EVALUATING THE EFFECTS OF INDUCED DEVELOPMENT ON FLOOD HAZARDS AND LOSSES IN U.S. COMMUNITIES WITH LEVEES

by

HERBERT EUGENE LONGENECKER, III

B.S., University of South Alabama, 2004

M.A., University of Colorado, 2009

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William R. Travis

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Stefan Leyk

Date ____________________

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Longenecker, III, Herbert Eugene (Ph.D., Geography)

Evaluating the effects of induced development on flood hazards and losses in U.S. communities with levees

Thesis directed by Associate Professor William R. Travis

The research undertaken in this study evaluates changes in the risk and vulnerability of residential building construction and valuation of eight cities in the United States to assess the changes in flood risk across levee-protected and non-leveed riverine floodplains. Floods cause more losses than any other hazard in the U.S. and losses continue to increase despite long-standing loss reduction policies and practices. To estimate whether levees increase the risk and vulnerability of residential buildings to flooding, this study analyzes residential tax parcels, levee and protected-area data from the U.S. Army Corps of Engineers' National Levee Database, and regulatory floodplain zoning data from the Federal Emergency Management Agency, which administers the National Flood Insurance Program, intended to discourage floodplain development when alternatives are available and encourage mitigation practices and participation in insurance coverage to lessen the necessity for disaster relief funding when flooding inevitably occurs. With empirical information about the history and locations of residential development, the study develops a taxonomy of floodplain occupation types and employs difference-in-differences regression to evaluate treatment (i.e. levee-protected) and control (i.e. non-leveed, non-floodplain) groups before and after levee construction; further, the study constructs a deep history of wetland reclamation to consider path dependency as a theory for explaining changes in residential flood risk and vulnerability. The results of the study indicate that levees are associated with increasing residential buildings' value-at-risk of flooding and increasing vulnerability to flood losses due to canceling of required insurance participation through levee accreditation.

DEDICATION

The research, investigation of history and data, and future work represented in this dissertation is dedicated to improving our knowledge of natural hazards, floodplain occupation, ecosystems, and choices about engineering, while attempting to further our understanding of human adjustments through experience, loss, and foresight. I also dedicate this research and future endeavor to my ancestors in the White family, whose optimism and exploration led to living in the floodplains of New Orleans, working to improve it for themselves and the greater good, all while inspiring a curiosity and drive in me to do the same.

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TABLE OF CONTENTS

Appendix

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Flood control and loss reduction measures in the United States (U.S.) deserve critical evaluation following decades of regulation and mitigation programs designed to alleviate the physical, social, and economic impacts of floods. More than 6 million buildings are located in floodplains and more than 40,000 kilometers (24,855 miles) of levees have been constructed by federal, state, local, or private landowners to protect life and property from floods (Tobin 1995; Pielke 1999; Burby 2001; Burton & Cutter 2008). Floods cause more losses than any other hazard in the US and continue to grow despite long-standing loss reduction policies and practices, and flood risks in the U.S. may be underestimated by as much as 40 percent, likely related to under-mapping or inaccurate representations of 100-year floodplains as stream reaches in headwaters catchments are not hydrologically analyzed (Simons et al 1977; Changnon 2000; Burby 2001; Tobin 2009; Kousky and Kunreuther 2010; Riessen 2010; Sayre 2010; Ludy and Kondolf 2012; Wing et al 2018). Research on the 2008 Iowa floods questions whether nonstructural floodplain regulations have failed to reduce losses and if structural flood control may increase losses (Riessen 2010; Sayre 2010).

By tracing a long arc of historical wetlands and floodplain drainage and reclamation efforts in some European nations that influenced American floodplain development styles, this dissertation establishes *path dependency* as a part of settling hazardous, flood-prone parts of the U.S. with institutions formed to carry out relatively benign and even noble goals. As a supplemental review offered in Appendix A, the establishment of a professional *Army Corps of Engineers* in France in the 1660s that, in peacetime, focused on elements of improving river navigation and transportation, would influence George Washington's establishment of a similar organization in the U.S. just prior to the Declaration of Independence, with an American *Army Corps of Engineers* forming officially in 1802 and earning assignments to improve river navigation and transportation in the 1820s, leading to critical decisions to embark on federal drainage and levee construction projects into the 1840s and 50s. Chapter 2 describes the institutionalization of levee-induced development began in earnest in the 1860s under "levees only" flood control policy established by the U.S. Army Corps of Engineers, which continued as the primary means for reclamation of floodplains for agricultural—and eventually residential, industrial, and commercial—development for another century despite ongoing flood disasters. Typifying the difficulties in changing course from the structural favoritism for flood loss mitigation, the new forms of nonstructural flood loss reduction developed in the 1960s under the National Flood Insurance Program—which implemented federal insurance for flood losses and established building codes designed to decrease the physical vulnerability of buildings to flooding alongside improving flood forecasting and warning systems to reduce social vulnerability to flooding—were challenged by efforts to design levees and dams to effectively remove the needs for flood insurance or other nonstructural mitigation. In the 1980s, efforts to grant design accreditation for structural flood control projects, acknowledging that levees and dams do, in fact, reduce damages from frequent floods, effectively led to the removal of flood insurance and zoning depictions on regulatory cartography—flood zones showing a 1 percent chance of flooding in any given year no longer needed to be shown on flood insurance maps, and communities with such accredited flood control structures, including levees, dams, and floodwalls, would not be required to implement strict land use regulations or building codes. One can argue that path dependency—the institutional reliance on structural flood control, specifically on levees—continues to influence substantially the means by which flood risk management continues at present, even as nonstructural mitigation means have been demonstrated to be both effective for loss reduction and lowering up-front costs.

Historic flood events on the Souris, Missouri, Ohio, and Mississippi Rivers in 2011 revealed differential outcomes of flood control: while catastrophic damage was averted in certain locations, more than 30,000 people were evacuated, thousands of structures were damaged or destroyed, and billions of dollars were lost in affected floodplains. The 2011 flood experience was especially instructive: flood control structures performed as designed in some cases, but in other cases the structures proved inadequate to prevent losses, either because floods exceeded design criteria, or the systems failed to meet design goals. In the case of Minot, North Dakota, extreme spring precipitation produced hydrological conditions beyond structural design criteria in June 2011. The resulting failure of the Souris River flood control systems caused the evacuation of more than 12,000 people and loss of nearly $1 billion as levees were breached or overtopped, allowing floodwaters to damage more than 4,165 buildings in the floodplain (FEMA 2011a). Impacts to all structures in the floodplain occurred, but in this case significant damages occurred to residential buildings constructed after the regulatory floodplain map was reduced in area based on structural flood control improvements to nearby levees and dams, thereby abrogating nonstructural loss reduction policy incentives—in fact, local residents were encouraged to move in and build on the newly reclaimed floodplain of the Souris River (Minot Daily News 1995).

Floods greater than the design criteria of levees do occur and tend to place increasing populations at risk of catastrophic loss. The flood losses of 2011 are similar to other recent years: levee and other flood control systems were tested or exceeded during extreme floods along the Platte and Missouri Rivers in 2019; the Arkansas, Mississippi, and Missouri Rivers in 2015; in Nashville, Tennessee in 2010; along the Red River in North Dakota and Minnesota in 2009; throughout Iowa in 2008; and in New Orleans, Louisiana in 2005, among many other locations. Damages from these events occurred despite billions of dollars of investments in structural flood control. Conversely, flood control and flow regulation that was actively managed during 2015 demonstrated the benefits of structural measures, including levees and dams, for avoiding flood damages.

This research first examines national, regional, and local policies as potential causes of increasing flood hazard, vulnerability, and losses. Next, to address the problem of exposure in floodplains, the study measures changes in floodplain development through analyses of local tax assessor data reflecting locations, construction dates, and valuations of residential buildings in floodplain areas. This research addresses a knowledge gaps in our understanding of flood losses at multiple scales. Increased losses from induced development, possibly accompanied by a false sense of security in the form of levee protection and often influenced by development interests and public media coverage, drives a phenomenon colloquially referred to as the ***levee effect***. This study examines flood risk and offers a evidence in support of a *levee effect* theory. The large and recent flood losses in the U.S. underscore the importance of this research, particularly in consideration of development pressures and potential changes in climate and hydrologic regimes as the U.S. average annual flood losses were $8 billion in 2018 (NWS HIC 2018).

1.1 Definition of Terms

Simons et al (1977) offers comprehensive and useful definitions of flood and flood management terms in land use studies. *Flood control* is defined as "the set of all measures, physical or otherwise, that enable communities that inhabit the floodplain to live in harmony with the extreme natural events, minimizing undue hardship to the extent practicable" (Simons et al 1977, p. 118). Whereas *flood control measures* include all human actions contributing to flood control, *structural measures* include "engineering solutions [designed] to minimize the risk of a watercourse overtopping its bank[.];" *nonstructural measures* include various actions taken to reduce social and economic losses to individuals when flood waters run uncontrolled over a floodplain (Simons et al 1977, p. 127). Examples of *structural* measures include levees, dikes, dams, reservoirs, channel improvements, and floodways, all representative of human-engineered constructions and impediments designed to prevent flood damages or change the course of water; examples of *nonstructural* measures include flood-proofing (land use zoning, elevation of buildings, community awareness of hazard extent, etc.), public relief, and flood insurance (Simons et al 1977, p. 130). Simons et al (1977, p. 128) also defines *flood insurance* as a method to spread individual losses among a wider sector of society.

Referring to *structural* flood control measures, Simons et al (1977, p. 132) describes levees as "small earthen dams placed on the floodplain at a certain distance from the banks of a stream to serve as artificial banks during flood periods when the stream overflows its natural banks." As a result of levee engineering, flood waters may be contained within the artificial banks of a stream or river, but overtopping may occur when floods greater than the design level of the levees occur. When floods occur on streams without levees, water depth on the floodplain increases and water generally flows slowly down the floodplain valley; however, levees effectively eliminate the natural floodplain valley storage and conveyance of water. The hydraulic effects of levee confinement of a river are "1) to increase the rate at which the flood event travels downstream, 2) to increase the river stage for a particular flood event, and 3) to increase the velocity and the scouring potential through the leveed section[.]" (Simons et al 1977, p. 132). Since levees confine floodplains, they increase upstream flood stages, meaning that water may back up and rise in upstream segments as it is channeled into the confined space between levees. Simons et al (1977, p. 133-134) states that levees are the most direct means of flood protection; however, the report also states that uncertainties in calculating maximum probable floods can lead to levee overtopping and intense damage in the areas adjacent to levee "failure:" "[t]he decisive question to answer in assessing levee failure and associated damages is the extent and location of the failure."

In discussing structural flood control decisions, Simons et al (1977, p. 134) states that there are innate risks in all levee systems stemming from uncertainty in calculating maximum probable flood for which levees are designed. In engineering terminology, Moser (2011, p. 27) refers to probable maximum flood as the greatest or "last point in the tail of flood flow frequency distribution … so rare that its probability cannot be established … [which] provide[s] an operational design criterion to meet the engineering design goal of no failures." However, costs for implementing structural measures rise with flood levels; therefore, cost constraints result in levees built below the maximum probable flood stage, with the potential for system failure to occur when a large flood overtops a levee, thus levees provide a design "level of protection" (Moser 2011). FEMA (2006a) states that levees "only *reduce* the risk to individuals and structures behind them; [levees] do not *eliminate* the risk" (emphasis in original). Furthermore, FEMA (2006a, p. ES-3) states that "levees should be considered as *flood risk reduction* structures, not *flood protection* structures." As such, *residual risk* in floodplains "is the portion of the risk that remains after a flood damage reduction structure [that is, a levee] has been built—risk remains because of the possibility that the capacity design level of protection for the structure is exceeded by a flood event that the structure fails[.]" (FEMA 2006a, p. ES-3). The Association of American Floodplain Managers adds that *residual risk* includes the areas behind levees which would flood if a levee fails or is overtopped (ASFPM 2012).

1.2 Unique Data Analysis and Sources

White et al (1975) expressed concerns about both the lack of research into floodplain exposure development in the form of *levee effect* and about the available technologies for carrying out such research. Geospatial Information Systems capabilities advanced substantially in the 1980s with technology and methodological advances; however, studies by USACE found as recently as the late 1990s that comparative research evaluating floodplain restoration and influence of structural flood control on land prices were scant, developing inconclusive or insufficient evidence for demonstrating significant changes in land value in protected floodplains (cf. USACE 1998). While *levee effect* has become a more common, colloquial term with many different flavors and meanings: White (1945) referred to the *levee effect* as a false sense of security that levees would stop all floods and that areas protected were therefore safe from flooding, even as levees were only designed to stop frequent floods and not infrequent floods; Burton (1962) described *levee effect* as farmers with high value crops proceeding in speculative ventures to develop crops on top of levees and into floodways on the river channel side of levees hoping to increase crop productivity, thereby encouraging other farmers to expand crop development further into floodplains; Parker (1995) refers to such increases in floodplain exposure and the ensuing need to increase the heights of levees and floodwalls as the *escalator effect* in the U.K.; similar increases in exposure and flood control height was known as *levee wars* in early Sacramento, California, entailing rival property owners literally destroying levees that may direct floodwaters onto their neighbors' properties; Burby (2006) refers to a *safe development* paradox wherein the federal government tried to make hazardous landscapes safer and actually encouraged risky development, thereby increasing the potential for catastrophic property damages and economic losses; in a confounding twist of terminology, the Association of U.S. State Dam Safety Program managers refer to *hazard creep* occurring when residential construction increases in floodplains downstream of dams (FEMA 2017; ASDSP 2018), even as a more proper term should describe increases in exposure to such hazardous dams or the floods that may be sent downstream by a dam failure or overtopping—few studies have demonstrated how such increases in risky development come to be.

Di Baldassare et al (2015) introduce an intriguing new research framework detailing how floodplain areas without structural flood control measures have occupants who remember floods and associated damages, resulting in development better situated and adapted for expected floods—a green society modeled on coupled social and flood dynamics feedback, whereas communities that have structural flood control measures are less familiar with the frequency and destructive potential of flooding, yielding expansions of adverse development into hazardous floodplains and increasing flood damages—technological societies that take only snapshots of flood risk scenarios every so often, failing to identify fluctuations in flood risks. Other studies examine detrimental ecological aspects of levees disconnecting surrounding floodplains from flood pulses, resulting in habitat losses (cf. Junk 1989; Poff 2002; Opperman et al 2009). Pinter et al (2016) offers substantial evidence for how levees increase water surface heights within leveed-and-channelized floodplains, thereby increasing the residual risk of floodplain occupance—that is, the risk of flood losses should levees fail or overtop during highwater flows. Yet, as each of these studies offer ideas and some evidence for increasing flood losses, increasing flood hazards, or alterations in risk perception as forms of *levee effect*, fewer studies examine changes in exposure to potential flooding as a means to evaluate changes in risk. A study by McMaster (1996) offered intriguing evidence of increasing residential construction permits for building in newly levee-protected floodplains—an absolute measure of increasing exposure, indeed, but without sufficient counterfactual evaluation to assess whether the increase in permits was related to concurrently similar increases in permits for non-floodplain or non-leveed areas.

Pielke and Downtown (2000) established that losses from floods have remained steady on a national scale when data normalization techniques are employed in the analysis of damages, inferring that increasing exposure to flood hazards is a primary driver for loss potential. Annual flood losses vary from year to year, as some years have large floods and others do not, but the National Weather Service Hydrological Information System shows a steadily increasing trend of flood losses (in constant dollars), from about $2 billion per year in the 1990s to about $8 billion per year in the 2010s. The National Flood Insurance Program initially had poor participation in the late 1960s, leading the U.S. Congress to make flood insurance purchase mandatory for federally-backed mortgages via the Flood Disaster Protection Act of 1973; with nearly 8 million buildings in floodplains nationally, there were about 5.1 million flood insurance policies in effect in 2018, down from a peak of about 5.6 million policies in 2015. Research by Michel-Kerjan et al (2012) on flood insurance policy tenure, however, indicated that most homeowners dropped flood insurance policies within 2-4 years of first enrolling; as such, national participation in flood insurance is estimated to be about 50 percent, with many communities experiencing participation rates as low as 3 percent (FEMA 2019).

With all of this in mind, this dissertation employs robust new geospatial and analysis techniques to evaluate changes in residential exposure to potentially damaging floods in six American communities. Calls by the Federal Geographic Data Committee (NRC 2007) and others have led to publicly-available residential parcel data for many communities across the country (Leyk et al 2018), and this research benefits from using such data alongside statistical analysis techniques developed by Card and Kreuger (1994) and institutionalized by organizations such as the European Commission for use in evaluating counterfactual information relative to social program funds. In the following chapters, historical development of American floodplains is laid out in detail to establish the bases for conducting evaluations of residential construction and valuations that serve to increase flood risk locally and perhaps nationally—as such, empirical evidence for evaluating the *levee effect* on flood risk details how levee projects influence the value of and increase in residential construction in selected study areas, providing a critical means for improving knowledge of floodplain risks and filling a gap in research.

CHAPTER 2: A FRAMEWORK FOR LEVEE EFFECT AND INCREASING FLOOD RISK

2.1 Introduction

The problems of flood losses have been managed by modern societies through technical solutions since their very ancient roots, although modern science has provided little improvement to certain methods. By 5000 B.C., engineers had established inundation irrigation methods in Egypt, Mesopotamia, and later in Rome, with clay tablets from 2500 B.C. describing irrigation diversion canals in support of agricultural development on the Tigris, Euphrates, and Indus Rivers (Rogers 1993, p. 103). Around this time, in China, Gun's efforts to contain *The Great Flood*, which persisted through at least two generations, involved mainly structural flood control in the form of dikes, levees, and embankments; however, Gun's son, Yu the Great, changed the flood management policy to dredge river channels deeper to accommodate the inundating floodwaters of the Yellow River (Wu 1982; Luo et al 2015). Yu's efforts in accommodating floods led to significant agricultural development under the Xia Dynasty and, around 700 B.C., Guan Zhong postulated that the Chinese people could be governed only if floods could be controlled, leading to the later development of the Dujiangyan irrigation system that's still in use in modern China—control of the *Great Flood* is fundamental to Chinese agricultural development and culture (Wu 1982; Luo et al 2015). Similar flood management and engineering practices from the Roman empire, France, and England helped develop these states into highly productive centers of agriculture and commerce, laying foundations upon which scientific and economic advances influenced early decisions about river navigation and floodplain management in the United States (U.S.), with a supplemental review offered in Appendix A. These improvements in transportation and agriculture came with significant costs to the environment, however, and only some 37 percent of rivers longer than 1,000 kilometres (621 miles) remain free-flowing over their entire length globally, with "an estimated 2.8 million dams […] regulating more than 500,000 kilometers (310,686 miles) of rivers and canals for navigation and transport" (Grill et al 2019). Though flood risk management and exposure analysis are the central focus of the research conducted for this dissertation, riverine ecosystems have been substantially altered and degraded as the result of the lateral and longitudinal fragmentation of floodplain habitats from dam and levee construction, lessening natural flood storage and causing substantial impacts to biodiversity and flood risk perception, and, further, leading to substantial socioeconomic and political challenges (Junk 1989; Stanford and Ward 1993; Sparks 1994; Costanza et al 1997; di Baldassare et al 2009; Hupp et al 2009; Opperman et al 2009; Noe 2013; di Baldassare et al 2015; Christin and Kline 2017; Grill et al 2019). Appendix B offers a supplementary review of some of the environmental and ecosystems challenges caused by floodplain disconnection and habitat fragmentation. In the following sections, a brief history of levee construction in the U.S. is reviewed along with historical development at the sites selected as study areas for flood risk research; from there, policies and programs designed to manage and reduce flood risk in the U.S. are reviewed. In concluding this chapter, a preview of the experimental design and preliminary research is offered for a pilot case study which was utilized for assessing the feasibility of using certain datasets and spatial analysis techniques for an evaluation of flood risk relative to levee construction in the selected study areas.

2.2 Levee Development & Policies in the Early U.S.

The development of the Louisiana Territories in the U.S. was bound to the French economy of the last years of Louis XIV's reign in France, of which its highly centralized bureaucracy disfavored policies that would have nurtured the economic independence of its American colonies. Though the site of New Orleans represented a "least-cost, minimum distance route" connecting the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean with the vast North American interior which the French sought to develop, "the proximate cause motivating the foundation of New Orleans was the need for a convenient port and company office for the commercial development of Louisiana; the ultimate cause was the French imperial need to defend their Louisiana claim by fortifying its Mississippi River Basin gateway against the English and Spanish[.]" (Campanella 2008, p. 110). The flood hazard in New Orleans, Louisiana was recognized by the very first French settlers, and as city plans developed, royal French engineers allocated high ground to royal acquaintances and low ground areas at high risk of flooding to impoverished servants (Dawdy 2008, p. 64). French investors, recognizing the risky location for the city, argued for alternative sites, due to at least semi-annual flooding from the Mississippi River, with Campanella (2008, p. 110) noting that "establishing a settlement is one thing; ensuring its survival and prosperity is quite another." Despite these calls for relocation, and an awareness that local Indians never seemed to be short of corn based on their sustainable land use practices in the area—which some French settlers learned and implemented successfully, administrators and engineers began levee construction in 1722 (Morris 2000; Dawdy 2008).

Although the early levee system stimulated agricultural growth and prevented disease outbreaks by limiting standing water, the fledgling city encountered new problems: "to make way for new dikes built on top of the existing natural levee[s], farmers had to move buildings and other structures back from the river. […] Gradual movement back from the river [and the river's natural levees] placed settlers in greater risk of inundation, which in turn necessitated still higher levees[.]" (Morris 2000, p. 35). Additionally, buildings at risk of flooding were constructed from swamp trees, the cutting and clearing of which resulted in increased surface water runoff to the river from deforested swamps (i.e., increased runoff from clear-cut timber, not from royal dispossession; additionally, French and British scientists, having studied land use changes in the colonies, generally viewed deforestation and wetlands reclamation as beneficial to economic development despite growing awareness of hazards to settler populations—(cf. Grove 1995, p. 38). Constriction of the river within the artificial banks of the levee system caused the river to rise higher than usual. The first tests of the system by a hurricane in 1732, and again by river flooding in 1734, proved its inadequacy by flooding more than half of the then-developed agricultural land, thereby threatening the livelihood and sustainability of the settlement (Morris 2000; Dawdy 2008). Instead of heeding colonial investors' calls to relocate the city to another area of lesser risk, New Orleans became protected by nearly 85 km of levees by 1752 and 150 km of levees by 1812, with the ensuing creation of a U.S. Army Corps of Engineers in 1802, based on the French model, and the subsequent selling of the Louisiana Territory to the U.S. in 1803.

Federal interests in the development of river navigation in the U.S. often conflicted with traditional, state-based views of federalism at the time of the founding of the U.S. Army Corps of Engineers, leading to rejections of federal funding of canal projects in the early 1800s (Rogers

1993, p. 47). Nonetheless, Thomas Jefferson's Secretary of the Treasury, Albert Gallatin, issued a report in 1808 calling for the development of a nationwide system of canals and other improvements, which was confirmed by the Supreme Court's ruling in support of the federal authority to regulate interstate commerce in the case of *Gibbons v. Ogden* in 1824 (Rogers 1993, p. 48). However, multiple presidential vetoes of river and harbor survey bills occurred prior to the Panic of 1837, caused in part by land speculation and fiscal policy opposing expenditures on public infrastructure, leading to more calls by advocates of centralized federal power to fund and develop complex surveys and levee projects for which local governments and states either could not perform or fund themselves (Blake 1980, p. 20-23; Randolph 2018). Newspapers from Richmond to New York City to St. Louis and Mississippi argued for river improvements and flood control on the basis of federal authorities granted by the commerce clause (Randolph 2018).

In the 1830s and 40s, surveys of river systems commenced, and in 1848, following the report of a survey of the Florida Everglades by Buckingham Smith—who observed that Spain had attempted to drain the Everglades during its ownership of the territory during the late 1600s and early 1700s but failed due to conflicts with native Seminole tribes, and stated in his report that several hundred thousand acres of the Everglade swamplands were "worthless to civilized man for any purpose" and that the area could "only be made valuable by draining the Everglades—a bill was introduced to Congress calling for the drainage of the Everglades of Florida, then only a state for three years. The bill, recommended for passage by the Committee on Public Lands, noted that surveys by Spanish and British engineers were incomplete, that the subaqueous lands may become salable for local interests and to the U.S., and that no calculation on the future improved value of the reclaimed lands could be made based on data captured in survey explorations: "**The true consequences and results can only be ascertained by the experiment actually being made**" (Congress 1911, p. 45-47). In 1849, following levee breaks and substantial flooding that caused the evacuation of 12,000 residents of New Orleans, Congress passed the first Swamplands Act, donating to and allowing the State of Louisiana to sell its "valueless" wetlands in order to raise funds for constructing levees and drains (Treasury 1852; Rogers 1993; Changnon 2000; Randolph 2018). Large portions of wetlands areas in the Mississippi, Ohio, Sacramento, and Columbia River watersheds were transferred to the states for agricultural development so that these public lands, previously owned by the federal government, could be sold to private developers who would then construct levees and other flood control measures for agricultural development and control of new territories (Flood Control Act of 1917). Subsequent Swamplands Acts passed by Congress in 1850-1860 transferred nearly 65

Table 1. Wetlands (swamplands) transferred from the federal government to the states for drainage and reclamation, 1849-1860. (Data Source: USGS 1996)

Year	State	Hectares	Acres
1849	Louisiana	3,841,794	9,493,456
1850	Alabama	178,580	441,289
	Arkansas	3,110,588	7,686,575
	California	887,408	2,192,875
	Florida	8,225,087	20,325,013
	Illinois	590,896	1,460,164
	Indiana	509,583	1,259,231
	Iowa	484,154	1,196,392
	Michigan	2,298,697	5,680,310
	Mississippi	1,354,806	3,347,860
	Missouri	1,389,050	3,432,481
	Ohio	10,672	26,372
	Wisconsin	1,360,036	3,360,786
1860	Minnesota	1,904,619	4,706,503
	Oregon	115,782	286,108
	Total	**2,790,423**	**6,895,415**

million acres of wetlands to the states of Louisiana, Arkansas, Alabama, California, Florida, Illinois, Indiana, Iowa, Michigan, Mississippi, Missouri, Ohio, Wisconsin, Minnesota, and Oregon—a sign of the national interest in reclaiming wetlands for agricultural development and control of territories newly added to the U.S. (Congress 1911; USGS 1996).

There is substantial discussion of levees in an 1851 report by the U.S. Treasury, highlighting that individual “proprietors” constructed inadequate and unsafe levees along nearly 700 miles of the Mississippi River, from its mouth at the Gulf of Mexico to the confluence with the Ohio River, with piecemeal levee construction proceeding along the Ohio and points north of Missouri; further, there are references to constructing levees to the height of rooves of residential buildings near the mouth of the Mississippi in order to extend the delta into the Gulf some 20 miles, similar to development in the Po River delta in Italy—which the congress desired to create similar construction and economies in Louisiana (Treasury 1851). Discussion in the 1851 treasury report and a follow-on report on Mississippi River inundation investigations from the Secretary of War also centered around a few key observations: 1) that there would be no turning back from levee construction, as agricultural and proprietary interests in the Mississippi watershed depended on the levees for sustaining their economic viability; 2) that the US swamplands territories were being drained and settled, **with up to 100 million emigrants expected to occupy reclaimed wetlands by 1900**, and that newly deforested lands resulted in increased runoff into river channels, increasing flood heights (as opposed to decreasing channel depth, a topic of concern in these reports); 3) therefore, that levee construction would “inevitably” proceed, no matter the consequences to leveed lowlands from sending increasing amounts of water down the Mississippi River channel from uplands—indeed, there was substantial awareness of flood heights increasing as a result of levee construction (Treasury

1851). In particular, there was substantial awareness by the Secretary of War that "the recent increase in the height of floods in the lower Mississippi is a result, not of natural, but of artificial changes":

> It is only these most disastrous floods which now almost annually occur, sweeping over the works of industry from year to year, devastating extensive regions, and which are referable to causes that society has created, and is still creating, and which it is therefore in the power of society to prevent. […] The floods which now carry annual distress and destruction into the lower Mississippi, it is maintained, are essentially the result of artificial causes. The water is supplied by nature, but its *height* is caused by man. […] *This cause is the extension of the levees.* (Treasury 1851, p. 47-48, emphasis in original)

With canal projects connecting inland waterways in the northeastern parts of the country and levees moving north from the former French territories, the Army Corps of Engineers adopted a "levees-only" policy for improving river navigation and *protecting* agricultural developments into the 1860s following completion of surveys of the Mississippi River by Andrew Atkinson Humphreys. Though hailed as "one of the most profoundly scientific publications ever published by the U.S. government," the survey erroneously argued that the bed of the Mississippi River consisted of hard blue clay—which could not be scoured sufficiently by channel and flow restrictions from levees so as to keep the river channel free from blockages (Reuss 1985; Randolph 2018). Notably, states began using convict labor to construct levees following the conclusion of the Civil War as a means of race control and discipline for the labor force (Cardon 2017, p. 419). Whereas African slaves had economic value prior to abolition, and were not used as labor for levee construction prior to the Civil War due to the inherent dangers (*e.g.*, Cardon 2017 describes a case involved a black convict forced to work with no shoes in freezing temperatures, resulting in severe frostbite and amputation of both legs, among other cases), convicts had no inherent economic value and were viewed as a commodity which could be exploited for labor—building levees—while preserving power among rural white farmers and plantation owners (Figure 2.1):

> Confined to labor on dangerous levees and railroads, the convict lease suggested to many observers that African American labor needed to be compelled. The convict lease, like other forms of racial intimidation, was used to maintain the power of white planters and employers in the New South. [...] In the antebellum period it was in the economic interests of slave owners to ensure the survival of their slave population, whereas the lessee's only concern was the forcible extraction of a convict's labor. In economic terms, it made sense to keep the convict at a subsistence, if not lower, level. […] On Louisiana's levees and railroads African American men were forced to labor in the construction of a modern state. […] An 1897 report by the state warden fixed the death rate for the years 1882 to 1894 at approximately 10.5 percent. The reason given for such a high death rate was that most of the convicts worked on levees where malarial rates were extremely high." (Cardon 2017, p. 420-23, 436)

Figure 2.1. Leased convicts building a levee along the Atchafalaya River, Louisiana, 1901. (Source: Cardon 2017)

Inspired by the attempts to control floods in Louisiana, settlers in California introduced levees to the Sacramento and American Rivers to assist with agricultural development in accord with the Swamplands Act (Flood Control Act of 1917; O'Neill 2006; James and Singer 2008). Similar to the investors of New Orleans, who called for the city to be located somewhere that did not flood so often, surveyors, including adventurer John Sutter, "derided the decision to erect a settlement [i.e. present-day Sacramento] at the confluence of the Sacramento and American Rivers [because] the land was so low that a rise of the river above normal would cause a flood … with heavy loss of life and property[.]" (Holmes 2013, p. 119). Just after settlement commenced in 1848, severe flooding in 1849-50 prompted the new city of Sacramento to allocate funds to construct 14.5 kilometers (9 miles) of levees at heights of about 1 meter (3 feet) along the banks of the American River and to heights of 1.8 to 6.1 meters (6 to 20 feet) along portions of the Sacramento River using an estimated 3,400 cubic meters (4,444 cubic yards) of earth placed by the shovels and barrows of Chinese labor crews (USDA 1993; Holmes 2013). Prior to 1850, however, the Sacramento River had a uniform and consistent channel, with consistent depths of 3-4 meters (9-13 feet), allowing seagoing ships to pass with little disturbance, regardless of flood conditions (Flood Control Act of 1917). Transferring authority for levee construction to newly formed local districts, "increased flooding and local *levee wars* resulted," with "the lands of the wealthy […] fortified at the expense of the poorer farmers both on the other side of the river and downstream" (Holmes 2013, p. 122, emphasis added). Though the Sacramento basin was prone to flooding, the floodplain rose by nearly 2.44 meters (8 feet) in less than 40 years due to nearly 677 cubic meters (885 million cubic yards) of debris washed into the waterways of the Sacramento Valley waterways—"amid the anarchy that followed [transfer of flood control authorities from the state to local districts], a masked party rowing to a disputed high [levee] embankment with dynamite in hand attempting to save their lands from flood was not an uncommon sight along the Sacramento and its tributaries [as] residents of one bank of the river [were] frequently pitted against those of the other bank" (Holmes 2013, p. 122). Further, exacerbated by use of convict labor for building levees and Folsom Dam, local "wars" of increasing levee heights to protect one property over another caused a "levee building spiral" as property owners, levee districts, and municipalities "sought to protect itself with levees to deflect water on its neighbors" (NRC 1995): "the time was apparently approaching when the cost of levees, high enough and strong enough to keep above the rising flood plane, would exceed the value of the lands which the levees sought to protect[.]" (Flood Control Act of 1917; Fair Oaks 2018). Made aware of the environmental damage and flooding caused by hydraulic mining and levees, Congress would pass the Flood Control Act of 1917 with the intent of repairing the damages to agriculture and river navigability (Flood Control Act of 1917; O'Neill 2006; James and Singer 2008).

As the structural flood control effort on the Mississippi River evolved into a "levees-only" policy implemented by the Army Corps of Engineers from the 1860s through 1920s, policy calling for widespread development of structural flood control—levees and dams—led to efforts to control other major rivers and flooding problems throughout the US during the 1930s and 40s with billions of dollars spent to construct these defenses largely as a result of the Mississippi River flooding of 1927, described at the time as the "greatest peace-time calamity in the history of the country" with more than 700 people drowned, 330,000 rooftop rescues, 637,000 people displaced from their homes, and more than $5 billion in property losses (2018 dollars)(White and Haas 1975; Arnold 1988; Changnon 2000; Pearcy 2002; Randolph 2018). A similar incident in Franklinton, Ohio in 1889 foreshadowed the larger Mississippi River event:

following the allocation of about $50,000 for flood control along the west side of the Scioto River and subsequent levee construction, residential growth in the protected floodplain immediately increased exposure to potential flooding—in 1913, a major flood occurred and overtopped the levees, resulting in 500 buildings destroyed, 96 lives lost, more than 20,000 people left without homes, nearly $509 million in property damage (2018 dollars), and a decline in residential building values in the protected floodplain of more than 50 percent; President Woodrow Wilson named the American Red Cross the official disaster relief agency as a result of the incident (Fitzpatrick and Morris 1897, p. 29, 187; USGS 1964).[1] In response to calls for structural flood control implementation standards, the Mississippi River Commission, formed as part of the Army Corps of Engineers in 1879, established the *project design flood* in 1928 to provide a standardized goal for the level of protection to be provided by levees and dams; however, the ensuing reconsideration of the levees-only policy led to development of design and implementation standards for dams and reservoirs to control floods (Pearcy 2002; MRC 2012). Activists favoring federal flood control funding organized annual conventions and media campaigns "to sway public opinion and pressure Congress to fund flood control and river navigation projects"; furthermore, these lobbying conventions explicitly used newspapers to "represent their [own] interests as being aligned with that of a presumed public" (Randolph 2018). Local governments and flood control districts "had exhausted their financial resources"

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[1] After the 1913 flood, Franklinton residents began calling for additional flood control, which would take nearly 90 years to obtain in the form of improved levees and a floodwall. Notably, FEMA's first FIRM for the area in 1978 showed the SFHA constricted to the Scioto River channel only, with no zoning for levee protection shown on the map whatsoever. In 1983, a more detailed hydrological study of the river showed the areas behind the levee as not protected and in the SFHA via Zone A12 designation, thereby requiring flood insurance and resulting in the city imposing development restrictions in the area. Following completion and certification of the levees and floodwall in 2004, a 2004 version of the FIRM showed the levee-protected areas in Zone X, no longer requiring the purchase of flood insurance and resulting in the lifting of development restrictions. FEMA's most recent FIRM, issued in 2008, keeps the levee-protected areas in Zone X.

for building levees, with many issuing bonds “far beyond the total assessed valuation” of the flood control districts and reclaimed lands (Arnold 1988, p. 20). During development of the potential legislation for flood control following the 1927 floods, the Coolidge administration feared that federally-funded flood control would entail enormous costs and run counter to the Republican party’s strict fiscal conservatism; as a result, and in close coordination with the Chief of the Army Corps of Engineers, “the reassessment of flood control policy would be politically, rather than technologically, driven[.]” (Pearcy 2002, p. 174). Funding authorities provided by the Flood Control Act of 1917 and 1928 would later be augmented by similar acts in 1936, 1944, and 1955 to support the construction of levees, dams, and reservoirs across the country. It was not until the 1950s and 60s that nonstructural measures—including flood-proofing, relocation, insurance, and land use regulations—began to gain traction in the nation’s efforts to reduce flood losses as a result of Gilbert White’s seminal work on floodplain occupation and Ian Burton’s typifying of agricultural floodplain uses (White 1936; Burton 1962; Changnon 2000; White et al 2001). Still in use for designing structural flood control devices today, the current project design flood, updated in 1955, represents approximately 35 hypothetical combinations of atmospheric storms that could produce large amounts of precipitation and runoff affecting the Mississippi River and its tributaries (MRC 2012).

2.3 Brief Historical Review of Study Areas

In consideration of the widespread efforts to drain wetlands, channelize rivers, develop agriculture, improve navigation, and co-exist with significant flooding, several study areas are prime for research to evaluate changes in flood risk as a result of structural flood control measures implemented. This section describes the historical development of the sites where levees and flood risk have contributed to historical flood damages.

2.3.1 Establishment of Minot on the Souris River, Ward County, North Dakota

The Souris River originates near the town of Weyburn in the Canadian province of Saskatchewan and flows southward into the U.S., forming a southeastward-to-eastward-to-northward flowing, 338-kilometer (210 mile) loop in the State of North Dakota that reenters Canada in the province of Manitoba before merging with the Assiniboine River near the town of Brandon for a total channel length of about 700 kilometers (435 miles) (USGS 2016). The Souris ("Mouse" in French) River, draining approximately 61,000 square kilometers (23,552 square miles), was named by French fur trappers and is referred to officially as the Mouse River by state legislation passed in the 1960s (Picha and Gregg 2016). The Souris River Basin generally consists of gently rolling prairie landscape with deep, broad, flat alluvial floodplain valleys (Picha and Gregg 2016; USGS 2016). The Souris River Basin is prone to snowmelt flooding, though the basin only receives about 38 centimeters (15 inches) of precipitation per year, with two-thirds occurring between May and September (USGS 1960; Picha and Gregg 2016).

Following passage of the Homestead Act in 1862, agricultural and railroad construction opportunities brought American surveyors to the Dakota Territory in the 1860s and settlers en masse to river valleys in the 1880s, with overall population increasing from about 16,000 to about 191,000 from 1878-1890 and a large flood observed on the Souris River in 1881-1882 (Lounsberry 1919, p. 228; USGS 2016; Torbenson 2018). Earlier expeditions into the Dakota Territories noted substantial floods that flowed northward to Hudson Bay, occurring in 1828, 1861, and 1873, and Lounsberry (1919, p. 258) notes that surveys were conducted "with a view to Government action toward relieving the valley[s] from the disastrous effects of these floods, which [were] not as severe, however, as they were in the early days [of exploration and settlement]." Later, in the Souris River Valley, using swamplands granted to the state to aid in railroad expansion (Lounsberry 1919, p. 340), construction on the Great Northern Railroad stalled due to difficulty constructing a trestle bridge, and, with winter coming, the town of Minot was established as a temporary tent city with a population of about 400 construction workers in the fall of 1886; by 1887, Minot was incorporated as a city at this location, with nearly 5,000 people living in the nearby areas and growing to about 6,188 by 1910 (Torbenson 2018). Little of Ward County was cultivated for agriculture before 1900 (USDA 1974). Indigenous Sioux and Chippewa tribes protested the settling of the Dakota Territories, generally, and specifically the Souris and Red River Valleys, which Lounsberry (1919, p. 353) characterizes as fish and bird habitats being driven away by steamships and boat traffic; moreover, Quivik (2009, p. 308-310) describes such habitat disruption extending to the draining of nearly 8,094 hectares (20,000 acres) of wetlands by farmers straightening the channel of the Souris River in 1912 to increase cropland area, leading to "precipitous declines" in waterfowl reproduction habitats and populations: "In 1924, North Dakota's Game and Fish Commissioner reported, 'where ducks formerly bred in thousands, we [now] find tens or none.'" Perhaps worse than the habitat destruction was the finding that drained wetlands along the Souris River were unsuitable for many crops (Quivik 2009); however, as farms mechanized up to the 1960s, farms and cropland grew to nearly 486,000 hectares (1,200,000 acres) out of the county's total 532,502 hectares (1,315,840 acres)—about 92 percent (USDA 1974). By 1950, Minot's population reached 22,032 (USGS 1960), and about 66,946 people live in Ward County among 33,103 housing units with a median value of $211,900 as of 2018 (Census 2018).

2.3.2 Establishment of Iowa City on the Iowa River, Johnson County, Iowa

The Iowa River Basin was "a combination of forest, prairie, and wetland landscape" with mixed forest and tallgrass prairie ecosystems around 1620 (USACE 2014). As American exploration and settlement expanded westward, Congress allocated $20,000 in 1839 for constructing buildings and the establishment of Johnson County and a permanent seat of government in and capital of the Iowa Territories (Irish 1868). The present-day site of Iowa City (Figure 3.3) was, in 1839, a "perfect wilderness," and the city was chosen to be situated on high grounds to either side of the Iowa River, with land speculation and sales commencing in 1839 (Irish 1868). By 1850, the Iowa River Basin was largely deforested, and the landscape transformed to mostly hilly prairie with scattered wetlands and shallow lakes that were disconnected from rivers, with the Iowa River cutting a broad, flat alluvial valley across the county from north to south (USDA 1922; USDA 1983; USACE 2014). Between 1840 and 1915, "titles to land were obtained in due form, and the county steadily advanced toward highly prosperous agricultural conditions" (USDA 1922). By 1920, Iowa City had a population of about 11,267 and the entire county about 26,462 (USDA 1922).

Johnson County is about 1,603 square kilometers (619 square miles) in area and is drained by the Iowa River over gently rolling topography (USDA 1983). Farming is the predominant economic activity in Johnson County, with more than 139,617 hectares (345,000 acres) dedicated to farmlands by 1980; however, areas around Iowa City and its narrow floodplain were rapidly urbanizing through the 1970s due to increasing enrollment at the University of Iowa (USDA 1983). In 2018, about 149,210 people resided in Johnson County among 63,859 housing units at a median value of about $210,400 (Census 2018).

2.3.3 Establishment of Waterloo/Cedar Falls on the Cedar River, Black Hawk County, Iowa

The Cedar River originates in southern Minnesota and flows southward through eastern Iowa, draining more than 20,200 square kilometers (7,800 square miles) over about 482 kilometers (300 miles) in length before joining the Iowa River at Fredonia, Iowa (USGS 2018).

Based on physical characteristics, the Cedar River Basin is divided into the Upper, Middle, and Lower Cedar River Basins, with the City of Cedar Falls marking the beginning of the Middle Basin, which extends southward to Cedar Rapids, draining an area of about 6,242 square kilometers (2,410 square miles), with Prairie, Beaver, Black Hawk, and Wolf Creeks comprising major tributaries (USGS 2018). Average annual rainfall in the Cedar River Basin is about 88.24 centimeters (34.74 inches), and topography varies along the river from flat, poorly-drained topography in the Lower Basin to a gently rolling upland land surface with well-draining terrain in the Upper and Middle Basins (USGS 2018). The USGS (2018) states that "more than 80 percent of the basin is used for agricultural purposes" and that about 515,000 people live in cities and towns in the basin as of the 2010 Census; however, a USACE report from 1991 suggests that up to 95 percent of the Cedar River Basin is used for agriculture.

Prior to the arrival of European and American settlers in the 1830s, the Cedar River Basin was populated with dense timber forests and occupied by Fox (Meskwaki) and Sauk tribes, which sold millions of acres of land to the US following the Black Hawk War in 1832, and for whom Chief Black Hawk became the namesake for the county in 1843 (USDA 2006; Jung 2007; Black Hawk County 2018). A French fur trapper named Gervais Paul Somaneaux is the first known European to have settled Black Hawk County around 1837, followed by Americans William Sturgis and Erasmus Adams in 1845 at Cedar Falls, concurrent with Iowa's statehood, and by 1860 there were about 8,244 people residing in the county (USDA 2006; Black Hawk County 2018). Though started as a predominantly agrarian community by Sturgis and Adams, more than 50 percent of the county's population lived in the Cedar Falls-Waterloo urban area by 1895; by 2000, nearly 90 percent of the county population was centered at Cedar Falls-Waterloo (USACE 1991; USDA 2006). Of the county's 1,485 square kilometers (573 square miles), about

72 percent is cropland, 20 percent urban land with 132,648 people and 57,856 housing units at a median value of $139,300; 5 percent is designated for recreational activities, 2 percent is timberland, and 1 percent permanent pastureland (USDA 2006; Census 2018). Damaging floods occurred at Waterloo/Cedar Falls in 1947, 1961, 1965, 1968, 1969, 1974, 1990, 1991, 1993, and 2008.

2.3.4 Establishment of Burlington on the Mississippi River, Des Moines County, Iowa

Des Moines County is located in the southeastern corner of the State of Iowa and the Mississippi River forms the eastern boundary, giving an area of about 1,059 square kilometers (409 square miles). Topography of the county is comprised of "gently undulating upland plain having a gentle slope to the southeast" and "an alluvial belt along the Mississippi" River on the eastern boundary with a marked, "almost sheer drop" in elevation from the plains to the alluvial valley of about 50 to 58 meters (150 to 175 feet) (USDA 1925). The channel of the Mississippi River abuts the eastern boundary of the county, with alluvial floodplains extending about 5 miles into the county near the northeastern corner of the city of Burlington (USDA 1925). About 90 centimeters (36 inches) of precipitation fall in Des Moines County annually.

The first permanent settlement at Burlington occurred in 1833 when the Sho-Ko-Kon fur trading post was claimed by Doolittle, White, and McCarver, with businesses, homes, and river commerce starting in 1834; however, these original settlers were considered land speculators, and they sold their claims to newcomers before titles to the land were recognized by the federal government (Boeck 1961). The USDA notes that most homes in the area were built initially along streams for protection from prairie fires (USDA 1925). In 1836, Congress passed a law that directed the Surveyor General to divide the land at Burlington into town lots for public sale to the highest bidder with valuation determined by location; however, the "law reserved for public use a strip of land on the [Mississippi] river bank running the length of the town" (Boeck 1961, p. 9). The population of Burlington was 517 in 1836 and elections commenced in 1837, with Burlington becoming the capital of the Iowa Territory in 1839 (Boeck 1961). Speculation drove land prices and the local economy in Burlington into the early 1840s, with local papers "predict[ing] that money invested in or around Burlington would double itself in less than five years" given increasing population under emigration: "The Gazette [newspaper] looked forward to heavy immigration to aid the area and told its readers that in Ohio whole neighborhoods were about to emigrate [to Burlington.]" (Boeck 1961, p. 17). With little political representation in the early Iowa Territory, residents of Burlington were reliant on the federal government for aid in building infrastructure, particularly with regard to improvement of the Iowa and Des Moines Rivers, and also regarding clearing obstructions from the Mississippi River channel as editorials from the local newspapers drew attention to transportation issues and the dangers of individuals attempting to improve the channel themselves (Boeck 1961). Through the 1840s, residents became aware of a "shortsighted sense of security" in the town's location as settlements up- and downstream came into existence based on competitive, strategic advantages granted by more consistent, favorable river conditions—regardless, local newspapers boasted that "Burlington was increasing faster in wealth, population and buildings than any town north of St. Louis" (Boeck 1961). By 1850, nearly 40 percent of the adult men in Burlington were foreign emigrants (Boeck 1961). The local newspapers would continue to strongly influence public perception into the late 1850s, claiming Burlington to be an industrial city focused on railroad and river commerce with land "100 percent cheaper" than other sites along the Mississippi River, needing federal support for improving river navigation to stem competition from other river cities (Boeck 1961). About 93 percent of Des Moines County was farmland in 1880, and, by 1920, Burlington had a population of about 24,057 people, with about 32.3 percent of Des Moines County classified as rural and about 28 farmers per 2.5 square kilometers (1 square mile) (USDA 1925). In 1925, the USDA noted that "transportation facilities are excellent" in Burlington, with about 40 trains departing the city in all directions each day. The population of Des Moines County reached 46,982 in and the economy was primarily centered on agribusiness (USDA 1983). In 2018, about 39,417 people lived in the county among 18,590 housing units with a median value of about $101,400 (Census 2018).

2.3.5 Establishment of Tulsa on the Arkansas River, Tulsa County, Oklahoma

The Arkansas River is a major tributary of the Mississippi River system, with its headwaters forming east of the continental divide in the Rocky Mountains near Leadville, Colorado. The river forms from snowmelt in the Rockies, flowing eastward into Kansas and then southward into Oklahoma before turning eastward and flowing into Arkansas and eventually connecting with the Mississippi River for a total length of about 2,364 kilometers (1,469) and a drainage basin of about 440,300 square kilometers (170,000 square miles). Though initially flowing through steep, narrow valleys from the headwaters in the Rocky Mountains, the river widens on the plains and is subject to flooding from seasonal snowpack and melt conditions as well as heavy precipitation in spring and summer months (NHD 2018). Following early explorations of the river by Spanish conquistadors, French fur traders and trappers joined native Cherokee populations in using the river for commerce and transportation of goods.

Following decades of acculturation efforts commenced by the Washington and Jefferson administrations, the indigenous tribes of the Chickasaw, Choctaw, Muscogee-Creek, Seminole, and Cherokee Nations that resided in the southeastern states of Georgia, Florida, Alabama, and Mississippi were forced to move to federally-owned lands west of the Mississippi River under the Indian Removal Act of 1830 as Americans took over these tribes' ancestral farmlands with the expansion of the new United States (Roberson 1977). Among them, the Creek and Loachapoka peoples migrated to the present-day site of Tulsa, Oklahoma, and initially named the settlement "Tallahassee" in 1836 after their former settlement in Florida—notably, the settlement of Tulsa was situated upon a high-ground terrace above the elevation that the Arkansas River often flooded (Roberson 1977). The unsettled forests of the area were cut by men and communal farms cultivated by women (Roberson 1977). Administrative laws were established, and homes built while subsistence crops were cultivated; however, the Civil War divided many of the tribes among support for northern or southern armies and causes, and the settlement at Tulsa was plundered by traders and by in-fighting among the tribes supporting the conflicting U.S. sides (Roberson 1977). Following the end of the Civil War and numerous treaties between the tribal nations and the U.S., ranching ventures emerged around Tulsa into the 1870s and 1880s as longhorn cattle, abandoned during the Texas Revolution, were driven north from Texas and Mexico (Roberson 1977). As "maverick" cattle were organized and driven to markets that included Tulsa at the site of Tallahassee, organized markets at the settlement became the focus of railroad entrepreneurs who made leasing deals with Native American farmers to pen cattle bound for distant markets (Robertson 1977). Businesses, schools, and hospitals grew up around the new railhead at Tulsa, and, under the Dawes Commission, Tulsa was incorporated as a city in 1898, largely by the new population of white businessmen, who surveyed and platted the new city and devalued prime lands owned by the tribes, setting the stage for decades of ensuring racial tensions (Roberson 1977). Newspapers at the time persuaded new settlers to move to Tulsa's newly incorporated, affordable lands, and the population grew to more than 2,000 by 1905 (Roberson 1977, p. 56-57). The discovery of vast oil fields in 1901 drew more capital and business to Tulsa and nearly 7 million barrels of oil were produced each day by 1907, although tens of thousands of barrels were also destroyed by intense rainstorms at the time; Tulsa emerged as a financial and corporate oil hub into the 1910s, with real estate and housing in high demand as the city became industrial with a population of more than 18,000 by 1912 (Roberson 1977, p. 83). By 1928 the city grew to a population of more than 35,000 as development of the city expanded to the north and east of the downtown area originally settled by the Creek refugees (Roberson 1977). Damages caused by floods at Tulsa in 1923, with some 4,000 people evacuated, brought the Arkansas River to the national attention of the Congress, with particular focus on developing the river for transportation through flood control, hydroelectric power, and flow regulation; however, engineering reports provided to Congress in 1936 "found insufficient economic justification for navigation," even as the Flood Control Act of 1936 stated that "flood control on navigable waters and their tributaries is a proper activity of the federal government" (Flood Control Act 1936; Graves and Neushul 2009). Among other strong economic sectors, Tulsa thrived on capital from oil until the 1970s; however, the development of the Arkansas River for commercial transportation following U.S. surveys in 1909 deemed navigation feasible after the passage of the 1936 Flood Control Act based on "a continuous flow of information proving the economic feasibility for a waterway," with the Tulsa District of USACE opening in 1940 "solely for civil works in the Upper Arkansas Basin" (Roberson 1977, pp. 228-232; Graves and Neushul 2009, p.4). Following another survey of the Arkansas River in 1943, Congress authorized $1.2 billion in 1946 for developing the Arkansas River for "cheap, competitive transportation," flood control, and hydroelectric power, allowing the new port of Tulsa to ship wheat and oil to neighboring states, discounting prices to consumers afar and bringing great wealth to the city; as a result, the city expanded revitalization efforts to improve the downtown riverfront areas into the 1960s and 70s (Roberson 1977, p. 232, 239; Graves and Neushul 2009). Construction of the Keystone Dam began in 1956 and was completed in 1964 to the west of Tulsa as a means of flood control and providing hydroelectric power; however, stream flows significantly declined downstream of the dam, significantly altering aquatic populations and leading to degradation "negatively impacting the aesthetic, environmental, and aquatic and riparian ecosystems" that continues to be a focus of river conservation and restoration efforts at present (Graves and Neushul 2009; USACE 2015). As of 2018, 646,266 people reside in Tulsa County and there are approximately 282,942 housing units with a median value of $145,800 (Census 2018).

2.3.6 Establishment of Sacramento on the Sacramento, American, and Consumnes[2] Rivers, Sacramento County, California

Following Mexico's cession of territories in the present-day southwestern United States in 1848, the discovery of gold in the Central Valley of California attracted prospectors and settlers. The Swiss-American pioneer, John Sutter, first explored the area through the 1830s seeking to establish "New Helvetia" (New Switzerland) as an agricultural empire (USDA 1993), and a temporary camp was established at the confluence of the American and Sacramento Rivers that would become a permanent settlement against the wishes of Sutter due to the potential flood hazard. With the passage of the Swamplands Acts of 1849-1852 and 1860, wetlands were transferred to the new State of California for the purposes of reclamation for agriculture; however, the use of hydraulic mining in the late 1800s resulted in substantial waste mud runoff that clogged and altered the course of the American River, resulting in environmental degradation and diminished transportation capacity of the river. The American River watershed

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[2] The correct spelling of the name of this river is Cosumnes. However, the residents of this portion of Sacramento County refer to the river as the Consumnes, adding a consonant based on regional dialect. As such, the local spelling is used throughout this dissertation.

is comprised of an area of about 5,180 square kilometers (2,000 square miles) with headwaters in the high Sierra mountains at elevations around 3,170 meters (10,400 feet) decreasing to about 9.1 meters (30 feet) at the City of Sacramento as the river flows from east to west (NRC 1995; USACE 1997). The Sacramento River Valley is one of the two large lowland areas forming the Central Valley of California—the other is the San Joaquin Valley to the south of Sacramento County—and the headwaters of the Sacramento River form in the Klamath Mountains of Northern California near Mount Shasta, draining nearly 69,000 square kilometers (26,500 square miles) of land and running some 640 kilometers (400 miles) before joining with the San Joaquin River to form a large delta influenced by ocean tides (Garone 2011). The NRC (1995, p. 14) notes that high elevation precipitation does not generally yield flood conditions along the American River; however, annual precipitation varies from year-to-year and can be amplified significantly by subtropical or tropical monsoons from the southwest, leading to extended periods of rainfall and flooding. Whereas the Sacramento River Basin at Sacramento is extremely flat in relief, with the river descending about 0.19 meters per kilometer (1 foot per mile), the American River Basin topography is extremely rugged in the high Sierra mountain regions, forming deep ravines and steep canyons upstream of the Folsom Dam site, flowing downstream into the flat, broad floodplain in the Sacramento Valley (NRC 1995; USACE 1997). Drainage in the American River is comprised of three branches: the North and Middle forks, and the South Fork, which joins the main channel of the American River at the reservoir created by Folsom Dam (NRC 1995). The lower elevations of flat, lower relief of the American River is vegetated by grassland savanna and riparian hardwood trees in the Sacramento Valley, allowing for greater runoff from precipitation and naturally swampy wetlands prior to drainage efforts; moreover, drainage systems have altered the natural wetness of more than 54,633 hectares

(135,000 acres) of wetlands, and more than 8,094 hectares (20,000 acres) of natural soils were altered by hydraulic mining through 1962 (NRC 1995; USDA 1993). Elevations in the Sacramento River Valley range from near sea level in the west and southwestern parts of the county, with nearly level floodplains, to about 122 meters (400 feet) above sea level in the east; however, areas further south in the Sacramento-San Joaquin Valley junction area dip as low as 6.1 meters (20 feet) below sea level, with some areas subsiding as much as 6.1 meters (20 feet) due to drainage and reclamation efforts (USDA 1993). Prior to leveeing, floodwaters filled remnant terrace landforms in the American River Basin that would slowly spread across the entire Sacramento River Basin, creating what Mexican and American settlers described as an inland sea lasting for months at a time (USDA 1993).

Sacramento County is comprised of a total area of 258,820 hectares (639,557 acres), of which about 4,429 hectares (10,500 acres) are rivers, sloughs, and overland reservoirs (USDA 1993). The American River forms the northern boundary and the Sacramento River, flowing from north to south, forms the western boundary of the county; the southern boundary is formed by the Dry Creek floodplain and eastern boundary formed by foothills of the Sierra Nevada mountains; the Consumnes River originates in the Sierras and flows southwestwardly through the southeast portion of the county, running a total length of about 129 kilometers (80 miles) as it descends from about 8,000 in the Sierras to its confluence with the Sacramento-San Joaquin Delta—notably, the Consumnes River is unregulated by dams, has few agricultural levees, and is designated a nature preserve as a "very healthy" river with abundantly thriving ecosystems (Garone 2011)—with both the Sacramento and Consumnes Rivers are influenced by ocean tides (USDA 1993). With the discovery of gold in the Sacramento Valley, the population surged to nearly 10,000 people by 1849 and many farmers became miners before returning to agriculture in the face of industrial mines (USDA 1993). Levee construction commenced following major floods in 1851-52 and continued into the 1860s under state-managed planning; however, passage of the Green Act in 1862 removed the state's authority for flood control planning and transferred levee construction responsibilities to local flood control districts and private landowners, who, in turn, built levees to protect their property over others, resulting in decades of levee wars. In 2018, about 1,418,742 people resided in Sacramento County among 569,705 housing units at a median value of $299,900 (Census 2018).

2.4 The Evolution of Flood Risk Management Policies in the U.S.

As the historical development section reveals, management of flood risk became an increasingly difficult problem for federal-to-local governments over the first century of the U.S. Informal, uncoordinated efforts to build levees from New Orleans northward up the Mississippi and Ohio Rivers resulted in differential levels of flood protection and damages, as also demonstrated in Sacramento's history of protecting higher valued properties over those of lower value. The "levees only" policy of USACE introduced demands for standard flood control project design and numerous pieces of legislation dedicating federal funding to managing both floods and related damages. Yet, with flood relief programs experiencing larger losses by the mid 1900s, despite efforts to structurally reduce flood risk and losses, efforts to introduce nonstructural flood risk management practices were developed as described in the following paragraphs.

2.4.1 The National Flood Insurance Program

The National Flood Insurance Program (NFIP) was established in 1968 to provide affordable insurance coverage for high-risk, flood-prone properties in the U.S. by spreading the risk across whole communities and the country in order to finance losses from floods (Myers and

White 1995; CRS 2018). Although the federal government has provided some level of financial assistance to citizens for flood losses for more than 100 years, the administration of the NFIP, in combination with disaster relief, acts to transfer risk away from areas of high flood risk and loss, including those protected by federal flood control structures (Simons et al 1977; Etkin 1999; Platt 1999; Changnon 2000; White et al 2001; Moser 2011; Shugart 2011; Ludy and Kondolf 2012; CRS 2018). After extensive study and coordination with federal and state agencies in the 1960s, a committee of floodplain experts assembled by the Department of Housing and Urban Development (HUD) recommended that the 1-percent-annual-chance (or 100-year) flood be used as NFIP's standard for risk assessment, insurance ratings, and floodplain management (Hirsh et al 2004, p. 107). Myers and White (1995) state that "the NFIP provides flood insurance only in communities that agree to adopt and enforce land use regulations that guide new development and substantial improvement to existing development in floodplains to ensure it will be free from damage in the event of a 100 year or 1% chance flood." Signed by President Jimmy Carter in 1977, Executive Order 11988 restricts federal funding for development in 100-year floodplains when alternative development outside the 100-year floodplain is possible (CRS 2018). Yet development intensification stemming from structural flood control projects and policies may increase loss potential for private capital, and federal disaster relief policies may synergistically discourage public or private investors from effectively engaging in flood loss reduction or adaptation measures (Anderson and Kjar 2008; Shugart 2011).

Another factor potentially leading to larger losses behind protective flood control structures is a provision of the NFIP declaring protected areas behind federally-certified levees as outside the officially recognized, or regulatory, floodplain (Burby 2006; FEMA 2011b; Ludy and Kondolf 2012; Kousky 2018; Kunreuther et al 2018). That the physical elements constituting floodplains constantly change is a fundamental feature of the physical landscape, detailed in studies of hydrology and geomorphology. However, the changing social elements of human population, location, risk perception, media influence on public opinion, development pressure, political motivation, and engineered interferences or defenses in the physical floodplain are not well understood, possibly making significant contributions to increasing vulnerabilities and losses as a *normal* aspect of flood hazard due to flawed or ineffective loss reduction policies. Areas protected by levees are most certainly in the physical floodplain, yet flood risk and vulnerability to losses may be increased by decisions stemming from policies promoting unnecessary or unsustainable development in high-risk areas when other low-risk areas are available for development outside the physical floodplain (Burton 1962; Parker 1995; Tobin 1995; Pielke 1999; Bell and Tobin 2007; Brody et al 2007; Ludy and Kondolf 2012). Losses outside of the regulatory floodplain account for about 25 percent of flood losses in the U.S. (FEMA 2010).

2.4.2 The National Flood Insurance Program's Floodplain Mapping Process and Terms

The National Flood Insurance Program (NFIP) was created in 1968 as a nonstructural method to manage growing federal disaster relief and assistance costs while reducing future flood damages through implementation of local floodplain ordinances designed to constrain development and introduce non-structural mitigation risk reduction measures intended to replace vulnerable buildings with properly constructed, flood-proofed buildings over time (Myers and White 1995; Huber 2012; NRC 2013; Kousky 2018). Managed by the Federal Emergency Management Agency (FEMA), the objective of the NFIP is to provide flood insurance to homeowners and businesses while also *encouraging* local land management practices that serve to reduce flood risks and losses. The Flood Control Act of 1936 resulted in a massive flood control apparatus and still growing flood losses which required public flood insurance because consumers generally would not pay private risk premium rates. Insurance through the NFIP is generally available anywhere except for areas protected by the Coastal Barrier Resources Act (COBRA), which prohibits federal financial investments relative to any new development in such environmentally sensitive or unstable areas. The program was mandated to be affordable and participation voluntary at the community level. Participation, however, requires insurance purchase in areas designated as *Special Flood Hazard Areas* (SFHA), which are defined as the areas subject to a 1% annual chance of flooding based on engineering studies (hydraulics and hydrology), with goals of protecting existing buildings through various mitigation strategies (e.g. flood-proofing) and preventing new development from increasing flood risk.

Insurance, by definition, is a risk transfer strategy designed to move the risk of a loss from an individual, or policyholder, to another entity, such as the federal government, through the payment of a premium, which determines the level of coverage of exposed property or goods at risk. Insurance is priced according to the coverage required, and risk is reflected through an actuarial rate setting process based on physical hazard, market forces, and other economic considerations: generally, higher physical hazard risks would suggest higher premiums, whereas lower physical hazard risks would suggest lower premium rates. The process of setting the appropriate premium rate based on risks is referred to as underwriting, which refers to the financiers who would literally write their names under the risk information estimated for sponsoring a financial risk. Notably, underwriting is based on *measuring risk exposure* in order to insure risk. Currently, the NFIP insures about 5.6 million properties, covering about $1.2 trillion in asset exposure, and collecting about $2.3 billion in annual premiums with loss coverage up to $250,000 for residential building damages and up to an additional $100,000 for contents (Michel-Kerjan et al 2012; Kousky 2018).

Flood risk is unpalatable to the private sector due to loss clustering over space and time, as catastrophic events account for most losses and only the riskiest property owners buy insurance, requiring insurers to maintain large amounts of capital to pay claims when losses occur; further, properly-priced risk premiums are often disregarded by consumers, resulting in policy abandonment. These issues are commonly referred to as moral hazard and adverse selection. Fire risk insurance is held privately because most fire losses are localized and damage is consistent across years (with wildfires and losses growing, this may be an early signal that private insurers may abandon or reduce coverage in markets with ongoing WUI encroachment or that liabilities of fire ignitions will become unpalatable to insurers, particularly in light of substantial wildfire losses from 2015-2018). Private insurers hold about 260,000 total flood policies, and private insurers may be enticed to offer more policies if clustered risk could be transferred elsewhere through reinsurance or securitization. Notably, the NFIP insures an estimated 8.6 million housing units in 100-year floodplains (NRC 2013 p. 14; Kousky 2018).

Historically, private insurers avoided offering flood insurance to homeowners in floodplains due to a number of factors, including concerns about adverse selection, moral hazard, and the concentration of exposure to possibly catastrophic losses (Kunreuther et al 2018). From approximately 1986 through 2004 the NFIP was self-sustained through premiums raised for floodplain mapping and other administrative functions; however, the flooding of New Orleans by Hurricane Katrina in 2005 resulted in the program falling nearly $17 billion in debt due to subsidized, discounted, or other artificially low premium rates collections, and Hurricane Sandy’s flooding in the Northeast U.S. in 2012 brought the total debt to nearly $24 billion. These terms and issues are important to understanding the levee effect and exposure concerns, but first the *designation* of floodplain areas by FEMA and the NFIP must be reviewed.

There are a variety of other definitions for floodplains that are important for understanding the causes for increasing flood losses. FEMA defines a *floodplain* as "any land area susceptible to being *inundated* by floodwaters from any source." Moreover, the agency defines *flooding* as "a general or temporary condition of partial or complete *inundation* of 2 or more acres of normally dry land area or of 2 or more properties from overflow of inland or tidal waters [or] unusual and rapid accumulation or runoff of surface waters from any source[.]" (FEMA 2014; emphasis added). In a distinction from physical floodplain areas, FEMA defines its *flood hazard boundary map* as "an official map of a community issued by FEMA, where the boundaries of the flood, mudflow and related erosion areas having *special hazards* have been *designated*[.]" (FEMA 2014; emphasis added). That a floodplain can be *designated* reveals a distinction between *physical floodplains* and *flood hazard boundaries* that is very important to note.

Before further examining the nature of floodplain *exposure*, we must consider how floodplains are defined in the physical sciences and by the NFIP. In the physical sciences, riverine floodplains are defined as the low-lying areas adjacent to rivers that are comprised of sedimentary deposits from water overflowing the banks of the river. The sinuous or wavelike horizontal meandering of rivers causes erosion and sediment transport, and the natural deposition of sediments during these lateral water movements results in bars, which appear as islands in a river's channel, and levees, which appear as vertically-piled sediments forming the banks of a river. Accumulated upstream waters can cause a river to overflow its banks and leave sediment in the areas adjacent to a river. This is known as a flood and is characterized by greater than average water flows and overland inundation of adjacent floodplain areas. The physical process of erosional downcutting represents the scouring of water on land surfaces, and floodplains represent the spatial continuum of deposits from a river's channel to a certain distance from the channel, as limited by increasing slope and elevation of land perpendicular to the river channel, thereby comprising the boundaries of the physical floodplain. Floodplain sediment investigation can provide detailed records of both past and present geologic processes relative to flooding and physical floodplain delineation (Aslan 2003). Moreover, the U.S. Department of Agriculture, through its Natural Resources Conservation Service, according to FEMA training materials defines floodplains as having soils that are "recognizably different from soils that are not flooded" and exhibit no development or modification of material composition (FEMA 2015).

A community's participation in the NFIP is based on an agreement with the federal government to adopt and enforce a floodplain management ordinance to reduce future flood risks to new construction in a *Special Flood Hazard Area* (SFHA), also known as the 100-year regulatory floodplain, or Zone A (includes all Zone A designations). In return for implementing and enforcing local floodplain ordinances, FEMA issues Flood Insurance Rate Maps (FIRM) and provides flood insurance through the NFIP; structures located in a community's SFHA are required to purchase flood insurance. As a result of managing future flood risks through such ordinance adoption, the federal government makes flood insurance available to the participating community as a financial protection for losses incurred by flooding, with expected improvement in the vulnerability of buildings over time as more stringent construction standards are enforced. Areas outside the SFHA can also obtain flood insurance at rates determined by risk premiums for the specific flood zone designated on the community's flood insurance rate map (FIRM). Insurance purchase is mandatory within SFHA and optional outside the SFHA.

The NFIP defines the SFHA, wherein flood insurance purchase is mandatory, as the 0.01 probability of occurrence, which is a 1 percent annual chance of flooding. The SFHA is generally referred to as the "100-year floodplain" and is commonly misunderstood as an area where a flood occurs only once in 100 years; moreover, a 1 percent annual chance flood is equivalent to a 26 percent chance of flooding during the period of a 30-year mortgage (Bell and Tobin 2007; Ludy and Kondolf 2012; Eisenstein and Mozingo 2013). The SFHA is delineated on Flood Insurance Rate Maps (FIRM) and is estimated by FEMA using topographical, meteorological, hydrological, and hydraulic information, and the maps "are based on anticipated full development of the SFHA, but not on full development of the entire watershed. Consequently, the extent of flood prone areas is often underestimated[.]" (Myers and White 1995, p. 7-8; NRC 2013). In recent years, FEMA's RiskMAP program has begun mapping at the watershed level; however, headwaters catchments and drainages of less than one square mile are still not mapped, resulting in underestimation of flood risk nationally by up to 40 percent; moreover, the nationwide 100-year flood is expected to increase by up to 45 percent as a result of changing precipitation under some climate change scenarios (Christin and Kline 2017; Wing et al 2018). Myers and White (1995) note that the 1 percent flood was intended to be the minimum standard for regulatory development requirements and insurance purchase; Eisenstein et al (2007), among others, note that the 1 percent standard, as a statistical construct, is constantly changing and becomes a larger area as the historical set of flood observations expands—in other words, that the 1 percent standard, by itself, is an underestimation of flood hazard; and, citing Lord (1994), Myers and White note that the "federal 1% standard does not necessarily make sense as a local floodplain management standard because it is unrelated to the specifics of the local flood problem." Worse, and to the interest of this dissertation, Myers and White (1995, p.

7) highlight another problem with the 100-year standard: "In using this standard, by default there seems to be widespread belief that if a building is protected from a 1% chance flood (through elevation or floodproofing) or is located outside of a mapped SFHA, then it is 'safe' and not at risk from floods." The SFHA is the area where flood insurance purchase is mandatory under NFIP regulations and, notably, actuarial rates are set based on "the hydrologic model developed by the Army Corps of Engineers" (FEMA 2013b). The flood zones contained in the SFHA include A and V zones, which are distinguished by topography or high water flows during 100-year floods. Major components of the actuarial rate formula are tied to the probability of flood water elevations occurring in a provided range from hydrological study along with the occupancy type for a structure (i.e. various residential building types), type of structure (e.g. one-story wood home with no basement), and the elevation of the structure relative to the *base flood elevation*, of the expected water surface elevation of the 100-year flood (FEMA 2013b).

In the 1970s and 80s, FEMA provided communities *Flood Hazard Boundary Maps* (FHBM) that were "initially prepared to provide flood maps to many communities in a short period of time" as a part of the early efforts of NFIP to map flood risk nationally. These maps, however, were not developed based on detailed studies of hydrology or hydraulics, and in many cases the maps were not simply inaccurate but oftentimes relied on the simple existence of structural flood control to remove large areas of floodplain from regulatory or insurance requirements. Though uncertainty in hydrologic analysis itself may have introduced errors in floodplain mapping, the choice to issue floodplain maps expeditiously, with great uncertainties about both physical uncertainty and political uncertainties, introduced *information hazards* that may have both altered public perceptions about the accuracy of the maps and induced many residential buyers to purchase properties they may not have otherwise purchased had the floodplain map zones been either more accurate or less subject to revision based on the mere presence of levees—for example, a seller of a residential building may have knowledge of the flood risks posed by levee overtopping, whereas a buyer new to the area or without flood experience may not know of this hazard and buys the home but may not have purchased the home if s/he knew of the hazard or its consequences—personal losses and market failure—when flooding occurs (cf. Bostrom 2011). FEMA states the initial FHBMs "were intended for interim use in most communities until more detailed studies could be carried out" (FEMA 2007a). Notably, some key flood zones evolved across time and map revisions for areas protected by levees; as such, FEMA uses the following terms, defined in the Code of Federal Regulations (44 CFR 60), on its flood insurance maps relative to levees and structural flood control:

> Zone B and Zone X (shaded)—Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate the base floodplains of lesser hazards, such as areas protected by levees from the 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.
>
> Zone C and Zone X (unshaded)—Area of minimal flood hazard, usually depicted on FIRMS as above the 500-year level. Zone C may have ponding and local drainage problems that don't warrant a detailed study or designation as a base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from the 100-year flood.
>
> Zone A99—Area to be protected from base flood by levees or Federal Flood Protection Systems. BFEs are not determined.
>
> Zone AR—The base floodplain that results from the decertification of a previously accredited flood protection system that is in the process of being restored to provide a 100-year or greater level of flood protection.

FEMA (2015b) further explains the AR zone designation:

> To obtain a Zone AR designation, the flood protection system must have previously been shown as accredited on a FIRM, no longer meet NFIP accreditation requirements of 44 CFR 65.10, provide some risk reduction for residents in the leveed area, and be the subject of a restoration project to restore the flood protection system to provide risk

> reduction to the 1-percent-annual-chance flood. This designation cannot be applied to flood protection structures that have not been accredited previously.

Notably, the changes in flood zones may have been confusing by and of itself, yet the changes in zone designation represent policy changes occurring within the NFIP. Recall that the administrator of the Federal Insurance Administration protested by Congress that the USACE was developing levee projects simply to eradicate the 100-year flood zone insurance requirements in 1980: the FHBMs were mostly a mapping product of the 1970s, as by the 1980s detailed hydrological studies were replacing the FHBMs. Despite the introduction of the more detailed FIRMs in the 1980s, many flood zones remained the same where flood control structures—levees—were in place, and it was merely the flood zone name or classification that changed from, say, Zone B to Zone C or an unshaded Zone X. The Zone AR designation did not emerge until the 1990s and the decertification of the levees in the Natomas area north of Sacramento (Sacramento General Plan 2015): FEMA created this new flood zone based on the political pressures mounted by local and state interests around Sacramento that demanded some discount for the levee system—effectively forcing a cartographical manipulation through policy criteria, and going against the NFIP policy about inadequate or deficient levees: "A levee that provides a lower level of protection, and that is not certified or does not meet the requirements for levees, may be shown on the FIRM, and flood elevations are computed as if the levee did not exist[.]" (FEMA 2007a, p. 3-41).

2.4.3 Flood Insurance Studies (FIS)

FEMA allows both approximate and detailed levels of study for flood hazard determinations: approximate methods result in delineation of the 100-year, or SFHA, boundary but do not include base flood elevations (BFE) or depths; detailed methods generally provide both SFHA boundary and BFE that are displayed on resulting FIRM (p. 2-15). Approximate 100-

year flood elevation areas are based on “index-flood method of utilizing statistical analyses of data at meteorologically and hydrologically similar gages[,]” interpolated peak flows between upstream and downstream measurement points, from regional regression equations, or from hydraulic methods for estimating water depth using Manning’s equation (p. 7-32, 7-33). In this regard, “the decision to utilize one study method over another is based on existing and projected floodplain development pressures[,]” although detailed studies are favored and approximate determinations might include other or additional sources of flooding (p. 2-15). Regardless, both detailed and approximate studies “shall normally be terminated where the 100-year floodplain permanently narrows to a width of 200 feet or less:” “decisions to terminate studies at these points shall be guided by consideration of actual flood hazards and development projections […] planned to exist in the community within 12 months following completion of the draft [flood insurance study] report[.]” (p. 2-15, emphasis in original). Notably, future development conditions are to include public works projects and “various other flood control projects”—“if proposed structures are taken into account, when the preliminary map is issued, the [study contractor] must confirm that the structures were built or will be completed before the map becomes effective[.]” (p. 2-15). The FIS guidelines define *developing areas* as places “where industrial, commercial, or residential growth is beginning, and/or where subdivision is underway and where these trends are likely to continue. They include areas that are likely to be developed within 5 years following completion of the study[.]” (p. 2-15, emphasis in original).

An FIS study begins with an information search on the floodplains to be studied along with a “windshield survey,” or field reconnaissance, to visually assess extent of floodplains, flood control structures, and “*apparent* development pressures in floodplain areas[.]” (p. 2-16, emphasis added). Communities are to supply the study contractor information and maps showing current and planned development, urban growth boundaries, and topographic information (p. 2-16). During the initial meeting between FEMA's study contractors and the community being studied, physical changes in the floodplain are reviewed, including potential changes in discharge due to flood control or other structures, and whether accredited or deficient flood control structures are present, "it is the responsibility of the community to supply all information necessary to determine whether a flood control structure can be credited on the FIRM with providing 100-year flood protection[.]" (p. 2-16). During the information collection phase, "a detailed literature search shall be made to obtain published report and other available data dealing with flooding problems in the study area[.]" (p. 2-16). Remote sensing techniques may be used (passive)to draw channel cross-sections or field surveys may be conducted to cross the entire 100-year floodplain and validate *elevation reference marks*; however, floodplain geometry beyond the 100-year floodplain and up to the 500-year boundary is to be derived from existing ground elevation data (p. 4-19 and 4-20).

Chapter 4 of the FIS guidelines sets out detailed hydrological analysis protocols. Study contractors are to analyze the 100-year event at minimum and are *requested* to determine flood discharges for 10-, 50-, and 500-year flood events (FEMA 2007, p. 4-21). Notably, storage capability of reservoirs behind dams "for purposes other than flood control normally should not be considered in a FIS because the availability of such storage is uncertain[,]" with exceptions for "documented water control plan[s] [which] could affect the 100-year flood elevations in a community by 1 foot or more" and instances where "storage capability [is] totally dedicated to flood control[.]" (FEMA 2007, p. 4-21). Regarding hydrological analyses on gaged streams, "[f]lood flow frequency analyses shall be made in accordance with the latest methodology in Bulletin No. 17B" from the US Geological Survey, whereas hydrological analyses on ungaged streams should follow USGS methods and values in regional flood flow frequency reports (FEMA 2007, p. 4-21). Restudies may be required for four reasons, per the FIS guidance document from 2007:

> “(1) [l]onger periods of record or revisions in data; (2) [c]hanged physical conditions; (3) [i]mproved hydrologic methods; or (4) [c]orrecting an error in the original FIS. […] Examples of changed physical conditions could be the construction of hydraulic structures that have impacted the effected FIS analyses, or development within a watershed subsequent to the effective FIS analyses[.]” (FEMA 2007, p. 7-24).

The guidance document further states that “[r]apidly developing watersheds with increasing flood hazards will be chosen for restudies as a first priority” and both preliminary and detailed hydrological analyses will be performed that consider the effects of urbanization, presumably on flow conveyances or the general flood hazard, itself, only (FEMA 2007, p. 7-24). Detailed hydrological analyses in a restudy are only to be completed if new discharge values effect 100-year flood elevations: “[c]aution should be used when selecting a [hydrological analysis] methodology for watersheds that are undergoing or are projected to undergo development[.]” (FEMA 2007, p. 7-25). Generally, FEMA requires 1-dimensional hydrologic flow models for analyzing discharges but may permit 2-dimensional or other hydrologic models in special cases where 1-dimensional models are insufficient or error-prone for a specific location (FEMA 2007, p. 7-30). Where discharges result in “significant discontinuities” between original updated and existing FIS discharges, FEMA is to issue a “Special Problem Report,” and the proposed 100-year flood elevations and profiles “must be reconciled with all published or unpublished information[.]” (FEMA 2007, p. 7-25, p. 7-27).

Regarding the evaluation of levee flood control systems for assessing protection against 100-year flooding, the guidance document refers to several terms set out in the NFIP regulations by 44 CFR 65.10 for freeboard, maintenance, and flood control operations requirements.

Notably, the FEMA flood insurance study contractor is responsible for reviewing structural design project analyses to ensure that levees meet the requirements set out in 44 CFR 65.10(b)(2), (3), (4), and (5): generally, these provisions require a professional engineer to certify data and documentation demonstrating that structural design criteria are met, and that levee systems meet certification criteria in order to be accredited and considered in mapping the SFHA, as reviewed and approved by a FEMA regional project officer (p. 7-33). Assuming that a levee meets the criteria for accreditation, "**the protected area (landward side of the levee) will be designated as Zone X** or the appropriate zone determined by the interior drainage analysis such as Zone AH[.]" (FEMA 2007, p. 9-35, emphasis supplied). Levee failures are to be considered in evaluating the effect on flood elevations, but there are no specific procedures described in the guidance document.

Actuarial rate zones in the floodplain delineation are determined by FEMA's flood insurance study contractor. Areas in the 100-year SFHA are assigned A-zone designations that include a number (e.g. A1-A30) if a detailed study was done, otherwise an approximate study simply receives an "A" designation; Zone AH is for shallow depth areas, usually between 1-3 feet of water, in the SFHA from a detailed study; Zone AO refers to shallow sheet-flow flooding in the SFHA from sloping terrain; Zone A99 is for areas of the SFHA where federal flood control *will* provide *protection* based on specific statutory milestones but did not provide such protection at the time of map production; Zone AR refers to SFHA areas that once *had* flood protection that have become decertified; Zones V and VE are for waves and flood waters associated with coastal storms; Zone X is "**the flood insurance rate zone that corresponds to areas outside the 100-year floodplain** […] **or areas protected from the 100-year flood by levees**" on riverine FIRM, or the coastal FIRM is the area either outside the 500-year flood boundary or within the 100-year boundary where water depths are less than 1 foot or areas protected from the 100-year flood by levees; and Zone D indicates unstudied areas where flood hazards are possible but not specifically determined in an FIS (FEMA 2007, p. 9-37, 9-38). Notably, Zone X areas, those *protected* by levees, are outlined and labeled if they are within the 500-year boundary or simply labeled Zone X, with no outlines or shading, if the the area falls outside the 500-year boundary. Levees themselves, however, are not specified to be drawn on the map (FEMA 2007, p. 7-45). Generally, the scale of FIRM maps is 1:400 (one inch on the map is about 400 feet on the ground) to about 1:2,000 (one inch on the map is about 2,000 feet on the ground) depending on the spatial area of the floodplain featured on the map, although communities may request different scales (FEMA 2007, p. 9-42).

2.4.4 Estimating Hydrologic Recurrence Intervals

The statistical technique of *frequency analysis* is used to estimate the probability of a historical hydrologic event occurring again in the future. From a set of records of event observations, the probability of recurrence, or return interval or recurrence interval, can be estimated to give a percent chance of a given event being equaled or exceeded in any given year. If the water flow on a particular stream is estimated to have a 1 in 100 chance of being 10,000 cubic feet per second (cfs) based on past observations, the flow is said to have a 100-year recurrence interval of about 10,000 cfs—i.e., a 100-year flow. The U.S. Geological Survey states that at least 10 years of observation data are required to estimate recurrence intervals for stream flow, and that changes in development practices have greater impacts on peak flows for low-frequency events than for higher frequency events (USGS 2014, Water Science School [water.usgs.gov/edu/100yearflood.html]). The USGS also points out that a 100-year flood, or a flood event with a 1% chance of occurrence in any given year, is expected to occur about 10,000 times over 1 million years.

The period of observations used in estimating the frequency of flows and floods can substantially change the estimation of a 1% annual chance flood event, especially if a large flow event occurs within a certain period of observations. The USGS provides two examples of changes in 100-year flows based on data for Bellevue, Washington and Auburn, Washington. In the case of Bellevue, the 100-year flow is underestimated for the period of 1956-1977 as compared with flows observed during the period of 1978-1994. Conversely, the 100-year flow is overestimated for Auburn based on observations during the 1937-1961 period, as compared to the period of 1962-1994.

Spatial estimations of probable flood extent can change quite dramatically with changes in recurrence interval calculations. In some cases, the estimated 100-year floodplain extent is calculated on a short period of flood records and, ultimately, all flood recurrence intervals are estimated based on incomplete records, for observations of past flood events only extend so far into the historical past (e.g. coastal flood FIS records for Biloxi set SFHA based on only 2 historical storms, among other cases). The incompleteness of records, or the abbreviated selection of records on which to calculate recurrence intervals, leads to both over-estimation and under-estimation of 100-year flows and is known as *sampling error*. For example, the case of Ames, Iowa provides a case of recurrence interval changes that have spatial consequences: flood observations were documented for only 37 years prior to 1992 (i.e. since 1955), and the largest flood during that period of time had a recurrence interval of:

$$T_{37} = (n + 1)/m = (37 + 1)/1 = 38 \text{ years} = 0.026 * 100 = 2.6\% \text{ annual chance}$$

T is the recurrence interval calculated based on *N*, the number of years for which flood observations are available, and *M*, which represents the rank of the flow during the period of observation. The probability that a flood of a certain size will occur in any given year is the inverse of *T* (i.e., 1/*T*, or 1/38 above, or 0.026). Following the record flooding of 1993, that previous maximum flood for the same period of observation changed in probability rather significantly:

$$T_{37} = (n + 1)/m = (38 + 1)/2 = 19.5 \text{ years} = 0.051 * 100 = 5.1\% \text{ annual chance}$$

Figure 7 illustrates similar flow estimates for Ames, Iowa and issues with frequency estimation:

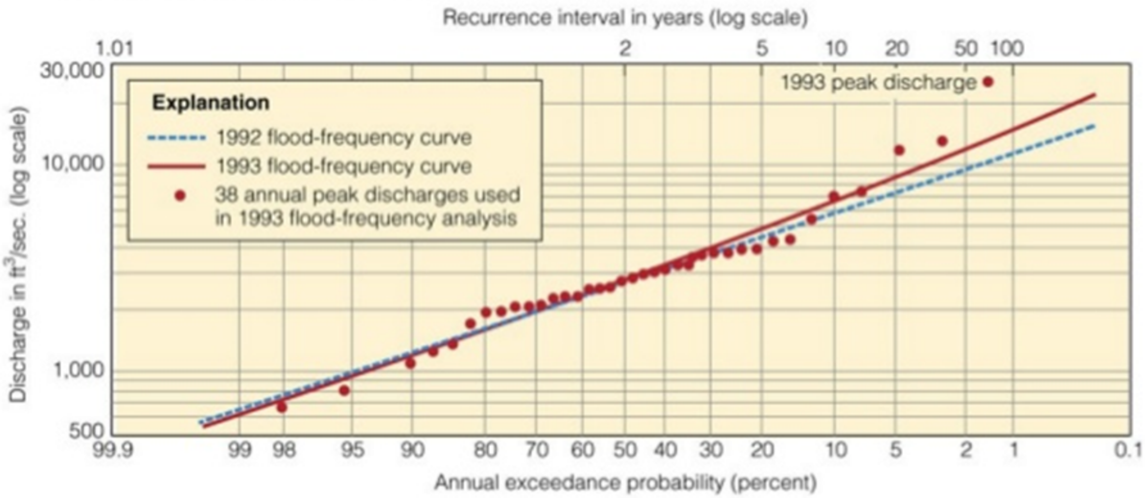


Figure 2.2. Flood frequency graph for Squaw Creek at Ames, Iowa. (Hyndman and Hyndman 2010, p. 330).

In the recurrence interval graph for Ames, a flood flow of 10,000 cfs in 1992 had an estimated 80-year frequency; however, with the addition of the 1993 flooding to the set of records, the 10,000 cfs flow becomes a 42-year frequency. Likewise, the estimated 10,200 cfs 100-year flow in 1992 becomes a 13,500 cfs flow in 1993, representing an approximate 32 percent increase in flood flow. The US Army Corps of Engineers (USACE) states that *measurement error* of large floods is the greatest influence on frequency estimates for 100-year flows; further, flow frequency statistics are assumed not to be “influenced by anthropomorphic activities, such as regulation, channel modification and land use change”—“[s]ampling error is due to the limited record lengths available for estimation of flow frequency distribution parameters[.]” (USACE 2010). In assuming that flood records are *homogenous* in this fashion, as in the case of the Des Moines River study, the USACE states, “the period of record was chosen to avoid the influence of land use change[.]” and that outliers, such as those large flood events reflected on the Ames graph in Figure 2.7, should cause further examination of flow measurement data (USACE 2010). In discussing the 1993 flood event at various stations on the Des Moines River, the USACE states:

> Graphical analysis of the observed event is used to describe this relationship for flows less than channel capacity. The description of this relationship is more difficult, and more important, for flows exceeding channel capacity. The difficulty stems from the lack of data. Only two events in the period of record, 1993 and 2008 significantly exceed the channel capacity, giving little information to estimate this relationship. Additionally, this region is critical in estimating the 100-year regulated flow value, which is important for regulatory purposes. (USACE 2010)

Though originally thought to provide an adequate level of protection “without overly stringent burdens and requirements for property owners,” Hirsh et al (2004) state that more than $3 billion were spent to map some 150,000 square miles of 100-year floodplains, and yet flood losses continue to increase in part due to inaccurate planimetric mapping of the 1-percent-chance water surface elevations; moreover, Wing et al (2018) demonstrate through model simulations that U.S. flood risk in 100-year floodplains may be underestimated by up to 40 percent nationally due to inaccuracies in statistical intervals and omitted stream reaches such as headwater catchments.

2.4.5 Mandatory Purchase Requirement and Participation Rates

Homes in the SFHA are required to purchase insurance through the NFIP, but compliance is at about 75-80 percent nationally with local variance (Kerjan-Michel et al 2012; NRC 2013;

FEMA 2014). Iowa City, Iowa notes, however, cites FEMA as claiming that around 90 percent of homeowners who are not subject to the mandatory flood insurance purchase requirement will not buy flood insurance; other recent academic studies reveal that 75 percent of homes outside of the 100-year SFHA do not have flood insurance (Meldrum 2016, p. 728; Iowa City 2018). A 2002 Fannie Mae review revealed that nearly 68 percent of buildings in a random sample of 9,500 loans resulted in flood determination companies disagreeing on floodplain status (Tobin and Calfee 2005). Only about 20 percent of homeowners outside the SFHA buy flood insurance (Huber 2012, p. 6), and about 1 percent of NFIP policyholders represent 25-30 percent of losses (Burby 2006; Kousky 2010; Ludy 2012; Patterson 2012; Kousky 2018; Kunreuther et al 2018). During the late 1980s and early 1990s, several hurricane and river flood disasters revealed low participation in the NFIP, even in flood-prone areas (Knowles and Kunreuther 2014); moreover, a 1998 flood in Vermont revealed that only 16 percent of damaged homes in the SFHA had flood insurance, even though about 45 percent were required by their lender to have coverage, and only about 40 percent of residents in Orleans Parish were insured at the time of Hurricane Katrina in 2005 (Michel-Kerjan et al 2012, p. 645). A 2006 RAND study suggested that about 50-60 percent of single-family homes are subject to the mandatory purchase requirement based on their location in the SFHA, with regional compliance rates between 45 and 90 percent and a national average around 50-80 percent (RAND 2006, p. xvii; NRC 2013, p. 6). The percentage of structures located within the SFHA that have insurance (i.e. the market penetration rate) is nationally about 30-50 percent:

> The current policy of mandatory flood insurance purchase appears to be ineffective in achieving widespread purchase of NFIP flood insurance policies. To date, relying on federal supervisory agencies to oversee and lenders to require purchase has not achieved widespread compliance with the [mandatory purchase requirement]. Extending the [mandatory purchase requirement] to areas behind levees where there are large numbers of structures, incomplete determination of flood risk, and varied evidence supporting its

> effectiveness is imprudent. At this time, there is no sound reason to institute mandatory purchase of flood insurance in areas behind accredited levees. (NRC 2013 p. 6)

Notably, homeowners only held onto their flood insurance policy for about 2-4 years after first purchasing a policy during the years 2001-2009 (Huber 2012; Michel-Kerjan et al 2012; Kunreuther et al 2018). Some possible reasons for the short maintenance of flood insurance policies includes migration (selling a home/mortgage or moving out of the SFHA), not understanding the probability of loss, underestimating exposure, misjudging economic or social impacts of a flood, and being inexperienced with flooding or having short memories of past catastrophes (Bell and Tobin 2007; Ludy and Kondolf 2012; Michel-Kerjan et al 2012; Kunreuther et al 2018). Other reasons for short policy-holding tenure include the failure to enforce the mandatory purchasing requirement by banks and government-sponsored financial institutions like Fannie Mae and Freddie Mac; moreover, mortgages are often transferred or resold in secondary securities markets in non-flood prone parts of the country where there is either a lack of awareness of flood risk or the mandatory purchase requirement (Michel-Kerjan et al 2012). Michel-Kerjan et al (2012) found no statistically significant difference in the periods of time that SFHA and non-SFHA policy holders maintained their flood insurance. Notably, the NRC 2013 levees report states that adding more policies does not necessarily improve the NFIP’s overall fiscal soundness.

