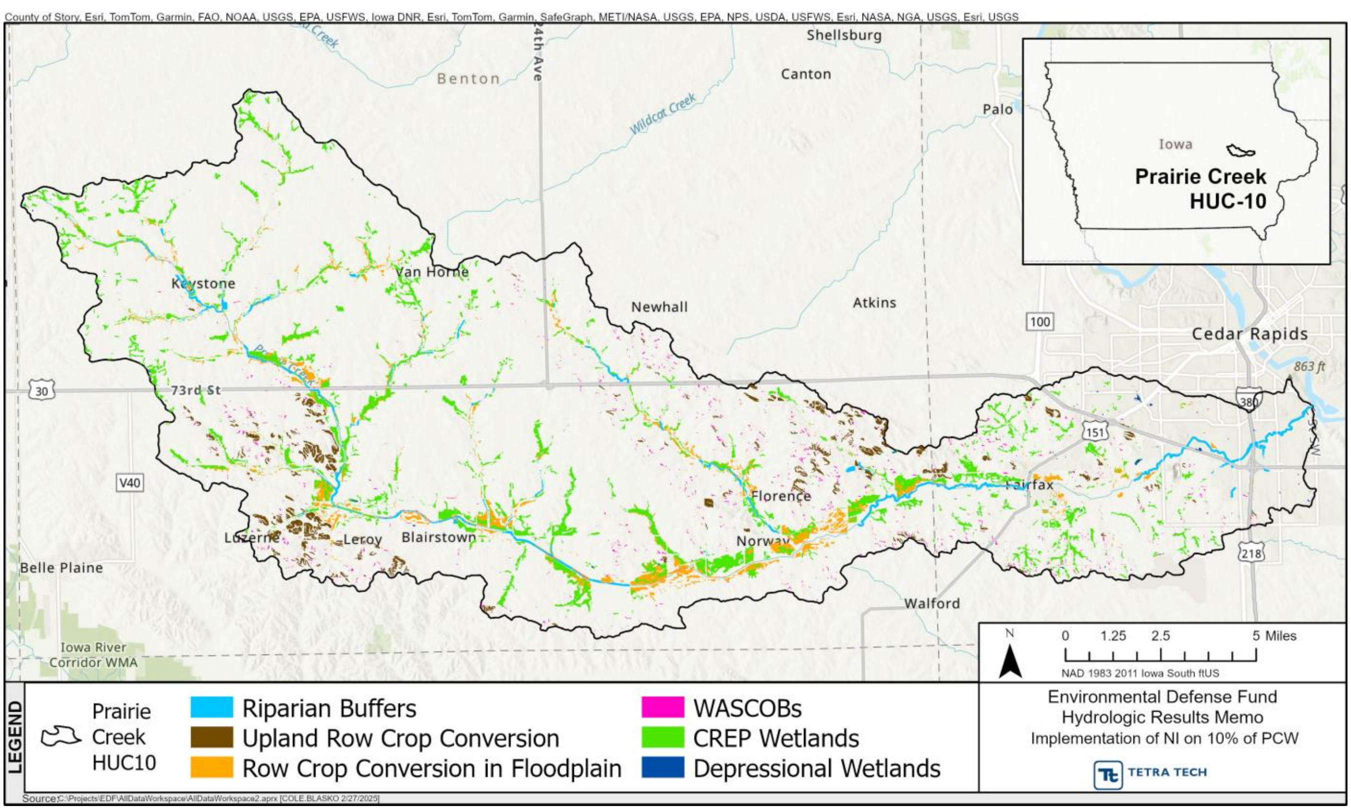

Figure 3-7. Location and extent of natural infrastructure implemented on 10% of the PCW area.

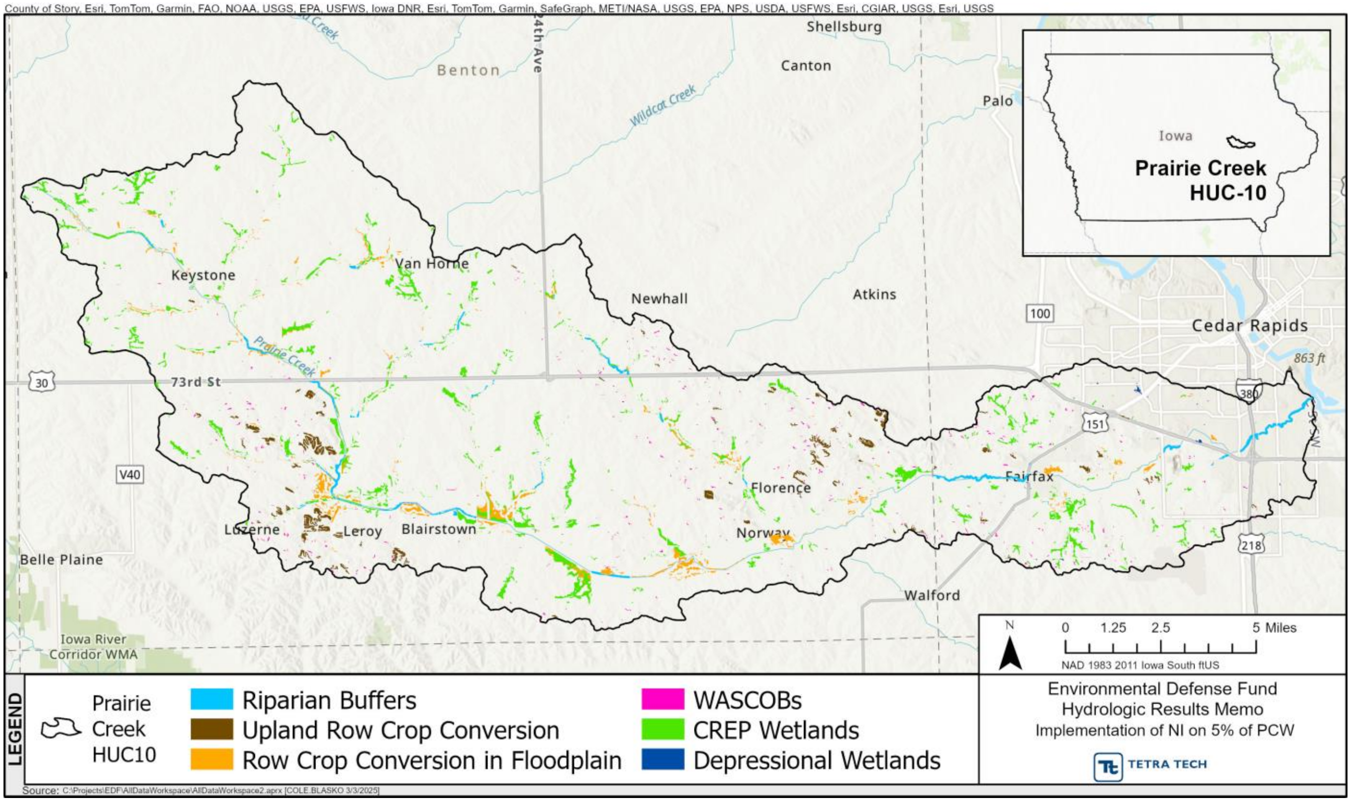

Figure 3-8. Location and extent of natural infrastructure implemented on 5% of the PCW area.

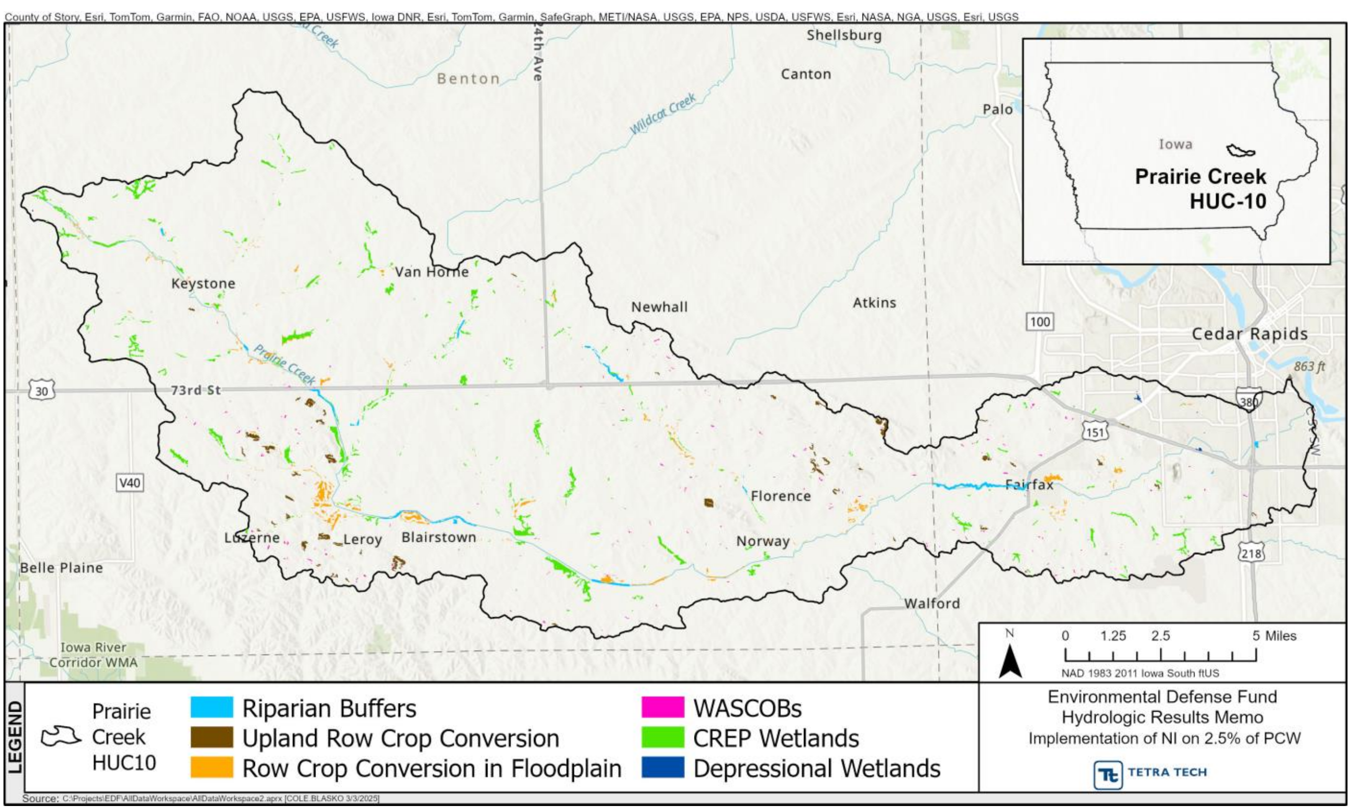

Figure 3-9. Location and extent of natural infrastructure implemented on 2.5% of the PCW area.

3.5 Summary of Model Runs

Tetra Tech completed a total of 32 different model runs; these model runs included a variety of 24-hour design storm recurrence intervals (i.e., 10-, 25-, 50-, 100-, 500-yr), rainfall conditions (i.e., present versus future), and a range of NI implementation percentages (i.e., 2.5, 5, 10, and 17.2% of the watershed area). The NI scenarios 2.5, 5, 10, and 17.2% of the watershed area corresponds to 14, 28, 56, and 100% of potential NI implementation for the PCW. The full list of model runs and their descriptions are included in **Table 3-2**. Furthermore, **Table 3-3** includes the percentages of the six individual NI used in each model run. These percentages are non-overlapping because NI incorporated into the HEC-RAS model runs cannot overlap.

In this report, Tetra Tech uses “baseline” to refer to the HEC-RAS model runs without NI modifications included. Put another way, no modifications were made to the BLE model from Iowa DNR. This is in contrast to HEC-RAS model runs where terrain, land cover, and Manning’s n have been modified to simulate NI of interest to EDF. Tetra Tech uses the term “present” to refer to the HEC-RAS model runs with historic rainfall applied to generate flood depth results.

For the net benefits analysis, which requires all five design storms to be run under present and future conditions, Tetra Tech only focused on the scenario where 17.2% of the watershed was implemented with NI. For all remaining scenarios, Tetra Tech compared total economic losses from Hazus results for the 10-yr and 50-yr design storms. Given the limited time duration of the project, Tetra Tech prioritized these design storms in collaboration with EDF; they represent rainfall events that are most likely to match the designed capacity of the NI implemented in this study. Tetra Tech recommends that future work include all five design storms for all NI scenarios under present and future conditions. As noted in the previous deliverable, *Hydrologic Model Results Memorandum*, this study includes six NI, which are each briefly described below.

Table 3-2. Description of the 32 model runs included in this analysis.

Model Run Number	Design Storm	Rainfall Time Period	NI Scenario
01	10-yr	Present	Baseline (none)
02	25-yr	Present	Baseline (none)
03	50-yr	Present	Baseline (none)
04	100-yr	Present	Baseline (none)
05	500-yr	Present	Baseline (none)
06	10-yr	Future	Baseline (none)
07	25-yr	Future	Baseline (none)
08	50-yr	Future	Baseline (none)
09	100-yr	Future	Baseline (none)
10	500-yr	Future	Baseline (none)
11	10-yr	Present	All potential NI
12	25-yr	Present	All potential NI
13	50-yr	Present	All potential NI
14	100-yr	Present	All potential NI
15	500-yr	Present	All potential NI
16	10-yr	Future	All potential NI
17	25-yr	Future	All potential NI
18	50-yr	Future	All potential NI
19	100-yr	Future	All potential NI
20	500-yr	Future	All potential NI
21	10-yr	Present	2.5% of watershed
22	50-yr	Present	2.5% of watershed
23	10-yr	Present	5% of watershed
24	50-yr	Present	5% of watershed
25	10-yr	Future	2.5% of watershed
26	50-yr	Future	2.5% of watershed
27	10-yr	Present	10% of watershed
28	50-yr	Present	10% of watershed
29	10-yr	Future	5% of watershed
30	50-yr	Future	5% of watershed
31	10-yr	Future	10% of watershed
32	50-yr	Future	10% of watershed

Table 3-3. Summary of NI acres and percentage of PCW area (%) for each model run included in this analysis. Note that model runs 01-10 do not have any NI implemented in the HEC-RAS model so they are not included in this table.

Model Run Number	Depressional Wetlands	CREP Wetlands	WASCOBs	Row Crop Conversion in Floodplain	Row Crop Conversion on Highly Erodible Land	Riparian Buffers	Total
11 through 20	133 (0.1%)	12,423 (9.1%)	1,151 (0.8%)	4,469 (3.3%)	3,061 (2.2%)	2,390 (1.7%)	23,627 (17.2%)
21 and 22, 25 and 26	18 (0.01%)	1,735 (1.3%)	130 (0.1%)	595 (0.4%)	444 (0.3%)	349 (0.3%)	3,270 (2.4%)
23 and 24, 29 and 30	31 (0.02%)	3,487 (2.5%)	277 (0.2%)	1,190 (0.9%)	882 (0.6%)	684 (0.5%)	6,552 (4.8%)
27 and 28, 31 and 32	69 (0.05%)	7,108 (5.2%)	561 (0.4%)	2,439 (1.8%)	1,766 (1.3%)	1,386 (1.0%)	13,329 (9.7%)

3.6 Net Present Value Analysis

Tetra Tech gathered relevant economic parcel and census datasets for the PCW from the Linn and Benton County GIS portals as well as the Iowa GIS portal (GCS, 2025). However, Tetra Tech found incongruencies between county and state datasets that would require significant processing time to remedy. As a result, Tetra Tech decided to use Hazus for the economic analyses presented here. The use of a national dataset such as the Hazus Inventory National Database serves as a standardized approach for the PCW. Furthermore, Hazus can be applied to other watersheds across the US. In addition to being a source of consistent data, Hazus provided significantly more data parameters than other datasets that Tetra Tech reviewed and compiled.

To estimate the net benefits of implementing NI in the PCW for the scenario where 17.2% of the watershed area was implemented with NI, Tetra Tech used a six-step process:

First. Tetra Tech used a depth-damage curve methodology to determine the relationship between flood depth and flood damages in the PCW and resulting average annual loss for each model run (**Table 3-2**). There are two general approaches used to develop depth-damage curves: (1) empirically from actual flood insurance claim data collected after flood events and (2) synthetically using a theoretical probabilistic model developed from inventories or interviews using hypothetical analysis and expert judgement and validated with actual flood loss data (Pistrika et al., 2014; Rahim et al., 2023). After conducting a comprehensive review of the peer-reviewed literature, and available data such as regional depth-damage curve equations and building datasets, the Hazus tool developed by FEMA was repeatedly identified as a nationally-recognized, standardized methodology for quantifying average annualized losses from flood events. Furthermore, Hazus provides the most comprehensive and up-to-date building stock dataset (i.e., the Hazus Inventory National Database; FEMA, 2023). Consequently, Tetra Tech used Hazus because it provided the most practical approach for the PCW case study. According to FEMA documentation (FEMA, 2024c), the Hazus tool (v7) relies on the National Structure Inventory (NSI) from the US Army Corps of Engineers (USACE), which was last updated in 2022. Therefore, Tetra Tech assumed that all USD outputs from Hazus are in terms of December 2022 USD and converted Hazus outputs to December 2024 USD by multiplying by the outputs by a factor of 1.07 (USBLS, 2025).

Second, Tetra Tech used **Equation 1** to estimate the average annual loss (*AAL*) for present and future hydrology model runs (FEMA, 2020; 2024a). Specifically, this function approximates the integral of damages for a range of design storms with respect to their probability of occurrence (Olsen et al., 2015; FEMA, 2020; 2024a).

$$AAL = \frac{1}{2} \sum_{i}^{\substack{10,25,50,\\100,500}} (p_i - p_{i+1})(L_i + L_{i+1})$$

Equation 1

Where p_i is the probability of the design storm (i.e., 1/10 for p_{10}), and L_i is the economic loss of corresponding design storm. AAL can be computed using economic losses from hydrologic model outputs under present (2025) or future (2065) conditions. In this study, Tetra Tech only calculated AAL and all subsequent net benefit calculations for present and future rainfall scenario where 17.2% of the watershed was implemented with NI. This is because only this NI scenario had model runs for all five design storms.

Third, Tetra Tech estimated net present value (*NPV*) over a 40-year time horizon (i.e., 2065 – 2025 = 40 years) by first estimating the average annual loss for a given year (AAL_t; **Equation 2**) and then summing these values over the 40-year year time horizon (**Equation 3**).

$$AAL_t = AAL_{2025} + t * (\frac{AAL_{2065} - AAL_{2025}}{40})$$

Equation 2

Where $AAL_{present}$ and AAL_{future} are the results of **Equation 1** using the hydrology model runs with present and future rainfall conditions, respectively, *t* is the year time step ranging from 1 to 40, and *n* is the time horizon number of years (i.e., 40).

$$NPV = \sum_{t=1}^{40} AAL_t (1 + r)^{-t}$$

Equation 3

Where AAL_t comes from **Equation 2**, *t* is the year time step ranging from 1 to 40, and *r* is the standard discount rate (i.e., 2%; OMB, 2023).

Fourth, Tetra Tech calculated the NPV of avoided losses (NPV_A; **Equation 4**) as the difference between NPV of losses in model runs with NI implemented and the NPV of losses in model runs without NI implemented (i.e., the baseline scenario).

$$NPV_A = NPV_{NI} - NPV_B$$

Equation 4

Where NPV_B and NPV_{NI} are the results of **Equation 3** using the hydrology model runs without NI (i.e., the baseline scenario) and with NI, respectively.

Fifth, Tetra Tech determined the NPV (cost) of implementing NI (NPV_C) using **Equation 5**.

$$NPV_C = I + \sum_{t=0}^{40} \mathrm{M}_t (1 + r)^{-t}$$

Equation 5

Where *I* is the initial installation costs for each practice (e.g., cost of earth removal, cost of a weir/control structure), *M* is the annual maintenance costs for each practice (e.g., time spent mowing), *t* is the year time step ranging from 1 to 40, and *r* is the standard discount rate (i.e., 2%; OMB, 2023). Additional information about the costs of implementing NI are included in Section 3.7.

Finally, Tetra Tech calculated the net benefit (*NB*) of implementing NI using **Equation 6** based on the results from **Equation 4** and **Equation 5**.

$$NB = NPV_A - NPV_C$$

Equation 6

For scenarios where not all five design storms were available (i.e., Model scenarios 21-32, **Error! Reference source not found.**), Tetra Tech compared Hazus reported losses for the 10-yr and 50-yr design storms by calculating the percent change (*PC*) in total economic losses from the baseline scenario without NI using **Equation 7**.

$$PC = \left(\frac{L_B - L_S}{L_B}\right)100$$

Equation 7

where L_B and L_S are the total economic losses from the baseline and NI scenario (e.g., 10-yr present rainfall with 2.5% of the watershed implemented with NI), respectively.

Additionally, Tetra Tech calculated the change in losses from the baseline scenario relative to the total area of NI implemented for that case (*CA*) using **Equation 8**.

$$CA = \left(\frac{L_B - L_S}{A_S}\right)$$

Equation 8

where L_B and L_S are the total economic losses from the baseline and NI scenario and A_S is the total area of NI implemented for the associated scenario. It should be noted that this approach assumes the benefits from an acre for each of the six NI practices is treated equally; however, this may not necessarily be true for water storage or other ecological benefits. Therefore, this approach provides a good first step at estimating the relative impact of NI across the watershed for each NI scenario, but more computationally intensive calculations may be necessary to measure the impacts of specific water resources management and ecological benefits.

Tetra Tech did these calculations in R (v 4.4.0; R Core Team, 2024).

The Hazus model is a well-documented, nationally standardized, geospatial risk assessment tool for natural hazards such as flooding, hurricanes, earthquakes, and tsunamis (FEMA, 2024a; 2025). Hazus provides (1) historic and scenario-based modeling, (2) economic losses, building damage and social impacts from historic events, and (3) planning scenarios (FEMA, 2024a; 2025). Hazus relies on a baseline dataset called the Hazus Inventory National Database (FEMA, 2023) and Hazus version 7 released in 2024 (FEMA, 2024b) can be run within an ArcGIS Pro toolbox. Hazus leverages over 900 depth-damage curves developed and evaluated by FEMA and the USACE to estimate building damage and economic losses (Yildirim and Demir, 2019; FEMA, 2022). These depth-damage curves vary depending on several factors such as the building occupancy category (e.g., residential versus commercial), number of stories, building material, and regional/spatial location (FEMA, 2022). The Hazus documentation also provides detailed descriptions of how the other loss outputs are derived (e.g., lost wages; FEMA, 2024a). The total economic loss output components provided by Hazus include (all in 2022 USD adjusted to 2024 USD as described in the previous section): building loss, contents loss, inventory loss, relocation costs, income loss, rental income loss, wage loss (FEMA, 2024a). To quality control Hazus results, Tetra Tech selected a handful of model run outputs and confirmed that the sum of total economic loss components was equal to the total economic loss value reported by Hazus. This quality control analysis confirmed that the components are independent of one another; there is no double counting. Loss components are categorized as "capital stock loss" or "time dependent income loss" based on whether they represent loss of value of a capital asset or loss of income over a period of time due to flooding and its aftermath. Each loss component is described briefly below based on the Hazus documentation (FEMA, 2020; 2024a).

- *Building loss (capital stock loss)* – Economic losses due to structural and non-structural repair and replacement, which is dependent on building occupancy type, number of building stories, census block, and building material type.
- *Contents loss (capital stock loss)* – Economic losses from damaged furniture, equipment that is not integral to the structure (e.g., computers) and other supplies. It is a function of building loss times a scale factor. For non-residential building occupancy categories the scale factor ranges from 100 - 150%.
- *Inventory loss (capital stock loss)* – Economic losses due to damaged business inventory and loss of sales.
- *Relocation costs (time-dependent income loss)* – Economic loss due to the cost of shifting and transferring activities as well as the cost of renting temporary space.
- *Income loss (time-dependent income loss)* – Economic losses due to delays in restoring business operations to normal.
- *Rental income loss (time-dependent income loss)* – Economic losses due to buildings not being able to be rented.
- *Wage loss (time-dependent income loss)* – Economic losses in the form of wages to the business owner/proprietor.

The Hazus ArcGIS Pro toolbox interface guides users through a 3-step approach to estimate flood damages and associated economic loss. First, Tetra Tech selected the appropriate HUC 8 scale watershed for analysis. Hazus outputs results for HUC 8 scale watersheds so Tetra Tech selected the Middle Cedar River Watershed (HUC 8: 07080205), which contains the PCW. Since the hydrology model outputs are at a smaller, HUC 10 watershed scale, Hazus outputs were constrained to this smaller HUC 10 watershed scale extent. Second, Tetra Tech created a flood scenario by providing a flood depth raster grid tif file, information on the hazard type (i.e., riverine), and setting the flood depth raster grid unit (i.e., feet). The flood depth raster grid tif file was the output of work detailed in the previous deliverable, *Hydrologic Model Results Memorandum*. Before Tetra Tech used these data in Hazus they were aggregated from a 1 ft spatial resolution to a 100 ft resolution for faster processing in Hazus. Finally, Tetra Tech ran the Hazus model and exported all ESRI geodatabase model attribute table outputs as comma-separated variable (CSV) files for post-processing. For each model run, there were five associated CSV files, which are described in more detail in **Table 3-4**. This approach was repeated for each model run (**Table 3-2**). The Hazus user guides and technical guides strongly remind readers that Hazus outputs are estimates that depend on the quality of inventory data (FEMA, 2024a). While it is possible to compute annualized results in Hazus, Tetra Tech did not use this functionality, but instead used Python (v 3.9.16; Python Software Foundation, 2022) and R (v 4.4.0; R Core Team, 2024) to post-process Hazus results for the PCW. This was necessary to avoid having to rerun earlier baseline scenarios in Hazus.

Table 3-4. Hazus output descriptions. The asterisk ("*") in the file name is a placeholder for the model run number.

Output	Output File Name	Description
Economic loss	Model*_EconomicLoss.csv	Economic losses for each Hazus census block processing unit
Economic loss by building type	Model*_EconomicLossByBuildingType.csv	Economic losses by building material type for each Hazus census block processing unit
Economic loss by general occupancy	Model*_EconomicLossByGeneralOccupancy.csv	Economic losses by general occupancy type for each Hazus census block processing unit
Building damage counts	Model*_BuidingDamageCounts.csv	Building damage counts for each Hazus census block processing unit
Shelter	Model*_Shelter.csv	Shelter needs for each Hazus census block processing unit

Tetra Tech then developed and applied a Python script to automate the summation of individual Hazus census block processing units into a single watershed-wide value. The script iterated through each model run (n = 20, **Table 3-2**) and file type (n = 5, **Table 3-4**). Tetra Tech then imported the summarized results into R and determined average annual loss and net present value of avoided losses. Tetra Tech used R to create all data visualizations associated with this economic analysis.

3.7 Quantifying Natural Infrastructure Costs

Quantifying the cost of NI implementation is important to assessing the overall net benefits of these practices in the PCW. As discussed in Section 3.6, Tetra Tech calculated the NPV (cost) of implementing NI (NPV_C) using **Equation 5** for scenarios where NI implementation was 17.2% of the watershed area. Furthermore, Tetra Tech then subtracted the results of **Equation 5** from the NPV of avoided losses (**Equation 4**) to determine the overall net benefit (*NB*) of implementing NI using (**Equation 6**). However, before determining the NPV of implementing NI, Tetra Tech collaborated with EDF and Iowa Geological Survey (IGS) to identify the corresponding US Department of Agriculture Natural Resources Conservation Service (NRCS) practice code for each NI (**Table 3-5**).

Table 3-5. NI practices implemented in this study and their corresponding NRCS practice codes and descriptions.