Lenders are required to verify that flood insurance is purchased only when a mortgage or loan is initiated or modified. There are no laws requiring the review of loan portfolios for flood risk, despite lenders knowing of significant exposures, “meaning that flood risk may not be clearly reflected in the price of a mortgage asset[.]” (Tobin and Calfee 2005; Huber 2012, p. 6). Huber 2012 (p. 6) states that adverse selection in flood insurance reflects homeowners buying subsidized insurance when they perceive flood risk to be high, and “under-pricing premiums for high-risk homeowners has the unintended consequence of systematically limiting participation rather than accomplishing the intent of increasing overall coverage." Although uninsured structures in the SFHA create a welfare burden on taxpayers through disaster assistance support (Michel-Kerjan et al 2012, p. 646), a RAND study found that the number of NFIP policies in force had only a slightly negative affect on disaster assistance grants but no overall effect on disaster assistance expenditures (RAND 2006). As a result of catastrophic flooding in Minot, North Dakota in June 2011, caused by overtopped levees, the private credit rating agency Moody's issued a public comment stating that the city's municipal bonds would be negatively affected by the flooding due to a potential inability to pay on the principal borrowed over prior years for various infrastructure projects in the community:

> Last week and today, Minot, North Dakota and surrounding areas are experiencing severe flood conditions with more rain forecast. Rising water has already topped the previous high reached in the flood of 1881 and is not expected to crest until today. The disaster has negative credit implications for the City of Minot (Aa2 stable), Minot Water and Sewer Utility (Aa2), Minot School District (Aa2), Minot Public School District Building Authority (Aa3), and Unified Public School District No. 1 (A2). The City of Minot bears the largest burden of expenditures.
>
> Immediate credit pressure is caused by overtime payment for relief workers, repairs, and clean-up at a time of drastically reduced sales tax revenues and fees. Potential credit stresses are reduced sales taxes and issuer inability to provide services and generate revenue from a damaged tax base. Favorably, there are no looming debt service payment dates for several months. Both the city and the school district maintain healthy reserves at roughly one third of annual operations to help manage unexpected events.
>
> In a similar case, after flooding in 1997, Grand Forks, North Dakota experienced a period of growth owing to necessary rebuilding efforts that ultimately resulted in a strengthened credit profile.
>
> **Emergency aid provided by the federal government after the disaster will likely allow issuers to avoid the most severe financial stress allowing them to fulfill their mandates and make debt service payments on time and in full.** (Moody's 2011, p. 36)

However, Huber 2012 (p. 7) suggests that "[d]isaster risk does not factor into municipal bond ratings as the combination of state and FEMA disaster aid typically reimburses between 80 percent and 100 percent of expenses, blocking the risk price signal from reaching municipalities." Notably, the City of Minot maintained its AA2 municipal bond credit rating through November 2014, although city officials were concerned that recent bond issuance for infrastructure development relative to the Bakken shale development and oil and gas extraction may negatively affect the city's rating due to the size of the bonding—"We have never seen the kind of bonding that we are having to do tonight" (Minot 2014a; Minot 2014b; Minot 2014c); Moody's credit rating agency reflects that Minot's municipal bonds stayed in the AA2 class through 2018 (Moody's 2019a). For reference, a AAA credit rating is the "highest quality" and with minimal risks; AA ratings are judged to be of "high quality" and very low risk; A is "upper-medium-grade and subject to low credit risk"; B level ratings range from moderate to high credit risk; and C ratings range from very high risk to financial obligations that are in default with either little or no prospect of recovering principal and interest; each of these ratings definitions apply to short-term risks that are less than 13 months to maturity (Moody's 2019b). Moody's states that nearly 100 percent of municipalities are implementing resilience measures to quickly recover from exposure to flood losses and other natural hazards; however, the former head of FEMA's Federal Insurance & Mitigation Administration, which administers the NFIP, states that "catastrophic damage from severe weather in communities all across America" from 2016-2018 indicate that natural hazard risks are not under control (Flavelle 2018). Moreover, Flavelle (2018) notes that floods "can do measurable damage to a city's tax base and therefore its ability to pay back bonds," with vulnerable areas experiencing both decreasing property values and increasing costs for infrastructure as residents and businesses leave: impacts from severe weather and flooding appear to be discounted or not factored into municipal credit ratings, otherwise creditworthiness would be negatively rated. Flavelle (2018) also notes that ratings agencies, specifically S&P, are aware of the vulnerabilities to "changes to the environment affecting land use, employment, and economic activity that support credit quality," with Moody's credit rating agency stating that exposure to flooding is factored into credit ratings; however, Flavelle (2018) reveals that both Moody's and S&P have assigned AAA ratings to numerous cities that are the most exposed to flooding and flood losses, including Boston, Massachusetts and Ocean County, New Jersey, which "is home to the zip code that has lost more in relative property value than anywhere else in the country because of increased tidal flooding." Notably, Flavelle (2018) cites Fitch Credit Ratings, Inc. as stating that "if there were a situation where the risks [of flooding and climate change] were quantifiable and obvious, we would certainly not sit back and avoid taking rating action." In any case, the City of Minot's Finance Department states that the city's financial position "remains sound" following the millions of dollars caused by the 2011 flood; further, the Finance Department states that property values have generally increased since the 2011, with 50 percent of the 1 percent sales tax going to flood control (Minot Finance 2017). However, improvements to the levees and flood control for Minot are expected to cost about $193 million with the city the expected to contribute 35 percent of the project cost, or about $67.5 million, "which would require more sales tax funds dedicated to flood control"; the city raised $5.6 million in sales tax funding for flood control during fiscal year 2016, suggesting that, if this revenue is sustained, it would take approximately 12 years to pay for the flood control project—that is, without further increases in the cost of the flood control project, which was noted to have increased by more than $16 million during the 2016 fiscal year (Minot Finance 2017, p. VI, p. 9, p. 15). Interestingly, the "Flood Control Capital fund" ran a $265,822 deficit in fiscal year 2016, as several transfers from the flood control fund went to the city's general or water/sewerage fund, but, since the 2011 flood, Minot's net financial position increased almost

160 percent, from about $245 million to almost $657 million, which is attributed to grants and contributions to the city: Minot received a $67.5 million Community Development Block Grant (CDBG) from the U.S. Department of Housing and Urban Development Disaster Recovery Funds for the 2011 flood recovery in 2016, and another $35 million CDBG for 2011 flood recovery in 2016, and also $74.3 million in 2016 for “reducing flood risk and increasing resilience” from a National Disaster Resilience Fund (Minot Finance 2017, p. 76).

It is important to note that the NFIP’s Community Rating System (CRS) is another voluntary flood mitigation program encouraging risk reduction through nonstructural means, including elevating buildings, flood-proofing, or even relocation to less hazardous areas through buy-out programs sponsored by FEMA’s Hazard Mitigation Grant Program. FEMA estimates that the CRS prevents about $1 billion in flood damages (Huber 2012, p. 8); Lloyd’s of London estimates that future flood losses could be reduced to about 3 percent of 2012 levels if all mitigation measures were implemented (Huber 2012, p. 8). Rather, **the increasing number of billion-dollar or greater losses is primarily caused by increasing value-at-risk and insurance density in hazard-prone areas (Michel-Kerjan et al 2012, p. 645).**

The catastrophic losses associated with claims from the 2005 hurricane season led the NFIP into about $17 billion in debt related to subsidized premiums and the large number of claimants, forcing Congress to borrow from the treasury funds beyond the NFIP’s specified credit line (Huber 2012, p. 4). Following Katrina in 2005, the NFIP's borrowing authority was raised from $1.5 to $20.775 billion, and then up to $30 billion following Hurricane Sandy in 2012 (Knowles and Kunreuther 2014). Interest on the treasury loans to cover NFIP claims topped $400 million in 2012, and that was before an additional $7 billion was added to the claims payout debts relative to 2012’s Hurricane Sandy in the Northeast U.S. Between 1978 and

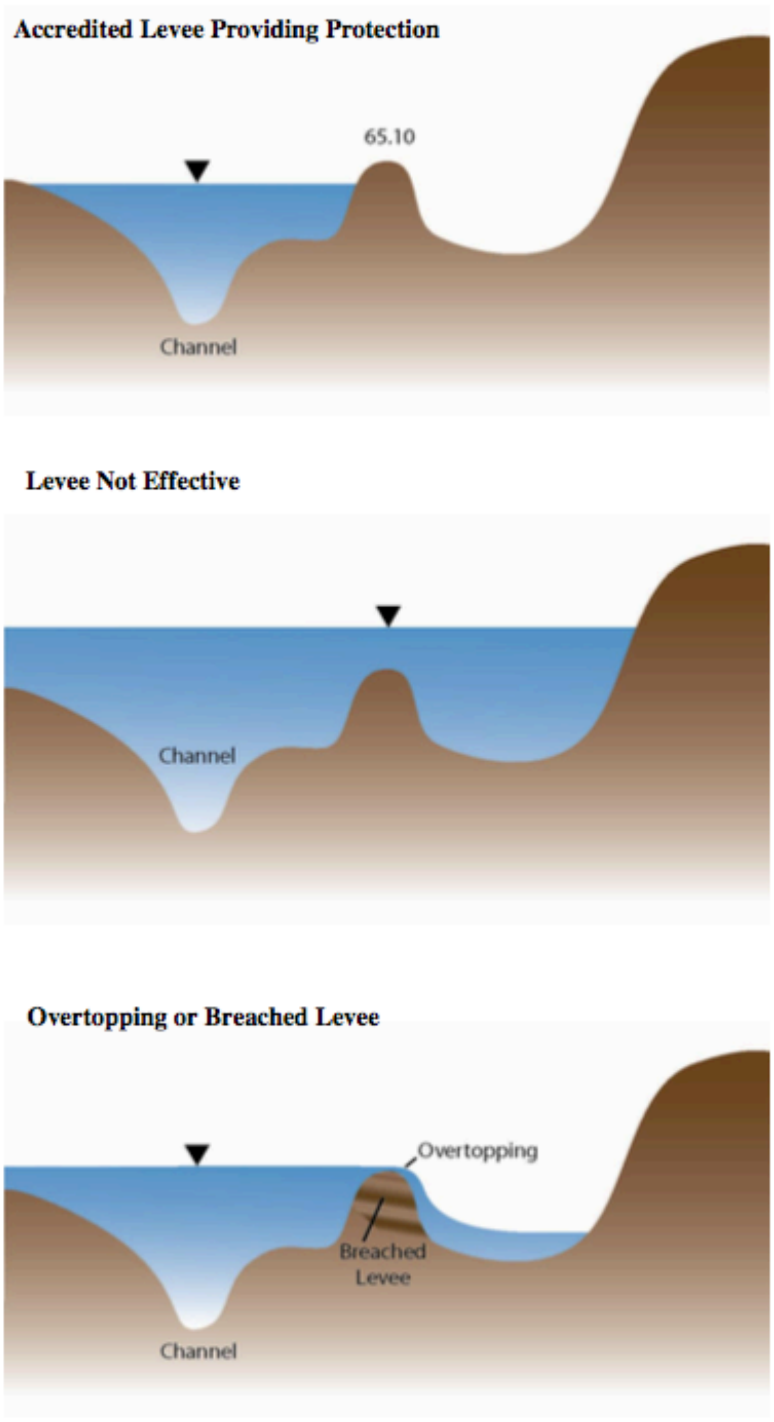
2004, NFIP claims exceeded premiums by about 5 percent on average; however, the debts incurred by the 2005 and 2012 seasons reflect NFIP's shortfall caused by catastrophic risk exceeding premium levels. Annual NFIP claims are about $1.3 billion per year, whereas the NWS estimates the 30-year average annual flood loss rate to be about $8.2 billion, with future annual losses expected to total nearly $300 billion by 2043 (NWS HIC 2018).

The NFIP reviewed its premiums and concluded that "it is impractical for the NFIP to be actuarially sound in the aggregate[.]" (Hayes and Neal 2011). Homes built prior to NFIP regulations were *grandfathered* into the program and not subject to the same flood mitigation requirements as new construction as a result of the 1973 Flood Protection Act (Knowles and Kunreuther 2014), and premium rates are subsidized at about 60-65 percent below their true actuarial risk (Huber 2012). Premium rates are set using *Flood Insurance Rate Maps* (FIRM) that must be updated frequently to improve upon low-quality physical data used in past floodplain delineations in addition to changing physical and socioeconomic variables in floodplain areas. Areas that are re-mapped from non-SFHA to SFHA are granted a probationary period of up to two years at "preferred risk" rates before assuming high hazard rates under the mandatory purchase requirement, resulting in a cross subsidy. These *discounted* risk premium rates are mandated by law however, and are not specifically the result of actuarial unsoundness—and a result of these discounted policies is revenue lost to the NFIP: "FEMA is legally unable to raise premiums in a manner sufficient to allow the NFIP to be financially sound or to build a contingency reserve fund sufficient to pay for a catastrophic future loss[.]" (NRC 2013, p. 5). The Biggert-Waters Flood Insurance Reform Act of 2012 directed FEMA to remove the grandfathering process and begin raising premiums to a level reflective of actual flood risks; however, during the phasing-in of actuarially sound premium rates, many communities across the US saw premiums raise by 1,000 percent or more and, as a result, the Act was amended to remove these provisions.

2.4.6 The NFIP Levee Accreditation Program Since 1984

As a result of many leveed communities successfully withstanding 100-year flood conditions, where floodwaters remained riverside of the levees, there was a push to exclude areas protected by the 1-percent annual chance flood from the SFHA. Following congressional hearings in 1973, the Federal Insurance Administration agreed to recognize flood control structures by removing areas behind levees providing 100-year protection from the SFHA (NRC 2013, p. 25): "As a result, areas behind levees were not labeled on early flood maps as being within the SFHA where levees had provided or were thought to have provided protection from the one percent annual chance flood or had been constructed by the U.S. Army Corps of Engineers (USACE) to withstand the one percent annual chance flood or higher." (NRC 2013, p. 1). In 1977, USACE indicated that the 100-year flood level as a design standard for levees was imprudent as it did not provide "a high degree of protection." Accordingly, USACE recommended using the *Standard Project Flood* for new levee construction (NRC 2013, p. 25). Although first established by USACE as the *project design flood* in 1928, the *Standard Project Flood* was updated in 1955 to represent 35 various combinations of hypothetical atmospheric storms that could produce large amounts of precipitation and runoff affecting the Mississippi River and its tributaries (MRC 2012).

Potential Flood Scenarios



Accredited Levee Providing Protection

Levees that are designed, built, and maintained to provide protection from large floods such as the 1-percent-annual-chance flood and meet the requirements of 44 C.F.R. Section 65.10 are accredited as preventing the flood waters from getting behind the levee for floods of that magnitude or less.

Levee Not Effective

Some levees are not effective during large flooding events such as the 1-percent-annual-chance flood, and the flood waters are not impeded by the levee.

Overtopping or Breached Levee

When the height of water is above the top of the levee, floodwaters will flow over the levee at which point it is overtopped.

When a part of the levee breaks/fails, leaving an opening for water to flood the land behind the levee, the levee has been breached.

Figure 2.3. Levee effectiveness graphic from FEMA (2011) depicting accredited versus ineffective or overtopped levees. Notably, development in the areas behind levees is absent.

By 1980, however, the NFIP became concerned that levees were being designed to the 100-year SFHA with the sole intent of removing the SFHA from FIRM, thereby removing the mandatory insurance purchase requirement for federally-backed mortgages:

> Under NFIP regulations, homes and commercial buildings located in the SFHA within a participating community may be exempted from the mandatory flood insurance purchase requirements and land use regulations when located behind a levee system that has been recognized by FEMA as providing protection against the one percent annual chance flood event, i.e. 'accredited.' Certification is the technical evidence provided by a levee owner to FEMA demonstrating that the levee system meets the requirements to reduce risk from at least the one percent annual chance flood[.] (NRC 2013, p. 1, p. 26).

In 1984, FEMA created the "Credited Structures Inventory" to identify all flood control structures shown to protect against the 0.01 flood event on NFIP floodplain maps (FEMA 2002, Procedure Memo 30). Indeed, Burby and French (1985) noted a positive correlation between "the degree to which communities used flood control works to limit their vulnerability to flooding and the amount of new development taking place in their flood hazard areas *after* the flood control works were completed[.]" (Burby et al 1985; Burby 2006).

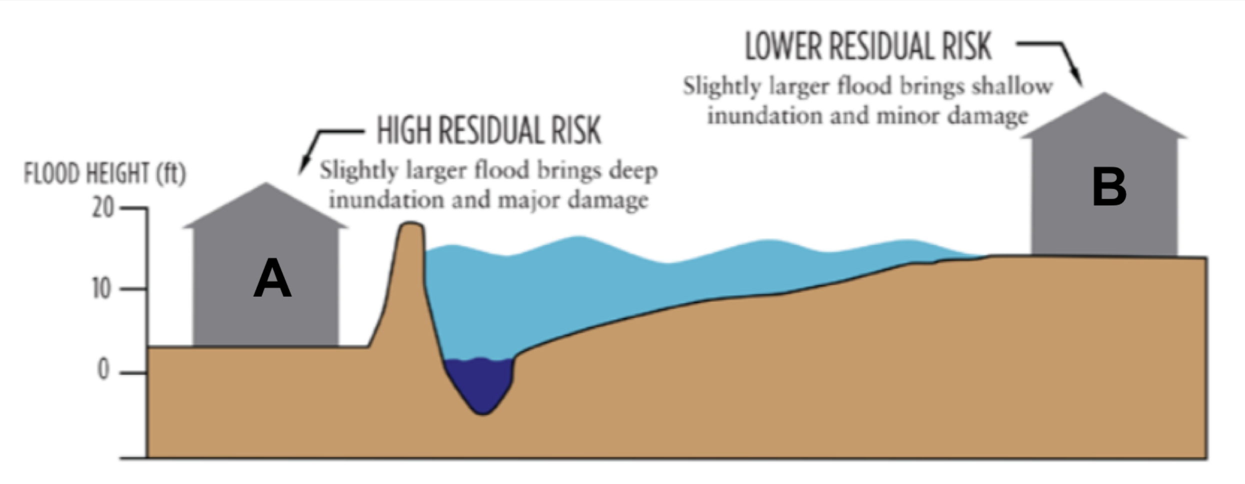


Figure 2.4. Residual risk in leveed versus non-leveed floodplains. Structure A, left, is protected by a levee from frequent flood events but is neither protected from infrequent flooding nor required to purchase flood insurance. Structure B, right, is not protected by levees from flooding and, as a result, is situated further from the river channel. Structure B is subject to flood insurance requirements and construction standards to reduce vulnerability to floods. (Adapted from Eisenstein and Mozingo 2013 with building labels.)

FEMA became concerned, after the initiation of the flood Map Modernization program in 2003, that many levees did not meet the 1-percent annual chance protection level. As a result of communities requesting some level of credit for the presence of the levees, deficient or not, FEMA developed the *Levee Analysis and Mapping Procedure* (LAMP) to replace the *without levee* map designation approach which considered deficient levees as not present at all (NRC 2013). Levees or levee systems that are not accredited by FEMA are not included in flood risk mapping for SFHA designation and, according to NRC 2013 (p. 2), "[t]his encourages communities to construct levee systems that only protect to the one percent annual exceedance flood, enabling new development in areas with significant, but un-quantified exposure to catastrophic flood risk"; further, FEMA changed its non-leveed mapping procedure in 2011 in order to depict some level of protection from non-accredited levees on flood zoning maps after political pressure to discontinue the "'without levee'" analysis and mapping approach, resulting in FEMA "delay[ing] finalizing FIRMs and FIS reports for communities where levee systems did not meet accreditation requirements" (FEMA 2011b; FEMA 2013a). The NRC 2013 levees report states that, as a result, the 0.01 chance flood event is the design standard for most levees in the U.S. seeking accreditation status, regardless of residual risk consequences; however, the National Levee Database and numerous reports from academic and media sources document well the decertifying of levees failing to meet the 100-year design standards, with levee systems in large cities such as Sacramento and Dallas having their entire levee protection systems de-accredited by NFIP: in the state of Washington, 91 percent of levees were found to provide insufficient protection from 100-year floods (State of Washington 2010). Since its inception, enforcing land-use restrictions in floodplains has been a major challenge, in part because the federal government does not have the authority to supersede local land-use decisions under constitutional delegation of powers to states (Knowles and Kunreuther 2014).

2.4.7 USACE National Economic Development Policy

For planning and implementing flood control projects, the USACE follows a national economic development policy to assess economic and societal benefits, environmental impacts, and alternatives, with its policy document explaining that “contributions to national economic development (NED) are increases in the net value of the national output of goods and services, expressed in monetary units” and that a “plan recommending Federal action is to be the alternative plan with the greatest net economic benefit consistent with protecting the Nation’s environment” (USACE 2009a). USACE NED analysis “can be generally defined as economic benefit-cost analysis for plan formulation, evaluation, and section that is used to evaluate the federal interest in pursuing a prospective project plan” (USACE 2009a). Generally, the USACE economic analyses rely on price signals for goods and services, or for public and collective goods, which USACE calls “market failures” based on excludable goods—i.e., those with well-defined private uses and rights are excluded from analysis, whereas “pure public goods” cannot be supplied through a market price mechanism, such as “water resource services”; the USACE describes an example of a canal built solely for one private company’s use as compared to a canal built for public use (USACE 2009a, p. 5). Further setting out examples of exclusive public goods, market failure, and a rationale for federal involvement in flood control projects, the USACE describes a case of a city seeking flood damage reduction infrastructure for protection of city residences and businesses:

> To the extent that [such] infrastructure would provide flood damage reduction benefits only for properties that lie within municipal city limits, then it might be argued that the city should pay the full costs of the project under the presumption that those people who benefit from a project should pay for it. But if project

> benefits would be realized by the owners of widely-dispersed properties extending well beyond city boundaries, then an economic case could be made for sharing project costs with higher levels of government. (USACE 2009a, p. 6-7)

The USACE states that most federal civil works programs operate in "grey areas" because it's often not possible to elucidate all market failure cases involving broad public benefit as opposed to benefitting singular private enterprises; moreover, regardless of the explained project participation rationale, USACE states that Congress:

> ultimately determines when and where the Corps [Civil Works Program] shall participate in civil works planning, by conferring to the Corps general programmatic and specific study authorities. Congress is the final decision-maker for the authorization and federal funding of recommended plans for specific projects. These congressional decisions appropriately consider political factors, such equity and ability-to-pay considerations. (USACE 2009a, p. 7)

The USACE project planning process sets out a basis for implementing a project "on the marginal analysis of benefits and costs for the formulation, evaluation, and selection of alternative plans that provide incremental changes in the net value of desired goods and services" (USACE 2009a, p. 9). Further, to assess NED benefits, the USACE uses a counterfactual "without-project condition" to establish "a baseline from which the incremental NED benefits and costs of project plans are evaluated" and to assess "the cause-and-effect relationship between project plans and NED benefits and costs" (USACE 2009a, p. 9). Using a simple supply and demand curve, the USACE offers an example of a with-project and without-project market price estimate for agricultural benefits to strawberry production—notably, exogenous cost factors of external influences, such as, say, increased seed cost or higher fertilizer costs due to other market pressures, do not appear to be factored into USACE analysis (Figure 2.10):

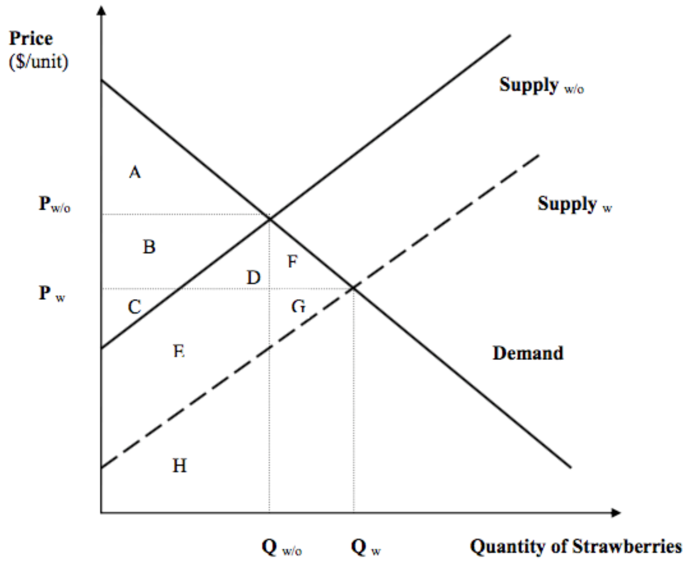


Figure 2.5. Price of strawberries based on with and without-project conditions, indicating that greater supply from the with-project conditions yields lower prices for and higher supplies of strawberries. (Source USACE 2009, p. 21)

In separate studies, the USACE researched whether location benefits—those ascribed to properties located in floodplains—could be attributed to non-floodplain areas and, therefore, be counted in assessing the benefits of flood control projects. In a 1998 study of Frankfort, Kentucky and Abilene, Texas, the USACE found that some non-floodplain location benefits occurred and some did not occur, owing to limited data and limited research from academia; however, the USACE found that lower-priced homes in the floodplain did receive benefits from a location discount, yielding higher prices, and noted that flood insurance subsidies "may lessen the floodplain location discount of lower-valued houses" (USACE 1998, p. vi). The results of the 1998 study and its cases "are insufficient to conclude that flood damages borne by floodplain activities either are or are not capitalized into the fair market value of floodplain properties"—which is an interesting finding for two reasons: 1) "the assumption that *all* consumers are fully aware of the flood risk and are risk neutral is not supporting by the findings"—this statement from the USACE about discounting location benefits for floodplain damage is stating the obvious and should not influence non-floodplain location benefits (i.e., non-floodplain location benefits should not apply to flood control projects based on residential building values); and 2) "the benefits of permanent evacuation projects are underestimated"—again, this statement appears to state the obvious in that alternative projects such as locating homes outside of floodplains are not well-accounted for in justifying flood control projects (USACE 1998). Summarizing the findings of its "effect of flood risk on land values" study, the USACE states that:

> The findings suggest that greater effort be devoted to analyzing the theoretical and institutional bases for the relevant policies rather than focusing on an empirical basis for justifying the benefits of structural flood protection versus permanent evacuation. The Corps should not expend resources for investigations of the capitalization of flood damages into market values of floodplain properties, either as part of a research project or as part of feasibility studies for flood damage prevention projects. (USACE 1998, p. vii)

Interestingly, in its literature review, the USACE states that Muckleston (1983) found that property prices rose faster for riverside properties than other floodplain properties even as the NFIP made the flood hazard more aware to consumers; however, the USACE did not detail whether or not these particular riverside floodplains were protected by levees and also did not study non-floodplain properties for counterfactual analysis of potential externalities in the area, although in summarizing USACE states that "eight of the studies used a model that employed the dummy variable of location in or out of the 100-year floodplain" and that "these studies are inconclusive and expected to be so because this model implies that the flood risk is constant across the 100-year floodplain" (USACE 1998, p. 12). Notably, recent studies find negligible impacts on residential prices from NFIP zoning, "often finding no or limited evidence for the capitalization of flood risk into property values" and that location in the SFHA has no observable impact on sales prices of standalone properties in places like Boulder, Colorado (cf. Meldrum 2016, p. 726, 744).

The USACE NED procedures and guidelines policy estimates "project-induced reductions in damages" through avoided costs—i.e., damages avoided—and changes in land prices (USACE 2009a, p. 32). Reduced damages are measured in three ways: 1) benefits from reduced floodwater inundation; benefits from intensifying land use in project-protected areas where land use remains unchanged; and, 3) location benefits resulting from altered land use stemming from a flood damage reduction project—e.g., "an affected homeowner may add a garage or finish a basement if the flood threat is reduced" (USACE 2009a, p. 32). The following definitions are quoted from USACE 1988 (p. II-14, p. X-1):

> Location benefits result from new, more profitable activities locating in the floodplain because of a project reducing the expected value of flood losses. Benefits are the increase in net income of the activities over the alternative site (presumably outside the floodplain), less the net income lost to any displaced activity. […] Location benefits occur when a reduction in the level of flood risk makes it profitable for new activities to locate in the floodplain. There are three criteria that must be met before location benefits can occur. These include:
>
> 1) The land must become relatively flood-free. A minimum, there must be less than a one percent chance of a flood occurring in any year.
>
> 2) The land must go to higher economic use than it would with the project.
>
> 3) The land must have a location advantage over alternative sites. Physical, aesthetic, infrastructure attributes of the floodplain sight [*sic*] must be significant enough to allow considerable location advantages over alternative flood-free locations. This location advantage must be significant enough to allow an increase in net profit over and above alternative sites over and above any expected residual flood damage.
>
> 4) Finally, there must be a sufficient demand with the affected area to support the development of the new activity.
>
> Intensification benefits occur when, because of flood protection, a business finds it profitable to modify its operations at its present floodplain location, and that

> modification results in an increase in net income to the business. […] Intensification benefits have most often been applied to agricultural areas, realized through increased net income from crop production. **This benefit category has had limited application to urban land uses.** (emphasis added)

Interestingly, the USACE NED Procedures Manual from 1988 (p. II-13) specifically highlights that the costs of administering the National Flood Insurance Program can be counted as a benefit for structural flood control projects like levees—that is, as NFIP removes the mandatory purchase requirements for insurance in levee-protected areas, the USACE counts the per-insurance-policy administrative cost avoided as a benefit for the structural flood control project even when the structural flood control devices employed do not protect against all floods.[3] As such, floodplain occupants relieved of flood insurance requirements and who occupy structurally-protected floodplain areas—who are assumed to have full and complete knowledge of flood hazards—have no requirements to build homes or businesses differently in order to reduce flood risk and potential losses on an individual or community basis.

USACE (2009a, p. 32) states that "the primary benefit is avoided damages to residential and commercial properties" for typical flood damage reduction projects. For estimating property damages avoided, USACE (2009a, p. 33) assumes "that floodplain occupants possess the same knowledge and understanding of the probability and consequences of flood events as [flood damage reduction project] planners, and that [floodplain occupants] use the same time horizon and discount rate as planners do when determining [floodplain occupants'] Willingness To Pay [for cost-sharing provisions] for reductions in flood risk." USACE (2009a, p. 33) also notes that "the primary potential sources of human benefits associated with flood risk management include

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[3] USACE (1988, p. VII-12-13) states that the administrative costs per NFIP insurance policy are published yearly; however, a broad search found this information to be very dated. As such, the cost-per-policy estimate from the USACE 1988 guidance document is carried forward with inflation-adjustment: for 1987, the estimated cost-per-policy is $85—adjusted to 2018, the cost is roughly $188 per policy, ceteris paribus.

reductions in pre-flood anxiety, and post-flood trauma relating to flood-induced and displacement" but that measures of property damage avoidance benefits diverge from flood damage reduction estimates if floodplain occupants do not possess the same level of knowledge of flood hazards as project planners—in other words, since damage reduction projects are based on expected damages for project design, all "affected" floodplain occupants are assumed to be risk neutral: "however, to the extent that some affected people are risk averse, they would be willing to pay more than less risk-averse individuals for the same level of flood risk reduction." Further describing these human dimensions of supposed benefits from flood risk reduction, USACE (2009a, p. 33) states that "one potential source of risk aversion in the flood risk context relates to personal anxiety associated with the potential for flooding; thus, affected individuals who are risk averse may be willing to pay a premium over expected property damages to avoid the anxiety of living with a flood threat" and "community members may also be willing to pay to avoid post-flood trauma to others in the community and general community disruption." These statements of benefits assumption by USACE are very interesting because, as protested by the administrator of the Federal Insurance Administration in 1980, as previously discussed, most flood damage reduction projects such as levees provide only 100-year protection from flooding, meaning that the supposed benefits from such projects fail to account for the human dimensions of catastrophic flooding in the form of events larger than 100-year or from levee failures during more frequent flooding. For the estimation of intensification and location benefits, USACE project planners "are instructed to forecast land use patterns in the project area with versus without the project" (USACE 2009a, p. 34). Interestingly, USACE policy "prohibits claiming additional benefits for [permanent floodplain] evacuation plans using [property damages avoided] for the specific properties to be evacuated, based on the presumption that the market prices of properties to be evacuated are fully discounted for flood hazards" (2009a, p. 36)—notably, this prohibiting of benefits accounting for relocating residences and businesses would also seem to preclude buy-outs intended to permanently reduce flood exposure and risk of potential losses. Repeated throughout the calculation of benefits procedural guidance document are statements such as the following: "This guidance is underpinned by several explicit and implicit assumptions, including that land buyers and sellers have **full information** regarding flood risks for affected properties[.]" (USACE 2009a, p. 26, emphasis in original). Unfortunately, given the nature of uncertainty about flood hazards, both epistemic and aleatory (incomplete flood records and incomplete human knowledge of the specific flood hazards), it is impossible to have *full information* about flood risks for affected properties; moreover, when such information asymmetry exists, either the buyer or the seller or both may be affected by *information hazards* that result in consequences to either or both parties (cf. Bostrom 2011). As such, USACE states that a property damages avoided estimate "which implicitly assumes that land markets traders are completely ignorant of flood risks at the [property] site would provide an upper bound estimate of flood reduction benefits arising from permanent [floodplain] evacuation" (USACE 2009a, p. 36). Despite the USACE discussion of human dimension benefits in its 2009 document, the NED procedures manual from 1988 (p. VII-14) sets out a far more distinct indifference toward losses:

> The threat of flooding will often cause occupants not to use areas of their buildings that are subject to the most serious flood threat or cause a less valuable or inefficient use of the property. Arrangements of contents, although it may be considered inconvenient, is not a major economic loss.

In the case of levees, benefit-cost analyses conducted in risk and vulnerability assessments include existing or *future* development as beneficiaries of structural flood protection (TVA 2004; USACE 2009a; Moser 2011; USACE 2012a). The alleged future benefits, however, contribute to increasing exposure to flood losses (cf. Tobin 1995; McMaster 1996). For example, although New Orleans experienced frequent storm surge and other sources of flooding from its founding through the early 1900s, the USACE was authorized to construct the intricate hurricane protection system—a complex engineering project composed of levees, channels, pumps, and other structural devices—to protect newly-drained swamplands intended to be developed into "productive use" (Burby 2006, p. 174). Though the existing swampland development did not yet exist, the USACE cost-benefit assessment for the levee project included new developments accounting for *79 percent of the benefit* of the project, as opposed to 21 percent of benefits of the project for existing development to justify the cost of the project (Burby 2006, p. 174). This clearly speaks to intent to develop land *protected* by levees—or, in other words, to increase economic productivity by increasing exposure to flood hazards. Through the 1950s, more than 47,000 housing units were added to the New Orleans area, with development "exploding" into the swamplands subject to "dangerous flooding": despite Hurricane Betsy's major flooding in these *protected* areas, private investment continued through the 1990s, with housing plans to accommodate up to 250,000 residents and more 22,000 new housing units (Burby 2006, p. 175). Hurricane Katrina's flooding brought catastrophic damage to these areas, and storms of Katrina's intensity or stronger are predicted to have about a 7 percent chance of happening in any given year (Elsner et al 2006); further, the levees in New Orleans should be raised to a 400- to 1000-year recurrence elevation to provide a sufficient level of protection (NRC 2009).

The intended induction of development is codified into the future development specifications for benefit-cost assessments. As such, existing and future development in protected areas experiences residual risk—that is, the risk of flooding and losses if levees fail or are overtopped—for floods up to structural design criteria, as well as the risk of infrequent flood events beyond the design criteria of the particular protective structure. Thus, development in protected areas, while experiencing reduced losses from more frequent flood events, is vulnerable to less frequent events *ceteris paribus* and may experience much greater losses as a result of the flood protection (White and Haas 1975; Tobin 1995; Pielke 1999; Carter 2005; Burby 2006; Montz and Tobin 2008; Huber 2012; Knowles and Kunreuther 2014).

2.5 Flood Hazard & Development in the U.S.

The evolution of complex flood control systems in the US has created a cycle of "normal" system failures in areas protected by levees (Perrow 1984; Tobin 1995; McMaster 1996; Montz and Tobin 2008; Anderson and Kjar 2008; Hallegatte 2011). System failures—like those leading to damages from levee breaches or overtopping—are inevitable due to limitations on design capabilities and costs, and thus have become a *normal* feature of the system (Perrow 1984; Tobin 1995); moreover, the use of flood control structures has created a *path dependency* based on historical territorial settlement and development, once for agricultural cultivation and now transitioning into adverse residential occupation of levee-protected floodplains, from which deviation toward well-adapted, nonstructural risk reduction measures or settlement of lower hazard areas is very difficult to implement even when more optimal alternatives are available (Tobin 1995; Ludy and Kondolph 2012; di Baldassare 2015; CRS 2018). In the case of levees, benefit-cost analyses conducted in risk and vulnerability assessments include existing or *future* development as beneficiaries of structural flood protection (TVA 2004; USACE 2009; Moser 2011; USACE 2012); however, the alleged future benefits contribute to increasing exposure to flood losses (cf. Tobin 1995; McMaster 1996; Burby 2001; Burby 2006). Thus, existing and future development in protected areas experiences residual risk—the risk of flooding and losses if levees fail or are overtopped—for floods up to structural design criteria, as well as the risk of infrequent flood events beyond the design criteria of the particular protective structure. Therefore, development in protected areas, while experiencing reduced losses from more frequent flood events, is more vulnerable to less frequent events *ceteris paribus* and may experience much greater losses as a result of the flood protection (White and Haas 1975; Tobin 1995; Pielke 1999; Carter 2005; Montz and Tobin 2008).

2.5.1 Flood Risk & Vulnerability

Risk, vulnerability, and flood hazard act in coordination to produce damages and losses to physical and social structures that are great enough to cause a community to be unable to recover without some form of assistance (Burton et al 1993; Blaikie et al 1994; Cutter 1996; Etkin 1999; White et al 2001). This study considers risk as the probability of a flood event multiplied by its measurable consequences. Vulnerability, contextualized as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact[s] of a natural hazard" (Blaikie et al 1994)—or, more generally, the potential for loss (Parker 1995; Cutter 1996)—is not well understood in relation to changing land use and development in areas protected by flood control structures, particularly at local scales. Whereas flood control structures like levees are locally constructed and effective, decisions made and resources allocated to build these devices are based on national-scale policies and benefit-cost analyses (TVA 2004; USACE 2009a; USACE 2012a). Jones and Murphy (2009) suggest that vulnerability to disaster impact is mediated by larger social processes, including those of national-scale political economies; furthermore, exacerbation of flood hazard vulnerability may stem from political decision-making (Anderson and Kjar 2008; Jones and Murphy 2009). Blaikie et al (2004, pp. 52-56) describes a pressure-and-release (PAR) model which sets out three distinct potential causal mechanisms which generate vulnerability: *root causes*, which are "an interrelated set of widespread and general processes within a society" that may be spatially or temporally distant such that social actions and beliefs are often "taken for granted," and of which economic, demographic, and political processes are root causes of vulnerability; *dynamic pressures*, which "are processes and activities that 'translate' the effects of root causes both temporally and spatially into unsafe conditions," including rapid urbanization; and *unsafe conditions*, which "are the specific forms in which the vulnerability of a population is expressed in time and space in conjunction with a hazard." **Blaikie et al (2004) note that there are tendencies in the literature to refer to the pressures increasing vulnerabilities as "bad" or otherwise damning without considering historical or local contexts for explaining the reasons that, for example, certain root cause decisions were made**.[4] Further, Wenger (2015, p. 241) states that "adaptation literature often presents levees as a 'bad' hard engineering response, not only because of the many unintended side-effects but also because incremental changes can enable the continuation of 'business as usual' and inhibit the implementation of more transformational options." Additionally, Wenger (2015, p. 247) reviews how levees create *path dependency* by limiting future options for individual and collective mitigation strategies, "encouraging additional development of flood-prone land" and "increasing the assets at risk [of potential damages]." For the PAR model that results in flood damages, Blaikie et al (2004, p. 217) describe root causes of vulnerability as migration into or urbanization of areas prone to flooding, or, more simply, increasing population growth in the path of floods, with systems promoting unequal holding of assets prompting bias in precautionary and mitigative measures—

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[4] Indeed, the author recognizes, through experience and from literature about possible publication biases in recent years, that there exists some tendency to label or otherwise denote structural flood control projects as "bad for the environment" or "insufficiently constructed" or "providing insufficient flood protection." Some of these statements are borne in media, others in academic literature. Yet, the author tries to take no stance on "bad" versus "good" in this dissertation, attempting to offer objective analysis and empirical findings without invoking specific biases around very complex societal issues. *See* Murphy (1993) for further context.

all of which add to dynamic pressures such as lower incomes influencing individuals to live in more dangerous places with few assets available to recover from flood damages. In terms of unsafe conditions described for the PAR flood model, Blaikie et al (2004, p. 217) describes physical environments as potentially increasing vulnerability through siting of homes in lowland areas (floodplains) with no insurance protection and disruption to livelihood. Bankoff et al (2004) states that "vulnerability expresses changing social and economic conditions in relation to the nature of hazard and is part of a dynamic, evolutionary, and accretive process"; moreover, Bankoff et al (2004) state that 1) vulnerability to hazards must consider local knowledge, which is often "the only remaining asset" possessed by local populations which can be manifest to confront development pressures; and 2) that vulnerability is equally a product of the past and history as it is to the present and future conditions for understanding disaster causality.

Perceptions of risk also influence flood losses. Research evaluating how people view risk can help inform risk reduction policy; however, media coverage may bias the public's perception of flood events, causing them to think floods occur more or less frequently than in reality (Slovic et al 1982; Fischhoff et al 1984; Pielke 1999; Ludy and Kondolf 2012; Randolph 2018). Under the National Flood Insurance Program ("NFIP"), the probabilistic characterization of flood risk is often misunderstood by risk-takers or miscommunicated by administrators of the program and the public (Bell and Tobin 2007; Ludy and Kondolf 2012). In the case of Minot, North Dakota, the *Minot Daily News* encouraged property owners and developers to "Go ahead and build" in 1995 following a FEMA decision to remove restrictions on construction in about 98 percent of the 100-year regulatory floodplain area of the Souris River originally delineated in 1983. This revision of the regulatory floodplain occurred due to completion of upstream dam and local levee improvements (Minot Daily News, 18 March 1995). The revision and reduction of the regulatory floodplain positively relates to increased physical vulnerability (potential for building damages and losses) from new development occurring after 1995 based on preliminary study results of the research proposed herein, and recent analysis of the NFIP by FEMA reveals increased social vulnerability (potential losses and inability to recover) in 100-year SFHA with non-participating individuals income substantially less than that of individuals holding insurance policies (FEMA 2017). Only 16 years after completion of the 100-year-designed structural flood control measures and improvements, the levees in Minot were overtopped and local floodplain residents experienced the consequences of residual risk of long-term floodplain occupation in the form of a nearly $1 billion flood loss. Public provisions of disaster relief may also act to worsen vulnerabilities or impede loss reduction incentives, thereby leading to increasing losses (Kaplow 1991; Shugart 2011; Jongman et al 2014).

Similar losses due to floods exceeding design criteria of structural protection measures occur frequently throughout the U.S. Other nations have adopted more reasonable risk assessment schemes for individuals and societies as a whole, while calls for such action in the U.S. continue unanswered, discounted, or approached in a piecemeal fashion (Griffiths 1994; Changnon 2000; White et al 2001; Zaugg 2002; Jonkman et al 2004; Pinter 2005; van Stokkom et al 2005; Roth and Warner 2007). Empirical evidence of levee effect phenomena will assist in the adjustment of floodplain loss reduction policies.

2.5.2 Definitions of Levee Effect

From 2003 to about 2014, nearly $100 billion was lost to riverine and flash flooding (Knowles and Kunreuther 2014). In 2011, however, levee systems in the central US prevented an estimated $19 billion during the 1993 floods and around $110 billion in damages in 2011, according to the USACE, demonstrating the value of levee protection (Pinter 2005; MRC 2011;

NRC 2013). The Code of Federal Regulations refers to levees as providing *protection* from flooding, which, according to Burby (2006) and others, leads to the incorrect assumption that levees are *safe* or instills a *false sense of security* to floodplain occupants (cf. White 1936; White 1945, p. 175; Burton 1962; Tobin 1995; Burby 2006). In trying to make floodplain areas *safer*, Burby (2006) states that the potential for catastrophic losses is actually increased:

> If development behind a levee substantially increases, the consequences of a levee failure or overtopping will also substantially increase. […] Because areas behind the 100-year levee are not shown on FIRM's as subject to the one percent annual chance flood and residents are not subject to the [mandatory purchase requirement], many residents assume they are protected against all flooding[.] (NRC 2013 p. 17).

Many flood disasters in the U.S. in recent years resulted from overtopping of levees or the failure of levees and other flood control structures, noted in at least one-third of all flood disasters up to 1979, causing significant direct impacts to affected populations and indirect effects to others through economic consequences (NRC 2013). In 1980, the administrator of the Federal Insurance Administration (FIA, a part of FEMA now known as the Federal Insurance and Mitigation Administration, or FIMA) stated that "**the use of a 100-year standard was encouraging construction of levees to the 100-year design level for the sole purpose of removing an area from the special flood hazard designation**[.]" (NRC 2013, p. 26, emphasis added). Criticizing the use of levees to reduce floodplain insurance requirements, the National Academies of Sciences states that "no matter what actions are taken to reduce structural systems risks, the residual risk of structure failure will always remain […]; moreover, residual risk generally changes over time with changes in land use patterns, development, and hydrologic variability. If development behind a levee substantially increases, the consequences of a levee failure or overtopping will also substantially increase[.]" (NRC 2013, p. x, p. 17).

During the Midwest Floods of 1993, nearly 70 percent of levees facing flood conditions failed and caused extensive damage, leading Tobin (1995) to declare that the nation's "undying affair with levees" was causing continuing and increasing flood losses. Tobin (1995) states that the calls for flood protection throughout the 1800s and 1900s reflect an "overwhelming bias" for building levees to eliminate flooding rather than mitigating flood losses. Simons et al (1977, p. 132-133) was also critical of levees, stating "damage will be very intensive" in areas nearest to levee failure because failing levee systems or floods exceeding the design criteria of levees will cause floodwaters to spill onto the floodplain at "a much higher stage than would have been the case had the levee system not been implemented." Furthermore, Simons et al (1977, p. 133-134) states that the long-term prediction of extreme meteorological events producing floods beyond design criteria and associated damages is uncertain "at best." Referring to the 1993 floods and recognizing that there were differential outcomes of some communities experiencing flood losses due to levee failures while others benefited from levee protection, Tobin believes that the communities would not have expanded onto the protected floodplain lands if levees had not been constructed (Tobin 1995, p. 360). Concluding that the "accounting system for benefits is somewhat flawed," Tobin identifies a version of levee effect:

> It has been argued that the area behind levees may be at greater risk than normal because of the 'levee effect.' While a comprehensive examination of the levee effect has not been undertaken, evidence suggests that the construction of levees can exacerbate flood losses under certain circumstances. […] Once the project [levee] has been constructed, however, the structure may generate a false sense of security to the extent that floodplain inhabitants perceive that all flooding has been eliminated. With the incentive to take precautions removed, few residents will be prepared for remedial action in the event of future foods. **Even more costly, however, this false sense of security can also lead to greater development in the so-called safe areas, thus adding to the property placed at risk.** Inevitably, a flood will occur that exceeds levee design standards, overtopping or breaching the levee system and inundating the community. It is important to remember that the project may be very effective up to its design standards, but any flood beyond that size will result in some flooding, assuming all calculations have been correct. **In effect, therefore, the breaking of the levee because of high water is not necessarily a**

> **failure of the flood alleviation strategy, but is actually a feature of the project itself.** Nevertheless, flood problems are exacerbated by the intensification of land use in the hazard area. […] Finally, **when the levee does fail, the increase in development can actually raise losses even higher than if no levee system had been constructed in the first place.** Thus, the large claims of levee induced savings … are somewhat fallacious. (Tobin 1995, p. 365, emphasis added)

Aside from a potential false sense of security, Blaikie et al (2004, p. 203) suggest that levee failures and damaging floods caused by levee overtopping in the mid-to-late 1990s "reduced the trust in conventional 'engineered' flood control measures," leading to increased interest in "living with floods" such that ecological services might be restored to provide natural flood storage through river restoration to realize the "considerable benefits [of floods] that have been lost through damming and flood control." Citing geomorphologist Jeffrey Mount, Blaikie et al (2004, p. 203) offers a possible root cause for reduced trust in engineered floodplains amid increased flood losses experienced following levee-failure and overtopping floods in California in 1997:

> In large measure, these increases in flood damages have been self-inflicted. Development of our flood plains has continued as a result of engineering hubris, disaster-denial mentality and a willingness to pursue short-term profit in the face of long-term risk. Integral to this problem has been an unhealthy over-reliance on levees too close to rivers and 100-year flood-plain zoning.

Research on floodplain mitigation often focuses on understanding flood hazard through hydrologic and hydraulic studies, risk and vulnerability analyses, and through structural and nonstructural measures to reduce flooding, exposures to floods, and flood losses (Simons et al 1977; Hewitt 1997; Burton and Cutter 2008; Moser 2011). Indeed, such research has focused on social, physical, economic, and political relationships related to flood risks, vulnerabilities, and losses, long noting the possibility of a *levee effect* phenomenon whereby the installation of structural—or *protective*—flood control measures potentially increases losses (Tobin 1995; Pielke 1999; Sarewitz and Pielke 2001; White et al 2001; Bankoff 2004; Carter 2005; Sayre

2010; SCCOR 2012). Notably, as the literature long focuses on risk perception and a false sense of security instilled by levees, from White (1945) to Tobin (1995) to NRC (2013) to Hutton et al (2018), Ian Burton's 1962 dissertation on agricultural occupance of floodplains highlighted how farmers were observed to undertake more risky utilization of lands between a river and a levee—where unprotected floodplains could yield greater crop production, private levees were built to increase land value: "just as the early cultivation of the non-floodplain land in human plains areas has been followed by invasion of the flood plain, so cultivation of the protected land in wide flood plains has been followed by the movement of cultivation over the levee onto the unprotected land. *This may be called the 'levee effect' in flood plain occupance*[.]" (Burton 1962, p. 39). Burton and Kates (1964, p. 380) describe the levee effect occurring as a speculative venture to develop more agricultural land, particularly given more secure farming behind the protection of a levee. Similarly, a dissertation by Linda Lee in 1977 demonstrated that agricultural lands were being converted for urban uses, highlighting the conflicts in land use create environmental degradation, dispersion of farmlands, and low-density residential sprawl that encroaches upon floodplains. However, very few studies have defined the levee effect in a measurable way, and even fewer studies have actually tried to measure it (White and Haas 1975; Smith 1992; Tobin 1995; McMaster 1996; White et al 2001; TVA 2004; USACE 2009). A Congressional Research Report states that the *increased consequences* of development behind *protective* structures "ironically" occurs because of protection provided (Carter 2005); however, it can be demonstrated that such development *intentionally* occurs based on federal benefit-cost analysis policy for structural mitigation measures (Tobin 1995; TVA 2004; USACE 2012b).

Thus, the levee effect has multiple definitions and is a potentially significant factor exacerbating flood losses that should be studied carefully, especially in consideration of increasing value and numbers of vulnerable residential construction. For the purposes of this dissertation, levee effect will be considered the change in residential building stock from a prior-to levee construction condition to a post-levee construction condition wherein both the changes in total building construction counts and average or cumulative valuation might exacerbate the potential for increased flood losses. The connotation of this definition of levee effect intends to highlight both the absolute increases in residential construction and value, but also to reveal underlying policies encouraging both levee construction and occupation of hazardous floodplains that leads to potential increases in vulnerability; furthermore, this definition of levee effect as increasing vulnerability through policy mechanisms implies and embodies emerging definitions of maladaptation, including insurance connotations of adverse development, moral hazard, and crowding-out of individual responses to and concentration of risk (Burton 1997; Barnett and O'Neill 2010; Michel-Kerjan 2010; Jongman et al 2014; Juhola et al 2016).

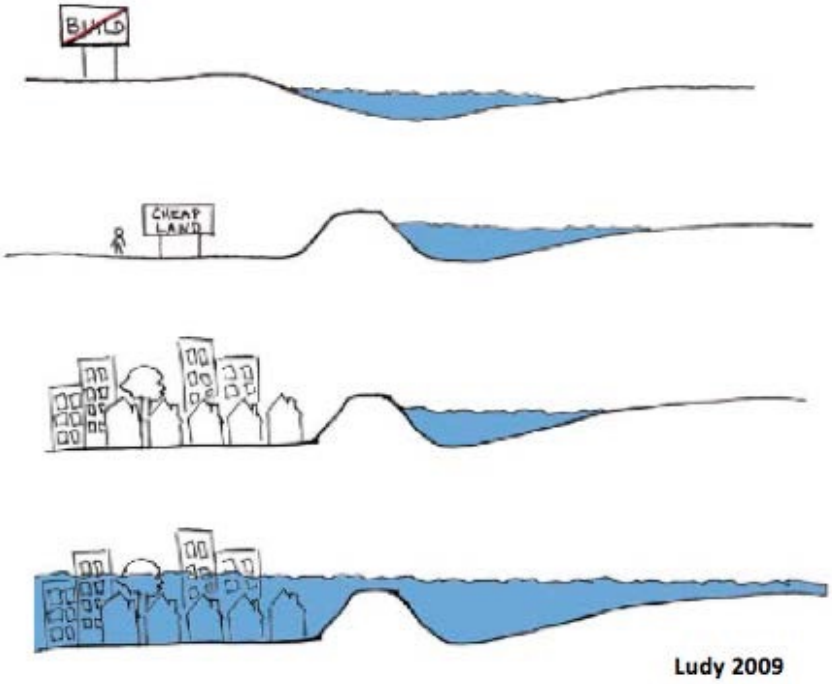

Figure 2.6. An illustration of induced development occurring in levee-protected areas that serves to increase land and real estate value while increasing flood risk. (Source: Ludy 2009)

2.5.3 Previous Research on the Levee Effect

Although significant references to the levee effect exist in contemporary literature (cf. White and Haas 1975; Tobin 1995; Pielke 1999; USACE 2009; di Baldassare 2015; Hutton et al 2018), very few studies have engaged in qualitative or quantitative research to demonstrate the phenomenon in an empirical manner. In Hutton et al (2018, p. 11), changes in census housing and population estimates intersecting with flood zones are described, specifying increases in floodplain occupation and declaring the "levee effect alive and well in Yuba County, California" based on levee improvements and expansion of urbanized, developed areas; however, the authors note that development trends at finer scales than census and land cover estimates should be pursued. In somewhat earlier research, a master's thesis by McMaster (1996) quantified the levee effect by evaluating new construction and restoration permits issued following levee installation in the Midwestern U.S. communities of Chesterfield and Hannibal, Missouri, and in Rock Island, Illinois. In a control group, McMaster also examined two cities which did not have levees installed. McMaster found significant increases in new building construction permits issued in the year following levee installation: for example, the number of new construction permits issued in Chesterfield, MO during the period of 1964-1983 was approximately 3.6 per year on average. After completion of levee reinforcement in 1983, McMaster found that the number of new construction permits issued annually nearly tripled to 9.5 per year during the period of 1984-1989 in Chesterfield. In the control group where no levees were installed or refurbished, McMaster found little to no new development occurring in unprotected floodplains, and that development was occurring much more slowly than in the protected communities. It is important to note that McMaster examined development both inside and outside the designated floodplains, based on regulatory floodplain maps and permit locations, in order to differentiate regional development trends from levee-induced development and to arrive at his conclusion that levees encourage new floodplain development.

In 2004, the Tennessee Valley Authority (TVA) conducted a benefit-cost assessment for the Rock Island, Illinois district office of the Army Corps of Engineers as part of a region-wide plan for flood protection on the Mississippi and Illinois Rivers. The TVA study presents detailed economic modeling for several flood protection options, described as confined or unconfined 500-year levee improvement projects (i.e. raising existing levees), costing between $2.7 and $5.8 billion, depending on the design configuration implemented. Based on a suite of regional and multi-regional economic modeling analyses, the TVA study estimated average annual regional economic development benefits of between $22 billion and $30.4 billion over a five-state area comprised of Illinois, Iowa, Wisconsin, Minnesota, and Missouri, along with positive job creation ranging from 18,966 to 25,690 jobs. Approximately 95 percent of the economic benefits were attributed to "economic development and construction," with the remaining benefits occurring in the form of increased land values and farm income, as well as damages avoided (TVA 2004, p. 37). A particular highlight in the economic analysis is that the total damages avoided are approximately $179 million; property values were expected to increase by about $72 million across the protection scenarios. Additionally, the damage aversion analysis completed in the TVA study only superficially quantifies damages, stating, "flood damages are averted over time with better flood protection," **and that residential and commercial establishments should be able to purchase flood insurance with reduced premiums**. The TVA concludes that the reduced insurance premiums should make available "increased dollars for consumption expenditures" and that "economic development impacts result as flood risks are reduced in the floodplains, increasing the likelihood of economic activity due to reduced risk and costs of operation[.]" (TVA 2004, p. 14).

In the TVA study, it is difficult to ascertain the specific long-term flood loss reduction benefits because many assumptions are made about macroeconomic variables and conditions in the multistate region. There is little to no discussion of specific modeling techniques or calculations, only of the *potential* benefits of opening previously restricted floodplains to development.[5] In a more critical review, the *potential* benefits could equally be seen as *potential* losses in a vulnerability analysis; however, the TVA study only considers regional benefits of economic activity while discussing the local nature of additional floodplain occupation or development—there are no references to the physical vulnerability of specific floodplain occupants in residual risk areas or the probability for losses in these areas as possible offsets to any local, regional, or national benefits. The TVA study reviewed the McMaster thesis (1996) and concluded that, based on their regional analyses and a separate county-level employment and earnings analysis, 200-year levees create more economic development than 100-year levees. Thus, the TVA and its subcontractor's studies redefined the levee effect as a positive contribution of long-term floodplain occupation and development provided by levee protection without considering alternate development scenarios based on lower-risk areas already open for development. The TVA analyses did not present any disaggregated or site-specific analyses of residual risk or vulnerability in their study; they also did not specify that the benefits of development or potential losses would occur in the protected floodplains versus other higher elevation, less risky areas.

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[5] USACE 2009a, p. 70, states that the model employed by the TVA 2004 study was proprietary and that "this reality limited the amount of information available about the model and prevents further analysis."

2.6 Research Preparation & Preliminary Case Study

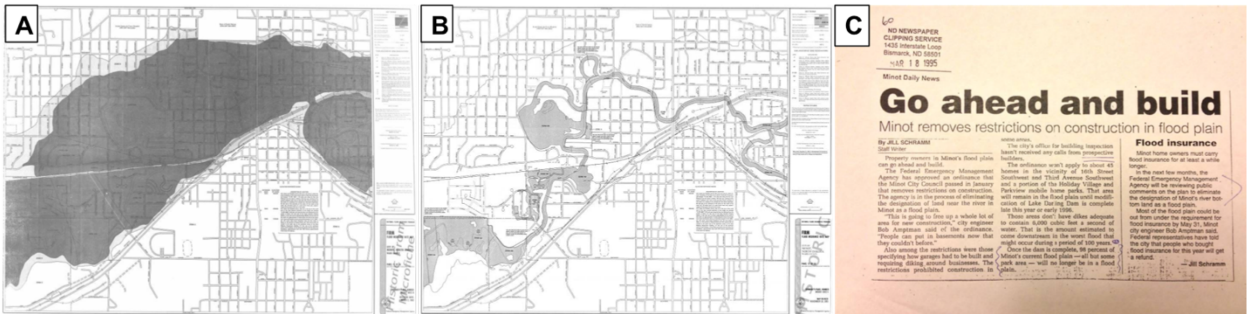
Several study areas were chosen for this study based on a history of flood losses to residential buildings located in floodplains. First, a preliminary study was conducted for the City of Minot, North Dakota following levee overtopping in 2011, which caused nearly $1 billion in losses and the damaging or complete destruction of more than 4,000 homes. In collaboration with FEMA's Region VIII office, data were collected for residential tax parcels that included three key attributes to studying changes in residential building valuation histories: 1) locational coordinates for the residential buildings; 2) the year that the buildings were constructed; and, 3) the local tax assessor's market valuation estimates for the residential buildings. With this information, spatial analysis of residential floodplain occupation over time revealed the feasibility of assessing both pre- and post-levee construction conditions, along with contextual information from media and USACE about levee completion and from FEMA regarding changes to the regulatory floodplain as a result of levee implementation. As such, the preliminary study indicated that additional parcel data were needed in order to control for non-leveed and non-floodplain areas and for estimating overall changes in residential valuation beyond the immediate floodplain. Thus, study areas described herein were selected based on the following criteria: 1) the cities are located on or near riverine floodplains, with or without levees; 2) residential tax parcel data was available and complete for all areas of the city or county; 3) sufficient data from the USACE National Levee Database was available and complete for the levees in the city or county; and, 4) historical and current flood zones were available from FEMA. The next section describes the preliminary analyses for Minot before describing the study areas at the subject of this research.

2.6.1 Structural Flood Control and Floodplain Mapping Affecting Minot

The City of Minot, North Dakota provides a very rich history of structural and nonstructural approaches to flood risk management, as the city experienced numerous floods from the Souris River dating back to early settlement, with the flood of record occurring in 1881-82. Early efforts to straighten the Souris River through channelization for expanding agricultural development yielded groundwater and waterfowl habitat depletion. Following substantial damage from floods in the 1950s, construction of a dam at Lake Darling, with channel improvements and levees constructed downstream to Minot, were authorized by the Flood Control Act of 1965 (USACE 1977; USACE 1983). Interestingly, the USACE's environmental impact report for the Lake Darling Dam and Reservoir project (1977, p. 118) reviews the potential for adverse impacts caused by an influx of project workers and local market services adapting to short-term demand and ensuing market "boom," followed by an under-utilized and costly service structure that "local residents must pay for through higher taxes" when the short-term construction workers complete the project and leave. The USACE advised that "prudent local restraint in response to temporary services demands will suffice to avoid such long-term and structural consequences" to market sustainability; moreover, in considering adverse social impacts caused by relocating several dozen homes and vacation structures due to permanent inundation caused by building the Lake Darling Dam and reservoir, USACE makes an interesting note that economic compensation does not address social impacts caused by disrupting ancestral family connections to the land used for the flood control project, along with other social factors such as "interaction frequencies with significant others," length of residence, socio-economic status, or "source of livelihood"—all similar issues that could be faced in a disruptive flood disaster (USACE 1978, p. 121). Estimating more benefits than consequences for the project, and noting that permanent evacuation of the floodplain as a project alternative would move 13,800 people out of the county's hazardous floodplain (12,000 from Minot alone) at a one-time cost of $266 million (with about $45 million to be paid by local entities, giving an annual benefit of permanent relocation at about $8.8 million or about $13.8 million for the flood control project at a benefit-cost ratio of 0.64) and destroy about 553 hectares (1,365 acres) of bottomland hardwoods—a "highly significant" loss for a state with "only about 400,000 acres [161,943 hectares] of natural woodlands remaining (less than any other state) […] this acreage represents about 27 percent of the woodlands" within Ward County, and "loss of bottomland hardwoods would cause a serious alteration to the biological productivity, ecological balance, and stability of the floodplain forest and functionally related ecosystems"—for a gain of about 405 hectares (1,000 acres) of new agricultural land, the USACE provided justifications to continue with the construction of the Lake Darling Dam to increase Souris River channel flow from 1,500 cfs to 5,000 cfs, representing, per USACE frequency estimates, the 100-year flow condition that would occur when the reservoir pool of Lake Darling filled to its 100-year flood storage capacity design limit (USACE 1978, pp. 122, 136, 156). The environmental impact analysis goes on to state that an alternative of taking "no action" to implement structural flood control would entail the alternative implementation of floodplain regulations, flood insurance, flood warning systems, and emergency measures when flooding occurs; however, in apparently arguing against such alternatives and for the flood control project, USACE (1978, p. 132-133) stated that the channel modification was already "almost 95 percent complete," having been "originally conceived to be an integral part of any flood control plan for Minot"—and then proceeding to state that "the 5,000-cfs channel […] can control floods up to those expected once every 25 years" and that "the 5,000-cfs channel does not provide an acceptable degree of protection for an urban area" but "it is the benefit/cost ratio, more than any other factor, that commonly determines or influences the selection and sizing of a particular project."

In 1983, FEMA issued a Flood Insurance Rate Map ("FIRM") that depicted a large area of the Souris River floodplain in the 100-year Special Flood Hazard Area ("SFHA"); however, following completion of the levee and dam improvements under a 1987 flood control plan (generally increasing both dam and levee heights), supported by the Water Development Resources Act of 1986, the 100-year SFHA was subsequently reduced to the area between the levees on a FIRM issued in 1995, alleviating the mandatory flood insurance purchase requirement set out in the Flood Disaster Protection Act of 1973. In local newspapers, city managers and developers declared the floodplain eliminated and encouraged residential construction in areas reclaimed from the 1983 SFHA (Figure 2.14). Only a few short years later, in 2011, significant upstream snowpack meltwater and spring rains resulted in serious risks to the Lake Darling dam, causing the USACE to "surcharge" the Souris River—releasing far more water into the channel than the 5,000-cfs design level. Flows on the Souris River reached nearly 29,000 cubic feet per second, almost six times the 5,000 cfs design for the levees—a volumetric increase that is exponentially greater, and nearly 4,165 homes were substantially damaged or destroyed at about $480 million in residential building losses (FEMA 2015a; USACE 2017). At the time of the 2011 flood, participation in the NFIP by Minot homeowners was about 2 percent (Pers. Comm. Bausch 2011). Residents of Minot displayed significant psychological trauma as a result of the flooding and damages, whereas nearby Fargo, North Dakota successfully mitigated the flood hazard through emergency measures, resulting in a comparatively lower level of flood disaster trauma (Schultz et al 2013). Following the flood, in 2013, USACE (2017, p. 15) notes that a local engineering firm revised the 100-year flow upward from 5,000-cfs to about 10,000-

cfs. Based on the new flood frequency calculations and decertification of the protective levees at Minot, the 100-year SFHA floodplain expanded to nearly the same area as that of the 1983 SFHA that depicts no levee protection due to FEMA's direction to use "natural valley" floodplain analysis due to levee decertification in 2014 (FEMA 2015a; USACE 2017).



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Minot Daily News

Go ahead and build

Minot removes restrictions on construction in flood plain

By JILL SCHRAMM
Staff Writer

Property owners in Minot's flood plain can go ahead and build.

The Federal Emergency Management Agency has approved an ordinance that the Minot City Council passed in January that removes restrictions on construction. The agency is in the process of eliminating the designation of land near the river in Minot as a flood plain.

"This is going to free up a whole lot of area for new construction," city engineer Bob Amptman said of the ordinance. "People can put in basements now that they couldn't before."

Also among the restrictions were those specifying how garages had to be built and requiring diking around businesses. The restrictions prohibited construction in some areas.

The city's office for building inspection hasn't received any calls from prospective builders.

The ordinance won't apply to about 45 homes in the vicinity of 16th Street Southwest and Third Avenue Southwest and a portion of the Holiday Village and Parkview mobile home parks. That area will remain in the flood plain until modification of Lake Darling Dam is complete late this year or early 1996.

Those areas don't have dikes adequate to contain 8,000 cubic feet a second of water. That is the amount estimated to come downstream in the worst flood that might occur during a period of 100 years.

Once the dam is complete, 98 percent of Minot's current flood plain — all but some park area — will no longer be in a flood plain.

Flood insurance

Minot home owners must carry flood insurance for at least a while longer.

In the next few months, the Federal Emergency Management Agency will be reviewing public comments on the plan to eliminate the designation of Minot's river bottom land as a flood plain.

Most of the flood plain could be out from under the requirement for flood insurance by May 31, Minot city engineer Bob Amptman said. Federal representatives have told the city that people who bought flood insurance for this year will get a refund.

— Jill Schramm

Figure 2.7. Floodplain maps for Minot and Minot Daily News headline. A) The 1983 FIRM for Minot depicts a wide floodplain not protected by levees, with the 100-year SFHA (dark gray shading) showing many downtown residential neighborhoods vulnerable to flooding, with the 500-year (light gray line to either side of the SFHA) flood zone (X) extending slightly beyond the SFHA. B) Following upgrades and completion of construction on levees in the late 1980s and early 1990s, FEMA provided accreditation status to the levees at Minot, substantially reducing the 100-year SFHA to only the channel side of the levees, "removing" much of downtown Minot's residential neighborhoods from flood insurance purchase requirements. C) As a result of the reduced floodplain area, the Minot Daily News persuaded developers to "Go ahead and build" following FEMA's "plan to eliminate the designation of Minot's bottomland as a flood plain." (Minot Daily News article provided by Ryan Pietramali, FEMA Region VIII.)

2.6.2 Preliminary Spatial Analysis for Minot

Using tax assessor data for structures in the City of Minot, North Dakota, acquired from FEMA Region VIII, preliminary exposure analyses were conducted to assess the feasibility of the cross-section approach to studying the levee effect. In this initial case study, the 100-year regulatory floodplain from a 1983 FEMA Flood Insurance Rate Map (FIRM) was georectified in GIS to visualize the extent of possible flood conditions without levee protection included. A 1995 regulatory floodplain map representing reduced flood areas based on levee and dam protection was also used in the preliminary analysis: the 1983 100-year floodplain is significantly larger than the 1995 100-year floodplain based solely on the exclusion of structural flood control. The difference in these 100-year floodplain areas allowed for quantification of structures (and their valuations) exposed to floods based on non-protected and structurally protected areas by decade constructed (as attributed in the tax assessor data).

Following the physical floodplain profile method for estimating flood frequency, two initial cross-sections were drawn on the Souris River floodplain. First, the Souris River layer was generalized in the GIS, to straighten the river, such that cross-sections could be drawn perpendicularly to the river channel without overlapping. Next, cross-sections were drawn perpendicular to the generalized river, extending across the entire width of the floodplain, as referenced by a minimum of the 500-year flood boundary. The cross-sections were drawn in a vector shapefile to a length sufficient enough to include areas well outside the physical floodplain. The cross-sections were then standardized into 100-meter segments, starting at zero distance from the river channel (center) and then proceeding away from the center point in 100-meter increments to either side of the river channel in a downstream orientation (that is, 100-meter intervals to the left of center or to the right of center when facing downstream). Each 100-meter interval from the river channel was marked with a point, and each point stored into a vector shapefile in the GIS. At each point location, a 100-meter search radius (buffer) was created. For each 100-meter point location, the 100-meter search radius was used to spatially join the tax assessor structure locations (and their corresponding attributes) for each respective interval location to establish the profile of floodplain occupation along each cross-section, thereby providing a count of structures with average valuations and year built for each 100-meter interval outward from the river channel. Based on the floodplain structures profile for each cross-section, histograms were developed to represent vulnerable structure counts and valuations at risk at each interval. The histograms were then used to develop exposure functions for each cross-section using linear regression analysis.

The histograms and exposure functions for each test cross-section in Minot provide interesting insight into floodplain development practices prior to and following structural flood control installations as well as guidance for continued development of the methods used in this study. Cross-section 01e, drawn through the old central business district of Minot, reveals a near total build-out of the floodplain prior to 1950 for that location—meaning that, prior to 1950, the capacity of the floodplain to house new or additional structures may have been reached or that local residents constructed in cognizance of a possible "safe distance" from the Souris River channel. Very few structures were constructed along this profile in the 1950s and 60s, and development essentially slowed to a halt after 1970. It is important to note that a major flood in 1969 damaged many structures along this cross-section and may have led to the reduction in development. It appears the levees in the area of Cross-section 01e have not encouraged additional development and may be serving the purpose of flood *protection* for existing structures, at least for frequent flood issues (less than 100-year recurrences).

Construction practices along Cross-section 02w represent a newly developing area of Minot. Prior to 1960, floodplain encroachment generally slowed at or near the 500-year flood recurrence boundary (which is roughly the same spatial extent on both the 1983 and 1995 regulatory floodplain maps). Within the 100-year floodplain boundary delineated on the 1983 FIRM, new construction grew quite rapidly during the 1970s. There are many potential explanations for this development which need further examination, including expectation of protection from the construction of the Lake Darling Dam upstream on the Souris River, or possibly expansion of the city or relocation from other "built-out" areas in the central business district related to the 1969 flood. Nonetheless, the nonstructural flood loss reduction measure, formalized in the 1983 FEMA FIRM, did not include levee protection in delineating the 100-year floodplain boundary. During the time the 1983 FIRM was effective, roughly up to 1995, no new development occurred in the 100-year floodplain space, which seems to represent a successful period of limited floodplain development as intended by NFIP policy. Once the 100-year floodplain area was reduced based on the inclusion of structural flood controls (levees and dams) in the 1995 FIRM, development in the 100-year floodplain delineated on the 1983 FIRM (without levee/dam protection) immediately commenced. With the nonstructural floodplain regulation from 1983, development was limited in this high-risk floodplain area during the period of 1979 to 1998, with total structural valuation at risk estimated at about $34 million during that time; however, new development added to the "unprotected" 100-year flood area (1983) added about $15 million additional structural valuation at risk, or about 45% in additional exposure, between 1998 and 2011. Local newspapers encouraged development in the 1983 100-year floodplain—the 1995 100-year floodplain, which included levee/dam protection, was essentially limited to the Souris River channel, and the average value of new structures built between 1998 and 2011 is roughly twice as valuable as the structures built prior to 1980.

The development profile represented by Cross-section 02w provides an important basis for predicting areas where the levee effect may be most influential in other study areas. As noted in Cross-section 01e, development occurred to such time that the floodplain essentially reached a maximum occupation capacity; however, the profile also demonstrates that there available high-ground, lower-risk areas which can be developed still. In the case of Cross-section 02w, the low-elevation, highest-risk areas were opened for development following a supposed reduction of floodplain area based on levee protection. Notably, abundant areas of higher-ground, lower-risk areas are available to development on Cross-section 02w, yet the new development occurred in the highest risk portions. Further analysis of the parcel valuations in the lower risk areas may reveal a disincentive to build based on cost; however, these exploratory analyses suggest that these lower-risk areas are no more costly than the higher-risk areas, in terms of valuation, and it should be noted that the lower-risk areas on the profile are not in the 1983 or 1995 100- or 500-year floodplains, so there would be no mandatory insurance requirements to add to construction costs there.

The preliminary research on Minot provided useful indicators for a larger, more in-depth study of leveed and non-leveed floodplains. First, the use of residential parcel data provided the ability to conduct site-specific evaluations of floodplain development and changes in flood risk over time; however, the residential parcel dataset for Minot was developed by FEMA Region VIII in response to the flooding of 2011, and, unfortunately, did not include non-floodplain areas of Minot, limiting the utility of the data for assessing other changes in residential parcel valuations and construction years across the entire city and county of Minot and Ward, respectively. Though changes in residential development in the floodplain is illustrative of general changes in flood risk, one cannot conclude decisively that floodplain or leveed-protected floodplain grew faster, slower, or in synchrony with other related urban areas. As such, this study cast a broader net for data collection in other study areas. Second, the changes in Minot's flood zone maps from FEMA indicated some significant policy influences on local flood risk, as flood zones are substantially altered by structural flood control accreditation, even when physical floodplains in and of themselves remain hazardous due to floods beyond design criteria, illustrated both by the removal of flood insurance requirements following levee accreditation in Minot and the subsequent catastrophic flood damage of 2011. Last, though useful for considering adverse and adaptive development on local scales, the cross-section analysis technique provides a means for a general typology of residential development types, indicating areas of exposure and encroachment; however, additional analysis techniques are required for evaluating residential valuation and pre/post levee construction changes across larger areas.

2.7 Conclusion

Flood risk in the U.S. was influenced substantially by the ideas, science, and engineering of the colonial period, with particular emphasis noted in English and French practices of river commerce, transportation, and reclamation for agricultural development and settlement of new territories (Appendix A). This long arc of historical practice led the U.S. into *path dependency* relative to levees for flood control, both with benefits for agricultural and market development but also with substantial costs to the disempowered and vulnerable populations forced to develop the infrastructure for controlling floodwaters and settling the hazardous floodplains whilst largely discounting the environmental degradation concurrently leading to greater flood hazard and loss potential (Appendix B). Numerous insufficiencies in the 100-year flood protection and insurance standard have led to increasing flood risk, at least in theory, based on conflicting policies and perverse incentives for continuing to place more assets at risk through floodplain development while destructive impacts to wetlands also continues. Few rivers in the U.S. remain unregulated by dams and levees, and in the following chapter the set of study areas and their floodplains and levees are described for research into the *levee effect* and the ensuing changes in flood risk.

CHAPTER 3: METHOD

The purpose of this chapter is to set forth the research methodology for a geospatial analysis of residential parcel data in leveed and non-leveed floodplains as a means for assessing whether levees change residential exposure to flood risks and serve to increase rather than decrease the potential for flood losses. The analytical techniques developed in the course of this study are novel and unique and are intended to advance a levee effect theory; as the literature review supports, there are few prior attempts to quantify the residential floodplain occupation changes over time. A broad range of analysis techniques could be applied for evaluating the effects of levee construction on residential construction in floodplains. This chapter sets out logical, efficient, and reproducible geospatial and statistical analysis that yields quantifiable changes in flood risk exposure prior to and after the construction of levees in six American communities.

3.1 Research Questions

The intersection of social systems and physical floodplain systems is the key focus of this research. This intersection is the overlapping space of physical and human systems where hazard—and, therefore, risk, vulnerability, and losses—may increase due to interactions between the two systems. Thus, this research addresses two primary themes: 1) quantifying and qualifying changes in residential development prior to and after installation or modification of levees; and 2) the legacy and implications of these changes in relation to the ongoing flood hazard and losses experienced in the US. The research questions for these themes are:

> 1) *Are structural flood control measures associated with increased residential exposure to flood hazards?*
>
> 2) *Do flood control and loss reduction policy decisions made at the national scale affect exposure to flood hazards at the local scale?*

In answering these questions, this research is situated within the disaggregated and localized study of floodplain development and losses. Patterns of land and land use are studied by geographers (Burton et al 1993), and localized increases in physical and social vulnerabilities due to increased floodplain development are considered to be root causes of flood losses in this study. While benefits of structural flood protection are statistically inferred to occur at local, regional, or national scales, localized losses from infrequent flood events may actually be larger following levee installation due to increased exposure to flood risk; moreover, national scale funding used in local floodplain levee projects or disaster relief reflects a transfer of risk to citizens not exposed to the specific localized flood hazard.

Research on floodplain mitigation often focuses on understanding flood hazard through hydrologic and hydraulic studies, risk and vulnerability analyses, and through structural and nonstructural measures to reduce flooding, exposures to floods, and flood losses (Simons et al 1977; Hewitt 1997; Burton and Cutter 2008; Moser 2011). Indeed, such research has focused on social, physical, economic, and political relationships related to flood risks, vulnerabilities, and losses, long noting the possibility of a *levee effect* phenomenon whereby the installation of structural—or *protective*—flood control measures potentially increases losses (Tobin 1995; Pielke 1999; Sarewitz and Pielke 2001; White et al 2001; Bankoff 2004; Carter 2005; Sayre

2010; SCCOR 2012). Yet, very few studies have defined the effect in a measurable way, and even fewer studies have tried to actually measure it (White and Haas 1975; Smith 1992; Tobin 1995; McMaster 1996; USACE 1998; White et al 2001; TVA 2004; USACE 2009b). A Congressional Research Report states that the *increased consequences* of development behind *protective* structures "ironically" occurs because of protection provided (Carter 2005); however, it can be demonstrated that such development *intentionally* occurs based on federal benefit-cost analysis policy for structural mitigation measures that serve to increase exposure to flood hazards (Tobin 1995; TVA 2004; USACE 2012b). Thus, the levee effect—increased residential exposure to flood hazards following completion of structural flood control projects—phenomenon is a potentially significant factor perturbing flood losses and should be studied carefully.

This study develops methods to disaggregate and identify potential development benefits and costs relative to flood hazard. Unique change detection methods will reflect actual locations of residential development as well as potential wealth accumulation in high-risk floodplains. This research targets vulnerability accretion at local scales through induced development in proximity to flood control structures while considering changes to non-leveed and non-floodplain areas. As inferred by Agnew (1996) and developed in social vulnerability indices (Cutter 1996), the context of structural flood control benefits must be evaluated when national-scale policies have the potential effect of inflicting cycles of loss on local development and social activities. In evaluating local vulnerability changes in the context of broad national flood control policy, a comprehensive assessment of levee benefits and costs may be achieved.

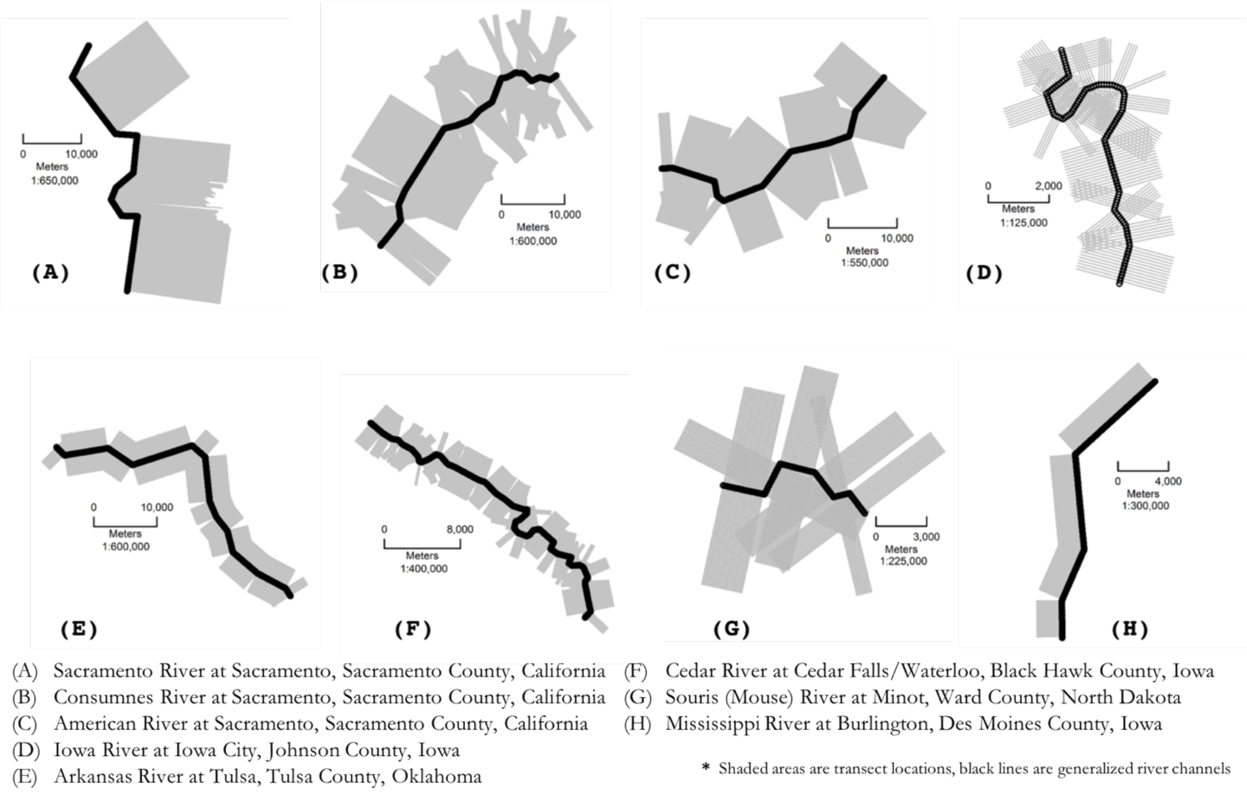
In response to the limited studies conducted since the calls by White and Haas (1975), this study engages "new research [that] could lead to great benefits in reducing deaths and property damage from floods[, …] research […] designed to gain new knowledge, identify[ing] new applications of existing knowledge, in the management of lands that are subject to flooding[.]" (p. 257). White et al (2001, p. 82-83) called for research to estimate the net benefits and losses of land use in hazard areas:

> Most of the reviewed texts give examples of great losses from specific hazard events; some describe the current state of losses; few describe trends, and none give more than passing consideration to the gains or benefits from locations, land use, and ecosystems subject to hazard. We are surprised by the lack of effort to draw and support larger conclusions. While some studies point out the lack of comprehensive data, few explain it and almost none address issues and remedies for this absence.

While this research is not broadly targeting all aspects referred to by White et al (2001), it is designed to quantify and qualify specific changes in residential floodplain development by explicitly examining flood control measures and development practices in a disaggregated, local approach. Existing datasets will be examined in new ways, and new datasets will be developed for use in understanding the evolution of residential floodplain occupation and loss reduction policies and measures.

3.2 Study Areas

In addition to the Minot, North Dakota preliminary case described in Section 2.8, the follow section describes additional study areas selected for examining residential flood risk changes in levee-protected floodplains (Figure 3.1; see also Table 3.1, p. 111). In particular, the Iowa City, Iowa study area was selected because there are no federal levees in Johnson County, thereby permitting an evaluation of counterfactual floodplain risk changes; moreover, the study areas described in the next section have a broad range of physical floodplains where residential flood risk has changed over time and where non-floodplain areas may also be assessed in consideration of overall residential flood risk changes both in and outside of levee-protected floodplains. The evaluation of residential growth in both floodplain and non-floodplain areas allows for attributing growth either to levees or other factors within the county study areas.



(A) Sacramento River at Sacramento, Sacramento County, California
(B) Consumnes River at Sacramento, Sacramento County, California
(C) American River at Sacramento, Sacramento County, California
(D) Iowa River at Iowa City, Johnson County, Iowa
(E) Arkansas River at Tulsa, Tulsa County, Oklahoma
(F) Cedar River at Cedar Falls/Waterloo, Black Hawk County, Iowa
(G) Souris (Mouse) River at Minot, Ward County, North Dakota
(H) Mississippi River at Burlington, Des Moines County, Iowa

* Shaded areas are transect locations, black lines are generalized river channels

Figure 3.1. Generalized rivers and accompanying cross sections used to evaluate changes in floodplain risks in selected study areas.

3.2.1 Iowa River at Iowa City, Johnson County, Iowa

Though the area does not have levees protecting urban areas, Iowa City is not fully without flood control, as the upstream Coralville Reservoir and Dam was authorized by the Flood Control Act of 1936 and completed in 1958 as a part of the USACE flood control plan for the Upper Mississippi River Basin. Specifically, the Coralville Reservoir is operated for flood control on the Iowa River, and, in concert with reservoirs on the Des Moines River, flood peaks on the Mississippi River and related damages can be attenuated through water flow management downstream of Iowa City at Burlington, Iowa (Needham et al 2000). The Iowa River Basin is long and narrow with an average slope of about 0.36 meters (1.2 feet) per 1 kilometer (0.6 miles); the river is about 226 meters (740 feet) wide at bank-full stage; and about 84 centimeters (33 inches) of precipitation falls on average each year in the basin (USACE 1977). The

Coralville Reservoir is located about 9.7 kilometers (6 miles) north of Iowa City and holds approximately 2,198 hectares (5,430 acres) of water at normal stages and can expand to about 10,037 hectares (24,800 acres) for flood storage behind a 30-meter (100 feet) high dam rated for 100-year protection, providing an annual flood control benefit of about $16 million and recreational benefits for another $16 million (USACE 1977; USACE 2014). The USACE states the Coralville dam "is integral to the life and safety of residents living alongside the Iowa River" at Iowa City, providing emergency assistance during major floods in 1965, 1993, 1999, 2004, 2008, 2013, and 2014 (USACE 2014).

Notably, Iowa City's floodplain management program adopted more strict regulations than required by the National Flood Insurance Program, with a goal of adapting future residential and other construction to be resilient to flooding following catastrophic damages in 1993. In 2008, flooding more destructive than the 1993 flood occurred, with flood conditions developing rapidly downstream of the Coralville reservoir—notably, Iowa City did not have a residential evacuation policy in place when the floods developed. After an emergency city council meeting, city ordinances were amended and a mandatory evacuation was ordered, resulting in about 1,531 homes evacuated. Yet, about 251 homes were flooded with about 100 completely destroyed (Press-Citizen 2018); downstream, in Cedar Rapids, called the "city that would never flood" and where local residents "never even thought about flood insurance [because] they said this place would never flood in 500 years," more than 10,000 people were evacuated or displaced and more than 5,900 homes flooded following overtopping of existing and emergency levees (New York Times 2008; FEMA 2009; City of Cedar Rapids 2018). The 2008 flood in Iowa City stands as the flood of record, at about a 500-year recurrence probability, and, with property buy-outs and nonstructural mitigation requirements enacted and enforced after the previously-record-setting

1993 floods, which requires all new structures to be elevated to 0.3 meters (1 foot) above the 500-year floodplain, damages were substantially lower than without land use restrictions and zoning ordinances that forbade development of high-risk areas (Press-Citizen 2018). Also, a result of the stringent nonstructural floodplain construction requirements and zoning ordinance, Iowa City residents receive a 20-percent discount on flood insurance premiums due to its favorable rating in the NFIP CRS (Press-Citizen 2018). Rather than pursuing levees for certain high-risk areas, once a goal of the city council, Iowa City continues buying homes damaged in the 2008 flood to mitigate future hazards with nearly $40 million in state and federal funding in support (Gazette 2010; Gazette 2018; Press-Citizen 2018).

Figure 3.2. Map of the Iowa, Cedar, and Mississippi River study areas for Iowa City, Waterloo, and Burlington. (Source: Needham et al 2000)

3.2.2 Cedar River at Waterloo/Cedar Falls, Black Hawk County, Iowa

Waterloo and Cedar Falls are located in north central Iowa along the Cedar River. Federal levees designed to protect the City of Waterloo from a 100-year flood, with freeboard of 3-4 feet, were authorized by the Flood Control Act of 1965 (Public Law 89-298) with construction generally beginning in 1972 and ending in 1982. The left descending bank (LDB) is comprised of approximately 12.42 miles of earthen levees constructed federally by the USACE and "turned over to public sponsor operations and maintenance" by the cities of Waterloo and Evansdale; the right descending bank (RDB) is comprised of about 4.54 miles of levees along the Cedar River and Black Hawk Creek; the RDB levees protecting Black Hawk Creek at the confluence with the Cedar River comprise 6.14 miles of levees protecting about 5,717 people at risk, 1,425 structures at risk, and about $945M of property value at risk. The levee protecting Waterloo ties into the Evansdale levee, with additional stages of construction completed in 1990. The LDB levee provides protection to about 16,786 people at risk, 6,695 structures at risk, and about $2.79B of property value at risk; the RDB levee provides protection to about 2,499 people at risk, 1,081 structures at risk, and about $596M of property value at risk (NLD 2019).

The levee system is noted on FEMA NFIP FIRM as a provisionally-acceptable levee (PAL), representing a levee system that FEMA previously accredited with reducing hazards associated with a 100-year flood, thereby removing the mandatory purchase requirement for flood insurance in the levee-protected area while awaiting data and/or documentation demonstrating the levee system's compliance with the NFIP regulations. Upon inspection in 2010, the LBD levee system was found to be in "unacceptable" condition based on deficiencies in the levee risk analysis conducted by a local contractor to the USACE Rock Island District. Follow-up inspections in 2016 and 2017 denote the levee system's ongoing "unacceptable" condition, requiring “corrective actions” to address deficiencies, less “prolonged problem[s] with the levees [cause] the Federal Emergency Management Agency to ‘decertify’ them, a move that would potentially throw large portions of the city into a flood plain with [high-risk] flood [zone] insurance requirements[,]” even as these cities do not “qualify for federal dollars to pay for needed improvements to insufficient levees built to protect downtown [areas.]” (Waterloo Courier 2012; Des Moines Register 2016; NLD 2019).

3.2.3 Mississippi River at Burlington, Des Moines County, Iowa

Levees in the area of Burlington, Iowa reflect a “levee spiral” where the heights of levees are increasing due to levees in other locations are increasing. Local residents began construction of levees along the Mississippi River near Burlington in the early 1900s, with construction complete around 1908; federal support to improve the levees in this “lower unit,” or southernmost in Des Moines County, was authorized by the Flood Control Act of 1954 with construction beginning in 1962 with completion in 1974. Construction on the “middle unit” of the levee system began in 1962 and was completed in 1967, with project notes stating this section of levee is designed “at a 2 percent exceedance event” with a low risk of overtopping and the nearly 9,105 hectares (22,500 acres) of leveed area protecting primarily agricultural land use (NLD 2019). Construction of the northernmost “upper unit” was also completed by local residents around 1908 with federal support bringing the levee up to 100-year design criteria by 1967; overtopping of this section of levees in 1993 and 2008 resulted in a federal rehabilitation project to restore the levee to design level, yet all three sections remain in “minimally acceptable” condition and with FEMA accreditation (NLD 2019). These three sections of levee protect 717 people, 409 structures, and about $105 million in property value (NLD 2019).

In 2016, the USACE Rock Island District released a report detailing local surveys of the levee conditions along the Mississippi River from Iowa southward through Missouri. Nearly 40 percent of the levees were found to be constructed higher than regulatory design criteria, causing residents in this area to call for reduced levee heights due to the adverse effects caused by flooding on farmland and local communities. In particular, the *overbuilt* levees are expected to increase heights of the 1993 by 1-2 feet over design criteria in some areas, which has the effect of diverting water toward areas of lower protection and raising risks for vulnerable communities: "building taller levees could encourage a phenomenon known as '*levee wars'* where one property owner builds a levee to fend off diverted waters caused by another raised levee" (STL Public Radio 2018).

3.2.4 Arkansas River at Tulsa, Tulsa County, Oklahoma

There are about 30 miles of levees, 71-years-old on average, protecting Tulsa County from the Arkansas River and its tributaries. The levees are identified by USACE as three distinct systems: the A, B, and C levees; the Jenks Levee; and the Haikey Creek Levee. Although initial authorization for construction of these levees was provided under the Flood Control Act of 1928, USACE lists its authority for these projects as tied to the Flood Control Act of 1948. Notably, the Flood Control Act of 1950 granted permission for the construction of the Keystone Dam for flood control and hydropower, creating Keystone Lake as a nearly 26,000-acre (hectare) reservoir just west of Tulsa County upon completion in 1964 (USACE 2018).

Construction of Levees A and B was completed in 1944 and in 1945 on Levee C. USACE states that approximately 6,000 people and about 3,000 structures are protected by Levees A and B, and, notably, no estimate of property value is provided; moreover, these levees are described as "very high risk" in a 2016 risk assessment, with "a history of poor performance" based on overtopping that occurred during flooding in 1984 and expected future overtopping, described as “highly likely” and that will cause rapid and deep flooding, significant property destruction, and loss of life (NLD 2019). Despite this context and “unacceptable” ratings from inspections in 2007, 2010, 2013, and 2015, the USACE lists Levees A, B, and C as accredited by the NFIP; further, FEMA’s FIRM shows most areas protected by these levees as 500-year Zone X with some locations in the 100-year SHFA (FEMA 2012; NLD 2019). Similarly, Levee C is described exactly as Levees A and B but with a “high risk” designation in a 2017 risk assessment, providing protection to an additional 4,000 people, with no structure counts or property value described (NLD 2019). Construction of the Jenks Levee was completed in 1944, providing protection from 100-year design flooding to about 3,600 people, 1,713 structures, and about $426 million in property value (NLD 2019). USACE states that the Jenks Levee “has performed well during three significant Arkansas River floods,” including in 1986 when flooding reached 60 percent of the levee’s average height (NLD 2019). Although inspections of the Jenks Levee in 2008 revealed many deficiencies, yielding a “minimally acceptable” risk rating, repairs and remediation brought the levees up to an “acceptable” risk rating by 2015, with USACE characterizing the levee as low risk; however, USACE also notes that property damage could reach $200 million if the levee were to fail under a fully-loaded condition (i.e., overtopped or breached; NLD 2019). The Jenks Levee is accredited by NFIP, reflected as Zone X on the most recent FIRM, and there is no mandatory flood insurance requirement for the area; however, some areas within the levee-protected area are designated as Zone AE, where flood insurance is required (FEMA 2012a; FEMA 2012b; FEMA 2012c).

Residential development near Haikey Creek in southeast Tulsa County commenced in about 1970 and was proceeded by a significant flash flood in 1974 that inundated some homes with more than 4 feet (1.1 meters) of water (NLD 2019). As a result, USACE, through authority granted by the Flood Control Act of 1948, authorized the construction of a levee to protect the neighborhood and its 47 homes, 130 people, and about $12 million in property value, with construction beginning in 1984 and completion in 1987 (NLD 2019). The levee provides protection for a 100-year design event, with inspection in 2015 finding the levee in “minimally acceptable” to “acceptable” condition. The levee is accredited by the NFIP, reflected as Zone X on the most recent FIRM, and there is no mandatory flood insurance requirement for the area (FEMA 2012a; FEMA 2012b; FEMA 2012c).

3.2.5 American River, Sacramento River, and Consumnes River at Sacramento, Sacramento County, California

There are currently 278 miles of federally-constructed levees and 227 miles of non-federally constructed levees in Sacramento County, with an average age of 61 years. Following initial levee construction to manage annual flooding of the Sacramento Valley, major flooding in 1862 prompted levee construction statewide by local landowners that continued into the early 1900s, with construction on the levees protecting the City of Sacramento and Natomas completed in 1914 by a mining and dredging company called Natomas Consolidated of California—a company initially incorporated in 1853 to drain and reclaim wetlands, and that began using prison labor in 1866 for construction of the Folsom Dam on the American River east of downtown Sacramento, first completed in 1891 (FOHS 1985; CA DWR 2016; NLD 2019). In 1917, Congress authorized the USACE to construct levees for flood control in Sacramento, with the USACE either accepting the levees previously constructed or building new levees from 1918 through the mid 1960s (Congress 1917; CA DWR 2016). Folsom Dam was reconstructed by the USACE to improve the structure, with work completed in 1956 (FOHS 1985; USBR 2018).

Construction of levees along the right bank of the American River was completed by USACE in 1955, with the levee generally performing well, including during flooding in 1986—the levee is considered high risk by USACE, with a 2010 inspection granting the levee a "minimally acceptable" rating (NLD 2019). Further downstream at Arcade Creek is another levee completed by the USACE in 1955 described as high risk, performing well, and with a "minimally acceptable" risk rating, that USACE states should experience overtopping once in 300 years if the levee performs as designed (NLD 2019). In the same area, a 500-year levee constructed at Dry Creek in 1995 is "minimally acceptable" and protects about 677 people, 195 structures, and $73.6 million in property value (NLD 2019). The levee protecting the City of Sacramento from the American River left bank and the left bank of the Sacramento River has been improved numerous times from 1955 through 2010 and ongoing, with USACE noting that flooding "could be catastrophic to the people and property behind the levee" should the system fail: a 2010 inspection of the nearly 37 miles (km) of American River left bank and Sacramento River left bank levees found numerous structural deficiencies in the system, resulting in an "unacceptable" risk rating (NLD 2019). With the exception of the Dry Creek levee, risk characteristics for people, structures, and property values are not provided by USACE, although each of the systems described above remain accredited by FEMA (NLD 2019).

The installation of flood control in the form of levees, dams, canals, ditches, and drains has exacerbated substantially flood risk and land conversion in Sacramento County. Agriculture became the predominant land use type in the Central Valley in the late 1800s and continues to present as such; however, reclamation and drainage activities combined with levee construction by 1930 resulted in the conversion of more than 126,721 hectares (313,000 acres) of wetlands for agricultural use (Delta Council 2010). The expansion of the Sacramento metropolitan area has placed significant urbanization pressures on both wetlands and agriculture, with levee construction and improvements pressuring conversion of agricultural lands to high density residential uses, as the City of Sacramento began annexing agricultural lands in the 1940s and 50s—the "Pocket" neighborhood rapidly developed into residential housing immediately adjacent to the Sacramento River levees following annexation by Sacramento in 1959 and the completion of Interstate 5, which allowed rapid vehicular transportation to the city (Sacramento General Plan 2015a). Accordingly, conversion of agricultural lands for urban uses has become a cultural preservation issue alongside greater understanding of both conservation practices and increasing flood risks. Approximately 80,937 hectares (200,000 acres) of land were dedicated to agriculture as of 1984, declining by about 24,281 hectares (60,000 acres) from 1974 due to rapid urbanization, particularly in the Sacramento area (USDA 1993). And that agricultural decline accelerated in the 1990s and 2000s across the greater Central Valley region: "Total acreage in agricultural lands declined from about 597,400 acres in 1984 to about 531,010 acres in 2008," a decline of about 6 to 7 percent; in the broader area of the entire state of California, about 734,000 acres of farmland were converted to urban use between 1988 and 2002, representing "an ongoing public policy issue" (UCD 2009; Delta Council 2010). Urbanization in Northern California and Sacramento is expected to increase by more than 22 percent between 2020 and 2050 (Energy Commission 2009).

Passed in 1965, the California Land Conservation Act property tax reductions to incentivize the maintaining of land in agricultural use. However, due to statewide budget problems, the tax refunds from the state to local governments was halted, with additional threats to agricultural land use in the form of urbanization and development pressures, levee failures and flood inundation, land subsidence, and changes in water quality and supply recognized as future risks: “Urbanization and development of agricultural areas is affected by local planning policies that do no limit areas for future urban growth or allow the subdivision of parcels within agricultural areas without a corresponding commitment that the land will still be farmed” (Delta Council 2010, pp. 6-1-2). In the northwestern portion of Sacramento County, just north of the city of Sacramento, is the community of Natomas—an area under continual development efforts and pressure since the Natomas Consolidated of California company incorporated and began levee construction in the 1860s. The Natomas area was annexed into the city of Sacramento and named “North Sacramento” in about 1964 (some tracts were annexed prior to and after 1964), with much of the land area “uninhabited” and was designated for agricultural use through 1993 (Sacramento General Plan 2015a). In the 1980s, however, development pressures mounted and the Natomas area “was identified by the city of Sacramento’s 1988 General Plan as a significant economic and social opportunity because of its potential as a major growth area for new housing and employment” Sacramento General Plan 2015a). In the 1988 plan, the Natomas area “at full buildout […] was projected to account for 35 percent of new housing and 30 percent of the new jobs” in the city of Sacramento, with each home added yielding about 1.2 jobs; however, levee overtopping due to floods in 1986 and 1987 “changed the FEMA flood maps, which prevented new development until flood improvements were completed”—the 2015 plan notes that “at the time [after the 1987 floods] there was little market demand for development” (Sacramento General Plan 2015a). Rapid residential growth and speculation on land prices began to occur following the completion of the area’s 1994 development plan; however, decertification by FEMA of the levees protecting the Natomas area in 1994 led to a brief construction moratorium as environmental and floodplain risks were studied (Sacramento General Plan 2015a). The levees protecting Sacramento and Natomas were again inspected following Hurricane Katrina in 2005, leading to findings that the levees had deteriorated and were not providing a sufficient level of protection, rated for only a 33-year storm rather than the 100-year design standard; therefore, FEMA again decertified the levees and placed most of the Natomas area in the 100-year SFHA, leading to two pivotal moments for planners: 1) the decertification yielded a construction moratorium in Natomas from about 2008 to 2015, while nearly $1 billion in federal funds were used to upgrade the levee system; and, 2) FEMA, under pressure to account for some level of protection from the levee system, created a new flood zone for the Natomas area—Zone A99, which required mandatory purchase of flood insurance but at a discounted rate as full 100-year protection from the levee system was expected in the short-term future (FEMA 2015b; Sacramento Bee 2015a; Sacramento General Plan 2015a; Sacramento City Council 2015b; City of Sacramento 2018). The A99 zone designation from FEMA was granted in 2015, and the city of Sacramento imposed a cap on residential building construction at 1,500 single family homes per year, valued to range in prices from $250,000 to $450,000, while the city moves to upgrade the levee system to 200-year protection—since that time, local newspapers report that some Natomas-area developments have ranked in the top 20 master-planned communities in the U.S., and a resident of the Natomas floodplain, who is a realtor and discussed flood risk for the area with KQED radio, stated that "people do—and don't—think about flood risk," continuing on to say: "There is such a demand up here.' […] But flood risk generally isn't on the minds of potential buyers. 'I have never had that come up[.]'" (Sacramento Bee 2015b; KQED 2017; Sacramento Bee 2018; City of Sacramento 2018).

Table 3.1. Residential parcel counts and values for the study areas, broken down by flood zones.

Study Area	**Res. Parcel Count**	**Res. Parcel Value**	**In All Flood Zones**	**SFHA**	**500-Year (X)**	**Min. Risk (X)**	**FEMA LPA**	**USACE LPA**	**NFIP Policies**
Sacramento, CA	375,502	$91,895,212,372	375,361	27,192	35,341	239,250	73,578	158,071	53,643
Burlington, IA	14,690	$1,391,939,600	14,690	262	29	14,289	110	200	257
Iowa City, IA	19,609	$3,533,980,410	1,234	716	500	-	0	0	800
Cedar Falls/Waterloo, IA	41,884	$5,518,123,510	6,782	1,471	710	5,311	4,601	8,410	773
Tulsa, OK	191,834	$29,269,242,001	191,799	3,311	13,717	174,720	51	3,679	1,155
Minot, ND	3,474	$461,430,800	3,474	7	705	155	0	2,301	2,154
Study Area Totals:	646,993	$132,069,928,693	593,340	32,959	51,002	433,725	78,340	172,661	58,782

3.3 Data Collection

This study uses land parcel, levee, floodplain, and hydrology databases to estimate exposure of residential construction and flood risks. Land parcel databases describe numerous features of residential construction and are based on land surveys and local tax assessor valuations, forming the basis for all land use and zoning conditions, and representing the locations of residences, among many other things (COLPA 2007). Residential land parcel data has become more commonly available in the 2010s, based largely on the Federal Geographic Data Committee's establishment of parcel content data standards and standardized parcel data models, with many counties and states in the U.S. making parcel data available publicly in GIS formats or viewable on websites; however, fragmentation of land data and information continues to be a cause of variable levels of parcel data availability and quality across the nation—inconsistencies in data format and attributes are problematic for some analyses (von Meyer 2004; COLPA 2007; Leyk et al 2018). For this study, land parcel data containing both an estimate of construction year and valuation of residential buildings for the year 2014 is the basis for estimating floodplain and non-floodplain as well as levee-protected and non-levee-protected changes in flood exposure and, therefore, risk. For the study areas, the author contacted either the county GIS administrators or tax assessor offices to inquire about public availability of residential parcel data and the specific attributes for valuation and construction year: in the cases of Sacramento, Tulsa, Johnson, and Des Moines counties, the local GIS administrators were eager to assist by packaging the residential data digitally and making it available for quick download. However, the simple requesting of data for Black Hawk County, Iowa resulted in a review by the City Council of Waterloo, requiring a written justification for the purposes of the research described herein; moreover, the residential parcel data was initially supplied in paper format, generating efforts by both the author and the GIS administrators of Black Hawk County to digitize the parcel data for study. Similarly, when considering other and additional study areas, including the City of Des Moines in Polk County, Iowa, data reviews with local GIS administrators initially revealed substantial, comprehensive-appearing residential parcel datasets; however, review of the data for consistency, spatially and temporally with the context of historical development and literature reviews as described previously, resulted in rejection of data to be used in this study due to inaccuracies and inconsistencies that neither pared well with historical contextual data nor could be explained in terms of processes for generating the datasets by either county GIS administrators or local tax assessor offices. Interestingly, in trying to expand on the residential parcel datasets for the Sacramento area, including the suburb of West Sacramento in Yolo County, California, the author encountered various explanations denying either the availability of parcel data or its public use, despite both local and state laws proclaiming the public availability of the data: in particular, data for Yolo County was deemed proprietary in nature, in part due to the county's revenue model for selling maps that depict parcel and tax assessor information, and in part due to several large companies establishing purchasing agreements with the county GIS and tax assessor offices, essentially making the datasets very valuable to both the county and the companies acquiring the datasets. Notably, after initially receiving a digital version of the Sacramento County residential parcel data in early 2015, the author followed up with county and city GIS administrators for updated versions of the residential parcel data and did not receive replies or revised data. As such, the residential parcel data for Iowa, North Dakota, Oklahoma, and California is temporally limited to about 2014 on average, with valuations estimated in 2014 dollars.

Under the Water Resources Development Act of 2007, the USACE was allocated approximately $23 billion in congressional funding for about 900 projects that include navigation, flood damage reduction, ecosystem restoration (including wetlands restoration in Louisiana and estuaries habitat restoration projects nationally), and, of particular interest to this research, the establishment of a National Levee Database ("NLD") to support a national levee safety program (Congress 2007; USACE 2012). Though initially restricted to official federal uses only, the NLD is publicly available in 2018 (Figure 3.4) and "contains information to facilitate and link activities, such as flood risk communication, levee system evaluation for the [NFIP], levee system inspections, flood plain management, and risk assessments" (HSDL 2018; NLD 2019). The NLD contains graphic features, data tables, maps, and attribute data on federal and non-federal levee locations, the general condition of each levee, protected areas, and estimates of the number of structures and population at risk that are protected by each levee and that "would be adversely impacted if the levee fails or water levels exceed the height of the levee" (USACE 2012; HSDL 2018; NLD 2019).

In combination with NLD and residential parcel data, this study uses the National Hydrography Dataset ("NHD") and FEMA's digital floodplain and flood zones data to evaluate residential parcel value, proximity, and construction year to assess changes in flood risks in leveed and non-leveed communities. The NHD was developed initially by the U.S. Environmental Protection Agency to estimate stream flow and velocities for pollution dilution modeling; however, the dataset has numerous applications for locating many types of streams, rivers, wetlands, and water bodies more generally. The NHD is derived from the USGS National Elevation Dataset (NED) in at least a 30-meter (about 100-foot) spatial resolution, providing publicly a GIS-ready vector stream network, local drainage areas, stream elevations and slopes, and watershed boundaries nationally (USEPA 2018). River flowline location data were downloaded for the study areas from the U.S. EPA website. For estimating ground elevations for the residential parcel data, the USGS NED was also downloaded: the NED is considered the "best available elevation data" for large area coverage in standard, consistent resolution with readily-available 30-meter (about 98 foot) spatial resolution with vertical accuracy ranging from about 2 to 7 meters (14.83 to 22.97 feet) depending on location (Sanders 2007; Gesch 2007). Since about 2002, and upon development of data format standardization, FEMA has provided for public download its digital versions of flood zones and insurance rate maps (DFIRM) via GIS-ready databases through a Map Service Center on the world wide web. The FEMA DFIRM data represents the engineering data used in floodplain studies and zonation estimates of the 100-year and 500-year year flood areas as well as information on levee-protected areas (Zone X). Additionally, to consider changes to flood zones in leveed areas, static images of historical FIRMs were also downloaded. Taken together, the NHD river channel locations, FEMA flood zones and levee-protected areas, NLD levee locations and levee-protected areas, and the residential land parcel data provide a robust means for estimating levee-induced changes in flood risk.

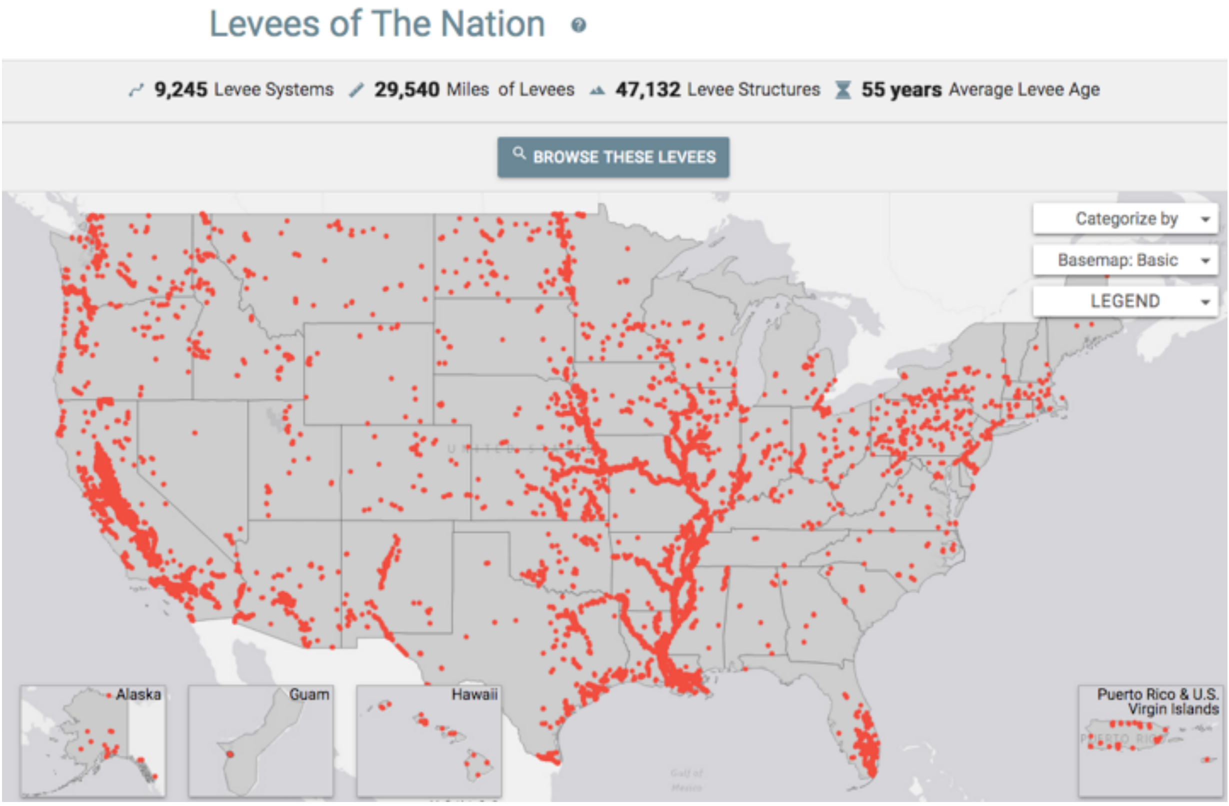


Figure 3.3. USACE National Levee Database provides data and information about the levees of the U.S. Federal levees are identified on the map as red dots. (Source: NLD 2019)

3.4 Geospatial Analysis Techniques

An efficient geospatial analysis means for evaluating residential floodplain exposure and risks was devised for this study as a combination of GIS, data sampling, and statistical analyses. Many of the techniques are not complicated but do involve many steps to extract and prepare the residential parcel data for analysis. While some custom data processing scripts were developed, many of the tools used for both preparing and analyzing the residential parcel, hydrography, flood zone, and levee area data are built into the Esri GIS and separate statistics software packages.

3.4.1 Residential Cross-Section Exposure Analyses

River cross sections were developed to evaluate residential construction years and valuations in the study areas. First, the NHD river flowlines for the study areas were generalized to straighten the rivers in order to develop non-overlapping, perpendicular-to-channel, extending laterally across-the-floodplain cross sections at intervals of 100 meters (328 feet) along the path of the river. Each cross section was supplied a unique identification code. Similarly, each cross section was split into 100-meter (328 feet) intervals, and, at each interval, a unique identifier and point was applied to assign distances outward from the river channel based on left or right side of the river (to the left: 100, 200, … 3,000, 3,100 meters, etc; to the right, 100, 200, … 3,000, 3,100 meters, etc). At each 100-meter interval point along the cross sections, a radius buffer was applied to create circular polygons of 100-meter diameter for sampling the intersecting residential parcels as a function of lateral distance from river channels, thereby allowing the number of residential parcels and value at risk of flooding to be estimated along each cross section as both an aggregate count of residential buildings on the sampled parcels and total value as a linear function that either decreases or increases with increasing distance from channel (i.e., count of residential buildings and value are high near the channel and lower further away, are flat, or increase in count and value with increasing distance from the channel). Residential parcel polygons were converted to centroid points for ease of using spatial joins to append the flood zones and levee-protected area designations to the residential buildings (Figures 3.5 and 3.6), and then the residential parcel points were intersected with the cross-section buffer polygons to provide raw counts of residential buildings and aggregated values for statistical analysis. Regression analyses on the dependent variable, residential parcel value, as a function of distance, the independent variable, were conducted to apply a development type (AC, AD, BC, BD) for each cross-section and are described in Section 3.7.1 and 3.7.2.

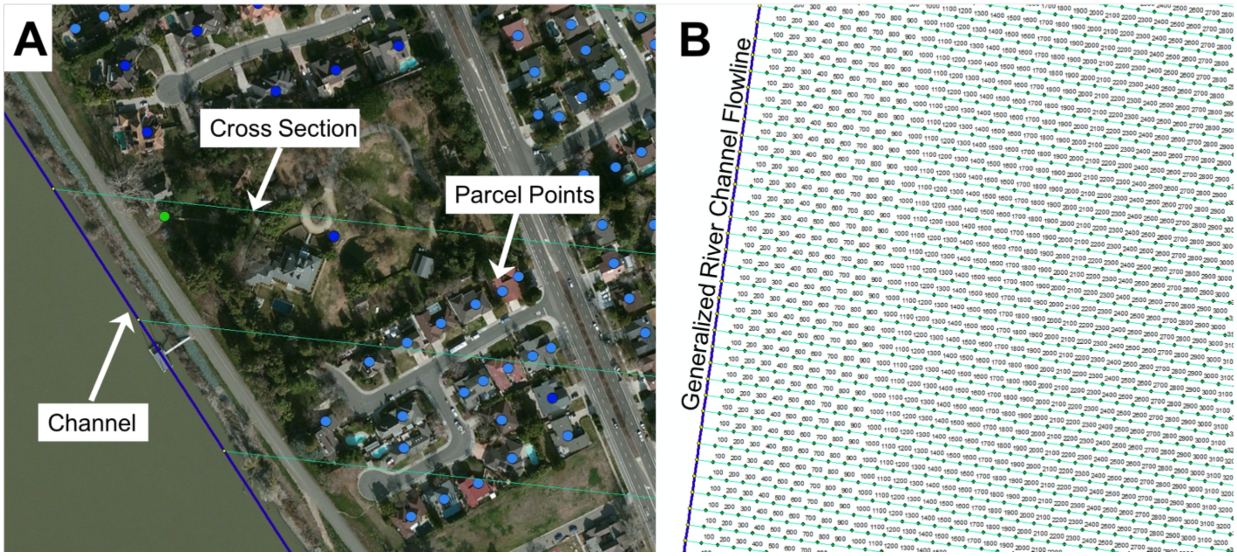


Figure 3.4. Generalized river channel (blue line) and cross-section (green lines) sampling approach, overlaid on aerial imagery to verify locations, with cross-sections drawn every 100-meters along the river channel and sampling points every 100-meters along cross-sections. A) Generalized Sacramento River channel with cross sections extending laterally to the east (left) of the river flowline with residential parcel points (blue dots) reflecting residential building locations. Note that these particular cross sections were manually adjusted to prevent overlap and not fully perpendicular to the river channel as a result. B) Generalized river channel with cross sections reflecting 100-meter intervals from the channel along each cross section.

3.4.2 Decadal Parcel Value Density Analysis

To visualize and assess changes in residential parcel construction and values over time, parcel density analyses were conducted for the study areas using the parcel points described in Section 3.5.1. First, parcels with null values for either construction year or value were discarded to avoid skewing average construction year or parcel value, and a raster resolution was considered based on parcel area. Most residential parcels in urban and suburban areas are about one-quarter of an acre, about 1,010 square meters, with some parcels larger or smaller in area based on location-specific building codes or legislation guiding development practices. In most study areas, the density raster resolution was set to 1 square kilometer or finer, with some parcel data supporting a resolution of 100 square meters. For each decade starting at 1901 and proceeding to 2015, parcel values were averaged and summed for each grid cell to represent a cell-by-cell average and sum of parcel values for each county. Though not providing a substantial analysis per se, the density maps serve to visualize well the areas wherein parcel values increased near or far from levees, in both floodplains and non-floodplain areas, and across flood zones or levee-protected areas.

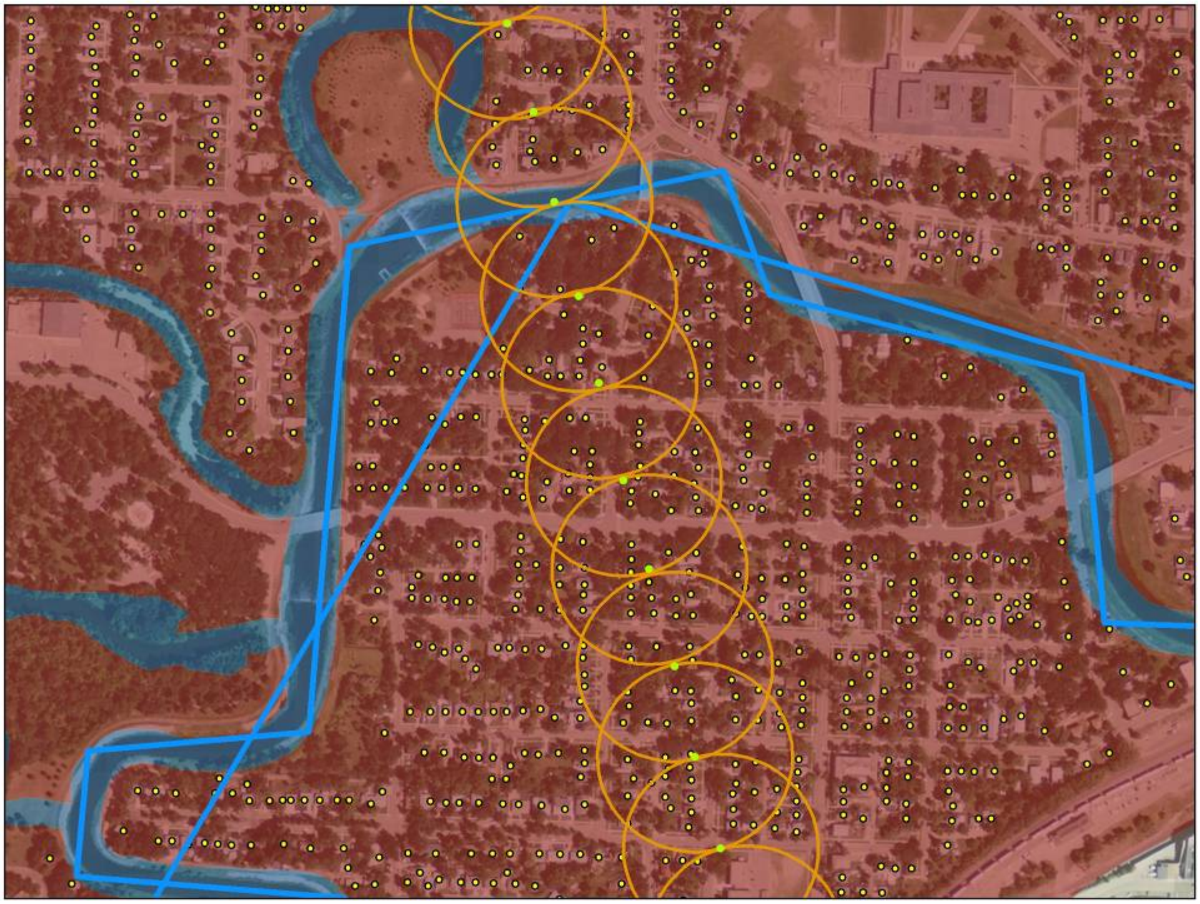


Figure 3.5. Generalized Souris River (blue line) at Minot, North Dakota with cross section sampling points (medium green dots) with sampling buffers (orange circles) overlaid on DFIRM flood zones (blue = SFHA, red = 500-year flood zone) with residential parcel points (small yellow dots).

3.5 Data Analysis Techniques

A variety of regression analysis techniques are applied to the parcel data sampled along the cross sections for estimating relationships between the dependent variable of aggregate residential construction value along the independent variable of distance from river channel. For developing a residential exposure typology for floodplains that explores relationships between development value as a function of distance from river channels, exponential regression models tend to fit value at risk over distance best. Difference-in-differences regression analyses are used to eliminate bias between pre-and-post levee construction by using control groups—parcels neither in levee-protected areas nor floodplains—to evaluate development changes in treatment groups—those parcels in levee-protected floodplains. Given the time series data that exist in the form of residential parcel construction years, a suite of linear regressions that are either polynomial or Fourier series are used to find a best fit of total parcel value over time, with a forecast period of about 35 years extended beyond the historical record for considering potential future changes in parcel values.

3.5.1 Residential Flood Exposure Typology

Using the sampled residential parcel values, an exposure typology is developed for characterizing residential occupance of floodplains based on four general categories: undeveloped, fully developed, adversely developed, and development well-adapted to floodplain occupation. Burton (1962) developed an agricultural typology identifying physical characteristics of floodplain topography, hydrology, and seasonality; however, the typology applied here uses distance and floodplain zoning as the primary characteristics for identifying residential development types along the cross sections described in Section 3.5.1. In essence, the levee effect to be measured in this study focuses on identifying levee-related increases in exposure that drive increases in flood risk and losses locally, often as the result of floods occurring more frequently than estimated in floodplain mapping studies. As such, the before and after conditions of residential development in floodplains, or outside floodplains, can be characterized as a distance-decay relationship or an inverse relationship. The parcel density analyses described in

Section 3.5.2 provide a means to assess the slopes of residential parcel value when a third dimension, *z* value, is characterized as cumulative value for parcels within a specified spatial resolution (either 100-meter or 1-kilometer, depending on study area); however, similar to hydrologic studies that estimate and characterize riverine water flows and volumetric expansion onto surrounding topography, the concept behind using cross sections for residential parcel valuation is to lay a framework for including built environment valuation into a more comprehensive socio-physical modeling approach that could consider both the characterization of flooding and built environment impacts as a unified model—at present, loss estimation models couple hydrological flow modeling and built environment through separate function relationships for depth-damage relationships generally (cf. Davis and Skaggs 1992; FEMA 2018). Further, adding a conceptual approach for employing built environment exposure relationships for cross sections could allow planners to quickly assess alternate or future development scenarios by, say, converting a set of cross sections from undeveloped to fully developed residential land use and potential consequences. Regardless, the typology developed here establishes a means to identify residential exposure in proximity to levees and into non-floodplain spaces for cross sections, assisting with the identification of levee-influenced construction.

The cross sections described in Section 3.5.1, having been processed to provide both distance at 100-meter intervals along the cross section laterally from a river channel and the cumulative value of residential parcels at each interval, can be characterized by the slope of cumulative value as a function of distance. For example, at 100 meters from channel with a cumulative value of $1 million, decreasing to $500,000 at 500 meters, and further decreasing to near zero cumulative value at 1,000 meters, establishes a negative, decreasing value slope; conversely, cumulative value of near zero at 100 meters that increases to $500,000 at 500 meters and to $1 million at 1,000 meters establishes a positive, increasing value slope. Value slopes that are flat may represent either low, medium, or high cumulative values representing undeveloped, developing, or fully-developed residential construction. As such, measuring outward from the

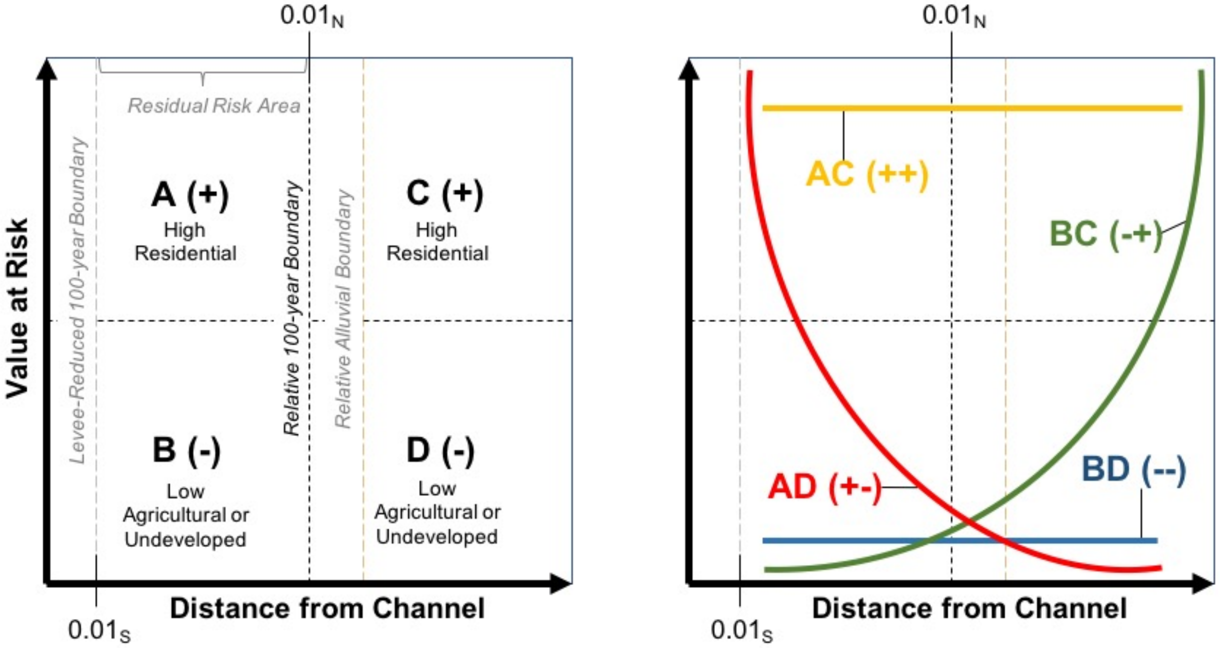


Figure 3.6. Residential VAR exposure types across floodplains with 0.01_N representing the relative boundary of the 100-year SFHA without levees and 0.01_S representing reduced 100-year floodplains protected by levees. **Left)** A letter symbol is applied to observations of parcel densities (counts) by distance to river channel along cross sections based on the sum of parcel value at each 100-meter interval from a river channel, giving four exposure types: A (many parcels, high value, near river channel or levee), B (few or no parcels, low to no value, near river channel or levee), C (many parcels, high value, far from river channel or levee), and D (few or no parcels, low to no value, far from river channel or levee). **Right)** Modeled residential floodplain VAR for each cross section gives four combinations of residential value at risk with increasing distance from a river channel or levee: AC, or ++, represents high value at risk and many residential parcels both very near and very far from a river channel or levee—this most likely reflects a fully built-out floodplain and/or high density residential development in both floodplain and non-floodplain areas; AD, or +-, represents high value at risk nearest the river channel and low to no value at risk farther from the channel or levee—and most likely reflects adverse development in the form of levee effect where non-floodplain areas remain under-developed; BC, or -+, represents low to no value at risk nearest the river channel and high value at risk far from the channel—this most likely reflects well-adapted residential development where floodplains remain undeveloped or well-preserved; and BD, or --, represents both low to no residential value at risk near or far from the river channel, which is most likely either agricultural or undeveloped land.

channel with a levee present, a negative slope can be characterized as a type of adverse development reflecting levee-induced development; a positive value slope that reflects residential development occurring farther from a channel may represent an adaptive form of residential development where flood hazard is well-identified and influences development to allow room for floods or natural wetland growth. The four categorical residential exposure types are illustrated in Figure 3.6.

3.5.2 Normalization and Regressions for Exposure Typology

The value of residential parcels varies greatly over space, especially in the case of urbanized or suburbanized neighborhoods abutting agricultural or undeveloped areas. Similarly, low-value residential parcels may abut residential parcels of much greater value due to a number of reasons that include construction style, living area, number of stories, lot or parcel area, or other amenities that may or may not be attributed in a county's parcel databases. Further, given the sampling design of this study, the aggregate value of residential parcels can increase or decrease quickly over short distances—either increasing with increasing distance from river channels (perhaps a well-adapted residential development style where residential exposure to flood risk is low), or, conversely, decreasing with increasing distance from river channels (perhaps an adverse development style where residential exposure to flood risk is very high). Thus, after residential values are sampled, exponential regression analyses in the following form are conducted for each cross section in order to apply a residential development type for identifying potential levee effect:

$$y = ab^x$$

To compare the exponential regressions across study areas, normalization of both the aggregate value at risk and the regressed, fitted value at risk for each cross section is applied in the form of data scaling. Additionally, the distance from channel along each cross section is normalized through data scaling. In both cases of normalized distance and normalized value at risk, values for the scaled value at risk by scaled distance is represented as a function along *x* (distance) and *y* (value at risk) axes:

$$x' = a + \frac{(x - x_{min})(b - a)}{x_{max} - x_{min}}$$

With the normalized value at risk by distance, the midpoint distance, 0.5, is assumed to represent a relative 100-year floodplain boundary for developing a residential exposure typology as described in Section 3.3 for all study area rivers and parcel data. In wide, flat floodplains, such as Sacramento, the relative 100-year floodplain boundary may extend further along cross-section samples, perhaps as far as 0.8 or 0.9, depending on the specific topography of the county; similarly, in narrow floodplains, such as Iowa City, the relative floodplain boundary may be 0.3 or 0.4. Regardless, the function of value at risk over distance yields similar results for a typology, with either fully built-out floodplains representing an AC form (++, high value at risk near and far from channel), undeveloped floodplains representing a BD form (--, low value at risk near and far from channel, adversely developed floodplains—with or without levees, but more likely with levees—representing an AD form (+-, high value at risk near channel and decreasing with increasing distance from channel), and well-adapted floodplains representing a BC form (-+, low value at risk nearest river channel and increasing with increasing distance).

3.5.3 Database Techniques & Discount Estimation

The voluminous residential parcels, having been attributed with flood zone and levee-protection information as described in Section 3.5.1, are imported into a Microsoft Access database for grouping, sorting, querying, and summarization by construction year, valuation, ground elevation, and areal zoning designations for each study area. The parcel data were grouped by year to provide both average annual valuation and counts of parcels added by year as well as cumulative valuation for each year. Similarly, minimum, maximum, and average ground elevation values were applied to the parcels for each year in order to assess hypsographic changes in residental development. The parcel data were also grouped by FEMA flood zone and by USACE levee-protected areas to identify parcels both inside and outside of floodplains or levee protected areas, with discounts or premiums for each flood zone estimated as the average parcel value by year subtracted from the average value of all parcels by year. Finally, the grouped and summed parcel data were transferred to Microsoft Excel for charting and graphing of results.

3.5.4 Difference-in-differences Analyses

Difference-in-differences (DID) estimation is used to assess changes in VAR prior to and after levee installation. The DID technique was developed and demonstrated by Card and Krueger (1994) as a means for estimating the effects of policy effects on treatment and control groups with a design that can avoid introducing biases from omitted variables by double differencing; the technique permits evaluation of before and after changes in both treatment and control groups by removing biases to isolate the treatment effect. The DID technique is demonstrated in numerous studies and has been adopted by the European Commission for counterfactual impact evaluations on policy changes (European Commission 2012). Given levee construction completion data from the National Levee Database, VAR data for each study area is grouped into pre-levee and post-levee conditions for non-levee-protected (control) and levee-protected (treatment) areas in order to assess the average increase or decrease in VAR without biases that might be related to general economic growth trends; further, given the availability of data in a non-leveed study area (Iowa City), the DID regression allows comparison between unobserved counterfactuals and observed counterfactuals across time and study areas. The DID regression model for these study area conditions is

$$y = \beta_0 + B_1 dB + \delta_0 d2 + \delta_1 d2 \cdot dB + u$$

where y is the average VAR outcome of interest, d is the pre-levee (control) time period, dB is a dummy variable used to assess differences in pre- and post-leveed-protected average VAR prior to levee construction, $d2$ (treatment) is a dummy variable for the post-levee time period used to assess unobservable aggregate factors that may change average VAR in the absence of levee construction, δ_0 is a dummy variable equal to 0 (false) for the non-levee-protected control data, and δ_1 is a dummy variable equal to 1 (true) to represent the levee-protected treatment data. The difference-in-differences estimate is

$$\hat{\delta}_1 = (\bar{y}_{B,2} - \bar{y}_{B,1}) - (\bar{y}_{A,2} - \bar{y}_{A,1})$$

where the first subtraction is between control group data (pre-levee [0], non-levee-protected [0]) and the second subtraction is between treatment group data (post-levee [1], levee-protected [1]). The estimator, $\hat{\delta}_1$, reflects the *levee effect*—the difference in average VAR between the pre-levee, non-levee-protected and post-levee, levee-protected residential parcel data—or lack thereof. The product of the DID estimation which is positive represents an average gain in VAR, and increase in exposure, and, therefore, risk, and a negative product represents an average decrease in VAR and exposure, or risk. Similarly, the DID estimation technique is employed to assess overall differences between pre- and post-NFIP average VAR for SFHA across all study areas to consider insurance effects on residential parcels in floodplains.

3.5.5 Parcel Growth Forecasts

To consider what future increases in residential parcel value may occur, a suite of linear regression models is used to find best fits for historical residential parcel values with an extension of the timeline to the year 2050. These parcel growth forecasts are generally speculative but are useful in considering potential residential value and flood risk change scenarios. Given that the true function of future parcel growth is unknown and speculative, regression in the form of

$$y_i = \beta_0 + \beta_1\beta_{1i} + \beta_2\beta_{2i} + . . . + \beta_p\beta_{pi} + \varepsilon_i$$

where y_i is the dependent variable, value at risk, summed for each i-th value in the parcel dataset, x is the independent variable for year of construction, and ε is the residual difference between the model fit and actual summed value of parcel values per year.

3.5.6 Software Employed for Research and Data Analysis

This study uses industry-standard geospatial information systems (GIS), database and spreadsheets, and statistics software for data and statistical analyses due to the common formatting of data collected as described herein. For GIS analyses, the ESRI ArcGIS suite of software platforms are used, including ArcMap, ArcCatalog, and the built-in spatial analysis toolboxes along with some custom techniques scripted in Python. To manipulate, organize, and query large datasets of residential construction data, Microsoft Access database software is used to list, sort, group, and condense data into desired presentation formats; similarly, Microsoft Excel is used for record-by-record calculations and charting. Custom scripts were written for statistically analyzing cross-section data and regression analyses in MATLAB which are used to estimate and categorize residential floodplain types. Finally, for difference-in-difference estimation, the Stata statistics software package was used to assess pre-and-post levee installation residential exposures as well as levee-protected floodplain areas as compared to non-leveed and non-floodplain areas. Licenses for the referenced software packages were provided by the University of Colorado.

3.7 Conclusion

This research approach moves away from the deterministic orientations of flood depth and estimated damage (e.g. Davis and Skaggs 1992) toward social-physical relationships of probabilistic flood exposure estimates for residential buildings floodplains with and without levees. The spatially-dispersed cross-section approach to exposure and vulnerability relationship development will reveal how some similar and some different topographies and development incursions into floodplains may aggravate flood risk or reflect harmonious social-physical adjustments made to co-exist in the flood hazard space. For example, cross-sections may reveal high exposure or physical vulnerabilities beyond levee-oriented thresholds, and social vulnerabilities may also be high as a result. Cross-sectional analyses in the study areas will provide a much larger sampling set from which to develop generalizations about flood exposure and vulnerability. That the case of Minot is intriguing is one thing, but to develop a large set of data from which to draw inference from must occur before any conclusions can be made about the existence or presence of the levee effect phenomenon. Of the approximate 40,000 kilometers of existing levees, at least 400,000 cross-sections can be drawn in the U.S., representing about 1.6 million square kilometers, and development can be measured over time for each profile developed—from which a representative sample can be developed for inference when not measured; moreover, counterfactual cases may be developed in such cases where levees were installed but no population or development increased behind the structures, or, rather, for such cases where either levees were not installed or development is otherwise neither in levee-protected areas nor in floodplains. Such counterfactuals should reveal an agricultural nature to such flood control levees—but may also indicate a propensity for potential population or economic development. Predictability of the levee effect will be a key outcome of sufficient sampling. The resulting vulnerability assessments will provide a method for estimating the effects of population and development changes in the floodplain in local profiles which may be related to elevation change or demographic composition along the flood frequency profile.

CHAPTER 4: RESULTS AND FINDINGS

The methodology set out in Chapter 3 provided a wide range of results for evaluating changes in residential parcel data inside and outside of floodplains and for considering changes in flood risk both prior to and after levee installation and for leveed and non-leveed areas. Prior research by McMaster (1996) established a *levee effect* of increasing building permits and construction in levee-protected floodplains, thereby increasing risk as a function of exposure. Further, USACE (1998) began to consider efforts to consider the change in property values in leveed floodplains, also in evaluation of local-to-national economic benefits. In this context, research presented here provides direct, empirical evidence of flood risk changes through changes in exposure and value of residential parcels located in leveed floodplains compared to those that are neither in levee-protected areas nor in floodplains. By providing counterfactual evaluation through difference-in-difference (DID) estimation of 2014 parcel value means by flood zone, flood risk is assessed by quantifiable changes in residential exposure to flood hazard based on year of construction. With this in mind, the results of the analytical methods established in Chapter 3 are presented: (1) in aggregate by overall results of the floodplain cross-section exposure typology; (2) sectionally for study area, beginning with the pilot case of Minot, North Dakota; (3) by floodplain cross-section exposure typology for each study area; (4) by parcel changes across construction years for four key areas of residential parcels categorized as in leveed, non-leveed, floodplain, and non-floodplain areas; then by estimated discount or premium for flood zone average values compared to average values of all parcels in 2014; (5) by DID estimation for said categories; (6) by residential parcel value at risk densities for said categories by decadal aggregation (full-size decadal parcel value density maps are provided in Appendix C); and, (7) by forecasted residential parcel value growth scenarios for four categories to construction year 2050. This research was conducted with the intent of discovering what the data and the analytical techniques may reveal about changes in flood risk by build year in leveed and non-leveed areas, but also with the intent of describing limitations in the datasets and techniques deployed to draw conclusions about levee effect in the context of historical developments and desired policy outcomes that will be discussed in the subsequent discussion chapter. In short, across the study areas, the exposure typologies revealed largely undeveloped areas around cities but also well-adapted, less exposed development as well as potentially maladapted, more exposed residential development, with a general pattern of increasing residential parcel values in all study areas with those residential parcels in floodplains generally lower in value than those in non-floodplain locations in 2014. The work thus provides essential evidence supporting induced value at risk in the form of *levee effect*.

4.1 Overall Residential Flood Exposure Typology Results

Figure 4.1 shows the 4,679 cross sections drawn for every 100-meter distance interval along the rivers per the methodology described in section 3.5.1. The cross sections were drawn to reach beyond the river channels, across floodplains and developed areas, to evaluate the residential parcel densities in terms of cumulative building counts and cumulative value at risk as a function of distance from the river channel. Cross sections were divided into left-bank and

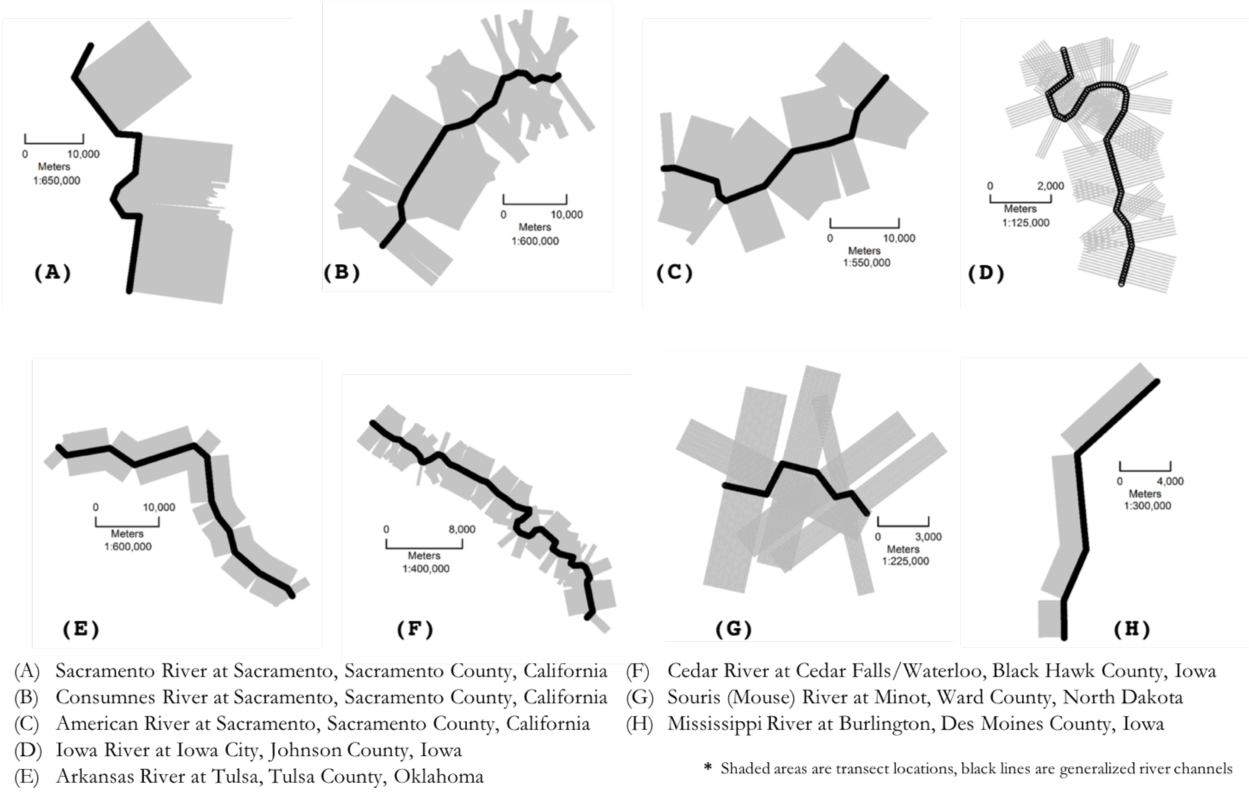


Figure 4.1. Generalized rivers and accompanying cross sections used to evaluate changes in floodplain risks in the study areas.

right-bank and were drawn from upstream to downstream, with some study area cross sections as narrow as 1,600 meters from channel to furthest, undeveloped maximum distance, as in the case of the Iowa River at Iowa City. Some cross sections were as wide as 16,000 meters, as in the case of the left side of the Sacramento River at Sacramento, thereby revealing some key differences in floodplain width among the study areas—that is, for example, the Sacramento River floodplain is substantially wider than the Iowa River floodplain, and, accordingly, has more potentially developable land area for residential parcels than the Iowa River floodplain. Each study area generally has a similar elevation pattern, with the river channel as the lowest elevation point on the cross sections, with ground elevation rising quickly and limiting floodplain area, observed in the cases of the Cedar, Arkansas, and American Rivers (Figures 4.2, 4.3, and 4.4, respectively), or rising more gently over larger distances, as in the case of the Sacramento

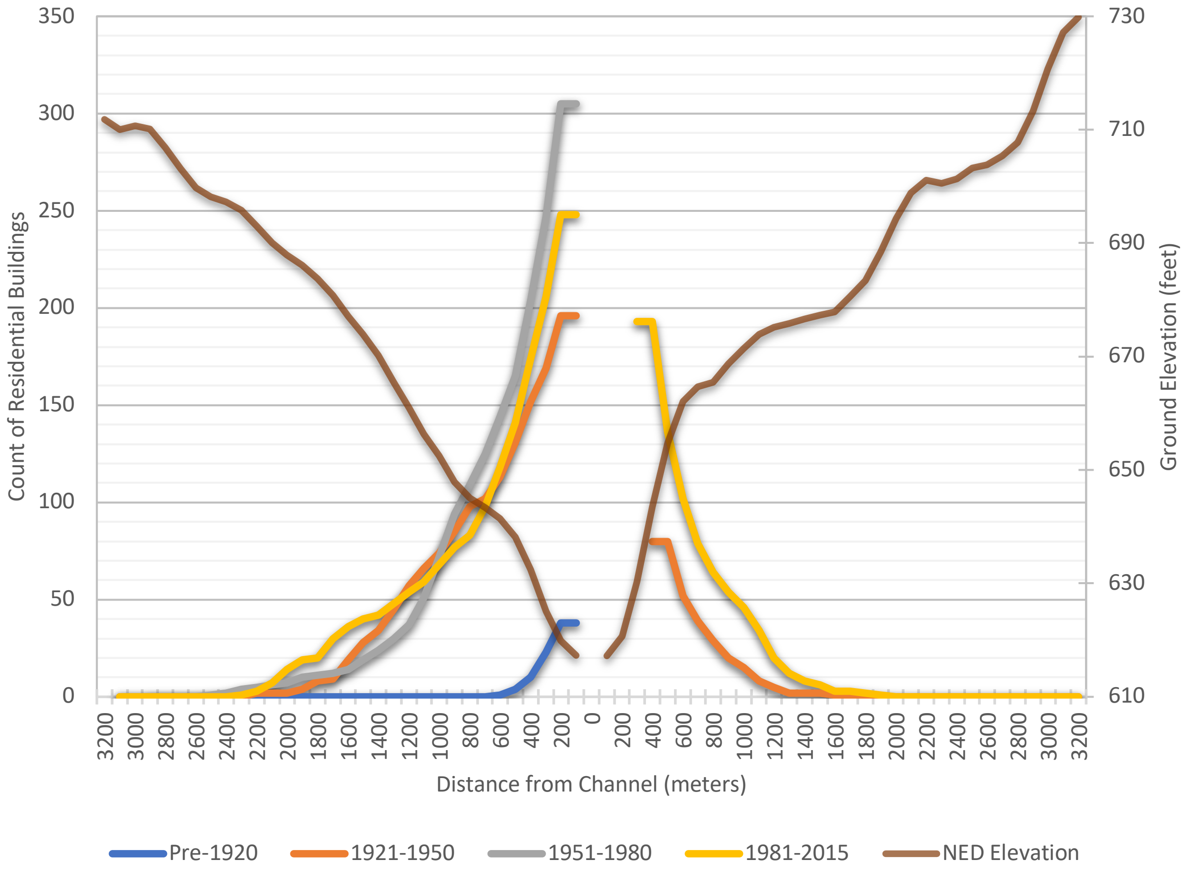


Figure 4.2. Residential building counts by decadal year-built groups and corresponding average ground elevation for cross sections along the Arkansas River at Tulsa, Oklahoma.

River left side, where the City of Sacramento is located (Figure 4.5). All study areas were observed to have their greatest numbers of residential buildings concentrated near the river, with decreasing densities of residential buildings as distance from the river channel increased. The greatest building densities nearest a river channel were observed at Sacramento, with 350-400 residential buildings every 100-meter interval outward from the channels of the American and Sacramento Rivers, decreasing to zero buildings at about 5,000 meters on the left side and 6,000 meters from the American River on the right side; and decreasing to zero buildings at about 10,000 meters from the left side of the Sacramento River. Residential buildings were located within 3,000 meters of the Consumnes River's channel in the southern portion of Sacramento

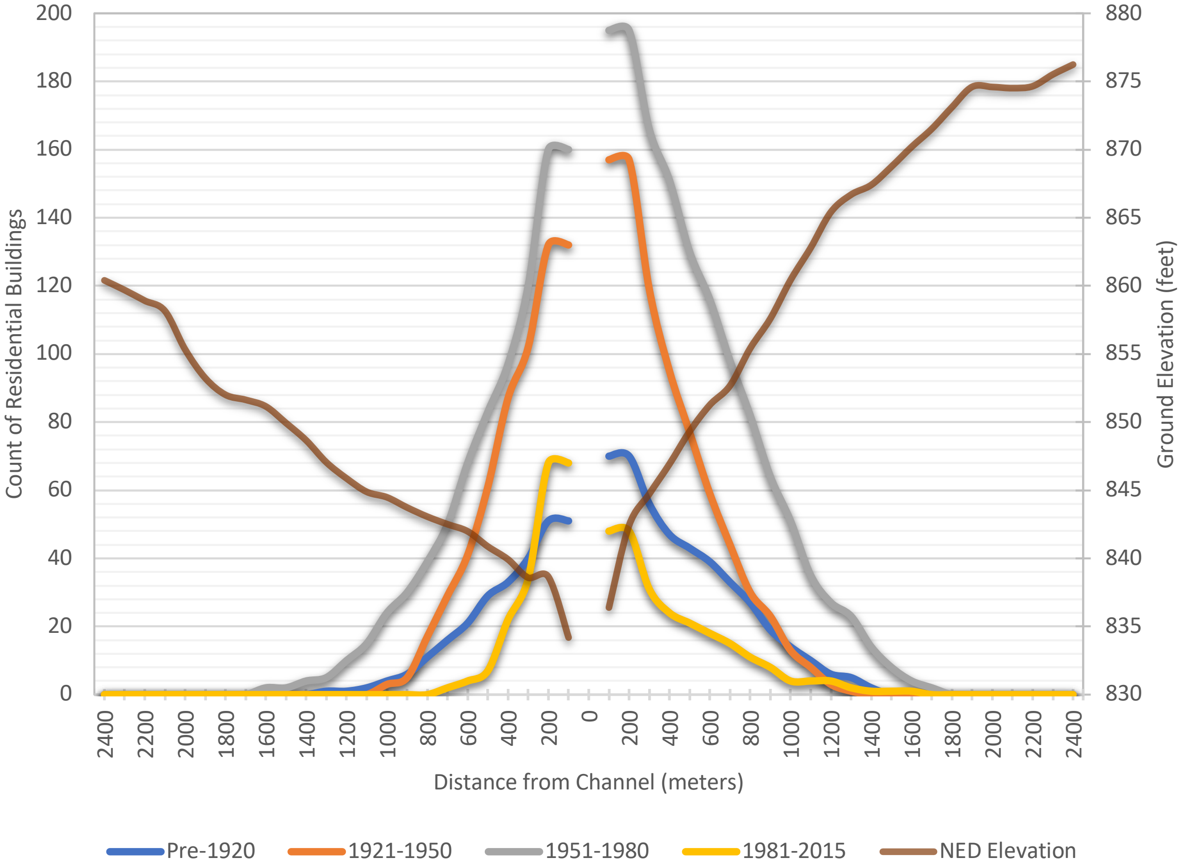


Figure 4.3. Residential parcel counts by decadal year-built groups and corresponding average ground elevation for cross sections along the Cedar River at Cedar Falls/Waterloo, Iowa.

County, California; within about 1,800 meters of either side of the channel for the Cedar River at Cedar Falls/Waterloo, Iowa; within 1,200 meters of either side of the Iowa River at Iowa City, Iowa; within 2,000 meters of the Mississippi River channel's right side at Burlington, Iowa; and within about 3,200 meters of either side of the Arkansas River channel at Tulsa, Oklahoma. Insufficient parcel data existed to evaluate comprehensively the residential building densities for the Souris River at Minot, North Dakota. Figure 4.2 shows the historical residential development pattern for Tulsa, with pre-1920 residential construction concentrated near the Arkansas River's left bank, expansion to the right bank for the period of 1921-1950, followed by a larger residential expansion on the left—or north—side of the Arkansas River between 1951-1980, and

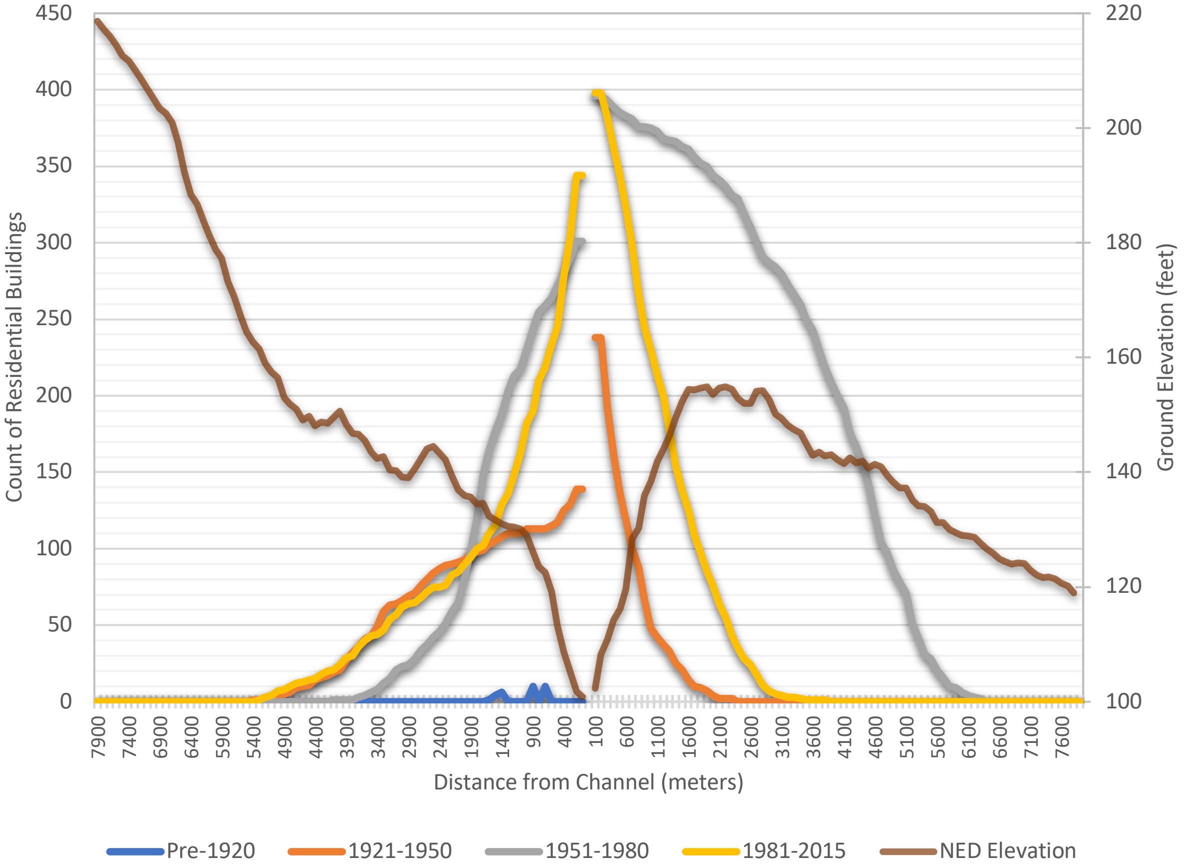


Figure 4.4. Residential parcel counts by decadal year-built groups and corresponding average ground elevation for cross sections along the American River at Sacramento, California.

fairly similar residential growth on both sides of the river from 1981-2015. A similar pattern is observed in Figure 3 at Cedar Falls/Waterloo, Iowa, with residential parcel densities greatest near the Cedar River Channel and expanding outward through the decades represented in the dataset, from pre-1920 through 2015. Notably, the historical center of residential development at Sacramento prior to 1920 can be observed in Figure 4.5 for the Sacramento River cross sections, but little to no residential buildings were observed for this period along the American River; however, substantial increases in building counts were observed for both sides of the American River from 1920-2015, displaying the expansive growth of Sacramento over the last century.

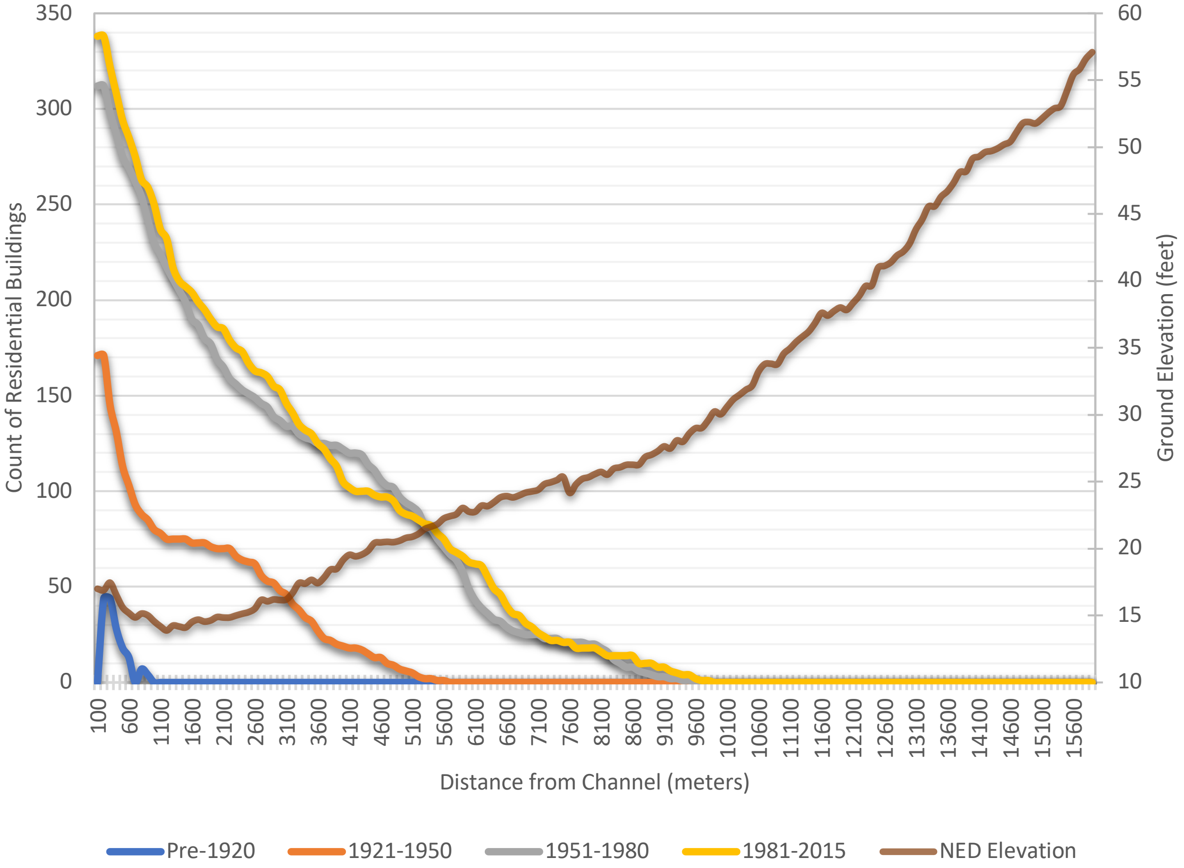


Figure 4.5. Residential parcel counts by decadal year-built groups and corresponding average ground elevation for cross sections along the left side of the Sacramento River at Sacramento, California.

The residential flood exposure typology described in Section 3.6.1 was applied to the cumulative parcel values for each of the 4,679 cross sections along the rivers in the study areas (Figure 4.6). Since the cross sections were applied for the length of the rivers through the study areas, and covered areas outside of heavily populated urban areas, most of the cross sections revealed areas yet to be developed or of low cumulative residential value at present, or about 2,810 negative-negative (BD --) cross section types. The next largest cross section type observation was positive-positive (AC ++), with about 720 cross sections in the study areas considered fully built-out or with equivalently high residential parcel values both near and far from the river channel: these AC types most likely represent urban core areas from where historical settlement and

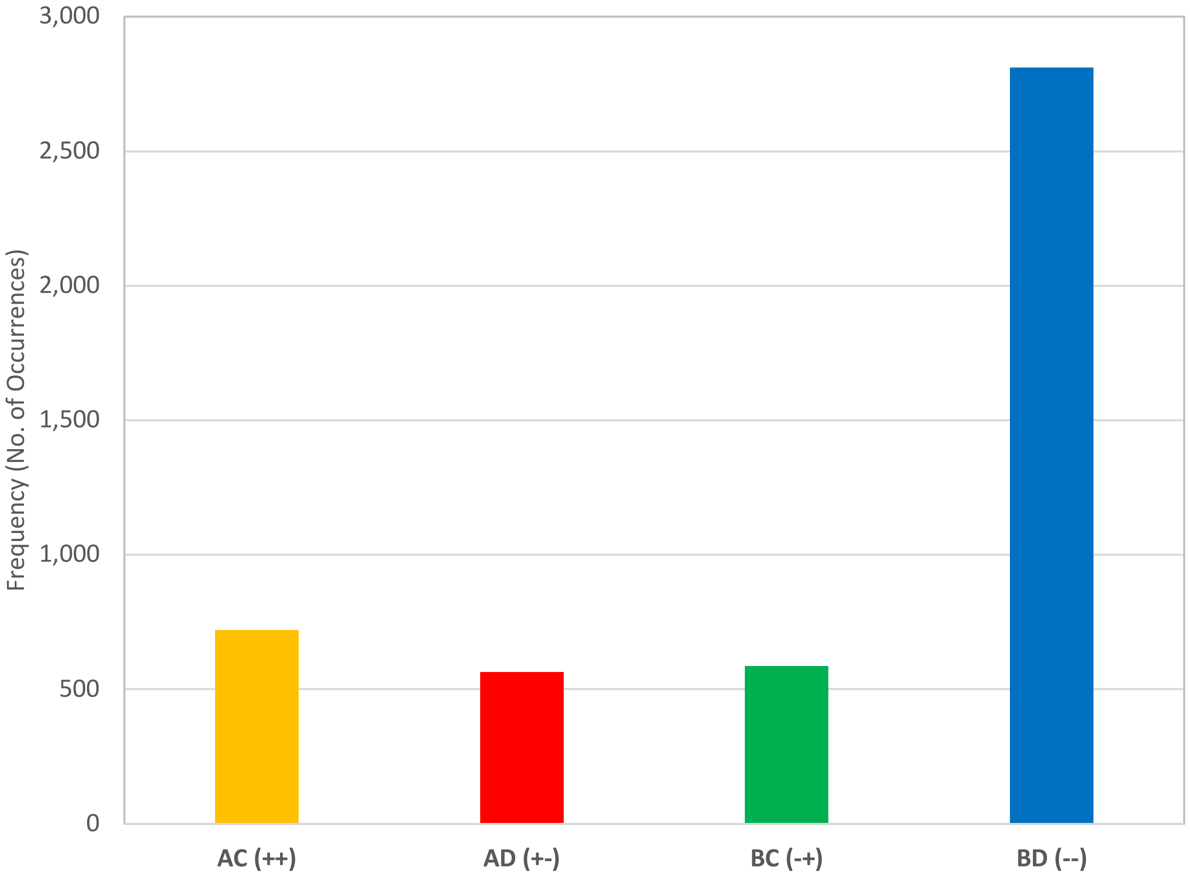


Figure 4.6. Application of the residential parcel value exposure types across all study areas (n [cross sections] = 4,679). Most cross sections revealed undeveloped or low-to-no value areas (BD, --, blue bar). About 586 cross sections revealed well-adapted residential exposure, with residential parcels constructed at distances farther from river channels (BC, -+, green bar). However, about 720 cross sections revealed fully built-out floodplains (AC, ++, yellow bar) and another 563 cross sections revealed signs of adverse development in the form of residential parcels constructed very near river channels and in floodplains (AD, +-, red bar).

expansion of cities began. About 586 cross sections were observed to be well adapted to flood hazards, with a negative-positive (BC -+) applied as residential value at risk was near zero or very low closest to river channels and high further from channels—or, in terms of length, about 59 kilometers of river length were well-adapted to riverine flood hazards to residential construction. However, about 563 cross sections, or 56 kilometers of study area river length, were applied a positive-negative (AD +-) type, potentially reflecting adverse residential building value concentrated in areas nearest to river channels and in hazardous floodplain areas. The cross-section types for each study area are shown in Figure 4.7.

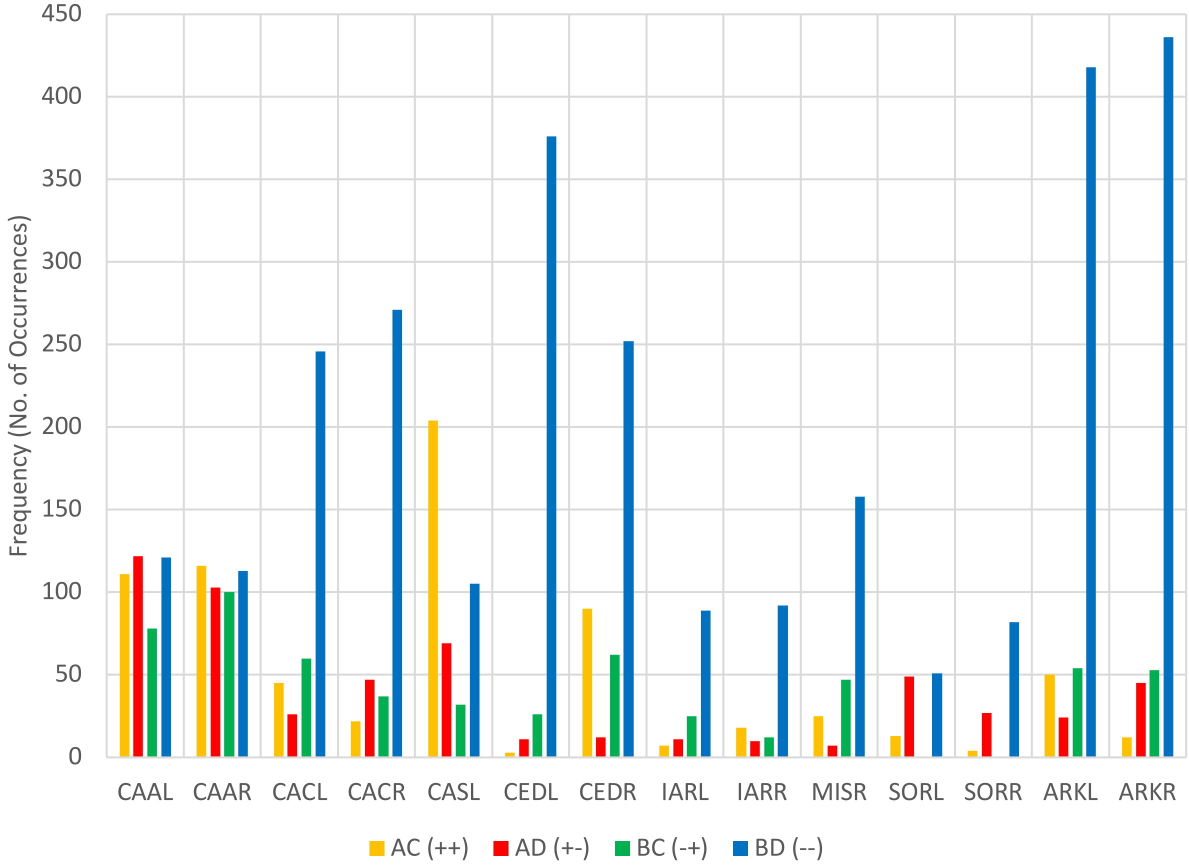


Figure 4.7. Results of typing residential floodplain development exposure types (n [cross sections] = 4,679). While most of the cross sections reveal undeveloped or agricultural values (BD, --), all study areas have some adverse development types (AD, +-), with the most occurring along the American River. All study areas also have well-adapted development types (BC, -+); however, all study areas also have fully built-out residential floodplain types (AC, ++), with areas along the Sacramento River having the most fully-built-out residential floodplain type as a proportion of all types. From left to right on the chart are the American River, left (CAAL) and right (CAAR) sides, Consumnes River left and right (CACL, CACR), Sacramento River left (CASL), Cedar River left and right (CEDL, CEDR), Iowa River left and right (IARL, IARR), Mississippi River right (MISR), Souris River left and right (SORL, SORR), and Arkansas River left and right (ARKL, ARKR).

4.2 Results for Minot, North Dakota

While Minot proved an excellent case study in which to assess various methods for evaluating the levee effect, limitations in the parcel dataset provided by FEMA yielded a biased, incomplete picture of floodplain development. The data reflected only those residential parcels either in the Souris River floodplain at Minot or those affected by the flooding caused by levee overtopping in 2011—data clearly needed for FEMA's mission to support damage assessments and disaster relief, but too limited in geographic scope to make specific claims about the existence of a levee effect at Minot. The cross-section exposure methodology demonstrated in the case study that, in fact, residential construction proceeded in the Souris River floodplain, as encouraged by the city council and discussed in Section 3.2.2 (Figure 3.1), following completion

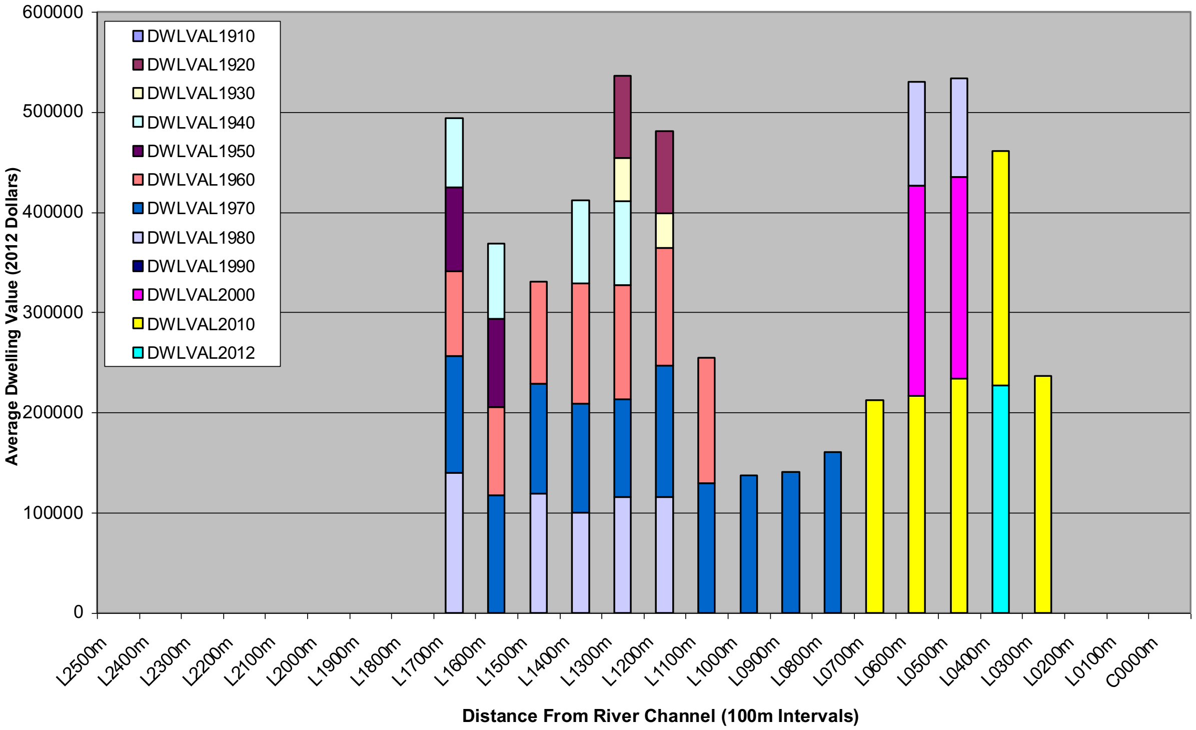


Figure 4.8. Residential parcel value for cross-section 02w in western portion of Minot, depicting an increase in residential value of about $15 million following Minot's "removal" from the FEMA 100-year floodplain (yellow, magenta, and teal bars at 200-to-700 meters from the channel). The cross-section is depicted as the left side of the Souris River floodplain, with the river's channel shown on the right side of the plot. Note that as distance from the channel increases, moving leftward on the plot, the absence of residential construction beyond about 1,700 meters reflects the limited parcel data availability for the Minot study area.

of the levee improvements and “removal” of the city from the FEMA-designated floodplain; however, this increase in value at risk in some floodplain locations cannot be compared to supposed counterfactual residential construction cases in non-floodplain or non-levee-protected areas due to the limited availability of parcel data. With these limitations in mind, certain cross sections revealed encroachment of residential development on the Souris River floodplain and channel, specifically, with Cross Section 02w, drawn in the western fringes of the City of Minot’s footprint in the floodplain, revealing new residential construction in the 100-year floodplain *after* the floodplain construction moratorium was lifted in 1995. Importantly, as shown in Figure 4.8, this cross section also revealed that no new residential construction in this area of the floodplain occurred following the publication of the FEMA FIRM in 1983, which depicted the 100-year floodplain as substantially larger in area than the later 1995, levee-factored FIRM, suggesting that the non-levee-protected floodplain drawn on the 1983 FIRM may have discouraged residential construction in the 100-year floodplain.

The exposure typology cross sections for Minot revealed a substantial set of AD (+-) development types for both the left (Figure 4.9) and right sides (Figure 4.10) of the Souris River through Ward County. However, given the limitations in the residential parcel dataset, these cross sections are likely heavily biased in suggesting that residential construction occurs nearest the Souris River channel and not as much in non-floodplain areas further from the river channel. Though normalized in both distance from channel and value at risk, the cross sections do reveal an exponential growth trend in value at risk nearest to the river channel, with relatively high value at risk decreasing quickly with increasing distance from the channel, revealing that the residential buildings nearest to the channel—i.e., those with the highest risk of flooding or potential damage from greater flood depths—are more valuable than those residential buildings further away from the channel and with lower risk.

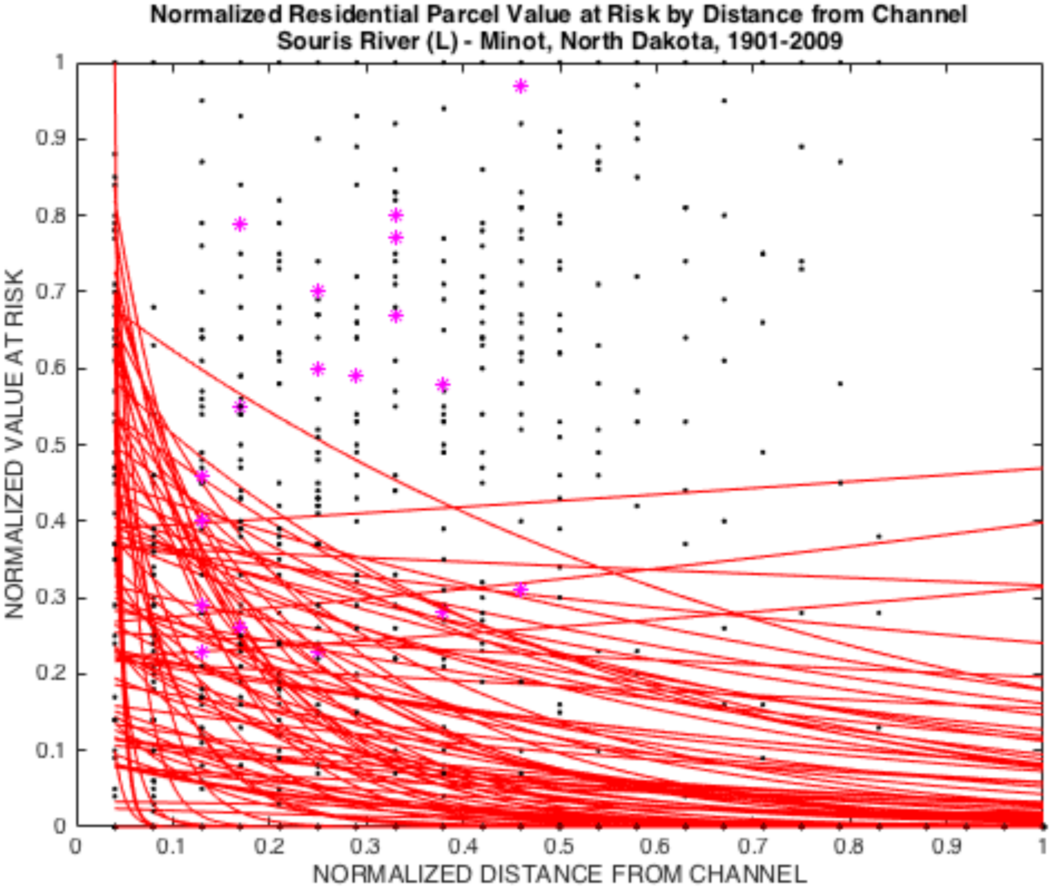


Figure 4.9. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Souris River channel, left side, yields a substantial set of AD (+-) development types at Minot, North Dakota, 49 out of 113 cross sections, perhaps representing adverse floodplain development (red lines). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

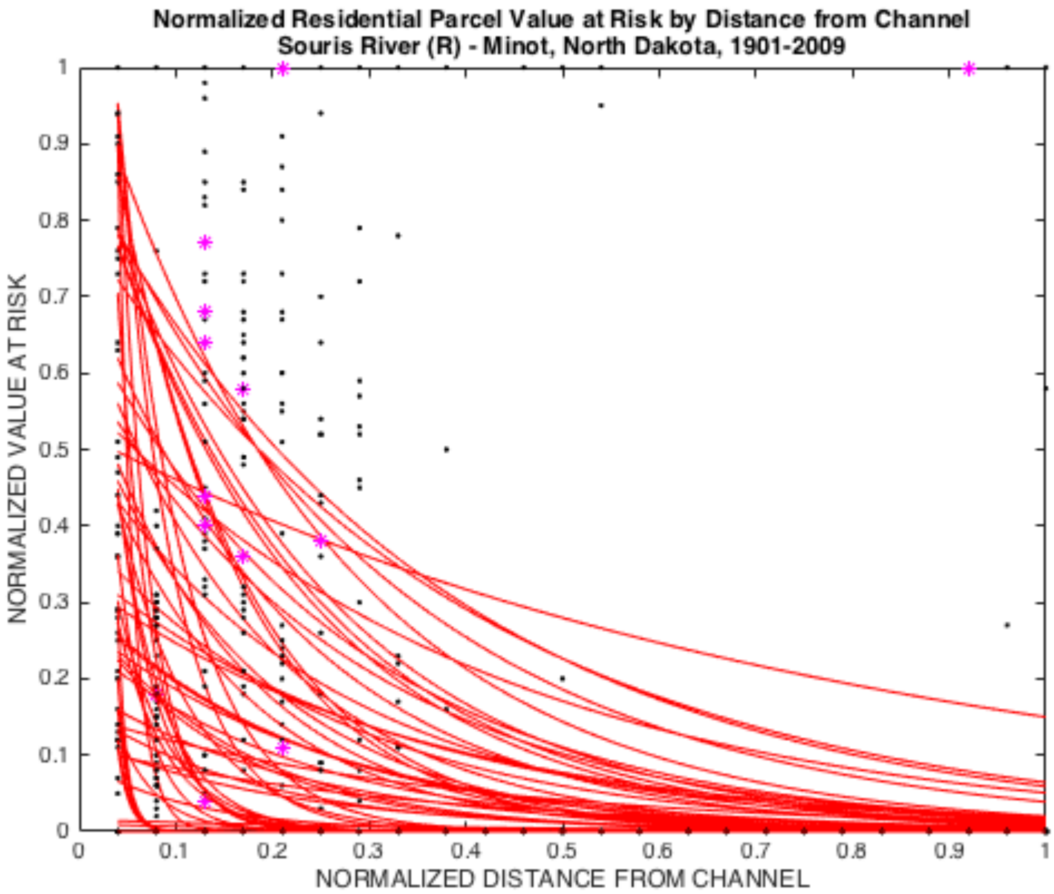


Figure 4.10. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Souris River channel, right side, yields a substantial set of AD (+-) development types at Minot, North Dakota, 27 out of 113 cross sections, perhaps representing adverse floodplain development (red lines). Most cross sections at Minot revealed undeveloped floodplains (BD, --, 82 out of 113). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

Unfortunately, the paucity of residential parcel data for the Minot study area resulted in an inability to reasonably perform density analyses or DID analysis for inferring any conclusions about the existence or nonexistence of levee effect. Given that the FEMA residential parcel dataset reflected only those parcels in the floodplain or affected by the 2011 flood, a density analysis gives the impression that residential construction only occurs in the floodplain, heavily biasing and distorting the true picture of construction practices. Similarly, there can be no assumed counterfactual evaluation without non-floodplain or non-levee-protected data with which to compare, and no reasonable parcel growth forecasts can be presented. With these limitations in mind, it remains plausible but not conclusive that a levee effect encouraging residential construction in the levee-protected areas of the Souris River floodplain, particularly in consideration of the local media's inducement and persuasion to such development.

4.3 Results for Johnson County, Iowa

Results for the Iowa City study area represent a real-world counterfactual case because the study area has no levees. There is a regulatory 100-year SFHA, however, and results are presented per the methods set out in Sections 3.5 and 3.6, first by cross-section typology, then temporally for floodplain and non-floodplain parcel values, then by results of the DID counterfactual analyses, then by decadal value densities, and finally by residential parcel value growth forecast.

4.3.1 Johnson County Exposure Typologies

Residential construction along the Iowa River through Iowa City represents a balanced mix of well-adapted (BC, -+), potentially adversely-adapted (AD, +-), and fully built-out, historical city-center cross sections (AC, ++), with most of the Johnson County cross sections outside of Iowa City revealing undeveloped (BD, --) types. Notably, the Iowa River floodplain appears rather narrow through Iowa City, with abundant uplands settled for residential parcels;

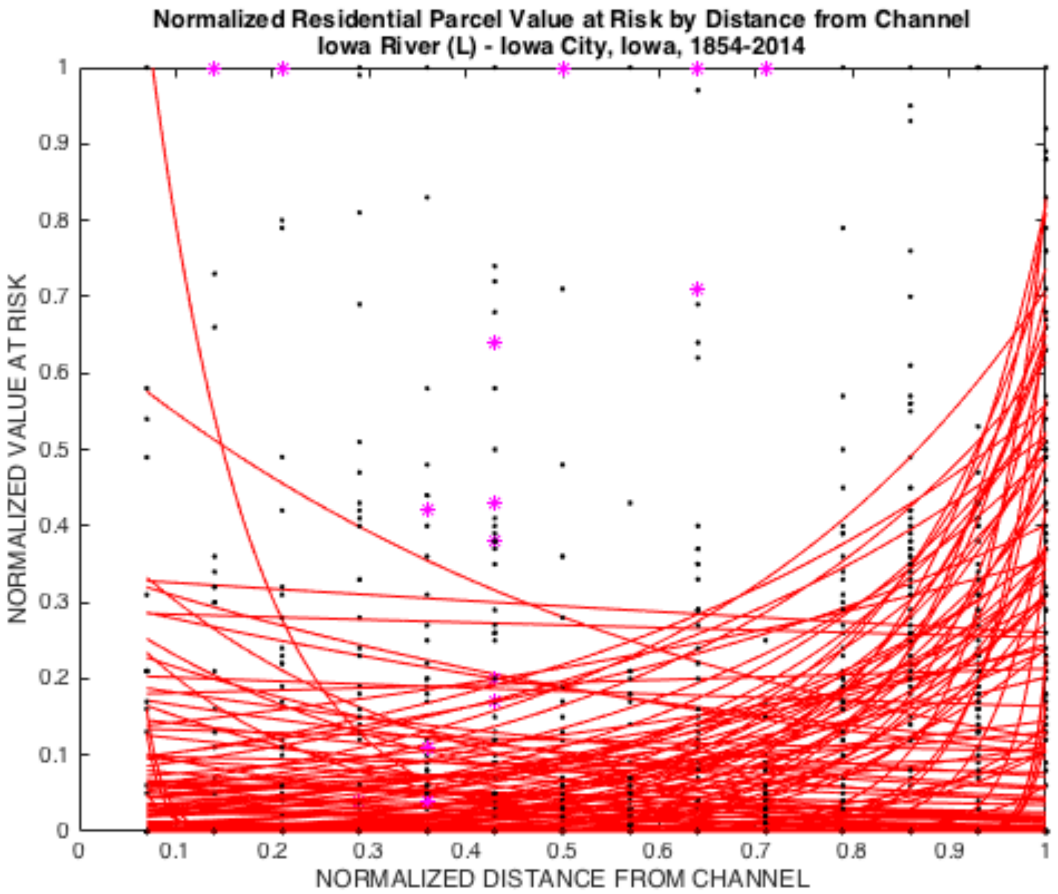


Figure 4.11. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Iowa River channel, left side, yields a substantial set of BC (-+) development types, 25 out of 132 cross sections, perhaps representing well-adapted floodplain development with room granted to the river for flooding (red lines). A few adverse development types (AC, +-, 7 out of 132) likely represent areas of downtown Iowa City where development, generally, is high density. Most cross sections revealed low-to-no residential development in floodplains (BD, --, 89 out of 132). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

however, the set of potentially adverse development types along the left side of the river (Figure 4.11) reveals the historical city-center, downtown area. The larger set of potentially adverse developments exists along the right side of the river (Figure 4.12) in the City Park neighborhood, likely connected to the University of Iowa and residential locations situated conveniently near the university. Well-adapted cross sections represent about 25 of the county's 132 cross

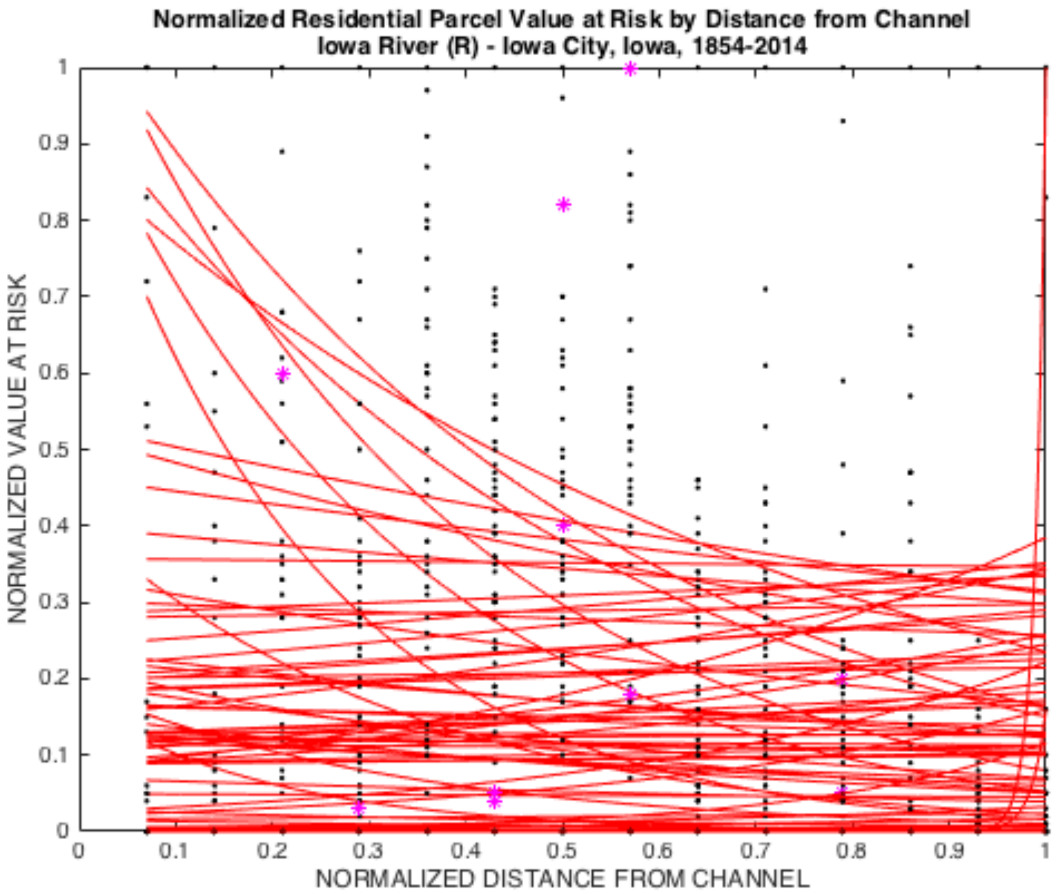


Figure 4.12. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Iowa River channel, right side, yields a set of AD (+-) development types, 10 out of 132 cross sections, perhaps representing adverse floodplain development encroaching on the river floodplains (red lines); however, some types also reflect undeveloped cross sections (BD, --, 92 out of 132) and medium buildout of other cross sections (AC, ++, 18 out 132). Well-adapted development types (BC, -+) represented about 12 of 132 cross sections. Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

sections along the left side, or about 19 percent of all cross sections, with only 7 of the 132 cross sections showing adverse development signals, or about 5 percent of the county's cross sections. The potentially adverse cross sections along the right side of the river represent about 8 percent of all cross sections; about 9 percent reflect well-adapted cross section types; and about 14 percent of the right-side cross sections reflect fully-built out residential conditions.