Potential NI Practice	NRCS Code	NRCS Description	NRCS Standard Reference
Depressional wetlands inside and outside the floodplain	657	Wetland restoration	URL
CREP wetlands	656	Constructed wetland	URL
WASCOBs	638	Water and sediment control basin	URL
Row crop conversion in the floodplain to native grassland	420	Wildlife habitat planting	URL
Row crop conversion on highly erodible land to native grassland	420	Wildlife habitat planting	URL
Riparian buffers	390	Riparian herbaceous cover	URL
Saturated buffers*	604	Saturated buffers	URL

*Saturated buffers were not included in the hydrological modeling modifications but are included in the economic analysis to estimate the potential costs associated with routing riparian flows via tile drains (see Section ***Error! Reference source not found.***).

Once the practice code was identified, Tetra Tech reviewed NRCS documentation and peer-reviewed literature to estimate three categories of NI implementation costs: (1) initial installation costs (i.e., in the first year), (2) annual maintenance costs, and (3) the cost of foregone farmland production. The results of this summary are provided in (**Table 3-6**). NRCS practice code documentation often provides a series of implementation scenarios and their corresponding costs as summarized by the state NRCS staff. Tetra Tech chose scenarios most similarly aligned to the NI modifications discussed in the previous deliverable, *Hydrologic Model Results Memorandum*. In some cases where NRCS documentation was not available, Tetra Tech leveraged costs documented in peer reviewed publications and published tools such as the Agricultural Conservation Planning Framework Financial and Nutrient Reduction Tool (ACPF FiNRT; Bravard et al., 2022a; 2022b). Specifically, Tetra Tech used the average costs for NI as reported in the ACPF FiNRT documentation. Tetra Tech analyzed farmland lost (foregone income) separately for further consideration. According to NRCS documents, producers are typically paid a per acre rate for the farmland loss during initial installation of the NI due to the lost opportunity associated with taking NI land out of crop production; however, some producers may also sign permanent conservation easements for NI practices that result in foregone farm income. Tetra Tech approximated the longer-term cost conservation easements by referencing surveyed rental land rates for Linn and Benton Counties (Iowa State Extension, 2024) and applying these on a per acre basis to NI.

Table 3-6. Estimated NI implementation costs for each of the six practices implemented in this study. Saturated buffers were not modeled, but are included in this study due to their relevance to tile drained landscapes. This is discussed more the ***Error! Reference source not found.*** Section. All dollar values are in 2024 USD.

Potential NI Practice	NRCS Code	Initial Install Cost ($/ac)	Annual Maintenance Cost ($/ac)	Initial Farmland Lost Cost ($/ac)	Annual Farmland Lost Cost ($/ac)
Depressional wetlands inside and outside the floodplain	657	$3,303.27	$133.92	$565.34	$286.00
CREP wetlands	656	$26,312.34	$739.65	$530.30	$286.00
WASCOBs	638	$2,755.28	$257.72	$546.99	$286.00
Row crop conversion in the floodplain to native grassland	420	$314.55	$77.90	$546.99	$286.00
Row crop conversion on highly erodible land to native grassland	420	$314.55	$77.90	$546.99	$286.00
Riparian buffers	390	$710.33	$162.03	$546.99	$286.00
Saturated buffers*	604	$1,079.67	$46.28	$545.32	$286.00

*Saturated buffers were not included in the hydrological modeling modifications but are included in the economic analysis to estimate the potential costs associated with routing riparian flows via tile drains (see Section ***Error! R eference source not found.***).

Finally, Tetra Tech multiplied cost of NI per acre (**Table 3-6**) by the acreage of each NI implemented (**Table 3-7**) and used the resulting information to calculate the NPV (cost) of implementing NI (NPV_C). It should be noted that Tetra Tech aimed for 2.5, 5, 10, and 17.2% of the area of the PCW to be implemented by NI, but in some cases the nearest whole practice percent of implementation is slightly less due to the randomization of NI selection and need to round to the nearest whole NI structure opportunity (

Table 3-8). More details on the procedure used to randomly select NI opportunities is included in the *Hydrologic Model Results Memorandum*.

Table 3-7. Summary of acres of NI implemented for each practice type and scenario.

NRCS Code	NI Practice Name	NI Scenario (% of Watershed Area)	Acres Implemented
390	Riparian Buffer	2.5	348.7
420	RCC on Erodible Land	2.5	443.9
420	RCC in the Floodplain	2.5	594.9
638	WASCOBs	2.5	129.7
656	CREP Wetlands	2.5	1734.7
657	Depressional Wetlands	2.5	17.8
390	Riparian Buffer	5	683.9
420	RCC on Erodible Land	5	882.2
420	RCC in the Floodplain	5	1190.0
638	WASCOBs	5	277.3
656	CREP Wetlands	5	3487.1
657	Depressional Wetlands	5	31.1
390	Riparian Buffer	10	1386.4
420	RCC on Erodible Land	10	1765.6
420	RCC in the Floodplain	10	2439.4
638	WASCOBs	10	560.9
656	CREP Wetlands	10	7107.5
657	Depressional Wetlands	10	69.2
390	Riparian Buffer	17.2	2390.1
420	RCC on Erodible Land	17.2	3061.5
420	RCC in the Floodplain	17.2	4468.8
638	WASCOBs	17.2	1150.9
656	CREP Wetlands	17.2	12422.7
657	Depressional Wetlands	17.2	132.8

Table 3-8. Summary of acres implemented and nearest whole practice percent for the corresponding NI scenarios.

NI Scenario (% of Watershed Area)	Total Acres Implemented	Nearest Whole Practice Percent
2.5	3,270	2.4
5	6,552	4.8
10	13,329	9.7
17.2	23,627	17.2

To quantify the cost of NI for each of the model runs in **Table 3-2**, Tetra Tech created two CSV files. The first CSV included each unique NI practice, the corresponding model run scenario (i.e., baseline without NI and NI making up 17%, 10%, 5%, and 2.5% of the total watershed area), and the acreage of each NI for a given model run. The second CSV file was a lookup table that included the unique NI practice along with the estimated initial implementation cost ($/ac), annual maintenance cost ($/ac), and estimated annual cost of farmland lost ($/ac). Tetra Tech used R to determined net present value of NI costs as described Section 3.6. Tetra Tech also used R to create all data visualizations associated with this economic analysis.

3.8 Social Vulnerability Analysis

Tetra Tech reviewed several vulnerability indices for this work, including: (1) the climate vulnerability index (CVI) developed by EDF (Lewis et al., 2023), (2) the environmental justice index (EJI) developed by the Centers for Disease Control (CDC; CDC, 2025a), and (3) the social vulnerability index (SVI) also developed by the CDC (Flanagan, 2011; CDC, 2025b). In the end, Tetra Tech and EDF decided to use the SVI because it was the most recent and comprehensive dataset available for the PCW. The EJI dataset was available for 2022 and 2023, but there were large regions of the PCW that did not have any data available. The CVI dataset did not have any missing data for the PCW, but it was developed using 2010 census data, which would make it nearly 15 years old.

The SVI is a publicly available dataset released regularly by the CDC at the county and census tract scale. It relies on 16 individual American Community Survey (5-year) variables, which fall under four main themes: (1) socioeconomic status, (2) household characteristics, (3) racial and ethnic minority status, and (4) housing type and transportation access (CDC, 2022). SVI is calculated by ranking each census track across the United States for a given variable and then calculating a weighted sum. SVI ranges from 0 to 1 with 0 being the least vulnerable community in the U.S. and 1 being the most vulnerable community.

After determining the best vulnerability index to use, Tetra Tech rasterized the SVI 2022 (vector) dataset to the same 100 ft resolution grid used for the HEC-RAS flood depth rasters and then used this rasterized SVI to explore the relationship between SVI, flood depth, and flood risk mitigation using NI for 10-yr and 50-yr design storms under present rainfall conditions. Specifically, Tetra Tech compared the rasterized SVI data to the flood depth rasters (10-yr and 50-yr under present conditions) as well as the difference between the baseline and NI implemented flood depth rasters (10-yr and 50-yr under present conditions).

To assess the relationship between flooding, NI implementation, and SVI, Tetra Tech developed Python code to rasterize the SVI and then overlap the SVI raster with flood depth difference rasters and convert this compared result into a CSV file. Therefore, the CSV file included the SVI value and corresponding flood depth difference value for each inundated pixel. Tetra Tech then used R to summarize and visualize these results.

4.0 RESULTS AND DISCUSSION

4.1 Hydrologic Analysis Results

This section presents the results of flood water depth analyses for three paired sets of scenarios: (1) baseline and future rainfall, (2) baseline rainfall conditions with and without NI, and (3) future rainfall conditions with and without NI. For each of these sections, Tetra Tech mapped flood results zoomed to show the full extent of PCW as well as for zoomed into the Cedar Rapids, IA area. Furthermore, Tetra Tech mapped each model run as well as the spatial differences. Additionally, Tetra Tech analyzed the flood outflow hydrographs from PCW for each model run as well as comparisons of water storage in PCW for each NI practice.

4.1.1 Present versus Future Rainfall

For this paired set, Tetra Tech compared the results of model runs 01-05 to model runs 06-10. Specifically, all model runs in these scenarios relied on the baseline BLE model from Iowa DNR; no modifications were included to account for NI. The goal of these simulations was to compare present versus future rainfall conditions.

Simulated maximum floodwater depth and inundation area for present and future rainfall design storms are shown in **Figure 4-1** for the overall watershed. A zoomed in region of the PCW near Cedar Rapids is shown in **Figure 4-2**. See the Appendix (Section 7.0) for results from select towns in the PCW, including, Keyston, Blairstown, and Norway. A comparison of flood inundation areas under present and future rainfall conditions is provided in **Table 4-1**. Consequently, future rainfall scenarios resulted in a greater flood inundation area as well as a greater flood depth across all rainfall design storms. For example, the flood inundation area increases by 11.2% and 5.0% for 10-yr and 500-yr storms, respectively. The increase in flooding extent is more pronounced for smaller storms. It should be noted that the Iowa DNR model was configured using a rain-on-grid approach. This approach results in upland wet pixels being included in the inundation area, which could potentially overestimate flooding extent from river channels.

Floodwater depth increases from the headwaters (< 1 foot) to the downstream areas, reaching a maximum of over 10 ft near the outlet for both present and future conditions. Larger rainfall design storms, such as the 50-, 100-, and 500-yr design storms, showed more significant increases in flood depth. Generally, increases were < 0.8 ft for all scenarios. **Figure 4-2** illustrates the change in floodwater depth near the outlet, close to the city of Cedar Rapids, under future rainfall conditions. As stated in Section 3.3**Error! Reference source not found.**, this study relied on downscaled CMIP5 c limate model data; however, Tetra Tech recommends incorporating downscaled CMIP6 climate model data and updated NOAA Atlas 14 raster datasets when this information is made publicly available.

Table 4-1. Flood inundation area comparisons for model runs 01-20. “Baseline” indicates model runs without NI.

Desing Storm	Baseline, Present Inundated Area (ac)	Baseline, Future Inundated Area (ac)	NI, Present Inundated Area (ac)	NI, Future Inundated Area (ac)	Change Present Baseline to Future Baseline (%)	Change Present Baseline to Present NI (%)	Change Future Baseline to Future NI (%)
10-yr	27,593	30,694	20,177	23,174	11.2	-26.9	-24.5
25-yr	33,499	36,362	26,380	29,062	8.5	-21.3	-20.1
50-yr	37,563	40,399	30,430	33,164	7.5	-19.0	-17.9
100-yr	41,308	43,866	34,193	36,812	6.2	-17.2	-16.1
500-yr	48,683	51,112	42,031	44,501	5.0	-13.7	-12.9

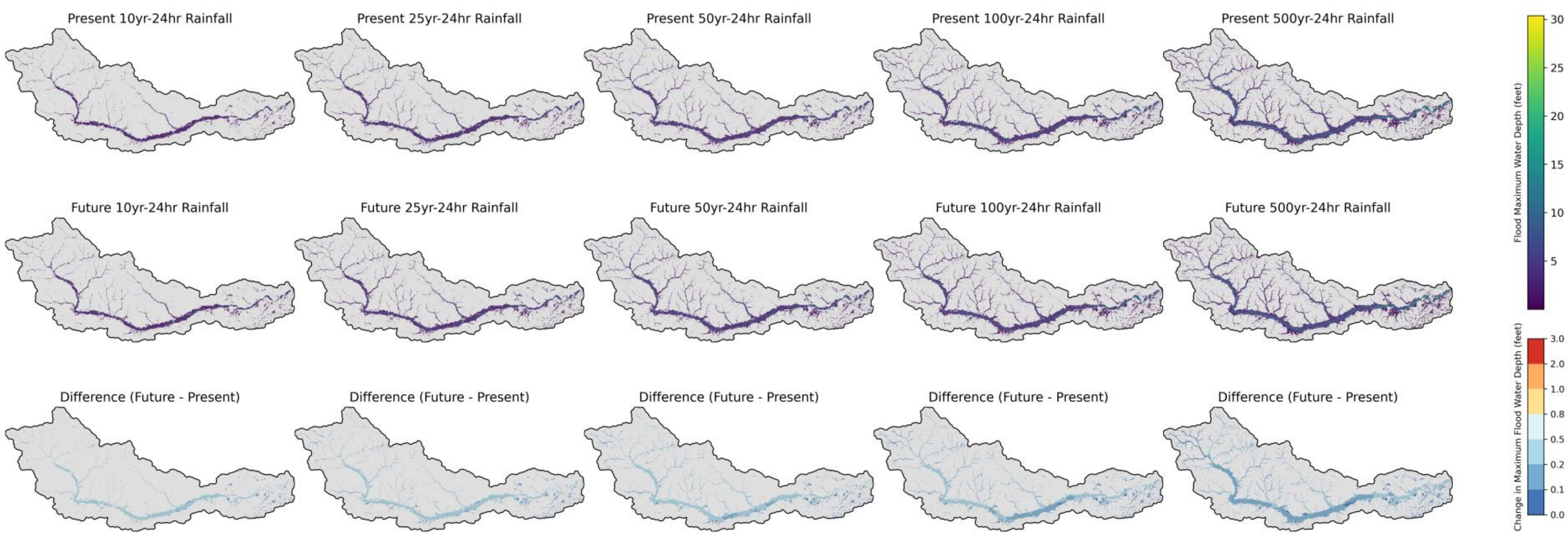

Figure 4-1. Maximum flood depths for baseline present and future rainfall modeling scenarios.

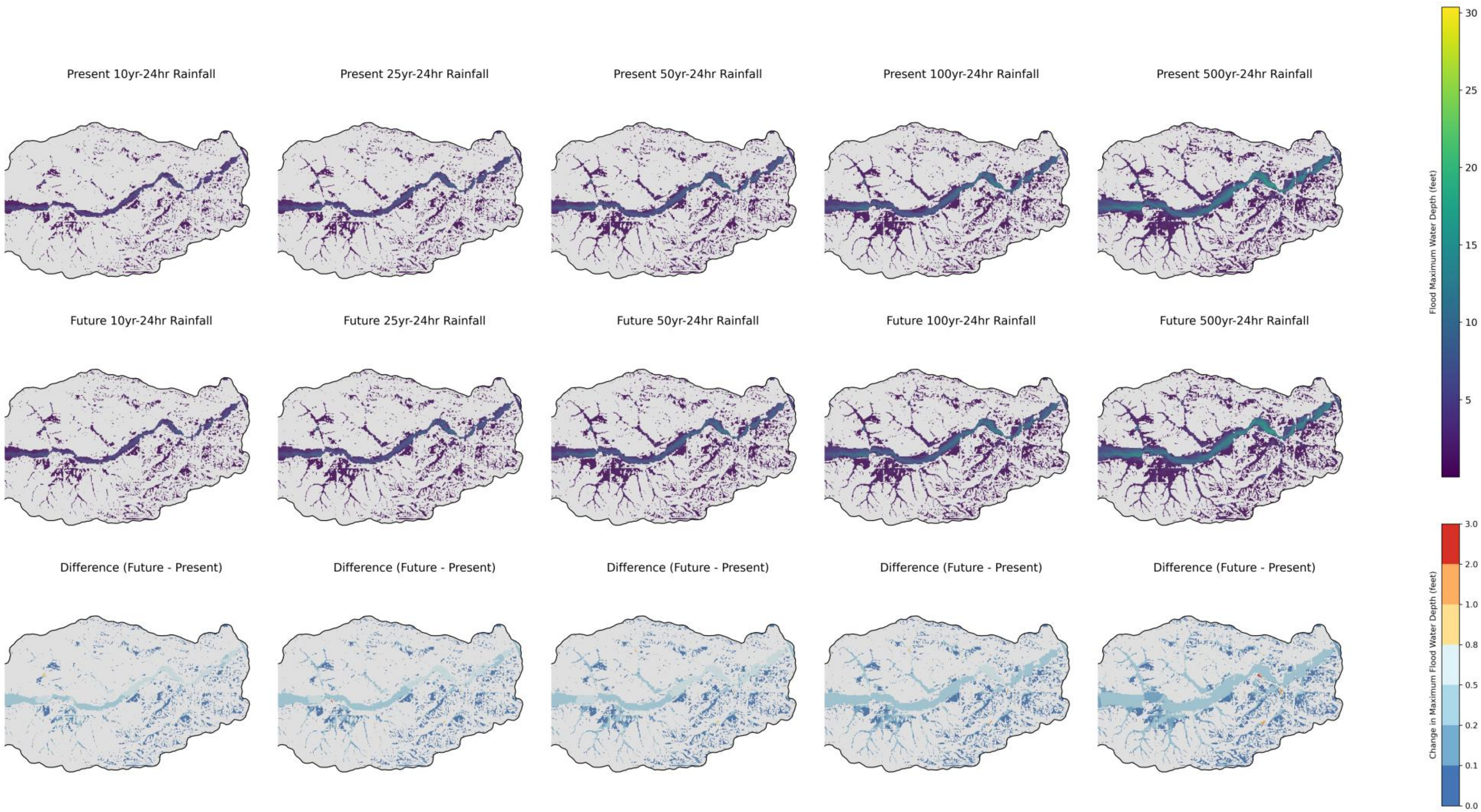

Figure 4-2. Maximum flood depths for baseline present and future rainfall modeling scenarios near Cedar Rapids, IA.

4.1.2 Baseline versus NI: Present Rainfall

For this paired set, Tetra Tech compared the results of model runs 01-05 to model runs 11-15. The goal of these simulations was to compare present rainfall conditions without (i.e., baseline models 01-05) and with NI practices implemented (i.e., NI modified models 11-15).

Flooding under the baseline condition (without NI practices) results compared to the NI scenario for present rainfall conditions are shown in **Figure 4-3** and **Figure 4-4**. See the Appendix (Section 7.0) for results from select towns in the PCW, including, Keyston, Blairstown, and Norway. These figures show that maximum floodwater depth and inundation area are consistently lower in the NI scenario across all rainfall design storms. For example, the flood inundation area decreases by 26.9% and 13.7% for 10-yr and 500-yr rainfalls, respectively, compared to the baseline condition (**Table 4-1**).

Tetra Tech implemented NI practices in the floodplain and in upland areas (**Figure 3-6**) to retain and store floodwaters. Tetra Tech hypothesized this would reduce the magnitude but extend the duration of flood peaks. This effect is clearly visible in the difference maps (bottom row, **Figure 4-3** and **Figure 4-4**), where pink areas indicate increased water retention and green areas represent reductions in floodwater depth. The results indicate that for smaller floods, such as those generated by the 10- and 25-yr rainfall design storms, NI practices were more effective at mitigating flood risk in terms of fractional changes. For example, reductions were 26.9% and 21.3% for the 10-yr and 25-yr rainfall design storms, respectively (**Table 4-1**). However, the absolute reduction in water depth was more pronounced in larger floods, including the 50-, 100-, and 500-yr design storms.

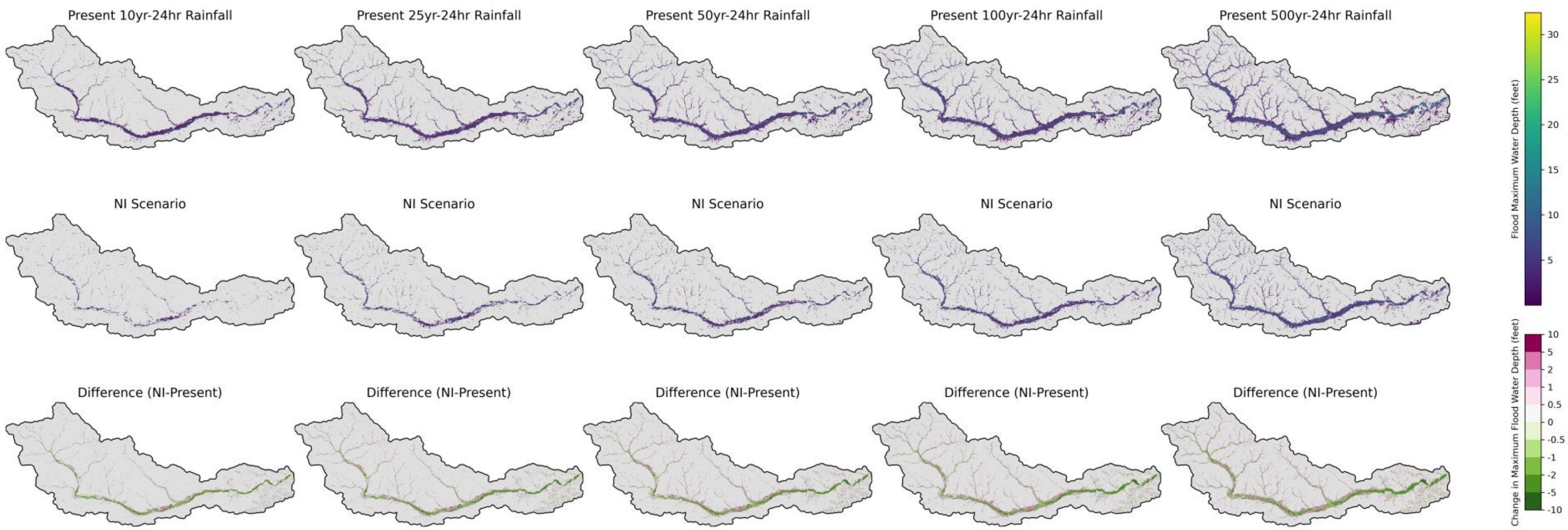

Figure 4-3. Maximum flood depths for baseline (without NI) and NI modeling scenarios under present rainfall conditions.

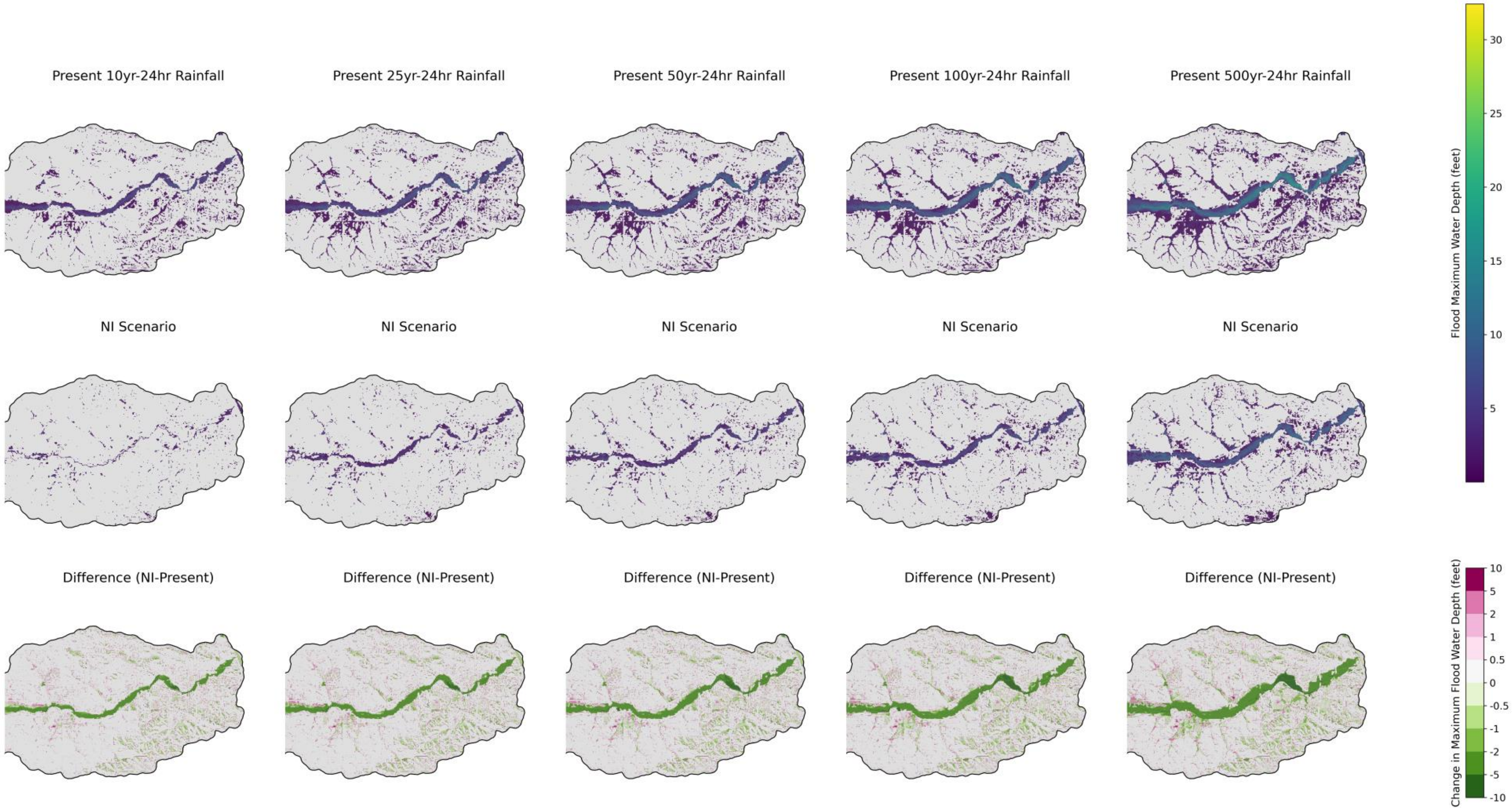

Figure 4-4. Maximum flood depths for baseline (without NI) and NI modeling scenarios under present rainfall conditions near Cedar Rapids, IA.

4.1.3 Baseline versus NI: Future Rainfall

For this paired set, Tetra Tech compared the results of model runs 06-10 to model runs 16-20. The goal of these simulations was to compare future rainfall conditions without NI practices implemented (i.e., baseline models 06-10) and with NI practices implemented (i.e., NI modified models 11-32).

Flooding under projected future rainfall conditions with and without NI practices is compared in **Figure 4-5** and **Figure 4-6**. See the Appendix (Section 7.0) for results from select towns in the PCW, including, Keyston, Blairstown, and Norway. Similar to the results for present rainfall conditions (Section 4.1.2), the future rainfall condition results show flood depth and flood inundation area were consistently lower when NI was included across all rainfall design storms. For example, the floodplain area decreases by 12.9% and 24.5% for 500-yr and 10-yr rainfall design storms, respectively, compared to the baseline condition for future rainfall (**Table 4-1**).