4.3.2 Johnson County Residential Parcel Values

Figure 13 reveals historical trends in the cumulative value of residential parcels in Johnson County for 2014. The residential parcel dataset reflects the extensive history of settlement at Iowa City, with some buildings dating back to 1850 or earlier, following the

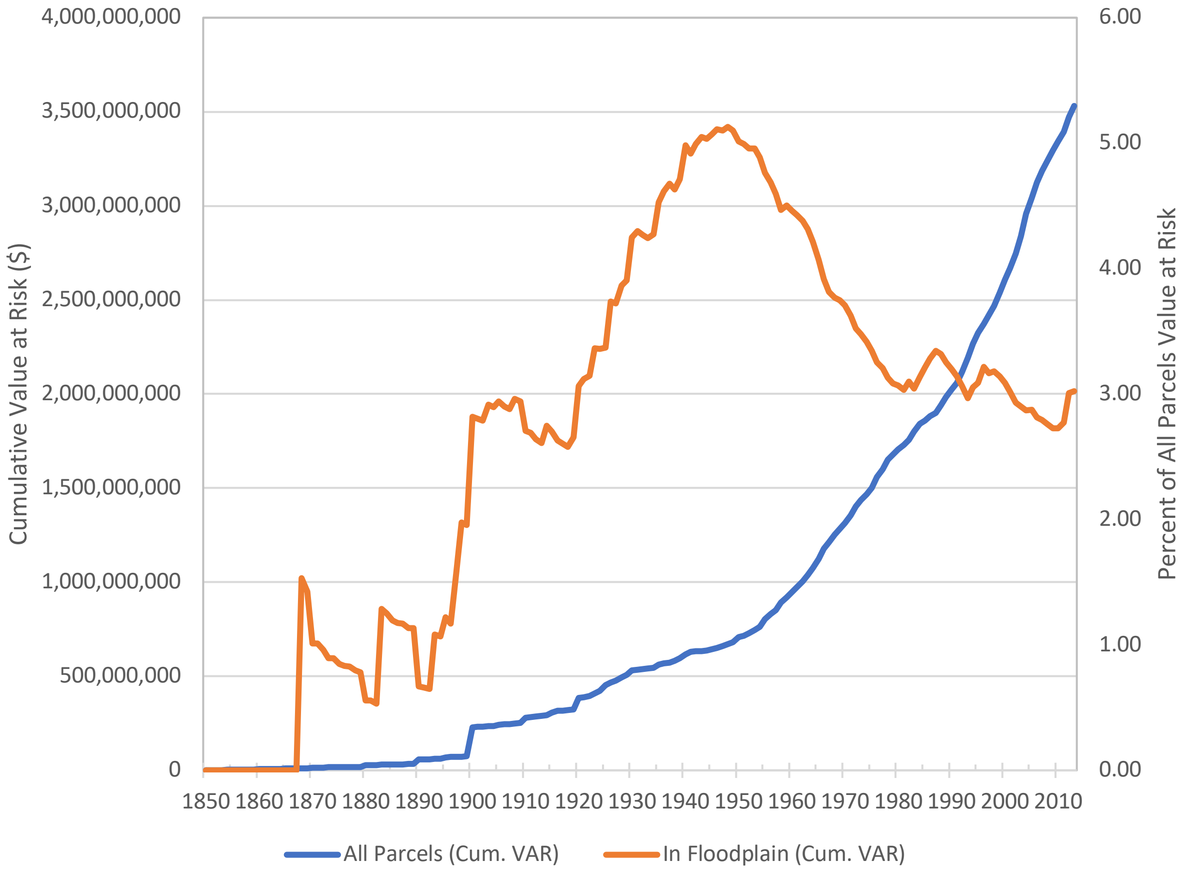


Figure 4.13. Cumulative 2014 residential parcel value for Johnson County by year of construction (blue line, left axis), Iowa with the percent of parcels in the floodplain (orange line, right axis). Overall, parcel growth over the prior 164 years illustrates how floodplain growth proceeded steadily into the 1940s before declining from about 1950-1980 as a proportion—this may represent full build-out of the floodplain by 1950, with growth occurring in places other than the floodplain thereafter. Notably, several large floods affected Iowa City in 1881, 1918, 1981, 1993, and 2008, with immediate growth in the floodplain following the floods—the proportion of residential parcels in the floodplain grew by about 2% after the 1918 flood up to about 1950; following the 1981 flood, residential parcels in the floodplain increasing by about 0.25% to 1988; by about 0.2% following the 1993 flood up to 1999; and followed by a brief decline in proportion of residential parcels in the floodplain following the 2008 flood before increasing about 0.25% by 2014. Notably, the increases in proportion of parcel growth in the floodplain following floods may reflect a recovery phase of about 6 years.

founding of the city in 1839 as a county seat. The cumulative value of residential parcels in 2014 appears exponential in form, with values reaching about $500 million around 1929 and then doubling about every 30 years to near $1 billion around 1960, $2 billion around 1990, and the growth trend likely to reach about $4 billion by 2020 or sooner (Figure 4.13, blue line, left axis). The percentage of residential parcel value at risk in the floodplains of Johnson County in 2014 is reflected in the orange line and corresponds to the right axis and reveals correlations to flood records. Assessed 2014 residential parcel value in the floodplains declined from about 1.5 percent to about 0.5 percent of the cumulative residential value during the 1870s; however, following a major flood in 1881, residential values surged back to about 1.5 percent of 2014 cumulative valuation. A similar decline in the proportion of residential value in the floodplains occurs in the late 1880s, based on construction year data, followed by a near 30-year period of growth that sees the proportion of residential value in the floodplains peak at about 2.9 percent of cumulative value in 1909, followed by a gentle decline to about 2.6 percent in 1918. Following a major flood in 1918, the proportion of residential parcel values in the floodplains again surges, this time reaching about 5 percent of cumulative values by about 1950 before declining to about 3 percent in 1981. Following a major flood in 1981, growth in residential values by year built in the floodplains jumps to about 3.25 percent in 1989 before falling to about 2.96 percent in 1993; growth occurs again after the major floods of 1993, reaching about 3.14 percent by 1999, followed again by a gentle decline to about 2.73 percent in 2008. Following the major floods of 2008, growth again jumps about a quarter-point to just over 3 percent of cumulative residential value in the floodplains by the end of records in 2014. Thus, it appears that major floods may have the effect of increasing residential parcel values briefly, on the order of about a 6-year cycle that may be related to disaster relief and recovery spending; however, while the 2-percent decrease in floodplain values from 1950-1980 likely reflects that overall growth in Johnson County occurred outside the floodplains, the proportionate decline in values in the floodplains since 1980, though briefly experiencing increases following major flooding, appears to be at a rate of about 0.25 percent.

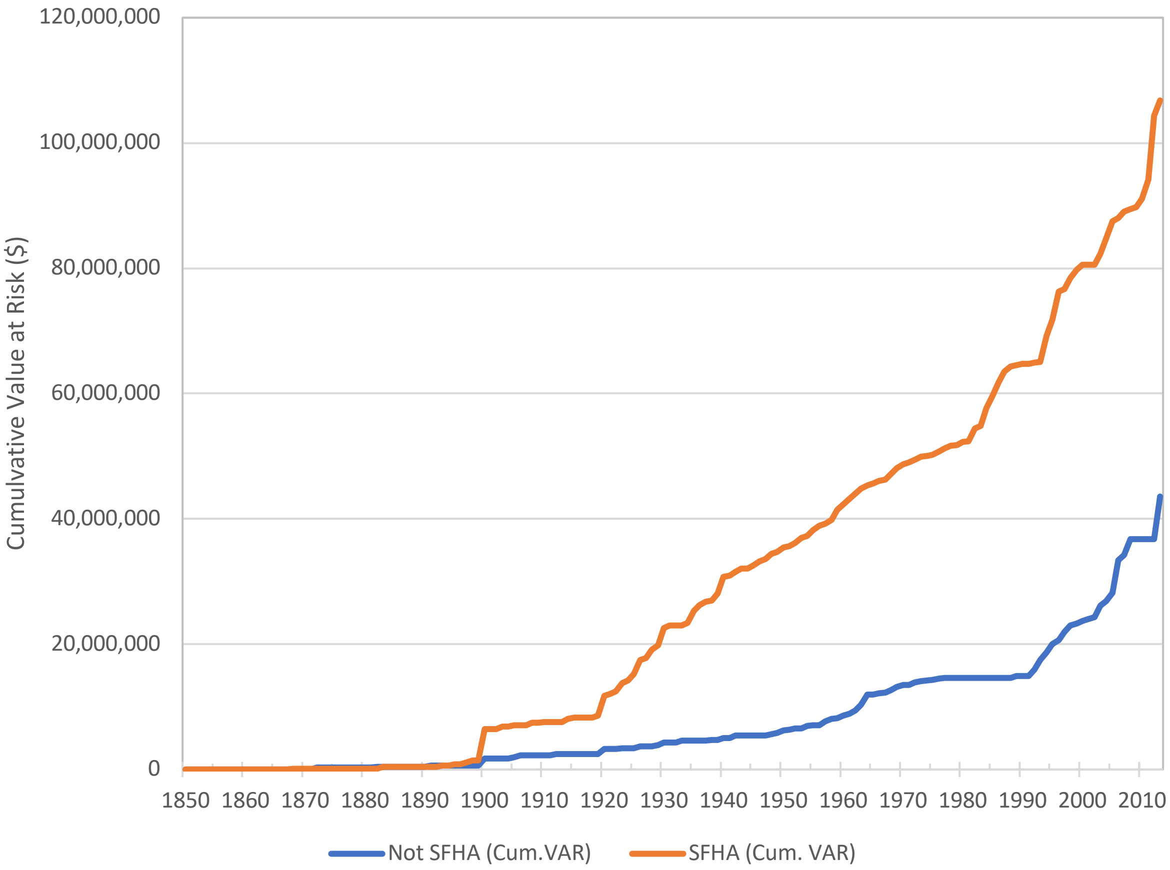


Figure 4.14. Cumulative 2014 at risk of flooding by year of construction for residential parcels located in the 100-year SFHA and 500-year floodplains of Johnson County, Iowa. Increasing value at risk in the SFHA has been a consistent, steady feature of residential development in Johnson County, with increases in the slope of growth following major floods in 1918, 1981, 1993, and 2008 (orange line). Increases in the 500-year floodplain occurred at a slower rate and represent the smaller area of the flood zone; however, sharp increases in development rate are observed following the 1993 and 2008 floods (blue line).

Though the post-flood increases in value at risk by year built are not as obvious as Figure 4.13, Figure 4.14 reveals that both the 100-year and 500-year floodplains appear to have linearly-increasing residential value at risk, with 2014 assessed cumulative values in the 100-year SFHA topping $100 million and 500-year floodplains topping about $40 million by the end of the parcel data in 2014. Growth in the 100-year SFHA outpaced growth in the 500-year floodplain from 1970 to 1990; however, increase in cumulative values by year built for the 100- and 500-year floodplains occurred at a rate of about $3 million per year from 1990 to the end of records in 2014. This is notable because the rate of growth for the 100-year SFHA appears consistent over a century, since about 1909, although this rate of growth for the 500-year floodplain is triple the average growth for the period of 1900-1990. Average residential parcel values in the 100-year SFHA are about $30,000 less than parcels not located in the floodplain (Figure 4.15).

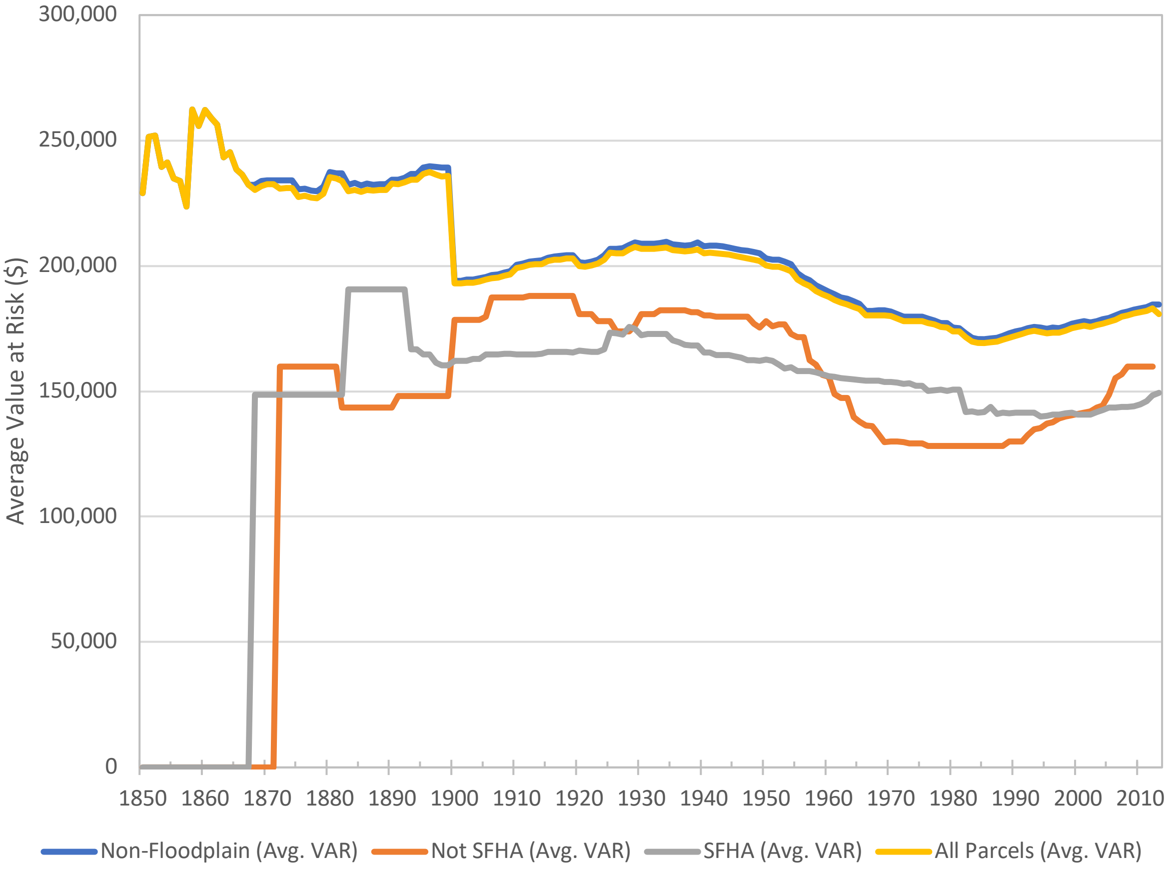


Figure 4.15. Average 2014 residential parcel value at risk by year of construction for Johnson County, Iowa from 1850-2014, showing an increase in overall average values since the late 1970s, with parcels in the 100-year SFHA about $20-30,000 less than non-floodplain parcels on average. Average residential parcel value at risk of flooding appears not to be affected by the major floods affecting the county in recent decades.

For Johnson County, Iowa, homes located in the 100-year SFHA appear to average about 16 to 17 percent lower in value when compared to non-SFHA home values over the period of record, based on 2014 assessed values (Figure 4.16). In particular, SFHA home values declined to about 20 percent below the average values of non-SFHA homes by 1950, and then proceeded to climb to about 13 percent below the average of all parcel values by the early 1980s, indicating that there were no immediate effects on SFHA home values from the NFIP. Average SFHA home values again declined in comparison to all home values from the early 1980s to about 2010, again reaching discounts of about 20 percent, before climbing back to about 15 percent below all parcel values by the end of records in 2014.

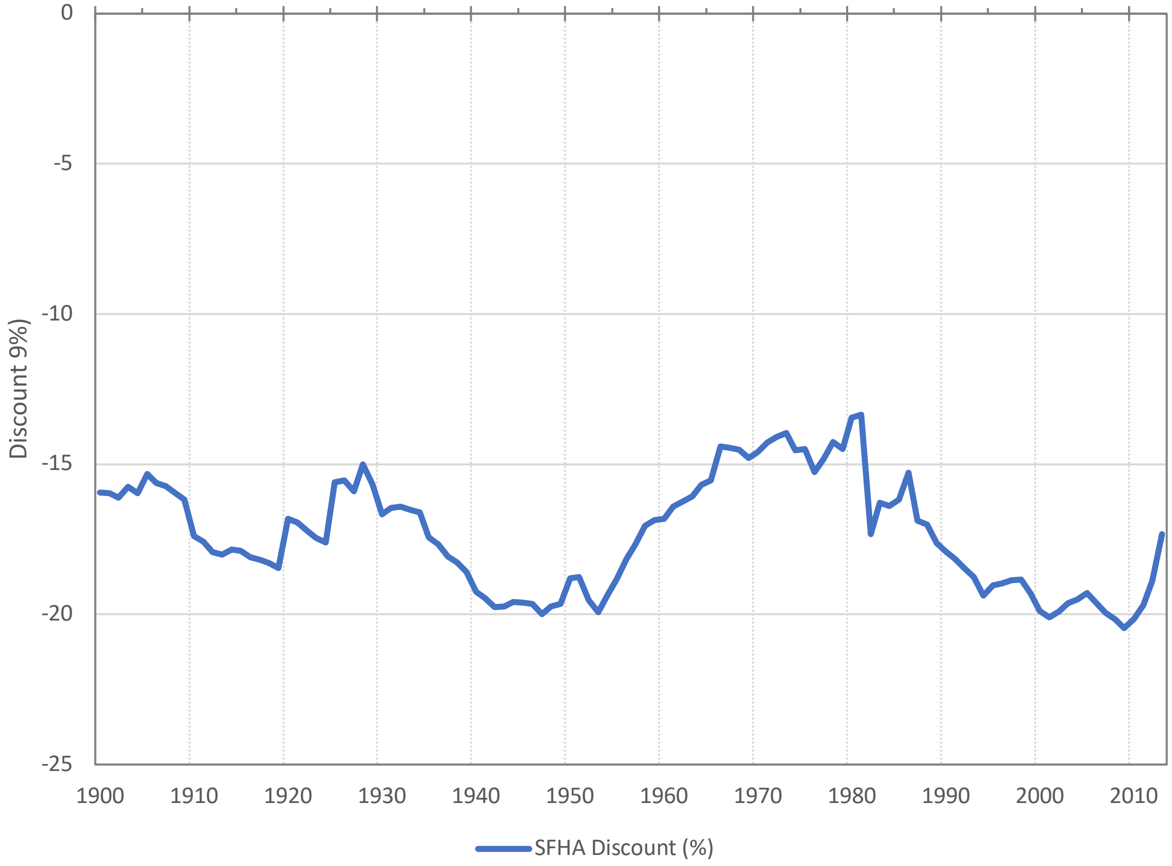


Figure 4.16. Estimated discount in 2014 SFHA home values by year of construction compared to all residential parcels for Johnson County, Iowa, 1900-2014.

4.3.3 Counterfactual Evaluation for Johnson County

Given that there are no levees in Johnson County, Iowa, DID estimation was conducted for two cases. The first case compares the difference in residential parcel values during the periods of 1973-1982 to those of the period of 1982-1994 for a pre-1981 major flood condition and post-1981 flood condition, with the pre-and-post flood values compared for parcels either in floodplains or not in floodplains per the methodology described in Section 3.6.4 (Figure 4.17). The average 2014 residential parcel values prior to the 1981 flood were $56,751 for floodplain locations versus $102,353 for non-floodplain locations, based on construction years, and the average values after the 1981 flood were $120,255 for floodplains and $162,962. While all residential parcel values increased sharply across construction years, the 2014 values for parcels located in the 100-year SFHA increased by $3,164 more than non-floodplain parcels. Thus, though the difference in average increase is slight, homes in the floodplains averaged more in value following the 1981 flood than those homes not in the floodplain based on construction year and 2014 assessed values.

The case for the second DID estimation for Johnson County compares the values of residential parcels either located in or not located in the 100-year SFHA prior to and after 1973, when the purchase of flood insurance became mandatory under the NFIP. As Figure 4.17 reveals, the average value of residential parcels in the 100-year SFHA are about $30,000 less than those of non-floodplain locations, based on 2014 assessed values. Figure 4.18 reveals that parcels in the 100-year SFHA averaged less in value after 1973 by about $6,822, whereas parcels not in the 100-year SFHA averaged more in value after 1973 by about $3,884, giving a net effect of about $10,706 in average difference between floodplain and non-floodplain parcel values after 1973. There may be two findings from this result: (1) that the effect of the mandatory purchase of flood insurance depresses residential parcel values, or, that (2) location in the 100-year SFHA, the physical floodplain, yields lower residential parcel values. In either case, the risk of flooding appears to cause lower valuation of residential parcels in Johnson County, irrespective of structural flood controls.

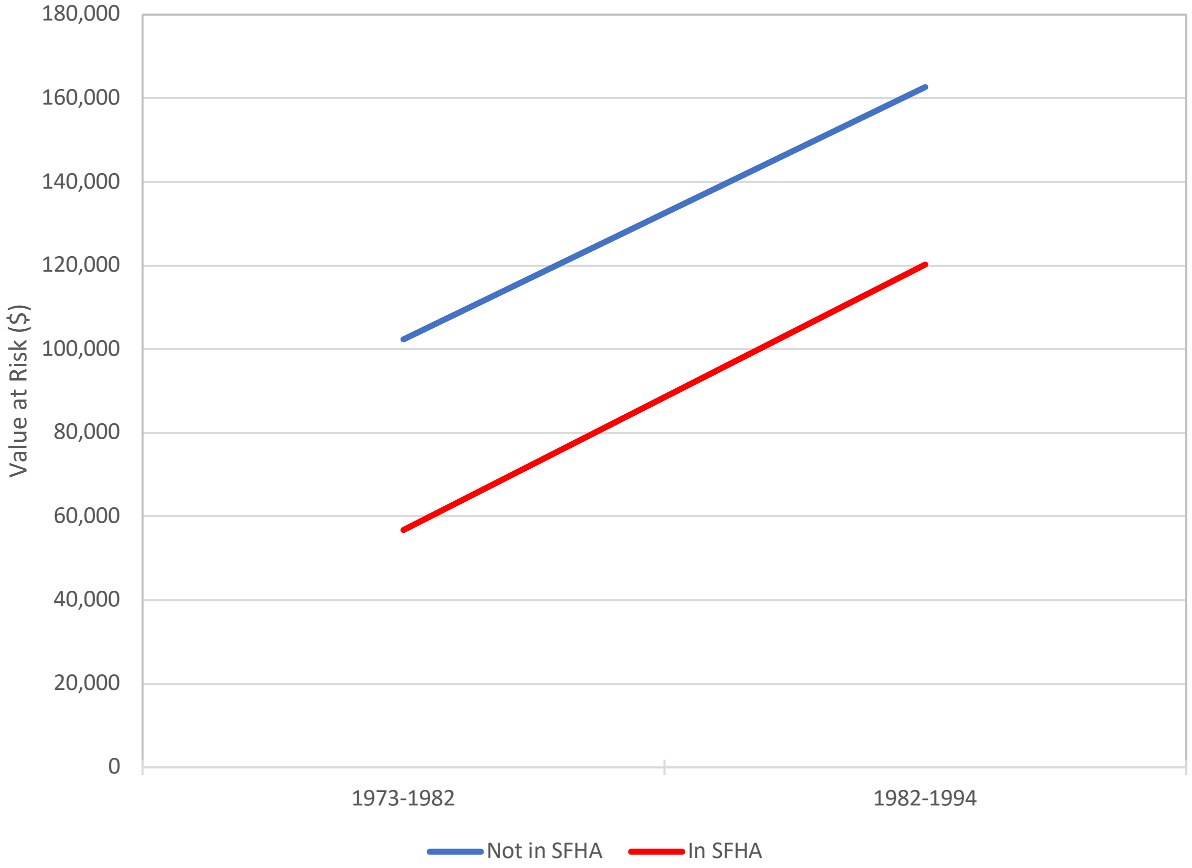


Figure 4.17. DID analysis for Iowa City showing steady increase in 2014 residential parcel values between 1973 and 1994. In 1981, a significant flood occurred, and the value of residential parcels in the 100-year SFHA (treatment) averaged about $3,164 more than homes not located in the 100-year SFHA, indicating that post-flood reconstruction may have boosted residential floodplain development values over non-floodplain areas. Notably, the average increase in value for SFHA (treatment) areas was $63,503 on average after 1982, whereas non-SFHA (control) areas increased on average by $60,340.

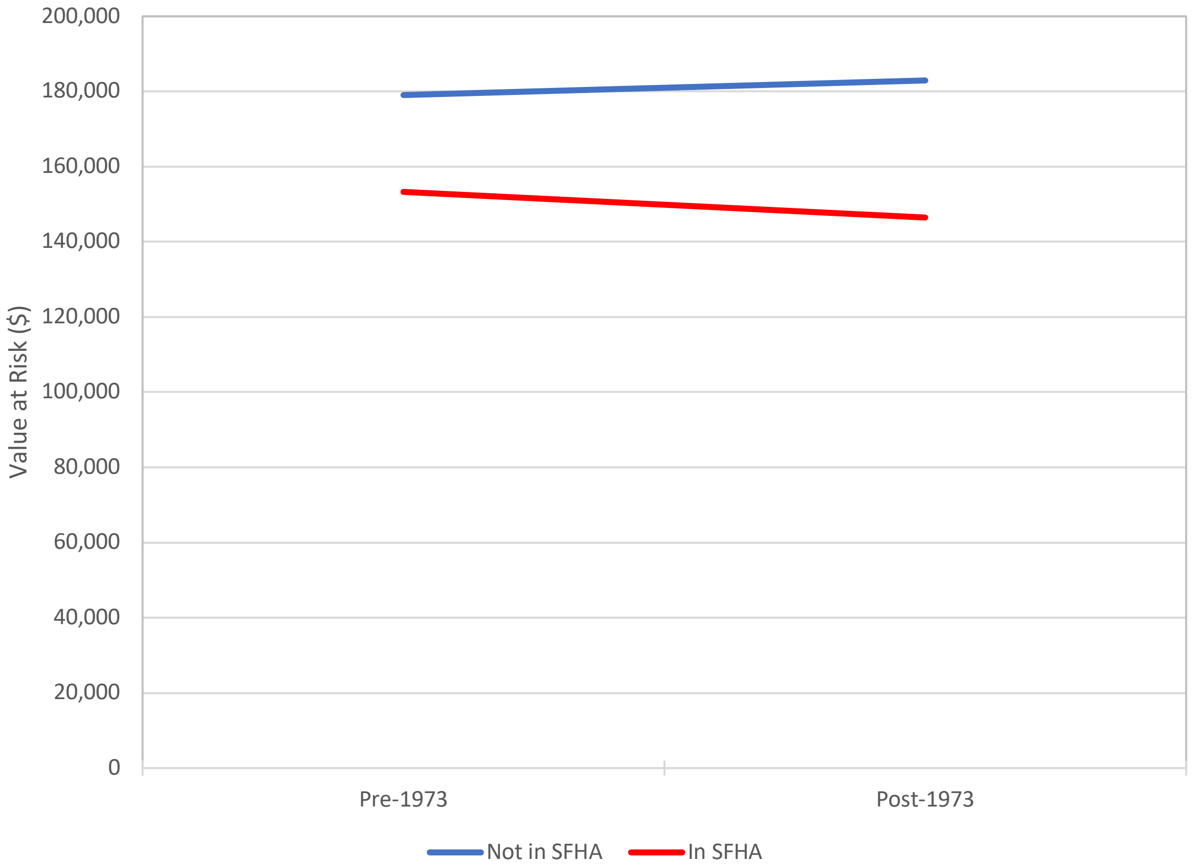


Figure 4.18. DID analysis for 2014 Johnson County residential parcel values prior to and after the 1973 mandatory purchase requirement for flood insurance was implemented. Notably, residential parcels in the 100-year SFHA averaged less in value by about $6,822 from 1973-2014, with parcels outside the 100-year SFHA increasing by about $3,884 on average for the same construction period, giving a net effect of about $10,706 difference between the areas on average.

4.3.4 Parcel Value Densities and 2050 Scenario for Johnson County

Cumulative 2014 residential parcel densities are reflected in Figure 4.19 on a decadal basis of construction years for period of record of 1850-2014 with all parcel values for pre-1901 reflected in Panel A. The 2014 cumulative parcel value densities reflect the historical development of Iowa City on the eastern side of the Iowa River when inspecting construction year data, with parcel values densifying mostly on the eastern side of the river until 1950. After 1950 and the expansion of the University of Iowa’s campus, residential parcel values increase in value on the western side of the Iowa River based on 2014 assessment. Figure 4.20 shows the best fit model for residential parcel values by build year in Johnson County since 1900, with values in the floodplains fitted to about $100 million cumulatively by the end of observations in 2014. The linear trend of increasing parcel values can be described in terms of counts of structures increasing, with cumulative 2014 assessed values for each year indicating more residential construction as average values by year built have remained steady for decades (Figure 4.15). For a scenario projected to 2050 residential parcels in the floodplains of Johnson County may increase $25 to $50 million over the proceeding 36 years, reflecting an increase in flood exposure in the 100-year SFHA of about $500,000, in addition to the near $1 million in present-day exposure for a total future exposure of about $1.5 million. Under a similar scenario, cumulative values by build year for all parcels may reach $6-$8 billion, of which only 0.02 percent would be at risk of flooding. The present-day risk of flooding from the Iowa River affects approximately 0.03 percent of cumulative residential parcel values, suggesting that future parcel value growth in non-floodplain areas will decrease the overall value at risk by 0.01 percent.

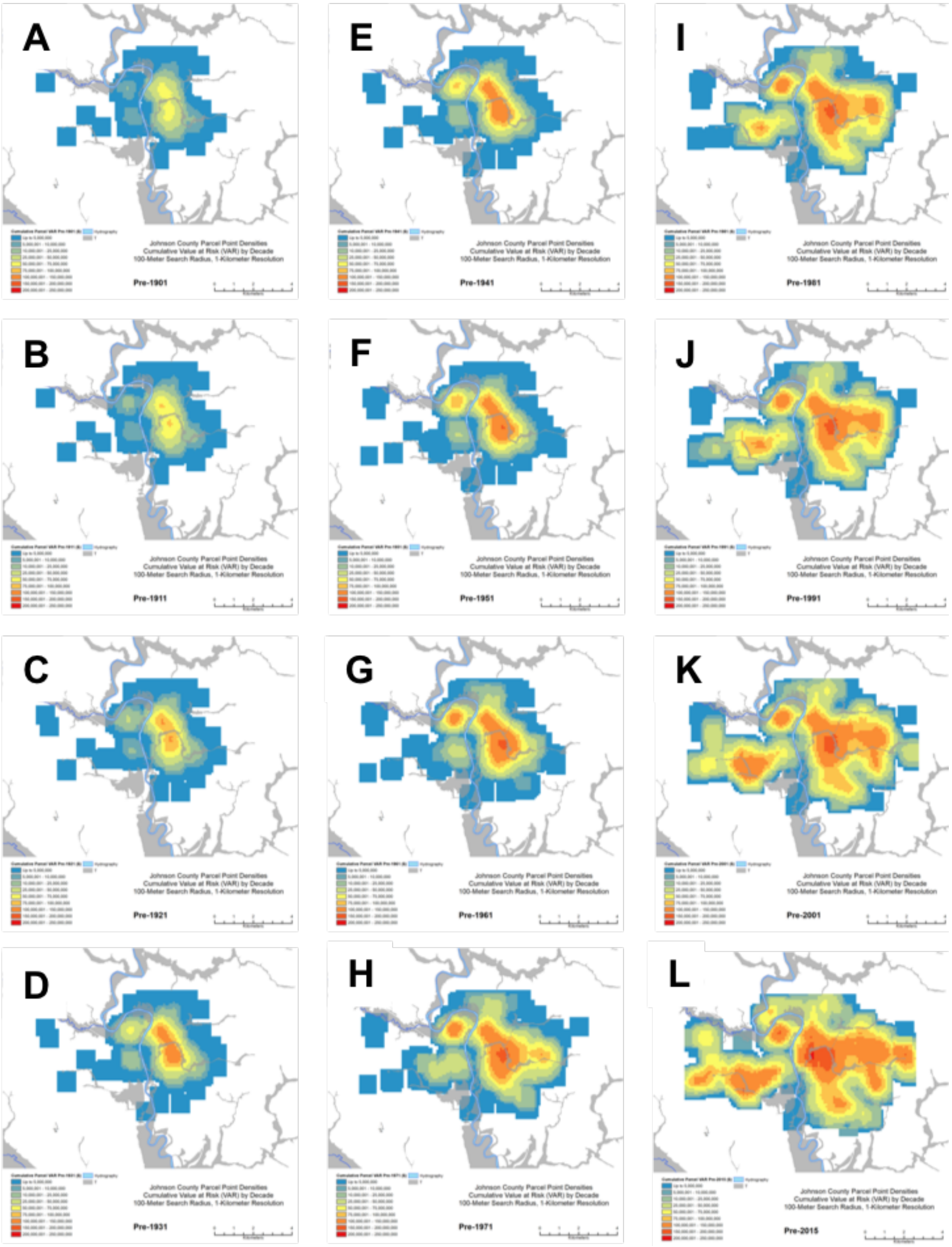


Figure 4.19. Cumulative 2014 residential parcel value densities by year of construction for Johnson County, Iowa: A) Pre-1901, B) Pre-1911, C) Pre-1921, D) Pre-1931, E) Pre-1941, F) Pre-1951, G) Pre-1961, H) Pre-1971, I) Pre-1981, J) Pre-1991, K) Pre-2001, and L) Pre-2015. Blue colors represent cumulative values up to $5 million, with red colors representing cumulative values up to $250 million. Shaded gray areas represent the 100-year SFHA.

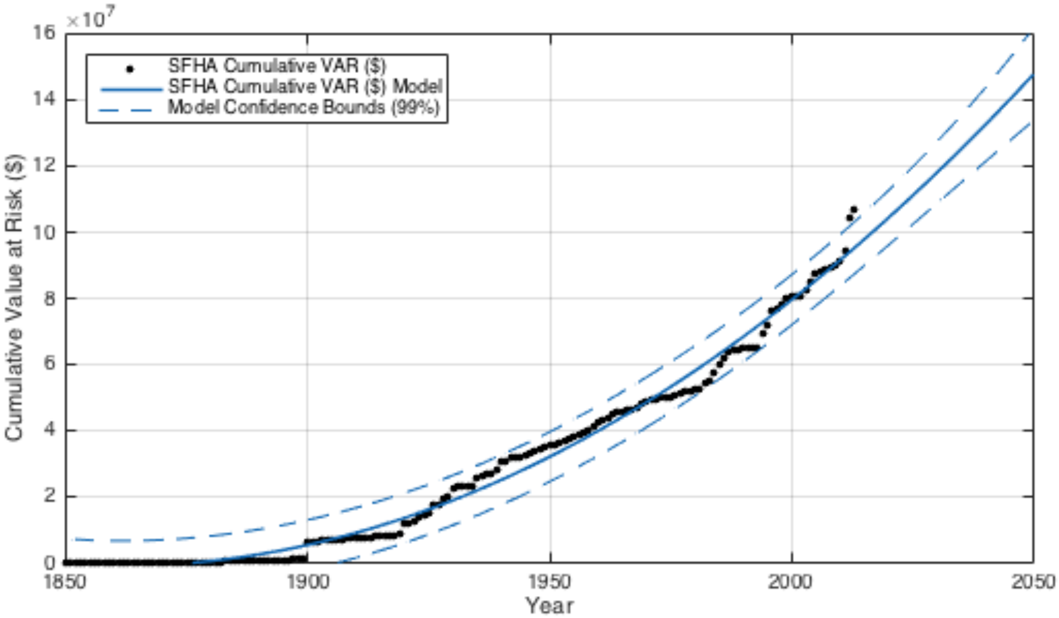


Figure 4.20. Forecasted increase in SFHA residential parcel values for Iowa City, Johnson County, Iowa through 2050. Under this potential growth scenario, residential parcel growth in the 100-year SFHA may increase by $50 million.

4.4 Results for Black Hawk County, Iowa

Results for the Waterloo-Cedar Falls study area represent the first attempt in this dissertation to evaluate residential parcel data in search of a potential levee effect that impacts flood risks in Black Hawk County, Iowa. Levees and levee-protected areas (LPA) are described in Section 3.3.3 and there is a regulatory 100-year SFHA present. Results are presented per the methods set out in Sections 3.5 and 3.6, first by cross-section exposure typology, then temporally for floodplain and non-floodplain parcel values, then by results of the DID counterfactual analyses, then by decadal value densities, and finally by residential parcel value growth forecasts.

4.4.1 Black Hawk County Exposure Typologies

Residential construction for Black Hawk County along the Cedar River reveals an interesting and mostly balanced set of well-adapted (BC, -+), fully built-out (AC, ++), and potentially adversely-developed exposure (AD, +-) types, again with the majority of cross

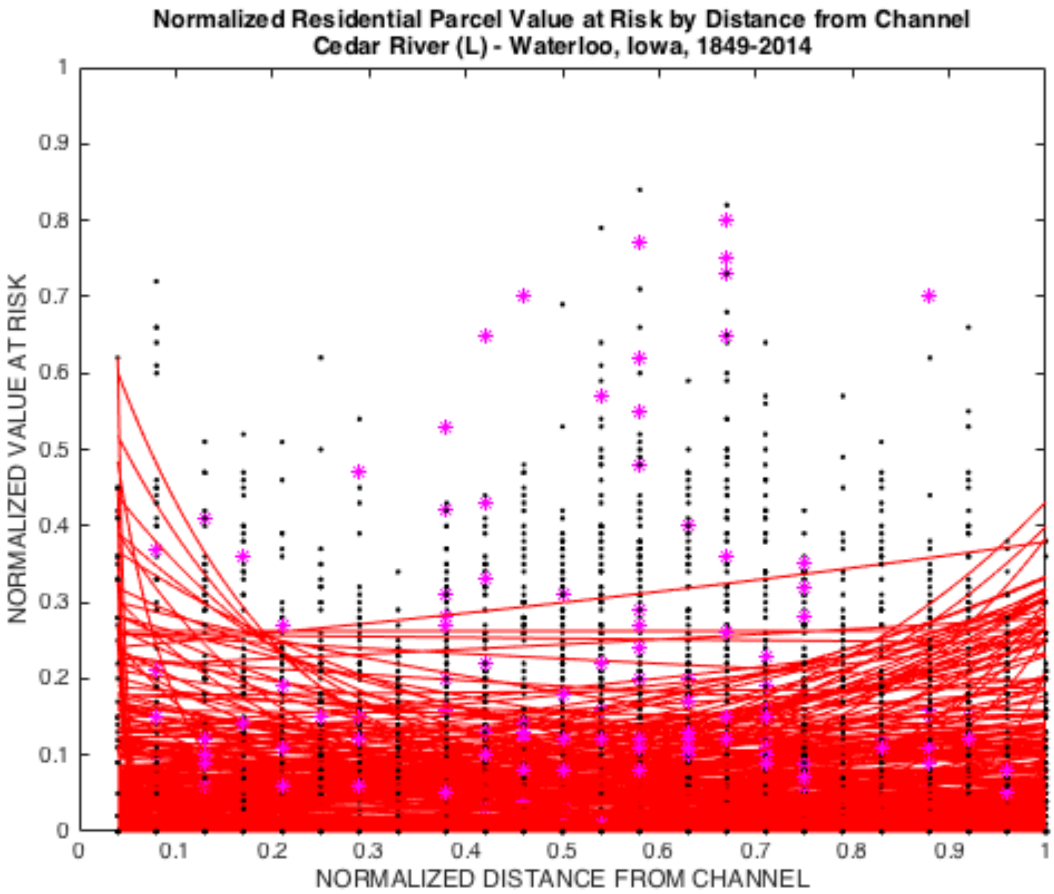


Figure 4.21. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Cedar River channel, left side, yields a set of lower value, fully built-out cross sections (AC, ++), about 11 of 416 cross sections, and about 11 AD (+-) development types (red lines), perhaps representing adverse floodplain development. Well-adapted cross sections (BC, -+) accounted for 26 of 416 cross sections, and the vast majority are undeveloped (BD, --, 376 out of 416). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

sections displaying undeveloped or agricultural values (BD, --). The cross sections follow the flow path of the Cedar River, generally progressing from upstream in the northwest, proceeding through the City of Cedar Falls, where residential development is primarily situated on the right side of the river, to the southeast, proceeding through the City of Waterloo, where residential development occurs on both sides of the river. About 2.6 percent of the cross sections, or 11 of 416, represent relatively lower value, fully built-out cross sections along the left side of the

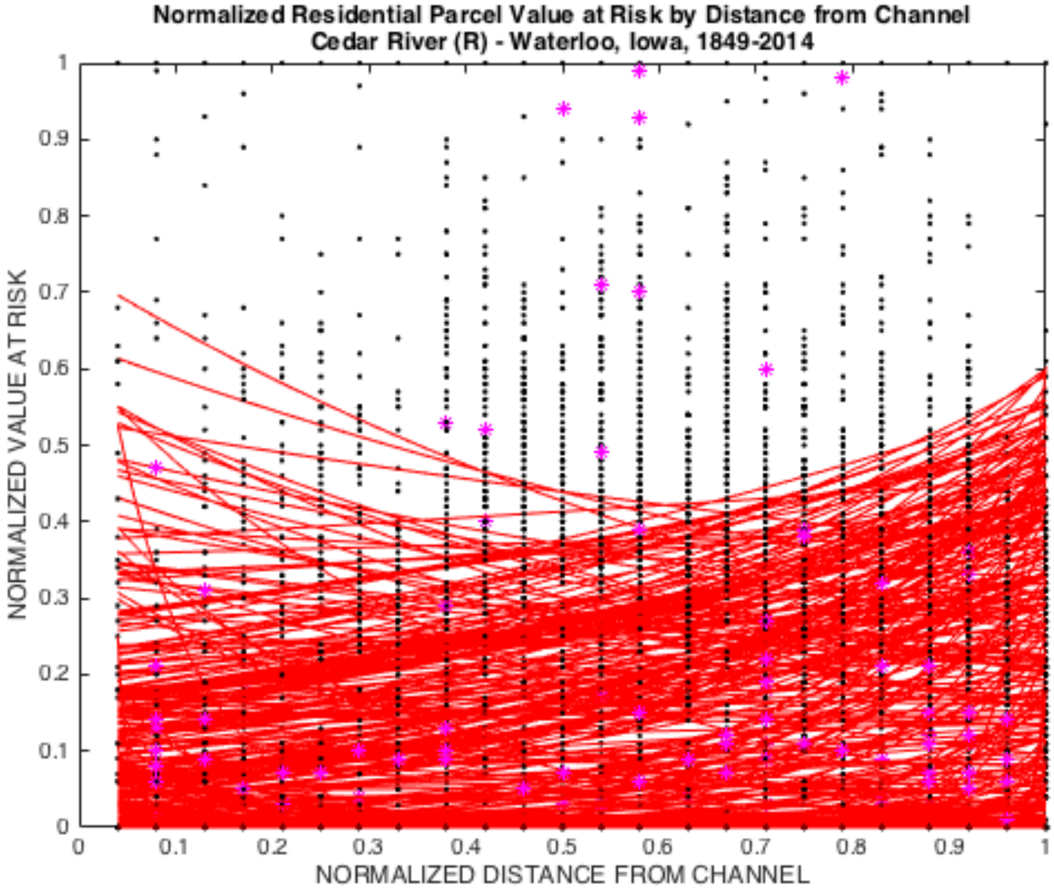


Figure 4.22. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Cedar River channel, right side, yields a substantial set of BC (-+, red lines) development types, about 62 cross sections out of 416, indicating well-adapted development with room for river flooding; however, there are also AD (+-) types, 12 out of 416, perhaps representing adverse floodplain development. Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

Cedar River (Figure 4.21), which likely reflects the downtown areas of Waterloo; however, along the right side of the river (Figure 4.22), the cross sections reveal a substantial set of fully built-out exposure type, 90 of 416, or about 22 percent, likely reflecting the downtown areas of both Cedar Falls and Waterloo, along with the populations and property protected by the right descending bank (RDB) levees along the Cedar River discussed in Section 3.3.3. In addition to those protected areas and parcels, there are 11 potentially adverse (AD, +-) exposure types along the left side of the river, about 3 percent of all cross sections for the county, and 12 AD types for the right, again about 3 percent of the cross sections. There are 26 well-adapted cross sections on the left side, a little more than 6 percent of the total, and 62 well-adapted cross sections on the right, about 15 percent of the total, indicating that residential construction occurred further from the river and likely outside of the floodplain, allowing room for the river to flood; moreover, these cross sections appear to coincide with the un-leveed right bank of the river between Cedar Falls and Waterloo. Undeveloped or low value cross sections (BD, --) represent 376, or 90 percent, of cross sections for the left side and 252, or 61 percent, of cross sections for the right side. Note that the residential parcels are denser than those observed for Iowa City, as the parcel values (black dots) are represented on Figures 4.20 and 4.21 much closer together.

4.4.2 Black Hawk County Residential Parcel Values

The residential parcel data for Black Hawk County reveals interesting historical trends, with the earliest residential construction in the Cedar River floodplains dating to 1850 (Figure 4.23) in the records and ending in 2014. Most buildings appear constructed after 1900, with an exponential growth trend similar to Johnson County and parcels reaching about $100 million in cumulative value by about 1920 and doubling in value about every 15-20 years until the end of the record (Figure 4.24). Residential buildings constructed in the floodplains of Black Hawk County reached nearly 20 percent of all buildings constructed in the county by the 1860s, likely reflecting the historical importance of the river to urban and commercial development of Cedar Falls and Waterloo. This trend of floodplain construction as a proportion of all residential buildings in the county remained generally flat at around 17 percent up to 1950, when the proportion gently declines to about 11 percent from the 1970s to 2014 (Figure 4.23, blue line). Residential construction in what would become USACE levee-protected areas (LPA) lags behind

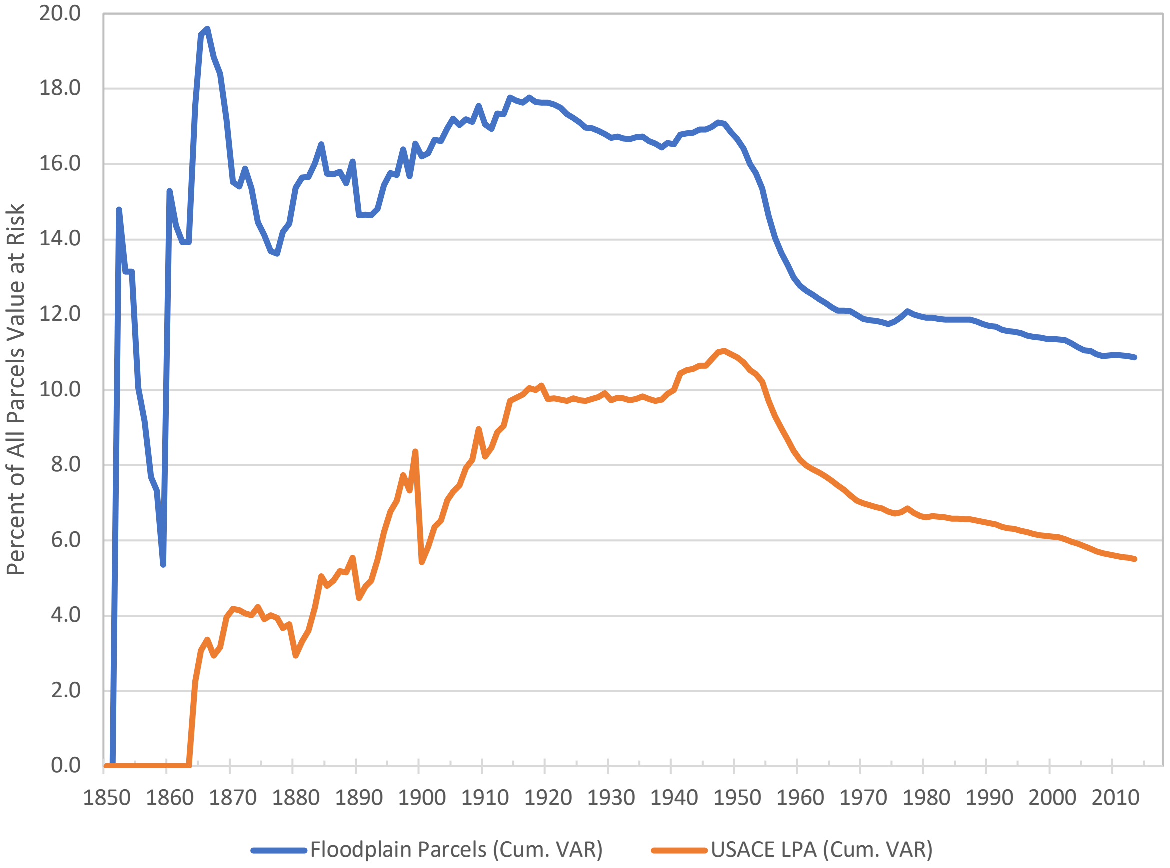


Figure 4.23. Percent of residential parcels in the floodplains and levee-protected areas of Black Hawk County, Iowa, 1850-2014. Residential parcels in floodplains initially comprised nearly 20 percent of all residential parcels for the county, with that proportion remaining steady between 16-18 percent until about 1950. From 1950 to 1970, there was a sharp decline in the proportion of residential parcels constructed in the floodplains and levee-protected areas, perhaps as a result of increasing residential construction in suburban areas on the sprawling fringes of Waterloo and Cedar Falls, further from the Cedar River. This proportionate decline may also represent full build-out of the floodplains.

overall floodplain development, with about 3 percent of residential parcels in LPA first appearing in the mid 1860s and slowly increasing as a proportion of all residential buildings to a generally steady 10 percent from 1920 through the 1950s, with a peak of about 11 percent in 1950 before declining to around 6 percent from the 1980s through 2014, perhaps indicating a development effect obviating future levee construction (Figure 4.23, orange line). Notably, the 6 percent in LPA corresponds very well with the exposure typology indicating potentially adverse development types (AD, +-) as about 3 percent for the left side of the Cedar River and about 3

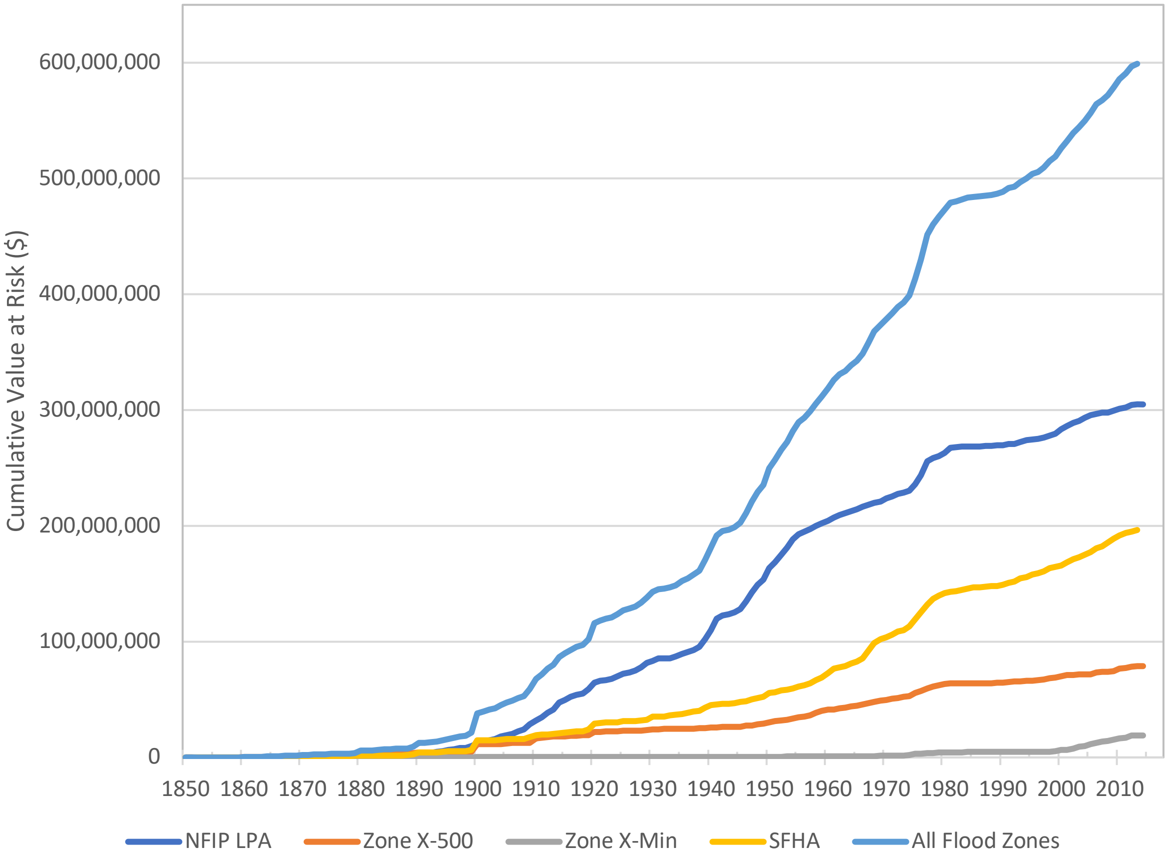


Figure 4.24. Cumulative 2014 value at risk by year of construction for Black Hawk County, Iowa flood zones—notably, with levee-protected areas recognized by the NFIP having the most value at risk among flood zones. Whereas the 100-year SFHA is subject to mandatory purchase requirements for flood insurance, the residential parcels in the NFIP levee-protected area are not, and, therefore, may be subject to increased vulnerability to damage and losses should flooding occur.

percent for the right side. It is also interesting to note that Figure 4.24 reflects a brief surge in cumulative residential parcel value at risk in all flood zones (light blue line), based on 2014 assessed values by construction year, and, in particular, in areas protected by levees (dark blue line), where an increase of about $40 million occurs between 1972 and 1982—the decade in which levee construction began and finished. After 1982, cumulative 2014 value at risk growth in the LPA generally flattens, adding only about $1 million per year through the end of record, whereas growth in all flood zones continues to follow the exponential growth trend, adding about $100 million in value from 1984 to 2004. As of 2014, the cumulative value at risk in the LPA

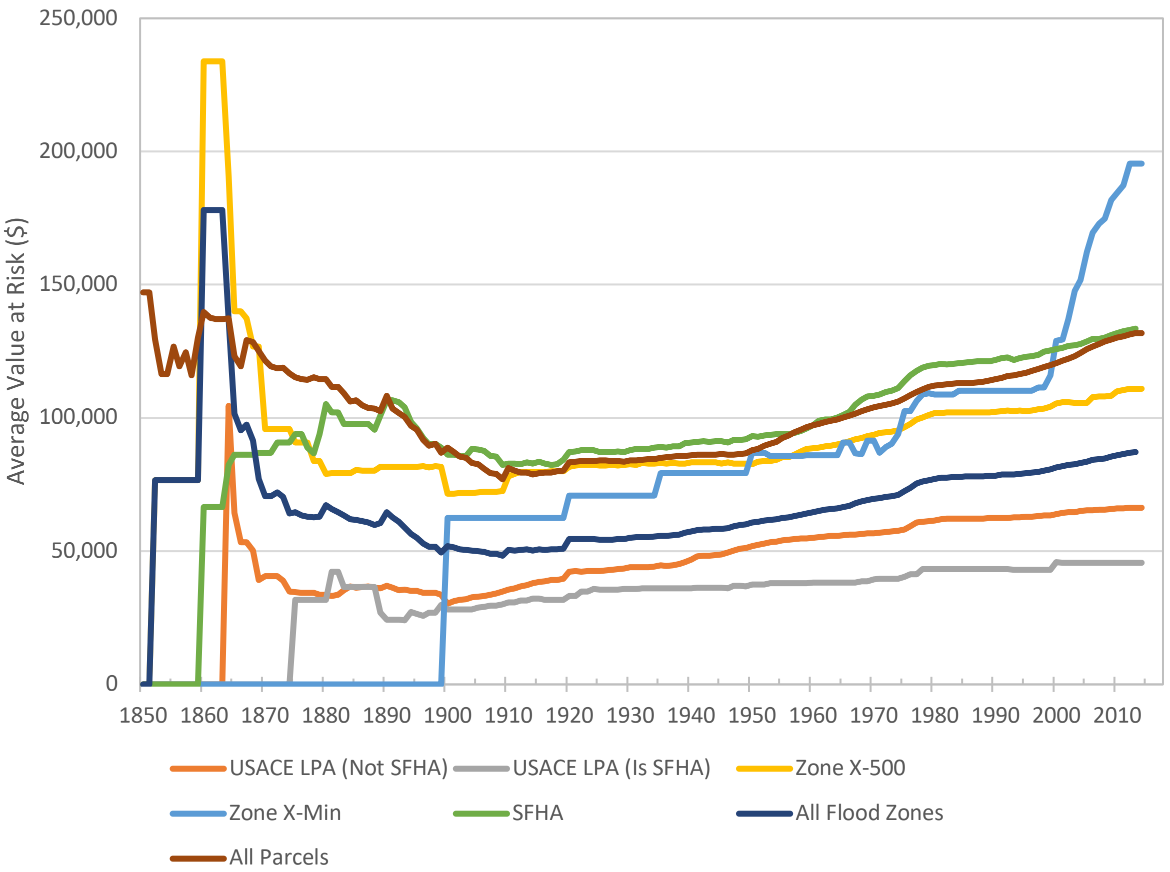


Figure 4.25. Average 2014 residential parcel value at risk by year of construction in floodplains and for all parcels in Black Hawk County, Iowa. The average parcel values for the entire county are roughly the same as residential parcels located in the 100-year SFHA; however, parcels located in USACE levee-protected areas are about half of the value of SFHA parcels in areas where insurance is required, and parcels are about one-third of the value of all parcels and SFHA parcels where no insurance is required and there is levee protection. Notably, areas of minimal flood risk are up to 50 percent greater in value on average compared to either all parcels or SFHA parcels for the county.

represents about one-half of parcel values in all flood zones, or about $300 million, with non-levee protected 100-year SFHA representing about one-third of cumulative values at about $200 million. Interestingly, there are two LPA designations for Black Hawk County—one area designed as protected by USACE determination and another by NFIP determination—and the areas are slightly different in total acreage; however, the USACE LPA contains two floodplain types, one designated as 100-year floodplain with insurance requirements and another without insurance types (Figure 4.25, orange and gray lines). The residential parcels in USACE LPA with an insurance requirement are about $45,000 in average value whereas the parcels without the insurance requirement are about $66,000 in average value; homes located in the 100-year SFHA with an insurance requirement but no levee protection are about $132,000 in value on average, based on 2014 assessment, nearly double that of those situated in LPA and roughly the same as the average for all parcels in the county. Parcels located in areas of minimal flood risk are the most valuable on average at just under $200,000 (Figure 4.25, light blue line).

For Black Hawk County, Iowa, there is a significant spread in average 2014 home values for 100-year SFHA and USACE LPA compared to all parcel values (Figure 4.26). In the early period of record, average home values in what would become both the SFHA and USACE LPA were discounted by about 40 percent compared to all parcels based on 2014 assessed values; however, homes in what would become the SFHA became commensurate in value compared to all parcels by about 1900, increasing to about a 5 percent premium over all parcels built by 1910 and maintaining the premium through the 1990s, except for a brief period around 1960 when average values were near equivalent to all parcel average. Since build year 1990, the SFHA premium steadily declined to about a 1 percent premium over the average value of all parcels by 2014. This SFHA home value premium appears contradictory to research indicating that the NFIP depresses home values in SFHA, particularly as Black Hawk's SFHA home values in 2014 are commensurate with the average of all parcels or average about a 5 percent premium through the period of record, with no clear signal emerging from construction years after the establishment of the NFIP. Also, very intriguing is the strong discount in average 2014 home values for the USACE LPA compared to all parcels: from the construction years of the 1870s to about 1905, USACE LPA home values were discounted by as much as 70 percent, with the discount decreasing to about 40 percent by 1950, and then steadily increasing to about 50 percent from 1950 to 2014. The strong discount in USACE LPA home values likely reflects the benefit of flood control or effect of flood hazard capitalized into home values, or perhaps flood risk is more significant in the USACE LPA than other areas, including the SFHA. Nonetheless, the significant discount in USACE LPA may also reflect other factors driving down the average value of homes in 2014.

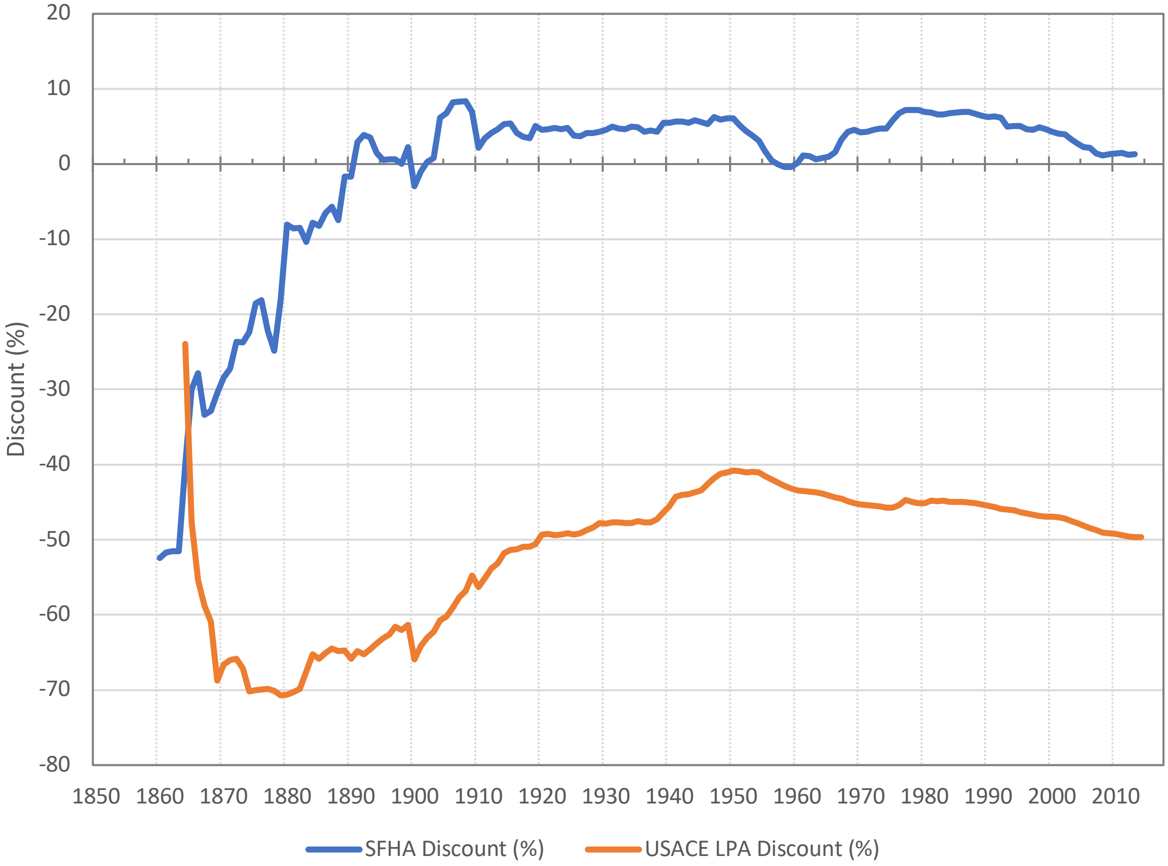


Figure 4.26. Estimated discount in 2014 USACE LPA home values by year of construction and estimated premium in average values for SFHA homes compared to all parcels in Black Hawk County, Iowa, 1850-2014.

4.4.3 Counterfactual Evaluation for Black Hawk County

Difference-in-difference estimation was conducted for three cases in Black Hawk County based on years of construction and 2014 assessed parcel values. Similar to the Iowa City analysis, the first case evaluated average residential parcel value prior to and after the 1973 mandatory flood insurance purchase requirement was implemented through the NFIP for homes both inside and outside of the 100-year SFHA where insurance is required (Figure 4.27). Prior to 1973, homes what would become the 100-year SFHA were slightly more valuable on average, $109,719, than homes that would remain outside of the SFHA, $104,758. Homes constructed after 1973 were valued at $213,092 outside of the SFHA and at $182,540 inside the SFHA in 2014. The control variable for average 2014 residential value is the difference in values for homes outside the SFHA in a pre-1973 condition subtracted from the post-1973 condition, or $108,333 in difference after 1973. For homes in the SFHA treatment pre and post conditions, the difference is only $72,821, based on 2014 valuation, and the difference between the SFHA versus non-SFHA homes is control subtracted from treatment, or a net difference of homes in the

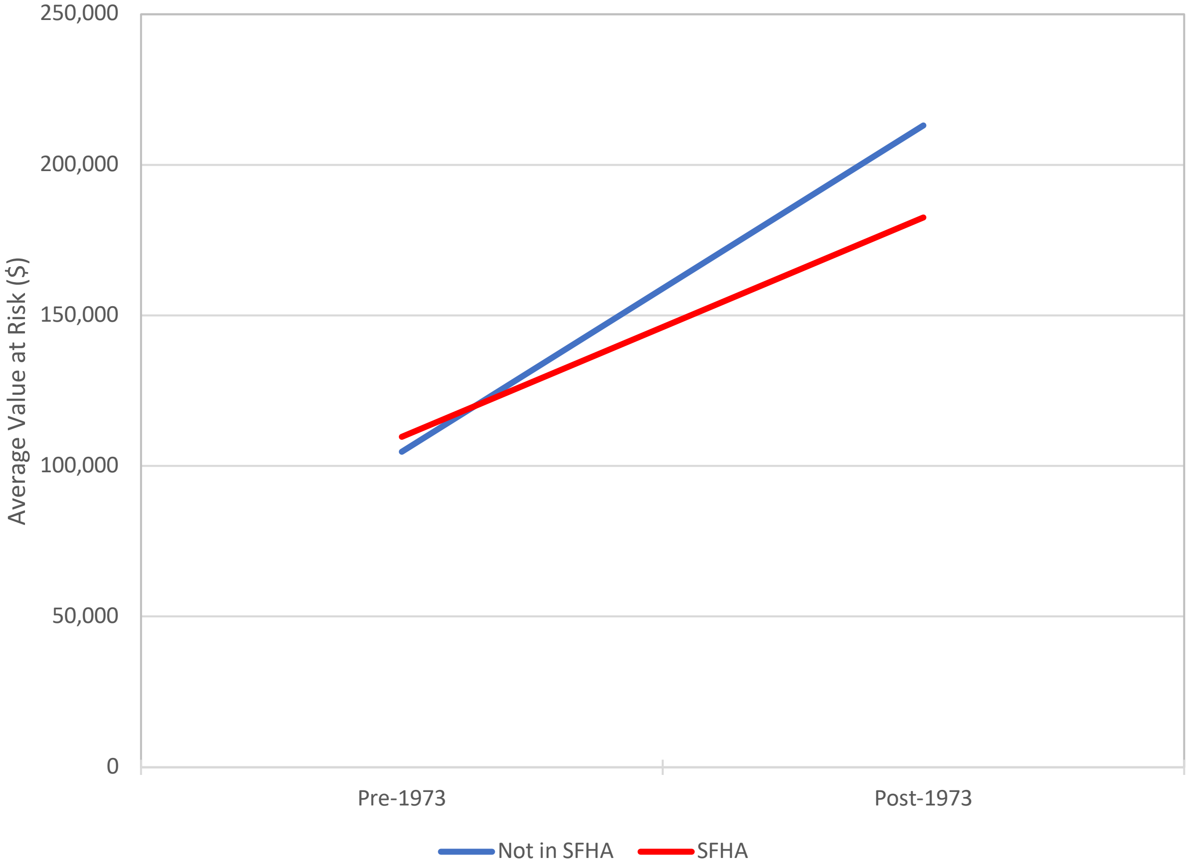


Figure 4.27. DID analysis for 2014 Black Hawk County residential parcel values prior to and after the 1973 mandatory purchase requirement for flood insurance implementation.

post-1973 SFHA being about $35,512 less in value than those outside the SFHA after 1973. Similar to relationships suggested about Iowa City, this net effect may reflect either a value-depressing effect of flood insurance or simply the riskiness of building homes in the Cedar River floodplain in 2014. Generally, homes inside and outside the SFHA gained in value after 1973, but homes outside of the SFHA increased a rate significantly greater than those in the SFHA.

The second case evaluated average residential parcel values for the same time period, both before and after 1973, but for parcels situated both inside and outside of the USACE LPA, which was considered slightly larger in area than the NFIP LPA (Figure 4.28). Similar to the first case for Black Hawk County, homes inside and outside of the USACE LPA increased in value after 1973. Prior to 1973, homes in the USACE LPA were about $57,193 on average, compared

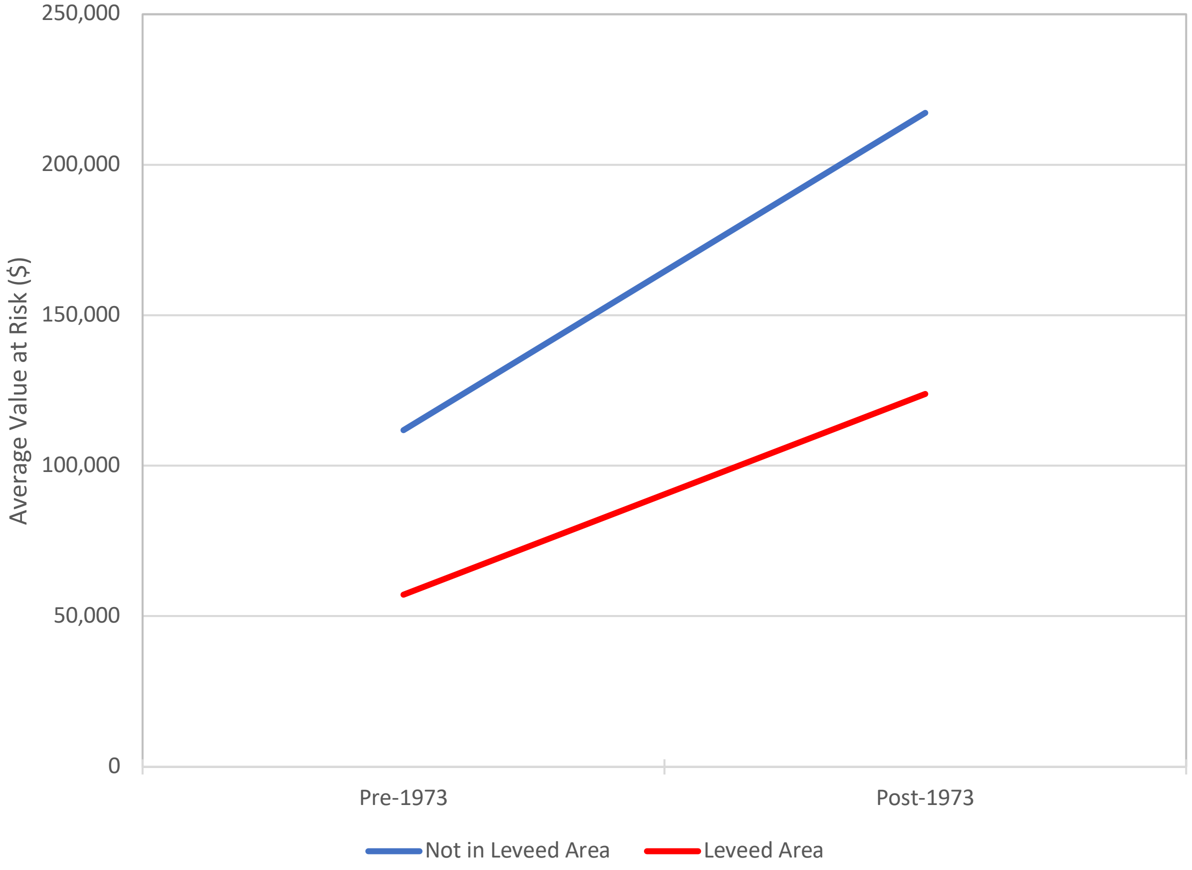


Figure 4.28. DID analysis for 2014 Black Hawk County residential parcel values in levee-protected and non-levee-protected areas prior to and after the 1973 MPR.

to those outside the USACE LPA at $111,842 on average. After 1973, homes in the USACE LPA were valued at $123,872 on average in 2014 versus $217,249 on average for those outside the USACE LPA. The difference in pre- and post-1973 conditions for non-LPA homes is $105,407 and $66,679 for homes in the LPA, meaning that homes in the LPA averaged less in value by $38,728 than homes outside the LPA in the 2014 tax assessed values. However, since these homes largely fall into the NFIP LPA, there is no insurance requirement; therefore, the average lower home value for those in LPA compared to those not in the LPA is consistent with flood hazard depressing value instead of insurance, an important contextual distinction because homes in the NFIP LPA, similar in area to the USACE LPA, are not required to purchase flood insurance, suggesting that the NFIP does not depress home values in this area. Moreover, homes described in the first case that are situated in the SFHA are required to purchase insurance; thus, SFHA and LPA homes may be lower in value due to flood risk, yet homes in the SFHA should have decreased vulnerabilities, generally, as insurance supports potential flood losses and there is a lesser flood hazard from levee failure that increases flow velocities and damage potential.

The third case evaluated those residential parcel values for homes constructed between 1970-1980, just prior to and during levee construction, and then for homes constructed between 1980-1983, comparing the before and after average values for homes inside and outside of the USACE LPA (Figure 4.29). This case directly evaluates the effect of levee construction on home values for Black Hawk County. For the homes constructed between 1970 and 1980, those that are outside of what would become USACE LPA were valued at $151,723 on average, and those that would become protected in the USACE LPA were valued at $81,971 on average. For the homes constructed between 1980 to 1983, homes outside of the USACE LPA were valued in 2014 at $162,224 on average, compared to those in the USACE LPA valued at $128,235 on average. As such, all average home values increased after levee construction, based on 2014 assessment; however, the difference between values for before and after conditions for those homes outside the USACE LPA reveal that the average increase in value was only about $10,501 compared to an average increase in value of $46,264 for homes in the USACE LPA, yielding a difference of control subtracted from treatment for a net effect of homes in the USACE LPA gaining $35,763 more in value than those outside the LPA. This is an important finding because it reveals that, while all home values increased, the values for homes in LPA increased much more than those outside of the LPA, based on 2014 assessment, despite the flood risk which appears to generally depress 2014 home values in the floodplains of the Cedar River, as the first two cases revealed. Additionally, the increased value at risk for homes in the USACE LPA is

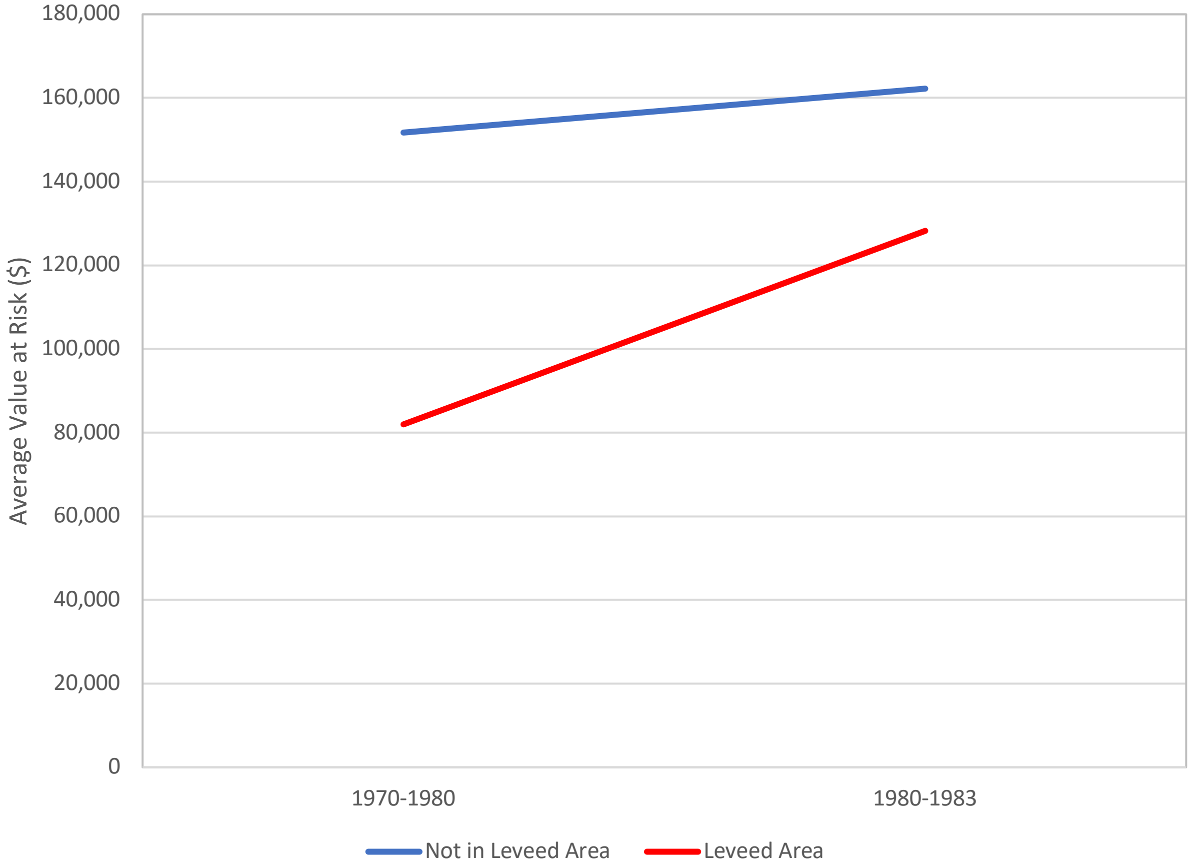


Figure 4.29. DID analysis for 2014 Black Hawk County residential parcels in levee-protected and non-levee-protected areas 1970-1980 and from 1980-1983.

also connected to the removal of the mandatory purchase requirement for flood insurance, suggesting that the homes in the USACE LPA gained value while increasing financial and physical vulnerabilities as a result of floodplain regulations removed. These findings appear to reveal a plausible case of increasing flooding risk in the USACE LPA of the Black Hawk County floodplains.

4.4.4 Parcel Value Densities and 2050 Scenarios for Black Hawk County

Cumulative residential parcel densities are reflected in Figure 4.30 on a decadal basis for period of record of 1850-2014 with all parcel values for pre-1901 reflected in Panel A. The Cedar River runs from northwest to southeast in these maps, and the cumulative parcel value densities reflect the historical development of Cedar Falls to the northwest and on the western side of the river with Waterloo just to the southeast on both sides of the river. Black Hawk Creek provides a physical water boundary between the two cities, running from the southwest corner of the maps to a confluence with the Cedar River in the center of the maps. The densest and highest residential parcel values can be seen emerging alongside the Cedar River in Panels A-E, 1850-1941, with increasingly higher values in these historical city centers gradually spreading southwestward in Panels F-I, 1941-1981, with values increasing further from the city centers in Panels J-K, 1981-2014, as suburban expansion and occupation of higher elevation occurs. Figures 4.31, 4.32, 4.33, and 4.34 offer parcel value growth scenarios, fitting regression models to historical observations and extrapolating to the year 2050 with 99 percent confidence bounding, each possibly contributing to increasing flood risk in the future. Figure 4.31 reflects a growth scenario for cumulative parcel value at risk in the NFIP LPA, suggesting that parcel values may increase from about $300 million in 2014 to near $400 million in 2050; however, the polynomial regression model seems to reflect unstable or unpredictable behavior past 2040, thus

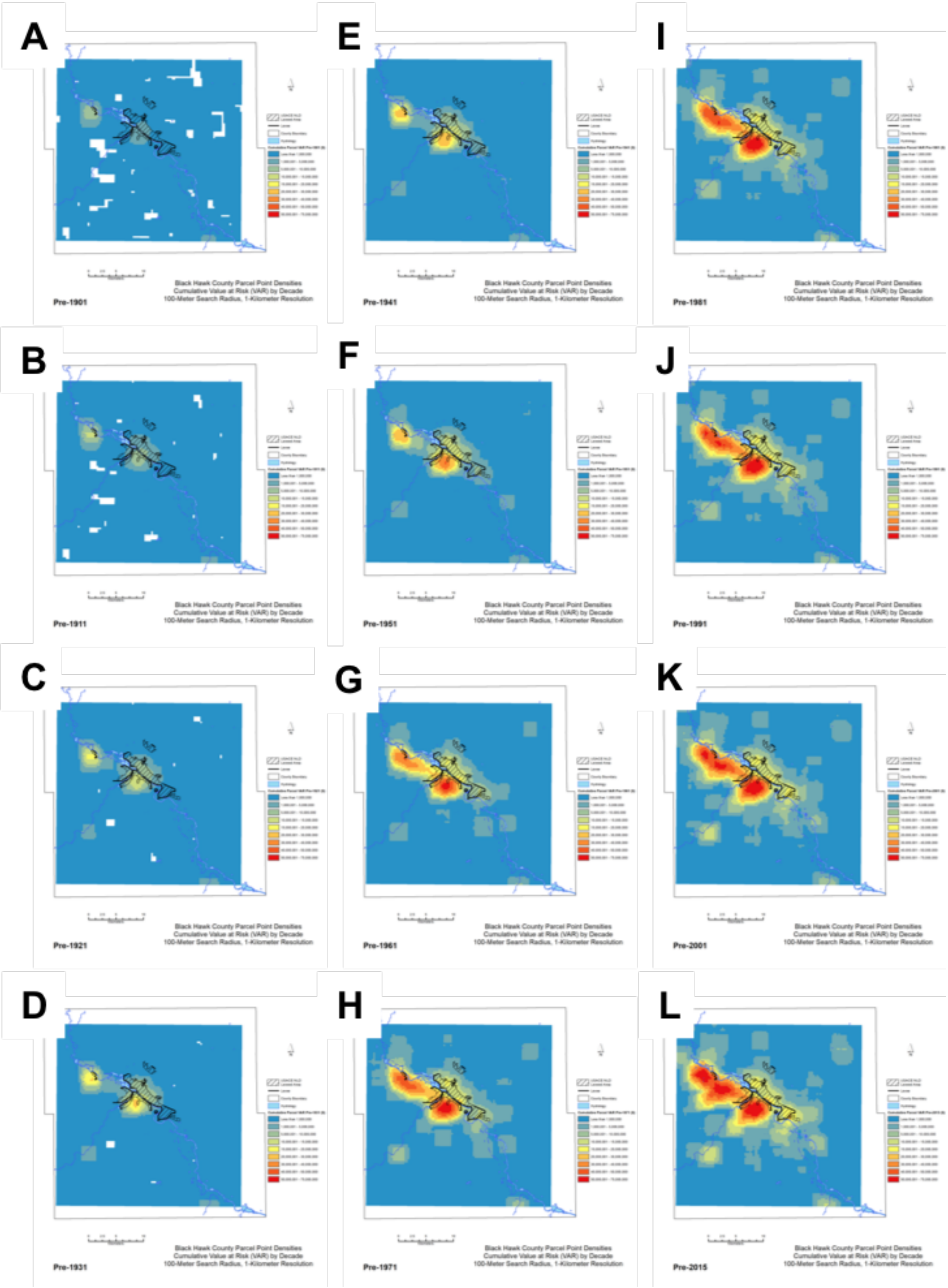


Figure 4.30. 2014 residential parcel values densified to 1 square kilometer resolution reveal that residential construction initially started at the urban core of Waterloo and Cedar Falls, Iowa, and expanded to both high-ground and suburban areas over the period of 1901-2014.

the confidence bounds suggest a wide range of value scenarios ranging from no growth, 2050 values near the same as 2014, and possibly reaching as high as $500 million by 2050. Figure 4.32 reflects a linear model for residential parcel value at risk in the 100-year SFHA, reflecting about $200 million in residential value in 2014 with future growth possibly ranging from about $225-300 million by 2050. Figure 4.33 reflects residential parcel growth scenarios for all floodplain value at risk, with the extrapolated best fit model suggesting an addition of about $150 million to the existing $600 million by 2050, with a range of $600-900 million for a slow-to-no growth outcome compared with a faster, higher growth upper bound. Finally, Figure 4.34 reflects a growth scenario for cumulative value of all residential parcels in Black Hawk County, generally indicating that values should increase similar to historical growth rates for the last 100 years, suggesting that cumulative parcel values may increase from about $5.5 billion in 2014 and range from $7-8 billion by 2050. Taken together, cumulative residential value at risk in LPA in 2014 represents about 5.5 percent of all home values in Black Hawk County, and, should LPA values follow a slow-growth scenario, that proportion of LPA value at risk may decrease to 3.8 to 4.3 percent of cumulative values in 2050; however, should LPA values increase to $600-$900 million in a higher growth scenario, LPA values at risk may range from 8.6 to near 11.3 percent of cumulative value at risk for all residential parcels.

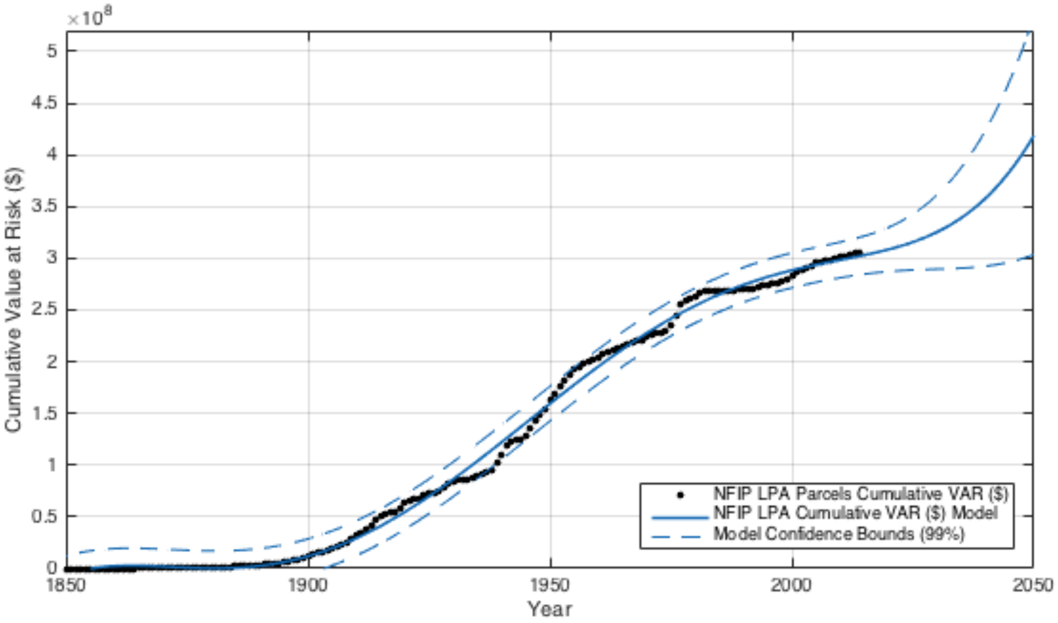


Figure 4.31. Forecasted increase in cumulative VAR in Black Hawk County levee-protected areas through 2050.

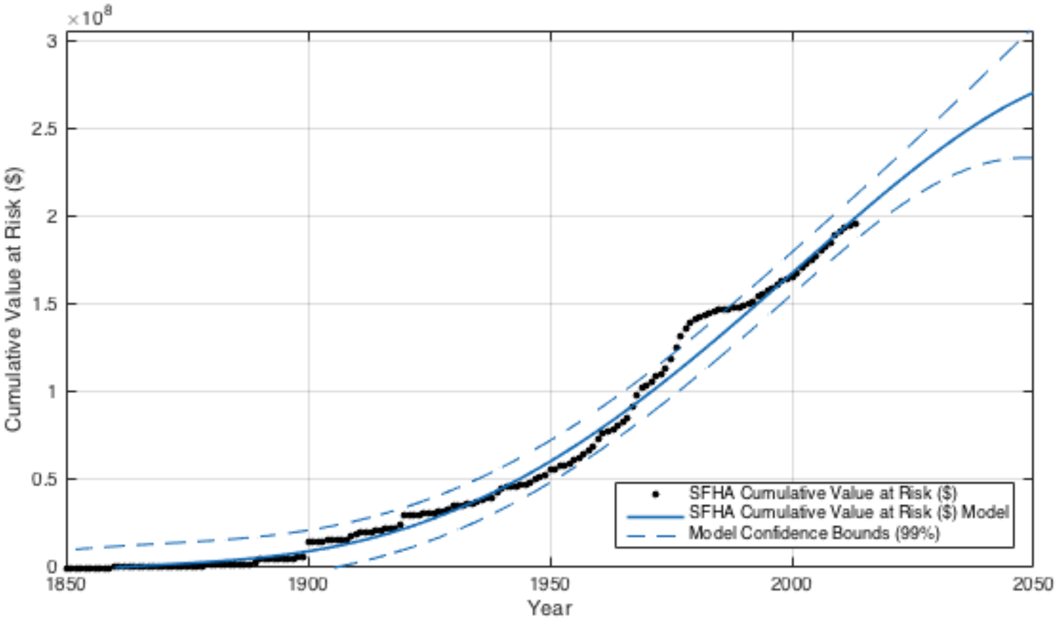


Figure 4.32. Forecasted increase in cumulative VAR in Black Hawk County 100-year special flood hazard areas through 2050.

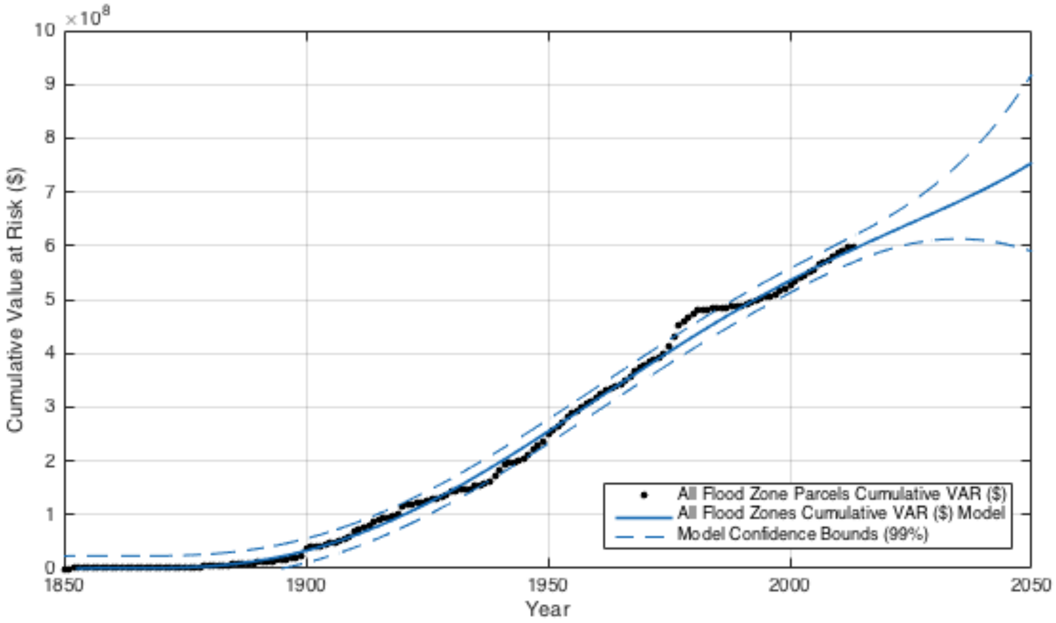


Figure 4.33. Forecasted increase in cumulative VAR for all Black Hawk County floodplains through 2050.

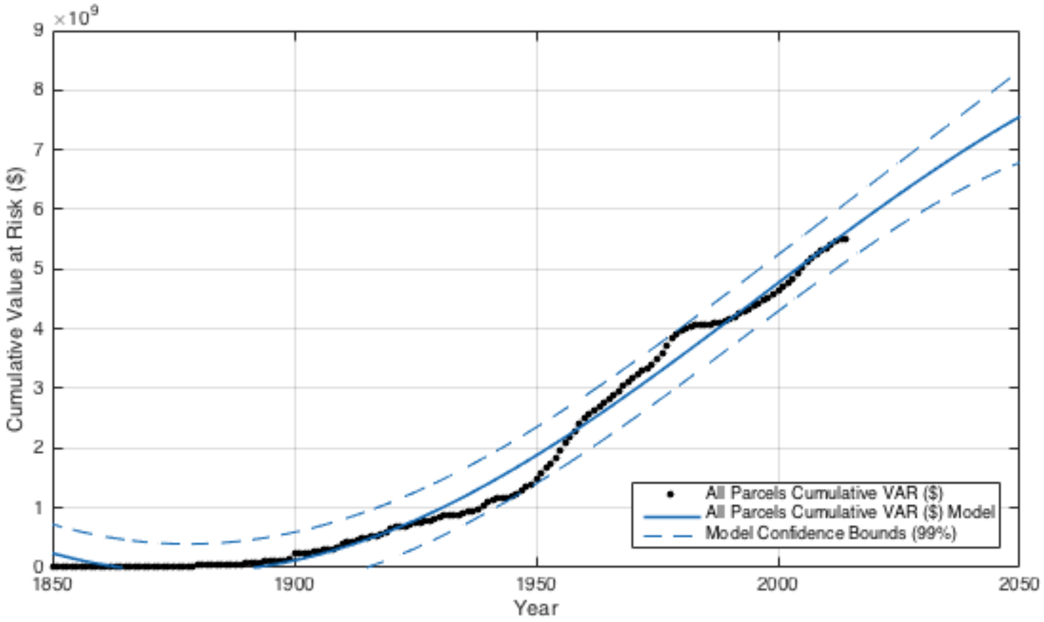


Figure 4.34. Forecasted increase in all Black Hawk County parcel values through 2050.

4.5 Results for Des Moines County, Iowa

Results for the Burlington study area represent a smaller population center with more agricultural production and a potentially different case of levee effect as possibly related to *levee wars*, wherein levee heights are increasing flood risk as described in Section 3.3.4. As the intent and purpose of this dissertation is to evaluate changes in flood risk as a function of residential exposure, levee heights are not evaluated. Evaluation of levee effect is revealed by the methods described in Sections 3.5 and 3.6, and results are presented first by cross-section exposure typology, then temporally for floodplain and non-floodplain parcel values, then by results of the DID counterfactual analyses, then by decadal value densities, and finally by residential parcel value growth forecasts.

4.5.1 Des Moines County Exposure Typologies

As the mostly agricultural Burlington is located in the southern end of Des Moines County and is on the right side of the Mississippi River flow path, cross sections reveal a large set of low to no value residential exposure types (BD, --), comprising nearly 67 percent (158) of the almost 24-kilometer section of river length evaluated. The next most frequent set of cross sections demonstrated well-adapted residential exposure types (BC, -+) with 47 of 237 cross sections, or almost 20 percent. About 11 percent (47 of 237) cross sections revealed a fully built-out residential exposure type, likely representing the downtown and neighboring residential areas of Burlington, which, notably, is situated on mostly higher elevation lands outside of the Mississippi River floodplain—though these cross sections, displayed in the full set represented in Figure 4.35, received an “A” or positive sign, some of the residential parcels likely fall outside of the relatively narrow floodplain at Burlington; however, in southern areas of the city, residential development does exist in the 100-year SFHA, validating the positive score. Only 7 of 237 cross sections, or about 3 percent, were found to have a possibly adverse exposure type for Burlington, likely representing the southern portions of the city, and an interesting finding in the context of the long history of levee presence on the Mississippi River.

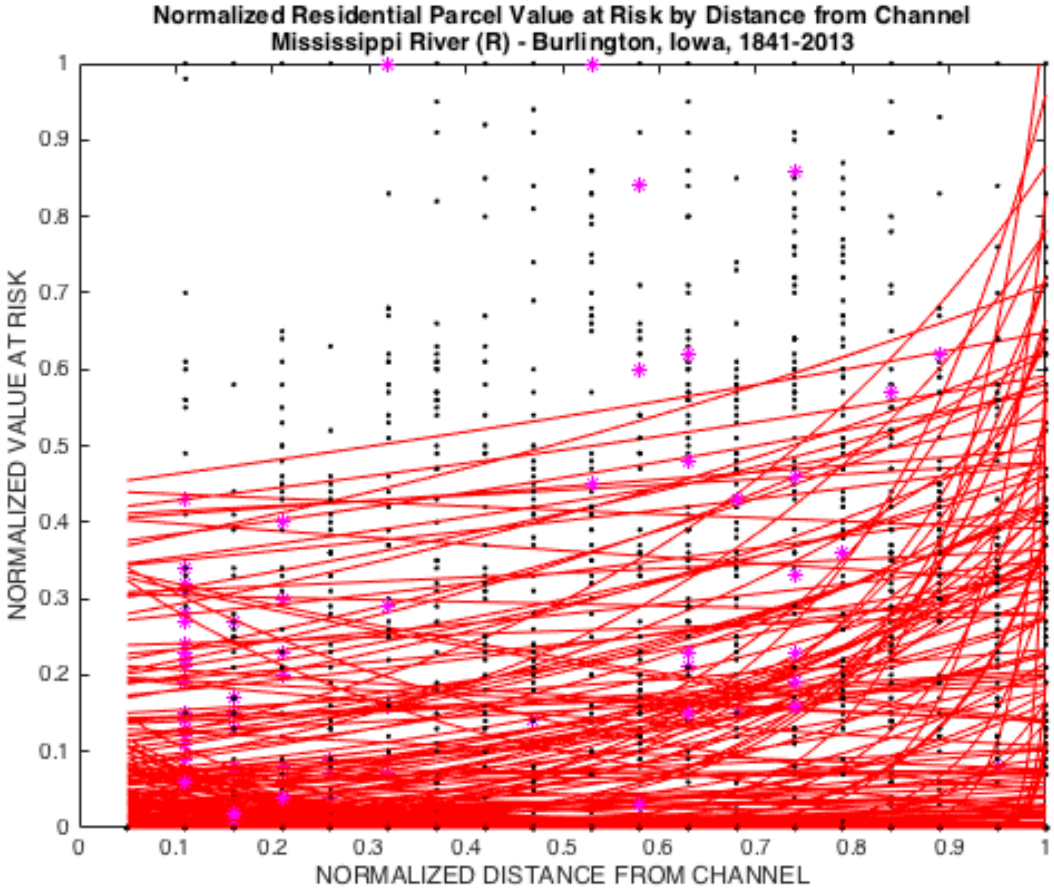


Figure 4.35. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Mississippi River channel, right side, yields mostly well-adapted development types (BC, -+, red lines, 47 out of 237 cross sections) with some low-to-medium fully built-out cross sections (AC, ++, 25 out of 237) and very few adverse development types (AD, +-, 7 out of 237), likely reflecting the rural nature of Burlington. Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

4.5.2 Des Moines County Residential Parcel Values

The residential parcel data for Des Moines County reveals the largely agricultural nature of home construction in and around the Burlington area as described in Section 3.3.4. The NFIP

DFIRM data for Des Moines County designates the entire county as having a risk of flooding, with most parcels in the county's areas that are non-adjacent to the Mississippi River, or some of the smaller streams, falling in a "Zone X – Minimal Flood Risk" category. Since the 1860s, the cumulative 2014 value at risk for residential parcels in all flood zones of Des Moines County, except for those designated as minimal risk, exhibited a near linear trend in growth over construction years, reaching about 2.5 percent of all home construction and values for the county by 2014 (Figure 4.36). However, even though levee construction was originally completed by

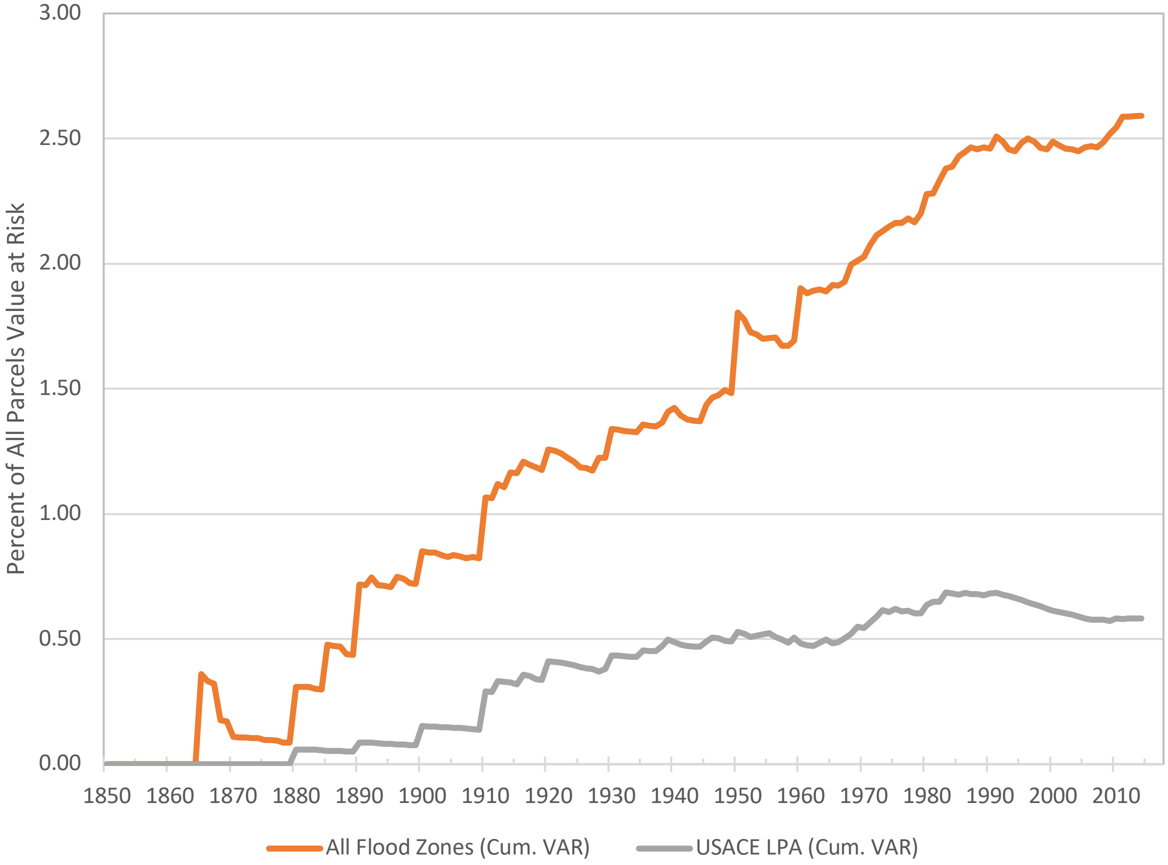


Figure 4.36. Percent of all residential parcels in floodplains and the USACE levee-protected areas of Des Moines County, Iowa by year of construction. Notably, residential growth in all floodplains has proceeded steadily since the late 1800s; however, as a proportion of overall growth in Des Moines County, residential floodplain growth remains less than 3%. Residential growth in the USACE levee-protected area has been consistent for decades, representing only about 0.5-0.6% of all residential parcels in the county.

1908, and although the proportion of cumulative 2014 home value in the USACE LPA initially doubled from about 0.14 percent in 1909 to about 0.3 percent in 1912, slowly rising to about 0.5 of cumulative value by the late 1930s, the share of homes in the USACE LPA generally stayed flat until about 1970, followed by a slow risk to about 0.7 percent during the mid 1980s. The proportion of cumulative 2014 home values in the USACE LPA, notably, decreased from about 0.7 percent to 0.58 percent during the build years of 1993 to 2014, perhaps relating to the major flooding of 1993. The areas protected by levees also appear to be almost spatially the same between USACE and NFIP protected-area polygons, as demonstrated by the similarity in

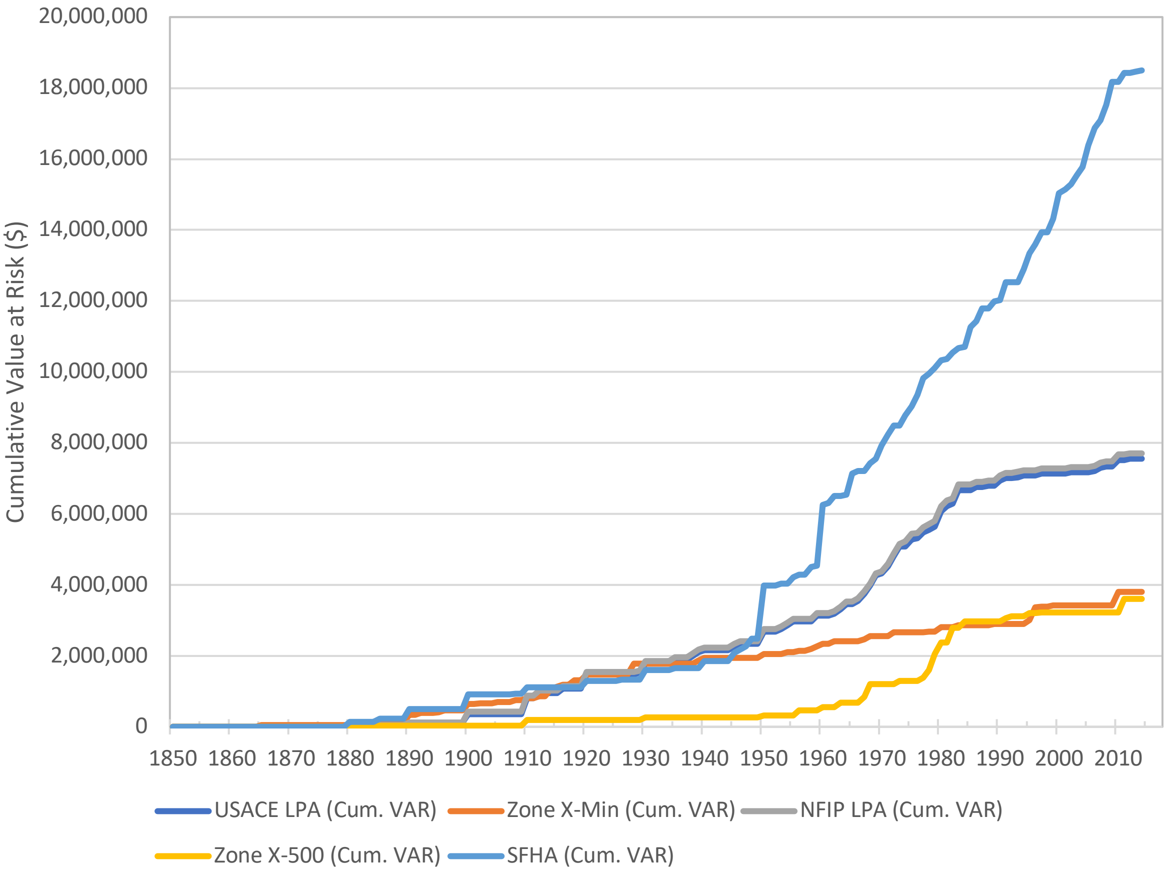


Figure 4.37. Cumulative 2014 residential parcel value at risk by year of construction for Des Moines County, Iowa flood zones and levee-protected areas. Growth in the 100-year SFHA has increased by a factor of about 4 since about 1950, while growth in the 500-year and minimal risk flood zones has remained steady and less than $4 million. Growth in the NFIP and USACE levee-protected areas has remained steady and slow since about 1980.

cumulative value at risk shown in Figure 4.37 (USACE LPA VAR in dark blue; NFIP LPA VAR in gray, nearly overlapping). With levee improvements completed in 1967, there may be a slight increase in the cumulative 2014 value at risk by build year in the USACE LPA that is greater than the annual increase prior to the 1960s, but any change in trend is likely not significant. However, by about 1980 the increase in cumulative 2014 value at risk for the USACE LPA becomes almost flat, remaining at about $7 million through the end of records in 2014. Around 1950, however, there appears to be substantial change in trend for homes constructed in the 100-year SFHA, with cumulative 2014 value at risk exhibiting an inflexion point where increases become more exponential, with cumulative 2014 values increasing from about $2 million in 1950 to almost $19 million by 2014—a change from an accumulating rate of about $20,000 per year from 1850-1950 to more than $265,000 per year from 1950-2014 (Figure 4.37, light blue line). Comparatively, cumulative 2014 home values for the minimal risk areas of Des Moines County began increasing in the 1860s, based on construction year, with an accumulative rate of about $24,390 per year over the set of parcel records based on 2014 assessment. Thus, it would appear that residential growth in the floodplains around the downtown areas of Burlington experienced a significant change around 1950. Figure 4.38 reveals that average 2014 home values in the 100-year SFHA were higher than other areas in the late 1880s and early 1900s (light blue line), and homes in the 500-year floodplain became more valuable than any other locations by the 1910s (yellow line), perhaps reflecting that agricultural homes moved into the floodplain fringe areas newly protected by levees. Homes situated in the USACE LPA and 100-year SFHA converged in the 2000s, with average 2014 home values around $65,000, or about $25,000 less than the average for all homes in the county.

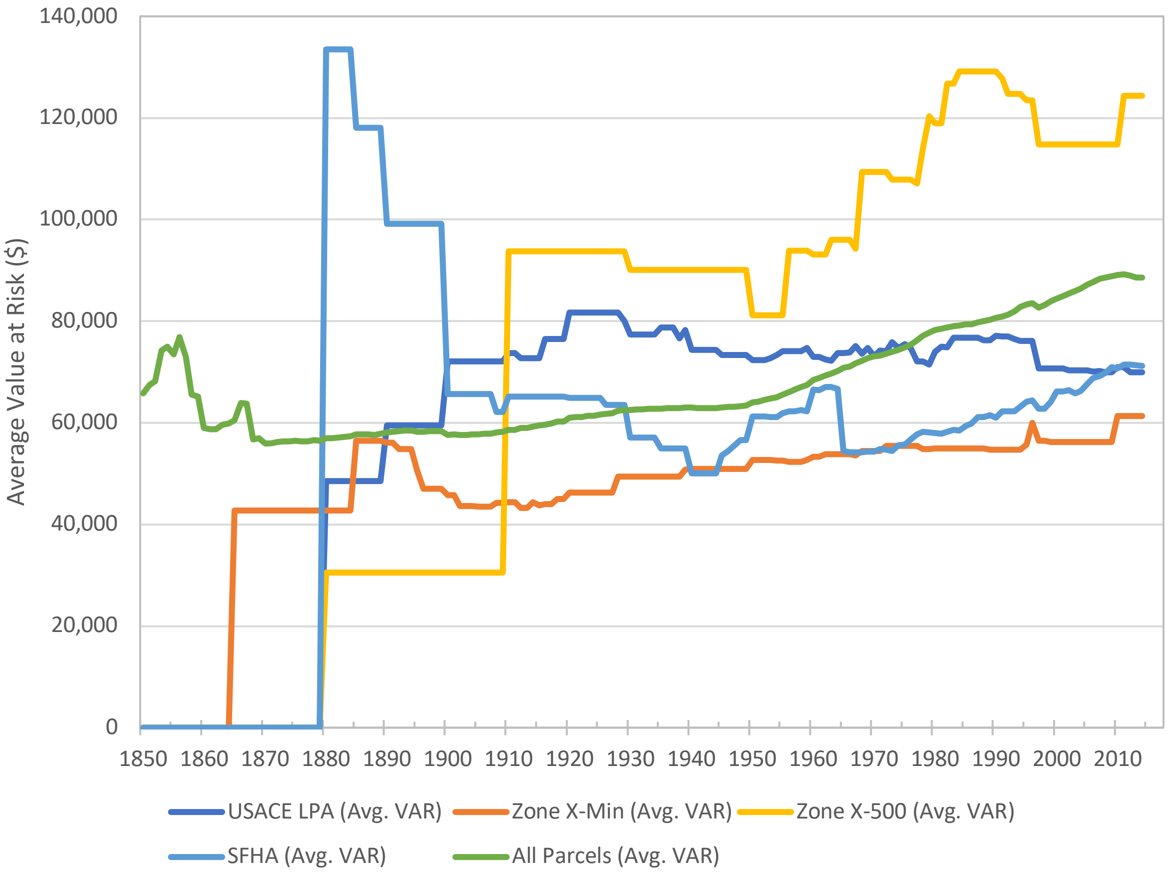


Figure 4.38. Average 2014 value at risk by year of construction for residential parcels in Des Moines County, Iowa. The average value of residential parcels in the 100-year SFHA is about $65,000, which is lower than the average value for residential parcels in the county at large, and about the same in values in levee-protected areas in the last decade. Residential parcel values for homes in the 500-year floodplain fringe areas appear to be nearly double the value of parcels in the 100-year SFHA, and about one-third higher than all residential parcels in the county. Notably, residential parcel values in areas of minimal flood risk are the lowest of all, likely representing areas that are largely undeveloped as either urban or suburban land uses.

For Des Moines County, Iowa, discounts in average 2014 home values for SFHA and USACE LPA are represented in Figure 4.39. Both SFHA and USACE LPA average home values in 2014 were initially found to be at a premium compared with all parcels in the county through 1930 for areas that would become the SFHA and through about build year 1970 for areas in the USACE LPA; however, average 2014 home values in the SFHA first became discounted sharply around build year 1930 before decreasing to about 5 percent under the average value of all

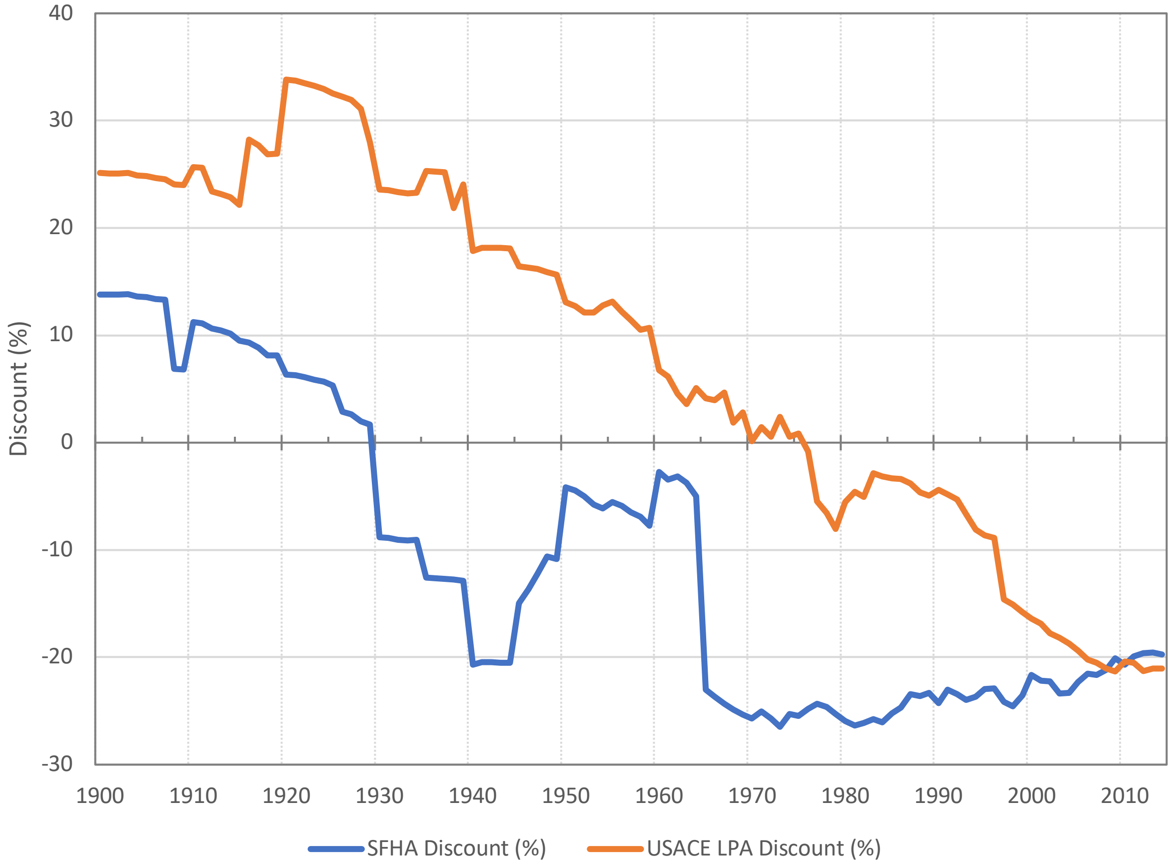


Figure 4.39. Estimated discounts in average 2014 home values by year of construction for 100-year SFHA and USACE LPA in Des Moines County, Iowa, 1900-2014, compared to all residential parcels.

parcels, and then precipitously declining to about 25 percent under the average of all parcels in the mid 1960s, coinciding with the completion of levee improvements. The average 2014 home values for USACE LPA realized a premium of almost 35 percent over all home values built in the 1920s, possibly coinciding with the completion of levee construction in the 1910s; however, since that time, average 2014 home values in the USACE LPA decline by about 5 to 10 percent per decade through the end of records in 2014, based on 2014 assessment, when average USACE LPA home values were discounted slightly more than SFHA homes at about 22 percent under the average value of all homes. Whereas the 2014 SFHA average home values appear flat by build year and consistently discounted by about 20 to 23 percent since the mid 1960s, the 2014

USACE LPA home values appear to realize a steady decline in values by build year, possibly as a realization of flood risk reduction benefits from levee construction or growing awareness of flood hazards in the area.

4.5.3 Counterfactual Evaluation for Des Moines County

To evaluate whether levees may have contributed to increased flood risk by means of increased residential value at risk in LPA, DID estimation was performed for two cases based on 2014 home values and construction years. In the first case (Figure 4.40), residential parcels were grouped into a pre-levee condition for the years 1850-1908 and a post-levee condition of 1908-1920, and then grouped as those situated in what would become LPA (treatment) and those that

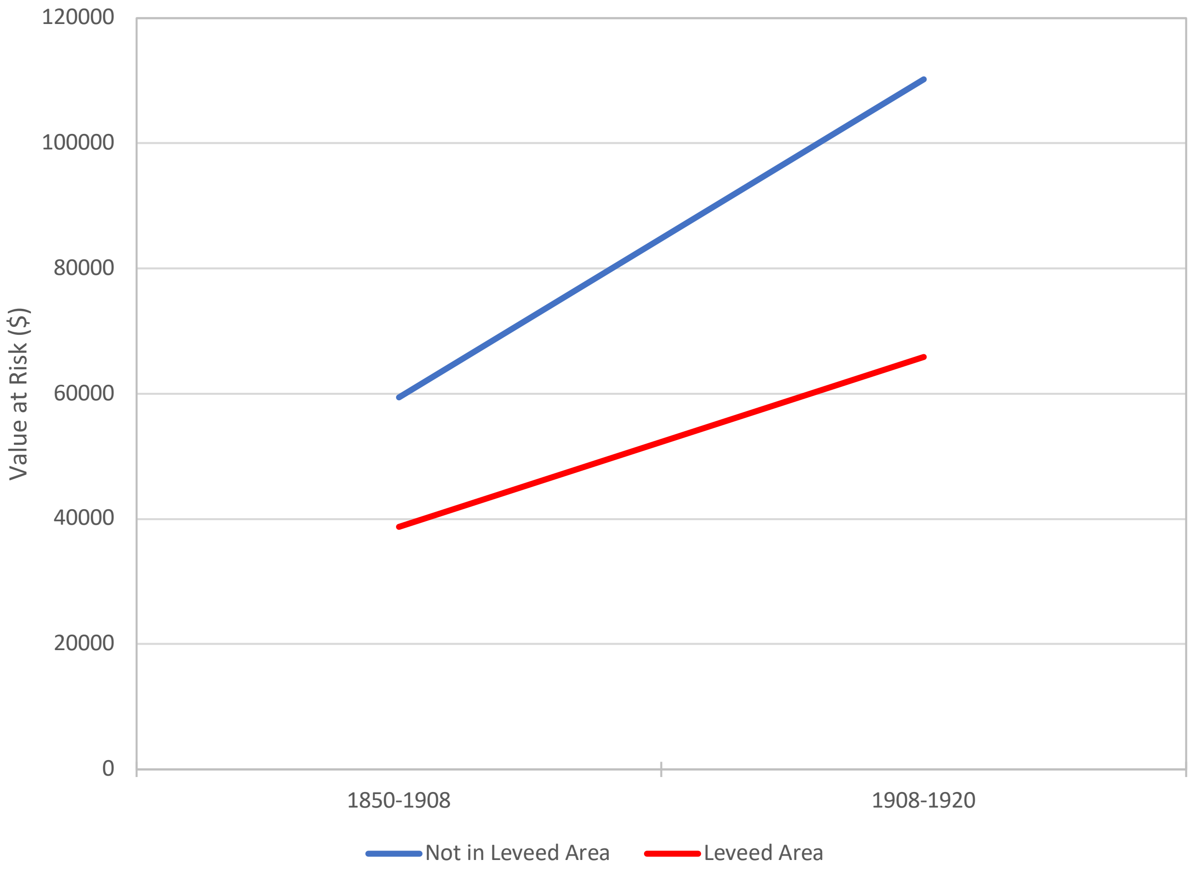


Figure 4.40. DID analysis for 2014 Des Moines County, Iowa levee-protected and non-levee-protected areas 1850-1908 and 1908-1920.

would remain outside of LPA (control). The DID regression estimation for the first case found that 2014 home values outside of LPA in the pre-levee condition averaged about $50,805 whereas those in the LPA prior to levee construction averaged about $27,134—again demonstrating the lower average 2014 values for homes in floodplains as observed in other study areas. In the post-levee condition, homes that were situated outside the LPA averaged $110,230 in 2014 whereas those homes in the LPA were $65,879 on average. Subtracting the average pre-non-LPA home value from the post-non-LPA home value yielded an increase in average home value of $50,805; subtracting the average pre-LPA home value from the post-LPA home value yielded an increase in average home value of only $27,134, indicating a net effect of homes being situated in LPA increasing by $23,671 less than those homes outside of the LPA. Another way of stating this observation is that for each dollar of home value in LPA prior to levee construction, there were $1.53 in home value for each home outside of the LPA; after levee construction, for each dollar of home value in the LPA, there were $1.67 in home value outside the LPA. For the first case, it appears that all homes increased in average value, but it does not appear that the installation of levees improved the average home values of those situated in LPA more than homes outside of LPA; thus, it appears there is no levee effect on flood risk for the first case.

In the second case (Figure 4.41), the residential parcels were grouped into a pre-1965 and post-1965 condition as well as either being situated in LPA or not in LPA, as the year was chosen based on improvements to existing levees and the new construction of the middle unit of the levee system, commenced in 1962 and completed in 1967 as described in Section 3.3.4. In the pre-1965 non-LPA group, average home values were $72,429; in the pre-1965 LPA group, average home values were $60,159. In the post-1965 non-LPA group, home values increased to

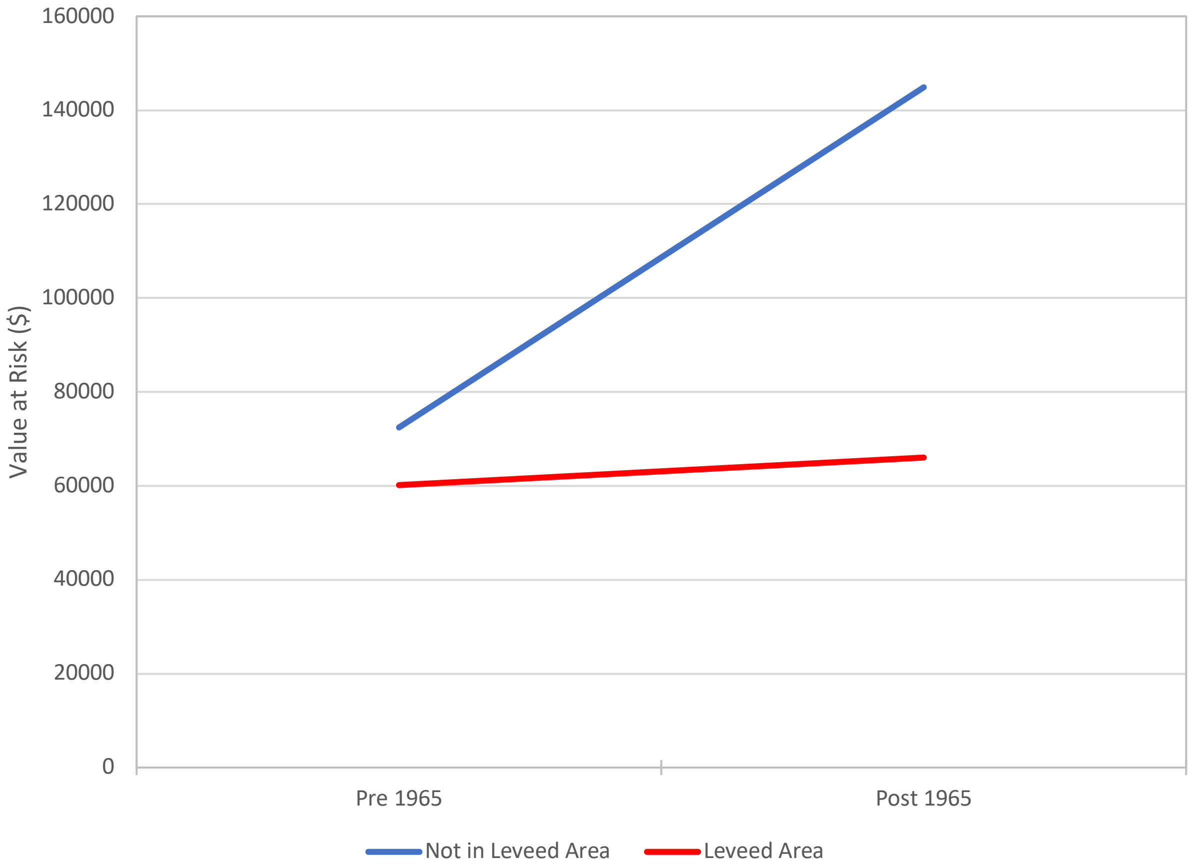


Figure 4.41. DID analysis for 2014 Des Moines County, Iowa in levee-protected and non-levee-protected areas following levee improvements in 1965.

$144,887 on average, an increase of $72,457, whereas the post-1965 LPA average home values increased only to $66,025, for an increase of $5,867. Thus, homes situated in the LPA saw a net effect of value increasing $66,591 less on average than homes situated outside the LPA. Similar to the first case, for each dollar of home value in the pre-1965 LPA, there were $1.20 in home value outside the LPA; for each dollar of home value in the post-1965 LPA, there were $2.19 in home value outside the LPA. This again illustrates that the levee improvements and additional construction appear to not increase flood risk by increasing home values in the LPA areas of Des Moines County.

4.5.4 Parcel Value Densities and 2050 Scenarios for Des Moines County

Cumulative 2014 residential parcel value densities are reflected in Figure 4.42 on a decadal basis by year of construction for the period of record of 1850-2014 with all parcel values for pre-1901 reflected in Panel A. On these maps, the Mississippi River is reflected as the eastern boundary of Des Moines County, flowing from north to south, with most LPA reflected in the northeast portions of the county. The City of Burlington is observed as the hotspot of high residential parcel values in the southeast portion of the county, where values are densest, highest, and generally remain concentrated through the period of record. Some modest increase in parcel values is observed through Des Moines County, with most rural areas increasing since the 1980s.

Given that cumulative residential parcel values in the USACE LPA remained relatively stable at about 0.58 percent, an extrapolated 2050 growth forecast was assumed to follow a more linear trend insensitive to exponential growth (Figure 4.43). With cumulative USACE LPA value at risk of just under $8 million at the end of records in 2014, the best fit model, extrapolated to 2050, estimates growth in cumulative LPA values to increase to about $11.5 million, with confidence bounds suggesting a range of $10 to about $12.5 million. With all parcels doubling in cumulative from about $600 million to $1.2 billion since around 1950, a second model assumes a similar increase in cumulative values of all parcels to about $1.8 to $2.1 billion by 2050 (Figure 4.44), suggesting that cumulative parcel values in USACE LPA will decrease from about 0.58 in 2014 to between 0.48 on the lower end or increase very slightly to 0.6 percent, consistent with DID estimation that does not find levee effect present at Burlington.

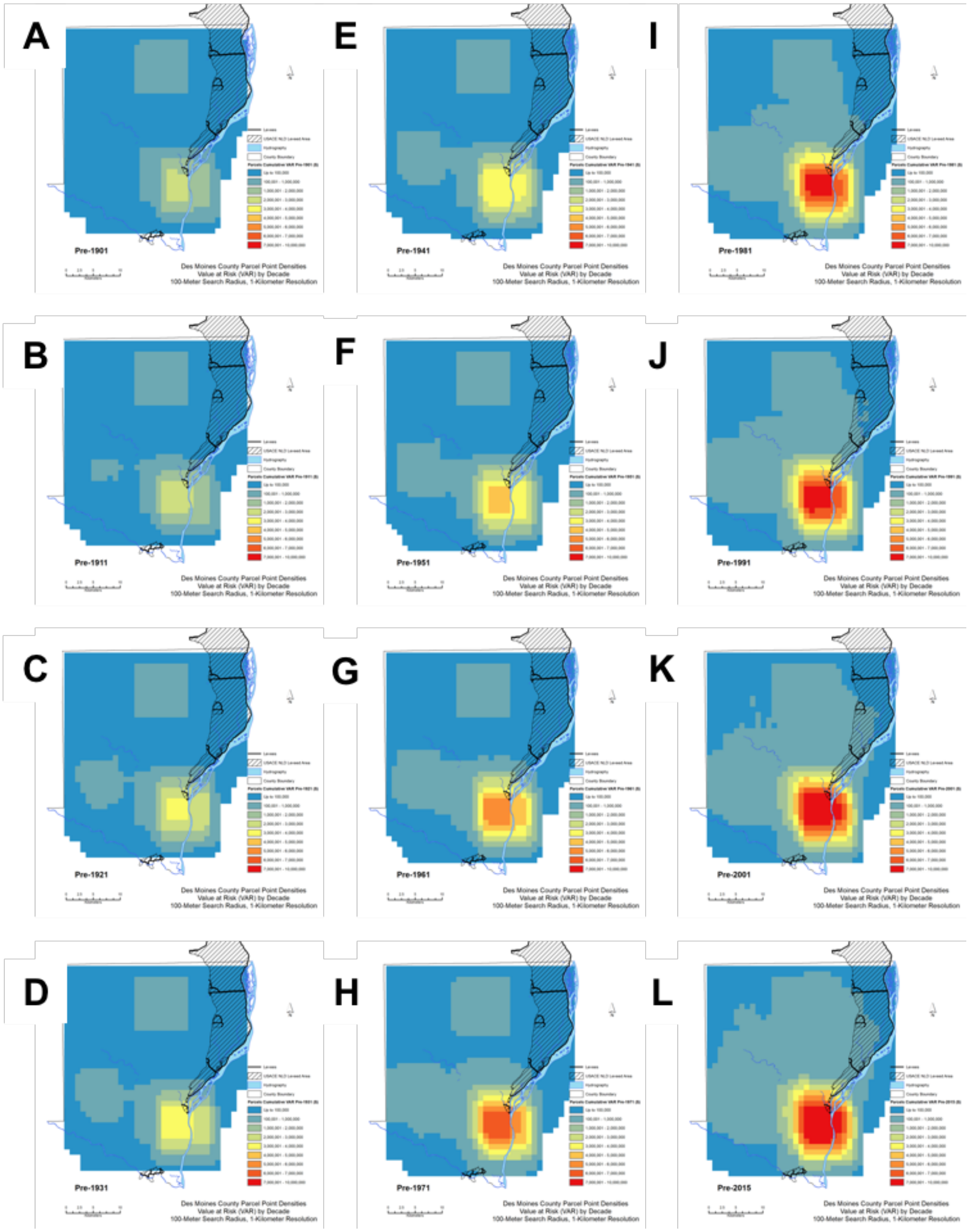


Figure 4.42. Cumulative 2014 residential parcel values by year of construction for Des Moines County, Iowa, 1901-2014. Areas shaded in blue represent lowest values at around $100,000 in cumulative value, whereas areas in red shading represent cumulative values between $7 and $10 million. The City of Burlington appears as the densest residential area in Des Moines County, with cumulative residential values in levee-protected areas generally less than $1 million per square kilometer.

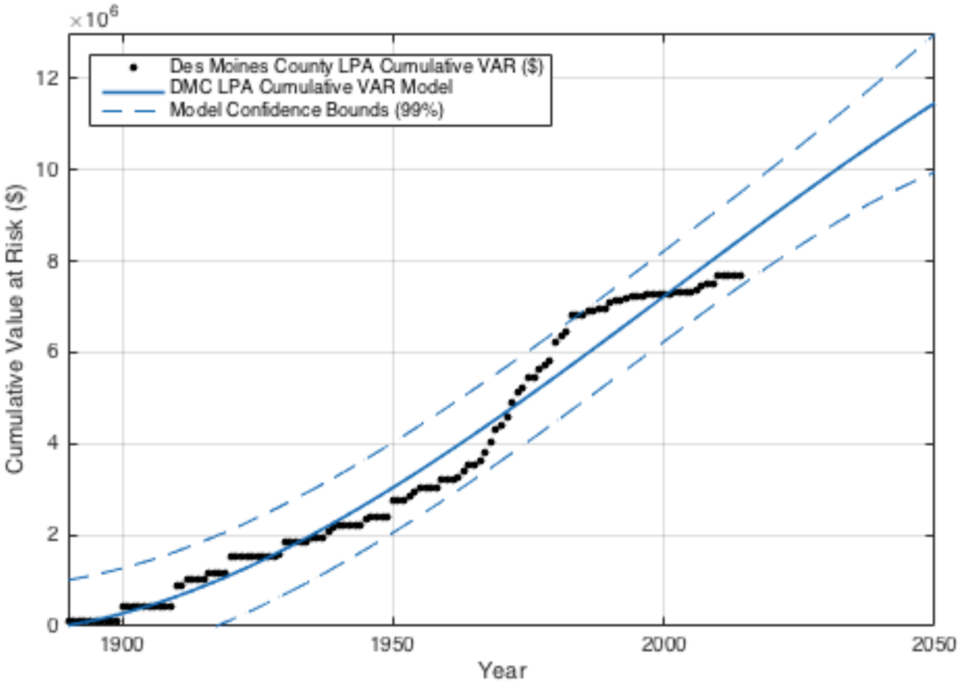


Figure 4.43. Forecasted increase in Des Moines County levee-protected parcel values through 2050.

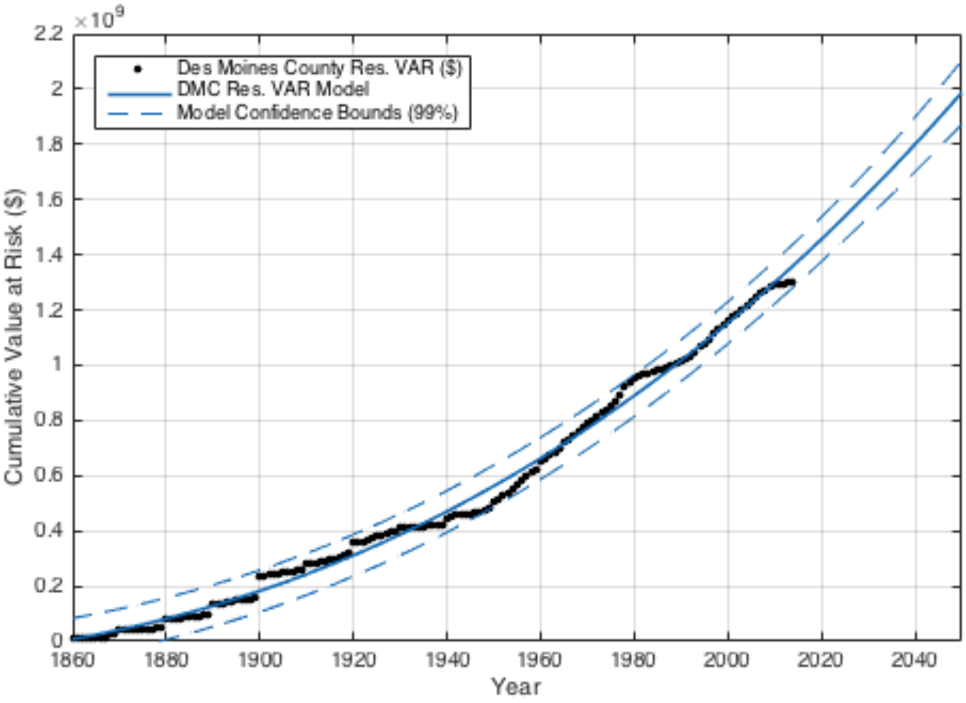


Figure 4.44. Forecasted increase in all Des Moines County residential parcel values through 2050.

4.6 Results for Tulsa County, Oklahoma

The Tulsa study area represents a more heavily populated larger city with a larger river, significantly engineered floodplain, and denser residential land use than previously evaluated in other study areas examined for this dissertation. The presence of the Keystone Dam just upstream of the City of Tulsa also presents a complicating factor for evaluating levee effect on flood risk. Levees and levee-protected areas (LPA) are described in Section 3.3.5 and there is a regulatory 100-year SFHA present. Results are presented per the methods set out in Sections 3.5 and 3.6, first by cross-section exposure typology, then temporally for floodplain and non-floodplain parcel values, then by results of the DID counterfactual analyses, then by decadal value densities, and finally by residential parcel value growth forecasts.

4.6.1 Tulsa County Exposure Typologies

Residential construction for Tulsa County along the Arkansas River, downstream of the Keystone Dam, represents an interesting and robust set of fully built-out (AC, ++), well-adapted (BC, -+), and potentially adversely-developed (AD, +-) exposure types with the majority of cross sections displaying undeveloped or agricultural values (BD, --). The Arkansas River runs a long course through Tulsa County, allowing the drawing of 546 cross sections spanning 54.6 kilometers of river length. On the left side of the river, about 9.2 percent of the cross sections, 50 out of 546, reflect fully-built out residential exposure, generally of low to medium value, as these flat cross sections generally do not represent the highest value residential parcels for the county. The highest value parcels on both the left and right sides of the river are situated the furthest from the river, with lower values nearest the river, representing about 9.9 percent, 54 of 546, exposure types on the left side of the river and a similar 53 of 546 on the right side; however, these well-adapted cross sections (BD, -+) reflect on the left side higher values near the river

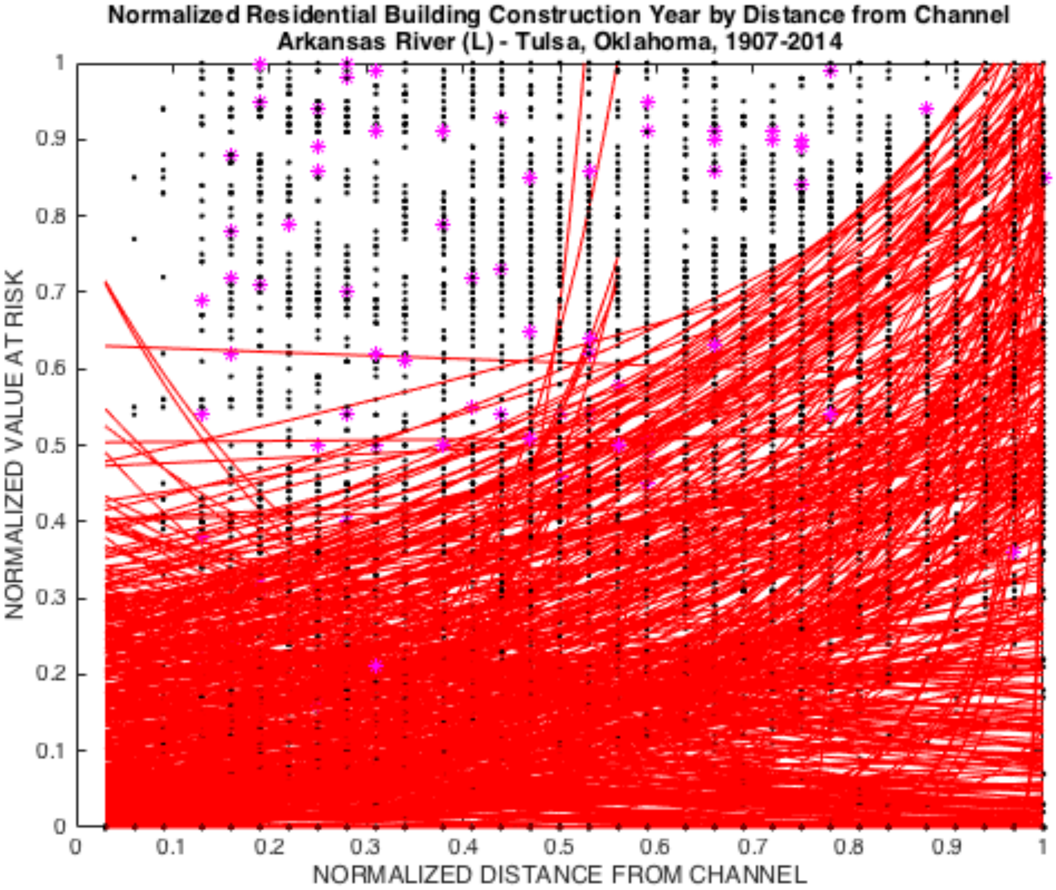


Figure 4.45. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Arkansas River channel, left side, yields a substantial set of low to medium buildout conditions (AC, ++, red lines), about 50 out of 546 cross sections, possibly reflecting areas of lower residential parcel values near floodplains, and very few adverse development types (AD, +-, 24 out of 546). Higher value residential parcels appear to be located farther from the Arkansas River channel, and there are 54 well-adapted exposure types (BD, -+). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

than the right side, likely reflecting the downtown area of the City of Tulsa, and still marginally conforming to the BD exposure type as opposed to becoming assigned the AC, fully-built out type. Also, on the left side are 24 potentially adversely-developed residential exposures, about 4.4 percent of the set, which are likely attributable to the City of Sand Springs, located within a few hundred meters downstream of the Keystone Dam, as well as a suburban neighborhood developed at Haikey Creek that occurred in the Arkansas River floodplain and prompted levee

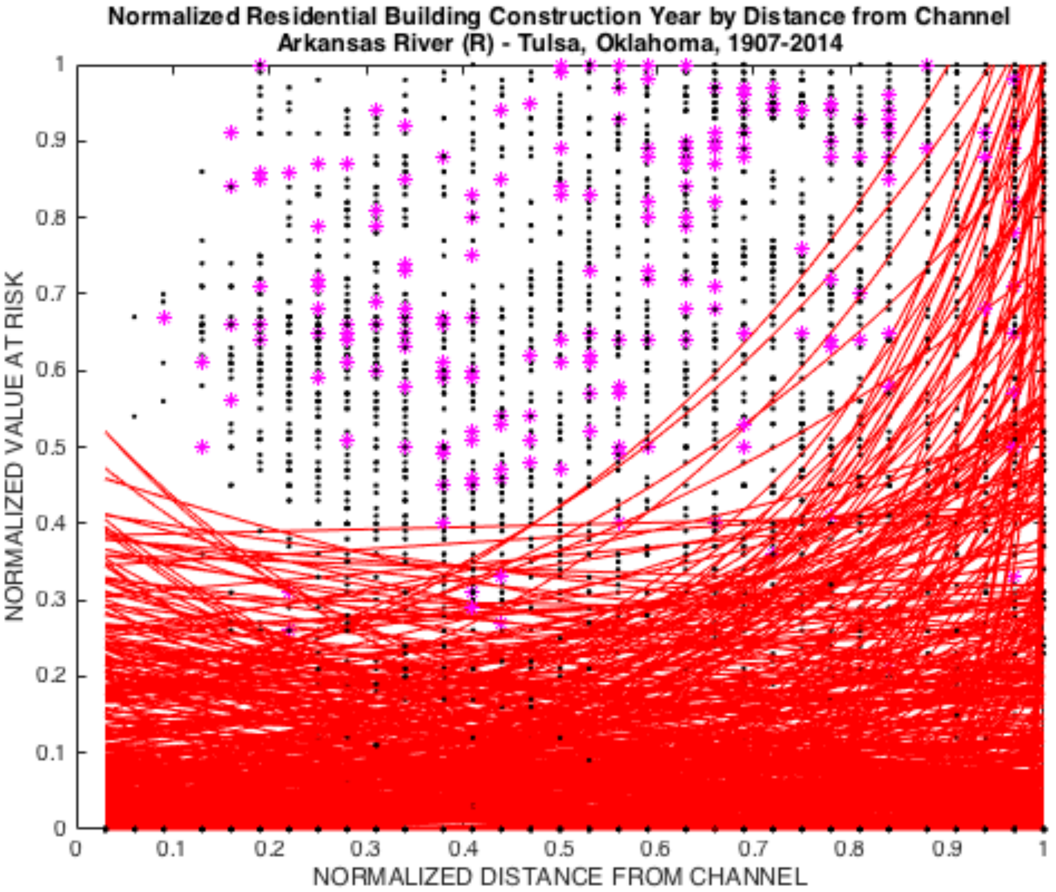


Figure 4.46. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Arkansas River channel, right side, yields a smaller set of low to medium buildout conditions (AC, ++), about 12 out of 546 cross sections, possibly reflecting areas of lower residential parcel values near floodplains stretching into suburban town centers, and quite a few adverse development types (AD, +-, 45 out of 546), likely reflecting development behind the Jenks Levee. Higher value residential parcels appear to be located farther from the Arkansas River channel and generally reflected better adapted, lower flood risk residential development, with about 53 cross sections (BC, -+). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

construction after the homes were constructed. On the right side of the river are more potentially adversely-developed exposure types, 45 of 546, or about 8.3 percent of the set, and these likely reflect the suburban City of Jenks, downstream of the City of Tulsa, and protected by levees as described in 3.3.5. The distance-normalized parcel exposure transects demonstrate the second-most densely developed residential parcels of the study areas, with as the parcel values (black dots) represented on Figures 4.45 and 4.46 are very close together.

4.6.2 Tulsa County Residential Parcel Values

The residential parcel data for Tulsa County reveal interesting historical trends from the 2014 tax assessment, with the earliest home construction occurring substantially in the river-adjacent floodplains of the Arkansas, likely representing the expansion outward from the original site of “Tallahassee” at Tulsa as ranchers and oil businessmen rushed into the area. Just after 1900, residential parcels situated in all flood NFIP-designated flood zones of Tulsa County represented almost 15 percent of cumulative 2014 residential parcel values with parcels situated in what would become USACE LPA representing almost 8 percent of cumulative 2014 values (Figure 4.47). As residential construction expanded to other areas of Tulsa County, the relative proportion of homes constructed in the flood zones decreased substantially by about 1908, based on build year data, dipping under 5 percent for all flood zones and under 1 percent for LPA; however, home-building in the flood zones and LPA increased to 8 percent and almost 4 percent, respectively, by about 1912. Though both types generally began a trend of decreasing proportion of cumulative 2014 residential values to about 1930, home-building in all flood zone areas of the county increased quickly into the early 1950s, reaching almost 11 percent of all 2014 value before beginning a 64-year decline back to about 8 percent as of the end of records in 2014. In LPA, the proportion of cumulative 2014 values declined to about 2 percent by around 1930 and continued a slowly-declining trend to about 1 percent by the 2000s. The lower LPA proportion is possibly depressed by the increasing proportion of 2014 home values in non-LPA and non-floodplain areas of Tulsa County, as the vast majority of residential values are located in Zone X-Min, or areas of minimal flood risk, and demonstrate an exponential growth trend that begins

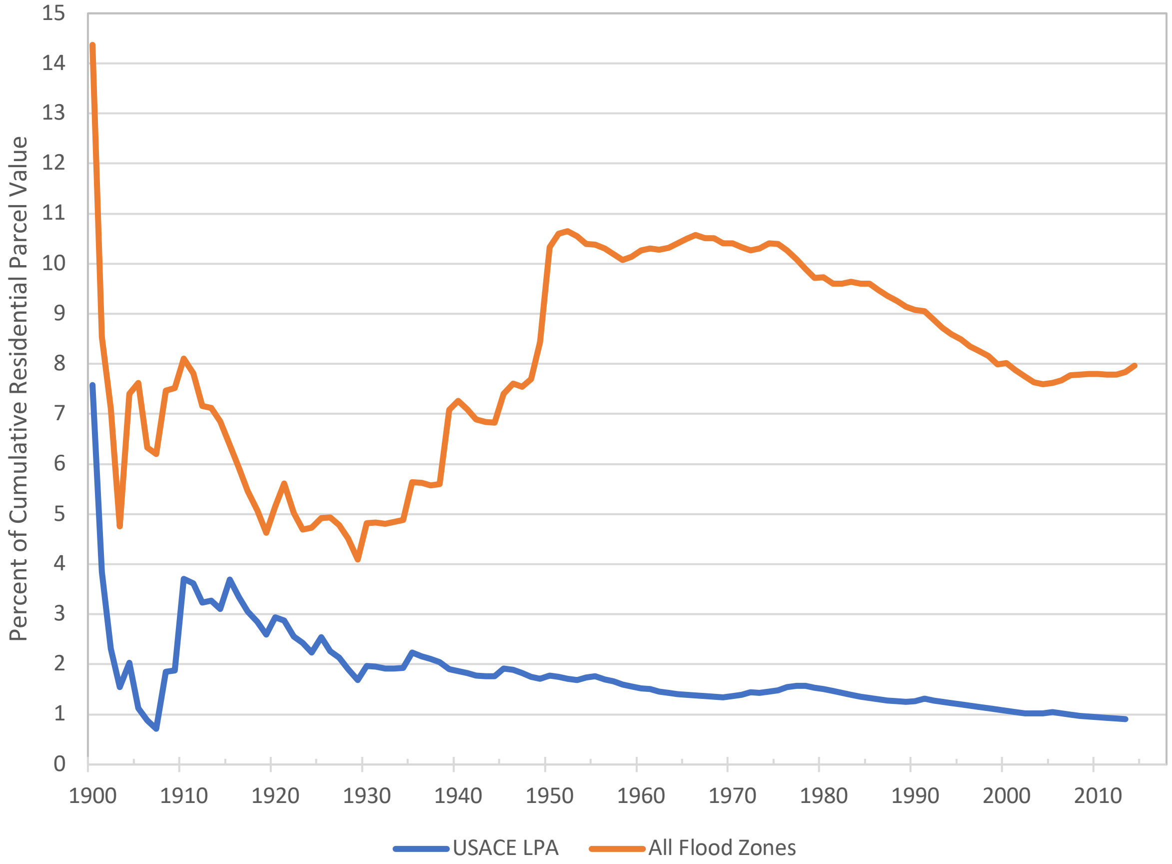


Figure 4.47. Percent of 2014 residential parcel values cumulative value by year of construction for levee-protected and all floodplains of Tulsa County, Oklahoma, 1901-2014.

around 1920, with about $5 billion in cumulative 2014 value built by the mid 1950s and with $5 billion added every 10-15 years thereafter to a cumulative residential valuation of almost $30 billion by 2014 (Figure 4.48, yellow and green lines, right axis). There are substantial differences in the spatial areas of the USACE LPA compared to the NFIP LPA also, with the USACE LPA encompassing much more floodplain land area than the NFIP LPA; in fact, the NFIP LPA appears only to exist behind the Haikey Creek Levee, which is interesting in that the Haikey Creek suburb seems to have expanded first into the floodplain in an area known to flood, as the development occurred almost immediately prior to a major flood with a levee constructed shortly after. The designation by NFIP that the Haikey Creek is in a levee-protected area removes a

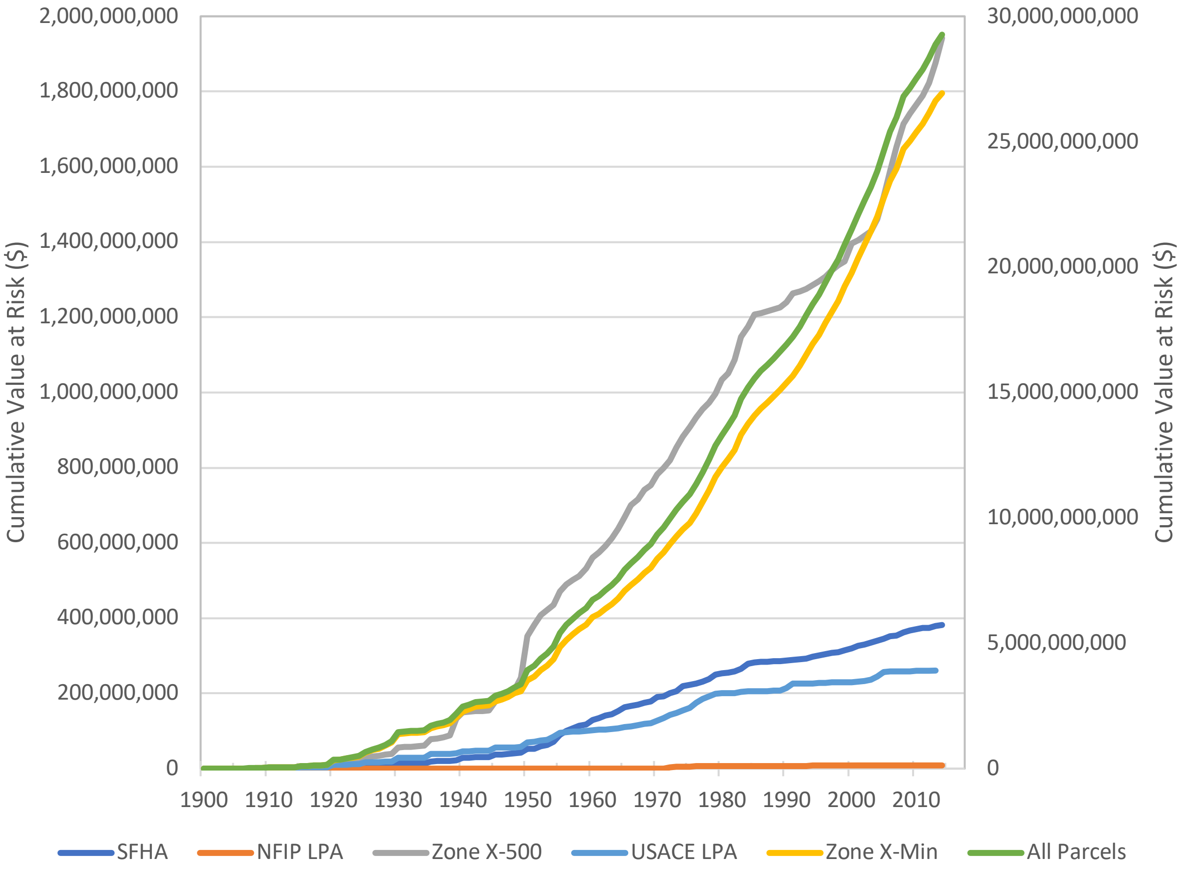


Figure 4.48. Cumulative 2014 residential parcel values for all flood and non-flood zones of Tulsa County by year of construction. Note that USACE and FEMA's NFIP levee-protected areas (LPA) are substantially different (orange and light blue lines, left axis), and that parcels in the 100-year SFHA add about $100 million in value to USACE LPA (dark blue line, left axis); however, a substantial portion of Tulsa County residential parcel value is located in the 500-year floodplain (gray line, left axis) at nearly 5 times the value of SFHA parcels. The vast majority of Tulsa County residential parcels are in Zone X, or areas of minimal flood risk (yellow and green lines, right axis).

mandatory purchase requirement for flood insurance, and the Jenks Levee also has no insurance requirement given its NFIP accreditation. Yet, the cumulative 2014 residential parcel value at risk by build year in these areas slowly rose to $100 million by about 1960 and more than doubled by the end of records in 2014 to almost $261 million (Figure 4.48, light blue line); simultaneously, residential value at risk in the 100-year SFHA not protected by levees increased to about $200 million by 1970 and nearly doubled to about $400 million by 2014 (Figure 4.48, dark blue line, left axis). Perhaps more concerning about residential floodplain occupation in Tulsa County is the exponential increase in value at risk in the 500-year floodplain areas, with cumulative 2014 value by build year reaching $200 million by 1950, doubling to $400 million by 1955, again doubling to $800 million by 1970, and again doubling to $1.6 billion by 2000, with cumulative value just under $2 billion in 2014 (Figure 4.48, gray line, left axis). Average 2014 home values in all areas of Tulsa County exhibit a slow, generally-linear trend upward throughout the period of record, 1900-2014, with a temporary lull in value increase observed in the 1950s, likely related to the rapid expansion of the 1950s increasing the overall availability of housing supply and thereby depressing values (Figure 4.49, yellow and green lines). The homes located in the 100-year and 500-year year flood zones are about $10,000 less than those located in areas of minimal flood risk by 2014 valuation assessment (gray and dark blue lines, respectively), and homes located in the USACE LPA are the least valuable on average, climbing to around $70,000 by 2014. Strikingly, however, are the 2014 values of the homes located in the NFIP LPA at Haikey Creek: though there are few homes, and none constructed until about 1970, these parcel values are the highest in the county on average at about $165,000, remaining flat at that valuation since construction through 2014 (Figure 4.49, orange line). The parcel dataset also reveals that the homes in the Haikey Creek NFIP LPA are constructed as slab on grade, indicating that no mitigation of the structures occurred under NFIP regulations, even though the homes are about 2.4 times more valuable than those protected by USACE levees in Jenks and the other suburban areas of Tulsa.

Estimated discounts for average 2014 home values in the 100-year SFHA and USACE LPA in Tulsa County, Oklahoma are represented in Figure 4.50. The average 2014 home values for both SFHA and USACE LPA are consistently discounted for the county throughout the

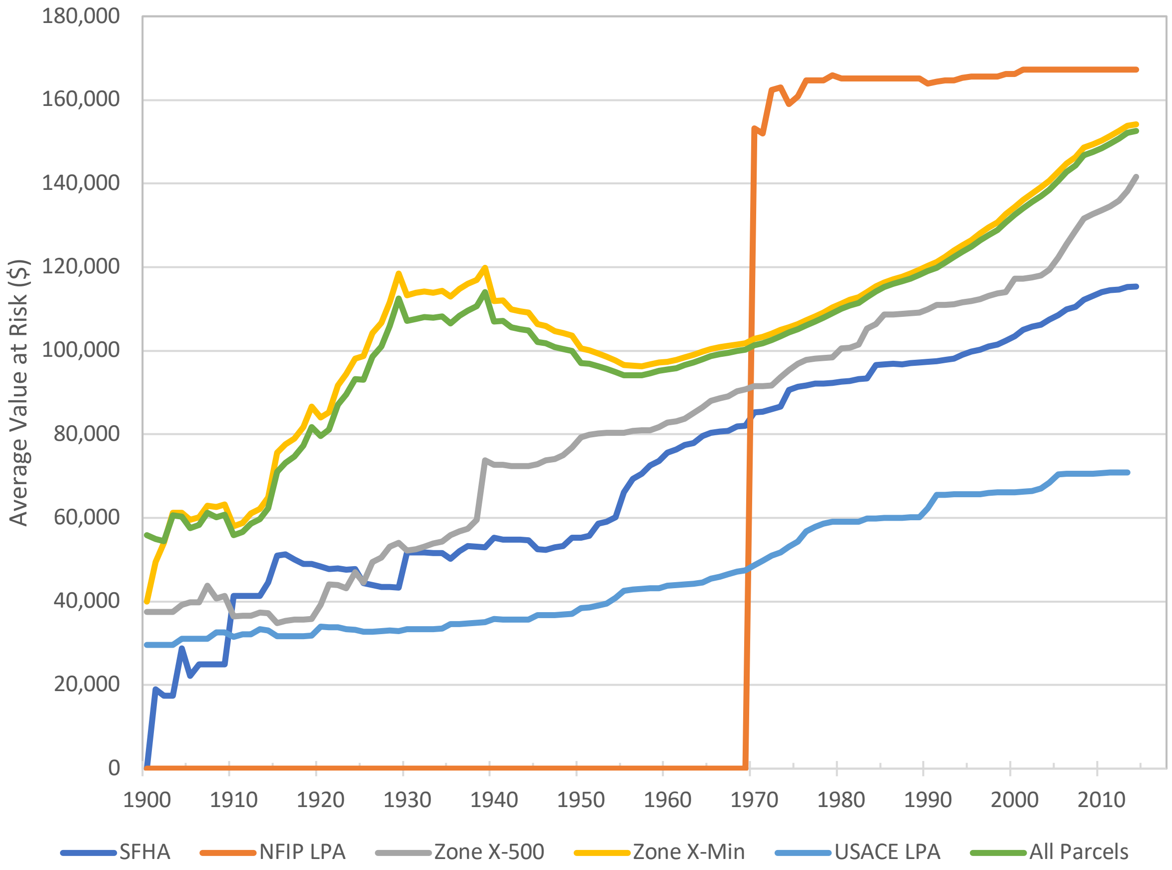


Figure 4.49. Average 2014 residential parcel values for Tulsa County by year of construction. In general, Tulsa County residential parcels reveal a steadily growing average value, although parcels located in the areas of minimal risk showed a decline from a first peak value attained around 1940, dipping through the 1950s and 60s, and then steadily increasing since (green and yellow lines). Residential parcels in the 100-year SFHA and 500-year floodplains have increased steadily in value over the last 100 years (gray and dark blue lines), with areas protected by USACE levees revealing a steady increase in value but at a slower rate. Strikingly, the addition of the Haikey Creek residential development around 1970, occurring prior to levee construction for the area, resulted in the most valuable residential parcels existing in the floodplains for the last 45 years on record: levees were constructed in the Haikey Creek area in the 1980s, with accreditation by FEMA removing mandatory flood insurance requirements. The Haikey Creek residential parcels in the NFIP LPA, also remarkably, are slab-on-grade structures at more than 2 times those of residential parcels in other USACE LPAs, meaning that the first floor of these homes is essentially at ground elevation and are, therefore, far more vulnerable to flood damage—this area likely represents an area of flood risk “grandfathered” into NFIP requirements and should be observed in future floods for applications of mitigation to reduce flood risk.

period of construction record, 1900-2014, although USACE LPA is consistently more discounted than SFHA. By 1930, the SFHA discount was near 60 percent compared to all average home

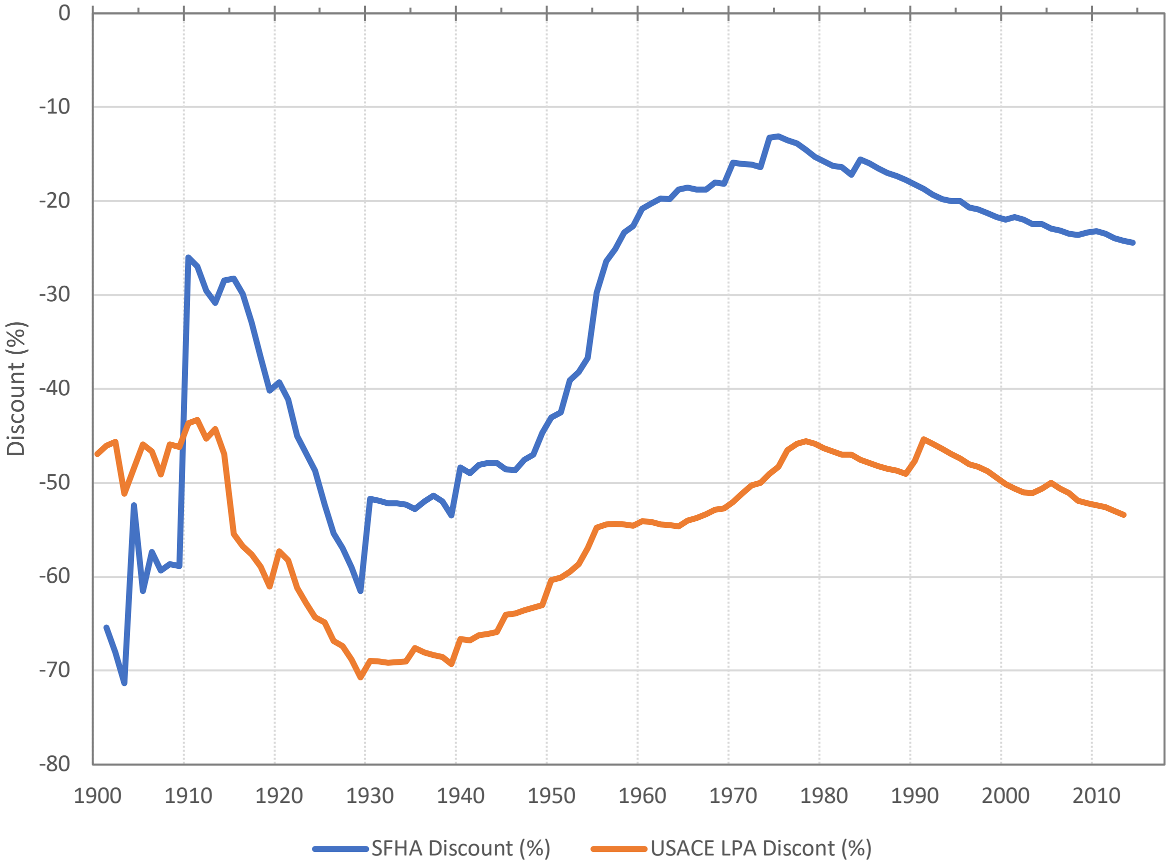


Figure 4.50. Estimated discount in average 2014 home values by year of construction for 100-year SFHA and USACE LPA for Tulsa County, Oklahoma, 1900-2014, compared to average home values for all residential parcels.

values for Tulsa County, based on 2014 valuations, and homes in the USACE LPA were about 70 percent discounted at that same time. A steady decline in the discount by build year occurs from about 1930 to around 1975, based on 2014 valuations, when SFHA home values averaged about a 13 percent discount and USACE LPA averaged about 43 percent: this spread of difference of about 30 percent between SFHA and USACE LPA continues through the end of records in 2014, with SFHA home values discounted about 24 percent over all home values in the county and USACE LPA approaching a 55 percent discount. This appears to be consistent with USACE LPA homes capitalizing flood risk and risk reduction benefits into average values, though there may be some additional factors depressing the average home value in such areas in 2014.

4.6.3 Counterfactual Evaluation for Tulsa County

Difference-in-difference estimation was conducted for three cases in Tulsa County based on 2014 valuation and construction year data. Similar to the Iowa City and Cedar Falls-Waterloo analysis, the first case evaluated average residential parcel values prior to and after the 1973 mandatory flood insurance purchase requirement was implemented through the NFIP for homes both inside the 100-year SFHA, where insurance is required, and for homes outside the SFHA (Figure 4.51). Prior to 1973, homes outside of what would become the 100-year SFHA were

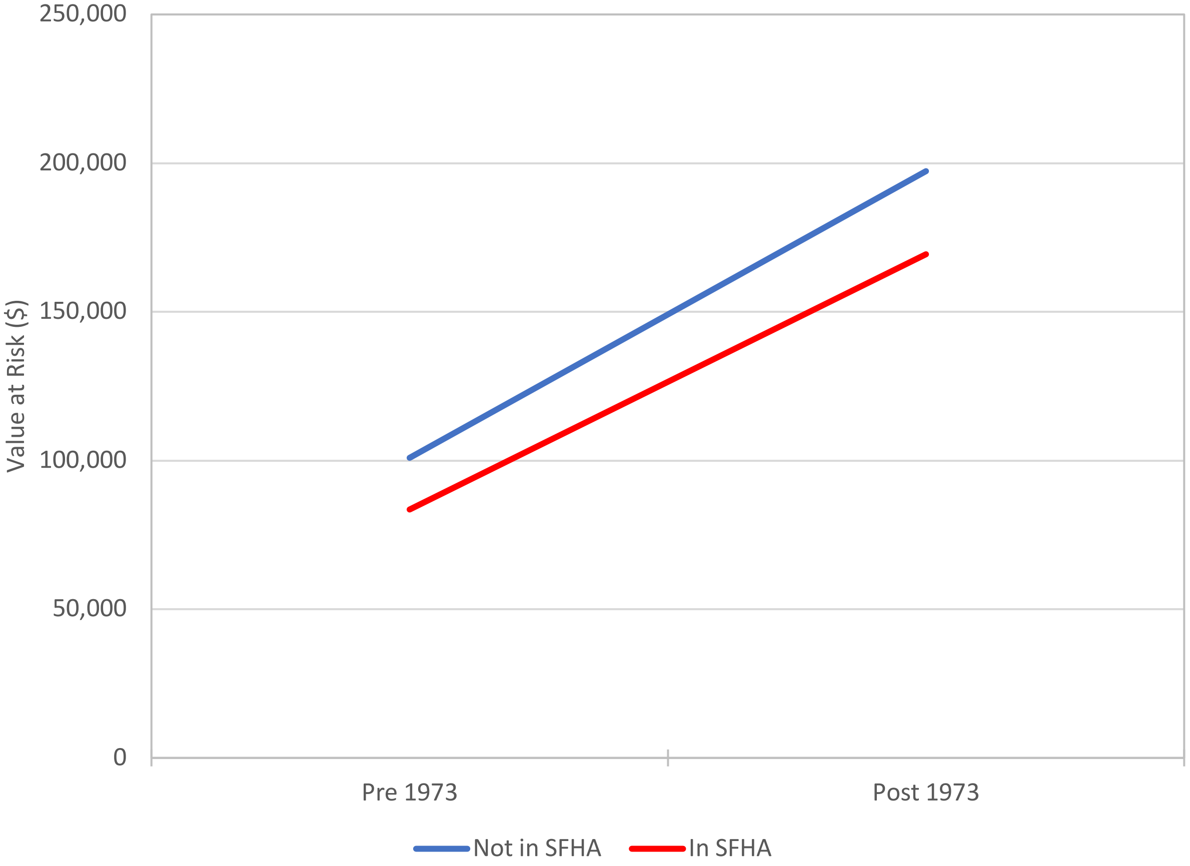


Figure 4.51. DID analysis for 2014 Tulsa County, Oklahoma residential parcels in and not in the 100-year SFHA before and after the 1973 MPR.

$100,903 on average, based on 2014 assessed valuation, and in the post-1973 condition average home values were $197,300. The control variable for 2014 average residential value is the difference in values for homes outside the SFHA in a pre-1973 condition subtracted from the post-1973 condition, or $96,398 in difference after 1973. Prior to 1973, homes constructed in what would become the SFHA were $83,527 on average, and, in the post condition after 1973, homes were $169,358 on average, a difference of $85,831. Thus, homes both inside and outside of the SFHA averaged more value in the post condition, but the homes outside of the SFHA averaged more than those in the SFHA. As observed in the Iowa City study area, the lower increase in home values in the SFHA could be related to a depressing effect caused by flood insurance, but the more likely case is that flood hazard yields lower value homes when situated in floodplains very near rivers.

The second case evaluated average 2014 residential parcel values for the construction periods of 1929-1940 and 1941-1952 to consider changes related to the passage of the Flood Control Act of 1928, which was substantially influenced by federal flood control and channel improvement projects advocated for by Tulsa politicians (Figure 4.52). Completion of Levees A, B, and C by USACE occurred in 1944-1945, with incremental progress in prior years. The parcels were also grouped into LPA and not in LPA conditions for evaluation of control and treatment results of the DID estimation for both time periods. In the 1929-1940 non-LPA group, average home values were $111,625, based on 2014 assessed values; in the 1929-1940 LPA group, average parcel values were $37,780. In the 1941-1952 non-LPA group, 2014 home values averaged $86,462, a decrease of $25,164, whereas in the 1941-1952 LPA group home values for 2014 were $45,756 on average, an increase of $7,976. Thus, homes in the post condition USACE LPA saw a net effect of value increasing $33,139 more than homes situated outside of the LPA

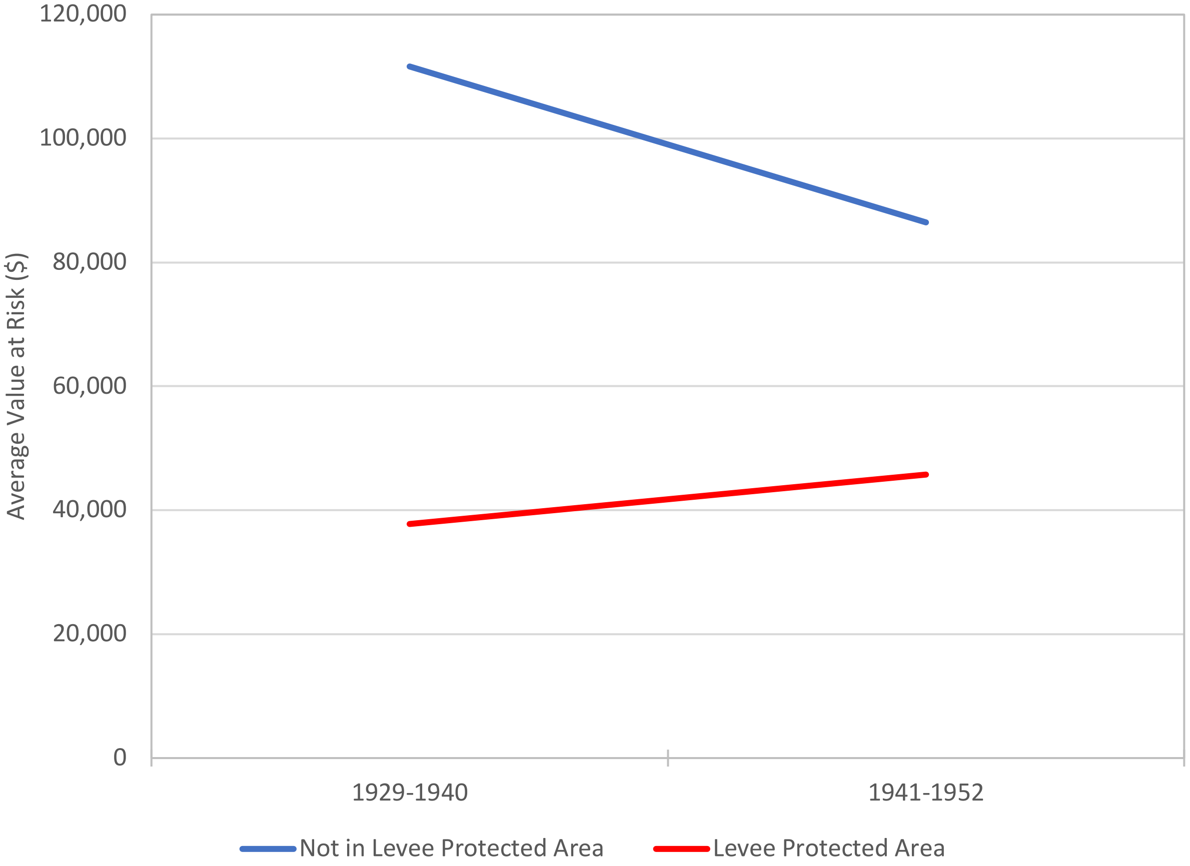


Figure 4.52. DID analysis for 2014 Tulsa County, Oklahoma residential parcels in and not in levee-protected areas before and after completion of levees, 1929-1940 and 1941-1952.

in the 2014 assessment. This is a notable result in that non-LPA homes appear less valuable while homes in the LPA were more valuable for this construction period, even as the LPA homes are likely lower in value overall due to the proximity of flood hazard; moreover, the treatment case of levees protecting homes in the post condition indicates that average values in the LPA in 2014 were higher despite the flood risk and potentially increased vulnerabilities, and also despite the broader economic or land use conditions effecting the non-LPA homes where values decreased. As a result of these findings, there appears to be a plausible case of levee effect increasing flood risk in the USACE LPA of Tulsa County for the decade following completion of levee construction.

The third case evaluated whether levee improvements and the completion of the Keystone Dam in 1964, authorized by the Flood Control Act of 1950, resulted in sustained increase in home values for LPA as compared to areas not in LPA based on 2014 assessed values (Figure 4.53). The period of 1941-1952, as evaluated in the second case, is considered the pre-flood control condition and the period of 1953-1973 the post-flood control completion condition, with homes grouped into both construction time periods and also into LPA and not in LPA conditions for control of treatment effects relative to 2014 home values in the LPA. In the 1941-1952 non-LPA group, average home values were $84,462, based on 2014 assessment; in the 1941-1952 LPA group, average parcel values were $45,756. In the 1953-1973 non-LPA group,

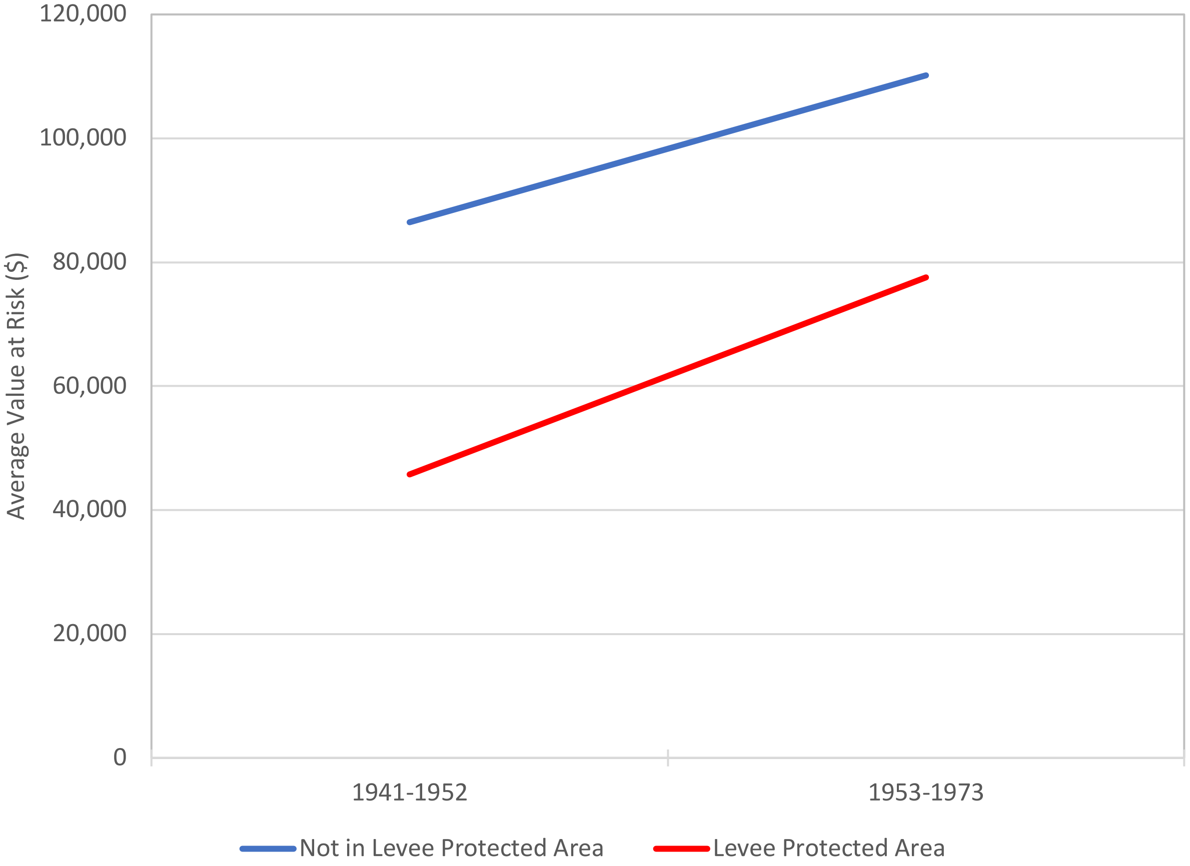


Figure 4.53. DID analysis for 2014 Tulsa County, Oklahoma residential parcels in and not in levee-protected areas before and after completion of Keystone Dam and levee improvements, 1941-1952 and 1953-1973.

home values averaged $110,170, an increase of $23,708, whereas in the 1953-1973 LPA group home values were $77,558 on average, an increase of $31,802. Thus, while homes in the non-LPA group appear to have both increased in value and recovered from external economic conditions depressing values, as suggested in the second case, homes in the LPA group both continued to average in value more than non-LPA homes with an observed net effect of average values differencing $8,094 more than non-LPA homes during the period after levee improvements and completion of the Keystone Dam. Although LPA home values averaged more than non-LPA homes, possibly indifferent to or despite flood risk, the third case may represent a levee effect or a phenomenon that dam safety officials refer to as “hazard creep”—very similar to the levee effect but described as exposure increasing as a result of encroachment into expanded floodplain area or enhanced flood risk caused by an upstream dam. With such an interpretation provided by dam safety officials, and with dams classified as structural flood control, as levees are, increased flood risk as a result of induced development is commensurate with interpretations of levee effect. As such, 2014 home values in the LPA for the period of 1953-1973 appear to have increased despite increasing flood risk and potentially increased vulnerabilities caused by structural flood control measures installed in the Arkansas River floodplains of Tulsa County.

4.6.4 Parcel Value Densities and 2050 Scenarios for Tulsa County

Cumulative residential parcel value densities are reflected in Figure 4.54 on a decadal basis for the period of record of 1900-2014, and there are some pre-1900 structures in the records with pre-1901 values reflected in Panel A. The Arkansas River runs from west to east into central Tulsa County before turning to a southeastward flow and exiting the county in the southeast corner. The historical development of the City of Tulsa occurs at the bend where the

Figure 4.54. Cumulative 2014 residential parcel densities for Tulsa County, Oklahoma, 1907-2014, reflecting the growth of the City of Tulsa into suburban areas to the southeast of the city and proceeding along the Arkansas River. Notably, residential values in levee-protected areas did not increase substantially until after the 1960s when flood control was formidably established through the Keystone Dam and reservoir project. Most residential value increases, however, have occurred outside of the Arkansas River floodplains.

river turns to the southeast, with residential parcel values demonstrating a hot spot that becomes more visible in Panel D. Although the vast majority of residential parcels are located to the north and east of the Arkansas River, demonstrated in Panels E-K, suburban development occurs throughout the county, with areas both to the south and west of the river densifying in recent decades; however, the more significant observation in the parcel record is that development of increasing residential tends to favor suburban areas, noted in the substantial increase in both parcel density and value in the eastern half of Tulsa County since the 1960s and 1970s. Areas further downstream of the City of Tulsa along the Arkansas River appear to not be building into either 100-year SFHA or LPA, as described in the previous valuation charts, perhaps indicating that additional levees or downstream flood control projects are unnecessary; however, there is substantial debate regarding the health and quality of the Arkansas River and its waters in the areas downstream of Tulsa, as a series of dams regulate the river's flow. With the densification and expansion of downtown Tulsa, parcels in presently-existing floodplains will also likely continue to densify, and Figure 4.55 depicts a linear best fit regression model extrapolated to 2050 for LPA, indicating that the cumulative value at risk for residential parcels may nearly double in value from 2014-2050, increasing from about $250 million to nearly $500 million in USACE LPA, further demonstrating a path dependency wherein homes protected by levees will continue to be protected by levees while increasing in both count and value of parcels without a disruption favoring relocation of homes exposed to flood risk. Regardless, as demonstrated in Figure 4.48 previously, Tulsa County residential parcels are accumulating about $5 billion in total value about every 10-15 years, suggesting that by 2050 cumulative residential parcel value will be around $50 billion or more, meaning that future densification in USACE LPA will likely continue to be a relatively minor proportion of cumulative value: in 2014, cumulative residential parcel values in USACE LPA represent about 1 percent of Tulsa's homes, and, if densification proceeds as modeled in Figure 4.55, that proportion of levee-protected homes should remain at or near 1 percent of the cumulative values for all of Tulsa's residential parcels.

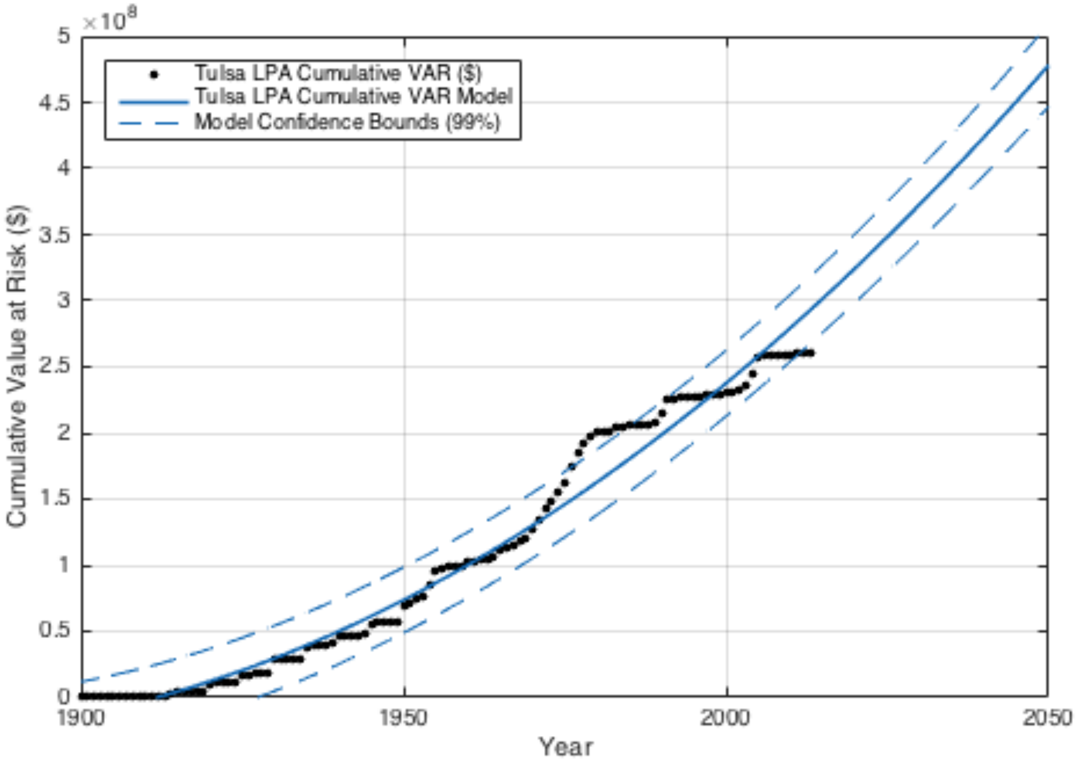


Figure 4.55. Forecasted increase in Tulsa County residential parcels in levee-protected areas through 2050.

4.7 Results for Sacramento County, California

The Sacramento study area represents the most heavily populated city with a set of large rivers, significantly engineered floodplains, and densest residential land use evaluated in this dissertation. The floodplains of three rivers—the American, Sacramento, and Consumnes—make up the land area of Sacramento County, with the Folsom Dam presenting a complicating factor for evaluating levee effects on flood risk for the American River floodplains. Levees and LPAs are described in Section 3.3.6 and there is a regulatory 100-year SFHA present with unique modifications to flood zones caused by policy considerations for structural flood control protections. Results are presented per the methods set out in Sections 3.5 and 3.6, first by cross-section exposure typology for the three rivers, then temporally for floodplain and non-floodplain parcel values, then by results of the DID counterfactual analyses, then by decadal value densities, and finally by residential parcel value growth forecasts.

4.7.1 Sacramento County Exposure Typologies

Residential construction for the areas surrounding the American River floodplain represent a substantial set of potentially adversely-developed floodplains. Exposure transects were drawn beginning at the Folsom Dam, and then proceeding westward along the meandering course of the American River to its confluence with the Sacramento River at the historic city center of Sacramento, with the transects drawn to cross floodplains and extend well into higher ground, non-floodplain areas (Figures 4.56 and 4.57). Of these 432 cross sections, the left side of the American River has the most potentially adverse cross-section exposure types observed yet, with 122, or 28 percent, typed as AD (+-), wherein residential parcel values are very high at or nearest to the river channel with values decreasing to low or no value at all with increasing distance into non-floodplain areas. The next most observed type is AC (++), with 111 cross sections, 26 percent, representing full build-out conditions with low-to-medium residential values both near and far from the river channel. Approximately 18 percent (76 of 432) of the American-left cross sections were observed to be well-adapted, with low to no value nearest the river channel and value increasing outside floodplain areas with increasing distance from the channel. The remaining 28 percent (121 of 432) of cross sections were typed BD (--), representing low to no residential parcel values both near and far from the river channel. On the right side of the American River, 24 percent (103 of 432) cross sections were observed to be

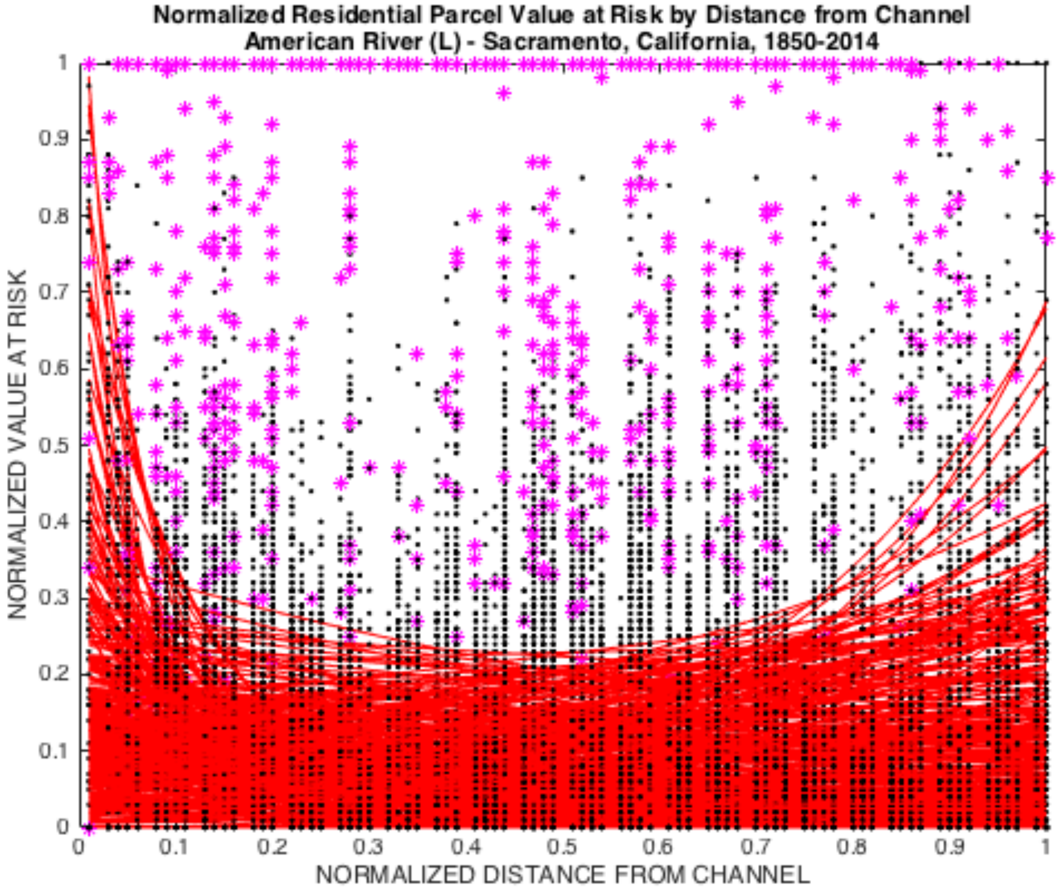


Figure 4.56. Exposure typology applied for normalized residential parcel value at risk over normalized distance from American River channel, left side, yields a substantial set of AD (+-) development types, about 122 out of 432 cross sections—the most observations in the study areas in total and proportionally, perhaps representing adverse floodplain development in levee-protected floodplains. A substantial set of low to medium buildout value cross sections (AC, ++, about 111 out of 432) is also observed, with a small set of well-adapted cross sections (BC, -+, 76 out of 432) observed (red lines). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

potentially adversely-developed, with medium high values nearest the river channel and low to no values furthest from the channel. Approximately 27 percent (116 of 432) cross sections were observed to fit the full build-out type (AC, ++), with low-to-medium residential parcel values both near and far from the river channel, or both inside and outside of the floodplains. About 23 percent (100 of 432) of the right-side cross sections were typed as well-adapted, with no low to no residential parcel values near the channel and medium values further from the channel and

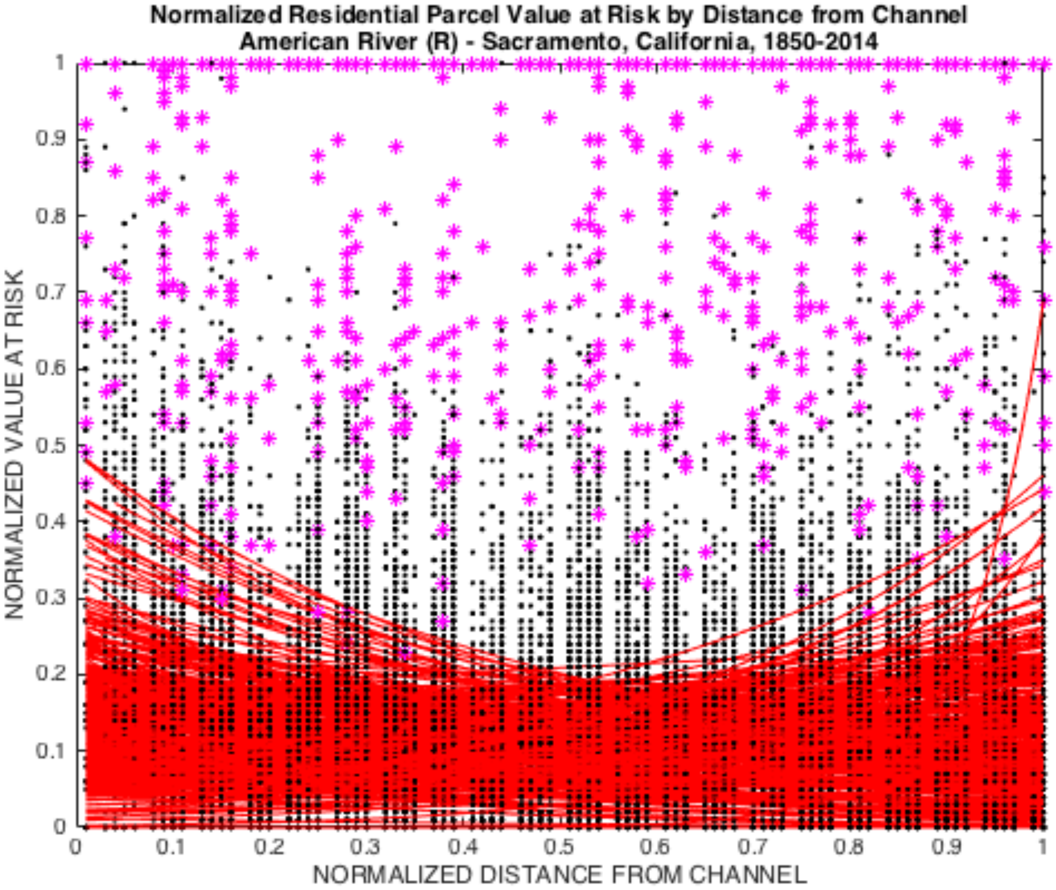


Figure 4.57. Exposure typology applied for normalized residential parcel value at risk over normalized distance from American River channel, right side, yields a substantial set of AD (+-) development types, 103 out of 432 cross sections, perhaps representing adverse floodplain development in levee-protected floodplains. A substantial set of low to medium buildout value cross sections (AC, ++, 116 out of 432) is also observed, with a small set of well-adapted cross sections (BC, -+, 100 out of 432) observed (red lines). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

floodplain. The remaining 26 percent (113 of 432) of right-sided cross sections were observed to be undeveloped, with low to no residential value near or far from the river channel.