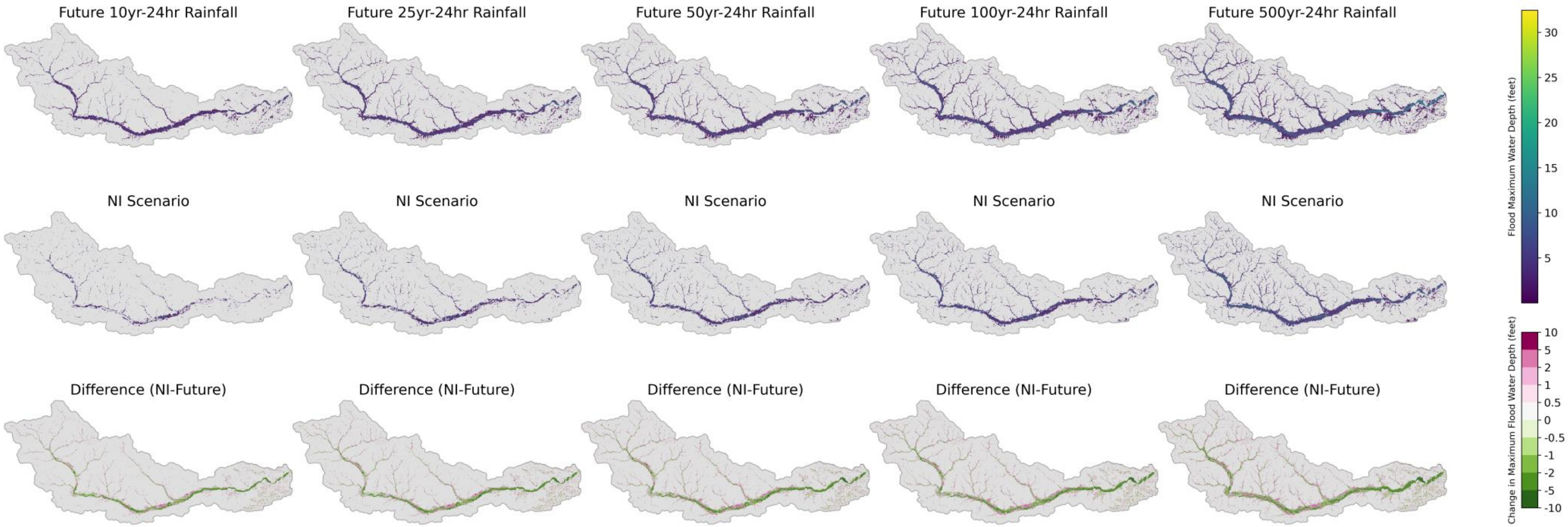

Figure 4-5. Maximum flood depths for baseline (without NI) and NI modeling scenarios under future rainfall conditions.

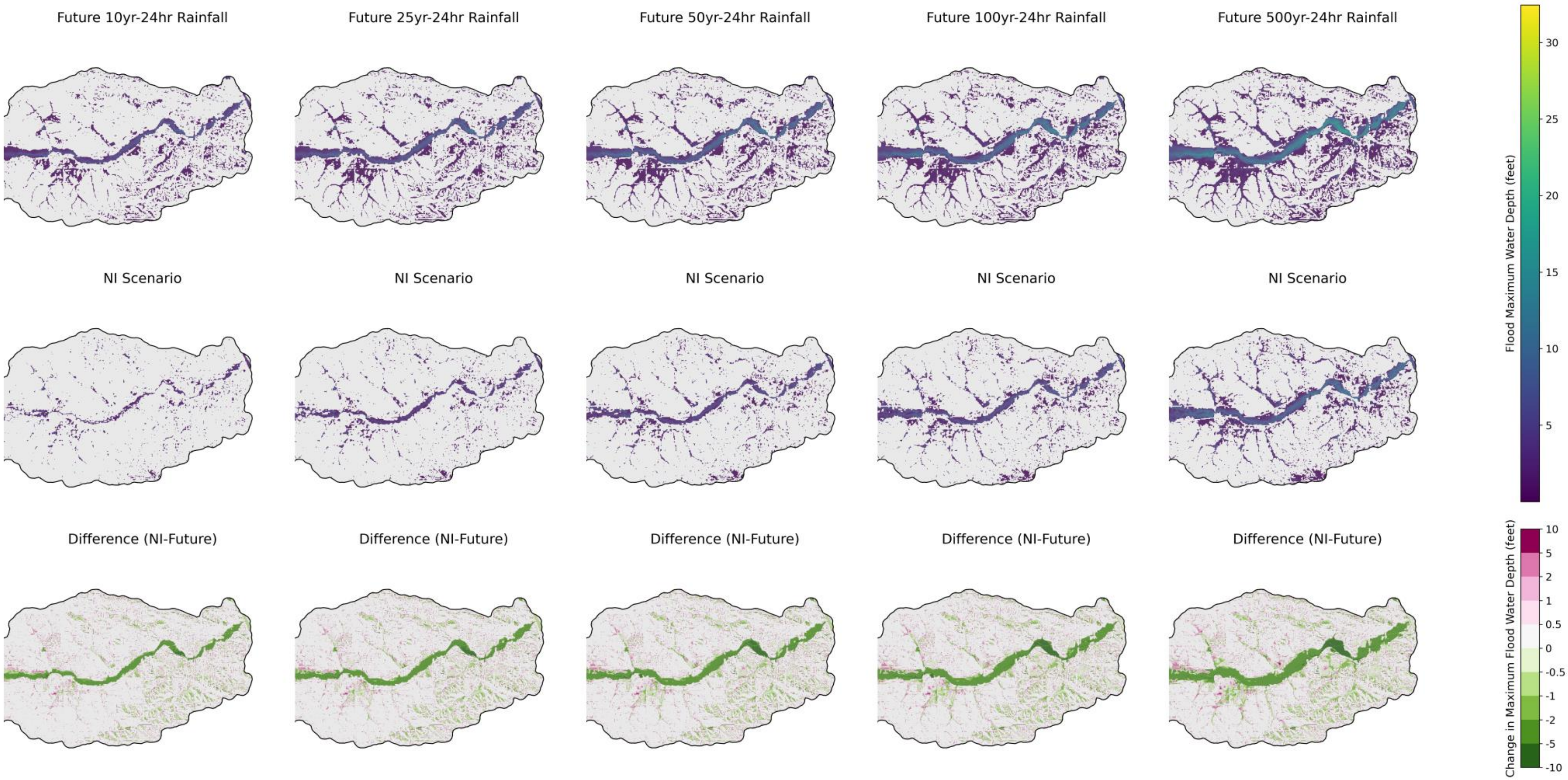

Figure 4-6. Maximum flood depths for baseline (without NI) and NI modeling scenarios under future rainfall conditions near Cedar Rapids, IA.

4.1.4 NI Impacts on Watershed Outlet Discharge

As discussed previously, HEC-RAS model results show that NI implementation in the PWC effectively reduces flood extent and water depth across various rainfall design storms under present and future rainfall conditions. NI practices such as wetlands, riparian buffers, and row crop conversions, are known to reduce flood peaks by enhancing water storage, increase infiltration, and decrease flow velocity. Although not the focus of this work, these results demonstrate another beneficial effect of NI: decreased peak flows by attenuating the flood hydrograph. Specifically, **Figure 4-7** compares flood hydrographs at the PCW outlet for model scenarios at each of the design storm modeled. NI implementation resulted in lower flood peak discharges across all five rainfall design storms. This effect is particularly pronounced for smaller and moderate design storms (**Table 4-2**). For example, the reduction in flood peak for the 10-yr design storm was 63.9% under present conditions and 61.7% under future conditions, while for the 500-yr design storm, the reductions were 39.8% and 38.9%, respectively. The observation of marginally less effective peak flow reduction for larger design storms can be explained by filled storage volumes in the watershed; flows into these storage volumes are equal to the flows out with minimal change to the hydrograph.

Table 4-2. Comparison of flood peak discharge at the watershed outlet for the various scenarios explored in this study. "Baseline" indicates model runs without NI.

Design Storm	Baseline, Present Discharge (cfs)	Baseline, Future Discharge (cfs)	NI, Present Discharge (cfs)	NI, Future Discharge (cfs)	Change Present Baseline to Present NI (%)	Change Future Baseline to Future NI (%)
10-yr	2,398	2,398	867	1,069	-63.9	-61.7
25-yr	3,757	4,220	1,484	1,755	-60.5	-58.4
50-yr	5,120	5,687	2,323	2,665	-54.6	-53.1
100-yr	6,779	7,334	3,384	3,735	-50.1	-49.1
500-yr	11,397	11,883	6,866	7,260	-39.8	-38.9

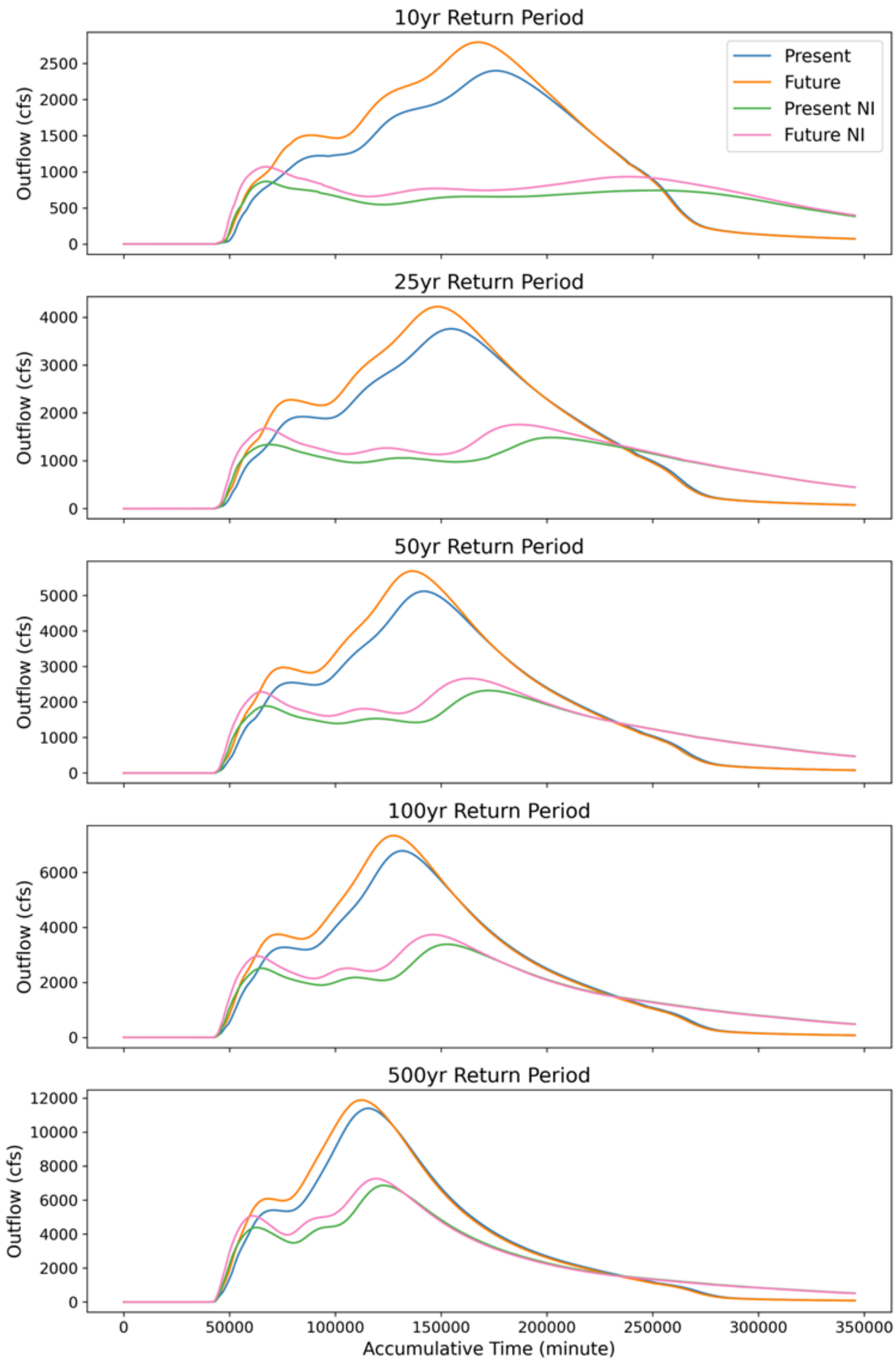

Figure 4-7. Prairie Creek Watershed outflow by return period (i.e., design storms) for different modeling scenarios. Baseline present (blue line) and future (orange line) outflows are overlapping for the 10-yr return period. “Present” and “Future” lines refer to the baseline scenarios while “Present NI” and “Future NI” lines refer to the associated rainfall scenarios with NI.

4.1.5 NI Storage Capacity

The storage capacity of NI practices varied across different types of NI interventions. Distributions of the maximum storage volume for three storage-based NI practices (CREP wetlands, WASCOBS, and depressional wetlands) under present and future rainfall conditions are shown in **Figure 4-8** and **Figure 4-9**. For these figures, storage is calculated as the maximum depth times the NI footprint area. Maximum and mean water storage depth for NI practices are summarized in **Table 4-3**. Among the storage-based practices, CREP wetlands stored the most excess floodwater (conditional on the assumptions for NI siting described in Section 3.4). Water storage capacity of CREP ranged from 14,097 to 42,354 ac-ft for 10-yr and 500-yr storms under present rainfall conditions and ranging from 16,431 to 44,387 ac-ft under future rainfall conditions, respectively.

CREP wetlands, row crop conversion in floodplains, and riparian buffers can be generally described as riparian (or lowland) NI due to their siting, which is primarily (and in some cases by definition) within the riparian buffer of Prairie Creek. The other three practices—WASCOBs, row crop conversion on highly erodible lands, and depressional wetland—are generally considered upland NI due to their siting largely or entirely in the uplands. Overall, row crop conversion and riparian buffer did not provide floodwater storage, but mitigated flooding by reducing runoff velocity and enhancing water infiltration.

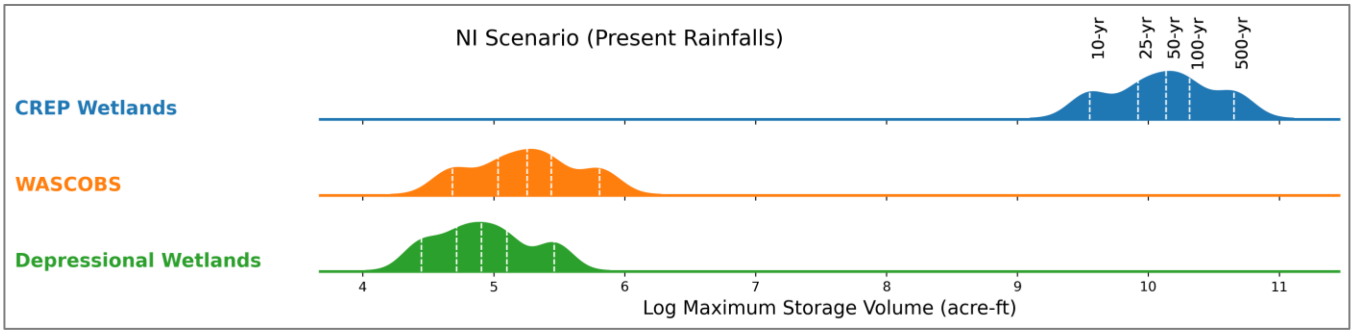

Figure 4-8. Distribution of maximum storage volume for water storage-based NI practices across five design storms under present rainfall conditions.

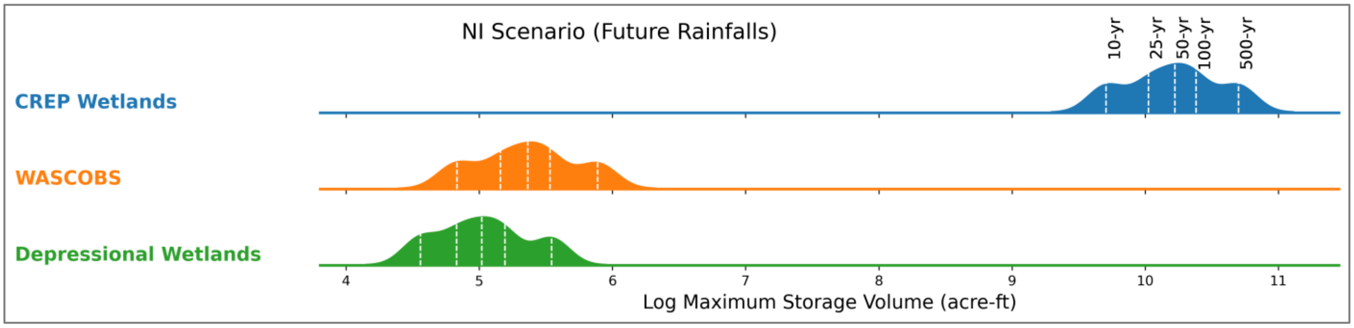

Figure 4-9. Distribution of maximum storage volume for water storage-based NI practices across five design storms under future rainfall conditions.

Table 4-3. Maximum storage volume and water depth for different NI practices.

		Present		Future	
Rain-fall	Land use	Max Depth (ft)	Maximum Storage Volume (ac-ft)	Max Depth (ft)	Maximum Storage Volume (ac-ft)
10-yr	CREP Wetlands	9.1	14,097	9.7	16,431
	Depressional Wetlands	8.0	84	8.1	95
	Row Crop Conversion in Floodplain	7.1	NA	7.6	NA
	Riparian Buffer	7.1	NA	7.5	NA
	WASCOBs	8.6	107	9.1	125
	Row Crop Conversion on Highly Erodible Land	5.8	NA	5.9	NA
25-yr	CREP Wetlands	10.9	20,389	11.3	22,570
	Depressional Wetlands	8.1	111	8.3	124
	Row Crop Conversion in Floodplain	8.8	NA	9.2	NA
	Riparian Buffer	8.3	NA	8.6	NA
	WASCOBs	10.3	152	10.8	173
	Row Crop Conversion on Highly Erodible Land	6.0	NA	6.0	NA
50-yr	CREP Wetlands	12.0	25,224	12.4	27,507
	Depressional Wetlands	8.4	134	8.6	151
	Row Crop Conversion in Floodplain	9.9	NA	10.4	NA
	Riparian Buffer	9.5	NA	10.0	NA
	WASCOBs	11.4	190	11.9	213
	Row Crop Conversion on Highly Erodible Land	6.0	NA	6.1	NA
100-yr	CREP Wetlands	13.1	30,161	13.4	32,284
	Depressional Wetlands	8.7	163	9.0	179
	Row Crop Conversion in Floodplain	11.0	NA	11.4	NA
	Riparian Buffer	11.0	NA	11.4	NA
	WASCOBs	12.5	230	12.9	252
	Row Crop Conversion on Highly Erodible Land	6.5	NA	7.0	NA
500-yr	CREP Wetlands	15.2	42,354	15.4	44,387
	Depressional Wetlands	10.2	234	10.6	254
	Row Crop Conversion in Floodplain	13.4	NA	13.7	NA
	Riparian Buffer	14.6	NA	14.9	NA
	WASCOBs	14.7	333	14.8	361
	Row Crop Conversion on Highly Erodible Land	9.2	NA	9.6	NA

4.1.6 Additional NI Scenarios

This section presents flood results for scenarios with NI implementation covering 17.2%, 10%, 5%, and 2.5% of the PCW under 10-yr and 50-yr design storms in both present and future climate conditions. The NI scenarios 2.5, 5, 10, and 17.2% of the watershed area corresponds to 14, 28, 56, and 100% of potential NI implementation in the PCW. The goal of these simulations was to assess the impact of varying NI implementation—or adoption—on flood mitigation.

Flood maximum depths from 10-yr and 50-yr design storms for the baseline scenario (without NI) are compared to four NI scenarios (17.2%, 10%, 5%, and 2.5%) under present and future climate conditions in **Figure 4-10** to **Figure 4-13** and **Figure 4-14** to **Figure 4-17**, respectively. Results for select towns in the PCW, including Keyston, Blairstown, and Norway, are provided in the Appendix (Section 6).

Overall, all NI coverages effectively mitigate flooding by reducing water depth in the river channel. For the 10-yr present design storm, full NI coverage (i.e., 17.2% of the watershed area) reduced flood depth at the watershed outlet by more than 3–4 ft. Flood depth reductions were approximately 2–3 ft for 10% NI coverage and less than 2 ft for 5% and 2.5% coverage. The results for the 50-yr design storm and future climate conditions show a similar trend.

Table 4-3 provides a comparison of flood inundation areas under present and future rainfall conditions for different NI scenarios. For the 10-yr design storm, inundation area reductions are 26.9% and 13.8% for 17.2% and 2.5% NI coverage under present rainfall conditions, and 24.5% and 12% under future conditions. For the 50-yr design storm, reductions in inundation area range from 19% to 7.9% under present conditions and from 17.9% to 6.9% under future climate conditions.

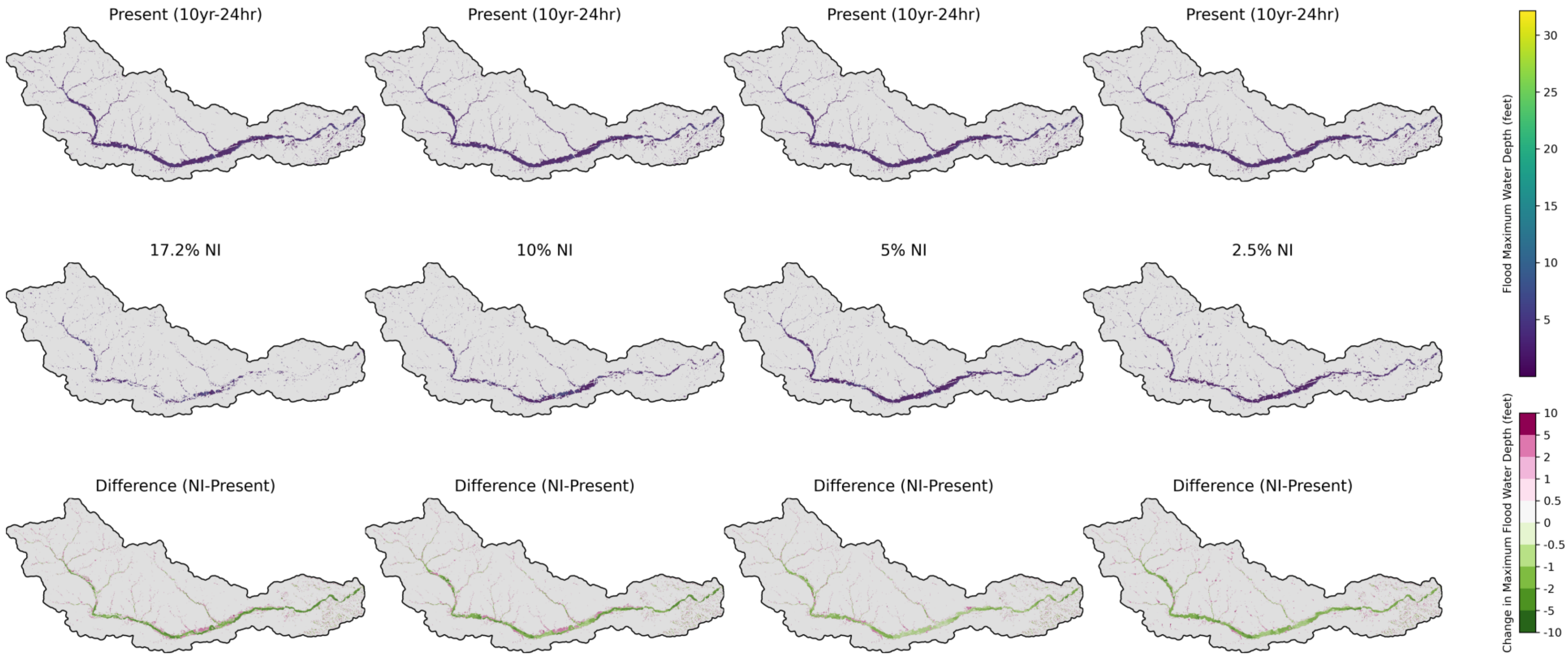

Figure 4-10. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions.

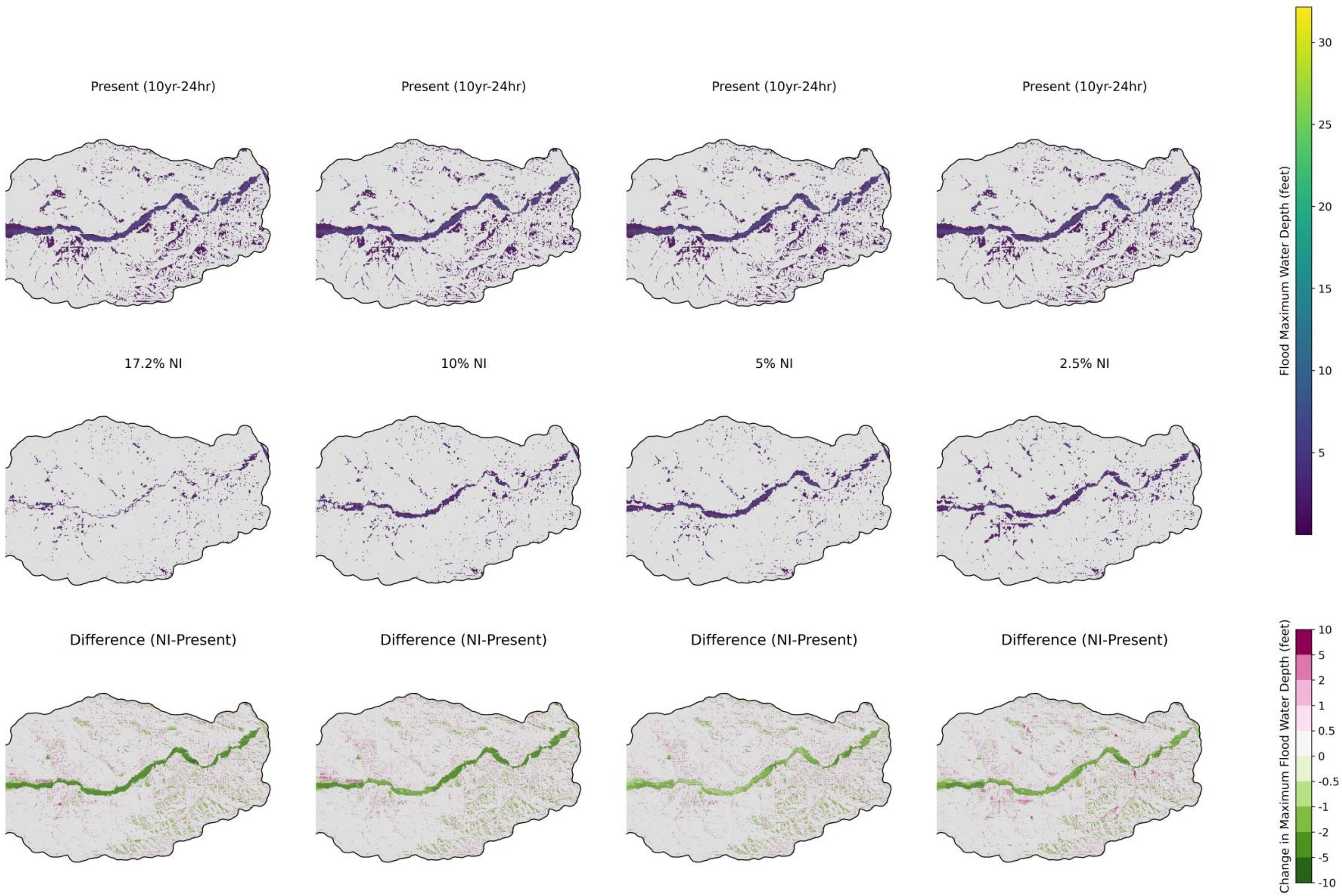

Figure 4-11. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Cedar Rapids, IA.