The Consumnes River in the southern end of Sacramento County also runs from east to west to its confluence with the Sacramento River; however, the Consumnes is one of few unregulated rivers remaining in the United States, with most surrounding land uses for agriculture and farming (Figures 4.58 and 4.59). As a result, the most frequent exposure types

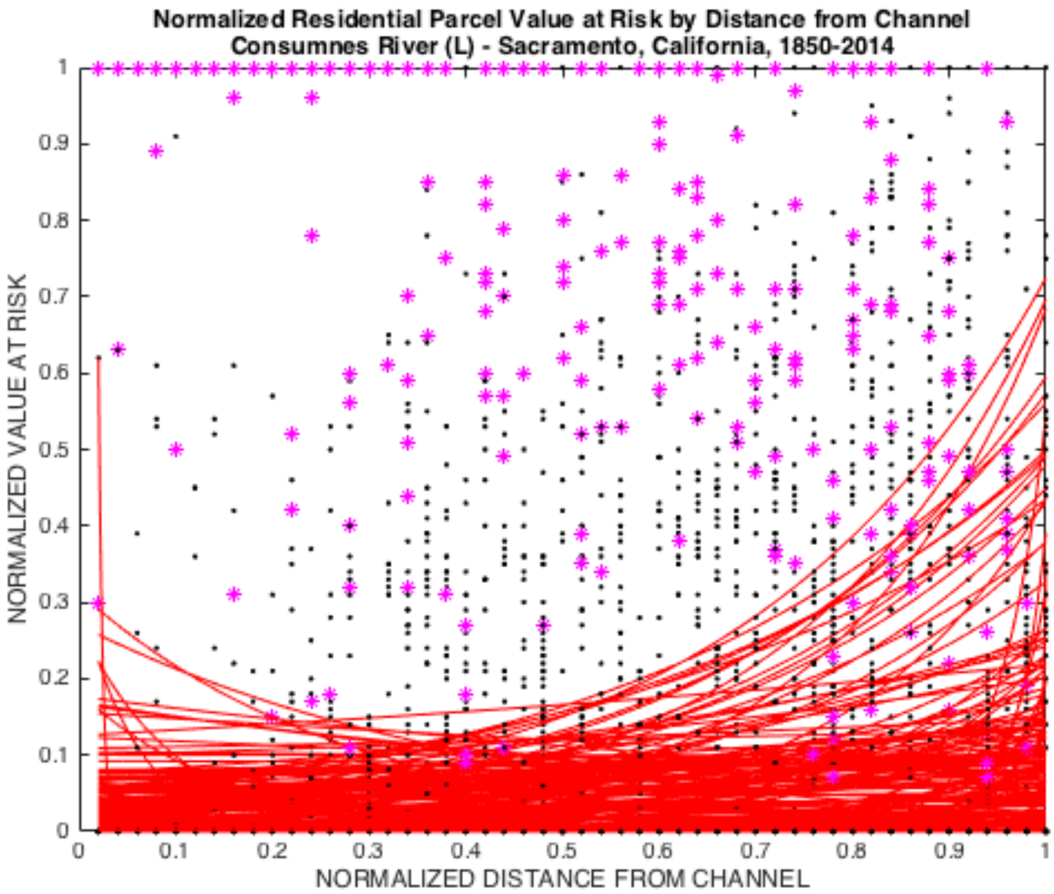


Figure 4.58. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Consumnes River channel, left side, yields mostly well-adapted development types (BC, -+, red lines), 60 out of 377 cross sections, likely reflecting both the non-structurally protected or regulated nature of the river and its floodplains, along with concerted efforts to conserve the river and its floodplains as a natural system. Some cross sections reveal residential encroachment on the river (AD, +-, 26 out of 337), however, and are likely related to the town of Wilton. Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

applied to the left side of the river is well-adapted, with 16 percent (60 of 337) observed as BC (-+); the right side had about 10 percent (37 of 377) observed as the same well-adapted type (Figures 4.54 and 4.55). There is residential encroachment on both sides of the river, with 8 percent (26 of 337) cross sections on the left side and 14 percent (47 of 337) on the right side typed as potentially adversely-developed (AD, -+); the residential parcels encroaching on the right side are related to the City of Elk Grove. A full build-out type (AC, ++) was observed for

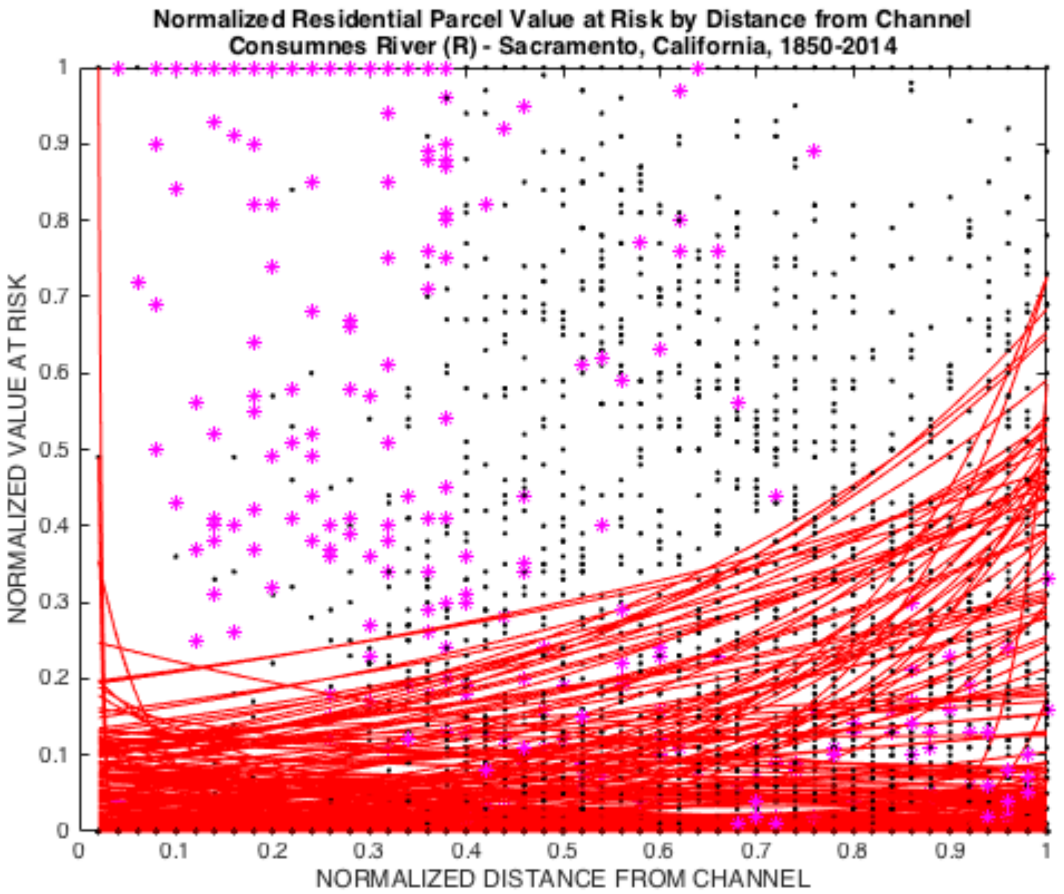


Figure 4.59. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Consumnes River channel, right side, yields mostly well-adapted development types (BC, -+, red lines), 37 out of 377 cross sections, likely reflecting both the non-structurally protected or regulated nature of the river and its floodplains, along with concerted efforts to conserve the river and its floodplains as a natural system. Some cross sections reveal residential encroachment on the river (AD, +-, 47 out of 337), and are likely related to the city of Elk Grove. Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values.

12 percent (45 of 377) of left side cross sections and for 6 percent (22 of 377) of the right side; however, these cross sections are not of high value, as rather low values were observed both near and far from the river channel, and it is possible that these cross sections could be typed as low to no development (BD, --), which were observed for 65 percent (246 of 377) and 72 percent (271 of 377) of left and right-sided cross sections, respectively.

The Sacramento River comprises the western boundary of Sacramento County, flowing generally from north to south, from the Natomas suburbs north of the City of Sacramento to the very wide delta at the confluence with the San Joaquin River in the southwest corner of the county (Figure 4.60). Residential development along the 410 cross sections for the left side of the river reflect the densest of the study areas, represented by the substantial number of black

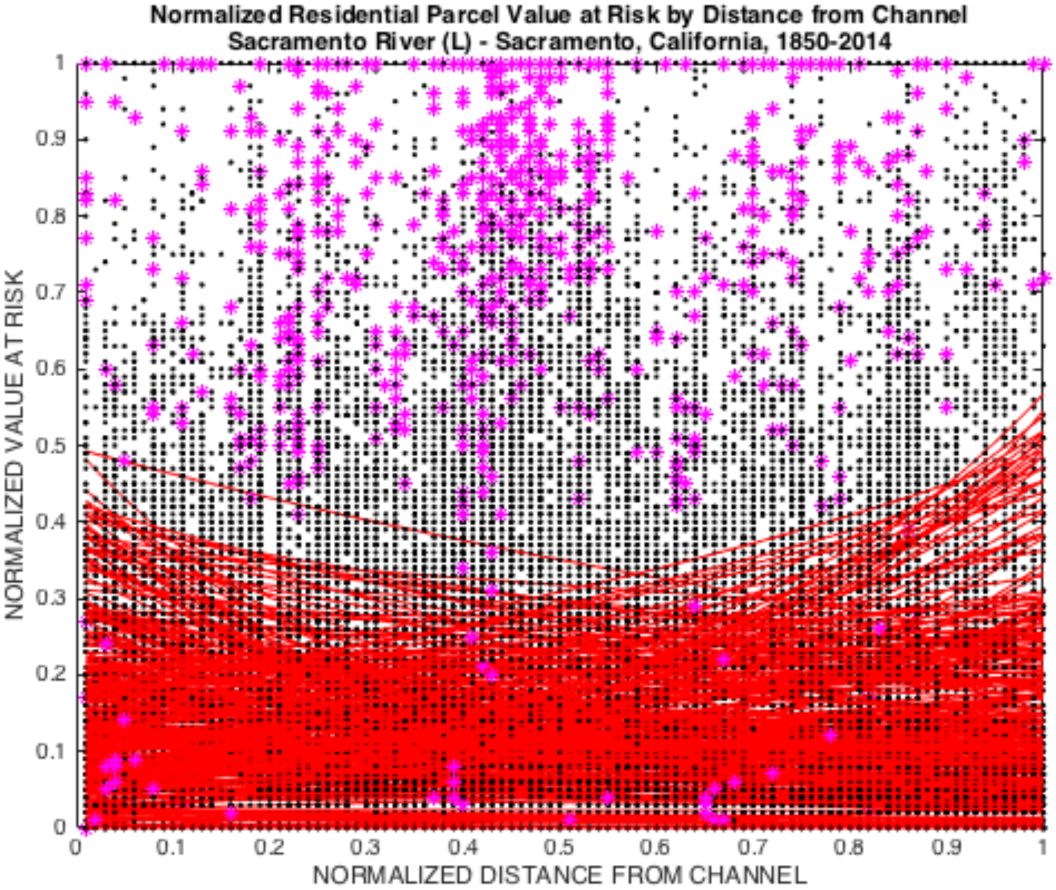


Figure 4.60. Exposure typology applied for normalized residential parcel value at risk over normalized distance from Sacramento River channel, left side, yields a substantial set of AD (+-) development types, 69 out of 410 cross sections, perhaps representing adverse floodplain development in levee-protected floodplains. A substantial set of medium buildout value cross sections (AC, ++, 204 out of 410—the most of the study areas in total and proportionally) is also observed, with a smaller set of well-adapted cross sections (BC, -+, 32 out of 410) observed (red lines). Black dots represent parcel value observations, and purple stars represent outlier values significantly departing from median values. Note that scaling the residential parcel data by distance normalization reveals the highly dense nature of residential development in Sacramento over the large area of Sacramento County.

dots on Figure 4.60. Similarly, the left side transects crossing the Sacramento River floodplain and non-floodplain uplands observed the most full build-out exposure types, with 50 percent (204 of 410) observed as AC (++), though the value observations are medium across the cross sections and not as high as observed for the American River left side. Although the next most frequent type assigned was low to no development (BD, --), with 26 percent (105 of 410) observed, another 17 percent (69 of 410) of cross sections were observed as potentially adversely-developed (AD, +-), with such observations occurring in the Natomas and Pocket suburban neighborhoods of Sacramento, where residential development immediately adjacent to the river channel and levee occurs, sometimes at distances of less than 100 meters from the channel and levee. Only 8 percent (32 of 410) of cross sections were typed as well-adapted (BC, -+), with these observations occurring south of the Pocket, where river-adjacent residential development has not yet occurred, and with the cross sections sampling the City of Elk Grove at furthest distances.

4.7.2 Sacramento County Residential Parcel Values

The residential parcel data for Sacramento County reveals interesting historical trends, based on 2014 assessed values by construction years, most notably for the very high proportion of homes built in levee-protected floodplains compared to the various NFIP flood zones (Figure 4.61). In the first half of the 1900s, almost 80 percent of homes constructed were in areas of the NFIP LPA (4.57, yellow line), which is about 15 percent less in area than the USACE LPA (4.61, black line). The USACE LPA is substantially different in area than the NFIP LPA due to levee accreditation which removes much of downtown Sacramento and its southern suburbs from the regulatory floodplain; moreover, the area marked as the Natomas LPA is the same as the NFIP A99 flood zone, which is based on marked improvements to the Natomas LPA that will

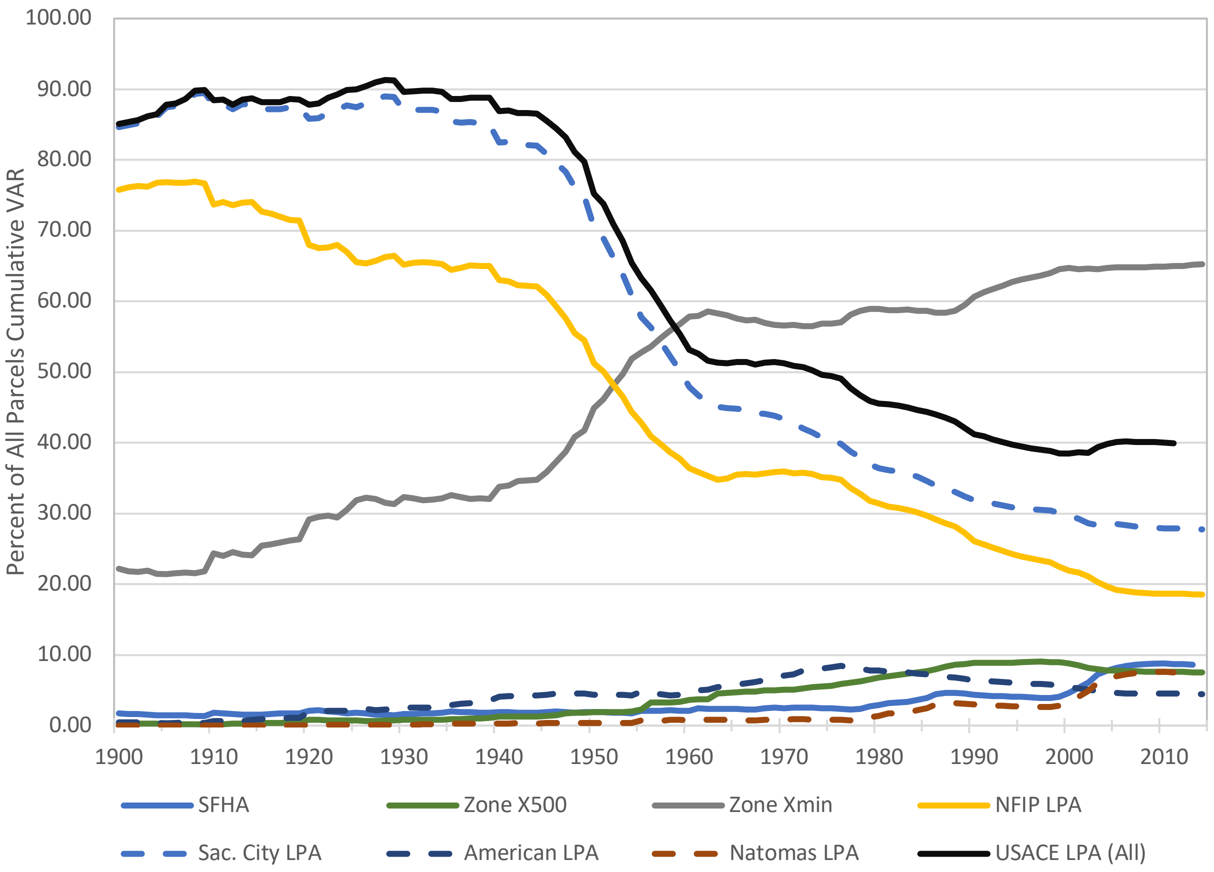


Figure 4.61. Percent of 2014 Sacramento residential construction year of construction and by flood zone and levee-protected areas. Proportions in LPA may add up to more than 100 percent due to overlapping LPA of the American and Sacramento Rivers.

result in complete removal of the area from the NFIP floodplain upon completion of improvement projects. There are several additional proportions of note on Figure 4.61, including the observation that only about 65 percent of residential development occurs in areas of minimal flood risk (gray line), and that less than 10 percent of homes in Sacramento County exist in the 500-year floodplain (green line) and, similarly, that less than 10 percent of homes are in the 100-year SFHA, likely reflecting the removal-by-policy as a result of the USACE levees protecting much of the City of Sacramento. Still, the proportion of homes built in the USACE and NFIP LPAs of Sacramento reflect a century-long decline, whereas homes built in areas of minimal flood risk demonstrates an increasing proportion since 1900 as construction appears to favor upland, non-floodplain areas; however, as of the end of records in 2014, nearly 30 percent of homes built in Sacramento County exist in the Sacramento River LPA, with another 10 percent in the American River and Natomas LPAs. Figure 4.62 demonstrates the substantial number of homes built in the LPAs of Sacramento County, with almost 120,000 homes built in the Sacramento River LPA in 2014 (4.62, solid dark blue line) with a cumulative value of about $26 billion (4.62, dashed blue line), more than 20,000 in the Natomas LPA (4.62, solid green line) with a cumulative 2014 value of about $8 billion (4.62, dashed green line), and about 18,000

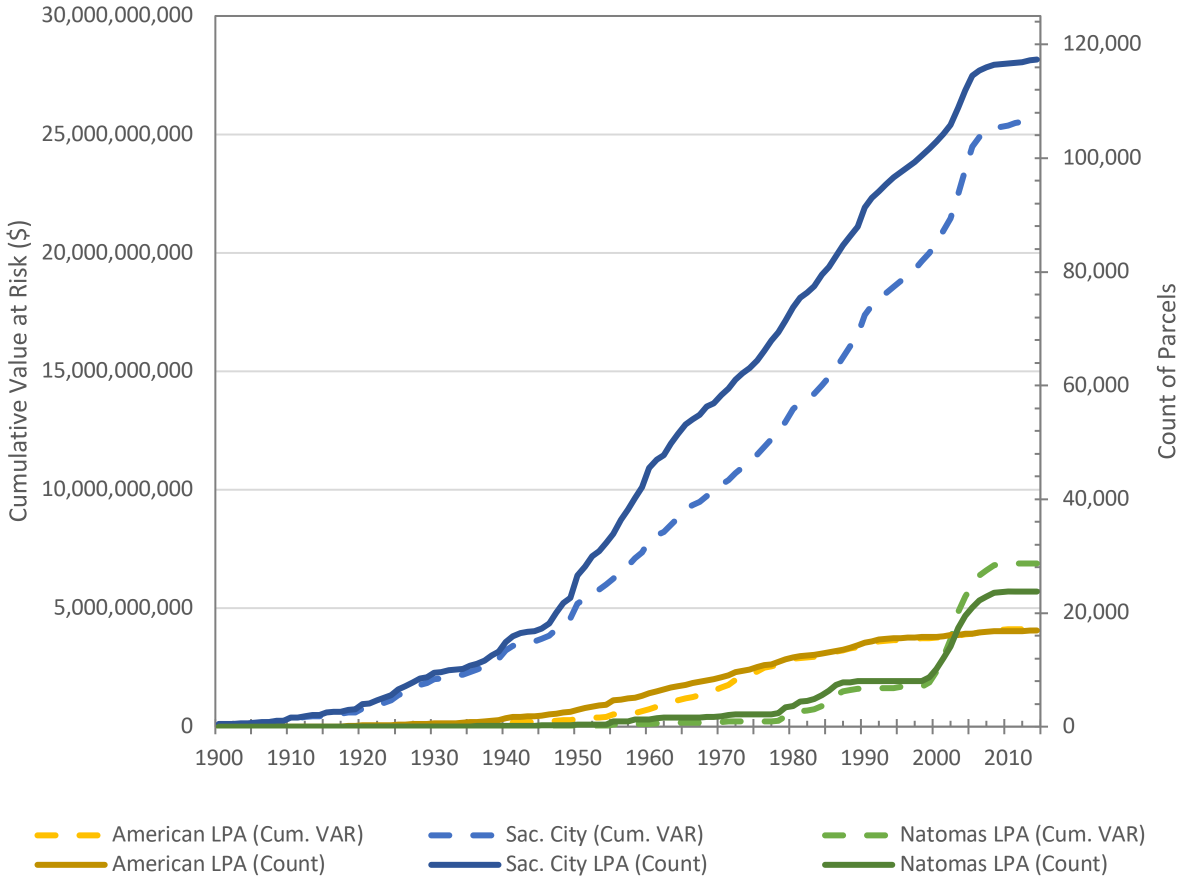


Figure 4.62. Cumulative 2014 value at risk and counts of residential parcels by year of construction in levee-protected areas of Sacramento County showing consistent increases in the city of Sacramento since levee construction in 1915, relatively steady growth in areas protected from the American River from 1950 to 2000 before leveling off, and rapid increases in quantity and value of residential parcels in the Natomas area in the 1980s and 2000s, notably reflecting flat growth during the construction moratoriums in the early 1990s and late 2000s.

homes built in the American River LPA (4.62, solid yellow line) with a cumulative 2014 value of about $4 billion (4.62, dashed yellow line). Taken together, nearly $38 billion of Sacramento County's residential parcels were constructed in LPA, which is notable for 100-year protection and lack of flood insurance purchase requirement, except for the Natomas Zone A99 LPA (Appendix D1 and D2, however, reveal a lack of insurance and construction requirements). Figure 4.62 also demonstrates a remarkable increase in 2014 value at risk by build year since the lifting of a construction moratorium: since 2000, about 14,000 new homes were built in Natomas with associated value at risk quadrupling over the same period.

Figure 4.63 demonstrates quite a bit of interannual value variability throughout the period of record (dotted gray line) for homes constructed throughout the period of record, based on 2014 assessed values, with homes valued at about $250,000 on average around build year 1900, declining to around $150,000 by 1950, and then increasing quickly to an average of about $400,000 by the 2010s. Second to the average of all parcel values are homes built in the USACE LPAs (4.63, solid dark gray line), at about $300,000, with homes not existing in the Natomas LPA until about 1918, about three years after levee construction was completed; homes in the Natomas LPA averaged about $100,000 in 2014 value from 1920 to 1980 (4.63, solid red line), when land speculation and development pressures began to promote residential construction. Since 1980, the average 2014 home value for the Natomas LPA tripled to nearly $300,000, which is about $50,000 more than the policy limits for NFIP coverage. Homes in the 100-year SFHA also averaged about $300,000 in value by 2014 (4.63, dark blue line), also about $50,000 over NFIP coverage limits, with homes in the areas of minimal flood risk averaging $50,000 less than the SFHA at about $250,000. Homes in the American River and NFIP LPA averaged around $240,000 by 2014 (4.63, solid yellow and gray lines, respectively), with homes in the

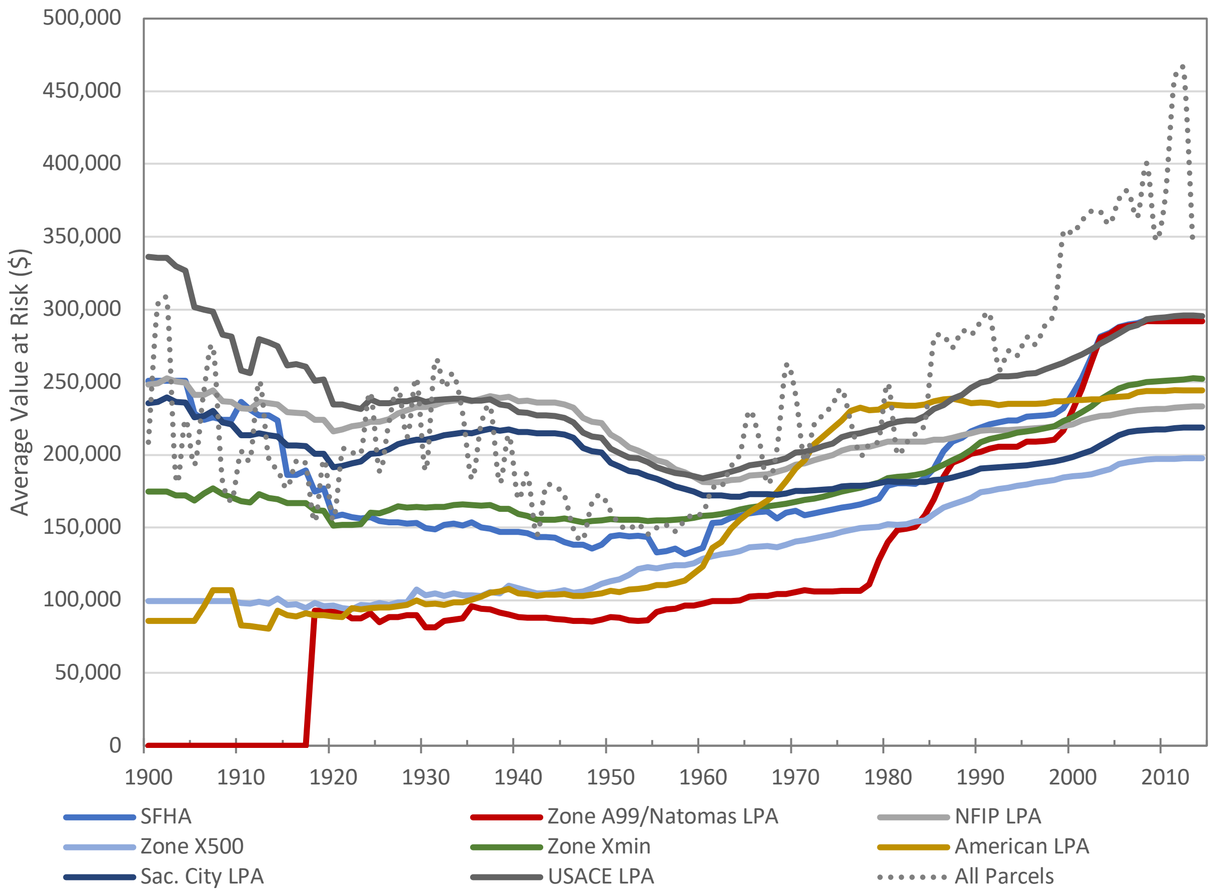


Figure 4.63. Average 2014 values by year of construction for Sacramento County flood zones and levee-protected areas. Parcels located in what would become the 100-year SFHA dropped substantially in value between 1900 and 1920. Average residential parcel values were generally stable from 1920 to 1950 before declining in the 1950s. Residential parcel values in all flood zones and levee-protected areas began steady increase from the 1960s to present, with levee-protected areas of the American River floodplain increasing rapidly following completion of the Folsom Dam in 1955. Levee-protected areas in Natomas as well as the 100-year SFHA increased in value rapidly since 1980 as a result of annexation into the city of Sacramento and ensuing real estate speculation.

Sacramento River LPA averaging about $230,000 in 2014 (4.63, darkest blue line). The lowest average home values occurred in the 500-year floodplain in 2014 (4.63, light blue line).

Average 2014 annual home values by date of construction vary much year-over-year in the 100-year SFHA and USACE LPA of Sacramento County, California from 1900 to 2014, with premiums realized early in the period of record but becoming consistent discounts through the second half of the record (Figure 4.64). Premiums for average 2014 home values in the USACE

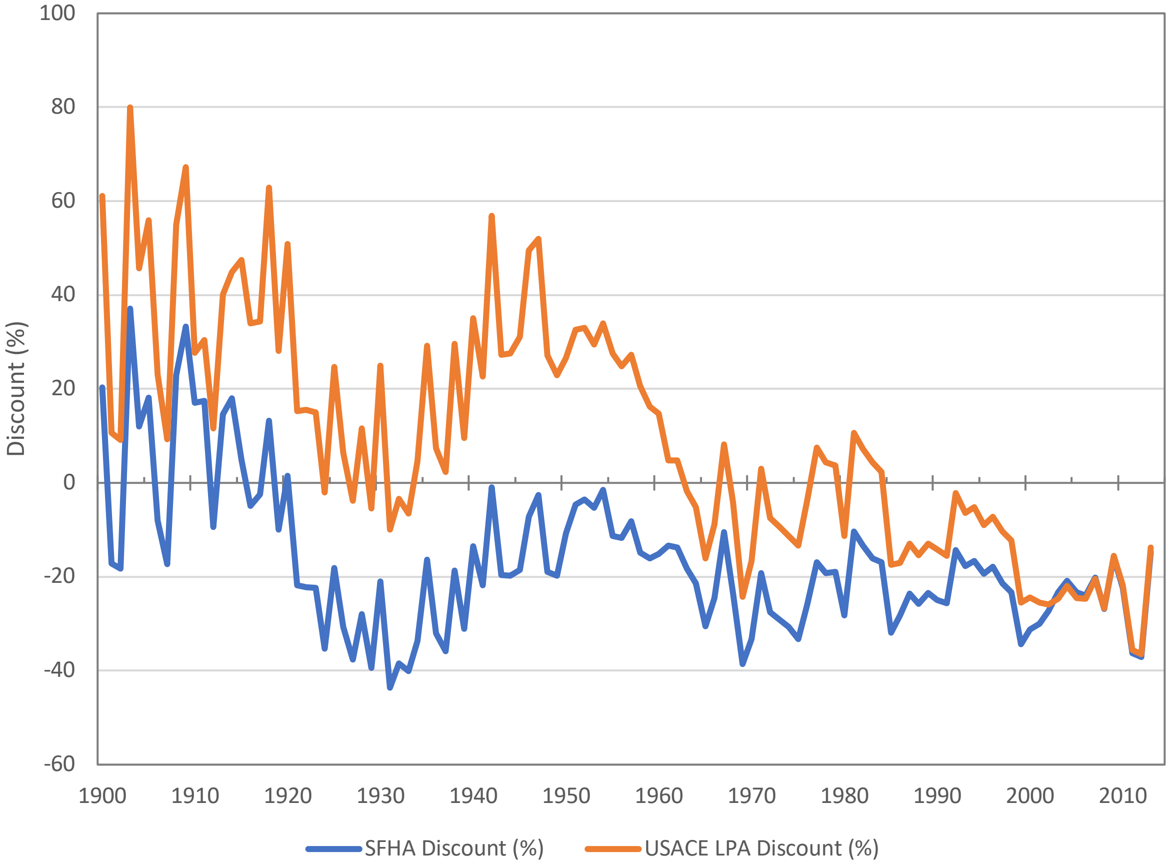


Figure 4.624. Estimated premiums and discounts for average 2014 home values by year built in the 100-year SFHA and USACE LPA of Sacramento County, California, 1900-2014, compared to the average value of all residential parcels.

LPA averaged about 50 percent over the value of all parcels in Sacramento County from 1900-1920, becoming near equivalent to all 2014 parcel values by 1930 before again increasing to about 35-40 percent over the average value of all homes through the 1940s. Notably, with the completion of Folsom Dam and levee improvements on the American River in the 1950s, the premium for average 2014 home values in the USACE LPA becomes a discount by the 1960s, slowly declining to a discount of about 20 percent under the average value of all homes in the county by 2014. Similarly, average 2014 home values in what would become the 100-year SFHA realized a premium of about 10 percent on average into the 1910s before becoming a consistent discount over the remaining period of record, dipping as low as 40 percent below the average of all parcels in the 1930s and then climbing to an average of about 5 percent discount into the 1950s. Since the 1960s, the SFHA discount averaged around 20 percent below the average of all home values in the county into the 2010s, with both the SFHA and USACE LPA average home values becoming nearly equivalently discounted at about 18 percent below the average of all homes in the county by 2014. While the premium for the USACE LPA was realized prior to 1960, the trend toward a discount from 1960 to 2014 appears to indicate that both flood risk and risk reduction benefits are capitalized into average home values for leveed areas at a rate commensurate with the 100-year SFHA average home values since about 2000.

4.7.3 Counterfactual Evaluation for Sacramento County

Given the abundance of data with which to evaluate potential levee effect on flood risk, DID estimation was conducted for seven cases in Sacramento using 2014 valuation and construction year data. Similar to the other study areas, the first case evaluated residential parcel values prior to and after the 1973 mandatory purchase requirement was implemented through the NFIP for homes both inside and outside of the 100-year SFHA (Figure 4.65). Prior to 1973, homes outside of what would become the SFHA were \$172,906 on average in 2014, whereas these non-SFHA homes in the post-1973 condition were \$293,797 on average—a difference of \$120,891. Homes in what would become the SFHA were \$177,663 on average in 2014 prior to 1973 and were \$278,825 on average after 1973, for a difference of \$101,163. Subtracting the control condition from the treatment yields a net effect of \$19,728, meaning that, while all homes averaged more in value throughout the county, homes in the 100-year floodplain averaged significantly less in value than homes outside the floodplain, consistent with findings in the other study areas previously described.

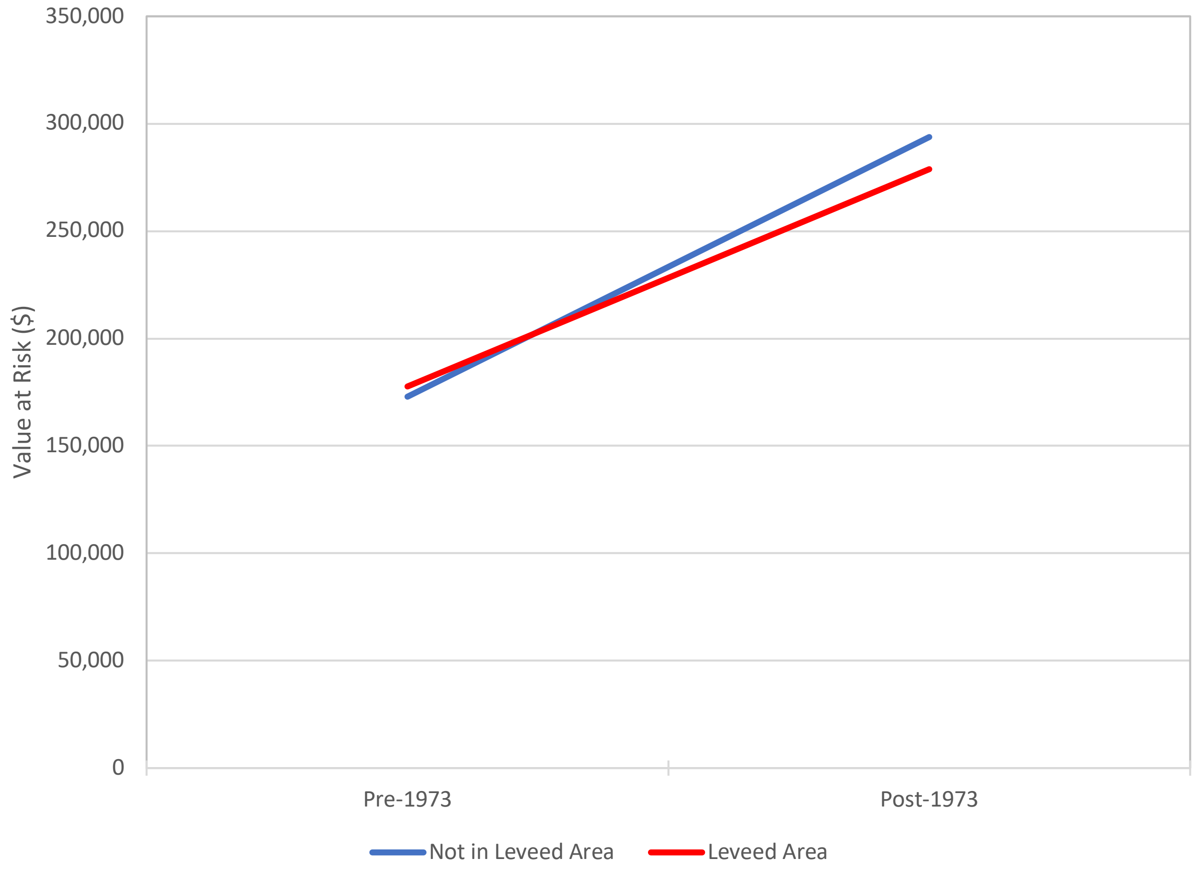


Figure 4.65. DID analysis for 2014 pre-1973 and post-1973 residential construction value, showing that homes in the SFHA and non-SFHA areas of Sacramento County increased in value overall. However, parcels in non-SFHA areas of Sacramento County increased in value at a greater rate on average (control, $120,891) than those in SFHA (treatment, $101,163), for a net effect of residential construction in SFHA valued at $19,728 less than non-SFHA residential construction on average.

The second case evaluated parcel values in relation to the completion of levee construction in 1915, comparing residential parcel values in leveed and non-leveed areas for the period of pre-1915 and 1915-1930 (Figure 4.66). Homes in the non-leveed areas of Sacramento County built prior to 1915 were valued at $228,084 on average, in 2014 and for the period of 1915-1930 these parcels were valued at $166,683 on average, a difference of $61,401 less on average in the post-levee construction period. However, homes in LPA prior to 1915 were valued at $209,412 on average and at $202,252 on average following levee completion, per 2014

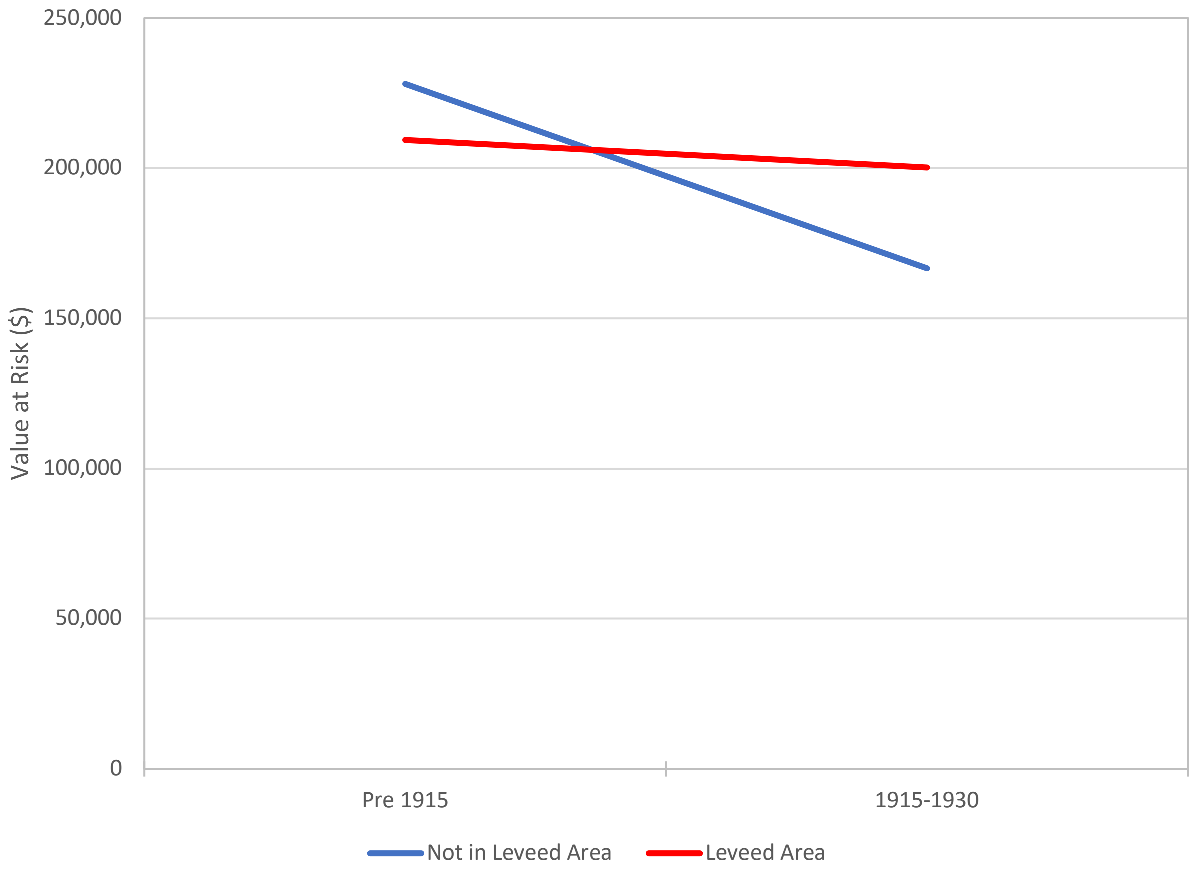


Figure 4.66. DID analysis for 2014 pre-1915 and 1915-1930 residential construction value, showing a substantial decline in non-leveed area residential value (control) and a slight decline in levee-protected residential value (treatment), giving a net effect of $55,241 increase in levee-protected residential construction.

valuations, a difference of only $9,160 less on average. Subtracting the non-levee control condition from the leveed treatment condition yields a net effect of $52,241, a significant difference wherein all homes in the county averaged less in value but where homes in the LPA maintained average values by much more than homes outside the leveed floodplains. This finding is consistent with both USACE policy intent of improving and protecting residential values in LPA and with increased residential flood risk in the form of levee effect.

For the next period, the third case evaluated whether the homes situated in the Sacramento River LPA maintained values compared with homes outside of the LPA throughout

Sacramento County following improvements to levees and the Folsom dam along with new levee construction, for a pre-condition group of 1930-1955 and a post-condition group of 1955-1973 based on 2014 valuation and construction year data (Figure 4.67). For the non-LPA homes constructed prior to 1955, the average value was $149,160; for the non-LPA homes constructed after 1955, average values were $186,561, an increase of $37,401 on average. For homes constructed in the Sacramento River LPA prior to 1955, average values were $175,679; for homes constructed in the LPA after 1955, the average 2014 values were $164,908, slightly less than non-LPA homes, for an average decrease in value of $10,771, yielding a net effect of homes

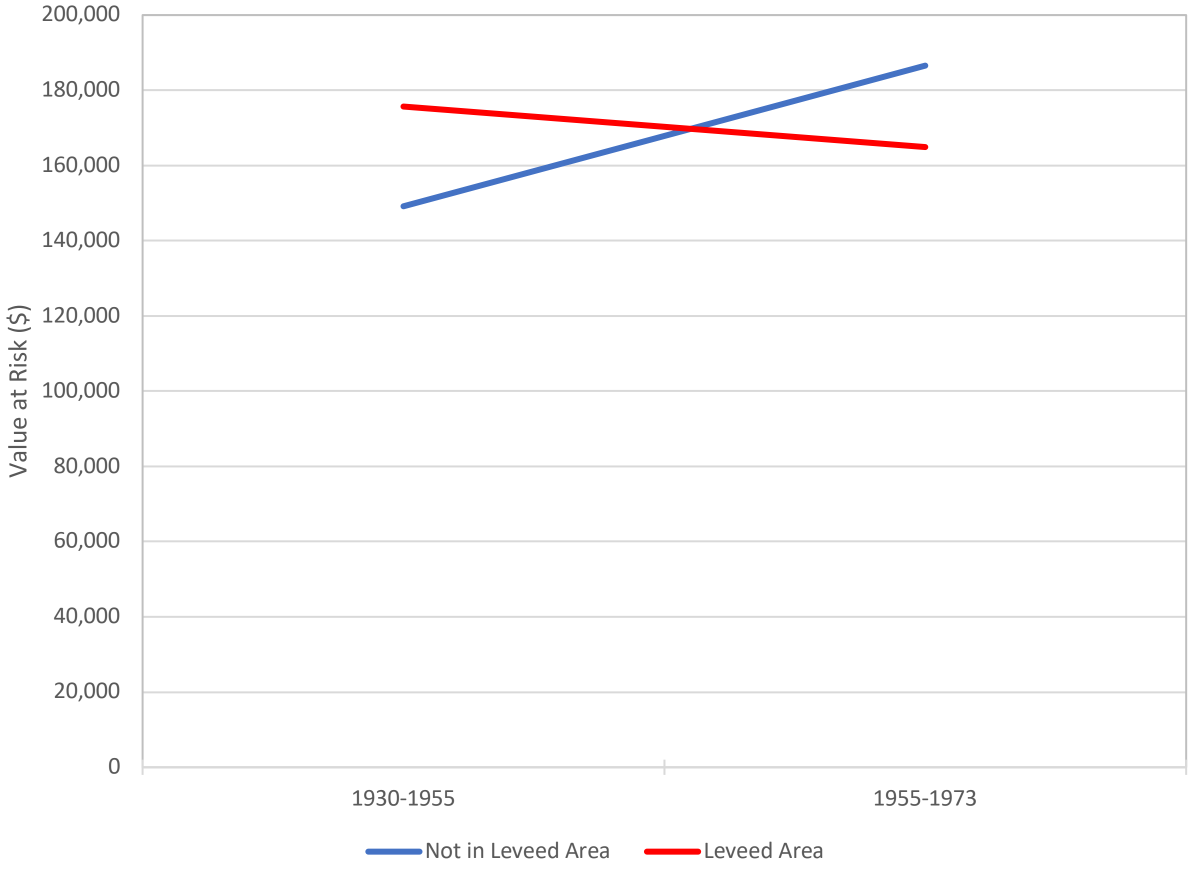


Figure 4.67. DID analysis for 1930-1955 and 1955-1973 residential construction value (2014) for the Sacramento River levee-protected area compared to the rest of Sacramento County, showing an increase in non-leveed area residential value of about $37,401 (control) and a decrease in levee-protected residential value of about $10,771 (treatment), giving a net effect of $48,172 decrease in levee-protected residential value over non-leveed areas.

in the LPA valued $48,172 less compared to non-Sacramento River LPA homes. This is an interesting finding demonstrating that the LPA homes constructed were less valuable compared to homes constructed outside of the Sacramento River LPA, suggesting that areas outside of the floodplain were more appealing for home construction. However, the fourth case demonstrates a more specific finding: homes both inside and outside the LPA for the same time periods, 1930-1955 and 1955-1973, were evaluated relative to the American River levee and Folsom Dam improvements as compared to the rest of Sacramento County (Figure 4.68). Homes in the non-American River LPA were $166,318 on average prior to 1955, and, after 1955, these homes were

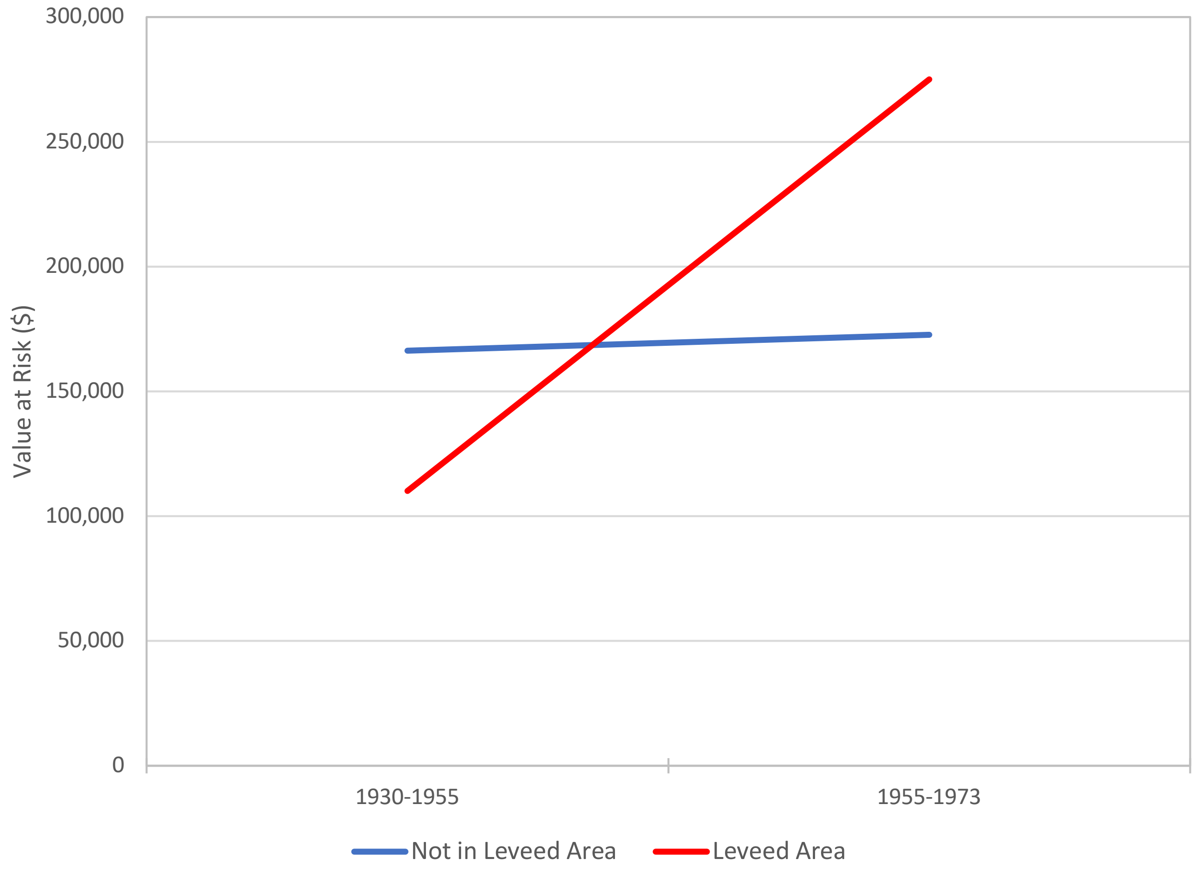


Figure 4.68. DID analysis for 1930-1955 and 1955-1973 residential construction value (2014) for the American River levee-protected area compared to the rest of Sacramento County, showing an increase in non-leveed area residential value of about $6,373 (control) and an increase in levee-protected residential value of about $164,923 (treatment), giving a net effect of $158,550 increase in levee-protected residential value over non-leveed areas.

valued at $172,691 on average in 2014, an increase of $6,373. In the American River LPA, homes were valued at $110,114 on average prior to 1955; after levee and dam improvements in 1955, homes constructed in the American LPA averaged $275,037 in value for an increase of $164,923 for a significant net increase of $158,550 more than homes constructed outside of the American River LPA—the American LPA construction for this period reflects the depressed post-condition for the Sacramento River LPA, revealing that one leveed area poached the values of another in the same county. This finding for homes constructed in the American River LPA is possibly related to the new and improved structural flood control and is a case of levee effect, given that non-LPA construction was available and, yet, potential adverse development occurred regardless.

The fifth case for Sacramento County used DID evaluation for homes constructed in the period following improvements to the American River levees and Folsom Dam, 1955-1973, to those constructed in the period following introduction of mandatory flood insurance purchase requirements for homes in the 100-year SFHA, 1973-1980 (Figure 4.69). For homes constructed in the non-LPA of Sacramento County from 1955-1973, values averaged $180,637 in 2014; after 1973 and up to 1980, homes constructed in the non-LPA averaged $210,655 in value, an increase of $30,018. For homes in the LPA of Sacramento County in the period of 1955-1973, values averaged $183,450, starting slightly higher than non-LPA homes for the same period; from 1973-1980, homes constructed in the LPA were valued at $225,631 on average, an increase of $42,181. As homes constructed in both LPA and non-LPA increased, subtracting the control group from the leveed treatment group reveals a net effect of LPA homes increasing in value by $12,163 on average more than non-LPA homes, based on 2014 valuations, maintaining an effect of increasing flood risk in all areas of Sacramento County's leveed floodplains by increasing

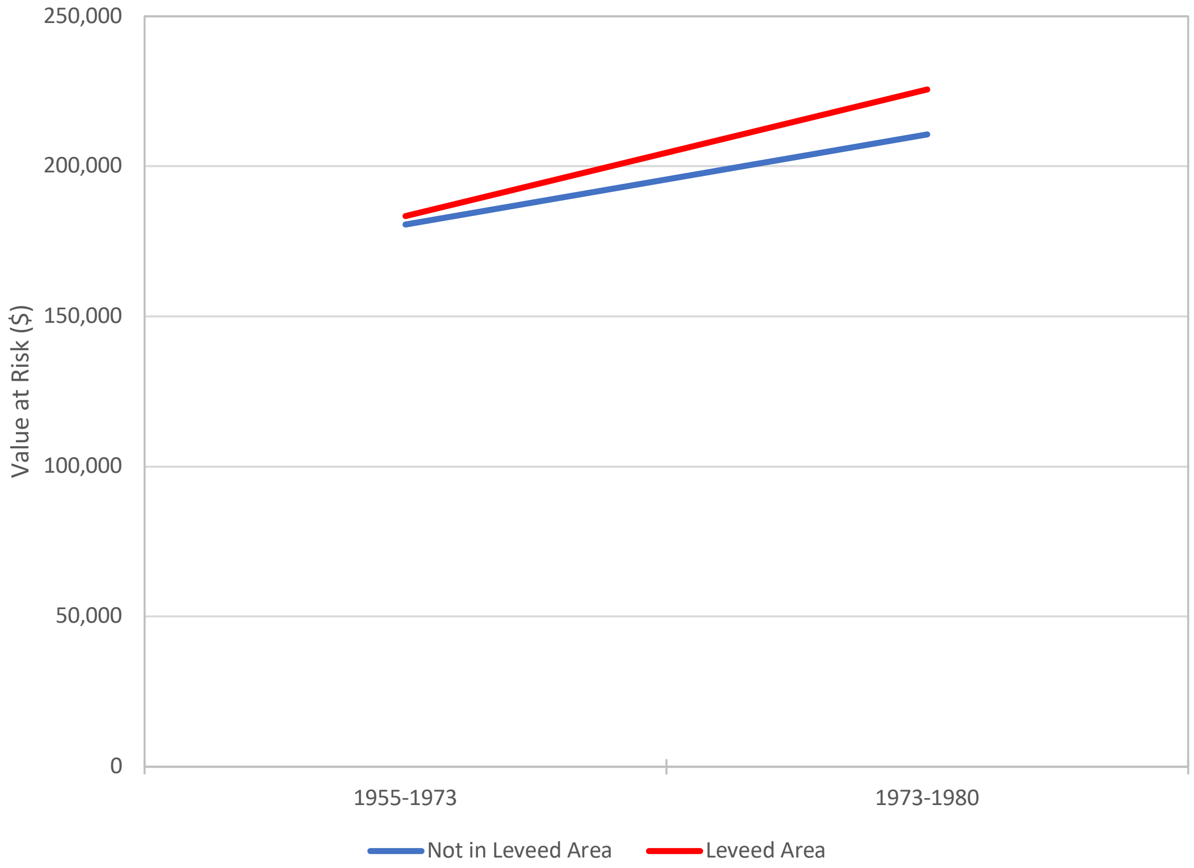


Figure 4.69. DID analysis for 1955-1973 and 1973-1980 residential construction value (2014), showing an increase in non-leveed area residential value of about $30,018 (control) and an increase in levee-protected residential value of about $42,181 (treatment), giving a net effect of $12,163 increase in levee-protected residential value over non-leveed areas.

exposure—there is also no notable effect of the NFIP mandatory flood insurance purchase requirement on the homes constructed in the LPA, likely due to the 100-year LPA not being depicted in FIRM.

The remaining two cases focused on a similar influx of residential development in the Natomas area north of the confluence of the American River with the Sacramento River following levee improvements and lifting of building moratoria. In the first Natomas case (Figure 4.70), DID evaluation for Natomas LPA home construction compared to the rest of Sacramento County for the periods of 1973-1980 and 1980-1994 was carried out. For the homes constructed outside of the Natomas LPA, 2014 values averaged $216,811 prior to 1980; after 1980, homes constructed outside of the Natomas LPA averaged $262,327 in value, an increase of $45,516. For homes constructed in the Natomas LPA prior to 1980, 2014 values averaged $165,758; after 1980 and up to 1994, homes constructed in the Natomas LPA averaged $260,055 in value, similar to non-Natomas home values, for an increase of $94,297. Subtracting the control condition from the treatment yields a net effect of homes in the Natomas LPA increasing $48,780 more on average by build year than homes outside the Natomas LPA. This finding reveals that the levees protecting Natomas may be related to increased home values, and,

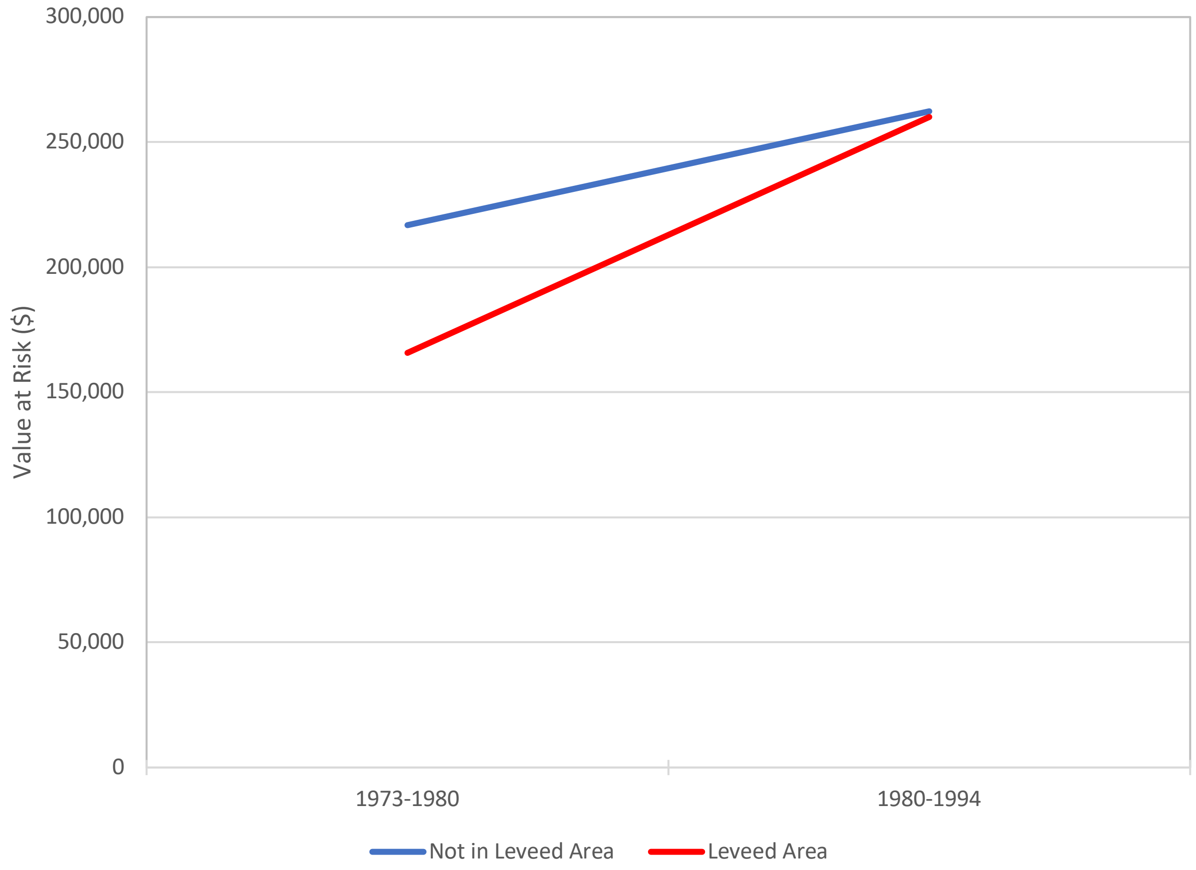


Figure 4.70. DID analysis for 1973-1980 and 1980-1994 residential construction value (2014) for the Natomas levee-protected area compared to the rest of Sacramento County, showing an increase in non-leveed area residential value of about $45,516 (control) and an increase in levee-protected residential value of about $94,297 (treatment), giving a net effect of $48,780 increase in levee-protected residential value over non-leveed areas.

therefore, flood risk. The final case for Sacramento again evaluates the Natomas area for the period of 1980-1994 and 1994-2014, the latter period chosen to follow the lifting of the construction moratorium (Figure 4.71). For homes outside of the Natomas LPA prior to 1994, 2014 values averaged $278,070; after 1994, homes constructed outside of the Natomas LPA were $351,725 in average value, an increase of $73,656. For homes constructed in the Natomas LPA prior to 1994, values averaged $233,713; after 1994, homes built in the Natomas LPA averaged $334,486 in value, increasing by $100,772. Subtracting the non-Natomas control condition from the Natomas LPA condition yields a net effect of homes in the Natomas area

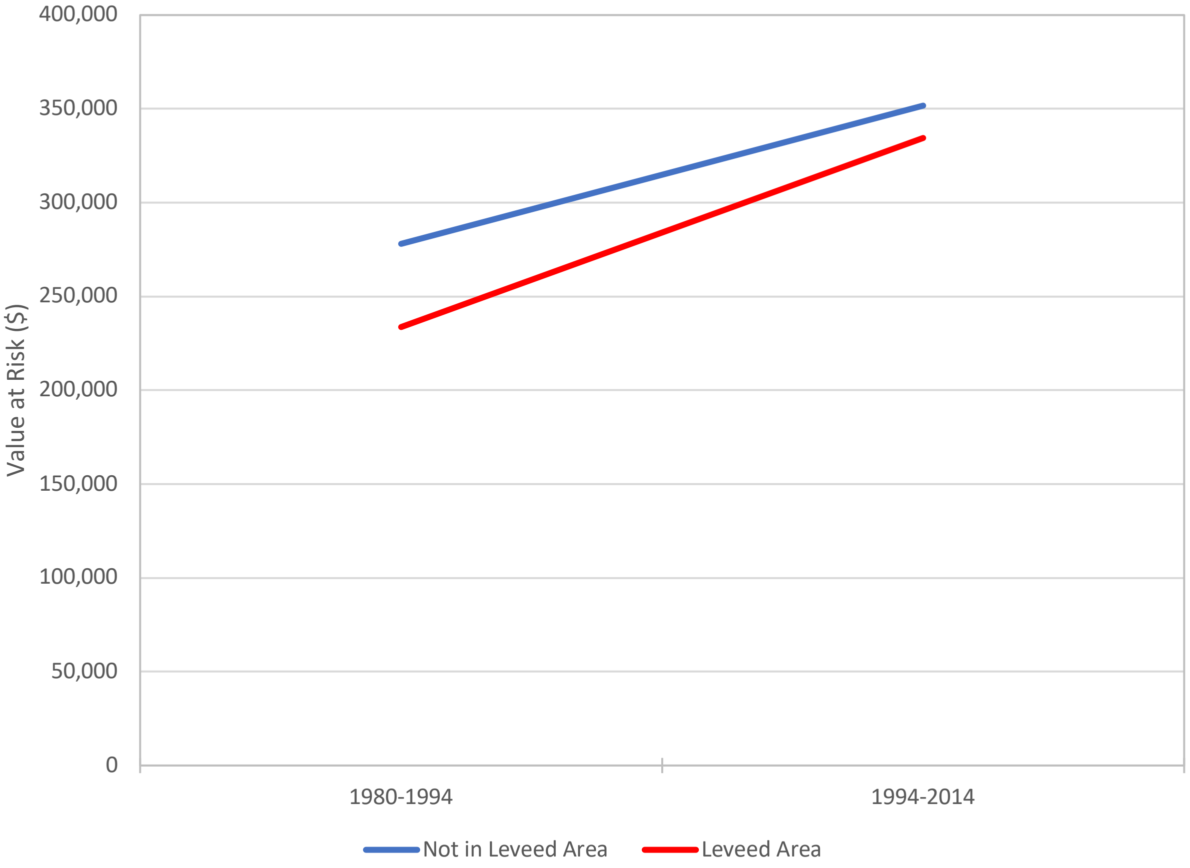


Figure 4.71. DID analysis for 1980-1994 and 1994-2014 residential construction value (2014) for the Natomas levee-protected area compared to the rest of Sacramento County, showing an increase in non-leveed area residential value of about $73,656 (control) and an increase in levee-protected residential value of about $100,772 (treatment), giving a net effect of $27,117 increase in levee-protected residential value over non-leveed areas.

assessed in average value by $27,117 more than the non-Natomas homes constructed, maintaining the increase observed from the prior case.

4.7.4 Parcel Value Densities and 2050 Scenarios for Sacramento County

Cumulative residential parcel value densities are reflected in Figure 4.72 on a decadal basis for 1921-2014 with all parcel values for pre-1921 shown in Panel A. The Sacramento River forms the western boundary of Sacramento County, with the American River flowing from east to west in the northern half of the county and the Consumnes River flowing from east to west in the southern half of the county. A distinct hot spot of higher residential values emerges by Panel C, 1931-1940, as the downtown area of the City of Sacramento becomes a locus of construction activity. This high value-density area grows through the 1940s, and residential development in the American River area stands out for high value-densities in the 1950s, Panels D-E, 1941-1960, with densification and higher values continuing through the 1970s around and north of the American River through the 1970s, Panels F-G, 1961-1980. After the Pocket neighborhood was annexed into the City of Sacramento, residential construction and high value-densities are observed in the 1980s along with development pushing further south in the Sacramento River

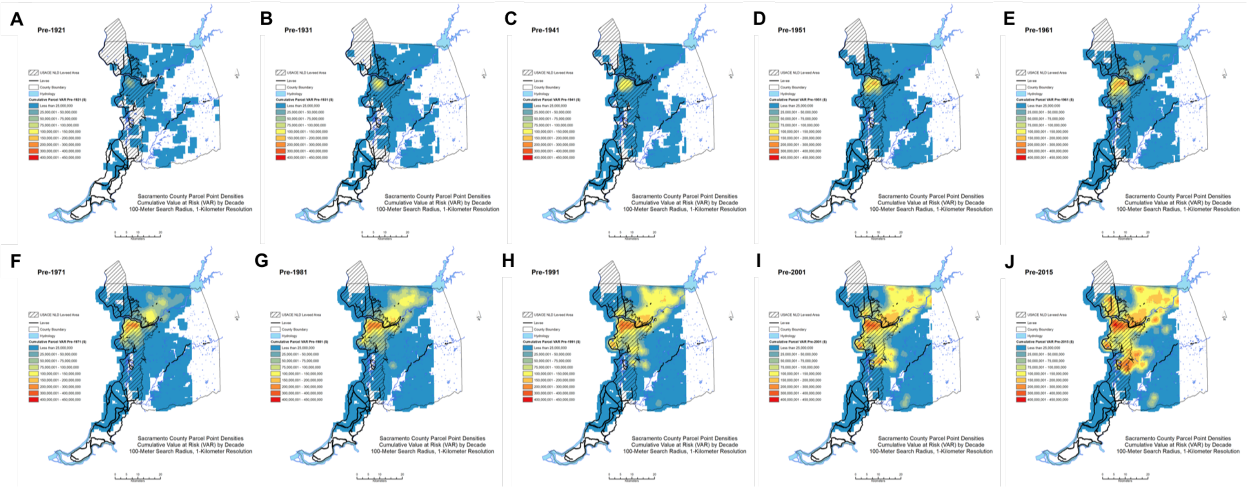


Figure 4.72. Cumulative 2014 residential parcel densities for Sacramento County, California, 1850-2014, reflecting the growth of the City of Sacramento into suburban and levee-protected floodplains along the Sacramento and American Rivers. (Full sized maps are located in Appendix B.)

LPA, Panels H-J, 1981-2014. Areas along the Consumnes River are lower in value and density, cumulatively, compared to the more urban areas of Sacramento County throughout the period of record.

With residential construction expanding through the USACE LPAs of Sacramento County, Figures 4.73, 4.74, 4.75, and 4.76 offer parcel value growth scenarios, fitting regression models to historical observations and extrapolating to the year 2050 with 99% confidence bounding. With cumulative value at risk of more than $30 billion in the Sacramento River LPA by 2014, Figure 4.73 reflects a linear growth model extrapolated to 2050, suggesting that cumulative home value may reach $40 billion; however, while this best-fit model performs quite well for historical values, the model demonstrates rather unpredictable behavior in latter decades,

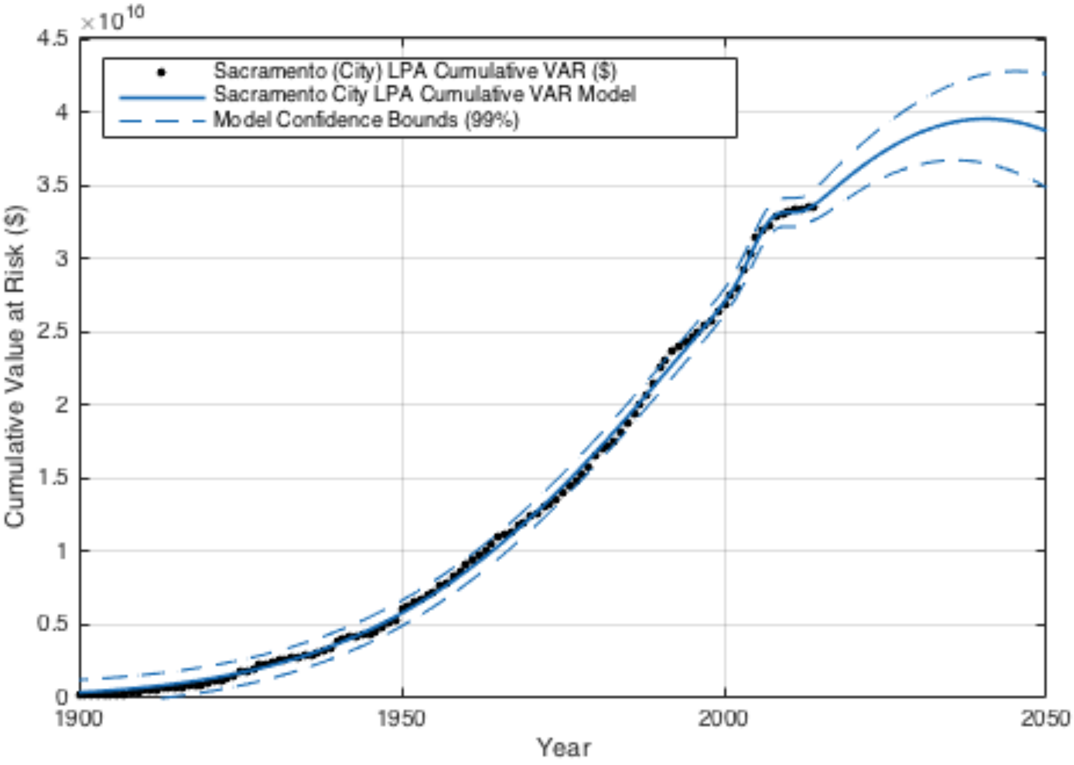


Figure 4.73. Forecasted increase in cumulative residential parcel values in the City of Sacramento's levee-protected areas.

thus, the confidence bounds offer a range of potential values of near same as 2014, indicating that full build-out may have been reached already, and up to about $43 billion. Similarly, Figure 4.74 demonstrates a best-fit linear model that agrees well with historical observations and model behavior that is very uncertain in the extrapolation to 2050; however, the best-fit model appears also to suggest that full build-out of the American River LPA has or will occur in the near future. Figure 4.75 depicts a best fit growth model for the Natomas LPA for a slow-to-moderate growth scenario. The paucity of higher value observations for the Natomas LPA, given its more recent growth compared to the other LPAs, yields a substantial spread in confidence bounds, offering a range of near-similar-to 2014 values of about $10 billion, or up to $30 billion by 2050. One can interpret Figure 4.76 in a number of ways: first, as a statistical construct, the regression model performs somewhat poorly for the dataset; second, given the understanding of flood hazard in the

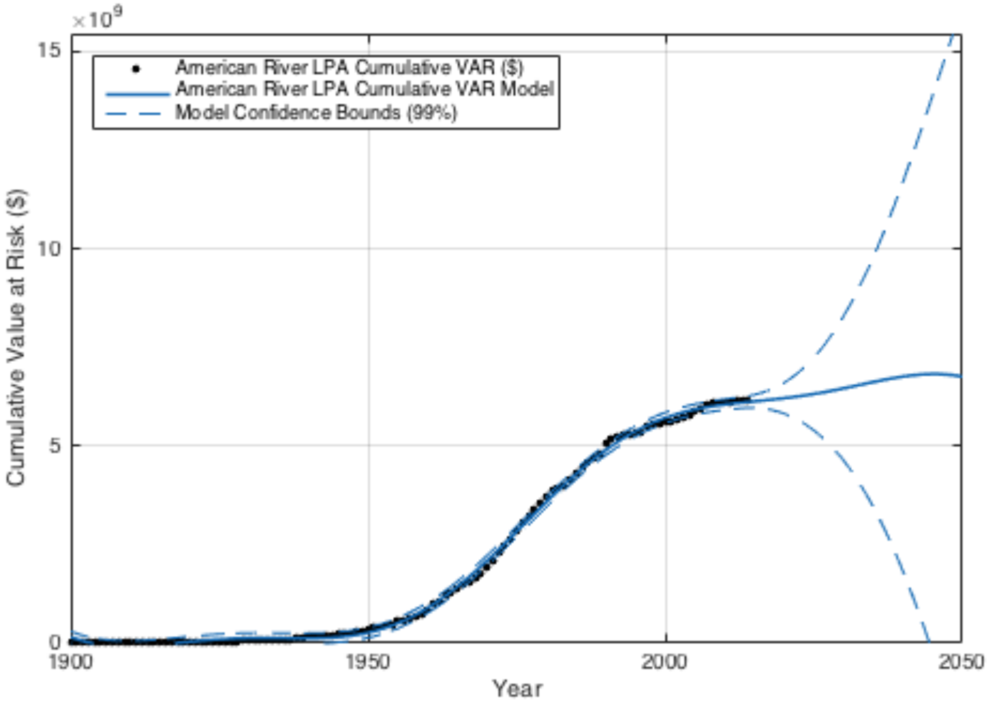


Figure 4.74. Forecasted increase in cumulative parcel value in levee-protected areas of the American River in Sacramento County.

area, the lower confidence bound may suggest a reduction in cumulative parcel values that could occur with a major flood; and, third, the upper confidence bound may reflect a more exponential growth trend, which is consistent with development speculation and pressure to build. Accordingly, Figure 4.77 offers a more exponential growth in cumulative values that both better agrees with historical observations and provides tighter confidence bounding, suggesting that values in aggregate for the Natomas LPA may range about $33 to $42 billion by 2050, quadrupling in value similar to the increase in average home value observed in the Natomas LPA since 1980.

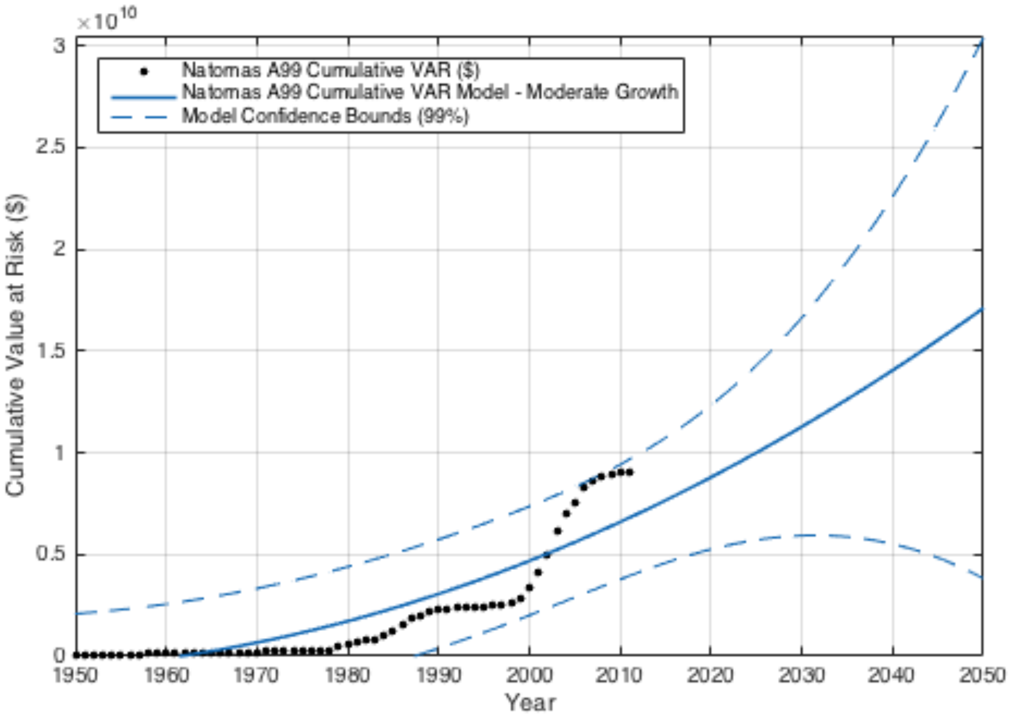


Figure 4.75. Moderate growth scenario for residential parcel values in Natomas levee-protected areas through 2050.

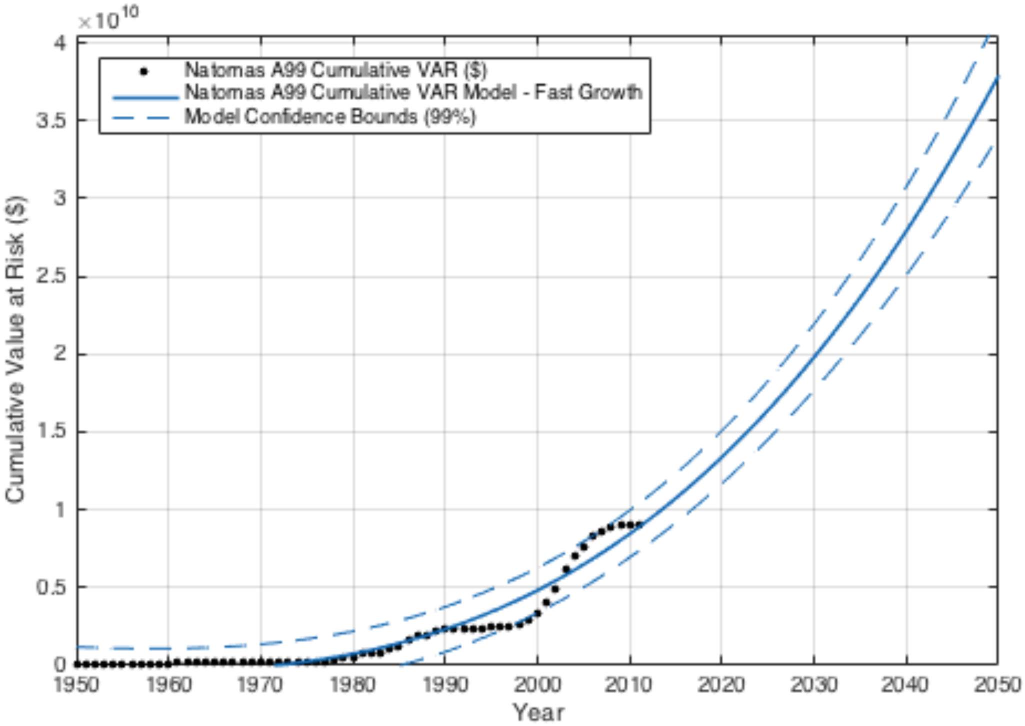


Figure 4.76. Fast growth scenario for residential parcel values in Natomas levee-protected areas through 2050.

4.8 Conclusion

The residential exposure typology applied to the study areas found that most riverine areas of the study area counties remain undeveloped. Given that the cities in the study area counties range from moderate to large populations, urban areas were observed to have potentially adverse to well-adapted residential development types, along with a robust set of full build types, as these cities were initially founded alongside rivers that offered support to transportation, agriculture, and territorial development. In general, the values of residential parcels improved greatly in each of the study areas, based on 2014 assessed values and construction years, demonstrating the economic development of the study areas. Notably, the Iowa City study area established a pattern repeated in each of the study areas—that floodplains and associated lowlands of riverine flood hazard are generally lower in 2014 assessed value than higher elevation uplands, except for the Sacramento area, which is substantially engineered to boost residential parcel values. The higher residential parcel values in Sacramento reflect the larger scale of this urban area, but the higher 2014 values in areas like the Natomas LPA also reflect exposure to flood hazard that exceeds NFIP policy coverage and, therefore, possibly higher vulnerabilities to flood hazards. By evaluating counterfactual conditions for homes not in levee-protected floodplains built both before and after levee completion, it is possible to evaluate how structural flood control affects flood risk, validating and building on studies that demonstrate a safe construction paradox: that flood losses, though increasing in absolute terms of exposed buildings and value at risk, remain flat as a proportion of total residential values in the study areas, based on 2014 assess value at risk by construction year. Further, residential value densities and forecasts illustrate conditions where such proportions, for some counties, should remain roughly the same through 2050; however, Natomas represents a case where both absolute and proportionate values at risk may increase substantially. Chapter 5 will synthesize these findings with other research to form some conclusions about flood risk and the levee effect.

CHAPTER 5: DISCUSSION & CONCLUSIONS

There are many findings from the methods used and analyses performed to evaluate the effects of levees and flood risk in the study areas. In addition to the empirical findings, the in-depth review of literature related to the issue of levee influence on flood risk provides a necessary background for the conclusions reached in this study. This chapter will reflect on the methodologies, findings, and relevant literature in a discussion and summation of the research conducted for this dissertation.

5.1 Summary of Findings and Results

The findings illuminated by the research methodology used in this dissertation revealed interesting observations and similarities across scales for the study areas and datasets. First, the development of a residential exposure typology established a basis to examine cumulative parcel value at risk as a function of distance relative to river channels and floodplain, whereby areas of potentially adverse development were identified; moreover, the cross sections were also useful for identifying areas of historic center centers, with full build-out conditions, and well-adapted, less risky residential exposure. Second, the use of year of construction as a means to evaluate differences in 2014 residential parcel values provides a basis for considering changes in exposure in floodplains, leveed areas, and non-floodplain areas.

5.1.1 Exposure and Risk

Surprisingly, the cross-section exposure analysis revealed substantial undeveloped areas throughout the riverine floodplain areas studied. These cross sections will be useful for future research and development of scenarios for how residential floodplain occupation may proceed: for example, a model for examining flood risk can be developed with weighting schemes favoring certain development types over others, allowing floodplain risk managers to assess a range of choices about exposures in certain areas (cf. di Baldassare et al 2015). However, while the undeveloped exposure type was the most frequent observation, accounting for 60 percent of cross-section types, the Sacramento study area was notable for having fewer undeveloped cross sections than those representing some level of residential occupation: in fact, the left side of the American River at Sacramento had more potentially adverse exposure types than any other, accounting for 28 percent of the samples along this river and 3 percent of all samples across the study areas. Likewise, the left side of the Sacramento River demonstrated the most full build-out types, accounting for 50 percent of the samples along this river—that is, full residential build-out along about 20-kilometers (9.1 miles) of river length—and almost 5 percent of all cross sections across the study areas. This shows the extensive scale of flood risk to homes in Sacramento County, the largest metropolitan area evaluated in this study and home to more than 1.4 million people and some 375,502 residential parcels valued at more than $92 billion—nearly one-quarter of residential flood exposure nationwide by some estimates (cf. Kunreuther et al 2018, p. 17). In contrast, the Johnson County, Iowa study area was the smallest, with only about 19,609 parcels valued at about $3.5 billion. However, while the research design used in this dissertation took into consideration assumed counterfactuals for all study areas, evaluating the difference in mean valuation for tax year 2014 for residential parcels located inside and outside of levee-protected areas and floodplains, the Iowa City study area provided a real-world case to observe changes in flood risk over time for a non-levee protected American city: accordingly, though its overall residential exposure to flood risk is lower on an absolute basis, Iowa City had the least potentially adverse development types sampled of the study areas and the least as a proportion of the types applied, accounting for 19 percent along the left and 9 percent along the right for all cross sections in Johnson County. There were, however, along the right side of the Iowa River, a larger set of full build-out types near the historical center of Iowa City, likely related to the development of the University of Iowa. Interestingly, both the Waterloo-Cedar Falls and Tulsa study areas had relatively substantial full build-out exposure types as a proportion of other exposure types, except for undeveloped, with full build-out observed most frequently for parcels with low to high value, except for the right side of the Arkansas River downstream of the City of Tulsa, where potentially adverse development occurs at the City of Jenks in a levee-protected area. The Haikey Creek area of Tulsa County also stands out for its NFIP-accredited levee, the only such area of Tulsa County, and an area demonstrating a potentially adverse development type as no residential development existed in this floodplain prior to the 1970s.

Some judgments about the residential construction types observed in Tulsa County at Haikey Creek are possible, given that the parcel data described these homes as slab-on-grade, concrete foundation structures with average values much higher than other levee-protected areas. With the NFIP accreditation of the levee at Haikey Creek, there is no mandatory purchase requirement for flood insurance. Without the levee, insurance would be required of these homes given their location in an otherwise 100-year flood zone; moreover, given the “removal” of this area from the regulatory floodplain, it becomes clear that these homes were constructed without obvious regard to flood risk or not required to mitigate since construction, and that the levee was intended to provide protection against flooding in this floodplain space. In other words, the levee is the insurance against flooding at Haikey Creek: the homes were built first and the levee second; therefore, an interpretation of the levee effect—that the levee encourages risky development—does not seem to apply in this case. Thus, the author interprets the exposure types in the other study areas similarly: for Des Moines, Black Hawk, Tulsa, and Sacramento County, the risk of flooding in historical city centers was an understood fact of proximity to the rivers of these study areas, with levees constructed *after* residential development occurred, except for the case of Johnson County at Iowa City. The full build-out types, however, do not all reflect such pre-levee conditions, as the City of Sacramento first had levees protecting its downtown area followed by substantial post-levee construction along the American River and in the Pocket and Natomas suburbs along the Sacramento River—residential development in the Pocket area reveals homes constructed within 100 meters (328 feet) of the Sacramento River channel, immediately adjacent to or literally abutting the levee. Unfortunately, the residential parcel data did not include for all study areas foundation attributes like Haikey Creek in Tulsa County that would permit further evaluation of flood risk or drawing conclusions for individual-level homes in other study areas; however, the use of difference-in-difference (DID) techniques to evaluate mean parcel values for pre-and-post levee and protected or not protected homes offered strong empirical evidence for detecting and evaluating differences in residential flood risks.

5.1.2 Residential Values

With the notable exception of Sacramento County, all study areas demonstrated lower 2014 residential parcel values for homes constructed in floodplain areas and a generally low proportion of homes constructed in floodplains compared to non-floodplain areas. Haikey Creek is another notable aberration from this trend. Although only a few dozen homes are in this area and it appear that average home values have been flat since the time of construction, the 2014 average value for all parcels in Tulsa County appears to be on a 60-year positive trend, based on construction years, and could exceed the average for Haikey Creek by 2020 or 2030 at latest. The observation that homes located in the 100-year SFHA of the study areas are lower in value in 2014 compared to other, non-floodplain areas is consistent with prior research that demonstrates how flood risk is capitalized into home value. However, a surprising finding demonstrated that the levee-protected areas of some study areas are different spatially for NFIP and USACE exposures: first, the land acreage is different in some cases, and, second, the average value-at-risk is also different, with the Haikey Creek area of Tulsa County providing one of the more stark contrasts, as the NFIP average exposure is more than $160,000 per home in 2014 compared with around $70,000 per home for USACE protected-areas. Further, Tulsa County demonstrated that homes in the 100-year SFHA, which are subject to insurance requirements, were more valuable in 2014 than homes in the USACE LPA in average value by almost $50,000. This finding suggests that the levees may increase the discount in home value for Tulsa County, further capitalizing flood risk, which appears contrary to the intended effect of increasing home value (USACE 1998). This pattern is repeated in the Des Moines County, Iowa study area, where, cumulatively, in 2014, homes located in the USACE LPA—the same as the NFIP LPA for this case—are about $10 million less in value than homes in the 100-year SFHA; in the Black Hawk County study area, homes in the USACE LPA are on average $150,000 less valuable than homes in the 100-year SFHA. Thus, if the intended effect of flood risk reduction through levee protection is to prop up or bolster home values in levee-protected areas, the empirical evidence to indicate that the attempt has failed.

The DID technique was used to evaluate the effect on mean 2014 home values for parcels grouped as protected by levees in comparison to homes not protected by levees for experimental control. Given that no levees protect Iowa City and that home values in floodplain locations were less on average compared to homes not located in floodplains, DID was also conducted to consider potential effects of the NFIP mandatory flood insurance purchase requirement, introduced in 1973, on home values in comparison to homes either inside or outside of the 100-year SFHA based on year of construction. For Iowa City, homes in the 100-year SFHA tended to be less on average for 2014 valuations after the introduction of the flood insurance requirement in 1973, though only slightly, and homes not in the SFHA increased slightly; however, comparison of the mean home values after the insurance requirement shows that non-SFHA homes were valued by about $10,706 more than homes in the SFHA in 2014. This is consistent with the capitalization of flood risk into home value, reflecting a discount in home value in the SFHA, though historical values should be evaluated instead of only year of construction. However, SFHA homes were valued in 2014 at $3,164 more than non-SFHA homes in the decade following the 1981 major flood when compared to the decade prior. Though only considering differences in 2014 values, this finding is generally consistent with Kousky (2010), which found no difference in home values prior to and after 1993's major flooding in Missouri but demonstrates that the consequence of the 1981 flood in Iowa City may have boosted SFHA home values regardless of flood risk, yielding a premium for SFHA homes relative to the flood but generally remaining discounted by more than $40,000 compared to non-SFHA homes. Similarly, in Black Hawk County, 2014 home values in the SFHA averaged slightly more than non-SFHA homes prior to the 1973 insurance requirement but were more than $30,000 less than non-SFHA homes after 1973, suggesting that the insurance requirement may have resulted in a discount to SFHA homes, potentially due to increased awareness of flood risk. Based on 2014 values, homes in the USACE LPA prior to 1973 were nearly half the value of homes not in the LPA, with the difference in mean values appearing to grow wider after 1973 to LPA homes averaging almost $100,000 less than non-LPA homes, providing some evidence that the Black Hawk levees may have increased the discount in home values. Also, in Black Hawk County, after levee construction, mean 2014 home values in leveed areas were greater than non-leveed areas in the early 1980s compared to the prior decade, indicating that levee construction may have had a short-term effect of boosting home values as intended by USACE policy—yet, compared to the entire parcel record, leveed areas appear substantially discounted over non-leveed areas. For Burlington, levee construction appeared to have a modest value-boosting effect in the 1910s, based on 2014 values; however, improvements to the levee system in the 1960s appears to have had little effect on home values in leveed areas for 2014 values, as values in non-leveed areas nearly doubled while leveed areas remained flat based on year of construction. Home values for the leveed areas of Tulsa in 2014 were more than non-leveed areas for the post-levee construction periods of the 1940s and again in the 1960s; however, values in the leveed areas remained substantially less than all home values and of home values in the 100-year SFHA, suggesting, perhaps, that levees bring increased awareness of flood risks and further discount rather than increase home values.

Sacramento is a unique and more complex floodplain than the other study areas, owing largely to the very wide very flat valley of the Sacramento River. Although more than 90 percent of residential development at Sacramento occurred in leveed areas for the first half of the 1900s, development increased in cumulative value for areas of the county with minimal risk based on 2014 values. Yet, growth in the leveed areas of Sacramento County accounted for about 32 percent of all homes constructed by 2014 and more than $35 billion in value at risk of flooding from levee overtopping or failure. Notably, though somewhat less than the average value of all homes in the county, homes added to the USACE LPAs averaged $300,000 in value by 2014, which is $50,000 more than the coverage limits for NFIP insurance policies; homes in the SFHA were similarly valued, with homes situated in 500-year floodplains averaging the lowest value at about $200,000. These findings appear to support the USACE efforts to boost home values with levees, at least in the Natomas area, as 2014 values in the Sacramento River and American River LPAs averaging $220,000 to $240,000, respectively, representing a possibly growing discount over the period of record, likely related to the benefits of flood risk reduction caused by levee policy. However, in absolute terms, both the 2014 cumulative and individual value at risk for homes increased substantially based on year of construction, with flood insurance policy limits not covering the full value of homes constructed in the Natomas LPA and 100-year SFHA. Following levee construction in 1915, homes in the USACE LPA appear to have higher mean values than homes outside of the LPA, based on 2014 valuation, possibly reflecting an oversupply of new homes in lower risk areas, or the increasing awareness of the flood hazard potentially driving down average home values in floodplains protected by the new levees. On the other hand, following completion of levee and dam improvements along the American River in 1955, home values were nearly threefold in value in leveed areas based on 2014 values, whereas as non-leveed areas remained rather flat when considering construction year; average home values appear to be discounted compared to homes outside the leveed areas and become the trend after the 1950s, based on construction year, with discounted average home values in the floodplains at about 30 percent less than the county-wide average home value in 2014. This substantial increase in value in the American River LPA following levee construction appears to meet the goals of USACE development policy by making more housing available to the expanding City of Sacramento; however, this finding also increases the absolute value at risk of the American River floodplain, based on 2014 values, and possibly indicates a temporary premium value on these exposed homes—further, the newly constructed homes in the American LPA averaged $275,000, again exceeding NFIP flood insurance policy limits. Most remarkable, however, is the substantial increase in average value at risk for homes constructed in the Natomas LPA based on 2014 values: these homes appear to outpace average growth in non-leveed areas in the 1980s, with equivalent values for the mid 1990s; in the 2000s, homes in non-leveed areas exceeded the average value of homes constructed in Natomas by about $15,000, based on 2014 valuation, but homes in Natomas averaged about $335,000, or $75,000 more than NFIP policy limits, and tripled in number between 2000-2014.