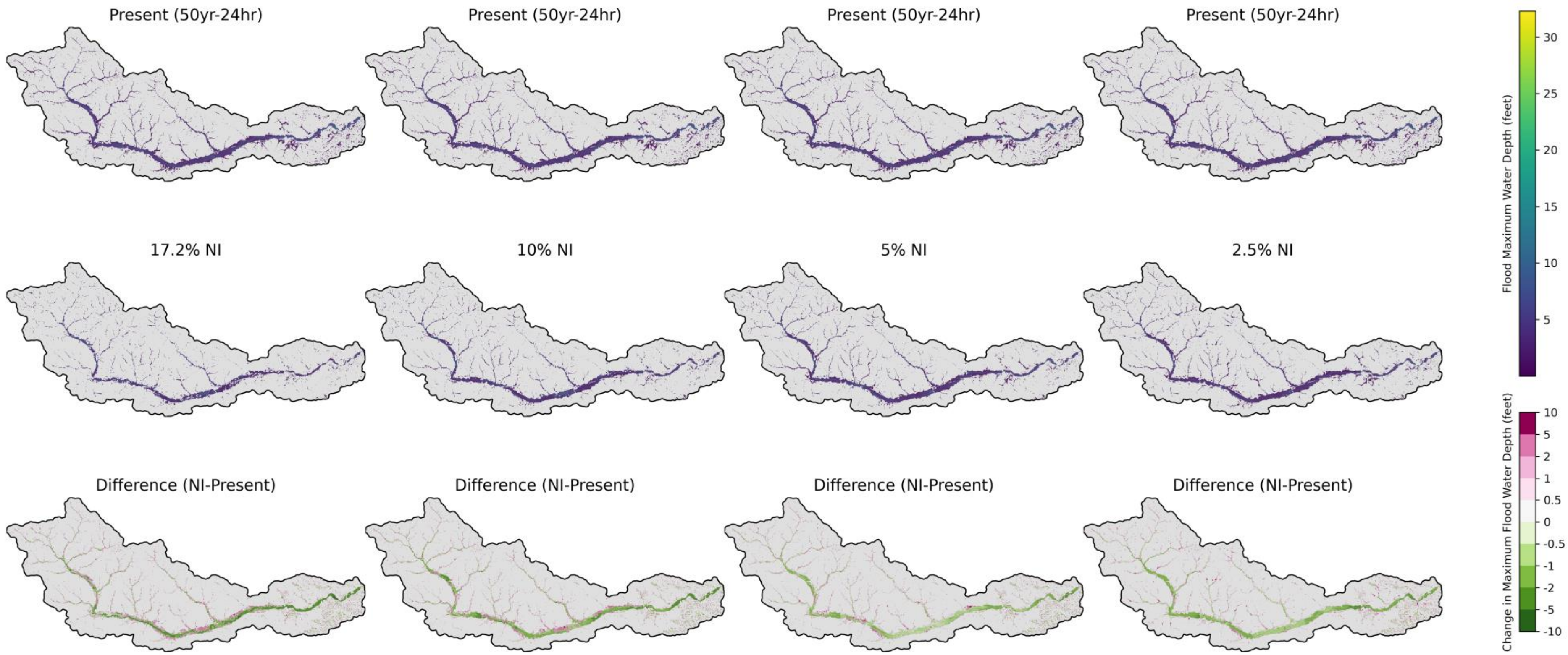

Figure 4-12. Maximum flood depths for 50yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions.

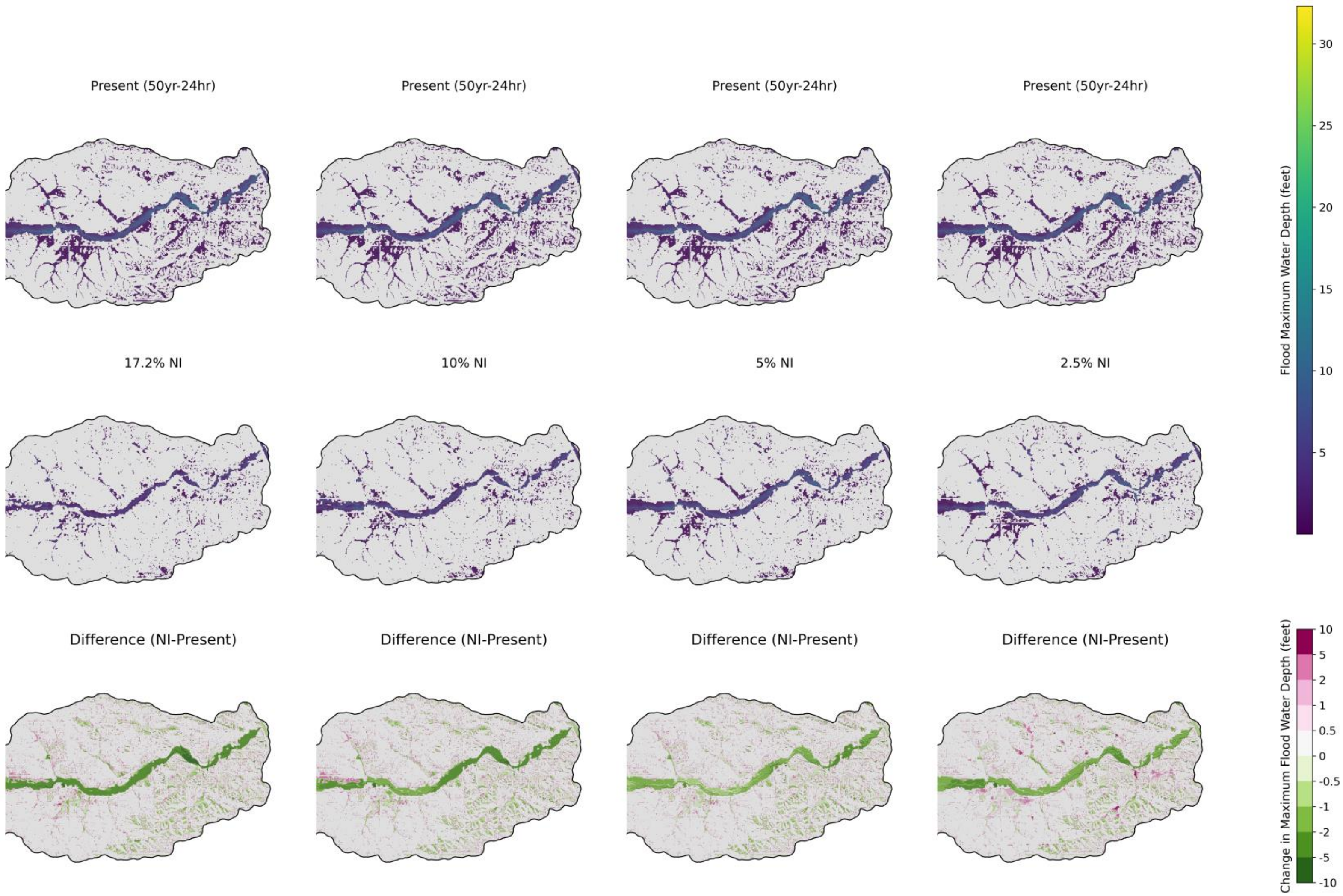

Figure 4-13. Maximum flood depths for 50yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Cedar Rapids, IA.

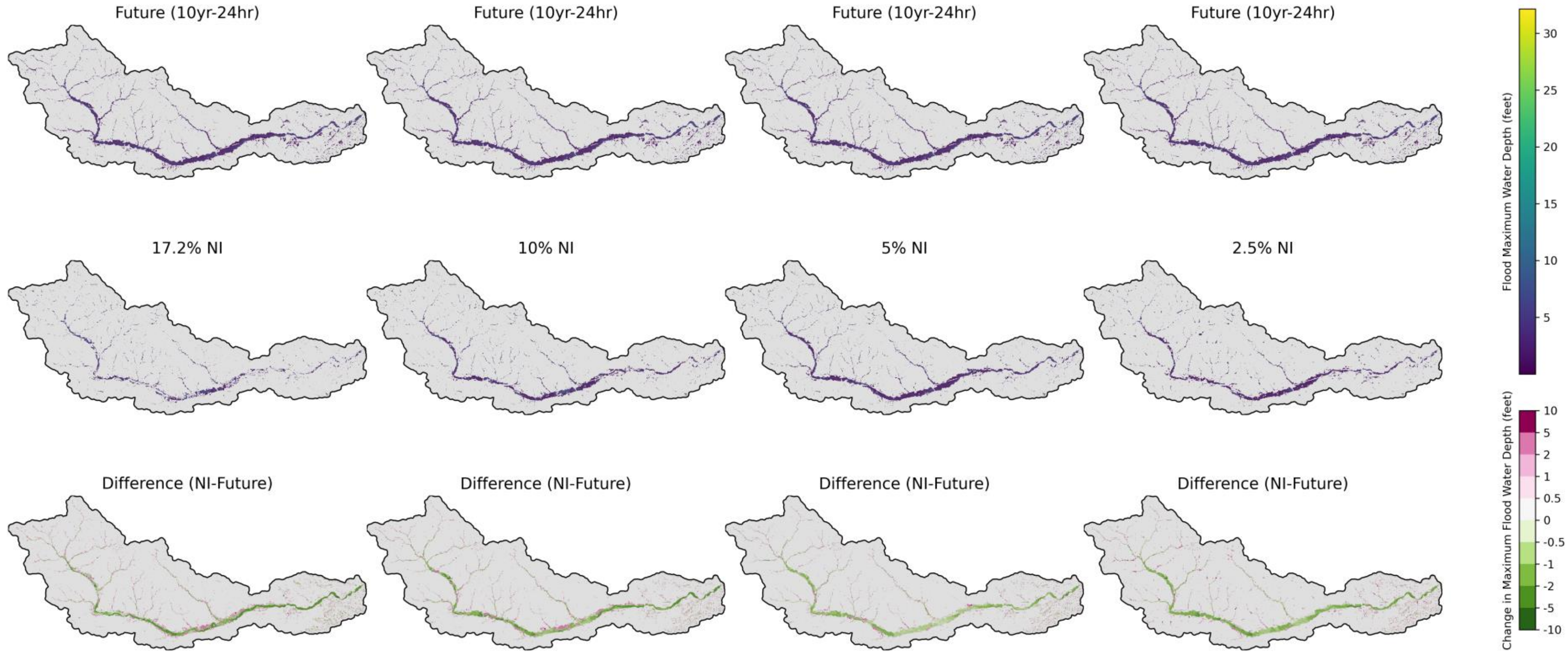

Figure 4-14. Maximum flood depths for 10y-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions.

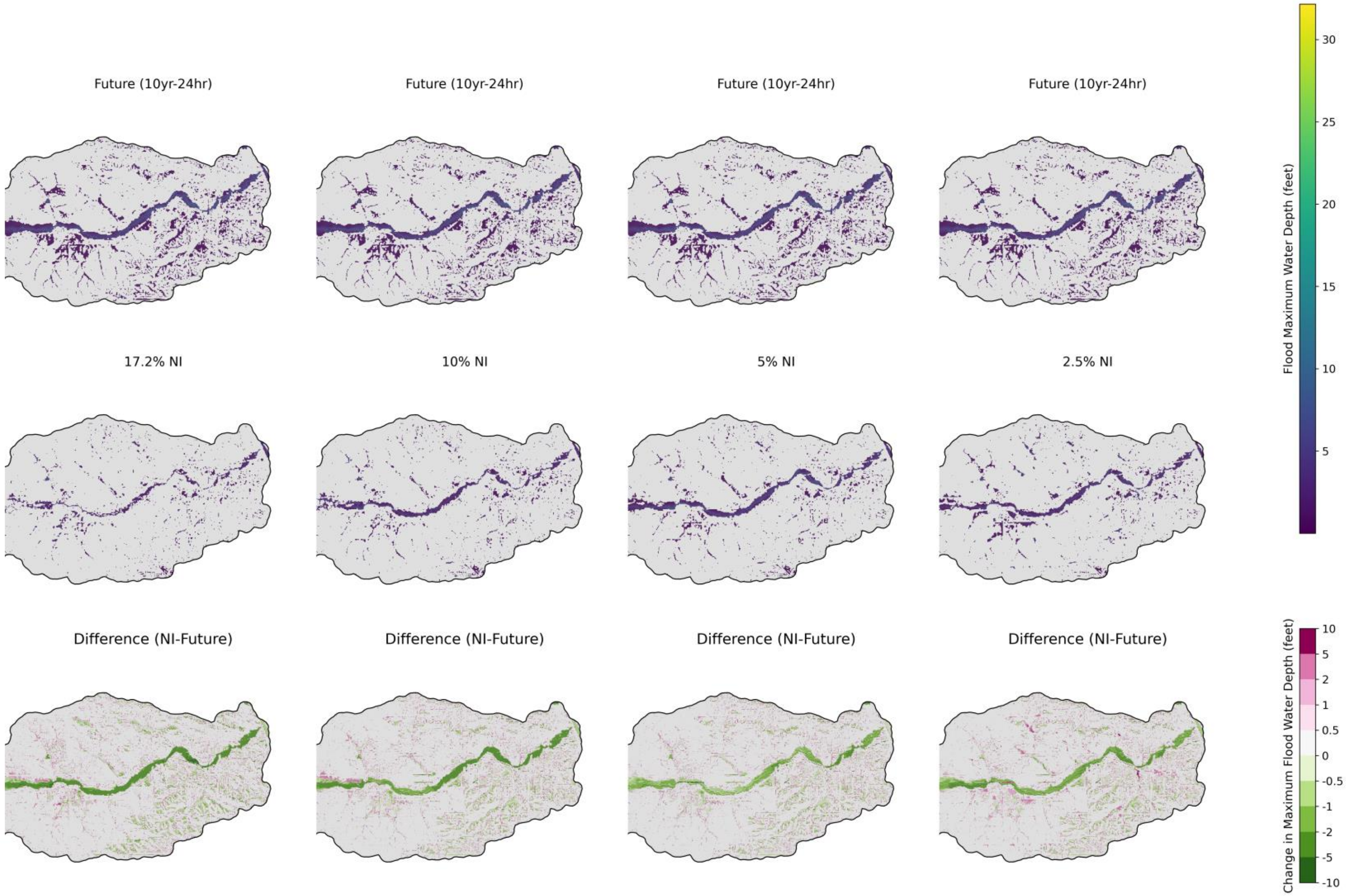

Figure 4-15. Maximum flood depths for 10y-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions near Cedar Rapids.

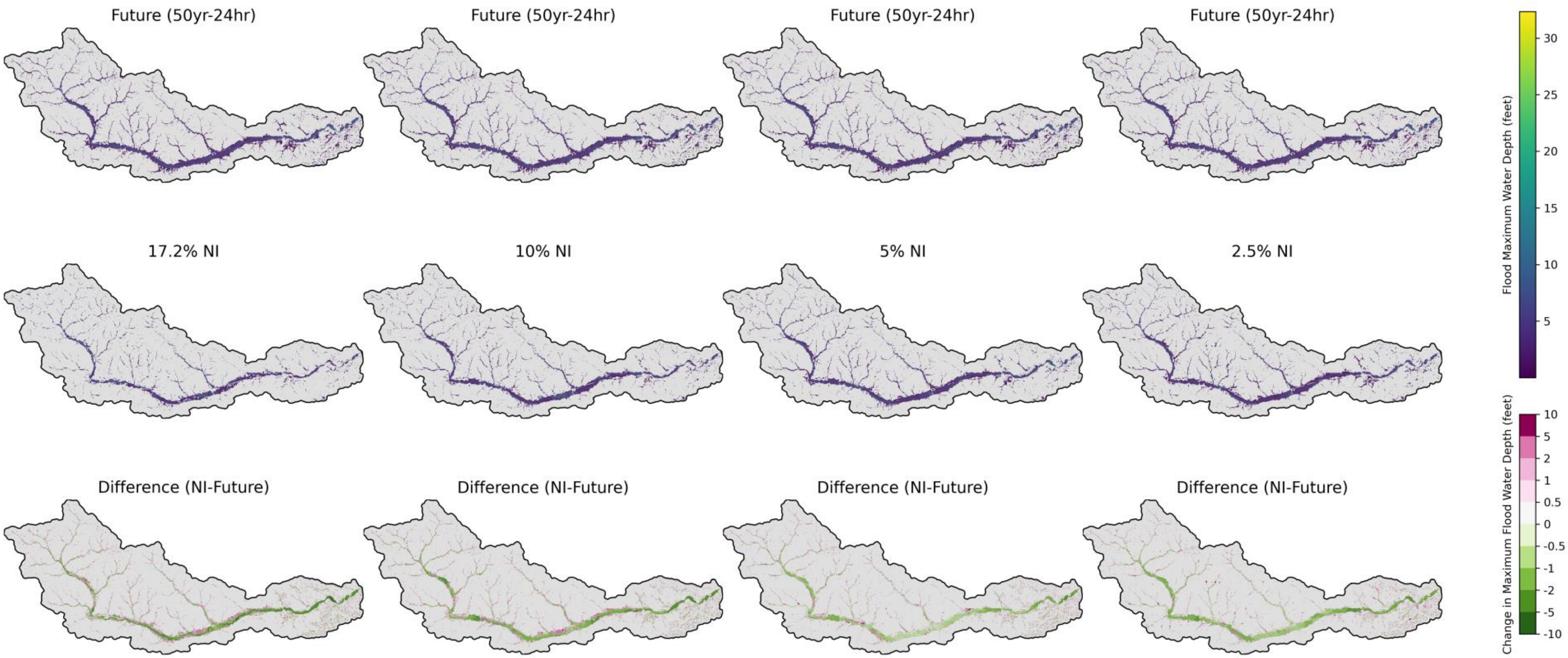

Figure 4-16. Maximum flood depths for 50y-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions.

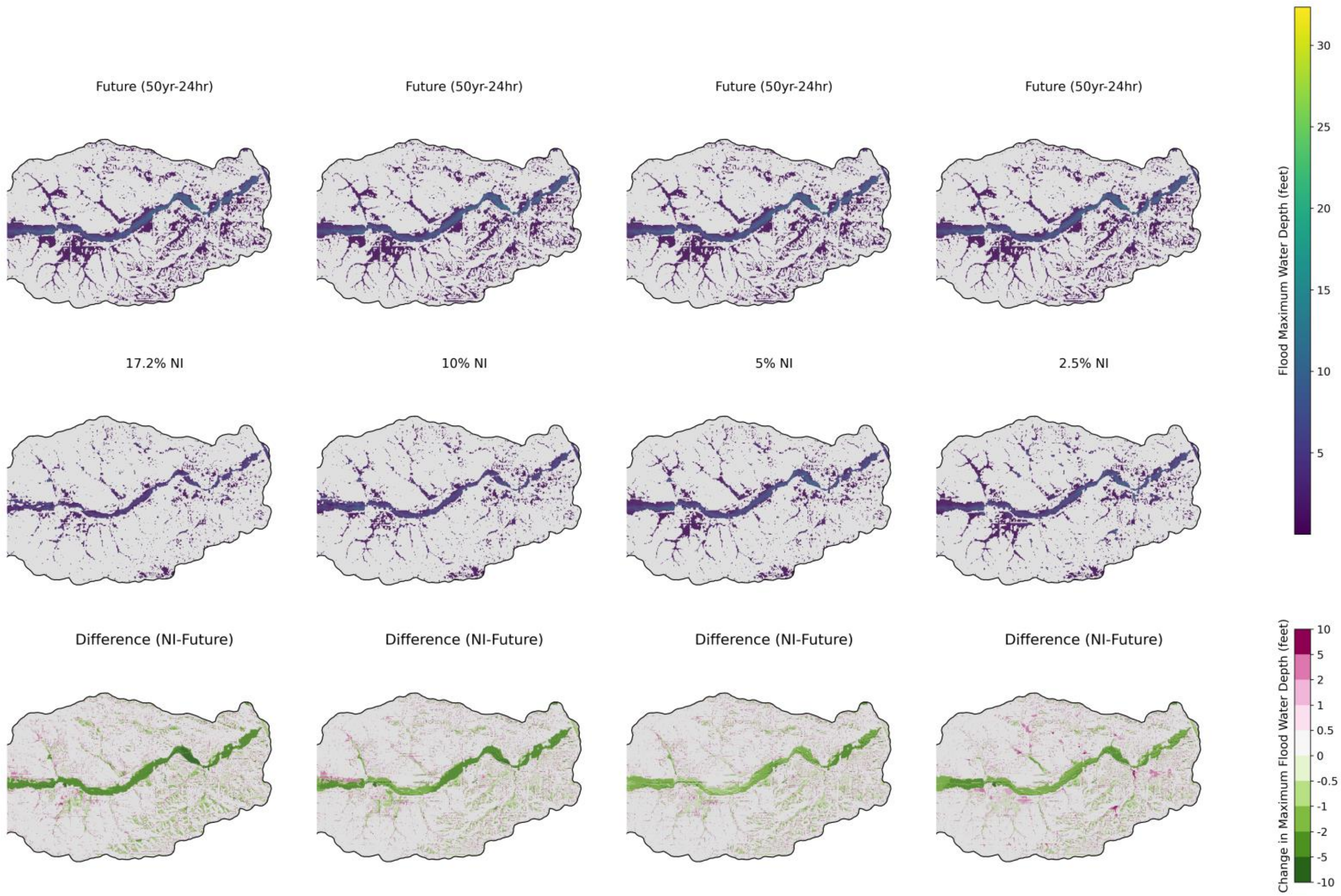

Figure 4-17. Maximum flood depths for 50y-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions near Cedar Rapids.

Table 4-4. Flood inundation area comparisons for model runs 21-32. "Baseline" indicates model runs without NI.

Design Storm	NI Coverage (%)	Baseline, Present Inundated Area (acres)	Baseline, Future Inundated Area (acres)	NI, Present Inundated Area (acres)	NI, Future Inundated Area (acres)	Change Present Baseline to Present NI (%)	Change Future Baseline to Future NI (%)
10-yr	17.2	27,593	30,694	20,177	23,174	-26.9	-24.5
	10	27,593	30,694	21,938	25,098	-20.5	-18.2
	5	27,593	30,694	23,407	26,578	-15.2	-13.4
	2.5	27,593	30,694	23,788	27,022	-13.8	-12.0
50-yr	17.2	37,563	40399	30,430	33,164	-19.0	-17.9
	10	37563	40399	32,525	35,490	-13.4	-12.2
	5	37563	40399	33,929	36,935	-9.7	-8.6
	2.5	37563	40399	34,610	37,603	-7.9	-6.9

4.2 Economic Analysis Results

4.2.1 Reduction in Total Economic Losses

Hazus results indicate that the implementation of NI will reduce the average annual loss under present and future rainfall conditions when considering 10-yr and 50-yr design storms (**Figure 4-18**). Future rainfall conditions are likely to lead to more losses compared to present rainfall conditions. This is expected as future rainfall frequency and intensity is projected to increase in the PCW region (Payton et al., 2023). The percent reduction in losses from the baseline condition is approximately 25% across all NI scenarios for the 10-yer design storm and this reduces to approximately 20% for the 50-year design storm (**Figure 4-18b**). When comparing the percent reduction in baseline between present and future rainfall conditions across NI scenarios (**Figure 4-18b**), there is no consistent pattern on whether the reduction is larger or smaller. This may be due to the interaction between the spatial distribution of NI implemented and rainfall received, or small effects of the randomization process for selecting NI siting; however, detailed spatial analysis is needed to further assess this hypothesis.

Hazus total economic loss results indicate that the reduction in loss per acre implemented decreases as the percentage of NI implemented increases (**Figure 4-18c**). Consequently, the scenario where 2.5% of the watershed is implemented with NI provides the largest impact per acre of NI implemented. As discussed previously, the approached used to scale the reduction between the baseline and NI scenarios assumes the benefits from an acre for each of the six NI practices is treated equally; however, this may not necessarily be true for water storage or other ecological benefits. Therefore, this approach provides a good first step at estimating the relative impact of NI across the watershed for each NI scenario, but more computationally intensive calculations may be necessary to measure the impacts of specific water resources management and ecological benefits. Last, the reduction in losses from the baseline relative to the area of NI implemented is consistently higher for future rainfall condition (**Figure 4-18c**). This indicates that NI implemented under present rainfall condition may plan an important role in mitigating future flood risk.

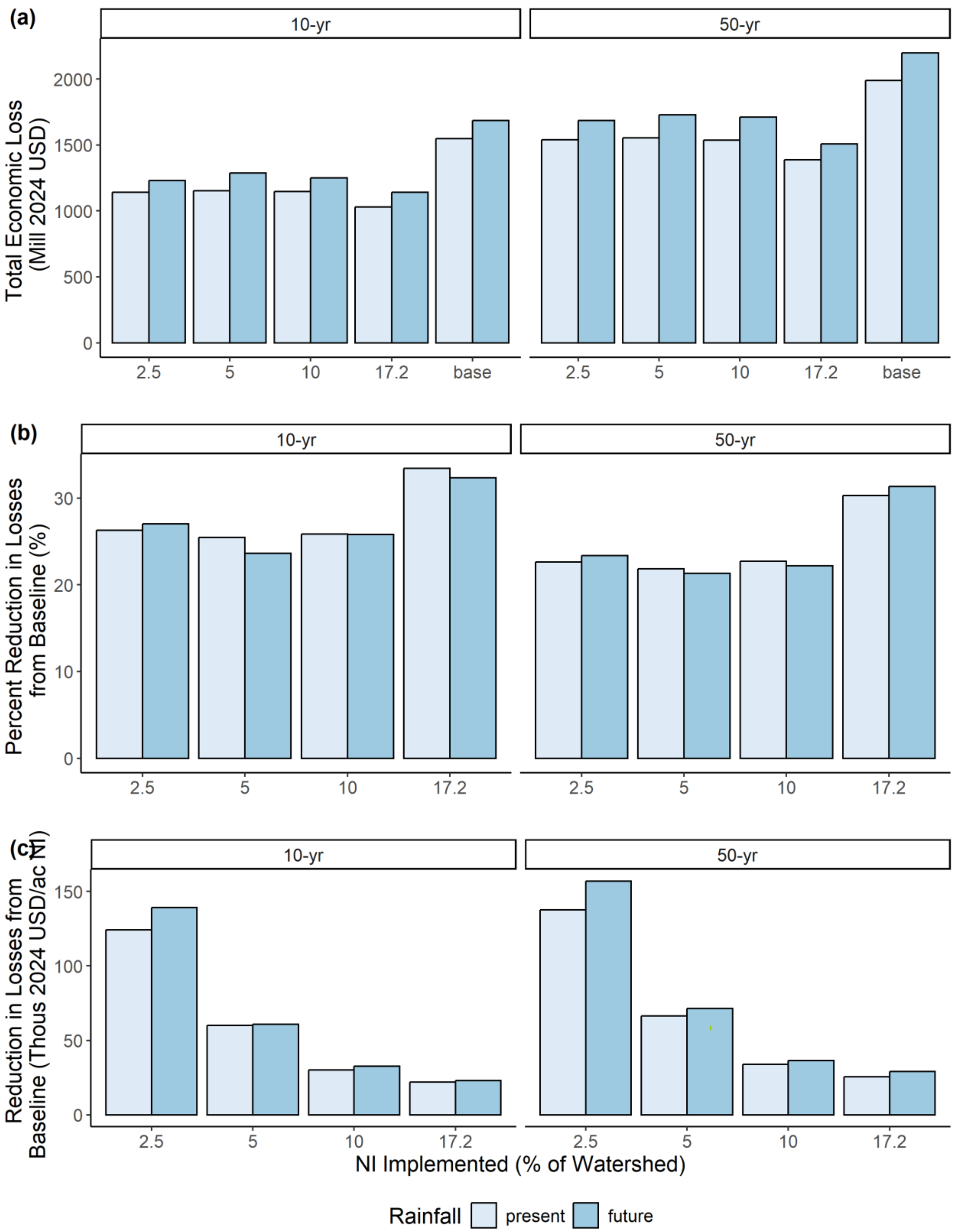

Figure 4-18. (a) Total economic loss versus percent of the Prairie Creek Watershed implemented with NI. (b) Percent reduction in losses from NI implementation compared to the baseline (no NI) condition vs NI implemented. (c) Reduction in losses from NI implementation compared to the baseline condition relative to acres of NI implemented vs NI implemented. Results are shown for 10-yr and 50-yr design storms.

4.2.2 *Average Annual Loss Results*

Tetra Tech observed a lower estimated average annual loss (AAL) when 17.2% of the watershed area is implemented with NI compared to baseline conditions without NI for both present and future conditions (**Figure 4-19**). According to these findings, implementing NI equates to a 32.3 and 31.2% change in AAL under present and future rainfall conditions, respectively, relative to the baseline condition. Of the losses estimated, wage and income losses made up a sizeable portion of the total economic losses; building and contents loss only made up a smaller fraction of the total economic losses despite having marked increases in the future. When comparing AAL between present and future rainfall conditions, Tetra Tech found that AAL increased 8.3 and 9.7% under future rainfall conditions compared to the present for baseline and 17.2% watershed area NI implementation conditions, respectively. Therefore, implementing NI results in a decrease in AAL under both present and future conditions, with the largest decreases occurring under present rainfall conditions.

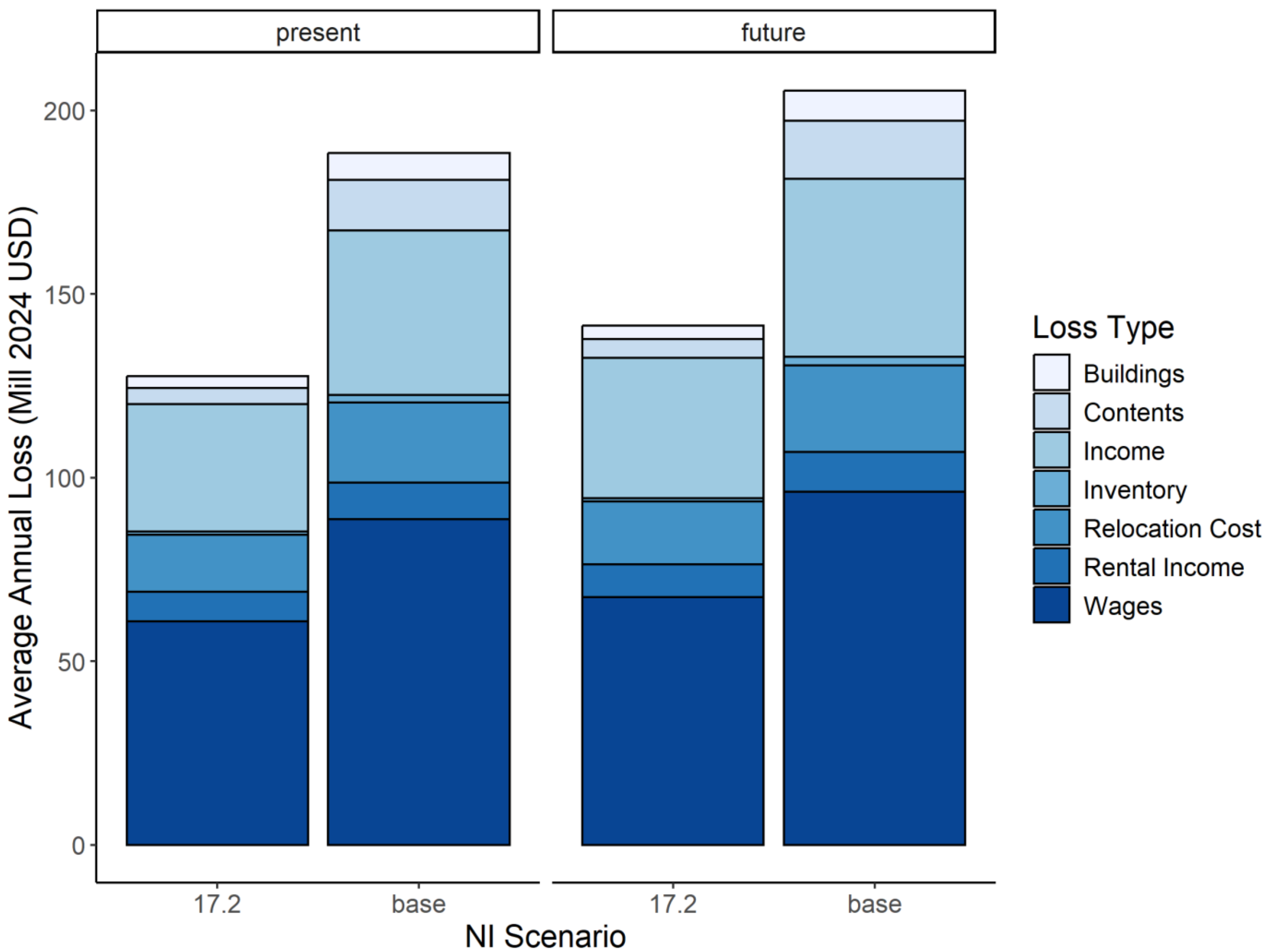

Figure 4-19. Average annual loss (in millions of USD) for various loss types versus the different NI scenarios included in this analysis under present and future rainfall conditions. NI scenarios shown include baseline results without NI implemented (shown as “baseline”) and maximum implementation of NI (17.2% of area of PCW, shown as “17_perc”). These results account for both 10-yr and 50-yr design storms.

Tetra Tech observed that commercial occupancy types experienced the largest AAL for under both present and future rainfall conditions for the baseline scenario without NI and when 17.2% of the watershed was implemented with NI (**Figure 4-20**). Surprisingly, residential AAL values totaled less than $25 million USD under present and future rainfall conditions.

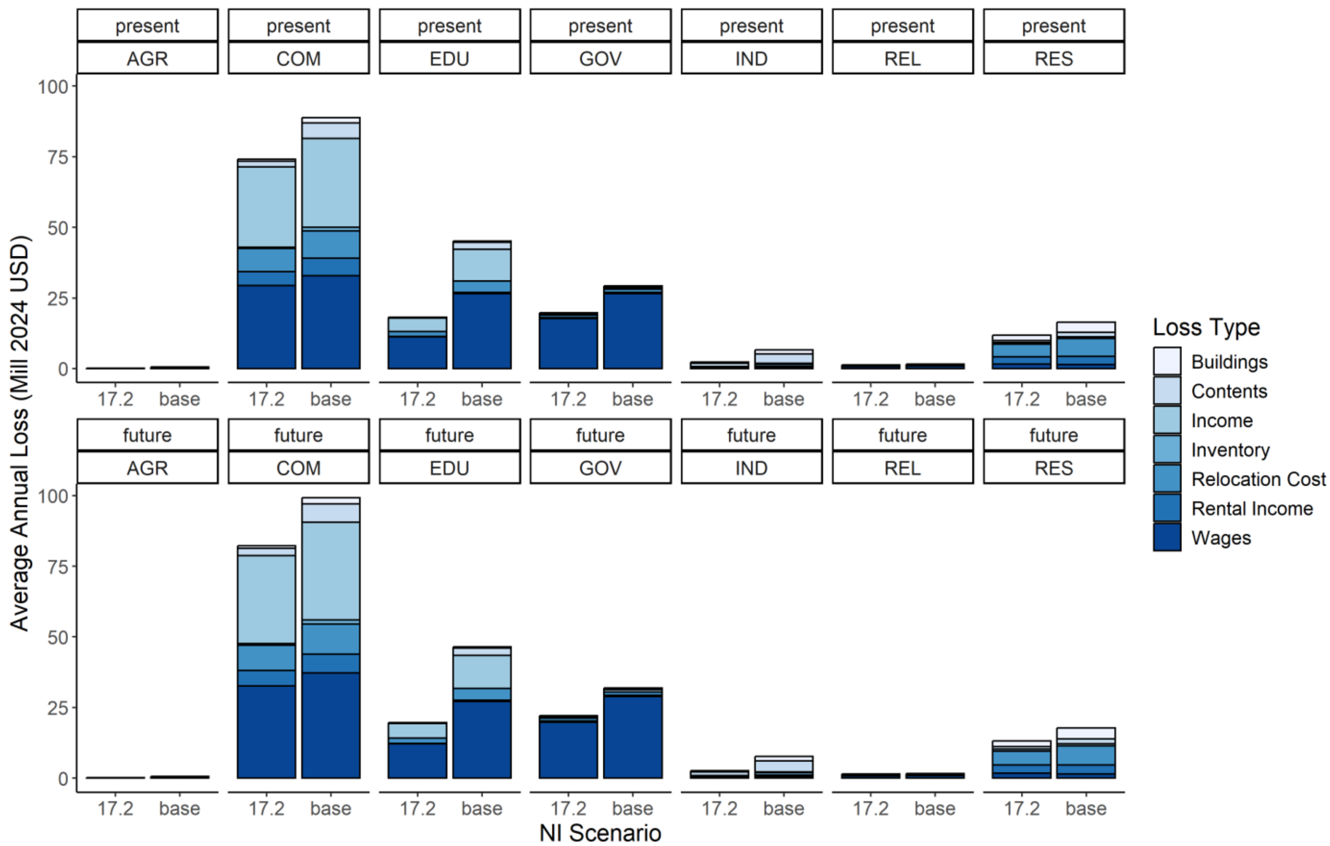

Figure 4-20. Average annual loss (AAL) in millions of 2024 USD versus NI scenario by present rainfall condition (top row) and future rainfall conditions (bottom row) by building occupancy type and colored by loss type. Note that this plot only shows results for the baseline (no NI) and scenario with 17.2% of the watershed implemented with NI. Abbreviations: baseline (base), agriculture (AGR), commercial (COM), educational (EDU), governmental (GOV), industrial ((IND), religious (REL), and residential (RES).

Focusing specifically on building material type, Tetra Tech observed the largest contributions of average annual building losses were due to damaged wooden structures while the smallest contribution was due to damage to concrete structures; this trend was observed regardless of whether NI was implemented or whether present or future rainfall conditions were taken into account (**Figure 4-21**).

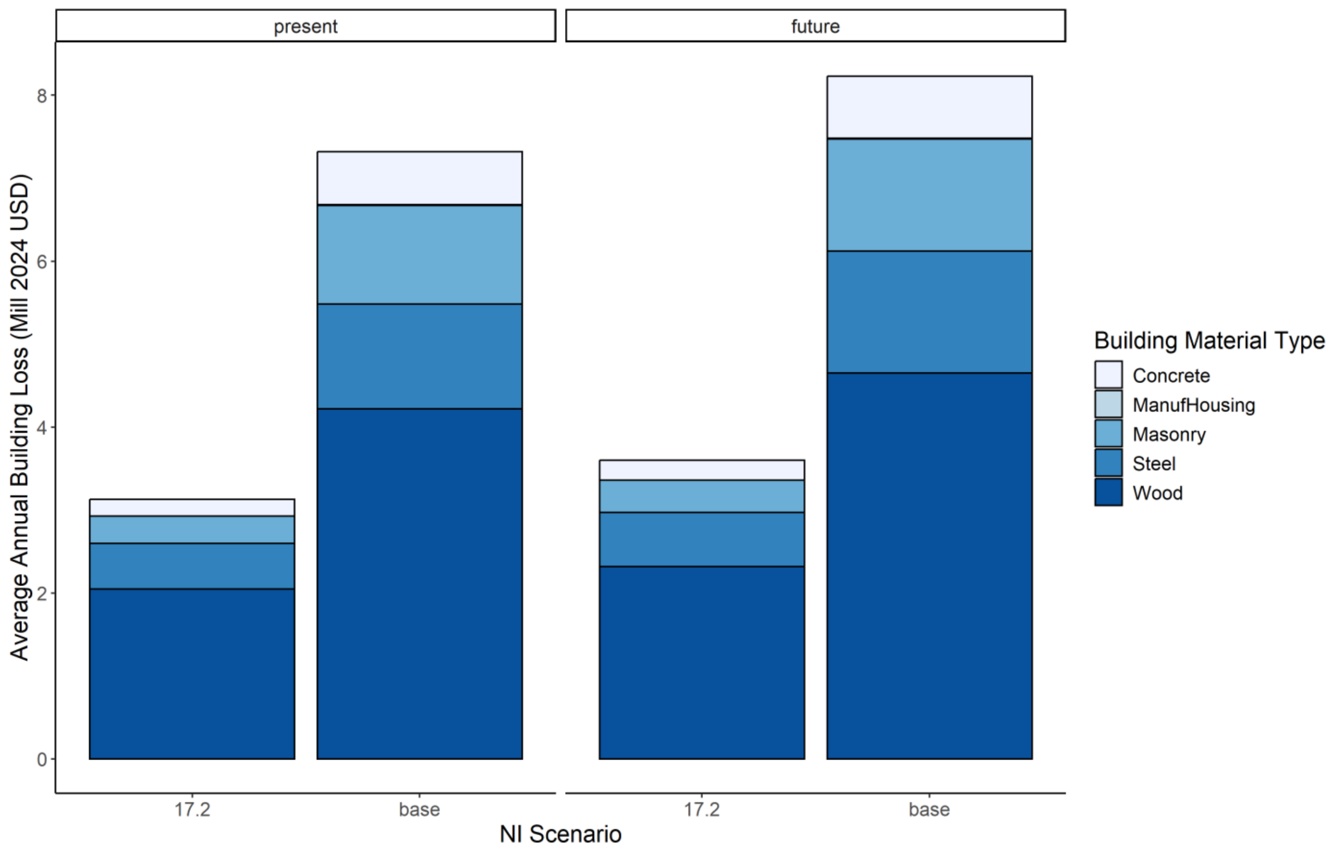

Figure 4-21. Average annual building loss in millions of 2024 USD versus NI scenario for present and future rainfall conditions by building material type. Note that this plot only shows results for the baseline (base; no NI) and scenario with 17.2% of the watershed implemented with NI.

Tetra Tech used AAL values under present and future rainfall conditions to calculate an NPV of avoided losses over a 40-year time horizon for the NI scenario where 17.2% of the watershed was implemented with NI. The overall (total) NPV avoided losses when 17.2% of the watershed implemented with NI was $1.7 billion USD (**Table 4-5**). Additionally, Hazus outputs allowed for the NPV of avoided losses to be broken up into various loss categories. Similar to patterns in AAL, wage losses made up a sizeable portion of the NPV avoided losses; building and contents lost only make up a smaller fraction of NPV of avoided losses. As mentioned previously, building content losses are likely larger than building losses because for non-residential building occupancy categories the scale factor can be 100% or 150%.

Table 4-5. Net present value of avoided losses broken out by loss category. NI implementation was simulated for 10-yr and 50-yr design storms. All values are in millions 2024 USD. Net present value was calculated over a 40-year time horizon.

NI Scenario (% of WS area)	Buildings	Contents	Inventory	Relocation Costs	Income	Rental Income	Wages	Total
17.2	$119.99	$269.71	$39.42	$173.35	$275.81	$53.34	$770.69	$1702.30

Using the dollar per acre estimates discussed in the NPV analysis, Tetra Tech determined the individual inputs (**Table 4-6**) needed to calculate the NPV of NI implementation cost over a 40-year time horizon and subtracted this from the overall NPV of avoided losses to get the overall net benefit of implementing NI. For the scenario with 17.2% of the watershed area under NI implementation, the net benefit was $1.1 billion USD (not including farmland lost costs; **Table 4-7**). Tetra Tech also determined the NPV of farmland lost over a 40-year time horizon. When this was subtracted from $1.1 billion USD, it resulted in an overall net benefit of $884 million USD (**Table 4-7**).

Table 4-6. Summary of initial and maintenance costs for each NI practice and scenario scaled to specific NI scenario acreages using information presented previously in **Table 3-6** and **Table 3-7**.

NRCS Code	NI Practice Name	NI Scenario (% of Watershed Area)	Initial Costs (Thous 2024 USD)	Maintain Costs (Thou 2024 USD)	Initial Farmland Lost (Thous 2024 USD)	Maintain Farmland Lost (Thous 2024 USD)
390	Riparian Buffer	2.5	$247.7	$56.5	$190.7	$99.7
420	RCC on Erodible Land	2.5	$139.6	$34.6	$242.8	$127.0
420	RCC in the Floodplain	2.5	$187.1	$46.3	$325.4	$170.1
638	WASCOBs	2.5	$357.2	$33.4	$70.9	$37.1
656	CREP Wetlands	2.5	$45643.4	$1283.1	$919.9	$496.1
657	Depressional Wetlands	2.5	$58.8	$2.4	$10.1	$5.1
390	Riparian Buffer	5	$485.8	$110.8	$374.1	$195.6
420	RCC on Erodible Land	5	$277.5	$68.7	$482.6	$252.3
420	RCC in the Floodplain	5	$374.3	$92.7	$650.9	$340.3
638	WASCOBs	5	$764.1	$71.5	$151.7	$79.3
656	CREP Wetlands	5	$91755.0	$2579.3	$1849.2	$997.3
657	Depressional Wetlands	5	$102.8	$4.2	$17.6	$8.9
390	Riparian Buffer	10	$984.8	$224.6	$758.4	$396.5
420	RCC on Erodible Land	10	$555.4	$137.5	$965.8	$505.0
420	RCC in the Floodplain	10	$767.3	$190.0	$1334.4	$697.7
638	WASCOBs	10	$1545.4	$144.5	$306.8	$160.4
656	CREP Wetlands	10	$187015.1	$5257.1	$3769.1	$2032.7
657	Depressional Wetlands	10	$228.5	$9.3	$39.1	$19.8
390	Riparian Buffer	17.2	$1697.7	$387.3	$1307.3	$683.6
420	RCC on Erodible Land	17.2	$963.0	$238.5	$1674.6	$875.6
420	RCC in the Floodplain	17.2	$1405.7	$348.1	$2444.4	$1278.1
638	WASCOBs	17.2	$3171.0	$296.6	$629.5	$329.2
656	CREP Wetlands	17.2	$326871.2	$9188.5	$6587.8	$3552.9
657	Depressional Wetlands	17.2	$438.6	$17.8	$75.1	$38.0

Table 4-7. Economic analysis results for each NI implementation scenario. NI implementation was simulated for 10-yr and 50-yr design storms and implementation costs do not include the cost of foregone land. All dollar values are in millions USD. Net present value (NPV) was calculated over a 40-year time horizon.

NI Scenario (% of WS area)	Total NPV Avoided Losses (Mill 2024 USD)	NPV NI Implementation Cost (Mill 2024 USD)	NPV Farmland Lost Cost (Mill 2024 USD)	Net Benefit (Mill 2024 USD)
2.5	--	$86.47	$27.34	--
5	--	$173.83	$54.78	--
10	--	$354.22	$111.46	--
17.2	$1702.30	$621.14	$197.57	$883.59

Given the limited time duration of the project, Tetra Tech was not able to run the remaining design storms needed to complete the net benefit results in **Table 4-7**. However, future work may consider completing these model runs to fully explore the net benefits of implementing NI at watershed area percentages less than 17.2%.

Tile drainage is extensively used in Iowa to remove excess water from fields and improve overall crop yield (Schilling and Helmers, 2008; Wan et al., 2024); however, the baseline hydrologic models developed by the Iowa Department of Natural Resources (DNR) did not include tile drainage (Iowa DNR, 2021; 2025b). While the justification is not documented by Iowa DNR, tile drainage was likely not included for several reasons. First, HEC-RAS primarily simulates direct runoff from rainfall and it does not solve for terrestrial hydrological processes like subsurface flow, which would be needed for tile drainage simulations. Second, flood events happen over short timescales, but tile drainage typically operates under relatively longer timescales as they are not designed to handle rapid flood events. Third, tile drainage is not intended to provide flood prevention, but rather, it lowers the water table by gradually releasing water. During large floods, tile drainage will likely reach full capacity before the peak rainfall event rendering them ineffective at mitigating flooding. See the Hydrologic Model Results Memorandum for additional details on how AECOM calibrated the Iowa DNR HEC-RAS models.

While saturated buffers were not included in the hydrological modeling component of this project, Tetra Tech included them in the economic analysis per EDF's request to assess their impact on cost as compared to riparian buffers, the latter of which were included in the hydrological modeling analysis. Saturated buffers are similar to riparian buffers, but have an additional control structure to route tile drainage to and through the riparian area. As such, tile drainage can be routed to the saturated buffers. Saturated buffers are a relatively new best management practice and research on their overall adoption and effectiveness in and around Iowa is currently limited (IDALS, 2025b); however, they were recently included in updates to Iowa's Nutrient Reduction Strategy (IDALS, 2025a). Tetra Tech determined that the NPV of implementing saturated buffers in place of riparian buffers for the 17.2% NI scenario was $5.6 million USD (**Table 4-8**).

Table 4-8. Scaled initial and maintenance costs for implementing saturated buffers (NRCS code 604) in place of riparian buffers as well as the resulting net present value (NPV) by NI scenario.

NI Scenario (% of Watershed Area)	Initial Costs (Thous 2024 USD)	Maintain Costs (Thou 2024 USD)	NPV Cost (Thou 2024 USD)
2.5	$376.50	$16.14	$817.97
5	$738.35	$31.65	$1604.13
10	$1496.86	$64.16	$3252.07
17.2	$2580.49	$110.61	$5606.35

The ACPF FiNRT documentation noted a wide variation in the cost of NI implementation (Bravard et al. 2022a; 2022b). Professionals who regularly manage regional NI implementation projects stated that NI implementation does not always scale linearly with the size of the NI practice (Hay and Pech, 2025). Put another way, due to "economies of scale", it is often less expensive on a per acre basis to implement larger NI practices or multiple NI practices in a spatial neighborhood at once compared to implementing one small NI practice in an isolated location (Hay and Pech, 2025). Consequently, while the relative magnitude of NI implementation costs used in this study is realistic based on NRCS documentation, peer reviewed literature, and professional experience, there are costs that may arise while installing and maintaining a practice that are difficult to fully capture and estimate.

4.2.3 Social Vulnerability Results

The census track SVI values in the PCW ranged from 0.01 to 0.98, where a value closer to 1 represented the most vulnerable communities across Iowa. SVI was highest near the outlet of the PCW; however, there were some vulnerable communities located in the headwaters on the western side of Benton County (i.e., orange polygon overlapping the towns of Keyston and Blairstown, **Figure 4-22**). High SVI values or the most vulnerable communities located near the PCW outlet in Cedar Rapids were primarily driven by higher SVI theme 1 and theme 3 values, where theme 1 represents socio-economic status and theme 3 represents racial and ethnic minority status.

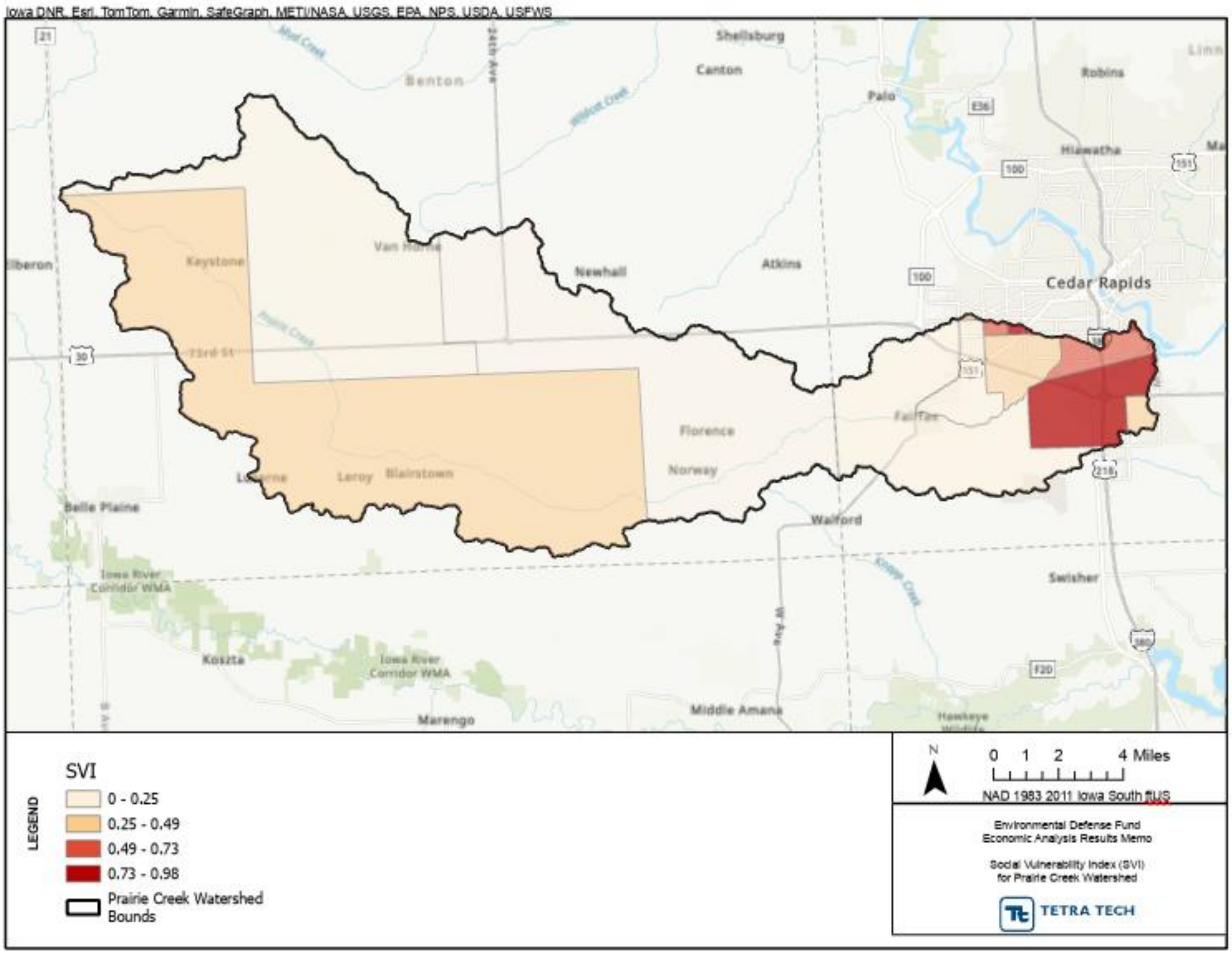

Figure 4-22. Social vulnerability index (SVI) results for the PCW. A value close to zero indicates a community is not socially vulnerable and a value of 1 indicates a very vulnerable community.

To assess the impact of NI on flood risk mitigation for vulnerable communities, Tetra Tech compared the difference in maximum flood depth between the baseline (no NI) and NI implemented on 2.5, 5, 10, and 17.2% of the watershed area for 10-yr and 50-yr storms under present and future rainfall conditions (**Figure 4-23**). Tetra Tech observed a couple of notable trends in these results. First, medium-high and high SVI categories tended to have a lower depth difference compared to low and medium-low SVI categories (**Figure 4-23**). Second, medium-high and high SVI categories tended to have a smaller variation in depth difference. Third, depth differences between the two least vulnerable categories (low and medium-low) and the two most vulnerable categories (medium-high and high) tended to shrink from present to future conditions. Consequently, vulnerable communities are still bearing the burden of flooding even with NI implementation so future work may look into ways to distribute NI equitably so that depth differences are similar across SVI categories. Furthermore, reductions in depth differences under future rainfall conditions indicate that the frequency and intensity of future rainfall projections will have a large impact on communities across the Cedar Rapids, Iowa region, regardless of their socio-economic status.