5.2 Answers to Research Questions

The policies supporting levee construction have consequences that cause effects over long periods of time, and the evidence discovered in this research demonstrates that structural flood control, particularly levees and possibly dams, increase flood risk by reclaiming hazardous floodplains and increasing the absolute numbers of homes exposed to flooding. Further, levee accreditation, a national policy allowing local governments to drop both mandatory insurance purchase and mitigative construction practices, increases vulnerability to flood damage by allowing both increases in exposure and laxity in construction standards intended to avoid flood damage. Such national-scale decisions encourage risk-taking in hazardous floodplains by encouraging low-income property owners to securitize flood risk without flood insurance, with the evidence from this research supported by recent research into incomes in 100-year SFHA (FEMA 2018). Given such local effects of NFIP policy, Michel-Kerjan (2010) questions whether the NFIP is truly a national program and not a federally-implemented local program. Destructive floods increase pressures on local and national governments to intervene in flood risk management, resulting in both structural and nonstructural risk reduction projects that change flood risk over time. Di Baldassare et al (2009) and Pinter et al (2016) demonstrate that the increasing heights of levees increase river flows and stage heights, thereby increasing flood hazard. USACE (1998) national economic development policy seeks to increase or prop up home values in areas protected by levees, which increases flood risk as a function of increased exposure in absolute dollars that may be lost in a major flood; moreover, the NFIP levee accreditation process allows for the removal of a regulatory floodplain, thereby removing the mandatory purchase requirement for flood insurance. The USACE national economic development, however, appears to fail in boosting floodplain home values, more often resulting in negative capitalization of home values as risk reduction benefits of levees appears to deflate home values—except in Sacramento, where homes in USACE LPA are commensurate in value to homes in the 100-year SFHA based on 2014 valuation. The distinction between these home values reflects the difference in vulnerability: USACE LPA, where levees are accredited, have no requirement for insurance or stronger building construction standards, whereas SFHA homes do, resulting in some financial protection in the event of flood damages.

In floodplain communities with levees, the absolute number of homes and the absolute cumulative value of homes at risk of flooding appears, in some cases, to outpace the increases in value at risk for homes in levee-protected areas compared to homes in non-leveed or non-floodplain locations, inasmuch as year of construction influences valuation. As such, observations of 2014 home values and counts in levee-protected areas support the statement that levees increase flood risk by increasing exposure to flood hazard, at least from a cross-sectional analysis of 2014 parcel data, with exposure increasing in construction years following levee. The dropping of mandatory flood insurance may increase the physical vulnerability of new homes constructed in leveed floodplains because requirements to build to regulatory standards intended to reduce the physical and financial consequences of flooding are also dropped. By increasing exposure and vulnerability, flood risk increases; however, in three study areas—Black Hawk, Des Moines, and Tulsa Counties—cumulative residential value at risk for 2014 in levee-protected areas tends to remain a steady or slightly diminishing proportion of cumulative value of all parcels as a function of construction year, building on the evidence of Pielke (1999) and Downton and Pielke (2002) that reflects an increasing trend in flood losses but a flat trend when flood risk is proportionate to overall increases in value for a city. These three counties also demonstrate that levees tend to further decrease residential values in 2014 over 100-year SFHA values, indicating that there may be a risk reduction that decreases risk by depressing home values; however, the USACE national economic development policy seeks to increase home values, which is contrary to observations of lower home values in these three counties for 2014. The benefit of increasing residential values appears to be achieved in Sacramento, somewhat, in 2014, with average home values in leveed-areas at or near values in non-leveed SFHA, at least in Natomas: this observation supports increased flood risk as a function of exposure and vulnerability by construction year, with higher value at risk and no insurance requirement along with average home values that exceed flood insurance policy limits, resulting in an under-insurance condition.

5.3 Discussion

The empirical evidence of flood exposure changes developed in this dissertation is presented with a few interpretations, both about the use of levees to prevent or control flooding and with alternative explanations for risk exposure and vulnerability changes. Literature reviewed in framing the levee effect as a societal problem appears to indicate a presence of publication bias against levees—that levees are “bad” (Blaikie et al 1994; Wenger 2015)—although more constructive criticism comes from framing the issue in adaptation strategies, as potentially well-adapted or maladapted outcomes from decisions to use levees for flood protection, reflecting choices to live with floods in technological, interventionist policies or less tolerant, risk averse policies supporting “green society” policies favoring restoration of floodplain ecosystems and services (Blaikie et al 2004; di Baldassare et al 2015). That either development or levees come first is not necessarily the problem at hand, as, historically, the site of New Orleans was chosen prior to both the potential for Mississippi River flooding and the choice for using levees to protect the city were made. Indeed, rather than residential exposure and vulnerability increasing after a levee is constructed, development may proceed first, prior to awareness or understanding of potential flood hazards, representing a *development effect* rather than a *levee effect*, as the case would appear in the Haikey Creek area of the Tulsa County study area. Lavell (2004) suggests that *development aggression* in Latin American countries yields unsustainable, adverse development in floodplain areas. Nonetheless, White’s range of choices about human adjustment to flood hazards (1945) underlies difficult decisions made in local flood risk management—namely, that one floodplain society may tolerate co-existence with flood risk whereas another floodplain society may not tolerate such hazards and chooses to permanently evacuate the floodplain to eliminate exposure. Such cases of the latter include the city of Valmeyer, Illinois, which, after being under 6-7 meters (18-24 feet) of Mississippi River floodwaters in 1993 at the cost of hundreds of millions of dollars of damage, chose to permanently relocate the city to a nearby location outside of the floodplain (Pinter 2005): at the time of writing, the ongoing Mississippi River Valley flooding of 2019 is not a threat to the city in its new location, whereas numerous levee-adjacent communities have already flooded or may yet flood, as the Mississippi River at Red River Landing exceeded the historic 1927 flood duration, surpassing 152 days at major flood stage in late May 2019, necessitating diversion of floodwaters into the Morganza Spillway in attempt to lower hydraulic pressure on levees at New Orleans.

5.3.1 Tax Parcel Data

A distinction between estimated home values for tax assessment purposes and real estate sales prices is important, as the latter reflects numerous market variables not evaluated in this research. The USACE (1998) review of hedonic modeling methods reveals a broad array of factors which influence home prices in the real estate markets, including, but not limited to, square footage of homes, number of bedrooms, access to highways or schools, and so on. The use of tax parcels, however, is not invalidated by not having the breadth of hedonic variables with which to evaluate home values across flood zones, but criticism of the findings may focus on location benefits as described under the USACE NED (1988). The accrued benefits or discounts of floodplain or leveed-area homes over time is not considered as such information is not well understood or estimated in literature beyond flood control project cost-benefit analyses. Tax parcel valuations, however, are directly reflective of home sales prices at the time of measurement, in this case annually and only for 2014, and, moreover, tax parcel valuations are used to estimate local budget and finance planning factors, such as how much tax revenue may be generated and applied to flood control and other projects. The tax parcel valuations are also applied to municipal bonding and fundraising to support flood control projects as well as bond interest payments, a key interest to credit ratings agencies and lenders with stakes in flood risk capitalization and management strategies. Further, local flood control districts are required to estimate the benefits to various public and private sectors based on tax collections; therefore, evaluation of counts of homes and the assessed valuation for tax purposes can and should be employed toward further evaluation of budget decision processes, especially as parcels not paying taxes toward local revenues for flood control, general services, or bond interest can substantially disrupt local markets and planning processes.

The evaluation of home values in this research should not be construed as an historical time series dataset for annual home values but rather for estimated 2014 values of homes by year of construction. The DID analyses indicate differences in 2014 values based on pre-and-post levee construction determined by year of construction—e.g., post-levee 2014 values in LPA are higher, and may represent an increase in LPA VAR for 2014 and not the immediate post-levee construction period. Regardless, the increase in VAR in LPA is based on year of construction and may reflect the influence of levee protection, or, the increase in VAR in LPA in 2014 may reflect local market influences increasing LPA values in 2014. That the increase in VAR in LPA in 2014 is greater than the non-LPA values still suggests a floodplain or levee influence. A more complete evaluation of levee influence would include annual home valuations for the years before and after levee construction, which is a goal for future research stemming from this dissertation.

5.3.2 Levees and Amenities

Levees are beneficial to reducing losses and frequent flooding—there are reasons people live near rivers, like riverfront amenities or access to river recreation and transportation. However, it is not a necessary condition for levees to be constructed for such access or use—the use of dams to create reservoirs may be better suited for such recreation or use conditions, though rivers without either dams or levees provide such resources. How do the accrued benefits from levees compare with the potential increases in risk or damage to the environment? Levees are without a doubt beneficial to reducing losses, as demonstrated in benefits realized in 1993 and 2011 flooding; however, simplifying the use of levees for flood control overlooks the consequences brought by levees, particularly with emphasis on ecological disruption and increased physical or social vulnerabilities, and possibly in the sense of encouraging or intensifying residential development in hazardous floodplains—or, in insurance terms, concentration of risk through intensification of adverse selection and moral hazard (Michel-Kerjan 2010). Do residents of leveed floodplains truly understand the residual risk of flooding or the potential for catastrophic damage resulting from levee failure or overtopping? Prior research from Bell and Tobin (2007) and Ludy and Kondolf (2012) reveal that the 100-year floodplain is not well understood by floodplain residents, and the removal of the 100-year floodplain by policy would seem to exacerbate the problem of risk communication and awareness of hazards. As reviewed in Chapter 2, benefit-cost assessment and real estate transaction processes suggest that floodplain occupants have <u>full knowledge</u> about flood hazards and the risk taken when residing in floodplains; however, numerous studies have demonstrated the existence of adverse selection in flood insurance, revealing that floodplain occupants or risk-takers neither have full knowledge nor awareness of the potential for flood losses—such sharing of hazard information is the basis of NFIP risk communication goals (Kousky 2010; Michel-Kerjan 2010; Ludy and Kondolf 2012; Kunreuther 2018). Bostrom (2011) suggests that risk communication, or more specifically the sharing of information about a relevant issue, increases risk; however, to clarify, relevant to adverse selection and asymmetrical information, Bostrom (2011, p. 12) suggests that market failures can occur when "when one party to a transaction has the potential to gain information that the others lack," further clarifying through the example of the sales of "lemons," defective or bad cars: information asymmetry inhibits the market for "good" high-quality used cars because buyers and sellers of defective, bad cars force sale prices into discounts, turning away the sellers of good cars who withhold them from depressed market prices, leaving predominantly bad cars in the market. Stated another way, the "false sense of security" argument against levees is predicated on levees not providing protection against floods, which is a somewhat fallacious argument in that levees that have not failed do provide some level of security. Regardless, the empirical evidence from the study areas may relate to adverse selection in floodplains, or the evidence may reflect negative capitalization of home values due to flood risk, or it may be the case that floodplain home values are negatively capitalized because of risk communication features or defects. Such conclusions cannot be made without historical valuations over many years and without evidence of changed outcomes through risk communication.

5.3.3 Maladaptation and Alternatives to Levees

The exposure typology developed in Chapter 3 and evaluated in Chapter 4 indicates that there may be a presence of adverse or *mal-adapted* residential construction in the floodplains of the study areas. Similar to the relation between Burton's (1962) agricultural typology, the residential typology considers whether the presence of levees yields increasing exposure to flood hazards; in more recent work on climate change risks, Burton (1997) introduced *maladaptation* into hazards literature to consider development that occurs or continues to occur in high hazard areas through policies and by which increase vulnerability. Building on Burton's concept, Barnett and O'Neill (2010) define *maladaptation* as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups." This definition of maladaptation can be adjusted and applied to flood risk as follows: action taken to avoid or reduce vulnerability to flood hazards that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups. Juhola et al (2016) highlight that criteria to identify maladaptation are neither widely accepted nor developed as a measurement metric. As such, expounding on the residential exposure typology, some findings from policy review, and review of the empirical findings, residential development in floodplains or levee-protected areas may be *maladaptive* if some concurrent conditions exist, including, for example, a lack of insurance building construction requirements. The history and literature reviewed in Chapter 2 along with the findings of floodplain removal by policy, alleviating insurance and building construction requirements, and evidence of slab-on-grade residential construction in Tulsa's floodplains, supports the residential exposure typology (specifically the AD +- type) identifying increasing value at risk with increasing physical vulnerabilities as *maladaptation* when occurring in concentration adjacent to levees, consistent with the definitions of a levee effect advanced in Chapter 2. Several types of levee developments were identified in this research, highlighting *levee wars* in California where the Green Act encouraged differential individual property protection, often by sabotage; *levee wars* (escalator effect) in the Midwest where differential increase in levee heights yields differential vulnerabilities and consequences to areas with lower levee heights or areas where diverted floodwaters increase both hazard and potential consequences; and a *safe development paradox* whereby federal efforts to reduce risk serve to increase risk instead by driving increased exposure and increasing vulnerabilities. Further, the effect of removing insurance requirements by levee accreditation appears both to increase exposure to flood hazards and increase either or both physical or social vulnerabilities, as homes are built without flood-proofing or mortgages secured without protective insurance, both yielding inabilities to cope with flood damages (Blaikie et al 1994). The pressure and release model for flood disasters identified by Blaikie et al (1994; 2004) identifies some metrics responsible for increasing exposure and vulnerabilities in floodplains, commensurate with both the levee accreditation policy finding and evidence of induced residential development in leveed floodplains; furthermore, di Baldassare et al (2015) establishes a feedback mechanism whereby societal adjustments to flood hazards is conceptualized to illustrate that *technological* societies that rely on levees tend to both repeat exposure to the hazard by reconstruction and increase exposure and vulnerability due to loss of memory of flood impacts over time, suggesting a maladaptive approach to flood risk reduction. Hino et al (2017) describe alternatives to river flood control structures like levees and dams as forms of *managed retreat,* described and defined as the engineering philosophy of moving away from riverine or coastal flood hazards "rather than fortifying in place," with a notable case of Valymeyer, Illinois seeing the benefits of such an alternative risk management strategy. Notably, di Baldassare et al (2015) also conceptualize a *green* society that chooses to adjust to flood hazards by granting rivers room to flood, suggestive of a well-adapted approach to flood risk reduction. By avoiding the construction of levees, or more smartly developing non-floodplain spaces, future losses are avoided in the green society.

5.3.4 Applied Theoretical Framework

The residential exposure typology developed for this research can be applied to the di Baldassare et al (2015) socio-hydrological flood model with some additional factors discovered in the empirical evidence also found in this study. Figure 5.1 displays the residential exposure typology applied to a cyclical pattern of residential development, where, after a flood, the mandatory purchase of flood insurance is a pre-requisite for receiving disaster assistance for

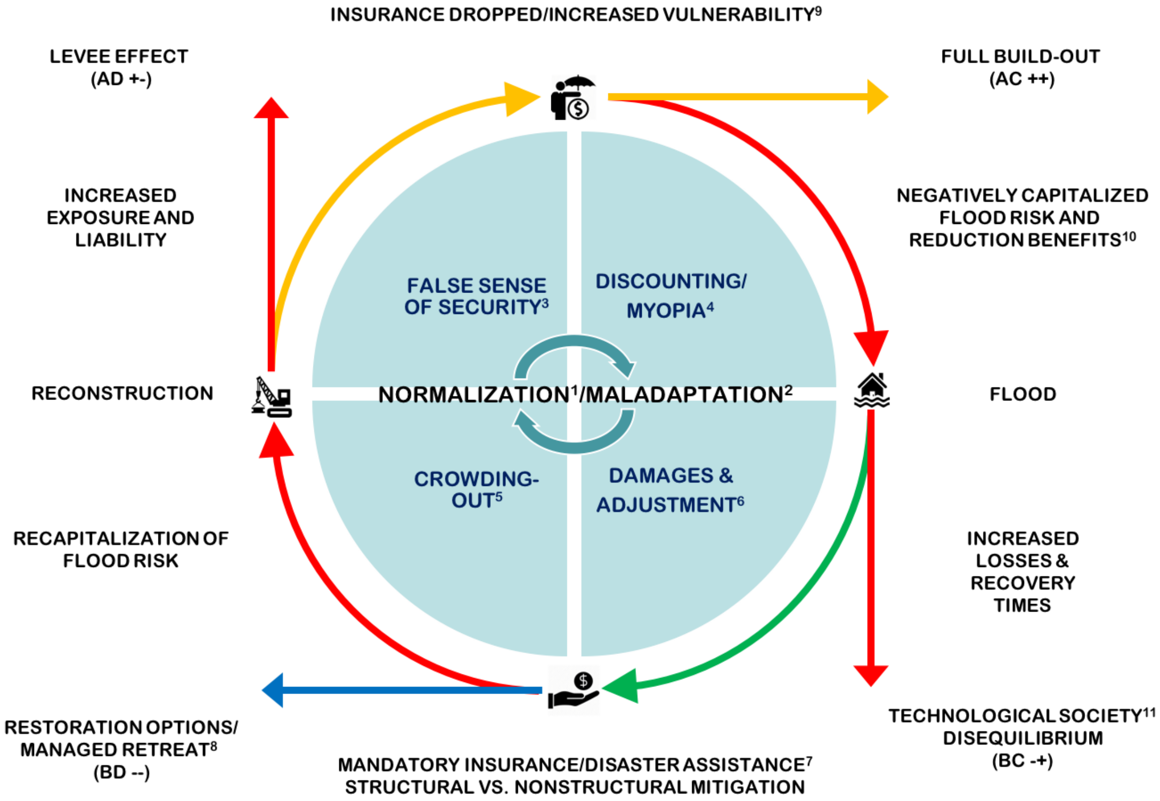


Figure 5.1. Exposure typology applied to normalized cycle of flood losses favoring structural flood control actions over non-structural mitigation post-flood, thereby increasing exposure, vulnerability, and property value discounting. Citations embedded: (1) Perrow 1982; (2) Burton 1997; Barnett and O'Neill 2010; Juhola et al 2016; (3) White 1936; White et al 1975; Tobin 1995; (4) Kunreuther et al 2018; (5) Husby et al 2014; Jongman et al 2014; (6) White 1945; (7) Kousky 2010; Kousky 2018; (8) Blaikie et al 2004; Hino et al 2017; (9) Michel-Kerjan et al 2013; Kunreuther et al 2018; (10) Troy and Romm 2004; Kousky 2018; Beltran et al 2018; Davlasheridze and Miao 2019; and (11) di Baldassare et al 2015.

damages incurred by flooding. As governments face increasing pressure to act aggressively in flood recovery, decisions must be made about both non-structural and structural flood mitigation options. When the decision to follow a path of non-structural mitigation options is chosen, buy-outs, relocation or elevation of homes, and wet and dry-proofing options can lead to lower exposure and vulnerability to future flooding; however, the choice to pursue structural flood control projects can crowd-out individual level responses to flood losses, yielding a levee effect wherein buildings are constructed and reconstructed in hazardous floodplains, increasing both exposure to flood hazards and increasing exposure to liability for flood damages caused by or in part by flood control structures like levees and dams. During this phase following the crowding-out of individual responses, a false sense of security may develop because of the government actions to build or rebuild structural flood controls; moreover, Kunreuther et al (2018) provides a range of means by which risk perception may be altered, and Figure 5.1 displays myopia only, as the effects of crowding-out individual responses followed by a false sense of security may lead to the dropping of flood insurance policies required either for disaster assistance or new construction, as the mandatory purchase requirement is discontinued in leveed areas per NFIP levee accreditation policy, leading to further increases in vulnerability to flood losses, as flood risk reduction benefits negatively capitalize and depress home values among lower-income homeowners. Thus, the myopia in this cycle is a failure of the government to disrupt this cycle of flood damage, which may be catastrophic given maladapted and full build-out of the floodplain, leading to increased losses and recovery times (AD +- and AC ++ exposure types). Notably, the post-flood exposure types may immediately reflect a well-adapted exposure type (BC -+), whereas severely damaged or uninhabitable homes *could be* permanently evacuated from the floodplain, if non-structural mitigation is favored, potentially leading to environmental restoration outcomes in exposure (BD --). In several study areas, including Black Hawk, Burlington, Tulsa, and Sacramento Counties, the structural approach to flood risk reduction appears long-term path dependent, yielding increases in exposure, vulnerabilities, and losses as a *normal* aspect of the solutions favored by a di Baldassare et al's *technological society*.

In contrast, Figure 5.2 displays the residential exposure typology applied to a cyclical pattern of residential development where exposures and vulnerabilities to flood damages remain low when non-structural mitigation is the favored response to flood risk. In this model of well-

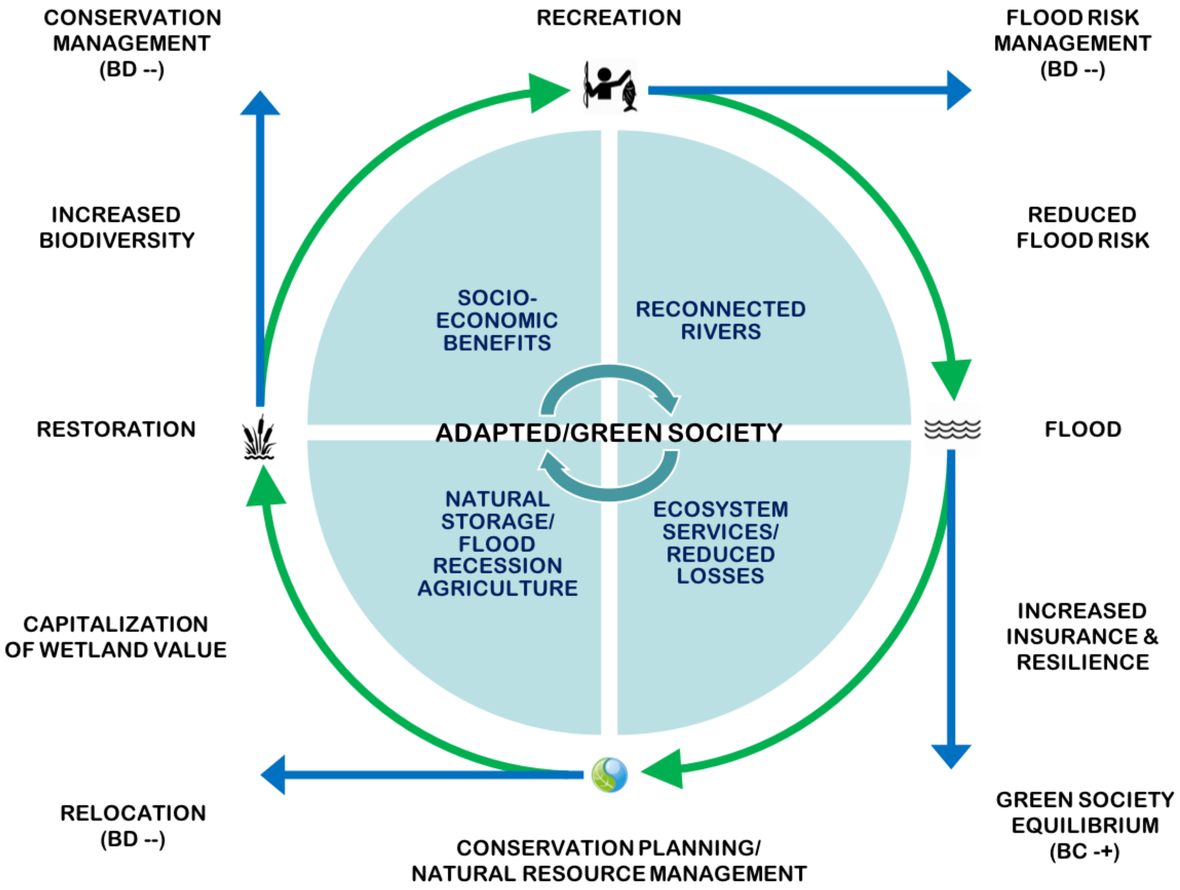


Figure 5.2. Exposure typology applied to normalized flooding favoring non-structural mitigation in favor of conservation planning and natural resource management, leading to increased biodiversity, reduced flood risk, and increased participation in insurance and post-flood resilience.

adapted development, rivers are given room to flood, restoring or increasing connections of floodplains to both store floodwaters and experience increased biodiversity with restoration of wetlands, whereas residential development tends to occur further from river channels (BC -+) or favors lower value flood recession agricultural types when occurring nearer to channels (BD --). In this scenario, rather than post-flood decisions about disaster assistance, which may be lower, societies can focus on natural resource management and conservation planning to restore ecosystems services in the form of recreation and other socio-economic benefits like ecotourism, increased resilience from floods as impacts are lowered. Opperman et al (2009, p. 1488) describe the benefits of large-scale reconnection of floodplains to river channels that might include productive agriculture like pastures, timber, and flood-tolerant or biomass crops, with ecosystem benefits such as natural flood storage, improved water and soil qualities with increased nutrient retention: "Achieving these benefits will incur large upfront costs for levee setbacks, flow easements, land acquisition, and restoration, along with periodic compensation for flood damages." In light of the Minot study area, the estimated one-time upfront cost of $266 million to permanently evacuate the Ward County floodplains in the late 1970s (USACE 1978) could have avoided the nearly $1 billion in flood losses occurring in 2011, perhaps while realizing the benefits of increased recreation, hunting, and fishing that were the highlight of the Souris River prior to the introduction of channelization and flood control in the 1920s that so notably damaged local ecosystems that congressional acts to protect were introduced (Appendix C). Opperman et al (2009) highlight the success of the Yolo Bypass in the Sacramento River Valley, noting that the "levees only" approach would not sufficiently reduce flood damages for the western portions of the City of Sacramento and much of Yolo County on the western side of the Sacramento River; moreover, Opperman et al highlight that more than two-thirds of the Yolo Bypass remain privately owned for productive agriculture. In a more sustainable approach to maximize floodplain benefits for society, the residential exposure typology highlighting well-adapted development found in the study areas could lead to better scenarios and planning decisions if modeled in di Baldassare's *green society*.

5.4 Conclusions

Some studies claim that the NFIP negatively capitalizes floodplains, possibly by communicating risk and increasing awareness of flood hazards (cf. Troy and Romm 2004;

Kousky 2010); however, the findings from this dissertation do not support such a claim, as it appears that homes in the floodplains of the study areas were negatively capitalized prior to the formation of the NFIP—also, some 100-year SFHAs are positively capitalized, realizing a premium. While it may be true that the NFIP negatively capitalized some floodplains, it appears that levees both negatively capitalize floodplains and intensify the negative capitalization. This appears to be the effect of flood risk reduction, which is intended. However, if levee effect is an unintended consequence whereby exposure is encouraged or increased, then this is also a finding of the exposure analyses conducted for this dissertation. No study area showed decreasing trends in exposure; however, the trends revealed support for a flat trend overall, with exposure increasing as a relatively consistent proportion of cumulative 2014 residential parcel values.

The use of levees as flood control and flood risk reduction measures reveals a long-term path dependency that both encourages absolute increases in residential structures and values exposed to potential flood hazards while decreasing the average value of homes in the levee-protected floodplains, thereby discounting home values as a benefit of levee protection and future levees to be built, continuing a cycle of maladaptive development. This conclusion is supported both by observation and empirical evidence developed in this research and by supporting literature on path dependence and the effects of flood risk on residential valuation (cf. Wenger 2015, Kunreuther et al 2018). As developed in the history and literature review chapter, the arguments for and against structural flood control policies from the 1850s to the 1920s tended to rely on the "experiment being made" in order to ascertain the "true consequences" of reclaiming wetlands and swamplands for agriculture and, ultimately, residential occupation of hazardous floodplains. The arguments set forth against substantial public spending by the Coolidge administration in the 1920s foresaw enormous costs for flood control that would be politically, rather than technologically, driven (Pearcy 2002), and historians such as Arnold (1988) found the flood control policy of the 1930s "confusing and even irrational in its specific policies and administrative machinery," with "the fundamental goals and direction of legislation in a major problem area like flood control are seldom reversed once the law is set in place." The long list of flood control acts introduced since the Coolidge administration led to some extraordinary feats of American engineering, often proving their value through flood damage avoided; however, at the time of writing, flood disasters involving both flood control failures and losses to induced residential development continue through the Spring of 2019, with damages topping $1 billion in the State of Nebraska alone and cumulative losses for 2019 expected much higher. The following conclusions are drawn from the research undertaken for this dissertation, and some speculation and discussion around the findings further develops some topics for additional consideration and research.

5.4.1 Flood Risk Influence & Capitalization of Home Values

Post-levee completion increases in value, based on construction year and 2014 values, appear temporary in many instances, indicating a rush to build in newly reclaimed areas with increasing absolute numbers of properties and value at risk. Though these post-levee periods appear to increase 2014 average property values, at least temporarily, the average 2014 property values appear to decline over time when compared to county-wide home value averages. Such divergence in values is observed in Burlington, Waterloo-Cedar Falls, Tulsa, and Sacramento, indicating that USACE policy to build affordable homes in proximity to city and business centers is achieved; however, the absolute increase in exposed homes to flood hazard is concerning, as flood insurance requirements in these lower-valued homes is removed, likely increasing at least the physical vulnerability of homes constructed in leveed-areas because regulatory mitigation requirements of the NFIP are removed. In a recent FEMA (2018) report on flood insurance affordability, median incomes of homeowners in SFHA areas that do not have flood insurance are substantially lower than those with insurance, $40,000 for non-policyholders compared to $77,000 for policyholders, indicating that vulnerability of homeowners to flood losses in leveed areas where insurance is not required is likely higher. In most study areas, discounts for leveed-area homes appear to be increasing, based on 2014 values and construction year indicator, likely as a result of flood risk reduction benefits being realized in the form of levee protection, except in the case of the Natomas area of Sacramento County, where average home values are about $50,000 more than non-floodplain areas and NFIP policy limits—notably, Natomas area homes remain about $50,000 less than the county-wide average, indicating about a 15 percent discount in 2014, although the trend in Natomas average values indicates a premium may be realized in the future.

For the Netherlands, Jongman et al (2014) found that average home values in flood-prone areas were less than non-flood-prone areas, consistent with the findings of this study generally. Kousky (2018) states that numerous studies found that the effect of NFIP requiring lenders to tell borrowers if a property is located in the 100-year SFHA is to discount home values relative to homes outside the SFHA. This effect is found in all study areas evaluated herein—except in Sacramento, where average SFHA home values are greater than both 500-year floodplains and areas of minimal flood risk—as average home values in the SFHA are lower in value (discounted) compared to non-floodplain homes. In a meta-analysis of 37 published works on residential values of homes in floodplains, Beltran et al (2018) found that there is a wide range of discount-to-premium for home values in floodplains that ranges from a -75 percent discount to a +61 percent premium; however, only 4 out of 37 studies suggest that such premiums exist and that coastal floodplains represent such premium valuations. Regardless, after adjusting their sampling techniques, Beltran et al (2018) indicates that riverine 100-year floodplains have discounted valuations ranging from -5.6 to -6.1 percent, with post-flood discounts around -4.6 percent following record flooding from Tropical Storm Alberto in Georgia in 1994 to -6.9 percent for combined coastal and riverine floodplain discount rates. From the meta-analysis across the 37 studies analyzed, Beltran et al (2018, p. 679) recommend a -4.6 percent discount rate for benefits estimation "whenever a flood relief project in effect changes the boundaries of a floodplain," which can be adjusted by subtracting the new flood zone from the old flood zone and multiplying by the discount rate: for example, if a 100-year floodplain becomes a 500-year floodplain as the result of flood control, the new discount rate is estimated as 4.6 x (0.01-0.002) = 0.037 of the average property value. Yet, Beltran et al (2018, p. 679) call for further research on such discounting, stating that "it would be interesting to examine the effect on property prices of major engineering projects that in effect change properties' floodplain designation." Thus, the subject research undertaken in this dissertation is both timely and illuminating, as discounts in leveed-floodplains range widely across the study areas for 2014, with Tulsa demonstrating a -53 percent discount in USACE LPA compared to -24 percent in 100-year SFHA, a 29 percent difference; Burlington demonstrating about a -20 percent discount for both USACE LPA and 100-year SFHA; Waterloo-Cedar Falls demonstrating a -65 percent discount for USACE LPA compared to a near zero discount for 100-year SFHA home values relative to all home values; about a -20 percent discount for 100-year SFHA homes in Iowa City, where no levees are present; and about a -20 percent discount for SFHA and USACE LPA homes in Sacramento compared to all average home values, with areas of minimal flood risk receiving a -27 percent discount and areas of the 500-year floodplain observing a -62 percent discount, both greater than levee-protected and higher risk floodplains. Interestingly, following passage of California's Natural Hazard Disclosure Law (AB 1195) in 1998, Troy and Romm (2004) found a -4.2 percent discount rate in California by for the value of homes in the 100-year SFHA or areas that may flood as a result of dam failure. The results from Troy and Romm (2004), however, are based on a proprietary residential property database, with properties aggregated by zip codes where data was available—not from county tax assessor valuation or comprehensively by county—and were analyzed only for a period of about 1.5 years before and after implementation of the hazards disclosure law. In contrast, the research conducted for this dissertation finds, for Sacramento County, an average SFHA discount of about -22 percent for the year built period of 1990-2000 and an average of about -25 percent for build years 2001-2014, with average annual discounts increasing from near zero in 1900 to near -30 percent by the 2010s, indicating that disclosure of flood hazard and flood zone is not necessary the primary driver of discounted value over longer development periods but rather the development of higher value, non-floodplain alternative locations drives down floodplain home values—simply stated, land values are higher for areas of lower flood hazard, and this effect appears to pre-date the risk disclosure and communication standards of the NFIP and state-level programs and laws.

The Troy and Romm (2004) study on the effects of the California Natural Hazards Disclosure Act drew the author's attention to an interesting requirement of the law. Notably, flood, wildfire, and seismic hazards require disclosure to potential borrowers; however, the flood hazard component of the disclosure is broken into two components, one for occupation of the 100-year SFHA and the other for situation in an inundation zone for possible upstream dam failures, both of which are regulated by FEMA through the NFIP and the Dam Safety Program, respectively. For the purpose of discussion, the differences between levees and dams becomes a notable case of semantics in some sense, as both levees and dams are artificial impediments to stream and floodwater flows, the former with water on only one side of the device and the latter on both sides. Dam safety program managers have, in recent years, identified *hazard creep* as a problem of risk increasing as the result of new homes being built downstream of dams in areas that would be inundated by failure of the dam (FEMA 2017). Pisaniello and Tingey-Holyoak (2017, p.60-61) state that *hazard creep* is an internationally-observed phenomenon, wherein new property development occurring downstream of dams increases risks to communities while increasing costs to dam owners: developers of property impose new design and maintenance standards on private dam owners, increasing the damage potential for dams, resulting in FEMA reclassifying once lower hazard dams as higher hazard dams, creating an "unfair situation" that further results in dam owners not maintaining dams at higher safety standards without state dam safety regulator supervision. Notably, in consideration of liabilities to the owners of flood control structures, a federal court recently found USACE liable for damages caused to numerous farm and private landowners during flooding on the Missouri River since 2004, except for record-level flooding in 2011, with specific focus on USACE's flood control project dating back to 1979 and recent changes in policy to improve habitat conditions for wildlife that were disrupted by construction of levees: the federal court found that the changes in water surface elevations caused increased and more severe flooding and damages to the farmers and property owners than would have occurred without structural changes to the river system by USACE, and the changes and consequences deemed as the "foreseeable or predictable result" of the government's flood control actions—"the Corps knew or should have known that the [Missouri] River's flooding pattern would change and that more flooding would occur," with evidence offered in numerous USACE reports that stated "additional flooding would likely result" and "there will be potential for flood damage on properties that are near the channel." (Ideker Farms v. United States, pp. 34-42). Interestingly, USACE's defense argument in the *Ideker* case plainly states that the increased risk of flooding caused by flood control activities would not necessarily cause additional flooding; however, the court found that the farmers and property owners suing USACE were able to show "the probability and foreseeability of [property] damage" caused by additional flooding, with levee failures and overtopping causing damage to properties further from the channel of the Missouri River (Ideker v. United States, pp. 43-48). Following major floods in 1986 and 1997 in California, notably, state court decisions in the *Areola*, *Paterno*, and *McMahan* cases held the Sacramento and San Joaquin Flood Control Districts liable for flood control project failures that exacerbated flooding and damages based on failure to maintain river channel and levee foundation conditions; further, the *McMahan* case required the State of California to both improve the Sacramento flood control system and discourage unsafe urban development in order to "<u>reduce its exposure to liability</u>" (Pineda 2004, p. 76, emphasis added). Yet, the *Ideker* case provides interesting insight into the consequences of changes to structural flood control policy—notably, the case focused on overtopping and failure of the Union Township Holt County Number 10 levee, described as protecting 17,400 acres of farmland, $71 million in property, 257 people, and 482 structures, and having "the likelihood of a flood overtopping this levee in the next year […] estimated at 20% (one chance in 5). This equals a 100% likelihood of water overtopping the levee over the life of a typical 30-year mortgage[.]" (NLD 2019). Indeed, during the time of writing this dissertation, the Union Township Holt County Number 10 levee was one of many overtopped by "bomb cyclone" flooding in March 2019 (KCUR 2019).

FEMA, in recent definitions of the problem, now refers to *hazard creep* as *risk creep*, where development in the downstream "dam breach inundation zone" results in higher potential consequences (FEMA 2017). Accordingly, California laws reflect both disclosure of the dam breach inundation possibility and potential losses of life or property to borrowers, along with development of emergency action plans that detail inundation zones, emergency response measures, and roles and responsibilities for dam owners and potentially-affected communities (Code of California 2019). However, in contrast, the USACE National Levee Inventory appears only to identify the potential flood hazard to properties in leveed-areas as an aggregate measure of exposure—that is, if population and homes are in the levee-protected area, the total population and count of homes, and related values, are listed as protected. It is not clear whether the existence of new homes in leveed areas changes the risk rating for levees from, say, low to high. The NFIP removes levee-protected areas from floodplain maps along with insurance requirements and does not appear to require development of emergency action plans for these areas, even though levee failures result in higher velocity flows into floodplains when breaks occur. Aside from a semantical or legal argument about the relative definitions of levees and dams, one could strongly argue that dam breach inundation zones are similar to levee-protected areas, depending on the volumes of water held back by either device, and that there should be regulatory land use restrictions similar to SFHA requirements to discourage additional increases in *exposure* to these flood hazards; moreover, that neither the design standards for levees nor the policy limits of flood insurance have changed much over recent decades (Jongman et al 2014; Kunreuther et al 2018), while exposure has increased in absolute numbers, begs for updated policy to address increases in both hazard and loss potential for the residual risk areas downstream of dams and in levee-protected areas. Given the requirements made by California law to develop and make disclosed inundation areas relative to dam failures suggests that the state and federal government should develop stronger requirements for levee failure inundation zones; the author believes that both levee and dam failure inundation areas should be depicted on FEMA's flood zone maps to improve awareness of the risks and continue to centralizing information about flood risks through the RiskMAP program due to its stated goals for providing both regulatory and non-regulatory risk information. Notably, in Sacramento's NFIP A99 flood zone for the Natomas area which will be protected by levee improvements, the city of Sacramento requires the signing of a hold-harmless agreement for construction of new properties but does not require flood insurance, contrary to the NFIP's requirement (Appendix D1 and D2). In any case, both levees and dams are instruments of flood control, albeit for different purposes at times, and "the very use of the term 'flood control' as the goal of the federal government, rather than the more restrictive and accurate term 'flood damage reduction,' represents a more optimistic human, institutional, and political response to a set of natural, engineering, and economic problems[.]" (Arnold 1988).

5.4.2 Influence on Flood Insurance Participation Rates

Kousky et al (2018) finds that federal disaster aid from FEMA's Individual Assistance (IA) program, which pays out about $2,984 on average for flood damage, reduces average amount of flood insurance purchased by $4-5,000 in the year following floods but does not affect participation rates, likely because the IA program mandates flood insurance purchase to receive aid. Davlasheridze and Miao (2019), however, find that increases in FEMA's Public Assistance (PA) grants reduce insurance take-up rates by about 1.5 percent for every 10 percent increase in PA project funding, thereby driving down total insurance coverage and premiums paid, possibly because of the impression that a government "bail-out" is forthcoming or that this public assistance program increases community resilience and reduces the perceived need for insurance. Similarly, Davlasheridze and Miao (2019) estimate that the IA aid registration that mandates flood insurance purchase increases participation rates by about 1.5 percent for every 10 percent increase in IA grant funding. In any case, the post-disaster take-up increase effect disappears after 3 years, as median policy tenure is estimated at 2-4 years, possibly due to people moving (Michel-Kerjan et al 2012; Kousky 2018).

In California in 2015, there were about 272,272 NFIP policies in force with a state-wide per capita participation rate in the flood insurance program of 0.7 percent (Davlasheridze and Miao 2019); moreover, that participation rate would be 73 percent of all homes in Sacramento, assuming that all policies-in-force are located in Sacramento County. The results of this study, however, observe that homes in the SFHA account for only 7.6 percent of homes in Sacramento County, and, if estimating local participation based on state per capita rates, there are only about 1,985 homes participating in the NFIP in Sacramento's 100-year SFHA. The NFIP LPA, however, where no flood insurance is required, accounted for 73,578 homes in 2014, with another 164,733 in the combined USACE LPAs for the Sacramento River, American River, and Natomas area. According to the NFIP, only 53,643 policies were in force in Sacramento County, however, representing about \$17.5 billion in insurance in force—which is less than half of the cumulative value at risk for homes located in just the leveed areas of the county, representing about \$20 billion in potential under-insurance. Thus, though disaster assistance may indeed influence perceptions of flood risk and participation in flood insurance, it would appear that the presence of levees influences flood risk perception and insurance participation rates far more significantly than expectations of disaster assistance, consistent with *levee effect* as stated by Tobin (1995). The effect of levee construction is consistent with Husby et al (2014) also, which suggests that government intervention in the form of structural flood control crowds out individual responses to flood risk, such as participation in flood insurance; moreover, the local scale government decision to not require more substantial building codes—including elevation of structures and wet or dry proofing—disincentivizes individual responses to reduce exposure and vulnerability to flood damages, similar to how the federal scale NFIP permits the removal of such requirements when removing levee-protected areas from the regulatory requirements established by SFHA zoning. Synthesizing Husby et al (2014) with Kunreuther et al (2018, pp. 12-13), the effect of crowding out individual responses to flood risk may reflect individual biases such as myopic thinking—i.e., a focus on short time horizons when appraising immediate costs and the potential benefits of protective investments, like flood control—or herd thinking—i.e., a tendency to base choices on the observed actions of others. Indeed, the latter bias is commensurate with path dependent institutional and local land use activities.

5.5 Assumptions & Limitations

In carrying out the analyses and estimations, a number of assumptions were made. The year of construction made available in the residential parcel data attained from county and city tax assessor data offers associated values for land and structures located on the respective parcels, allowed for a combined estimate of total value. However, these values represent only the value for the homes and properties for 2014, and, as such, do not represent how those values changed over prior years or how other economic factors may have affected annual valuations; moreover, these parcel values do not necessarily represent real estate pricing, which may be higher or lower based on hedonic factors like number of bedrooms, square footage, convenience of location, and other amenities. Hedonic regression modeling may capture or describe more external factors affecting home values, such as distance to city center or distance to levees, which might be an appropriate next series of analysis that employs the exposure typing developed in this research. Also, the flood hazard zones and levee-protected areas were assumed to be constant over time, whereas the regulatory flood zones did not exist prior to the implementation of the NFIP; moreover, the rivers, floodplains, flood zones, and protected areas have likely changed over time due to subsidence of both floodplains and levees, channel widths and shapes of river beds, and due to many other physical, hydrological, hydraulic, and climate factors.

5.6 Recommendations for Future Research

Further research into the levee effect through the examination of residential parcels should proceed. The research in this dissertation reveals intriguing development patterns in the leveed and non-leveed floodplains of the study areas, yet the residential parcel valuation data is only for 2014. Similar analyses should be conducted for more recent tax valuation years to consider whether the average values in pre-and-post levee construction areas stands up. If data for the years subsequent to 2014 illuminates similar patterns and trends, more evidence compiled would strengthen the argument for levee and development effects; however, it may be the case that such additional evaluation yields either flat or opposite trends reflective of market conditions unmeasured in the subject research.

Given that ongoing flood on the Mississippi commensurate to or surpassing the 1927 historic flood, to which ethnomusicologists attribute dozens of music relating the conditions of levee-enabled sharecropping lifestyles and forms of risk-taking, perhaps there might be an accounting of the effects of long-duration flooding on modern-day floodplain inhabitants? Might a levee effect be measured culturally? And over time? Might this be a source of refutation for economic interests in the floodplain? If there are fewer songs of levee-related struggles and hardships, would that prove that levees improve the underlying vulnerabilities of floodplain residents?

The broad list of empirical evidence discovered in this research may lead to improved knowledge of some mechanisms driving flood risk in the study areas examined and beyond. In particular, a synthesis of the evidence with vulnerability, risk, and loss modeling should be undertaken, perhaps with adjustment of the various parameters set out in the socio-hydrological model developed by di Baldassare et al (2015). In particular, di Baldassare introduced a population term to simply the model, and, while this term is insightful, maintaining a property value term would allow for long-term scenario and potential outcomes development that could influence benefit-cost and risk assessments, specifically in relation to disrupting long-term path dependencies created by institutionalization of flood risk reduction policies. For example, following a major flood, an adjust socio-hydrological model that accounts for a decision option breaking "technological society's" normal cycle of rebuilding in hazardous areas may lead to development of adaptation strategies favoring a retreat from the floodplains toward a "green society."

In light of the overtopping of more than 200 miles of levees along the Platt River in Nebraska, caused by a "bomb cyclone," the author recommends that the USACE update the evaluation of Probable Maximum Flood scenarios for structural flood control design criteria, as it appears that the combination of 55 or so hypothetical atmospheric conditions may not consider the effects of rapidly intensifying storms. Additionally, though not necessarily a primary topic of this dissertation, in light of Wing et al (2018) demonstrating the underestimation of flood risk in 100-year floodplains by about 40 percent nationally given inaccuracy of FEMA's flood maps based on age, newer development, limited hydrological modeling, and increased exposure to flood hazards, an updated hydrological model should be immediately evaluated and implemented to offer more comprehensive assessments of risk for local-to-national scale risk management concerns. The author is aware of, and participating in the development of, multiple national, comprehensive, expeditious and accurate hydrologic modeling techniques in development with the U.S. National Labs and the National Center for Atmospheric Research, whose WRF-Hydro model is the backbone for riverine flow and flood model decision support for real-time hydrologic analysis at NOAA's National Water Center. In short, both the accuracy and understanding of FEMA's 100-year SFHA are becoming outdated, with social and physical science research demonstrating substantial inadequacies; however, the research conducted in this dissertation also distinguishes substantial areal differences between FEMA's levee-protected areas when compared to USACE levee-protected areas, demonstrating underestimation of risk as related to NFIP goals. Further, the author recommends development of a socio-hydrological model capable of supporting both structural and nonstructural risk reduction initiatives across the federal agencies charged with such program goals.

As a matter of improving local-to-national scale residential exposure data, the author recommends that county tax assessors and all proprietary data managers be required to add attribution to parcel data for regulatory and non-regulatory flood zones delineated by FEMA, similar to individual parcel database record identifiers like Assessor's Parcel Number (APN); moreover, organizations with access to national-level parcel inventories, such as FEMA, should reproduce this study on a national basis for more clarity on home value capitalization of flood risks or reduction benefits in support of NFIP risk financing and the better informing of policy decisions for better flood zoning and control. Local tax assessor, or FEMA, should be required to publicly disclose the number of homes and their cumulative exposure values for flood zones to further increase awareness of local physical and financial exposure to flood hazard, perhaps as a means to further encourage flood insurance participation. Though regulatory oversight is required for flood zone disclosure by local banks and realtors, the associated of APN with flood zone may help with financial tracking of insurance requirements for federally-sponsored mortgage securities. Further, in this regard, federal financial agencies should consider enforcement of the Mandatory Purchase Requirement for flood insurance in a similarly binding way as the Internal Revenue Service's Voluntary Compliance Rate, which tracks tax payments as a means to estimate federal revenues for budget management. The semantical difference between *mandatory* and *voluntary*, here, is more than ironic: paying taxes is indeed mandatory, subject to civil fines, penalties, and garnishments if not in compliance, whereas the multiple studies published in academic literature demonstrate that the tenure of flood insurance policies is under 4-5 years, resulting in increased vulnerabilities for individuals not voluntarily or mandatorily participating in the NFIP—and with no enforced penalties. In a similar sense, flood insurance should be required in all levee-protected floodplains with a change in flood zone from X to A99, or some similar designation, with enforcement of the mandatory purchase requirement perhaps at a discounted rate for the duration of federally-backed mortgages relative to the residual risk of flooding, not because of an anticipating future state of design-level flood protection from the completed or improved levee. Moreover, FEMA should conduct a feasibility study for transforming the NFIP to require flood insurance nationally, similar to France's Catastrophes Naturelles (CatNat) insurance system, where penetration for households is more than 99 percent (Poussin et al 2013). The French CatNat system is regulated on a basis of "national solidarity, which in practice means that the compulsory natural disaster coverage is provided through a national reserve that is financed by fixed insurance premiums, [… which] enables a high market penetration rate and a large financial reserve at a low cost for policyholders" and encourages "damage reduction measures at the household scale" (Poussin et al 2013). Though speculative, such a national reserve could be established in the U.S. under an obligatory flood savings program, similar to Medicare, which would require individuals to save for flood losses upfront. The author could envision such a savings program providing financial support when flood losses occur, or, if at the end of a federally-sponsored mortgage and without realization of flood damage, a reinvestment or repayment program to reimburse policyholders or floodplain citizens for the discount in their property caused either by flood risk or flood risk reduction benefits at a scale proportionate to either a national average home value from the Census or derived from local real estate market analysis. Finally, though perhaps a radical or more speculative recommendation than transforming the National Flood Insurance Program into a National Flood Savings Account, but, in light of the federal government's transfer of wetlands and swamplands to state-level development and risk management authorities, the federal government should consider preemption of once-federal wetlands and floodplains in order to better assess and manage increasing flood risks and vulnerabilities. States often preempt local governments in order to stabilize markets or induce a desired outcome, and, given the ongoing conflicts in structural and nonstructural risk reduction programs, along with the federal government's delegation of powers to state and local governments that appear to not regulate floodplains per the standards required of the NFIP, federal preemption could significantly improve flood risk management.

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APPENDIX A: Pre-United States Flood Management Influences from Rome, France, and England

A.1 Roman Influence on French & English Flood Management

Flood control and engineering are fundamental to the establishment of the modern society of the U.S. as well, and can be traced primarily to Rome, France, and England. Though the topographical relief of Rome is diverse, with steep hills and deep valleys, many swamplands and marshes in the city experienced frequent floods. And although the Romans developed significant engineering techniques for the transport of water for municipal or drinking purposes, the public spaces of the city were designed with an indifference to periodic flooding, most likely due to the immense size of public buildings that could handily withstand flood forces and damage—nearly all of Rome's buildings for major political, religious, commercial, and entertainment centers are located in the most flood-prone areas (Rogers 1993, p. 103; Aldrete 2006, Ch.6, Para. 5). In the low elevation portions of the city, civilian apartments were well mixed in terms of race and incomes, although high ground locations in nearby hills were favored by the very wealthy and elites; however, there were deliberate efforts to raise the ground elevation of flat or wetland areas to improve drainage and make such depressions less flood-prone—an effort to raise the natural land surface at the Forum in the 600s B.C. from about 6 meters (19.7 feet) above sea level to 9 meters (29.5 feet) likely involved about 10,000 cubic meters (353,147 cubic feet) of fill and represented Roman practices of successive layering of streets and foundations to protect against flooding from the Tiber River (Aldrete 2006, Ch. 5, Para. 17-23).

The Romans also dug canals to link harbors and alleviate flooding from the Tiber, and notably situated bath houses in the higher elevation hillsides outside of the maximum inundation areas of the Tiber floodplain (Aldrete 2006, Chs. 5 and 6, *see* Ch. 5 at Para. 7). Notably, following a significant flood around 15 A.D., engineering proposals entertained by Cicero, the Florentines, and Reatines to dam outflow waters from the lakes and tributaries of the Tiber to reduce floods in Rome were met with disdain and concern for inundating farmland or causing new flooding in different cities: the various engineering proposals led to an understanding that changes benefitting one region can adversely affect another, with an overall policy adopted that "nothing be changed" because nature already provided an optimum arrangement of streams and rivers (Aldrete 2006, Ch. 5, Para. 38). Later, under Augustus, favored engineering actions included the removal of channel-constricting structures and dredging of the Tiber and its tributaries to increase carrying capacity and debris clearance; Suetonius noted at the time that these measures were intended to prevent flooding (Aldrete 2006, Ch. 5, Paragraph 42). Although there were some concrete embankments constructed along the Tiber by the second century, which would have provided some flood protection, these were likely designed as port facilities as there was no systemic plan to construct continuous lines of embankments along the river—river transportation for moving food in support of the growing population became a predominant theme of river engineering (Aldrete 2006, Ch. 5, Para. 51-52).

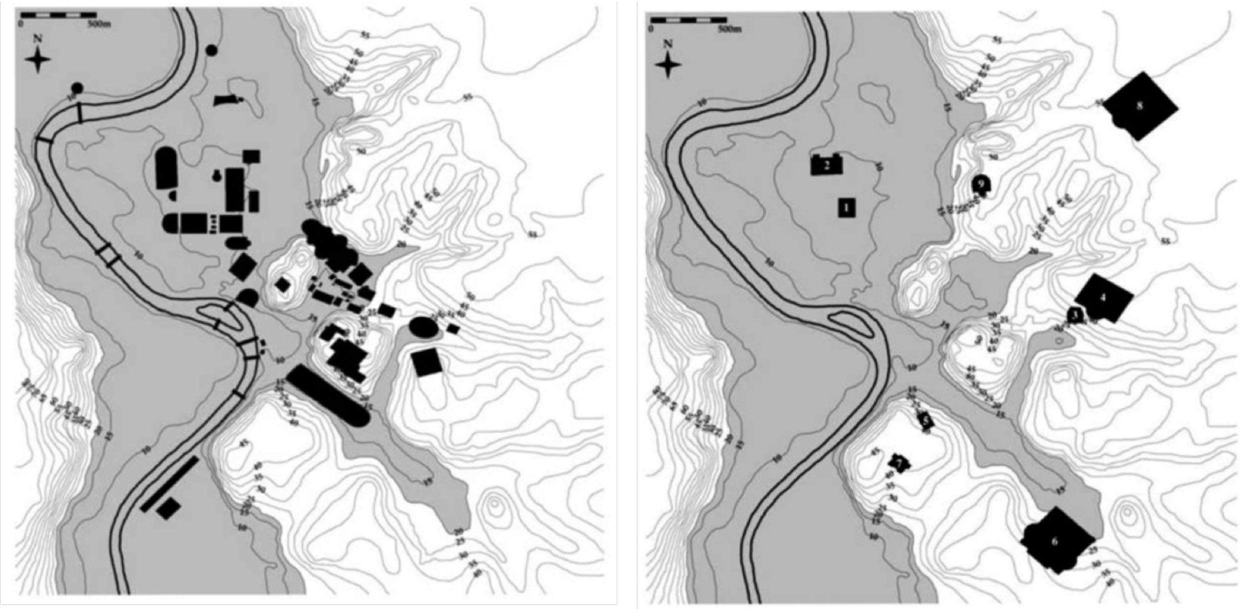

Figure A.1. Estimated locations of insulae and domus buildings in Rome. (Source: Aldrete 2006)

There were two primary types of residential buildings in Rome—private homes, or *domūs*, and apartment buildings, or *insulae*—with about 1,790 *domūs* and about 46,602 *insulae* per a fourth-century Regionary Catalog (Aldrete 2006, Ch. 6, Para. 12). According to Aldrete (2006, Ch. 6, Para. 13-16), anecdotal literary evidence suggests that apartments were built mostly in flat, lowland areas, intermingled among public buildings, while many aristocratic, wealthy, or elite private residences were situated on high ground, with as few as 15 percent of *domūs* in floodplains. The fresh air and abundant light available on hilltops, away from the crowded streets of Rome, ensured that the wealthy elite did not experience flood damage, whereas a substantial proportion of the city's poor and renter class, who had little say in political and economic policy decisions, bore the brunt of flood losses well into the 700-800s A.D. (Aldrete 2006, Ch. 7, Para. 6). As the Roman Empire weakened and lost power, from thereon Rome's population migrated to occupy the banks of the Tiber, as commerce and fishing were good sources of income; however, it was not until the late 1800s under Savoy rule that continuous and intentional flood control levees were constructed, marking a significant change in the city's master plan (Jones 2009, p. 5).

A.2 Conversion of the English Fenlands for Agricultural Development

In the early Middle Ages (500-1000 AD), Roman territorial expansion led to settlements in the East Anglian fenlands of present-day England. The Romans brought open field farming techniques to East Anglia as practiced throughout the Gallic lands of central Europe, with the introduction of large-wheeled, heavy plows, called caruca, capable of handling clayey English soils better than lightweight Roman aratrum plows (Fairlie 2009). Notably, these heavier caruca plows required more than one ox to pull, sometimes requiring as many as eight oxen; and, as a result, plows and oxen were often joint enterprises among peasants able to afford contributions to crop development: once this system was in place, peasant farmers did not change their practices because fields were grazed after harvests, so the open field system was communal and equitable (Fairlie 2009). Generally, the Romans constructed some sea walls to prevent occasional flooding of the East Anglian fenlands and support agricultural development, evidenced by the Car Dyke, a drainage ditch along the western edge of the fens, and the Fen Causeway, a road connecting East Anglia to central England; but the collapsing power of the empire led to Romans abandoning Britain and early attempts to drain or further cultivate the fenlands. Bond (2007) suggests that, following a visit by to Britain by the Roman Emperor Hadrian around the year 120 AD, the seawalls around the fens were built as either a physical boundary, protecting the fenland territory from raids from Mercia, or as a drainage mechanism, possibly serving the purpose of helping the Romans establish a settlement in the fenlands. Nonetheless, the fens reverted to a raw, natural state following retreat of the Romans as the empire weakened. Fairlie (2009) establishes that the open field system of agriculture and land tenure in and around the East Anglia fenlands produced economies of scale that benefitted native and remaining peasants more than other farming systems, and that there were still plenty of uncultivated plots of land available for private uses outside the fens.

Control of the English territories passed from the Romans to the Vikings and on to the Normans, following the Battle of Hastings in 1066. Concurrently, Christianity slowly replaced paganism, and Christian monks found solitude and built “no fewer than six large religious houses” in the raw nature of the fenlands (Page et al 1936). The Normans fiercely tried to conquer and control native peasants by thwarting uprisings, burning agricultural fields and enslaving peasants. William the Conqueror built a stone castle at Ely, essentially an island of higher ground surrounded by wetland fens, where local populations engaged in efforts to resist the converting of their lands into protected private lands through early means of *enclosure*—a legal act used to convert commonly-held land into private ownership, typically by low-ranking nobility. Hereward the Wake, an Anglo-Saxon landowner occupying the fenlands with other countrymen resisting Norman conquer, built a wooden castle in the fenland as an affront to William the Conqueror—becoming a storied protector of the wetlands—inspiring local populations to resist strongly the expanding Norman control. As a result of the Siege at Ely, fenland peasants were further inspired to resist any and all efforts to *enclose*—privatize—the fens. The peoples resisting Norman occupation became known as the Fen Tigers, and William the Conqueror enacted a system of *forest law* to dispossess, dislocate, and prevent fen dwellers from accessing the fens and other forest land owned by the crown; subsequently, and through the early 1600s, the Fen Tigers revolted against the privatization of the wetlands upon which they thrived (Fairlie 2009; Wood 2014).

Between the 1300s and 1600s, private land holders desired to improve the value of the open field agriculture system through the use of *enclosure*. Following the signing of the Magna Carta in 1215, which limited the powers of the king and expanded the powers of barons (i.e., low-level, land-holding nobility), efforts increased to establish private ownership of lands previously held in common. Whereas the common lands upon which open field agriculture took place were owned by a baron, and those common lands were part of a baron's manor and estate, the use of *enclosure*, or the enclosing of small land holdings to create one large land holding, became a means for creating additional financial value for barons by making exclusive to the baron the ground and other legal rights to the land enclosed. Barons erected fences to keep peasants out of enclosed lands, resulting in further dispossession of peasants' common rights established under a companion treaty to the Magna Carta known as the Charter of the Forests, which made legal the specified *common* rights of access to royal, or private, lands by *disafforesting*—or releasing rights of possession. In effect, the Charter of the Forests granted commoners some abilities to continue open field farming in areas not yet enclosed or made private and made exclusive the most productive royal forests, for things like crown-licensed hunting and fishing; however, the overall effect was dispossession and dislocation of commoners from forest lands upon which the commoners once subsisted—lands that came under private royal control for timber harvests delimited by legal enclosure—leaving commoners none but the most rugged and difficult terrains to cultivate, including, for a time, the East Anglian fens. Peasants and commoners deemed criminal, poor, or diseased by barons could be imprisoned at the Bridewell Palace in London, designated in 1553 as a correctional facility known for harsh reformative punishment (Page et al 1936; Schama 1987, p. 17; Fairlie 2009)

The fenlands of England were perceived as impure, associated with diseases such as malaria, and causing significant public health impacts. Commoners subsisting on wildlife in these wetlands were also perceived as impure, with nobility and religious leaders desiring to instill work ethic and Christian values into the commoners through farming practices dependent on draining the wetlands—a practice referred to as "discipline and drain" by Giblett (Giblett 1996; Ash 2017; Ley 2018). In the 1530s, England was in conflict with France and under threat of invasion. Accordingly, Thomas Cromwell and Henry VIII dissolved Christian monasteries and the Roman Catholic church's landholdings, essentially converting the church in England to the Church of England in order to further privatize land estates to raise funding for military defense and war (Solomon 1982). Further conflicts emerged with fen dwellers, as the newly privatized landholdings were economically advantageous to entrepreneurs seeing economic opportunities in agricultural development (Solomon 1982; Ash 2017). Under Elizabeth I in the latter 1500s, draining of fens and wetlands emerged as a priority for agricultural production, though up to the 1580s only a few dozen hectares (acres) could be reclaimed at a time; however, a General Draining Act was passed by Parliament in 1601, attracting the capital of "adventurers" (i.e. landowning investors) for larger projects that could drain thousands of acres under James I (Solomon 1982, p. 129; Ash 2017). Under Charles I, in 1629, with the perceived success of Dutch engineer Cornelius Vermuyden's major drainage and reclamation project at Hatfield Chase and the Isle of Axholme, and against the opposition of commoners who had been able to productively farm the fens for centuries at maximum utility to both private landowners and the commoners (Page et al 1936), the Duke of Bedford, Francis Russell, would be rewarded with 38,500 hectares (95,000 acres) of *enclosed* fenlands upon the successful straightening of the Nene River channel, drainage and reclamation of surrounding floodplains and fens, improved navigation, and control of fenland floodwaters for irrigation in the “Great Level” through partnership with Vermuyden and other landholding adventurers (Page et al 1936; Solomon 1982, p. 130; Knittl 2007; Ash 2017). The crown was the largest landowner in the fenlands at that time, and successful arguments were made to the Parliament and Charles I on the basis that great returns to the adventurers, commoners, and nation as a whole would be achieved through agricultural intensification on the fertile, reclaimed wetlands. In 1649, Parliament passed another national drainage act to continue the draining of the Great Level to increase agricultural production through new industrial techniques, leading to increasing wealth and commerce, along with benefits to the commoners by discipline in the form of forced labor to drain the fenlands (“Drainage Act” 1649). In all, some 161,875 hectares (400,000 acres) of wetlands and fens would be drained in a substantial conversion to very productive, industrial agricultural lands into the 1700s (Knittl 2007; Ash 2017).

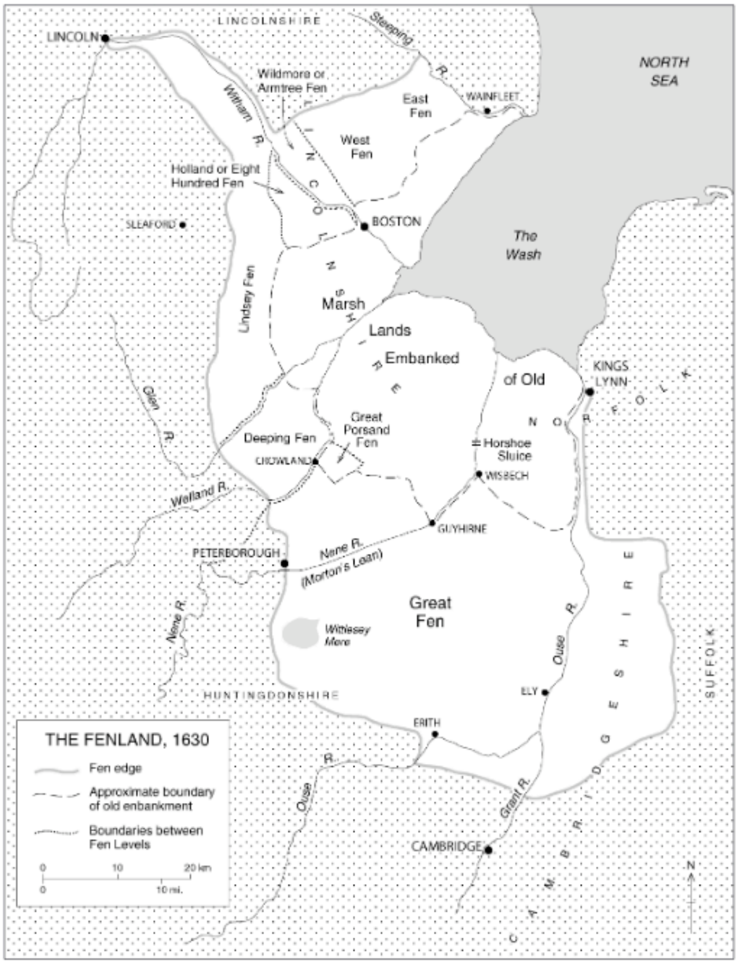

Figure A.2. Map of fenlands in England in 1630 that would be reclaimed under several Parliamentary drainage acts. (Source: Knittl 2007, p. 26)

A.3 A Legacy of French Influence on American Flood Control

Construction of flood abatement structures in France began in the late 700s under Louis the Pious, son of Charlemagne of the Holy Roman Empire, and later continued under the House of Capet and King Henry II. These early structures, known as *turcies*, were small dikes or weirs made of wood pile, soil, and rocks, consolidated into local batteries, serving as flood walls on the banks of the Loire River. Following a significant flood in 1150, Henry II commanded the construction of buildings in the Anjou Province of the Loire Valley for the purposes of *turcie* maintenance. *Turcies* were designed to deflect and prevent overflow of flood waters, lessening erosion from wave action while collecting silt deposition for fertilization as floodwaters passed (Lino et al 1970; Guillou and Maurin 2005). Given Henry II's efforts to encourage agricultural development, many houses in the Loire Valley were constructed on hillsides or mounds (Lino et al 1970). Local farmers were charged with maintenance of the *turcies*, as agriculture was their primary source of taxable income, with support from local feudal lords (local scale), the cities of the Loire Department (regional scale), and from the royal administration (national scale). Thus, the maintenance of flood defense devices—*turcies*—was carried out at the local level with some resources provided by higher levels of government along with some exemptions from military service and certain taxes granted for public service (Maurin and Guillou 2004; Fournier 2008). Open field agricultural systems were utilized in the most modern areas of France (Fairlie 2009).

Several large floods in the mid to late 1400s led to the strengthening of old *turcies* under Louis XI. After a particularly large flood in 1482, Louis XI ordered local residents and flood victims to raise the *turcies* to such a height that they would not be overtopped by floodwaters, a policy known as the "lifting of the Loire," or *levées de la Loire* (Vignon 1880; Maurin and Guillou 2004). There was growing awareness that flood disasters were becoming more frequent and expensive due to agricultural development and riparian population growth; therefore, new *turcies* and earthen dams—referred to as *levees*—were constructed at elevations up to 4.88 meters (about 15 feet) above low water conditions. Intensification of agricultural development in the Loire Valley was met with royal engagement, engineering, and control intended to enhance the *levees* as a system geared toward protection of inhabited lands and improved navigability—specifically, there were efforts to constrain the sometime 1-kilometer-wide floodplain to less than 400 meters (0.6 miles to 0.25 miles) (Lino et al 1970, p. 18). Damaging floods under subsequent monarchs in 1494, 1519, 1527, and 1549 resulted in new levee construction; however, farmers in the Loire Valley began to feel as though the levees were less for agricultural protection than for commercial development of inland waterways: "**L'ètat d'esprit du plus grand nombre n'est pas tant la conscience du resique encouru à l'ombre des ouvrages que l'illusion de protection apportee par ceux-ci[.]**" (Roughly, "*The mindset of most of the [rural population] was not so much the awareness of the risks encountered in the shadow of these structures but rather the illusion of protection they provided.*") (Maurin and Guillou 2004, p. 32).

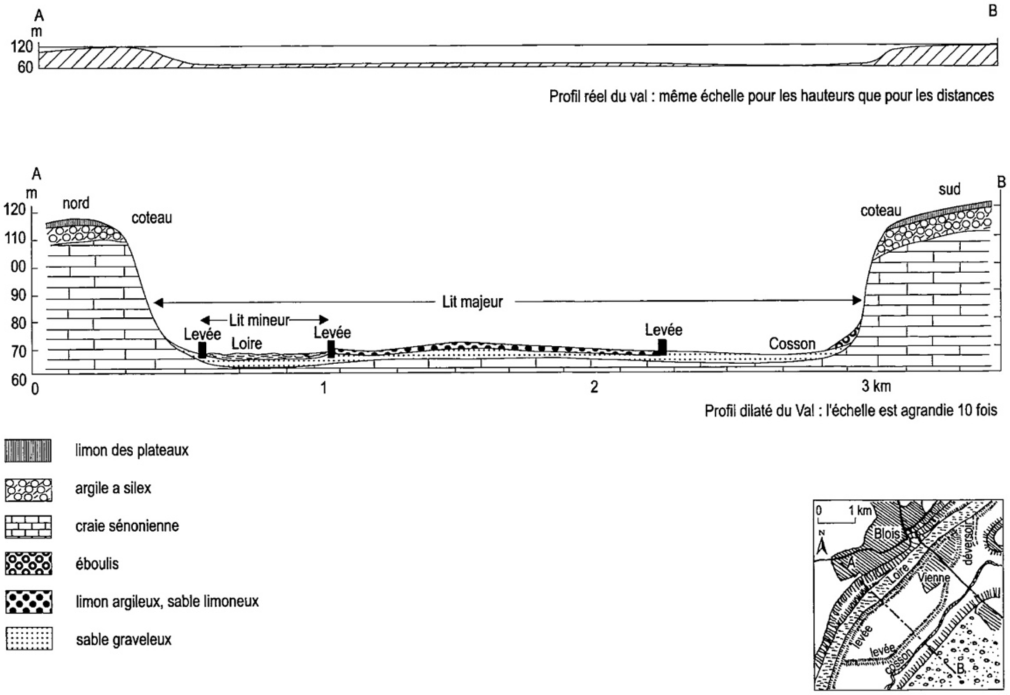

Figure A.3. Profile of the Loire Valley and levee locations at Blois. (Source: Lino et al 1970, p. 17)

Louis XI was particularly attentive to the concerns of the commercial bourgeoisie in the Loire Valley. Efforts to construct weirs and improve the Loire channel ensued, and in 1571, under Charles IX, a first attempt to establish a chief royal representative for *Turcies and Levees* failed due to civil unrest related to a lack of maintenance actions on the flood control system, placing the valley at higher risk of flood damages (Maruin and Guillou 2004, p. 32). In 1573, Charles IX attempted to have the local mayors and aldermen choose several experienced, and *wealthy*, local citizens to be charged with maintaining the flood control system, but this effort was rejected. Under Henry III, a superintendent of *turcies and levees* was appointed, and the action led to the overburdening of the superintendent with financing the repairs of the system, resulting in the usurpation of local commissioners taxing rights. Notably, the power to tax and efficiently collect taxes became a centralized endeavor through the 1500s, with tax revenues funding wars and public works: under Henri IV, the first *Department of Turcies and Levées* was formally established in 1594. The king's steward of *turcies* and *levees* was charged with ensuring the construction and maintenance of the flood protection system, ensuring that the rivers served as transportation routes with minimal flood interruptions; however, the taxing and financial accounting system imposed on the local city councils for flood control maintenance and repairs became a major point of contention related to national control over local matters (Maurin and Guillou 2004, p. 32-33).

Floods in 1608, 1615, and 1628 led to levee breaks and overall weakening of the flood control system. As a result, Louis XIII declared it impossible to contain very large floods and introduced the concept of *déchargeoirs* to the levee system—discharge ports at low points in the levees, with the intent of preventing ruptures, a particularly poor design concept that caused extensive damage to the levees during floods in 1649 and 1651. Failures to properly repair and maintain the levee system up to 1651 were related to improper accounting and corruption at local levels. Relief for local citizens damaged by floods often came in the form of tax breaks, provision of food, or sometimes the rebuilding of houses (McCloy 1941, p. 2). Concurrently, in the 1640s and 50s, there was significant debate over new knowledge and traditional knowledge of the past, particularly among the scholars of cosmology, medicine, and philosophy—the scientific and technological discoveries of Galileo, William Harvey, Descartes, and Torricelli were influencing faith, law, and society, leading to conflicts among the French Church, the Sorbonne, and the Parliament of Paris (Saunders 1984). As a result, when Louis XIV came to power in 1661, he created advisory positions, known as ministers of state, leading France into a period of absolutism and centralization of government (Saunders 1984).

The centralization of state functions is important to understanding the development of American flood risk and control projects. Under Louis XIV and his appointment of Jean-Baptiste Colbert in 1664 as the Superintendent of Buildings, the French government established permanent absolutist control of all public works carried out by the Loire River or in its floodplain (Lino et al 1970, p. 18). Colbert spent years developing a system of political patronage that extended into the academic and scientific communities of Paris as he rose to the ranks of Controller of Finances and Secretary of the Navy and Colonies. Concurrently, Colbert was concerned that public works projects related to flood control and river navigation were carried out by citizens who had insufficient training or expertise to implement such systems properly (Lino et al 1970; Saunders 1984; Maurin and Guillou 2004). As a result, despite opposition from established institutions that included the Sorbonne and the Faculty of Medicine, Colbert created a General Academy composed of scientists, historians, linguists, and philosophers that would become the Royal Academy of Sciences in 1666 and focus on the needs of the state (Saunders 1984).

When not meeting to discuss the intellectual matters of physical or biological sciences, Colbert's scientists were devoted to government engineering projects. In 1668, Colbert issued regulations calling for the improvements of existing levees and design standards for new levees—specifically, that the levees must be at least 5.85 meters (19.2 feet) above low water conditions, at least 7.8 meters (25.6 feet) wide, and covered in stone to protect against erosion (Lino et al 1970). Together with the scientists, engineers in the French military served a primary purpose in improving fortification of boundaries during wartime; however, during peacetime, engineers focused on issues of hydrology and hydraulics, constructing canals and water fountains to satisfy Louis XIV's interest in gardens (per Saunders 1984, some 1,400 fountains had been constructed at Versailles and Marly, resulting in significant attempts to develop hydraulic pumps to divert water from the Seine by forcing water uphill and reservoirs to manage the water at various stages of elevation gain).

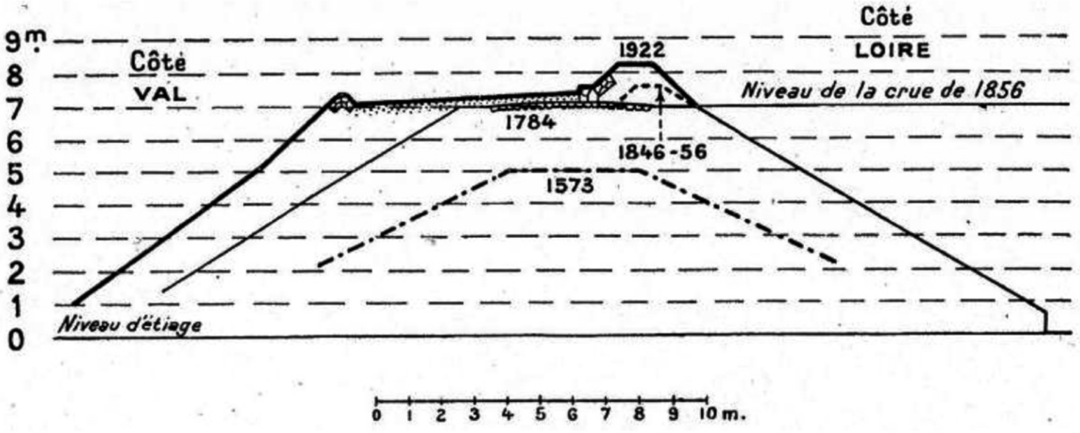

Figure A.4. Profile of increasing levee heights from original construction in the 1500s through the early 1900s in France. (Source: Maurin and Guillou 2004)

Prior to his death, Colbert actively managed the French system of corporate charters and ensured that wealthy and privileged bourgeois were rewarded with economic opportunities through the implementation of a strong mercantilist policy designed to increase the country's monetary assets (Byington 2011). River transportation and commerce was particularly important to supporting France's economy through the late 1600s because of financial distresses caused by unsustainable expansions of territories and numerous wars; moreover, religious intolerance had left the French workforce severely crippled, and Colbert advocated a strongly protectionist stance for distributing French products in international markets with the backing of the French navy (Byington 2011, p. 14).

The establishment of the Company of the Indies by Colbert's predecessor, Cardinal-Duc de Richelieu, resulted in the further consolidation of naval and commercial policies under direct control of the state, allowing the global trading company to expand French commercial activities abroad (Saunders 1984; Byington 2011, p. 13). Naval policy under Colbert became focused on the *disruption* of international markets such that products originating in France or its territories would replace those of the English, Dutch, and Spanish in their own markets; and, in order to accomplish those goals, the fusion of science and technology through the Royal Academy led to the development of an officers' corps that specialized in navigation, chart-making, surveying, and other hydrographical techniques (Byington 2011, pp. 24-25). Therefore, Colbert called for expansion of French port capabilities and operations as well as improvement of road and river systems linking France's forests to its major ports:

> The French navy was able to expand international commerce through markets previously unavailable due to the earlier absence of the market protection and expansion provided by a credible navy. The growth of the French navy was due to the centralizing efforts of the state. The navy in turn helped maintain a strong central government through the spread of trade, the growth of capitalism, and new business relationships and opportunities overseas[.] (Byington 2011, p. 17-18).

René-Robert Cavelier, Sieur de La Salle, explored the French territories that were established in North America in the late 1500s and early 1600s. In particular, through the early 1680s, La Salle navigated the Illinois River from the Great Lakes and then southward to the mouth of the Mississippi River on the Gulf Coast, declaring the territory *Louisiana*, after Louis XIV. Seeking to connect the territories held in present-day Canada, or *La Nouvelle France*, with the Gulf Coast, Colbert became dedicated to improving the French economy and commerce through the art of navigation by accurately mapping the world, leading to accurate determinations of one degree of latitude's distance and the precise determination of longitudes (Saunders 1984). Subsequently, Colbert recruited Jean Cassini, the Italian astronomer, to work with the Royal Academy on improving mapping techniques for determining the distances between major ports in France, Europe, and the Americas.

Colbert's successor, the Marquis de Louvois, did not share the same interests for overseas commerce, instead favoring French wealth relative to internal improvements and border security. Since at least the time of Henri IV, French military engineers focused on controlling terrain through fortifications and, as such, Louvois relied on a professional group of about 200 engineers in the French Army to design and enhance strategic forts to ensure that foreign armies could not pass through certain areas without being attacked or having supply lines cut. As a result, Louvois created a special military reserve commission—an ***army corps of engineers***—consisting of highly specialized engineers who were given a special status to protect their military careers, particularly when engaged in engineering projects not included in direct warfare or defense (such as building aqueducts from the Eure River to Versailles in the mid 1680s to water the king's gardens). Further, Louis XIV consolidated several sections of the Service of Fortifications into a centralized administration, thereby creating a professional structure for engineers to advance their skills and careers. (Saunders 1984)

With the discovery of the mouth of the Mississippi River, the French raced to establish a foothold that would separate the British and Spanish colonies. The French were particularly concerned that the British would establish a post that would separate France's Canadian and Caribbean territories (Saunders 1984). Following Louvois's death, Louis Phelypeaux, comte de Pontchartrain, became Controller General for Finance and Secretary of State for the Navy and

Colonies in 1691. Similar to Colbert and his interest in fostering overseas commerce and exploration, Pontchartrain established the Bureau of Maps and Plans within the Ministry of the Navy and Colonies in 1696, leading to a map published by Cassini in 1696 that displayed accurate locations and distances for 43 locations in these areas, including the French West Indies (Saunders 1984). The Bureau of Maps and Plans was directed to focus on the problems of the? empire posed by France's wars, and the "bureau drew together a group of engineers, cartographers, and military strategists who planned France's ventures into the Louisiana Territory[.]" (Saunders 1984). Working with Cassini, cartographer Guillaume Deslisle produced maps of the Gulf Coast, using information gathered by the La Salle explorations as well as *intelligence* gathered from plundered Spanish ships relative to Hernando de Soto's prior explorations, supporting Le Moyne d'Iberville's explorations and initial settlement in 1698-99 (Saunders 1984; Pelletier 2002). According to Pelletier (2002), "[f]or the king, the Mississippi [River] is the 'one place where you can export the goods of Louisiana […] which would be useless to [Louis XIV] unless he were master of this river-mouth.'"

Upon the death of Louis XIV in 1715, the war-bankrupted French economy and throne passed to the Duke of Orleans. Stocks previously issued under royal charters, intended to raise capital to continue financing the country's commerce, were significantly discounted at rates of 70-80 percent of their actual value, and the country's coins cost more to produce than they were worth (Thiers 1859, pp. 40-44). As a result, the Duke of Orleans was inspired to introduce a new monetary theory based on John Law's proposed concept of discount banking: essentially, that currency could be printed at will, reflecting the anticipation of future wealth developed by corporate monopolies, or, in other words, selling government debt through stock ownership (Thiers 1859, p. 44; Frehen et al 2012). Agreeing to Law's proposal, the Duke of Orleans sponsored the *Banque Royale* in 1716 and paper money became more valuable than coin when Law implemented a policy that made all notes payable on demand (Thiers 1859, p. 49-50). With the failure of the West Indies Company to establish a permanent French colony of the Gulf Coast, Law was awarded a royal charter—a monopoly to develop the Louisiana Territories, under which he created the *Mississippi Company*, a joint-stock company—and began speculating about the lands to be developed around the mouth of the Mississippi River (Thiers 1859). An underlying principle in John Law's speculative *Mississippi Company* held that banks were the result of anterior prosperity and that increasing the supply of money would allow for market expansion and commerce, allowing the development of infrastructure like roads, bridges, and canals (Thiers 1859, pp. 18-20). The Mississippi Company merged with the Banque Royale in 1720, thereby controlling most of the French treasury and essentially converting French money into equity shares. This caused a run on the bank, as investors realized that their shares were devaluing, and led to the crashing in value of the Mississippi Company and its ensuing inability to develop the Louisiana Territories properly, even though key administrative functions relative to internal improvements were transferred to the colonial government in New Orleans (Thiers 1859; Frehen et al 2012).

APPENDIX B: THE SERVICES OF WETLANDS AND DISCONNECTION BY LEVEEING

The environmental degradation caused by hydraulic mining on the American River in California in the 1800s led to some of the nation's first environmental protections laws, the breadth and detail of which are beyond the scope of this dissertation. However, given the nature of swamplands drainage and reclamation for agricultural development, it is important to consider the nature and benefits of wetlands, generally, particularly in light of the transformation of such landscapes and ecosystems from an innate natural resource to natural hazard as agricultural areas become residential areas of flood risk, exposure, and vulnerability to damages.

Wetlands and swamplands passed from federal ownership to state and local management were poorly surveyed at the time of the passage of the Swamplands Acts from 1849-1860. Moreover, identification and classification of wetlands "were motivated largely by agricultural interests that sought to convert wetlands to cropland" (USGS 1996). As previously reviewed in this chapter, the ownership and management of wetlands areas was poorly understood and led to numerous legal challenges over title and proper use, particularly as areas of wet and swamplands were poorly surveyed; further, distinctions between the composition of wetlands compared to floodplains remains contentious and under legal revision through the present time of this study, which is substantially relative to arguments over natural resource use and protection, conversion to more economically useful or valuable land uses through urban and agricultural development, and all generally relative to human population pressures on such landscapes. It was not until the mid 1950s that a framework was developed for creating a national inventory of a broad set of wetland types in the U.S. across marine, estuarine, riverine, lacustrine, and palustrine habitats from coastal to inland landscapes (USGS 1996).

In 1956, the U.S. Fish and Wildlife service introduced the term "wetlands" to replace the "older, more value-laden terms, such as *swamp, marsh, bog, fen, mire,* and *moor*" in order to introduce a classification system that accounted for the importance of waterfowl and fish habitats, and later introduced a far more comprehensive classification system in 1979 to add the terms *hydrophytes*—i.e., plants adapted to wet conditions—and *hydric soils*—i.e. anaerobic soils formed under wet conditions, both to indicate the presence of wetlands in an areas (Garone 2011, pp. 8-10). The present-day definition of wetlands is encompassed in the Code of Federal Regulations (CFR) that guides USACE and environmental protection:

> Wetlands are those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (USGS 1996 citing 33 CFR 328.3 and 40 CFR 230.3)

The U.S. Fish and Wildlife Service defines wetlands as:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification wetlands must have one of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes; 2) the substrate is predominantly undrained hydric soil; and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year. (USGS 1996)

And the U.S. Soil Conservation Service defines wetlands as:

> Wetlands are defined as areas that have a predominance of hydric soils and that are inundated or saturated by surface or ground water at a frequency and duration

> sufficient to support, and under normal circumstances do support, a prevalence of hydrophytic vegetation adapted for life in saturated soil conditions, except lands in Alaska identified as having high potential for agricultural development and a predominance of permafrost soils. (USGS 1996)

Although there are numerous definitions of wetlands among the many states, which are often broader than federal definitions, the above definitions give an important characterization of biological and ecosystems components often disregarded when considering flood risk, especially given that structural flood control systems were favored over other land use and development adaptations prior to the 1960s and 70s when wetlands resources gained legal protections against overuse, development, and contamination under the National Environmental Protection Act and Water Resources Acts; additionally, environmental flow science, in consideration of ecological flood regimes, has also rarely considered how highly modified, channelized, or other structural interventions have influenced ecological performance of altered rivers and floodplains (USGS 1996; Whipple et al 2016). Though federal policy changes removed the prior generation of policy incentives that made wetlands destruction economically feasible, the USGS (1996) reports that wetlands losses averaged about 235,000 hectares (580,000 acres) per year in the 1950s and 60s, lowering to about 117,359 hectares (290,000 acres) per year during the 1970s and 80s—Christin and Kline (2017, p. 9) state that floodplain function along 75 percent of streams in Vermont has been lost due to wetlands disconnection from rivers, and that, the state of Washington, “more than 90 percent of Puget Sound’s floodplains have been lost to development, agriculture, and other human activities[, with] most of the remaining floodplains in poor condition, especially in urban and agriculturally dominated areas.” In California, up to 95 percent of wetlands and riparian habitats have been lost due to disconnection from source rivers in the Central Valley (Eisenstein and Mozingo 2013; cf. Figure B.1). Costanza et al (1997) state that ecosystem services “consist of flows of materials, energy, and information from natural capital

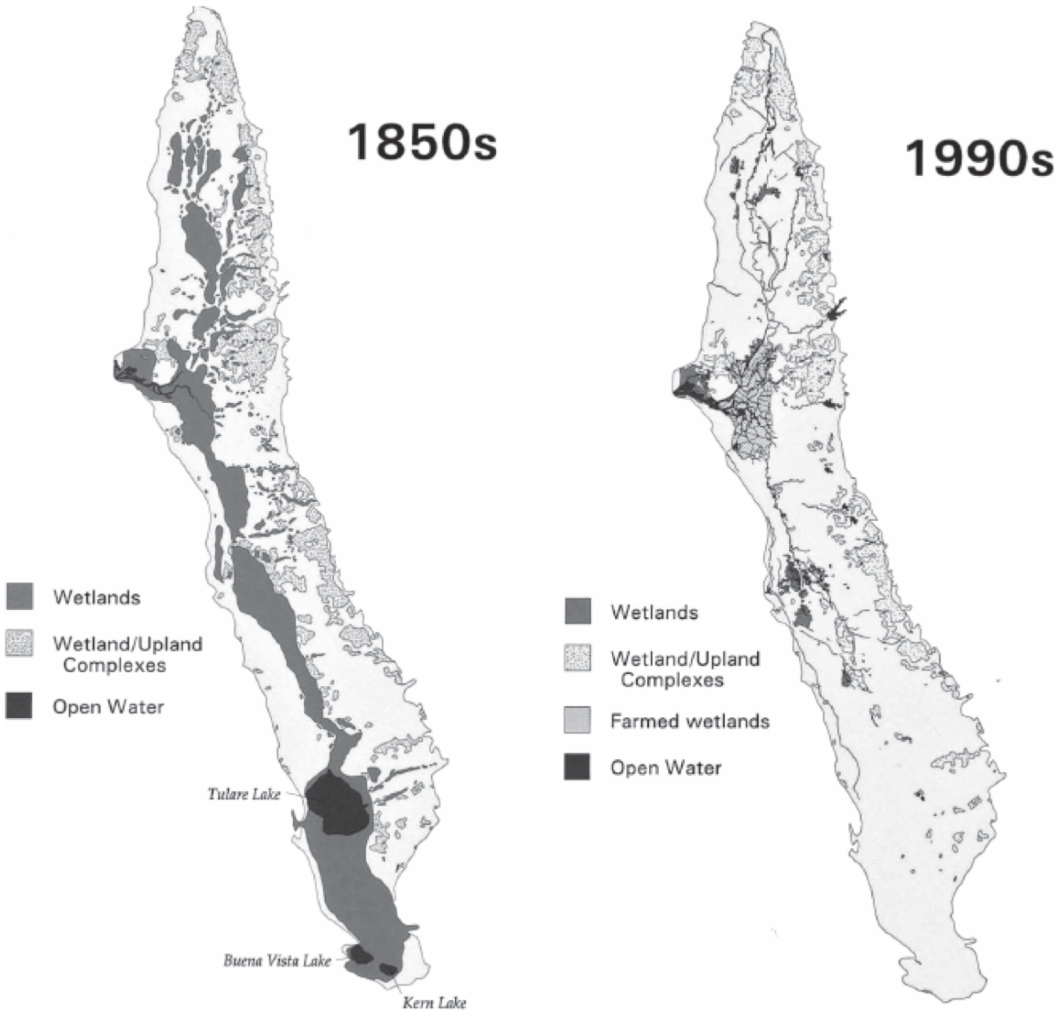

Figure B.1. Reclamation of wetlands for agriculture in California's Central Valley and subsequent wetlands loss between the 1850s and 1990s. (Source: Garone 2011)

stocks [such as trees, minerals, and ecosystems] which combine with manufactured and human capital services to produce human welfare." Further, Costanza et al (1997, p. 254) define some ecosystem services as regulation of atmospheric chemical composition and gases, climatic regulation of temperature and precipitation[1], regulation of hydrological flows and surface waters,

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[1] Notably, such ecosystem services were observed and studied under European colonial sciences in the 1700s and 1800s as "climate change" resulting from deforestation, crop development, and desiccation or changes in soil moisture—cf. Grove 1995, p. 37: "connections between rainfall, vegetation, and [the] hydrological cycle […] were elaborately recorded by officials of the East

erosion control and retention of soils within an ecosystem, soil formation and nutrient cycling, waste treatment through recovery of nutrients or breakdown and removal of compounds, pollination, biological regulation of ecosystem populations, food production, generation of raw materials, and, among other things, opportunities for cultural and recreational activities. In 1994 dollars, Constanza et al (1997, p. 259) estimated that ecosystem services and natural capital from wetlands could be valued at about $4.9 trillion globally, or around $3,208 per hectare ($7,924 per acre). Similar studies on English wetlands found annual benefits of wetlands buffering against flood damages, improved water quality, increased biodiversity, and cultural and recreational benefits at around $385 to $889 (2018 dollars) per hectare of inland wetlands ($951 to $2,196 per acre; Morris and Camino 2011). These wetlands valuation estimates contrast with agricultural uses—grazing land is estimated to be worth about $425 per hectare ($1,050 per acre) and fruit, nut, and vegetable lands around $2,227 per hectare ($5,500 per acre)—and with bare ground agricultural land to be converted for residential development at around $16,195 per hectare ($40,000 per acre) as of the early 2000s in California (Kuminoff et al 2001; Eisenstein and Mozingo 2013).

Structural flood control in the form of levees, dams, and channelization can cause extensive damages to river floodplain and wetlands ecosystems and diminish the overall ecosystem benefits and services provided by river-floodplain systems (Junk 1994; Sparks 1994; Ward and Stanford 1995; Costanza et al 1997; Hupp et al 2009; Noe 2013; Christin and Kline 2017). Poff (2002) states that "river channels and their flood plains are among the most naturally

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India Company[. …] The linking of deforestation to climatic change and rainfall reduction laid the basis for the initiation and proliferation of colonial forest protection systems after the Peace of Paris in 1763[.] Climatic change, it was believed, threatened not only the economic well-being of a colony but posed hazards to the integrity of the settler populations of the plantation colonies of the Caribbean and Indian Ocean."

dynamic ecosystems on earth, in large part due to periodic flooding," with "the components of a river's natural flood regime (magnitude, frequency, duration, and timing of peak flows) interact[ing] to promote great habitat heterogeneity and high species diversity" (Poff 2002, p. 1499). White (1945) highlighted that the effects of floods are not disastrous in every location "or even disturbing to the economy." In 1989, Junk et al introduced the *flood pulse* concept in order to better the ecological benefits of periodical flooding and an establish a hydrological basis for describing the ecological health of river-floodplain systems: floodplains are "areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater; the resulting physicochemical environment causes [local] biota to respond by morphological, anatomical, physiological, phenological, and/or ethological adaptations, and produce characteristic community structures." In other words, stating that the 100-year floodplain used for defining flood risk is "arbitrary" and "has little ecological meaning," Junk et al state that "[t]his ecological definition [of floodplains] recognizes that flooding causes a perceptible impact on biota and that biota display a defined reaction to flooding[.]" (Junk et al 1989, p. 112). Further, Junk et al characterize river-floodplain systems as neither simply terrestrial nor aquatic, offering that flood pulsing and movements of groundwater, surface water, and nutrients over space and time are connected in many more ways than defined by hydrology (Junk et al 1989, p. 112-114). Expanding on the flood pulse concept, Stanford and Ward (1993) describe connections between surface and groundwaters in large alluvial rivers, highlighting movement of organic and inorganic solutes and pathways that are defined by floodplain geomorphology, and specifically identifying that the "convergence of surface and groundwaters may be a primary determinant in floodplain landscapes and attendant biodiversity and bioproduction" relative to a *hyporheic corridor*—essentially, "the hyporheic zone may be defined by penetration of river water into fluvial deposits within the active channel and laterally and vertically through floodplain substrata" (Stanford and Ward 1993, p. 51). Stanford and Ward (1993) demonstrate that the areas of hydrologic connectivity between rivers and the hyporheic zone of floodplains can be observed on hydrographs displaying river channel elevations alongside floodplain wells dug to observe groundwater conditions at distances laterally increasing from the channel.