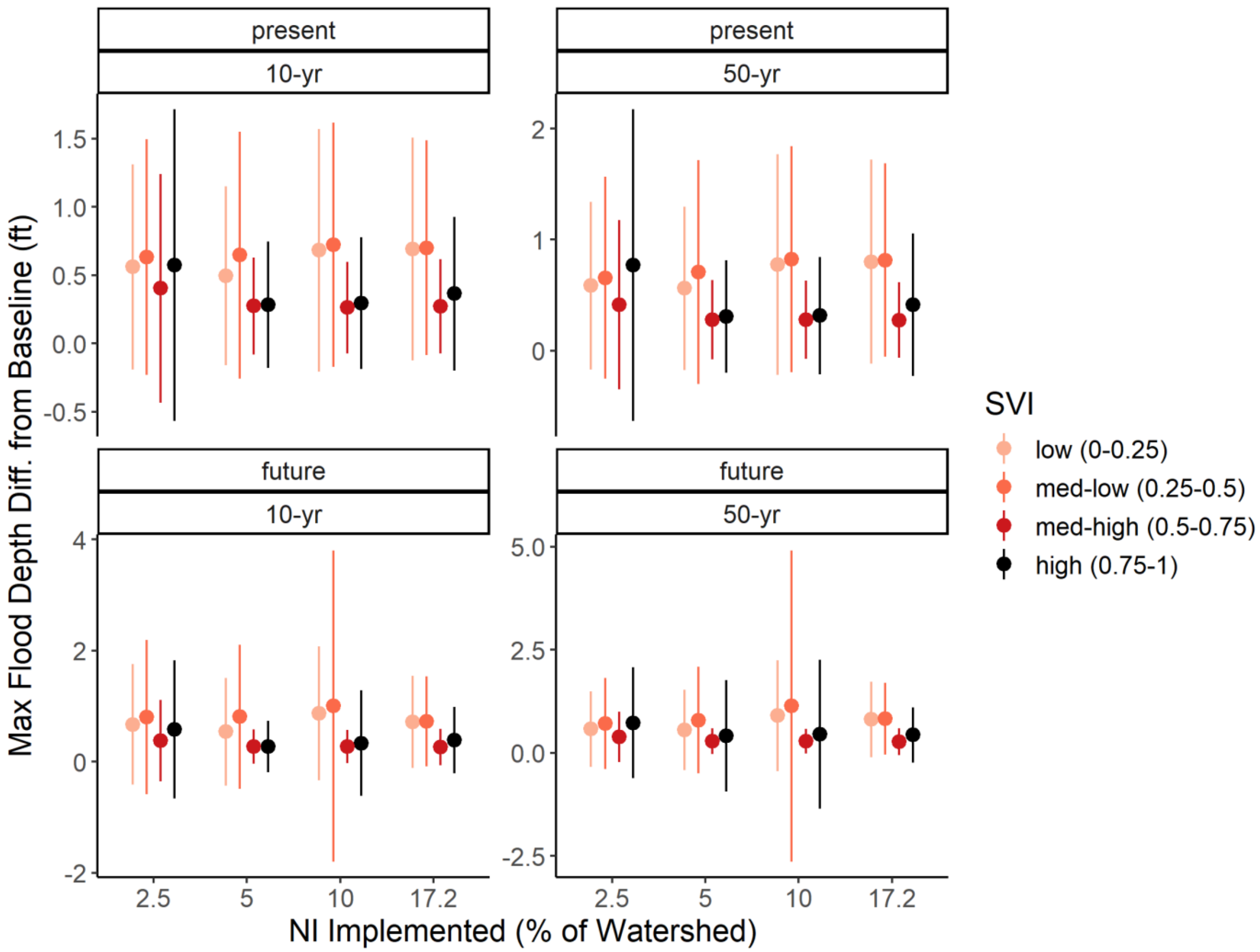

Figure 4-23. Baseline (no NI) maximum flood depth (ft) versus Social Vulnerability Index (SVI) for the 10-yr design storm (left) and 50-year design storm (right) under present rainfall conditions. Points represent the mean maximum flood depth and lines display the mean +/- standard deviation in maximum flood depth.

5.0 CONCLUSIONS

The hydrologic modeling and economic analysis components of the overall project *Opportunities for Natural Infrastructure to Mitigate Flood Risk in Mississippi River Basin Watersheds* illustrate potential changes to rainfall and flood magnitude under projected future (i.e., mid-century) rainfall conditions, the flood mitigation effectiveness of distributed NI, and the economic impacts of NI implementation. These results highlight the potential for NI to mitigate flood risks under present and future rainfall conditions.

The hydrology model simulations show that future rainfall scenarios result in increased flood depths and expanded inundation areas across all design storms, with the largest change in flood inundation area for smaller rainfall design storms. As an example, flood inundation area for 10-yr and 25-yr storms increased by 11.2% and 8.5%, respectively. This result underscores the need for proactive flood mitigation strategies that account for potential climate-driven changes in rainfall patterns. As stated previously, this work uses downscaled CMIP5 climate models and associated NOAA Atlas 14 raster datasets; however, Tetra Tech recommends incorporating downscaled CMIP6 climate model data and updated NOAA Atlas 14 IDF raster surfaces when this information is made publicly available.

The modeled NI solutions, which include land cover changes and natural storage features, exhibit effectiveness in reducing flood depth and inundation extent. While the NI implementation resulted in appreciable reductions in flood magnitudes across all design storms, their effectiveness was most pronounced for flooding associated with small-to-moderate recurrence interval design storms (i.e., 10-, 25-, and 50-yr design storms). Among the specific NI implemented, CREP wetlands stood out for their potential to store substantial flood waters. These findings suggest that NI implementation in the headwaters can be an effective tool for enhancing flood resilience near the watershed outlet, although diminished effectiveness at longer recurrence interval storms suggest it may need to be complemented with other flood management measures, such as traditional "gray" infrastructure or managed retreat from flood prone areas, to fully address flood risks associated with larger design storms.

This study demonstrated that the effectiveness of NI in flood control even when implemented in relatively small spatial footprints. Although maximum flood reduction was observed at our "maximum" implementation scenario (in 17.2% of the watershed), we observed appreciable flood mitigation even at the lowest modeled footprint of 2.5% of PCW. Results indicated that flood mitigation scaled approximately linearly within the range of implementation footprints within this study. This linear scaling suggests that, at least within this range, there is no clear threshold at which NI becomes more effective relative to its area of implementation. This finding is useful in that considerations of actual implementation can be made more simply based on other considerations.

Although relative effectiveness of NI is shown to decrease under larger design storms, it is important to emphasize that it has measurable impact across all flood scenarios, current and future. Further, the economic effects of flooding scenarios remain to be determined in the next phase of this project. However, Tetra Tech hypothesizes that even relatively small reductions in flood magnitudes during design storms will translate to substantial avoided economic losses.

Based on economic results, there are substantial (31-32%) reductions in average annual losses when 17.2% of the watershed is implemented with NI. This results in a net present value of $1.7 billion USD in avoided losses. When the cost of NI implementation and farmland loss are considered the overall benefit of implementing infrastructure on 17.2% of the watershed area is $884 million USD. Consequently, implementing NI has a large positive economic benefit now and into the future. Beyond the net benefits, NI reduced total economic losses on average about 25% from the baseline condition for a range of NI implementation percentages under present and future 10-yr and 50-yr design storm conditions. On a per-acre basis, the lowest NI implementation simulated (2.5% of the watershed area, equivalent to 14% adoption) achieved nearly twice the economic benefit of other implementation levels, illustrating the potential value in implementing even a relatively modest amount of NI. Future work may also focus on including economic analysis 2.5, 5, and 10% of the watershed implemented with NI because this will enable the calculation of net benefits for all NI scenarios.

Social vulnerability results indicated that vulnerable communities were still bearing the burden of flooding even with NI implementation. Future work may look to explore how spatial variation in NI implementation may reduce the flooding risk gap between highly vulnerable communities and communities that are less vulnerable. Notably, results also indicate that the increased frequency and intensity of future rainfall events may impact all communities regardless of their socio-economic status.

Taken together, the hydrologic model and economic results highlight an opportunity for NI implementation to reduce flood risk in the Prairie Creek Watershed under present and future rainfall conditions. This study also offers a novel approach at linking HEC-RAS and Hazus models to quantify these impacts, which can be useful to policy makers, watershed planners, and other regional stakeholders.

6.0 REFERENCES

Bravard, E. E., Zimmerman, E., Tyndall, J. C., and D. James. 2022. The Agricultural Conservation Planning Framework Financial and Nutrient Reduction Tool: A planning tool for cost effective conservation. *Journal of Environmental Quality*. 51:670-682.

Bravard, E. E., James, D. E., Zimmerman, E., Bowman, T., and J. C. Tyndall. 2020. *Financial Analysis for use with the Agricultural Conservation Planning Framework (ACPF): Data for the State of Iowa*. ACPF Financial and Nutrient Reduction Toolbox (FiNRT) User Manual, 44 p.

Butcher, J. B., Sarkar, S., Johnson, T. E., and A. Shabani. 2023. Spatial Analysis of Future Climate Risk to Stormwater Infrastructure. *Journal of American Water Resources Association*. 59:1383-1396.

Centers for Disease Control (CDC). 2022. *CDC/ATSDR SVI 2022 Documentation*. Agency for Toxic Substances and Disease Registry (ATSDR), Center for Disease Control (CDC). 17 p.

-----. 2025a. Environmental Justice Index. Agency for Toxic Substances and Disease Registry (ATSDR), Center for Disease Control (CDC). https://www.atsdr.cdc.gov/place-health/php/eji/index.html. Accessed 14 January 2025.

-----. 2025b. Social Vulnerability Index. Agency for Toxic Substances and Disease Registry (ATSDR), Center for Disease Control (CDC). https://www.atsdr.cdc.gov/place-health/php/svi/index.html. Accessed 14 January 2025.

Center for Transportation Research and Education (CTRE). 2005. *Iowa Drainage Law Manual.* Iowa State University. Sponsored by the Iowa Highway Research Board (TR-497).

Chow, V. T. 1959. *Open Channel Hydraulics*. McGraw-Hill, New York. 700 p.

Conservation Reserve Enhancement Program (CREP). 2016. *Landowner Guide to Operation and Maintenance.* Iowa Department of Agriculture and Land Stewardship.

Federal Emergency Management Agency (FEMA). 2020. *Multi-hazard Loss Estimation Methodology Flood Model: Hazus-MH Technical Manual (v2.1)*. US Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington, D.C. 569 p.

-----. 2022. *Hazus Flood Technical Manual 5.1.* https://www.fema.gov/sites/default/files/documents/fema_hazus-flood-model-technical-manual-5-1.pdf. Accessed 10 February 2025. 110 p.

-----. 2023. *Hazus Inventory National Database Data Dictionary*. https://www.fema.gov/sites/default/files/documents/fema_hazus-inventory-national-database-dictionary.pdf. Accessed 10 February 2025.

-----. 2024a. *Hazus Flood Technical Manual 6.1.* https://www.fema.gov/sites/default/files/documents/fema_hazus-flood-model-technical-manual-6-1.pdf. Accessed 10 February 2025. 109 p.

-----. 2024b. *Hazus User Guide: Hazus v7.0.* https://www.fema.gov/sites/default/files/documents/fema_hazus_7_user_guide.pdf. Accessed 10 February 2025. 61 p.

-----. 2024c. *Hazus Inventory Technical Manual, Hazus 6.1*. Accessed 10 February 2025. 61 p.

-----. 2025. *Hazus*. https://www.fema.gov/flood-maps/products-tools/hazus. Accessed 10 February 2025. 61 p.

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., and B. Lewis. 2011. A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management*. 8(1):3.

Hay, C. and S. Pech. 2025. Personal communication. Spoke to Chris Hay of Haywater Solutions and Spencer Pech of ISG Inc. on 3 March 2025 about the estimated NI implementation costs in **Table 3-6**.

Iowa Department of Agriculture and Land Stewardship (IDALS). 2025a. Iowa Nutrient Reduction Strategy. Available online: https://www.nutrientstrategy.iastate.edu/sites/default/files/documents/2025%20INRS%20Complete%20Feb%202025.pdf. 207 p.

-----. 2025b. Principals Modernize Iowa Nutrient Reduction Strategy to Incorporate New Insights, Science and Technology. Iowa Department of Agriculture and Land. https://iowaagriculture.gov/news/iowa-nutrient-reduction-strat-2025. Accessed: 28 March 2025.

Iowa Department of Natural Resources (Iowa DNR). 2021. *Iowa CTP Preference Guidance Draft: 2D Base Level Engineering (BLE).* Version 2.0. 14 p.

-----. 2025a. *Flood Plain Mapping*. https://www.iowadnr.gov/Environmental-Protection/Land-Quality/Flood-Plain-Management/Flood-Plain-Mapping. Accessed 10 January 2025.

-----. 2025b. *Iowa DNR 2-D BLE Model Supplemental Calibration Files for HUC 0708020514.* https://idnr.engage.stantec.com/#/map-component. Accessed 5 March, 2025.

Iowa Geospatial Data Clearinghouse (GDC). 2017. *Historic Vegetation (GLO)*. https://geodata.iowa.gov/datasets/historic-vegetation-glo/about. Accessed 14 January 2025.

-----. 2025. *State of Iowa Geospatial Data*. https://geodata.iowa.gov/. Accessed 14 January 2025.

Iowa State Extension, 2024. *Cash Rental Rates for Iowa 2024 Survey*. Ag Decision Maker. Iowa State Extension File C2-10. 12 p. https://www.extension.iastate.edu/agdm/wholefarm/pdf/c2-10.pdf. Accessed 10 February 2025. 61 p.

Lewis, P. G. T., Chiu, W. A., Nasser, Ellu, Proville, J., Barone, A., Danforth, C., Kim, B., Prozzi, J. and E. Craft. 2023. Characterizing vulnerabilities to climate change across the United States. *Environment International*. 172:107772.

National Oceanographic and Atmospheric Administration (NOAA). 2024. *Precipitation Frequency Data Server (PFDS)*. https://hdsc.nws.noaa.gov/pfds/. Accessed 15 December 2024.

Natural Resources Conservation Service (NRCS). 2004. *National Engineering Handbook*, Part 630 Hydrology, Chapter 9 Hydrologic Soil-Cover Complexes.

-----. 2017. *Terrace/Basin Plan*. Engineering Standard Drawings for Erosion and Water Management Structures. https://efotg.sc.egov.usda.gov/references/public/IA/IA1500.pdf. Accessed 13 January 2025.

-----. 2020. *Riparian Forest Buffer (Ac.) (391) Conservation Practice Standard. National Standard Document*. https://www.nrcs.usda.gov/resources/guides-and-instructions/riparian-forest-buffer-ac-391-conservation-practice-standard. Accessed 15 December 2024.

-----. 2022a. *Riparian Herbaceous Cover (Ac.) (390) Conservation Practice Standard. National Standard Document*. https://www.nrcs.usda.gov/resources/guides-and-instructions/riparian-herbaceous-cover-ac-390-conservation-practice-standard. Accessed 15 December 2024.

-----. 2022b. US Department of Agriculture Natural Resources Conservation Service (NRCS) Major Land Resource Area (MLRA). https://www.nrcs.usda.gov/resources/data-and-reports/major-land-resource-area-mlra. Accessed 14 January 2025.

-----. 2024. *Water and Sediment Control Basin (Ac.) (638) Conservation Practice Standard*. National Standard Document. Conservation Practice Standard Water and Sediment Control Basin (Code 638). Accessed 13 January 2025.

Olsen, A. S., Zhou, Q., Linde, J. J., and K. Arnbjerg-Nielsen. 2015. Comparing Methods of Calculating Expected Annual Damage in Urban Pluvial Flood Risk Assessments. *Water*. 7:255-270.

Office of Management and Budget (OMB). 2023. *Circular A-94 Append D: Discount Rates for Benefit-Cost Analysis*. U.S. White House Office of Management and Budget. https://bidenwhitehouse.archives.gov/wp-content/uploads/2023/11/CircularA-94AppendixD.pdf. Accessed 19 March, 2025. 1 p.

Payton, E.A., and others. 2023: *Ch. 4. Water. In: Fifth National Climate Assessment*. Crimmins, A.R. and others, Eds. U.S. Global Change Research Program, Washington, DC, USA. 46 p.

Pistrika, A., Tsakiris, G., and I. Nalbantis. 2014. Flood Depth-Damage Functions for Built Environment. *Environmental Processes*. 1:553-572.

Porter, S., Tomer, M., James, D., and Van Horn, J. *Agricultural Conservation Planning Framework ArcGIS Toolbox User's Manual Version 6.0*. USDA-ARS National Laboratory for Agriculture and the Environment. Ames Iowa.

Python Software Foundation. 2022. *Python Language Reference, version 3.9.16*. Released 6 December 2022. http://www.python.org.

Quinn, P., O'Donnell, G., Nicholson, A., Wilkinson, M., Owen, G., Jonczyk, J., Barber, N., Hardwick, M., and Davies, G. 2013. *Potential Use of Runoff Attenuation Features in Small Rural Catchments for Flood Mitigation*.

R Core Team. 2024. R*: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rahim, M. A., Assi, A. A., Mostafiz, R. B., and C. J. Fiedland. 2024. Effects of damage initation points of depth-damage functions on flood risk assessment. *npj Natural Hazards*. 1:6.

Schilling, K. E., and M. Helmers. 2008. Effects of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: Exploratory hydrograph analysis. *Hydrological Processes*. 22:4479-4506.

Schilling, K.E., Mount, J., Suttles, K.M., McLellan, E.L., Gassman, P.W., White, M.J. and Arnold, J.G., 2023. An approach for prioritizing natural infrastructure practices to mitigate flood and nitrate risks in the Mississippi-Atchafalaya River Basin. *Land*, 12(2), p.276.

United States Army Corps of Engineers (USACE). 2024. *Applying NOAA Atlas 14 Temporal Patterns*. https://www.hec.usace.army.mil/confluence/hmsdocs/hmsguides/flow-frequency-simulation-options-in-hec-hms/applying-noaa-atlas-14-temporal-patterns. Accessed 15 December 2024.

United States Bureau of Labor Statistics (USBLS). 2025. CPI Inflation Calculator. https://www.bls.gov/data/inflation_calculator.htm. Accessed 20 March 2025.

United States Geological Survey (USGS). 2023. *Annual National Land Cover Database (NLCD) Collection 1 Land Cover Conterminous United States*. U.S. Geological Survey, Sioux Falls, SD. Data release: https://doi.org/10.5066/P94UXNTS. Accessed 15 December 2024.

Wan, L., Kendall, A. D., Rapp, J., and D. W. Hyndman. 2024. Mapping agricultural tile drainage in the US Midwest using explainable random forest machine learning and satellite imagery. *Science of the Total Environment*. 950:175283.

Worley, L. C., Underwood, K. L., Diehl, R. M., Matt, J. E., Lawson, K. S., Seigel, R. M. and D. M. Rizzo. 2023. Balancing multiple stakeholder objectives for floodplain reconnection and wetland restoration. *Journal of Environmental Management*. 326:116648.

Yildirim, E., and I. Demir. 2023. An integrated web framework for HAZUS-MH flood loss estimation analysis. *Natural Hazards*. 99:275-286.

7.0 APPENDICES

Additional figures depicting maximum flood water depths and flood water depth differences are presented below for multiple combinations of past and present rainfall, as well as different NI scenarios. These figures illustrate more detailed patterns in smaller areas of PCW chosen to be close to smaller municipalities within PCW upstream of Cedar Rapids: Keystone, Blairstown, and Norway.

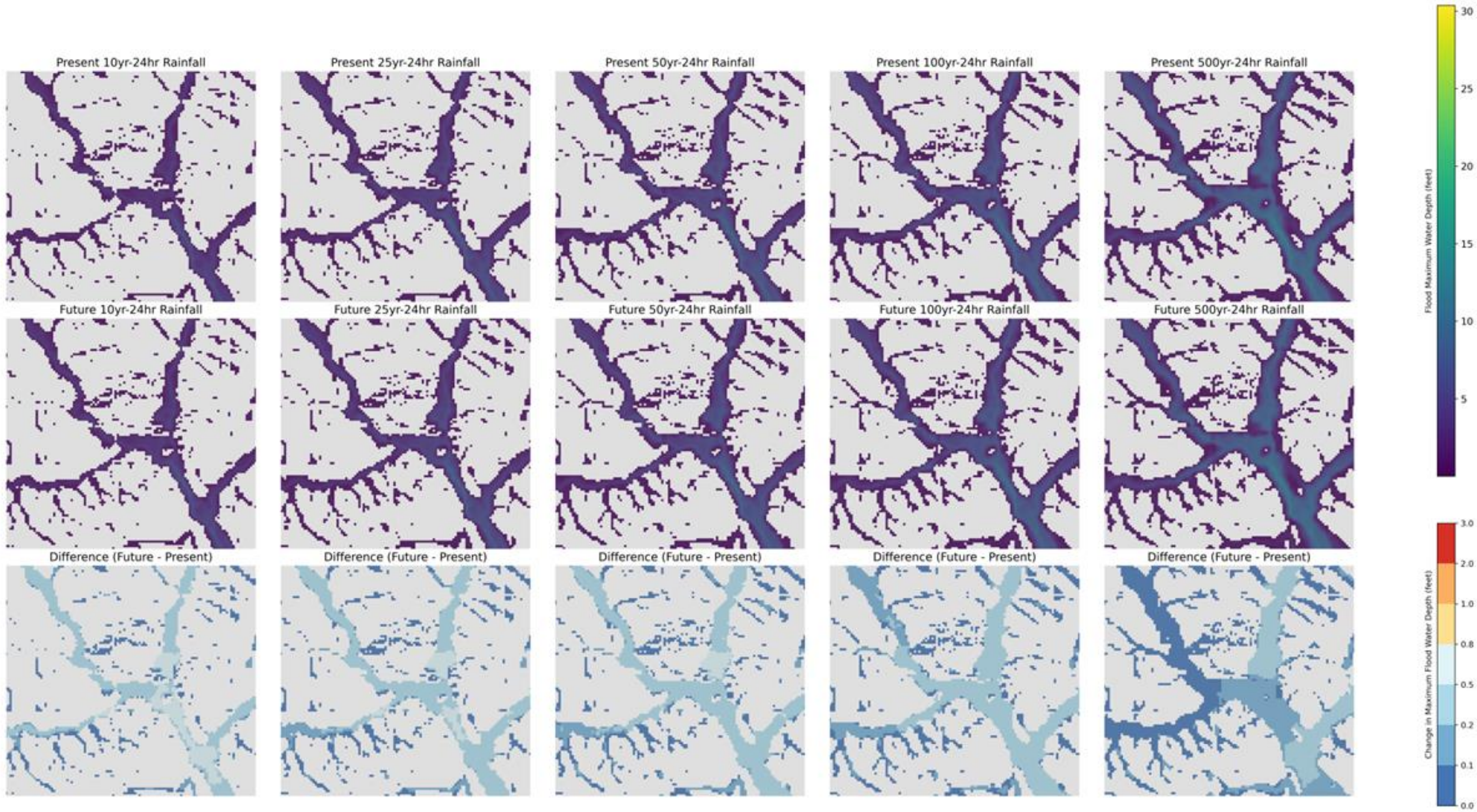

Figure 7-1. Maximum flood water depths for present and future rainfalls, near Keystone, IA.

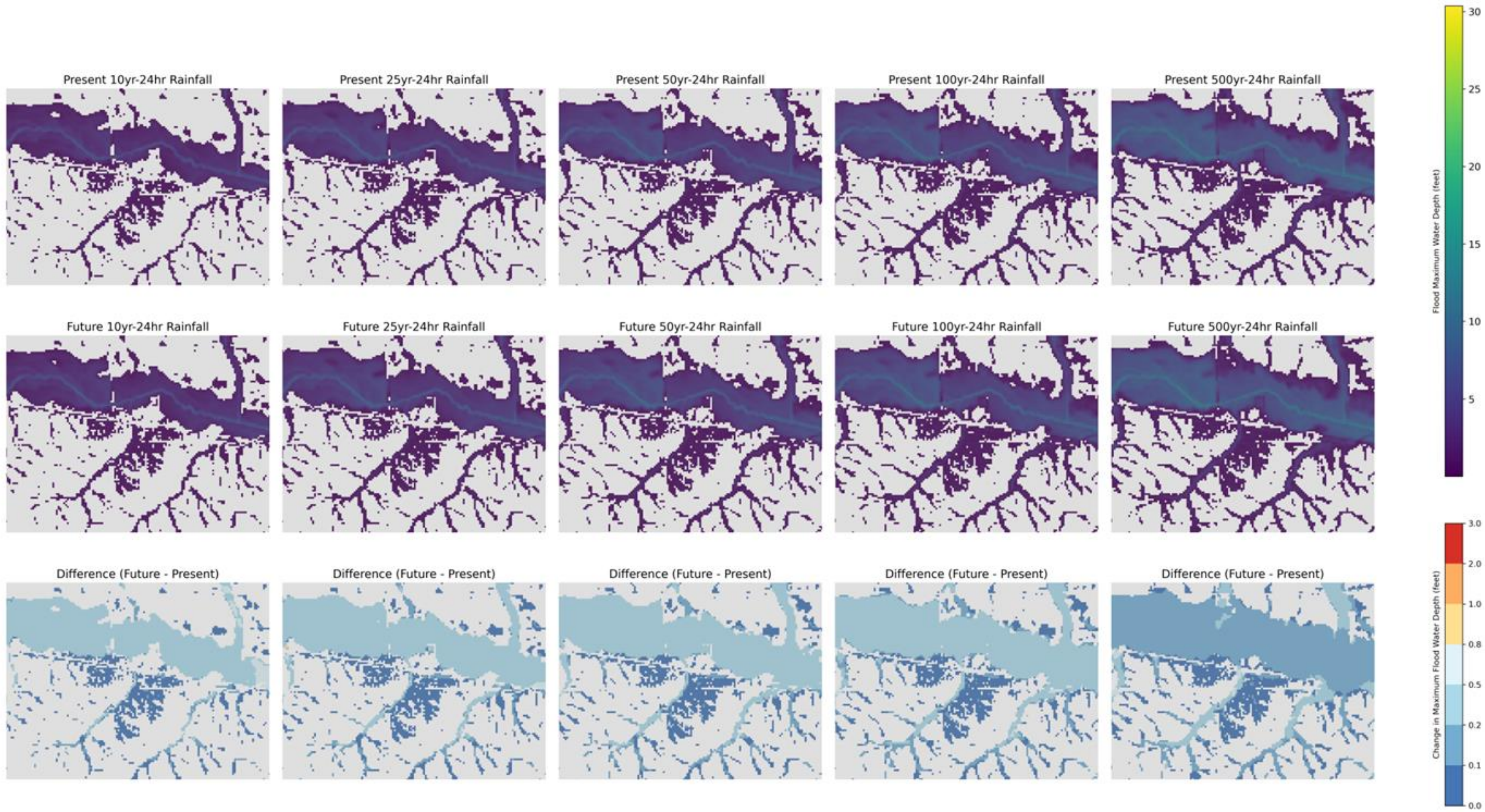

Figure 7-2. Maximum flood water depths for present and future rainfalls, near Blairstown, IA.

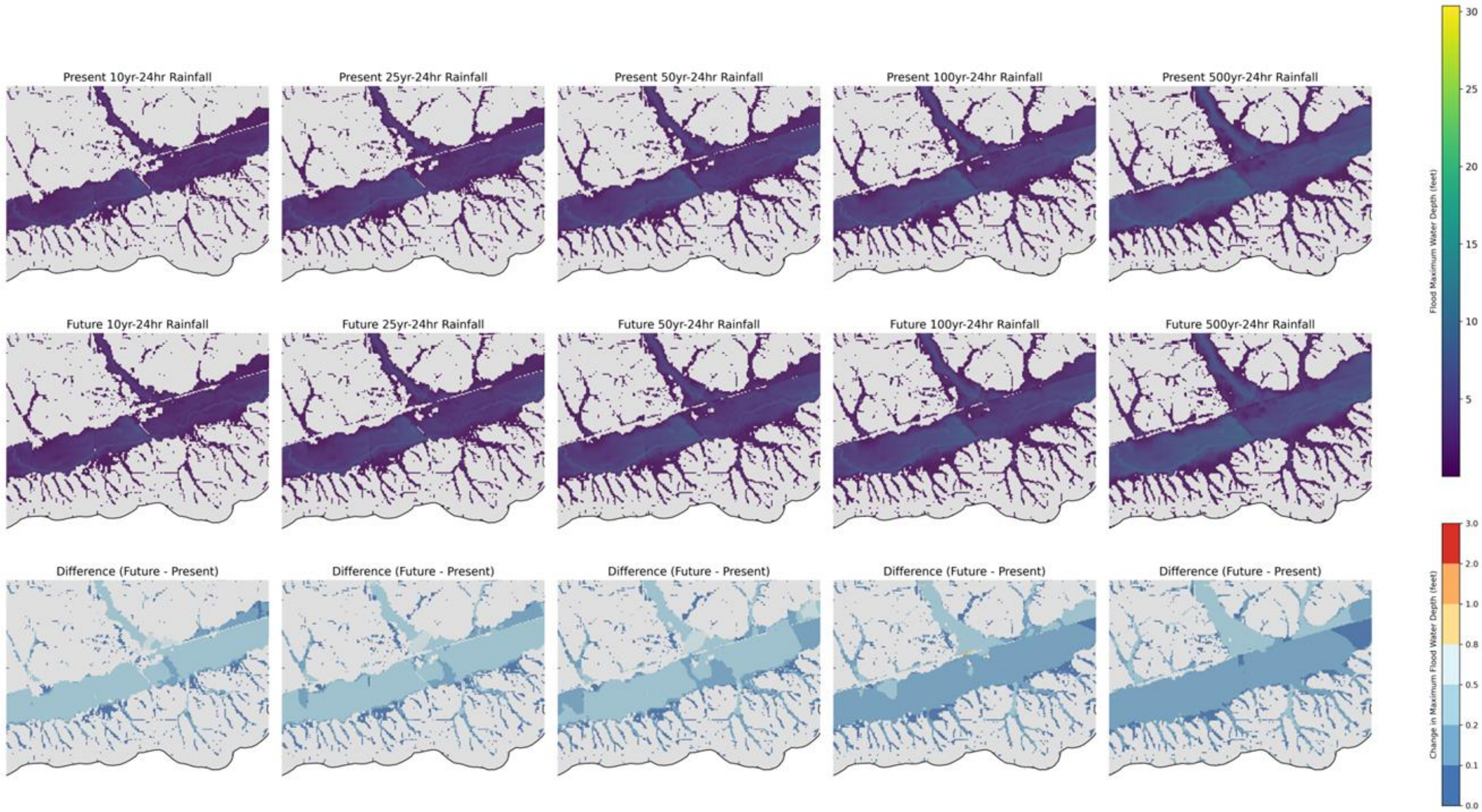

Figure 7-3. Maximum flood water depths for present and future rainfalls, near Norway, IA.

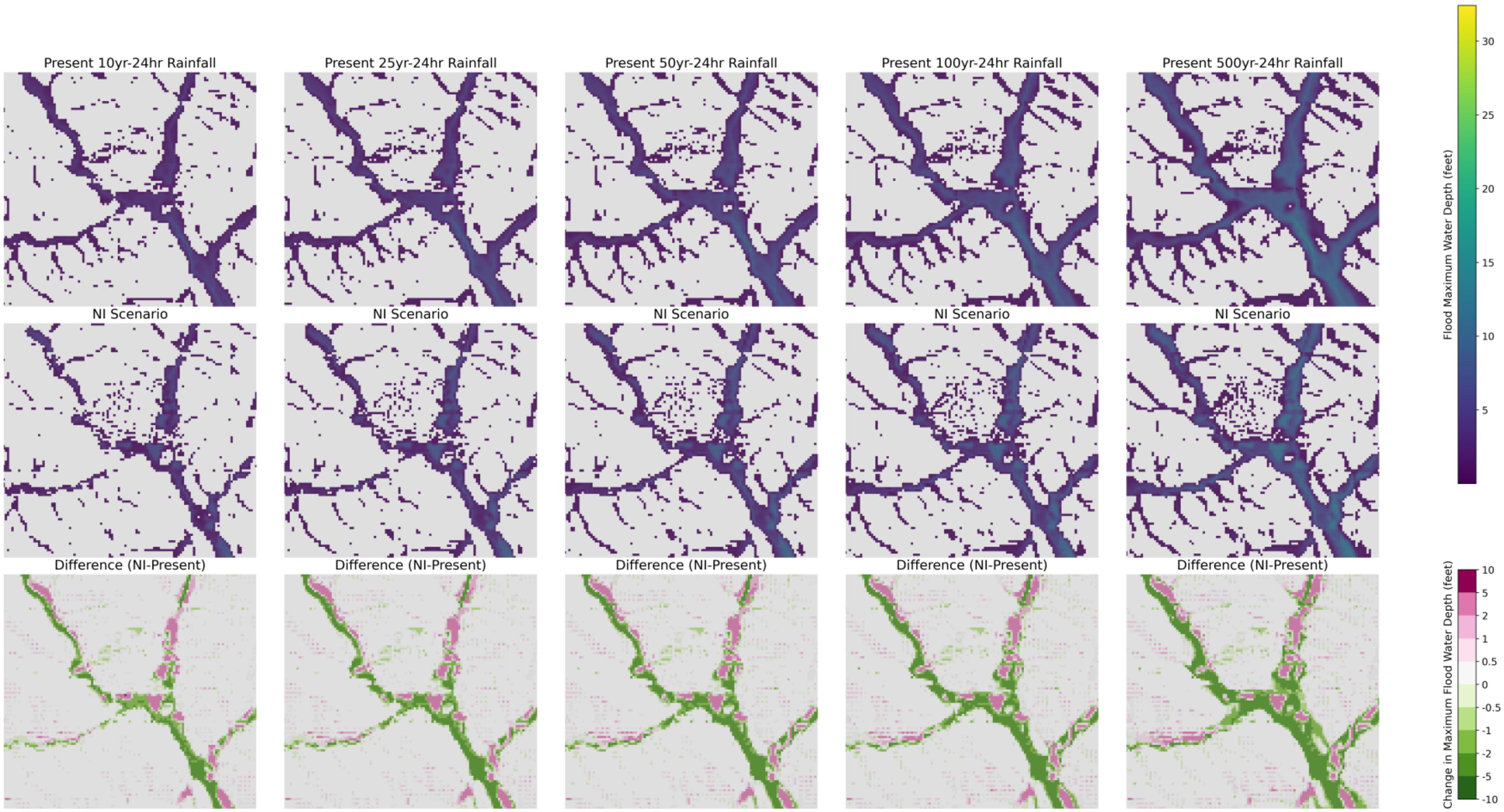

Figure 7-4. Maximum flood water depths for present rainfalls and NI scenario, near Keystone, IA.

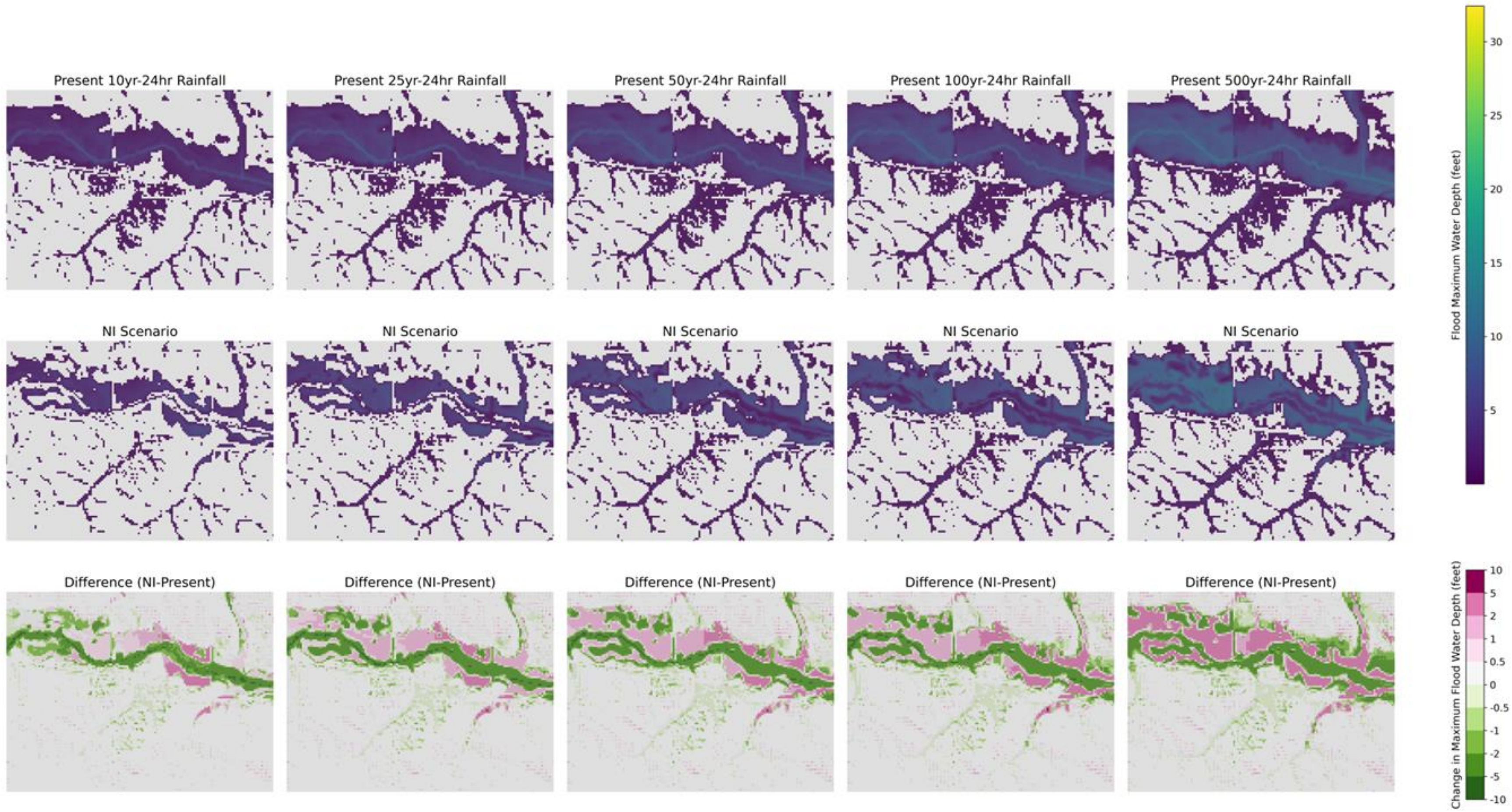

Figure 7-5. Maximum flood water depths for present rainfalls and NI scenario, near Blairstown, IA.

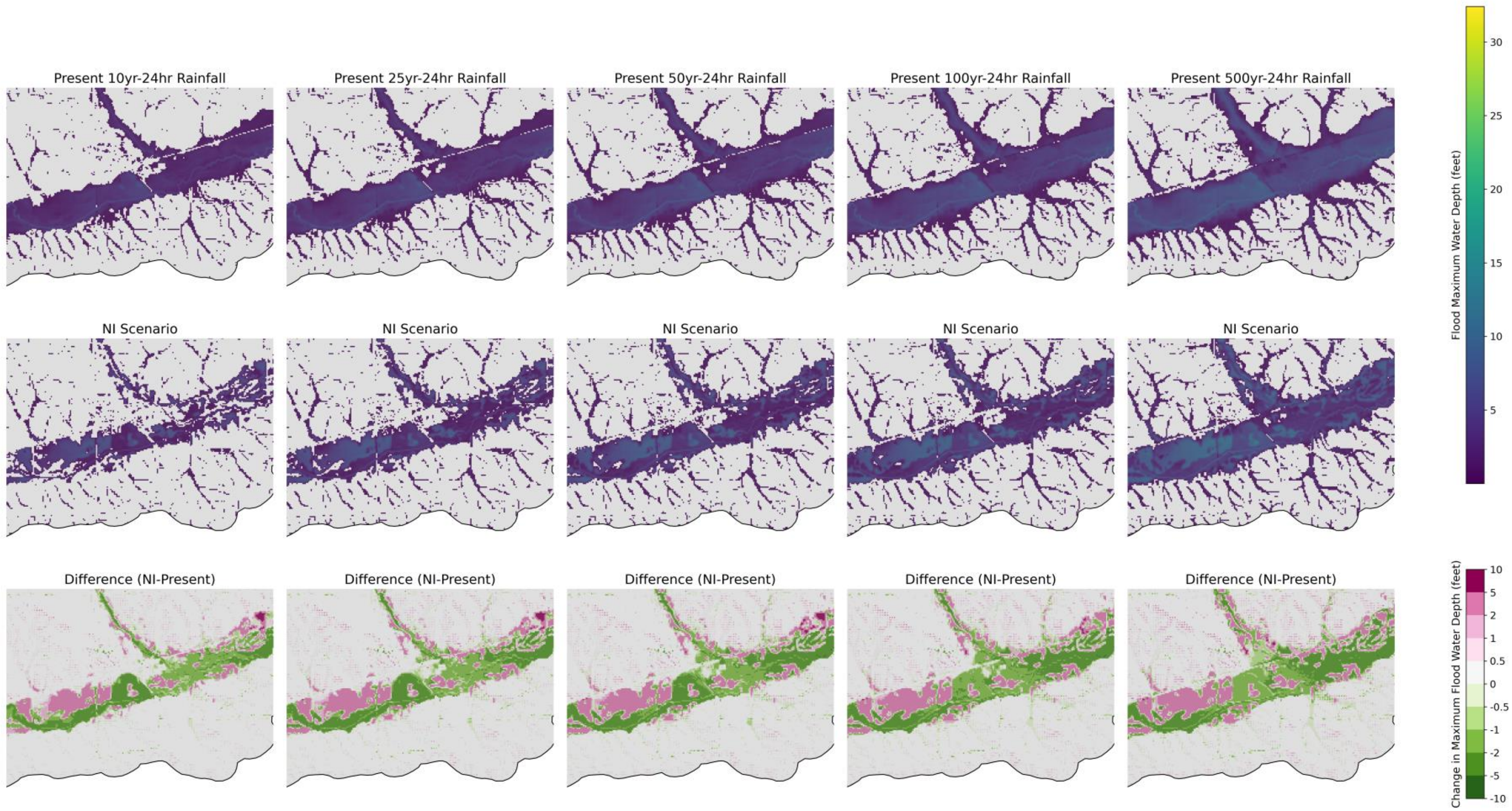

Figure 7-6. Maximum flood water depths for present rainfalls and NI scenario, near Norway, IA.

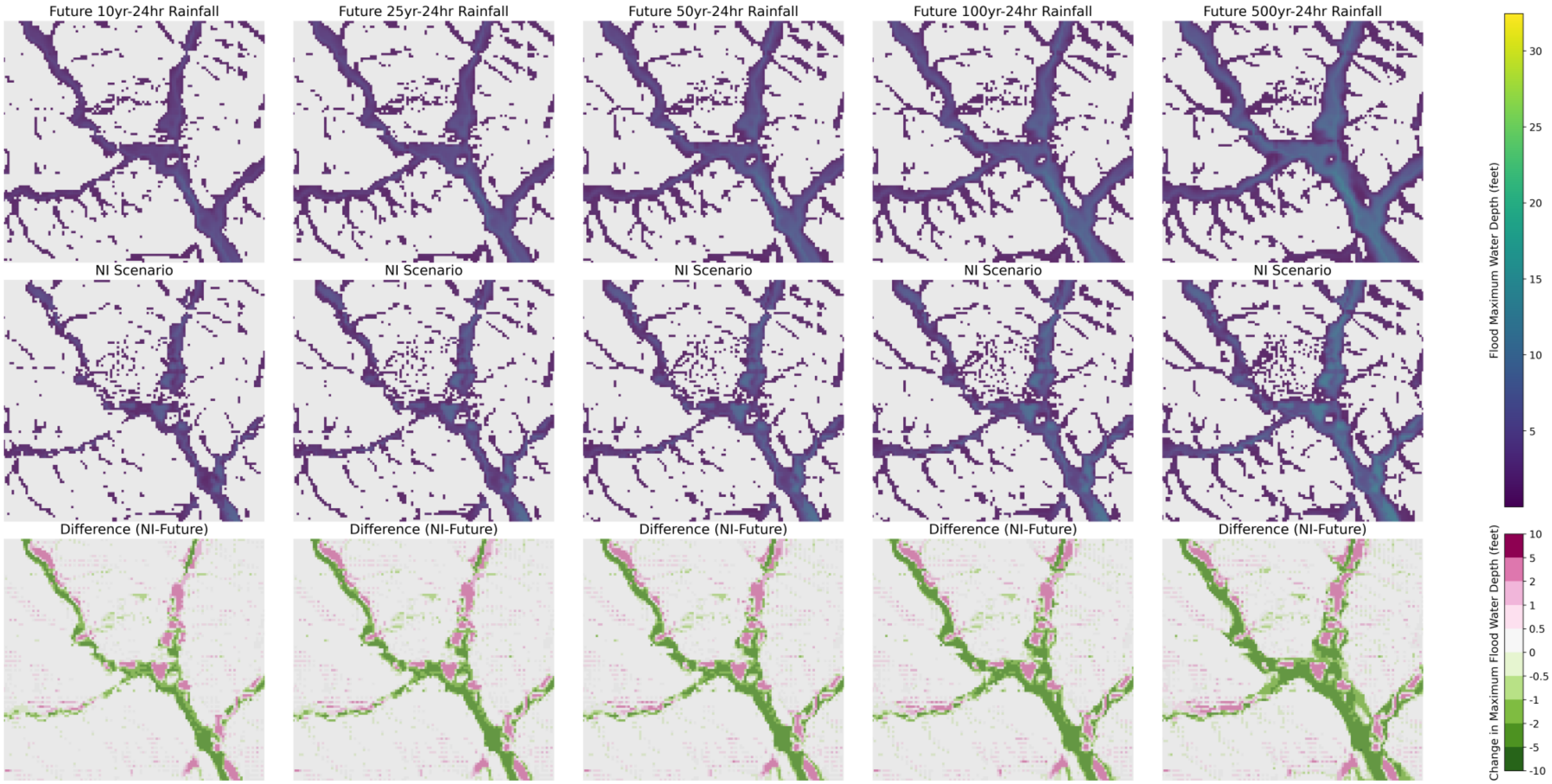

Figure 7-7. Maximum flood water depths for future rainfalls and NI scenario, near Keystone, IA.

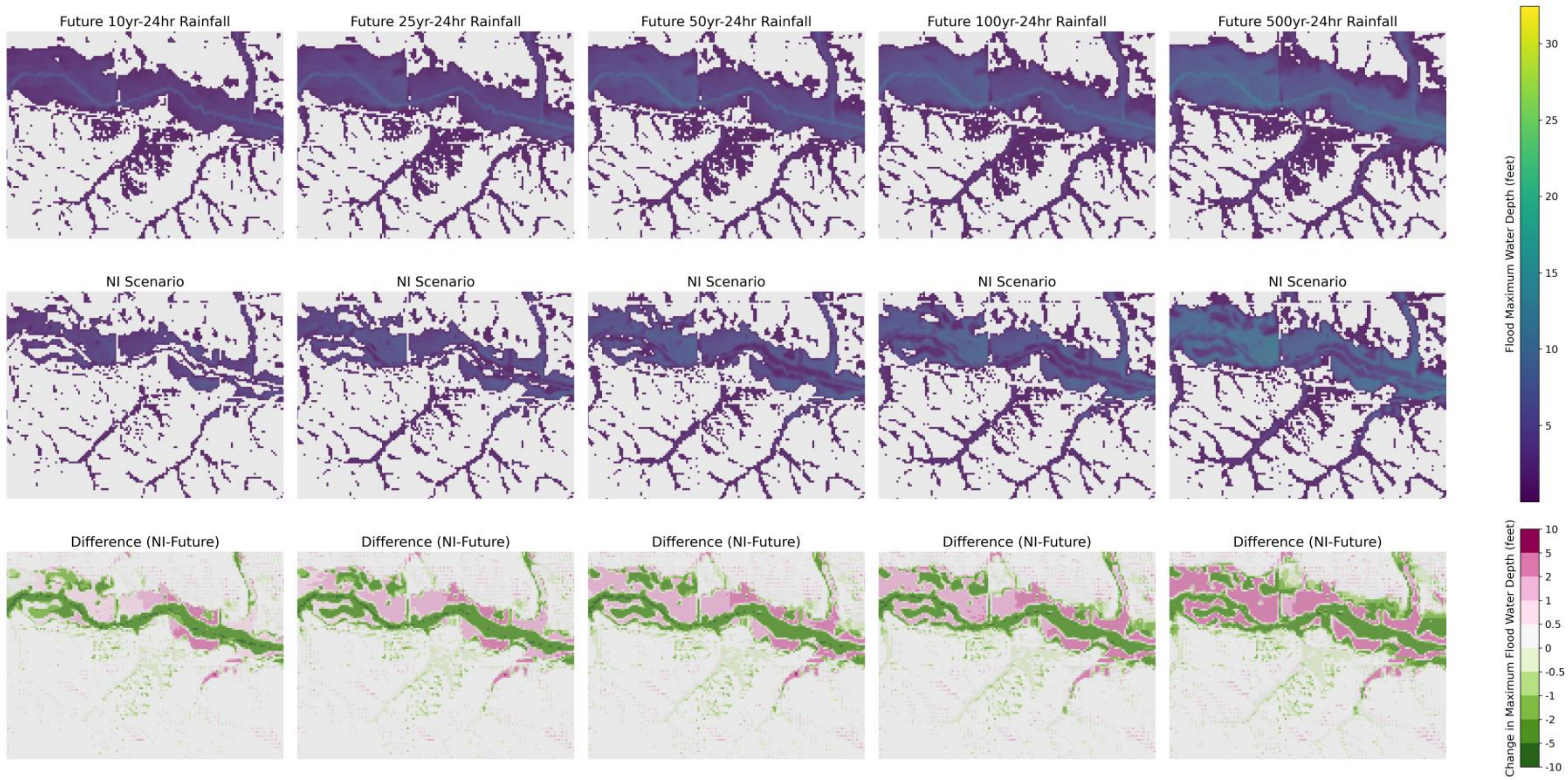

Figure 7-8. Maximum flood water depths for future rainfalls and NI scenario, near Blairstown, IA.

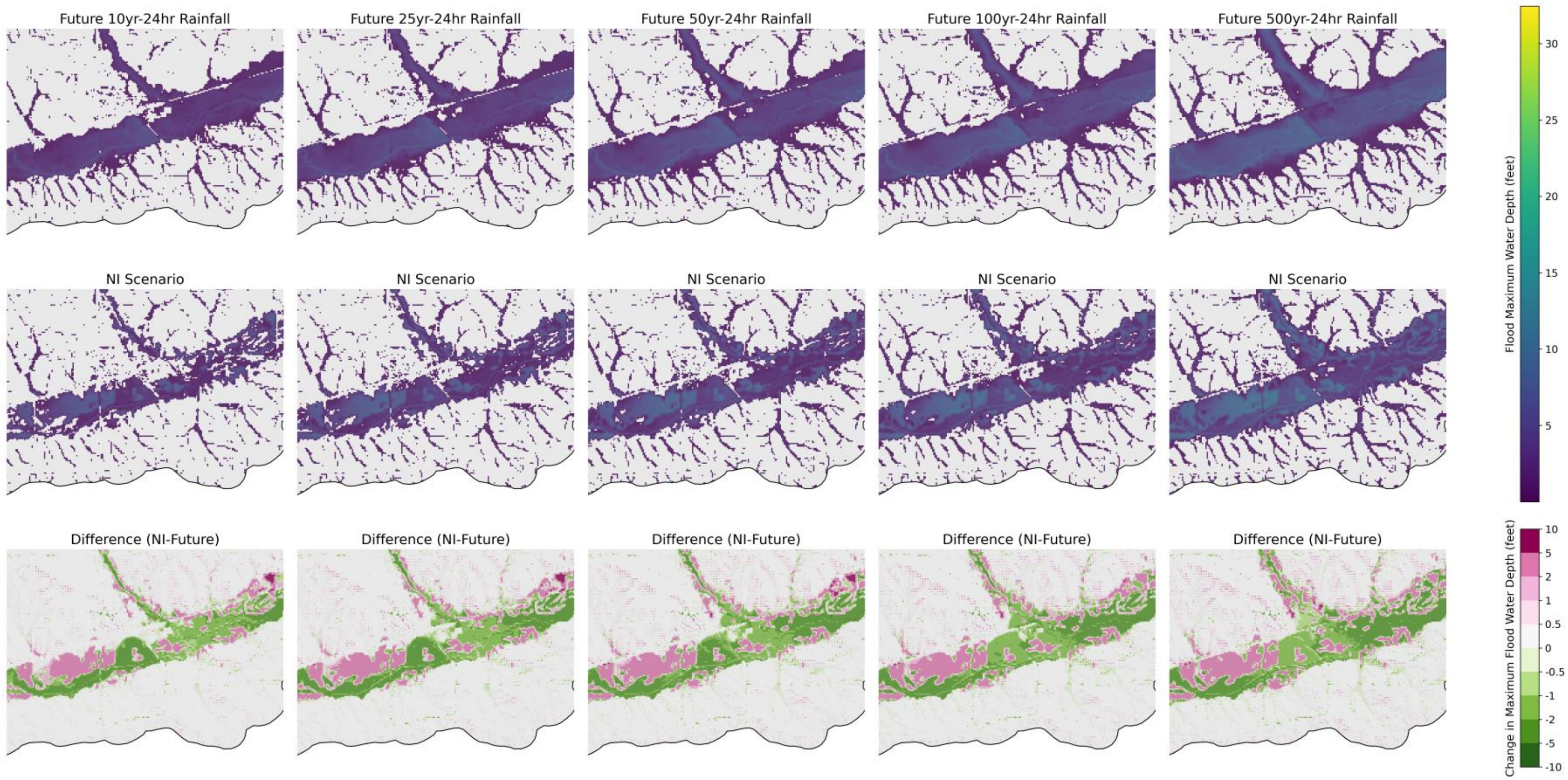

Figure 7-9. Maximum flood water depths for future rainfalls and NI scenario, near Norway, IA.

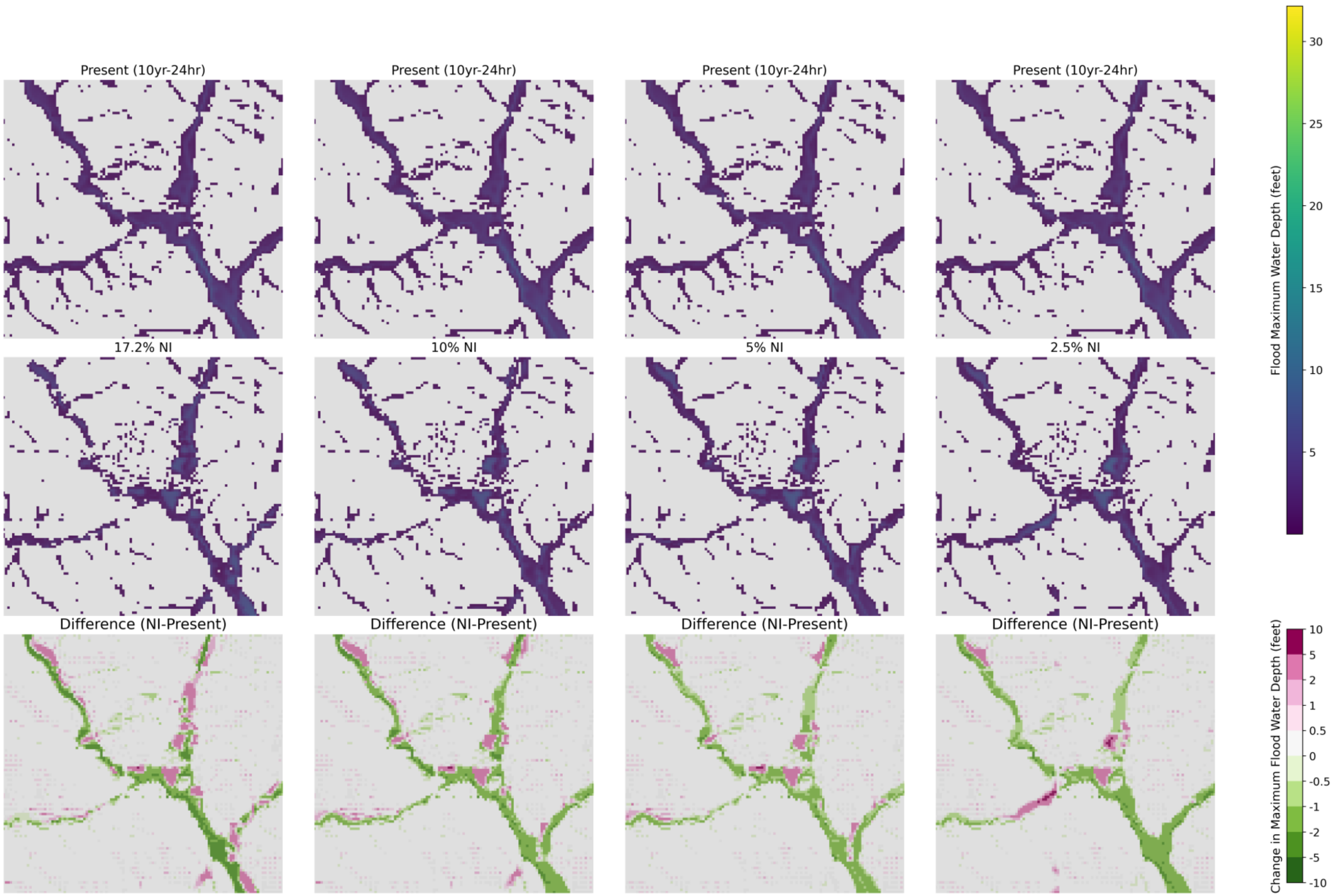

Figure 7-10. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Keystone, IA.

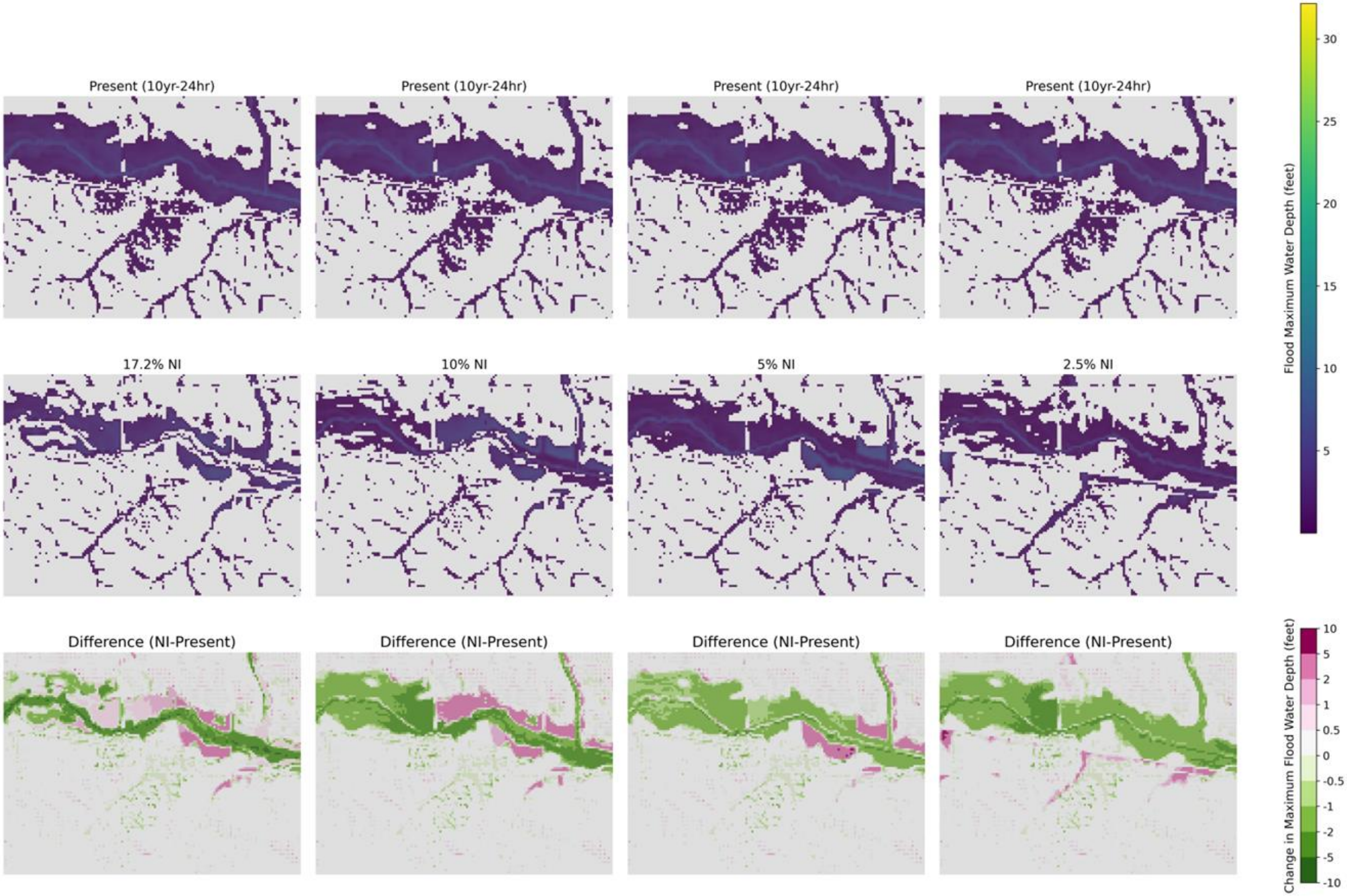

Figure 7-11. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Blairstown, IA.

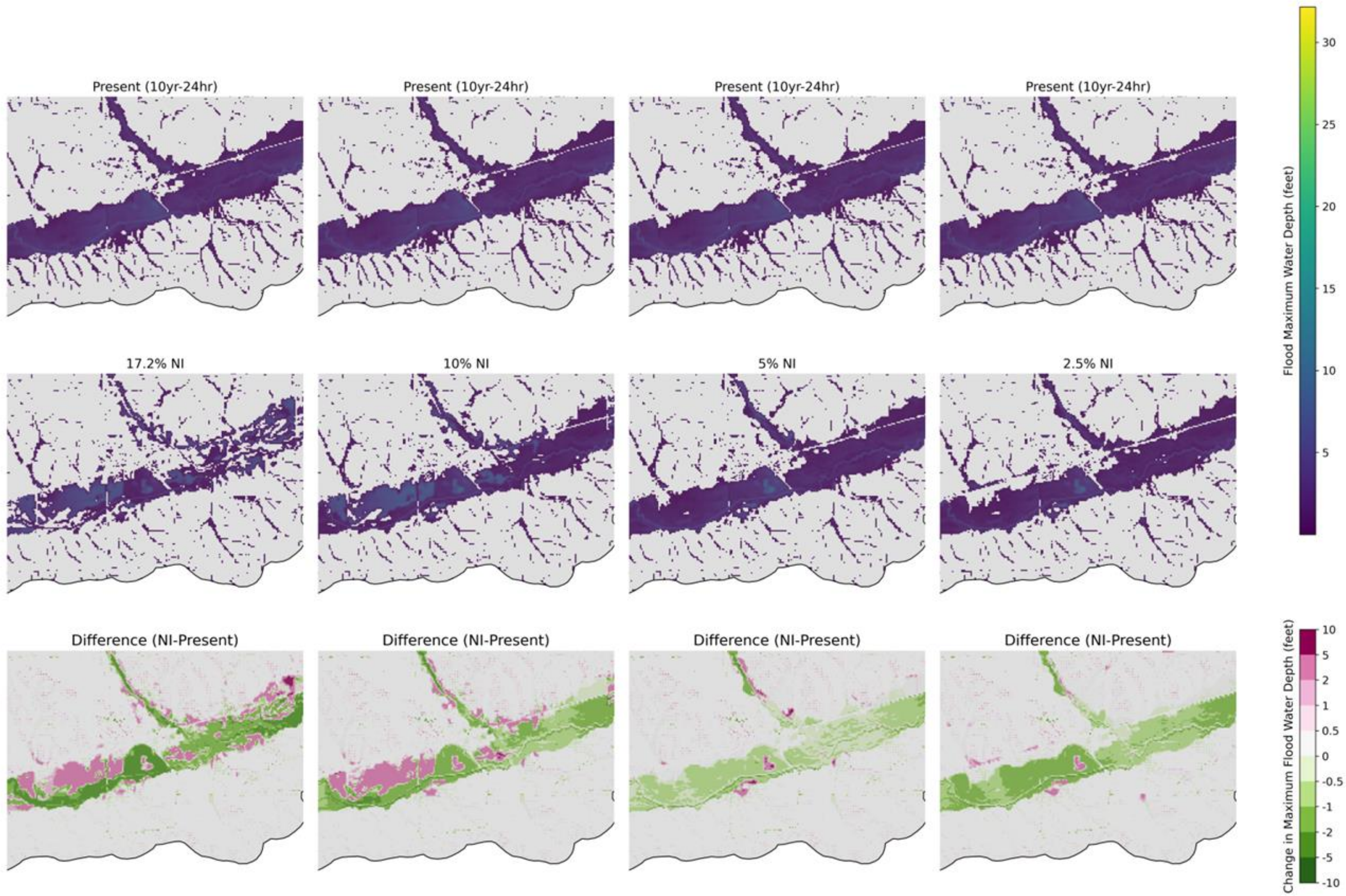

Figure 7-12. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Norway, IA.

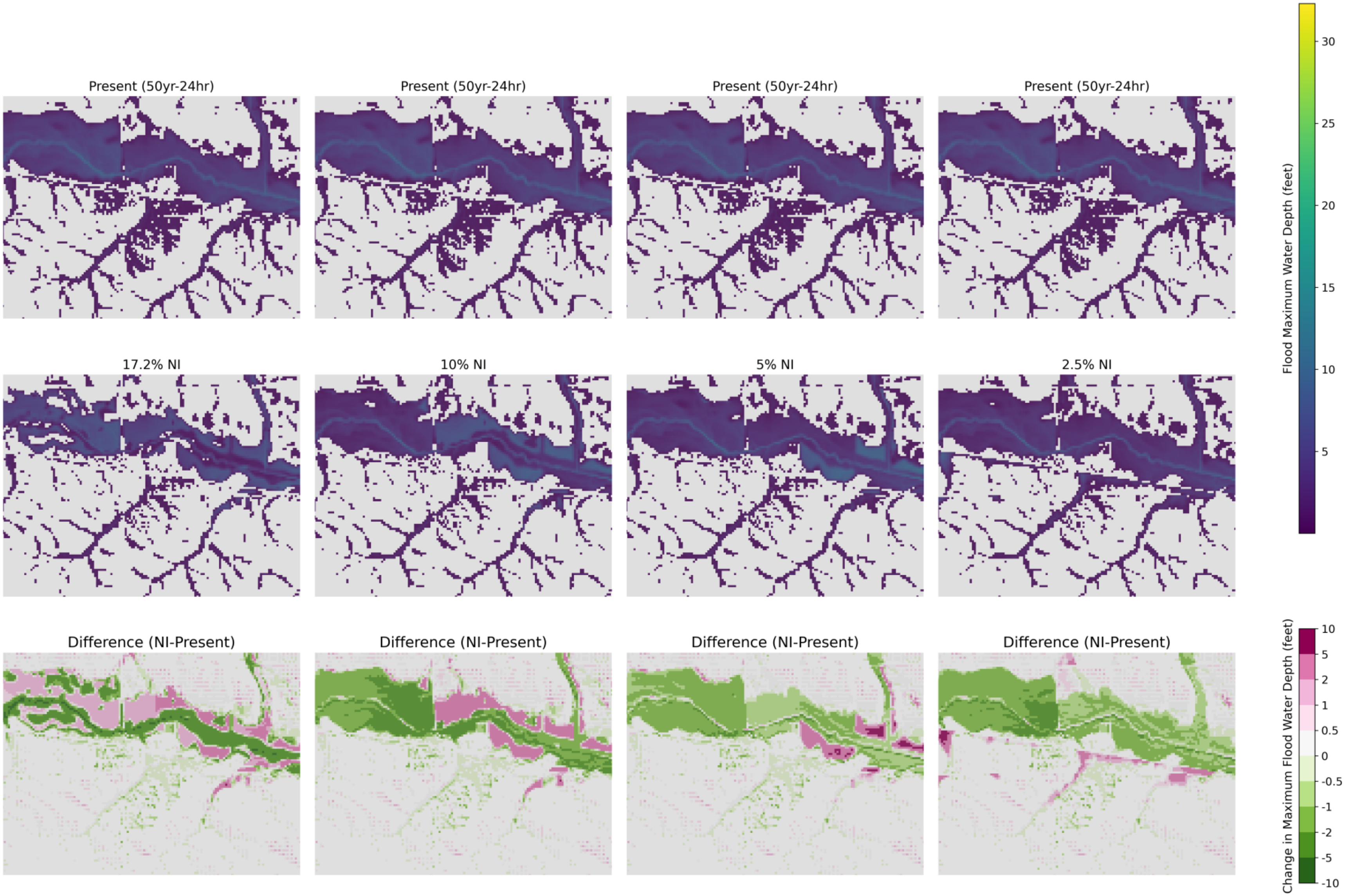

Figure 7-13. Maximum flood depths for 50yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Keystone, IA.

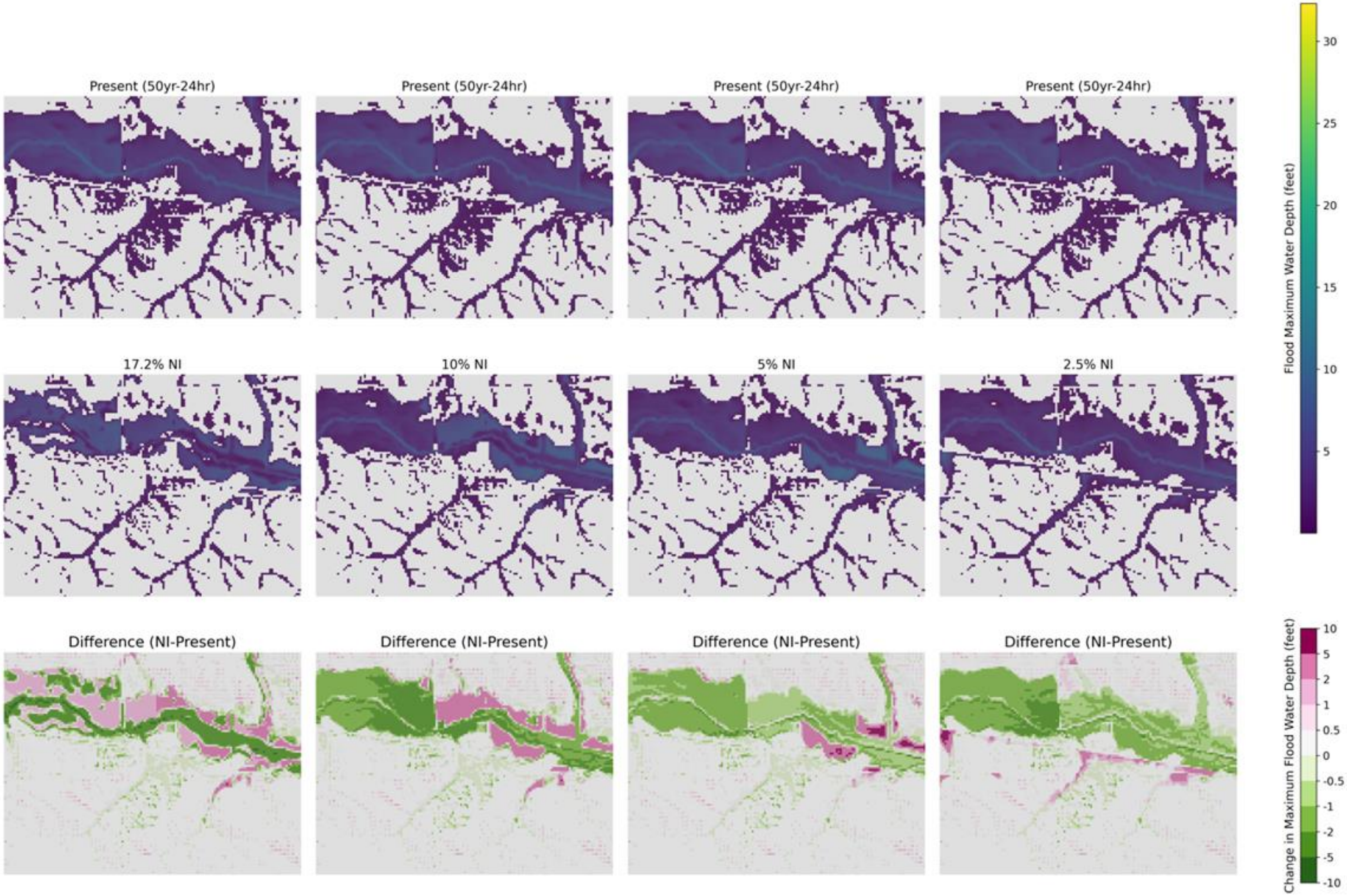

Figure 7-14. Maximum flood depths for 50yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Blairstown, IA.

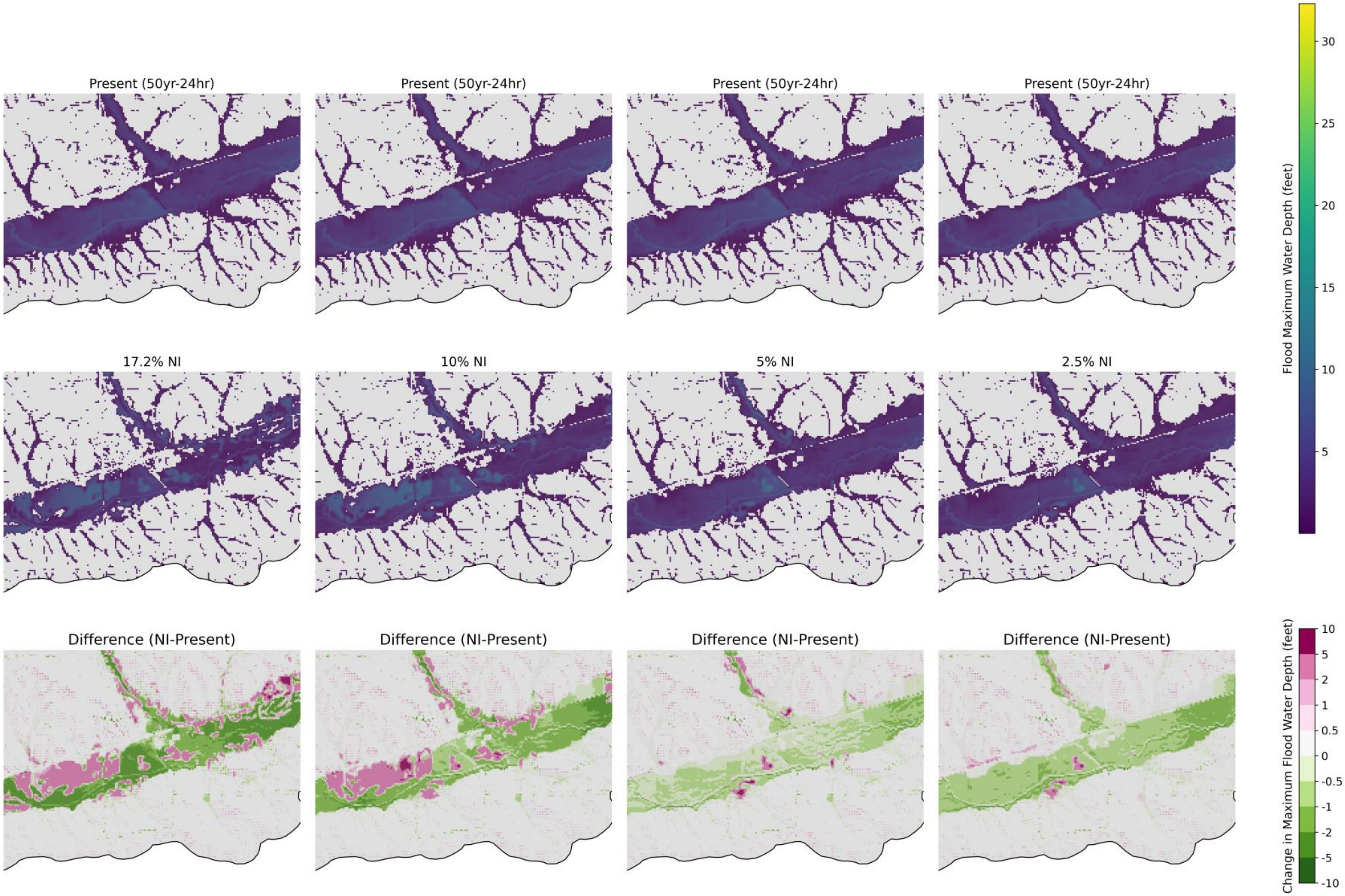

Figure 7-15. Maximum flood depths for 50yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under present rainfall conditions near Norway, IA.

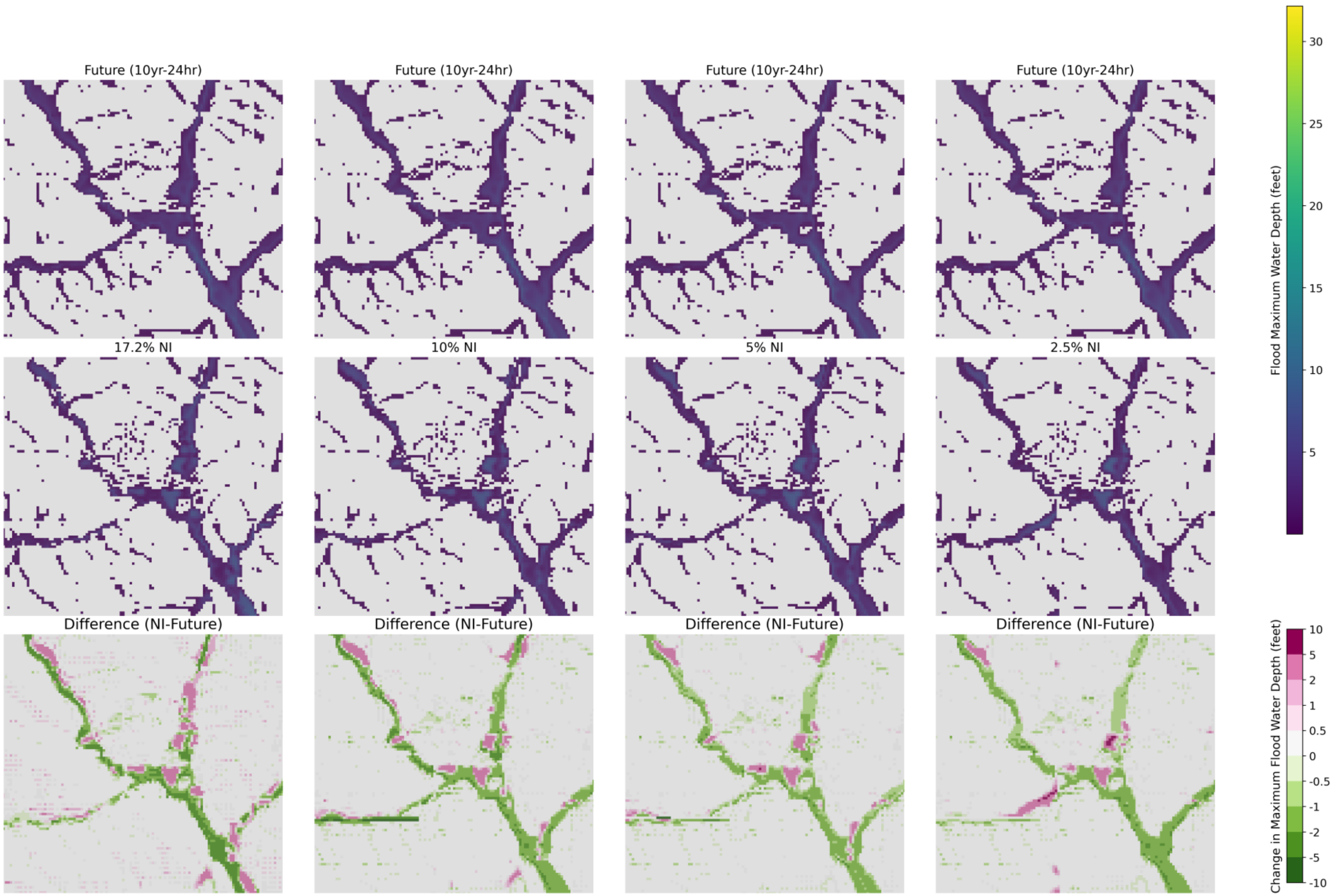

Figure 7-16. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions near Keystone, IA.

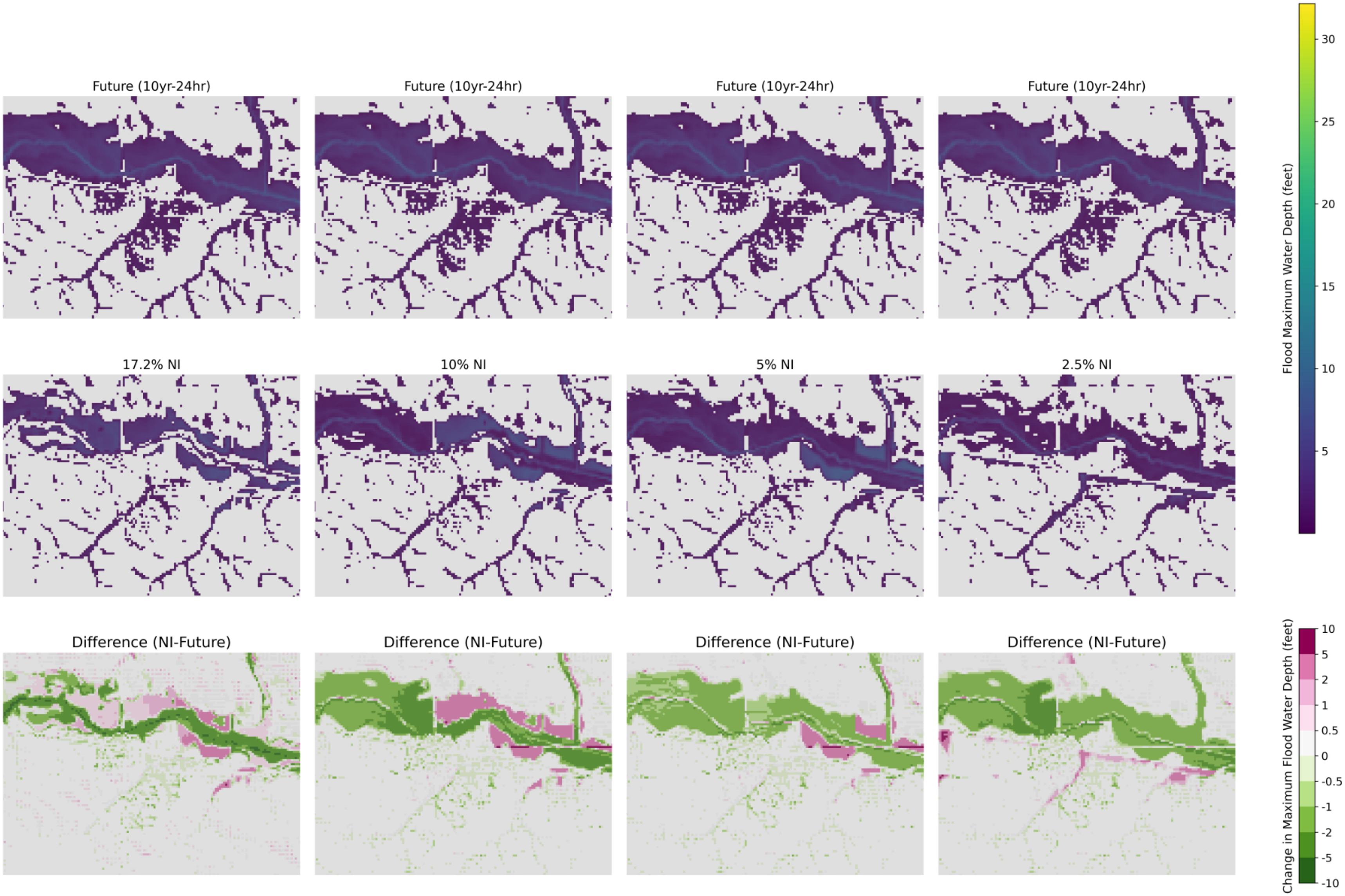

Figure 7-17. Maximum flood depths for 10yr-24hr rainfall: baseline (without NI) and NI modeling scenarios at 17.2%, 10%, 5%, and 2.5% under future rainfall conditions near Blairstown, IA.