Levees serve to disconnect surround floodplains and wetlands from the main river channel—a feature of drainage and reclamation efforts for conversion to a different land use type—and the resulting deviation in the dynamic flood regime yields a decline in species diversity and ecosystem productivity (Figure B.2). Notably, disconnection based on levee construction may "produce drastically different levels of residual risk" (Eisenstein and Mozingo 2013). Frequent, small flood events maintain healthy ecosystems, whereas rare, large flood events may be viewed as catastrophes to surrounding environs (White and Pickett 1985); moreover, ecologists suggest that levees increase flood magnitude and frequency by disconnecting floodplains from the main river channel, with observations that "[l]arger river

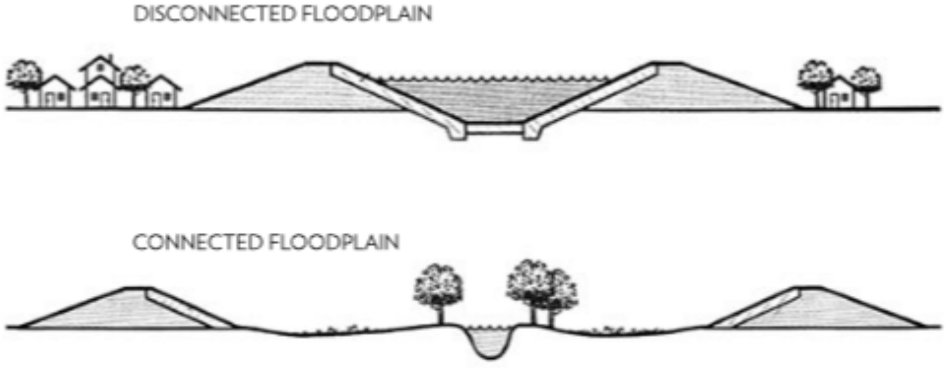


Figure B.2. Illustration of floodplains disconnected from a river channel by levees, with increased urbanization in levee-protected areas. (Source: Eisenstein and Mozingo 2013) systems in [the Upper Mississippi River] basin that have not experienced extensive flood-plain disconnection have not flood so extensively" during the 20th century (USGS 1999; Criss and Shock 2001; Poff 2002; Christin and Kline 2017). A number of studies have shown that levees increase flood heights in the channel substantially—and, therefore, serve to increase risks to properties and assets protected by levees by increasing flood hazards (cf. White 1945, p. 142; GAO 1995; Pinter 2005; Pinter et al 2016; Christin and Kline 2017). To this point, Eisenstein and Mozingo (2013, p. 12) state "it is entirely possible for a given community's overall flood-hazard risks to increase as a result of levee construction, if the construction of the levees results in widespread development in the area." However, Poff (2002, p. 1505) describes a nonstructural approach to flood control on the Charles River in Massachusetts wherein the USACE purchased the development rights for floodplain wetlands in order to preserve the wetlands ability to attenuate flood damages and at a discount of more than 90 percent over the costs of an alternatively planned dam and levee project: "When near-record flooding occurred in 1979 and 1982, 'the wetlands performed effectively each time, absorbing flood surges and then gradually passing them downstream.'" On the Consumnes River in California, levees were breached during floods in the 1980s and 1990s and the floodplain reconnected to the main channel of the river. As a result of sediment deposition on the floodplain from these floods, vegetation in the floodplain flourished; furthermore, in recognition of these of these floods and the subsequent revitalization of floodplain ecosystems, levee removal has become "central to restoration planning in the Central Valley of California," with a goal of repairing ecosystem structure and function (Andrews 1999; Florsheim and Mount 2002; Whipple et al 2016; Whipple 2018). As previously discussed, Quivik (2009) describes ecological destruction occurring on the Souris River as a result of channelization and leveeing in the early 1900s and the subsequent passing restoration legislation in the 1920s; however, numerous pieces of legislation and programs through the mid 1900s to present have sought both to improve the environmental degradation occurring in wetlands and floodplains and protect or preserve remaining wetlands resources, including the Migratory Bird Conservation Act (1929), Estuary Protection Act (1968), Wild and Scenic Rivers Act (1968), Clean Water Act (1972), Comprehensive Environmental Response Compensation and Liability Act (1980), among others (USGS 1996). Notably, the USGS (1996, p. 58) identifies the National Flood Insurance Program as having the effect of "encouraging development in flood plains, which contain wetlands, by providing low-cost federal insurance." These policies often have conflicting goals or are not enforced, however, and conservation is often superseded by floodplain development policies (Christin and Kline 2017).

APPENDIX C – PARCEL VALUE DENSITY MAPS

C.1.1 Johnson County, Iowa Decadal Cumulative VAR Densities

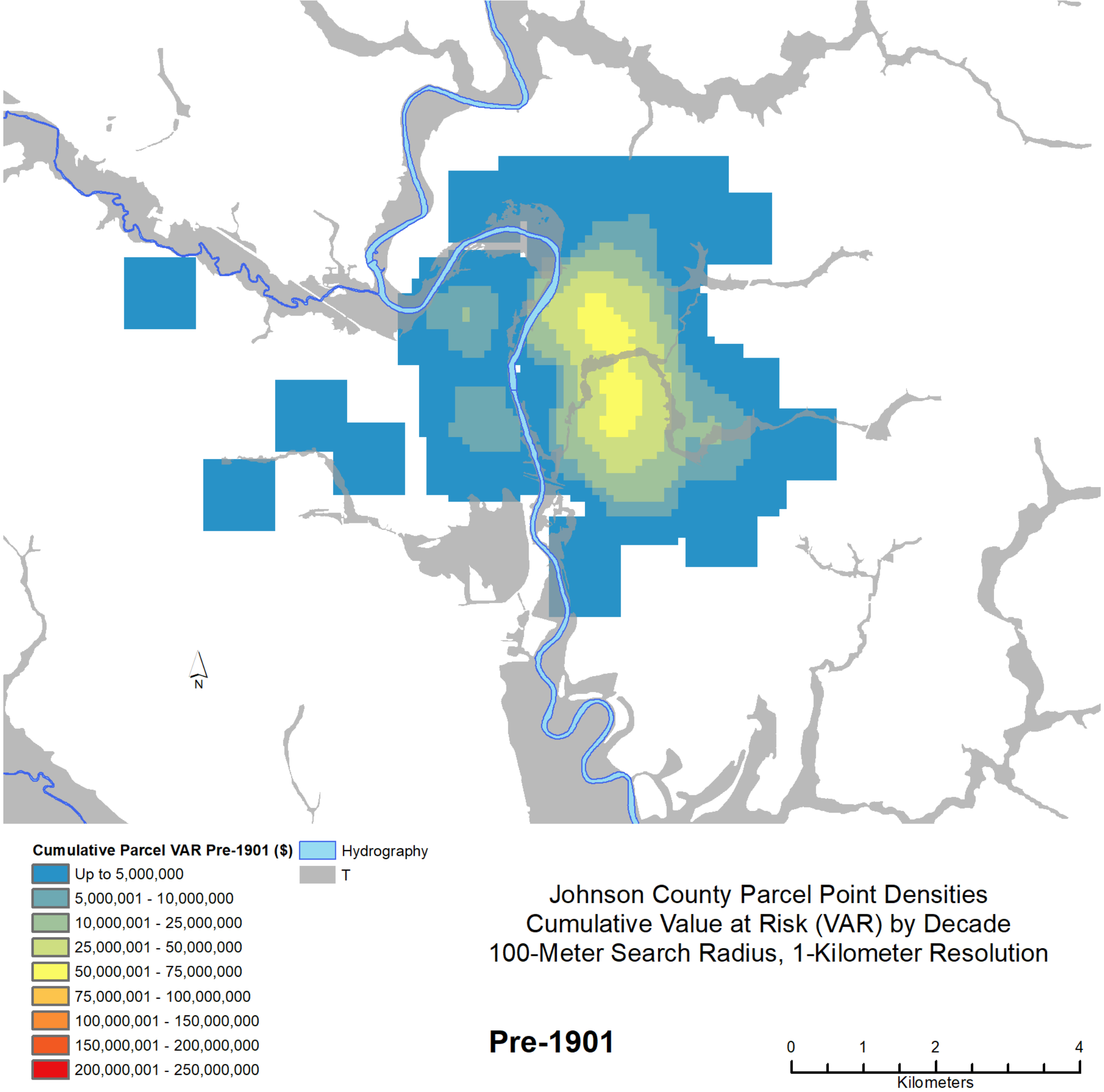


Figure C.1. Cumulative value at risk for Johnson County, Iowa, 1851-1900.

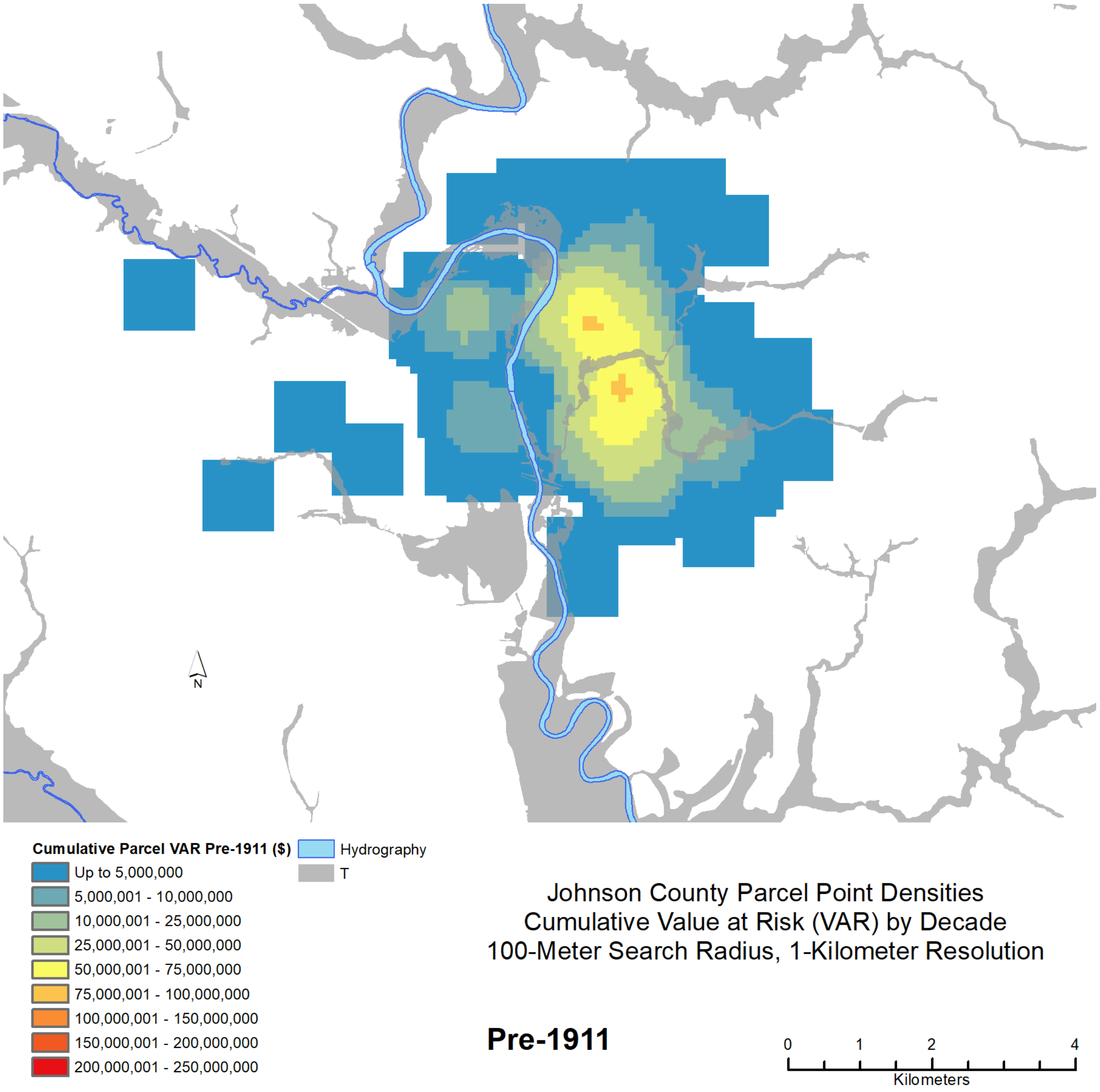


Figure C.2. Cumulative value at risk for Johnson County, Iowa, 1851-1910.

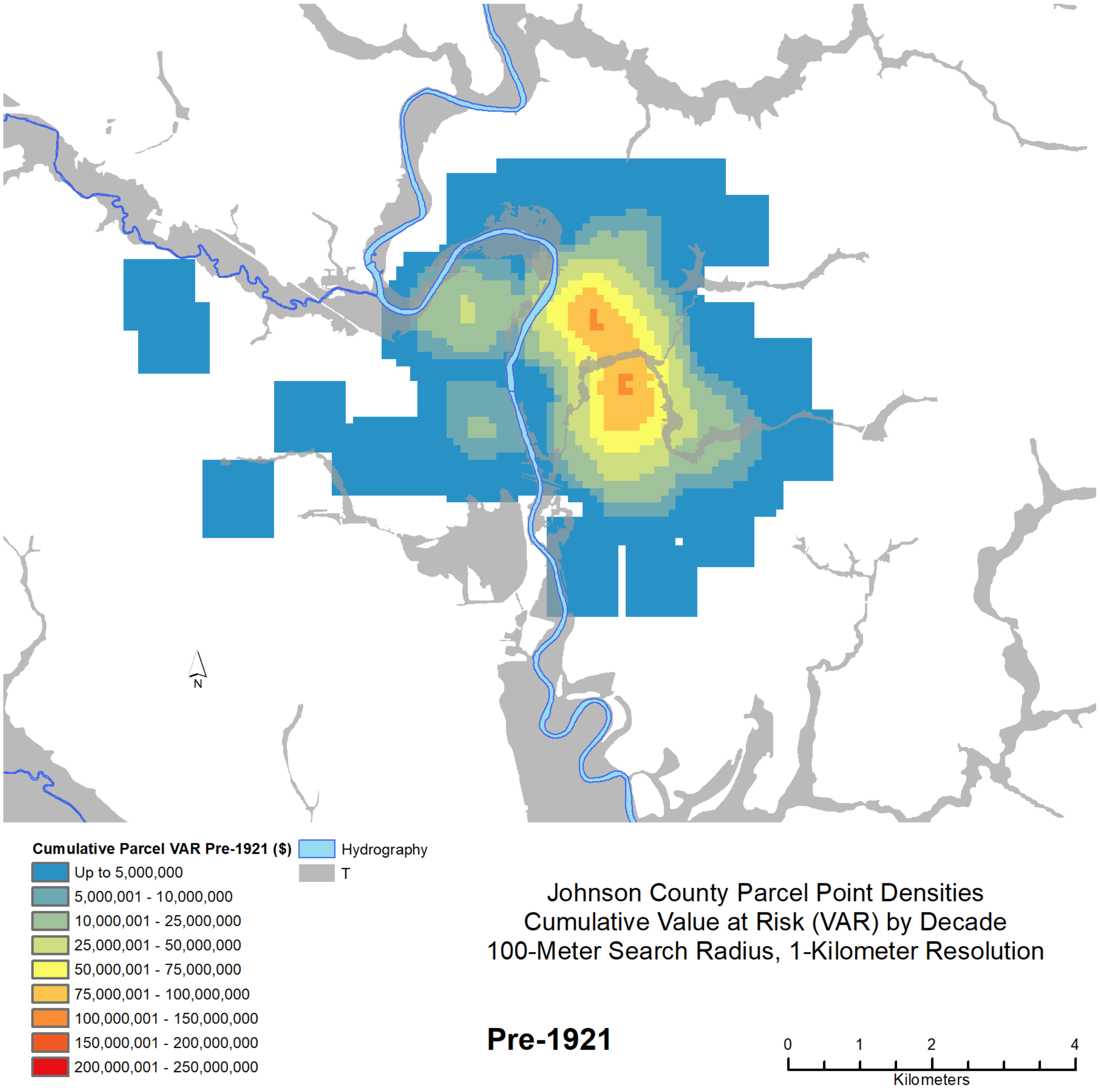


Figure C.3. Cumulative value at risk for Johnson County, Iowa, 1851-1920.

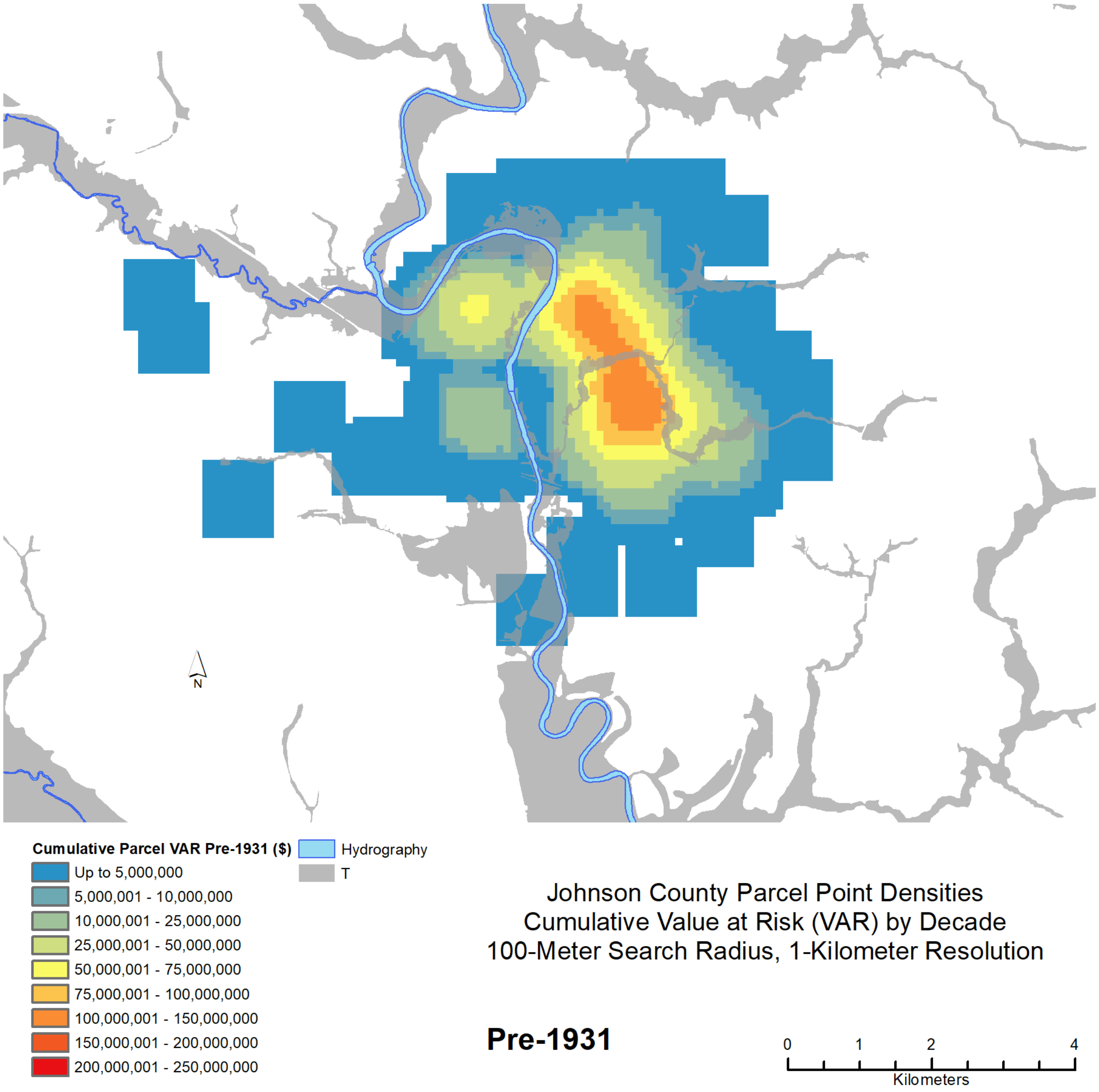


Figure C.4. Cumulative value at risk for Johnson County, Iowa, 1851-1930.

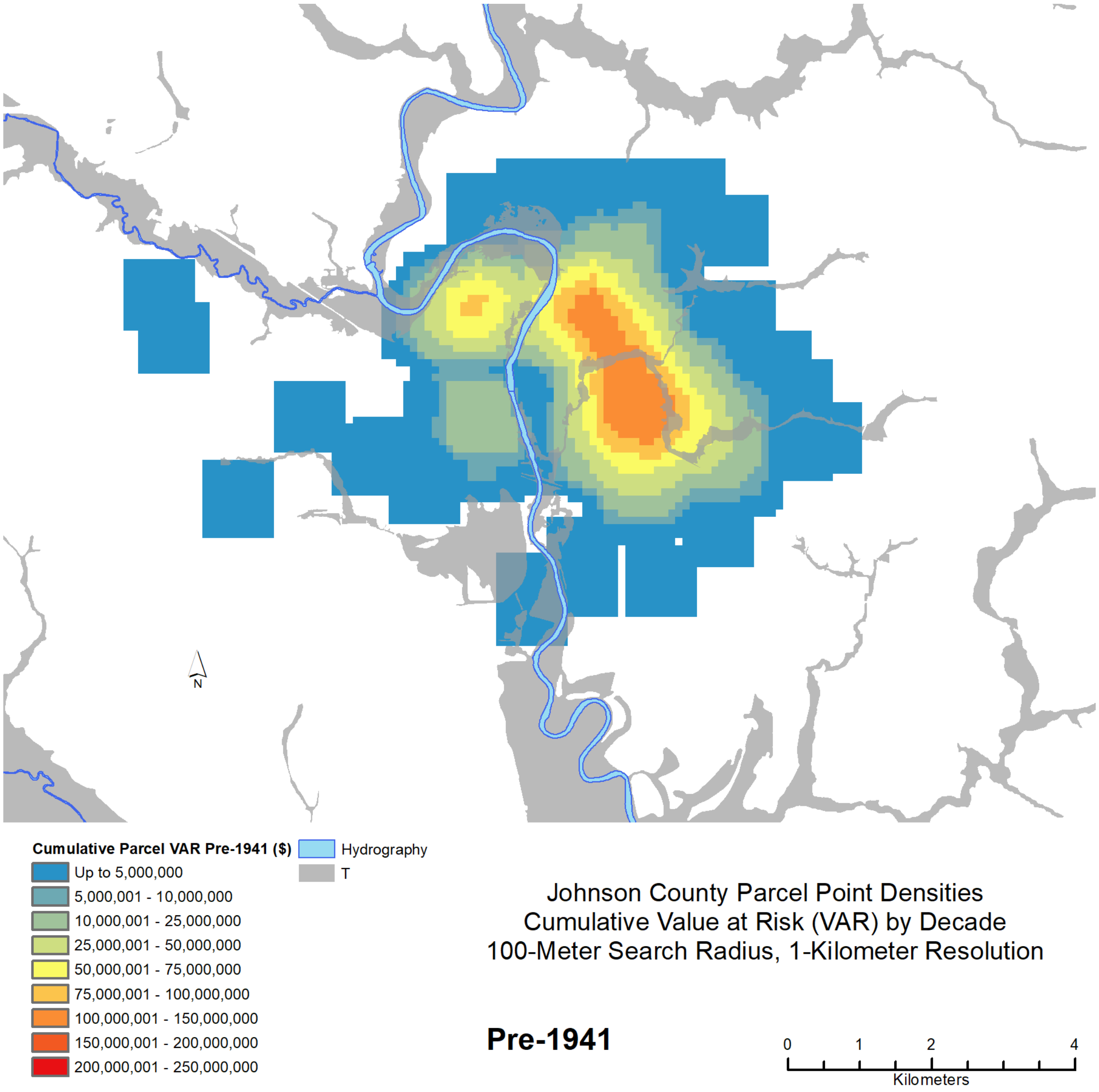


Figure C.5. Cumulative value at risk for Johnson County, Iowa, 1851-1940.

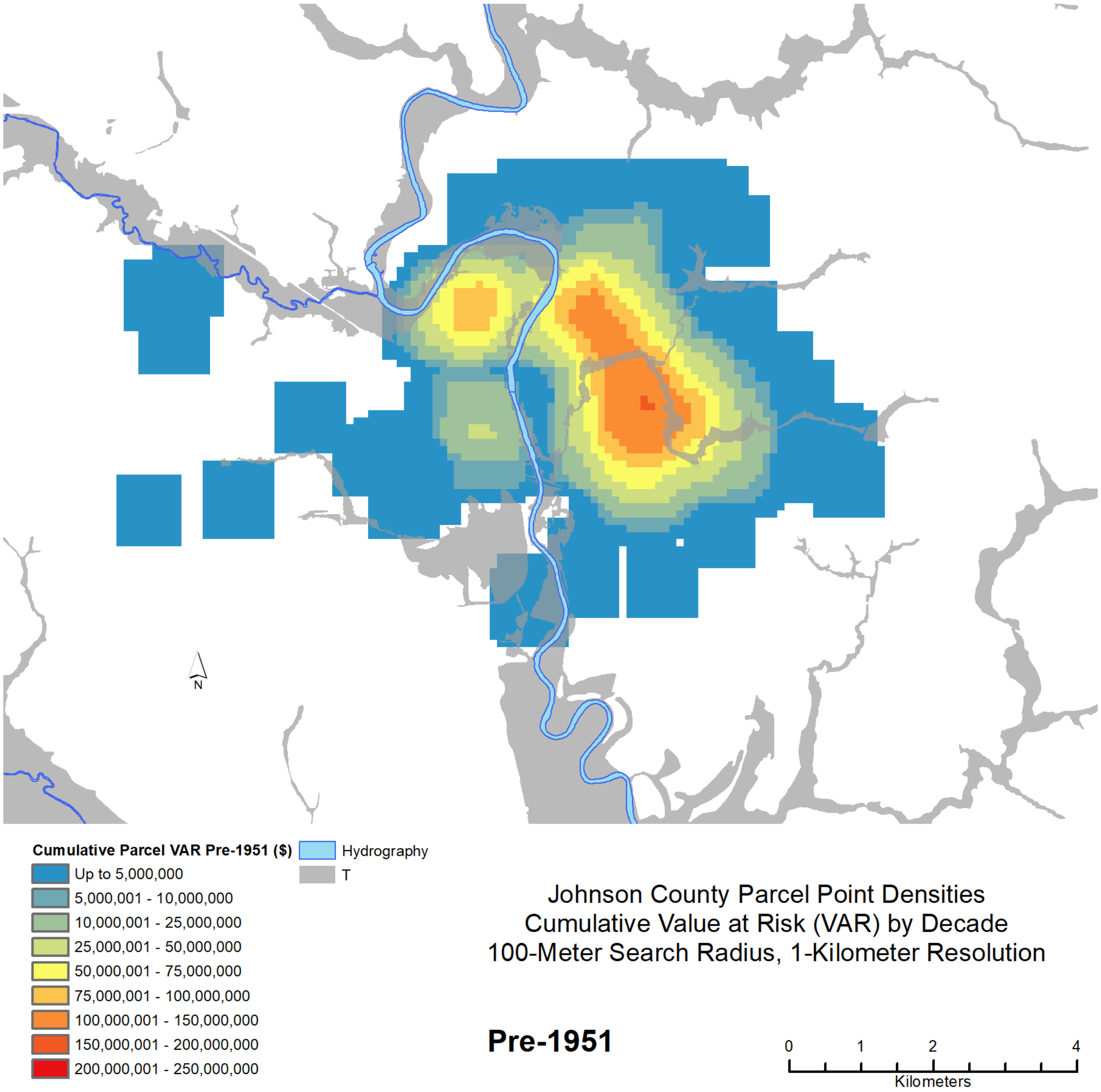


Figure C.6. Cumulative value at risk for Johnson County, Iowa, 1851-1950.

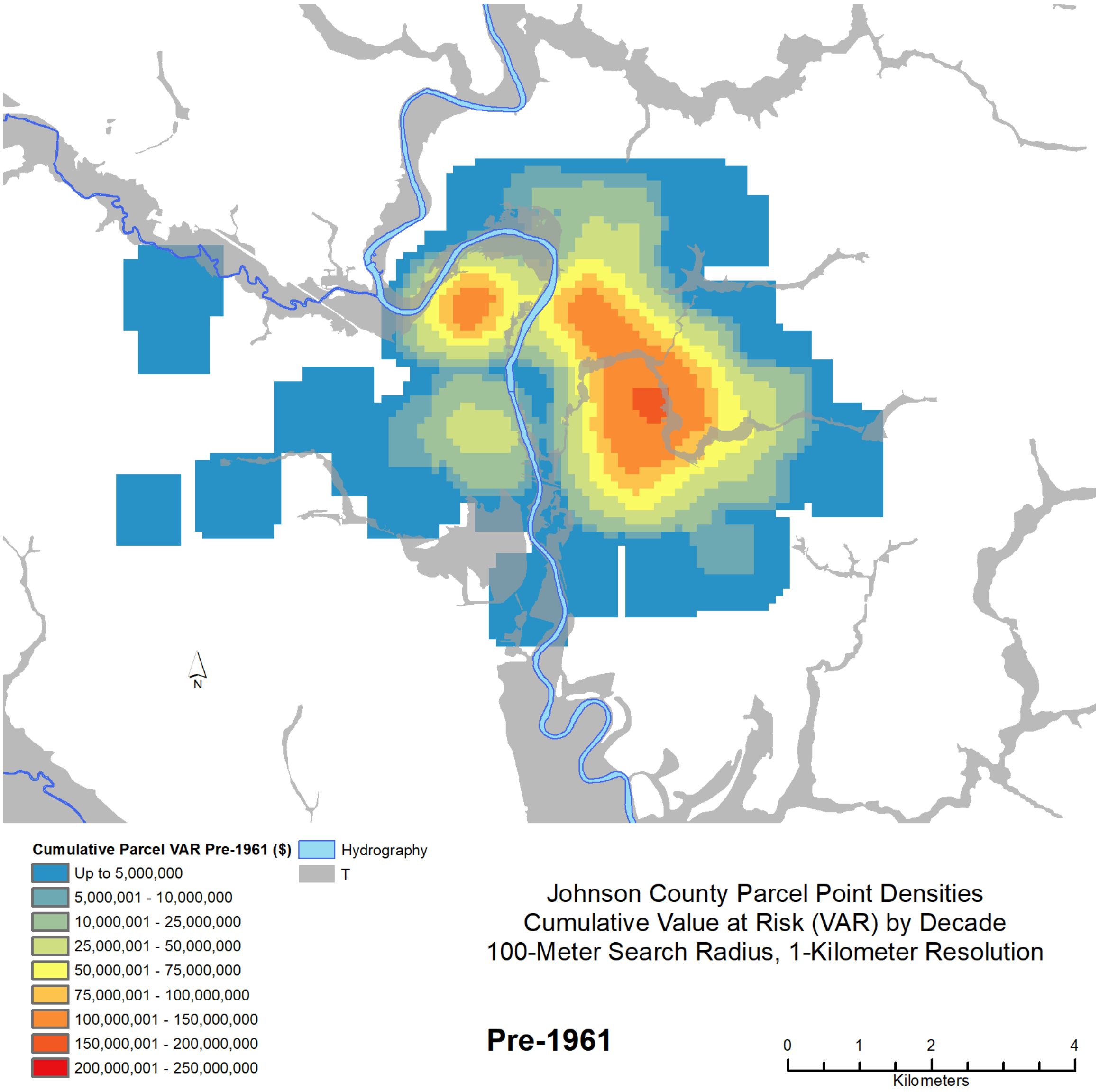


Figure C.7. Cumulative value at risk for Johnson County, Iowa, 1851-1960.

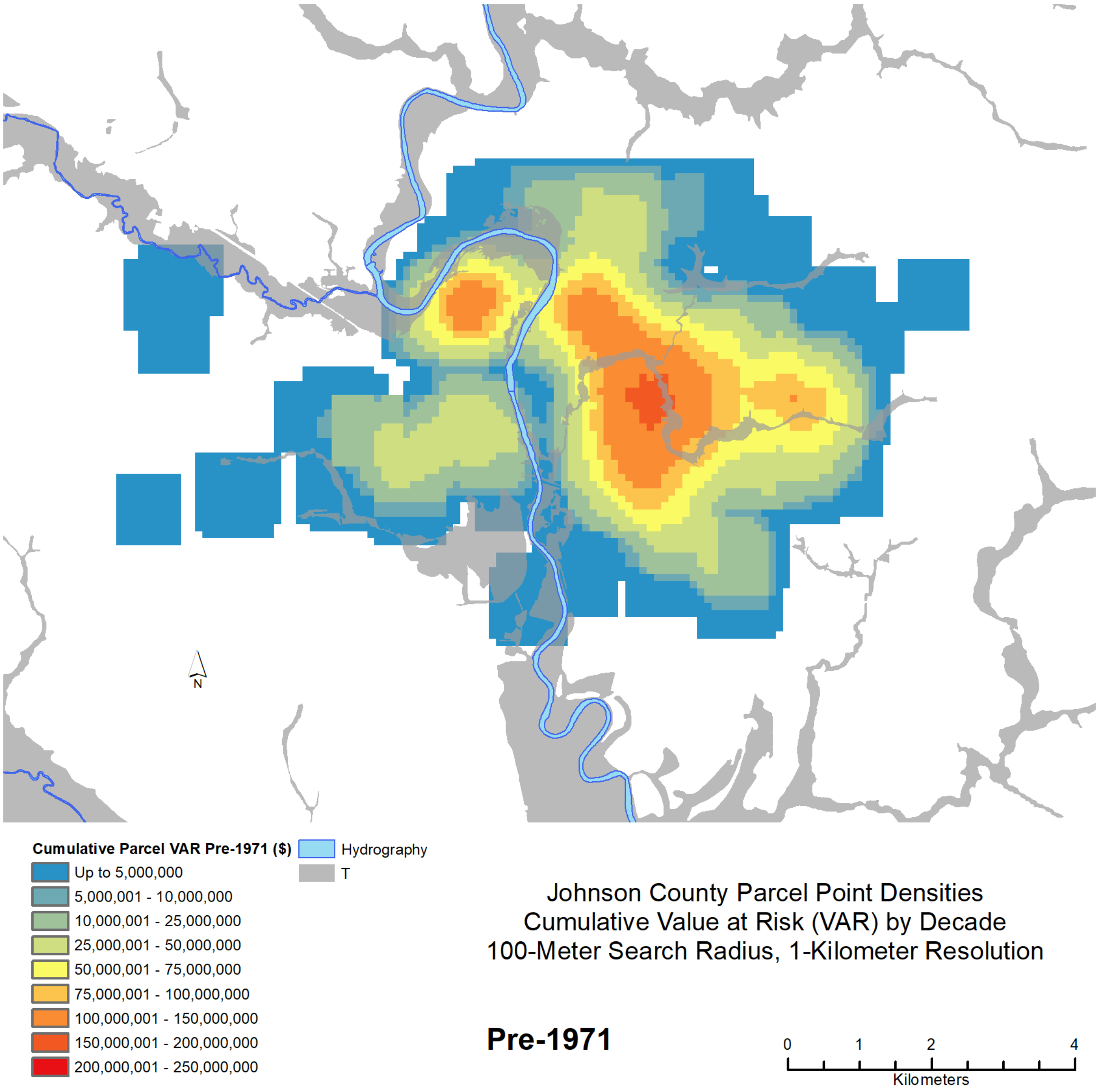


Figure C.8. Cumulative value at risk for Johnson County, Iowa, 1851-1970.

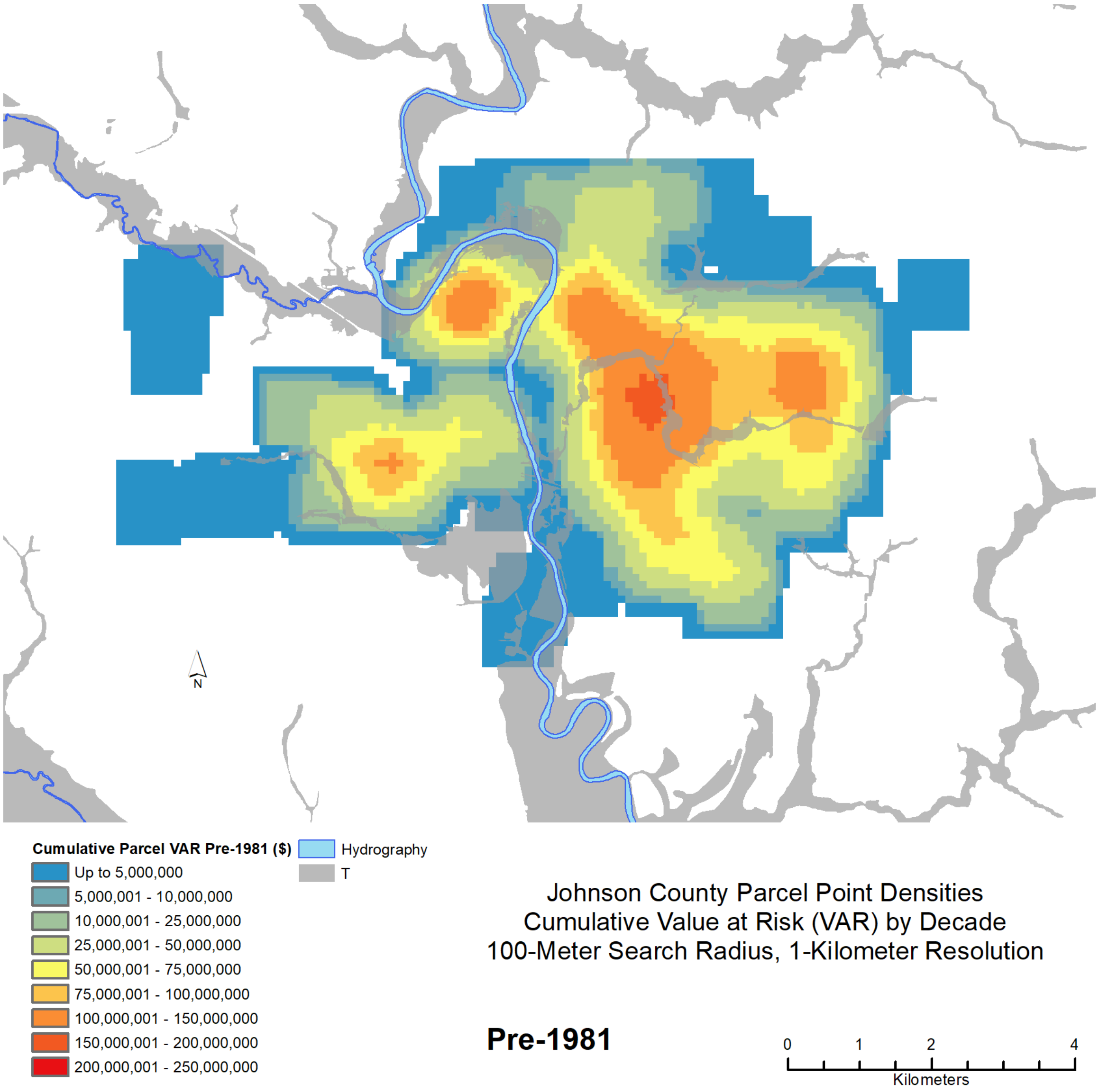


Figure C.9. Cumulative value at risk for Johnson County, Iowa, 1851-1980.

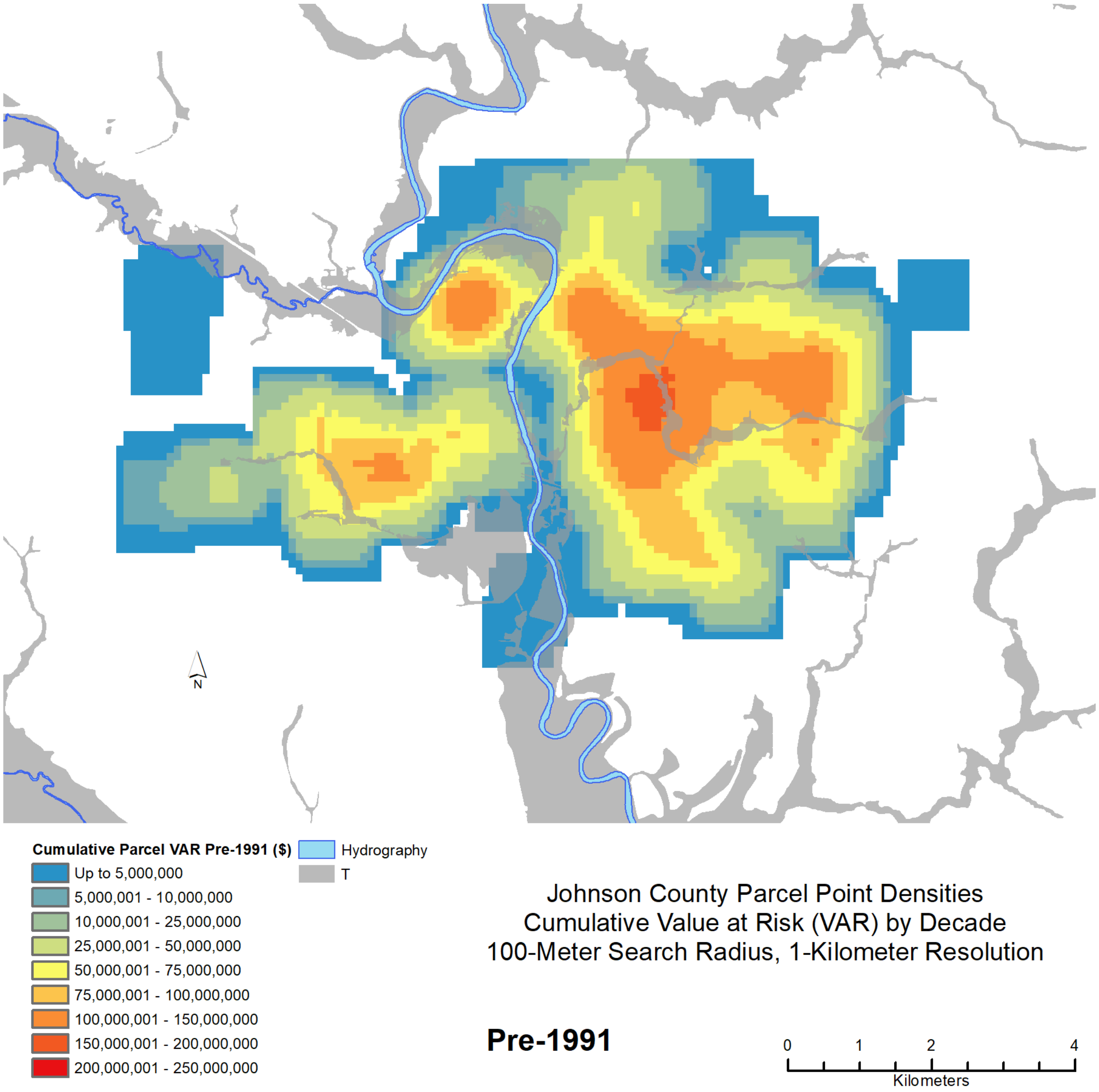


Figure C.10. Cumulative value at risk for Johnson County, Iowa, 1851-1990.

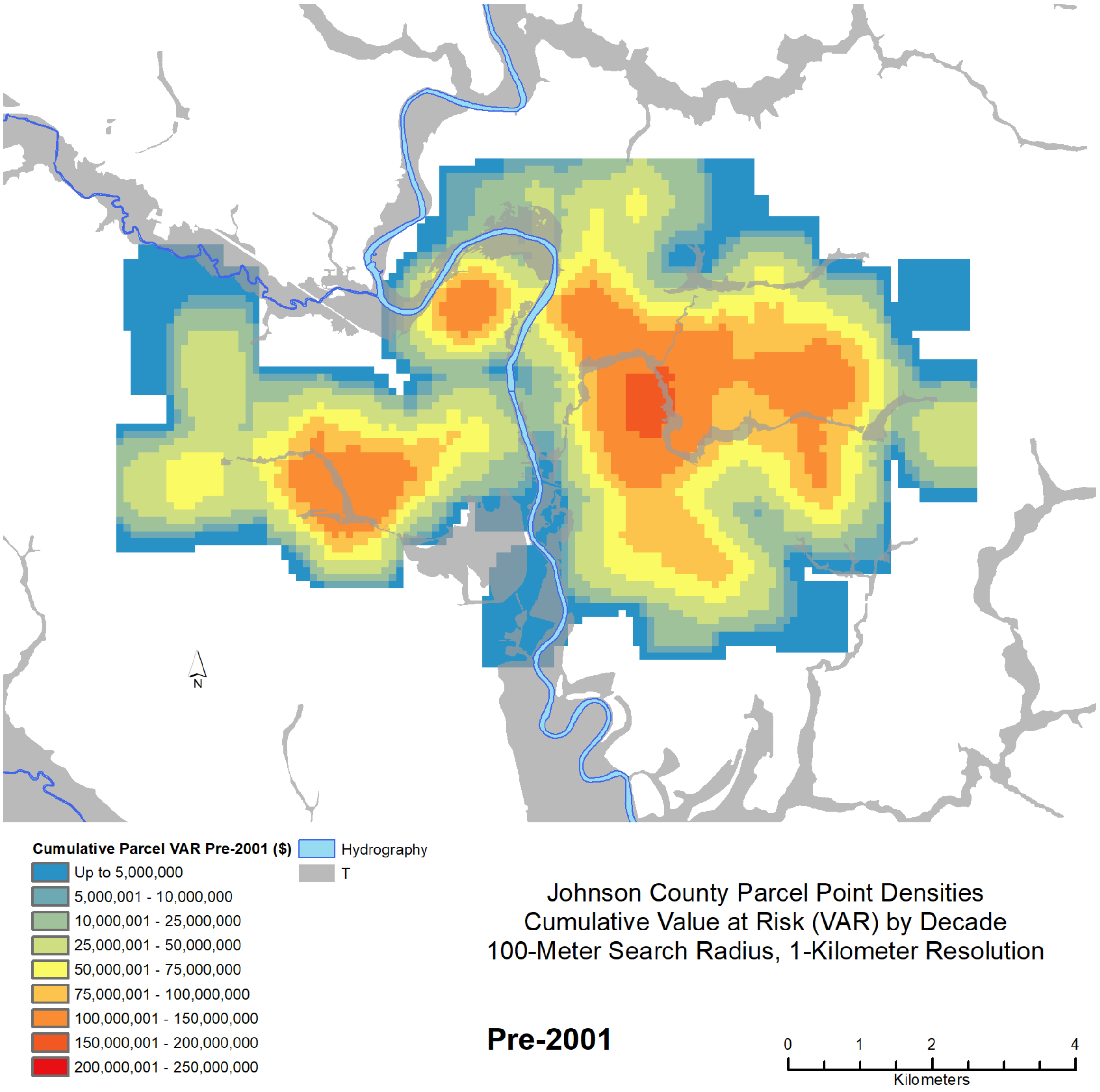


Figure C.11. Cumulative value at risk for Johnson County, Iowa, 1851-2000.

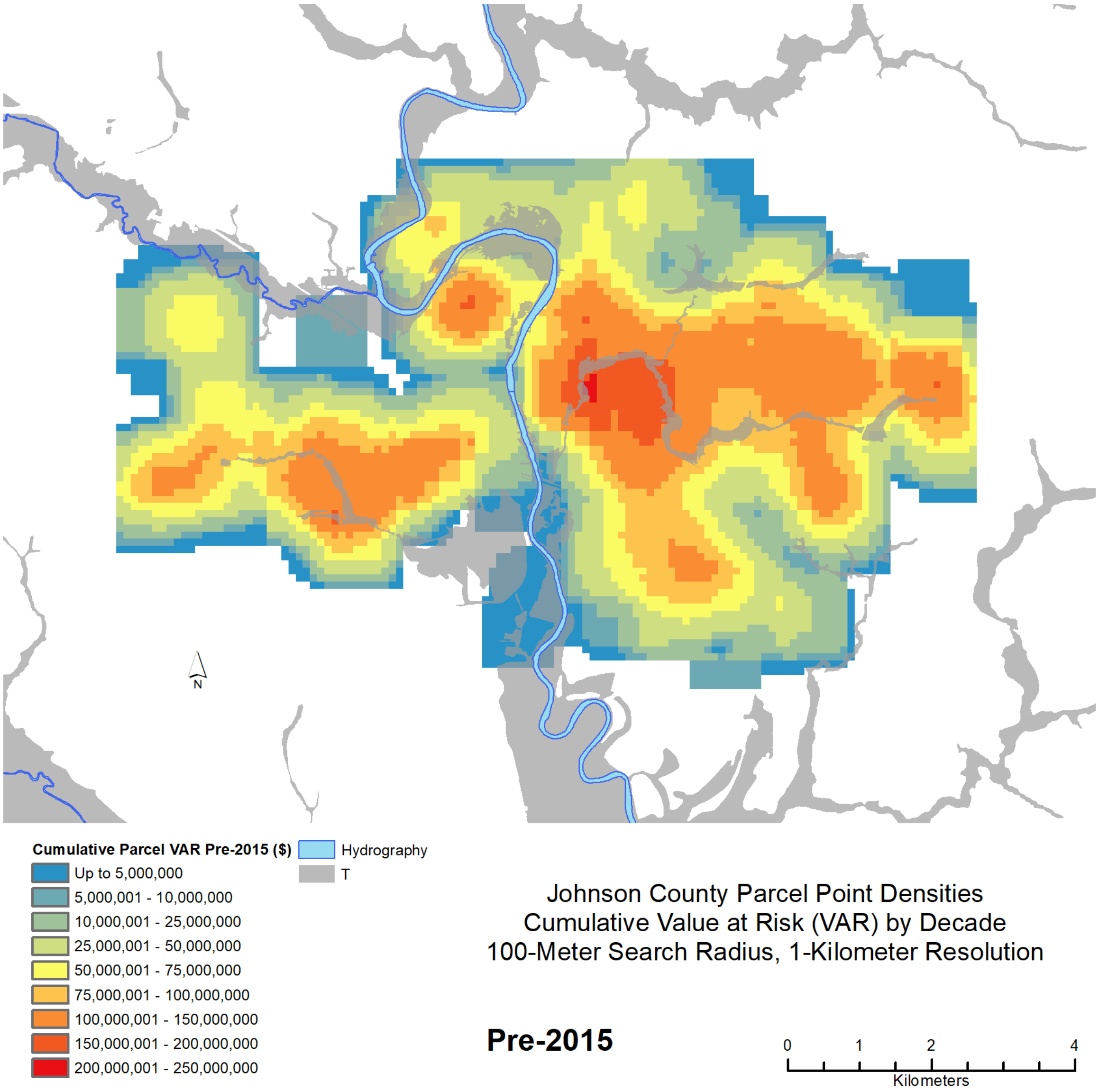


Figure C.12. Cumulative value at risk for Johnson County, Iowa, 1851-2015.

C.1.2 Johnson County, Iowa Decadal VAR Densities

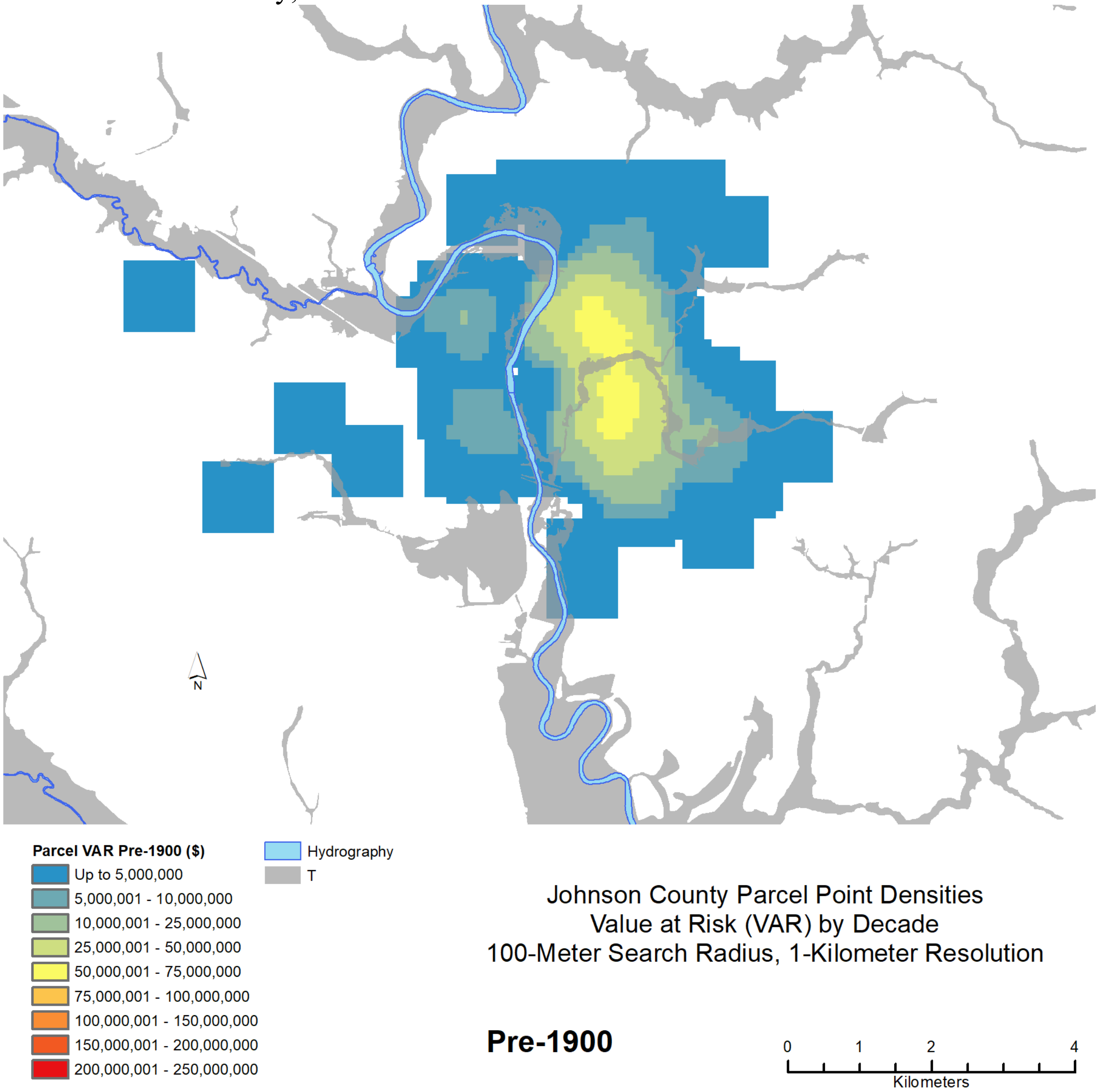


Figure C.13. Value at risk for Johnson County, Iowa parcels, 1851-1900.

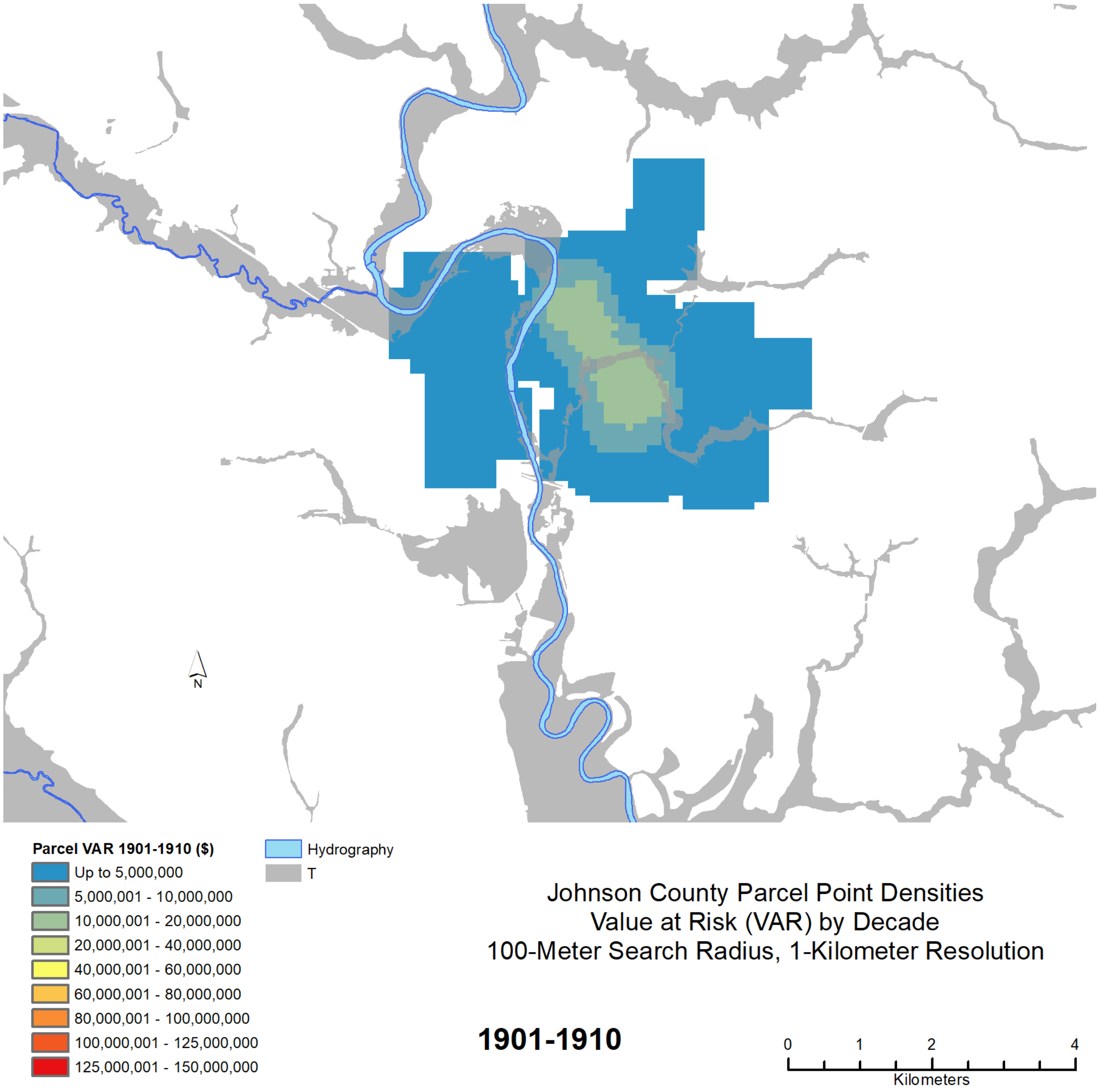


Figure C.14. Value at risk in Johnson County, Iowa, 1901-1910.

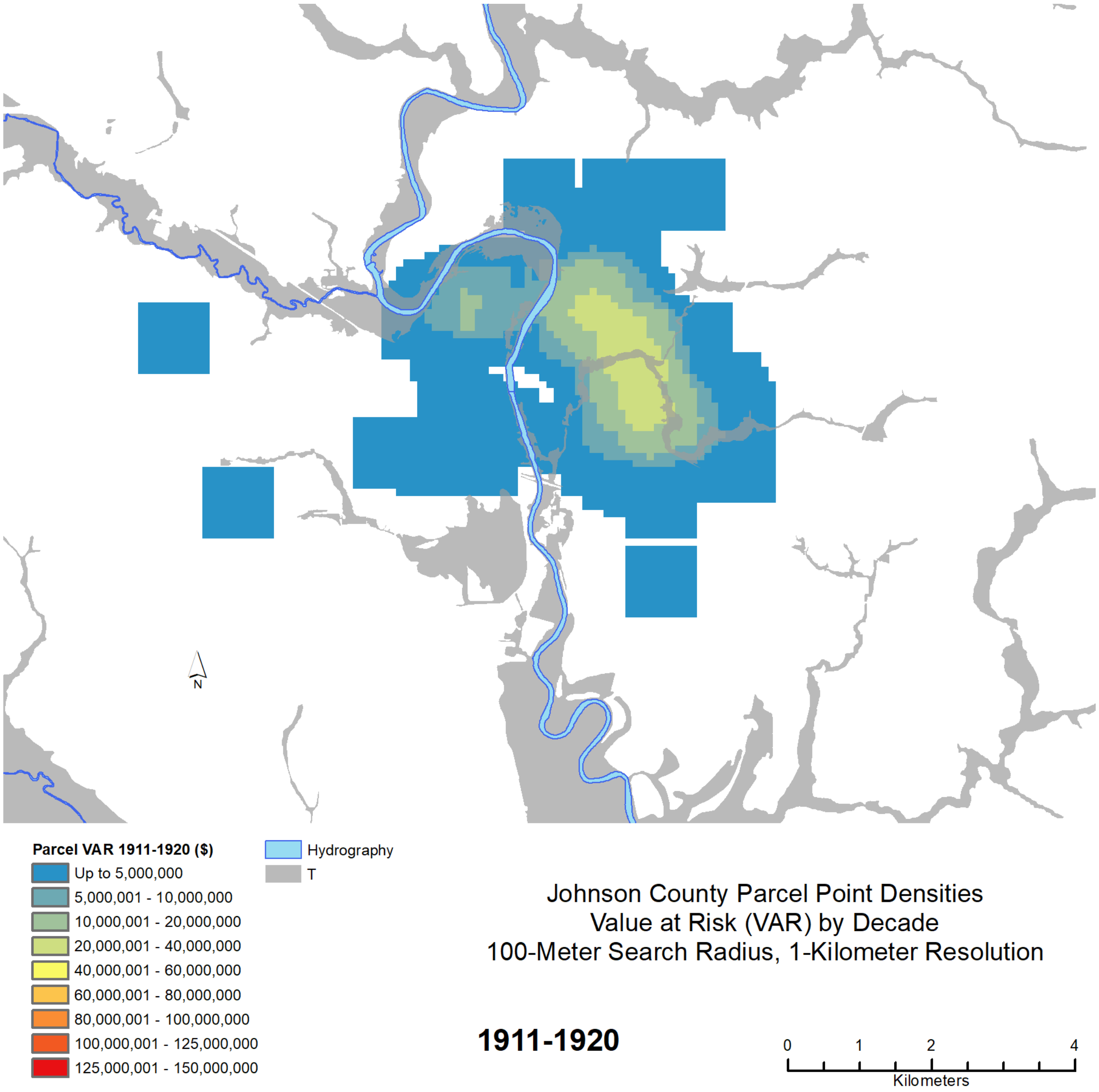


Figure C.15. Value at risk in Johnson County, Iowa, 1911-1920.

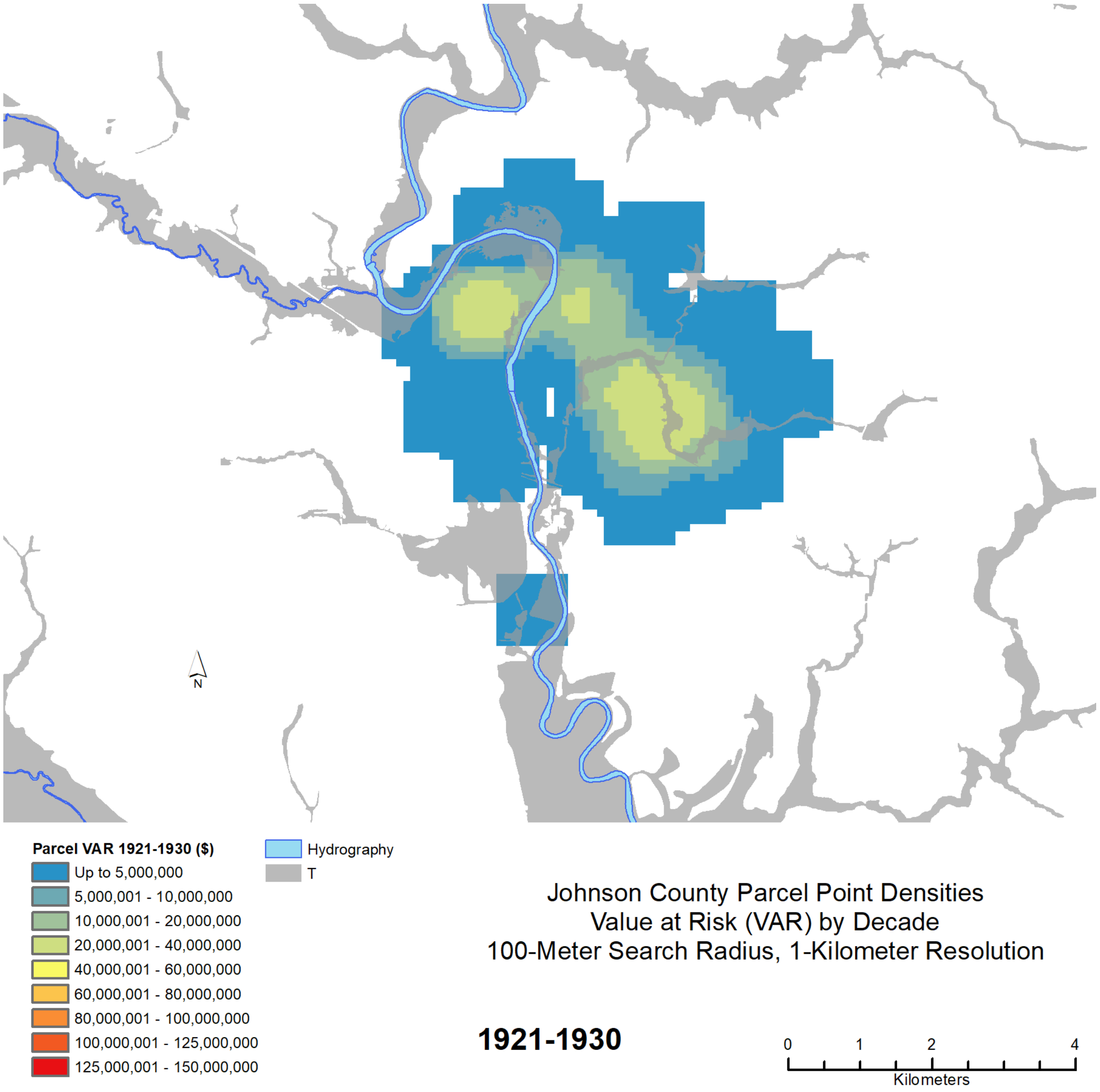


Figure C.16. Value at risk in Johnson County, Iowa, 1921-1930.

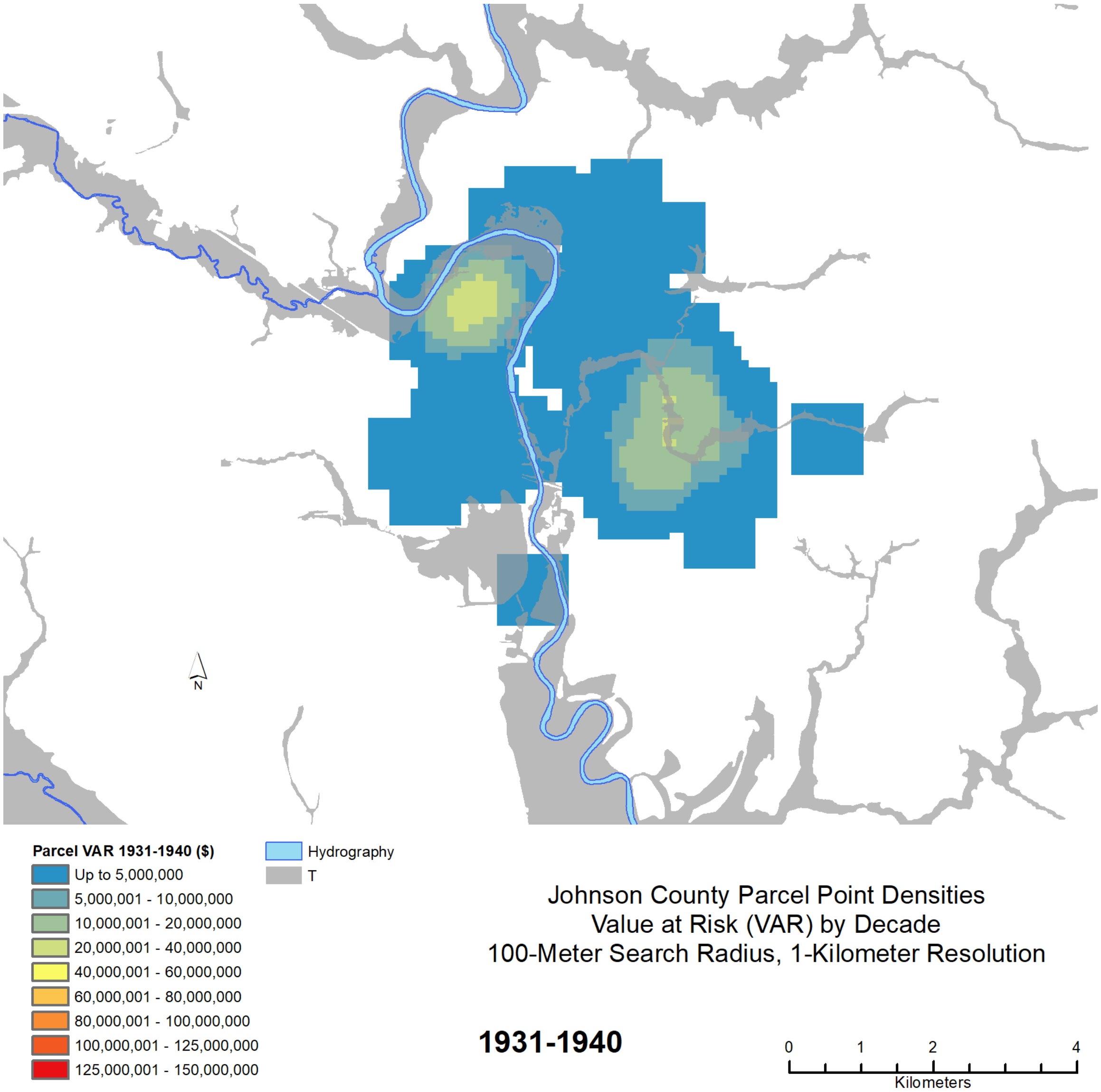


Figure C.17. Value at risk in Johnson County, Iowa, 1931-1940.

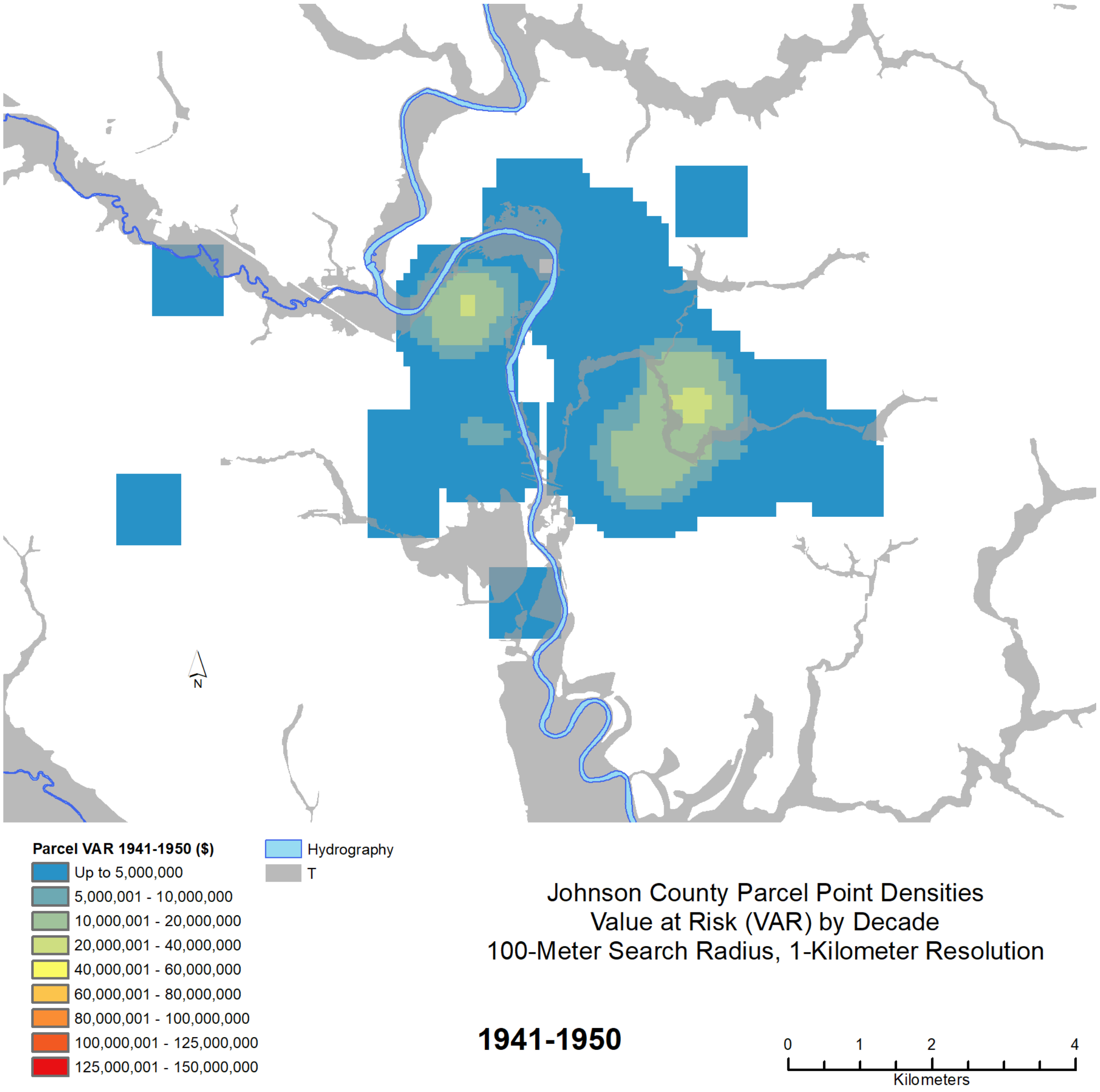


Figure C.18. Value at risk in Johnson County, Iowa, 1941-1950.

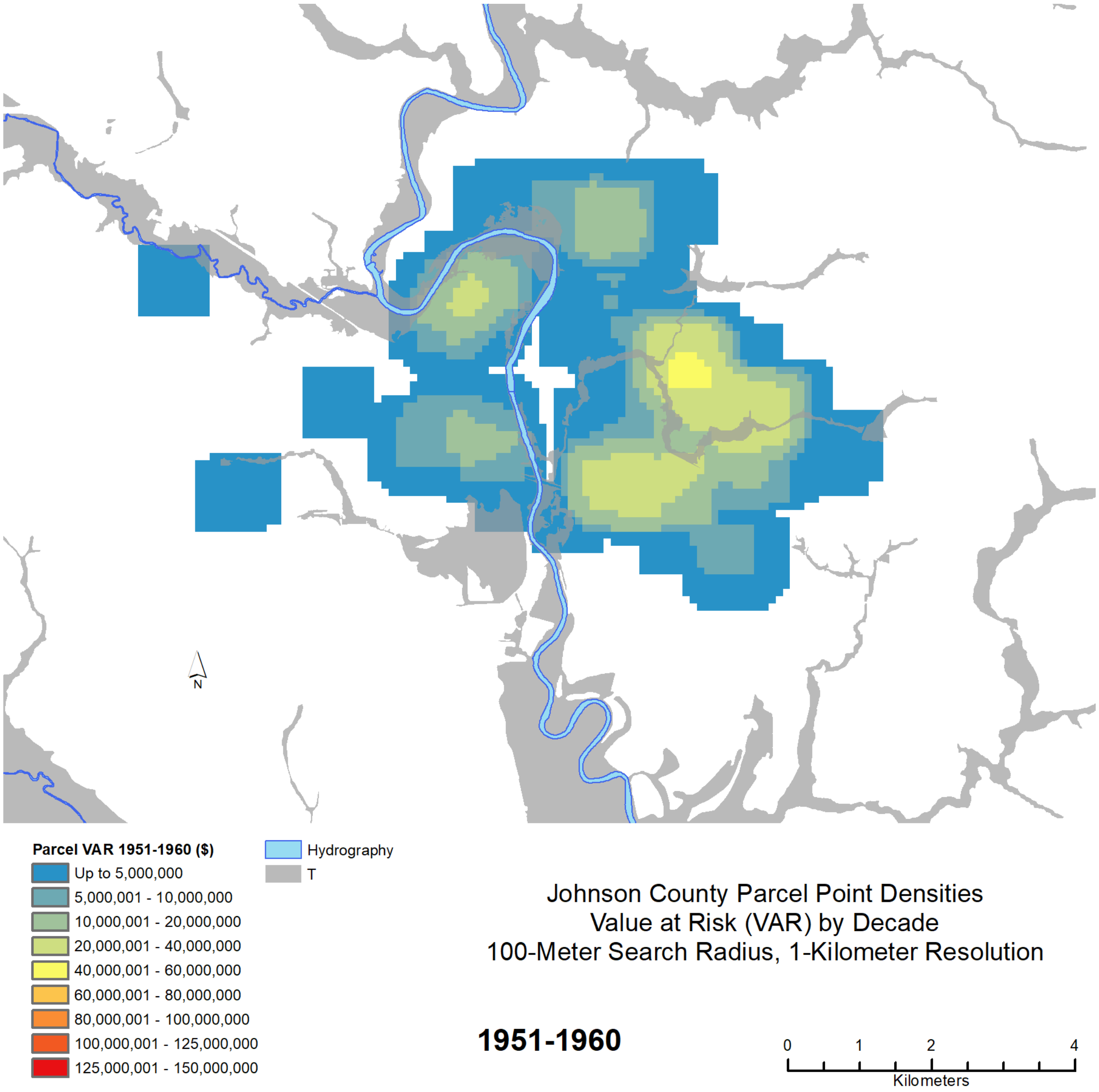


Figure C.19. Value at risk in Johnson County, Iowa, 1951-1960.

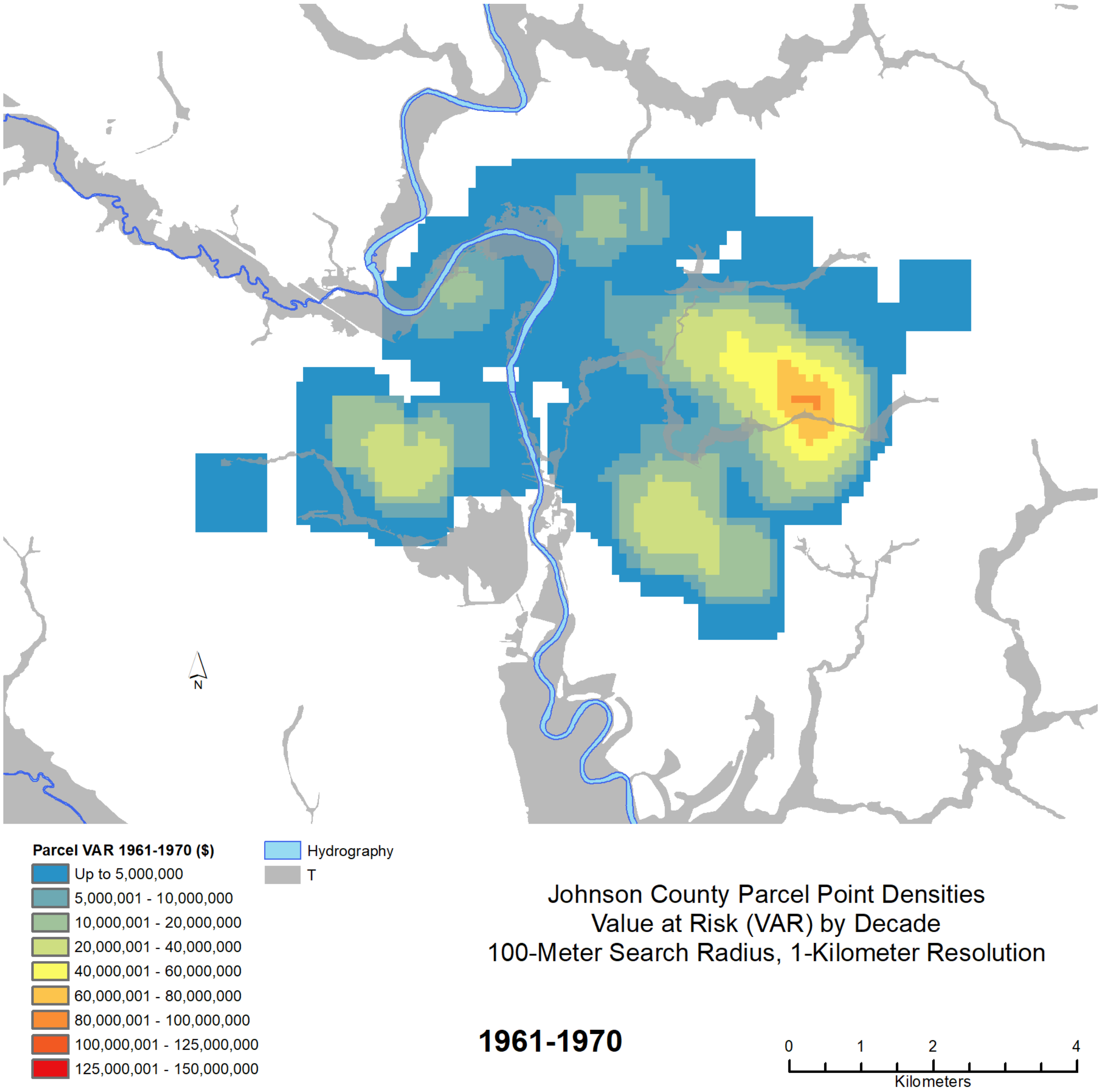


Figure C.20. Value at risk in Johnson County, Iowa, 1961-1970.

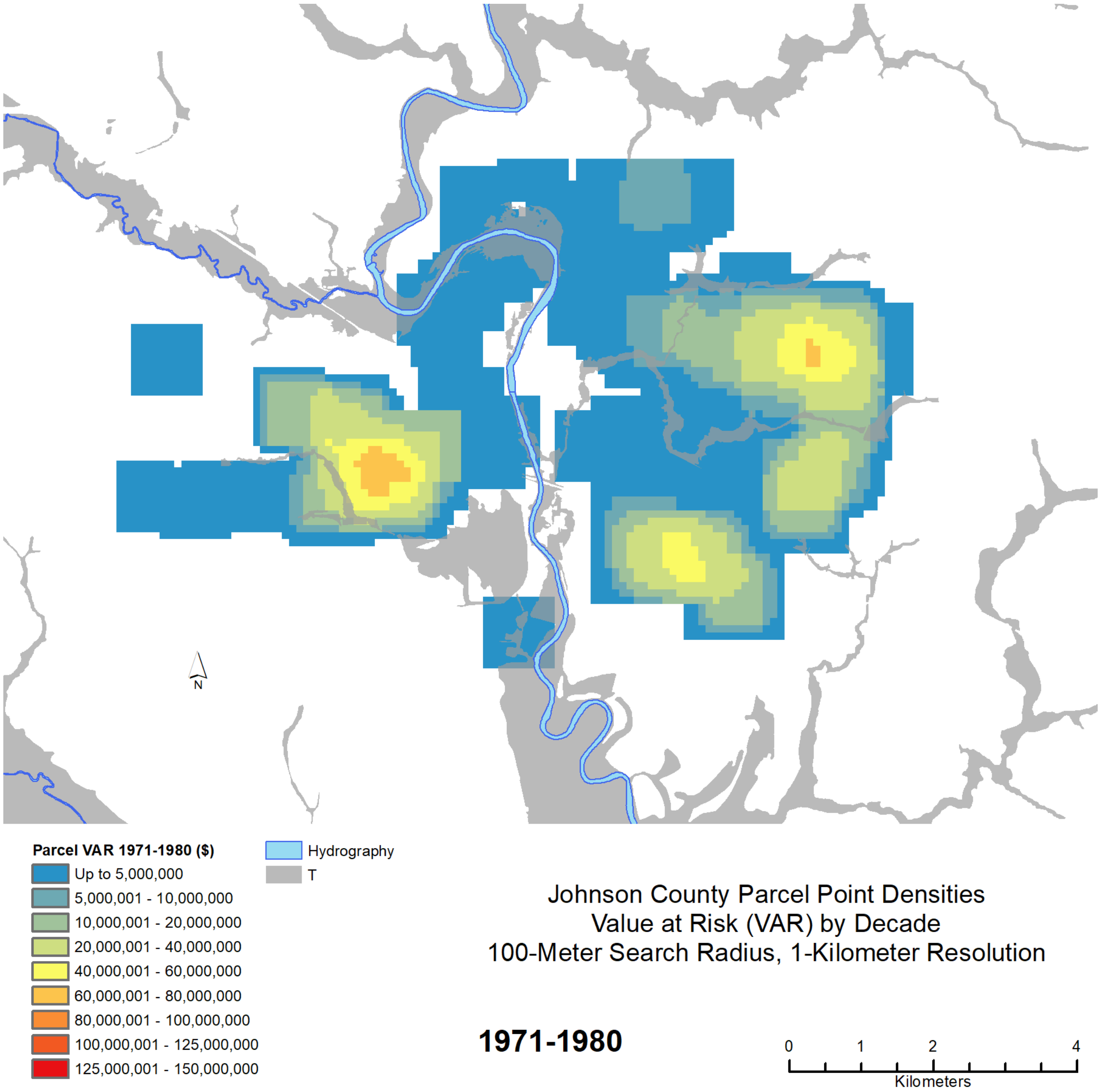


Figure C.21. Value at risk in Johnson County, Iowa, 1971-1980.

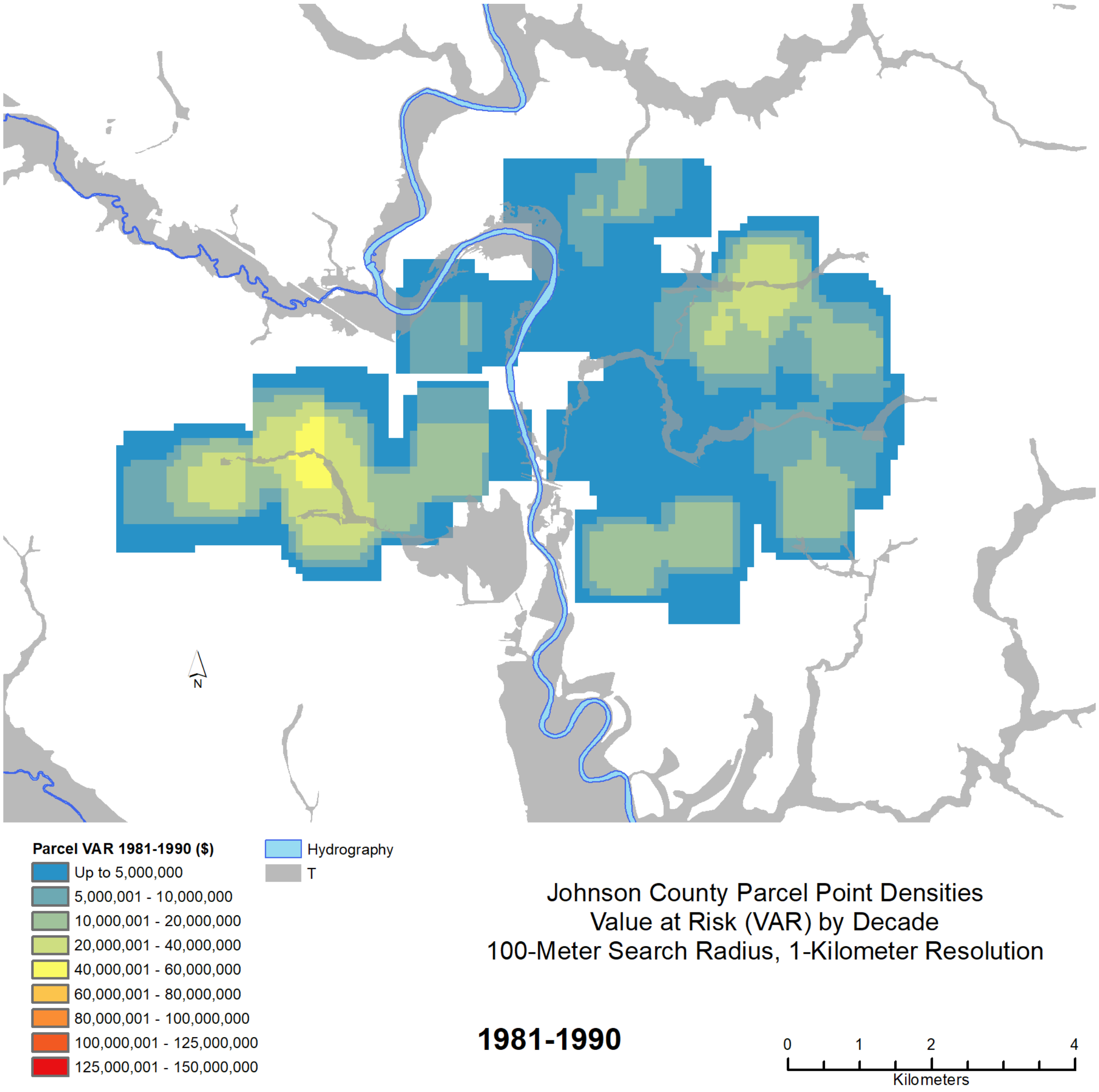


Figure C.22. Value at risk in Johnson County, Iowa, 1981-1990.

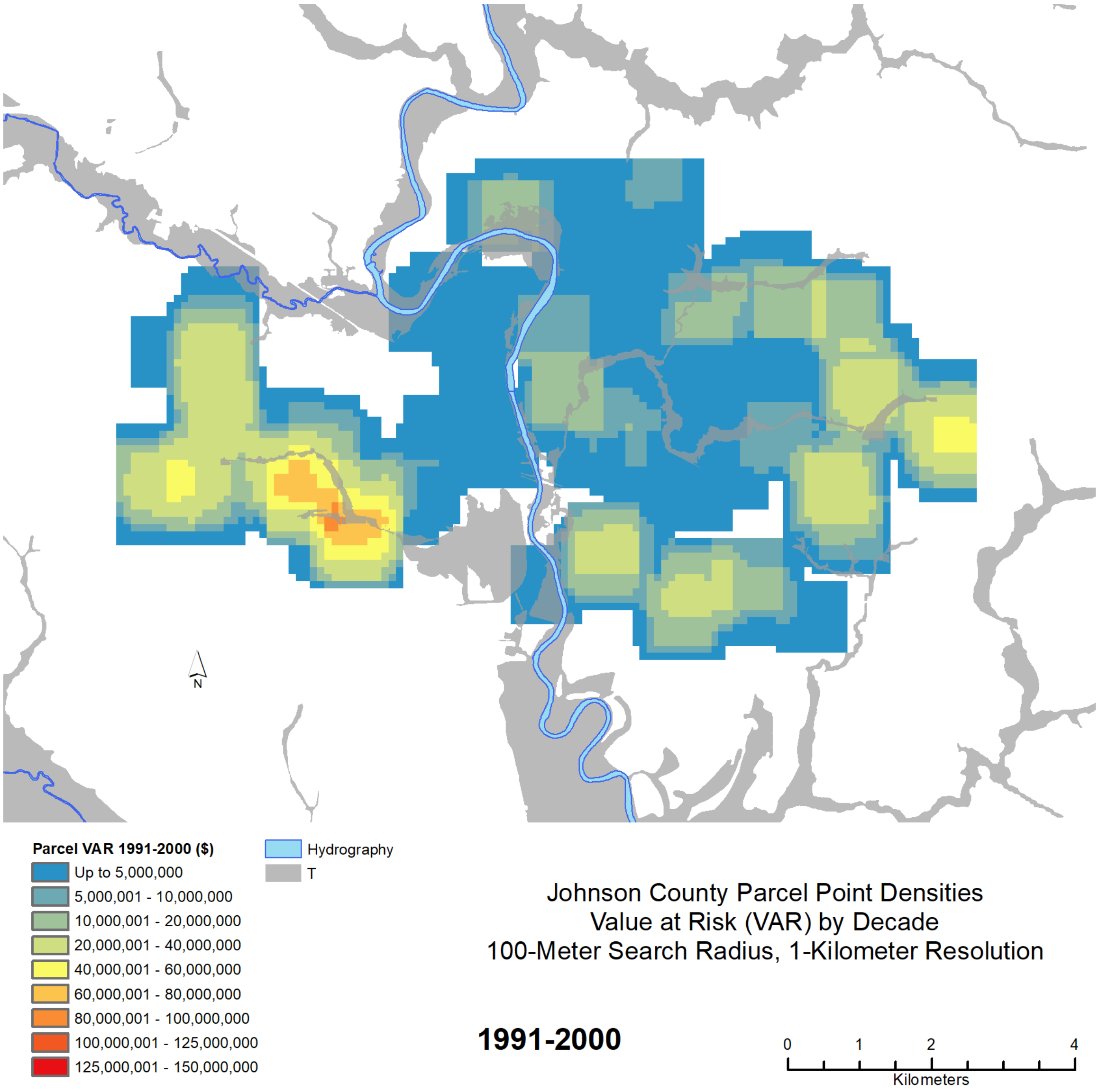


Figure C.23. Value at risk in Johnson County, Iowa, 1991-2000.

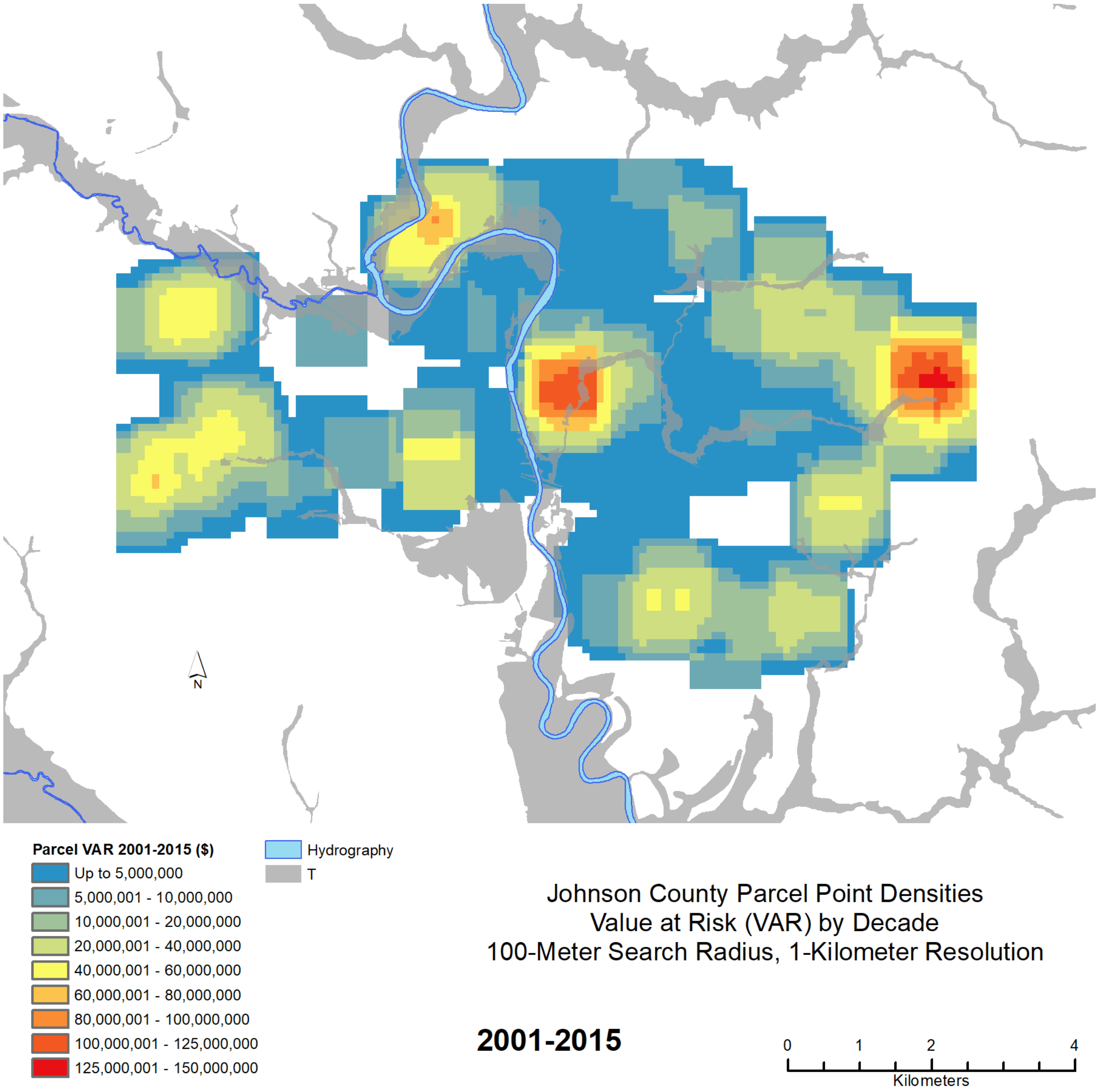


Figure C.24. Value at risk in Johnson County, Iowa, 2001-2015.

C.2.1 Black Hawk County, Iowa Decadal Cumulative VAR Densities

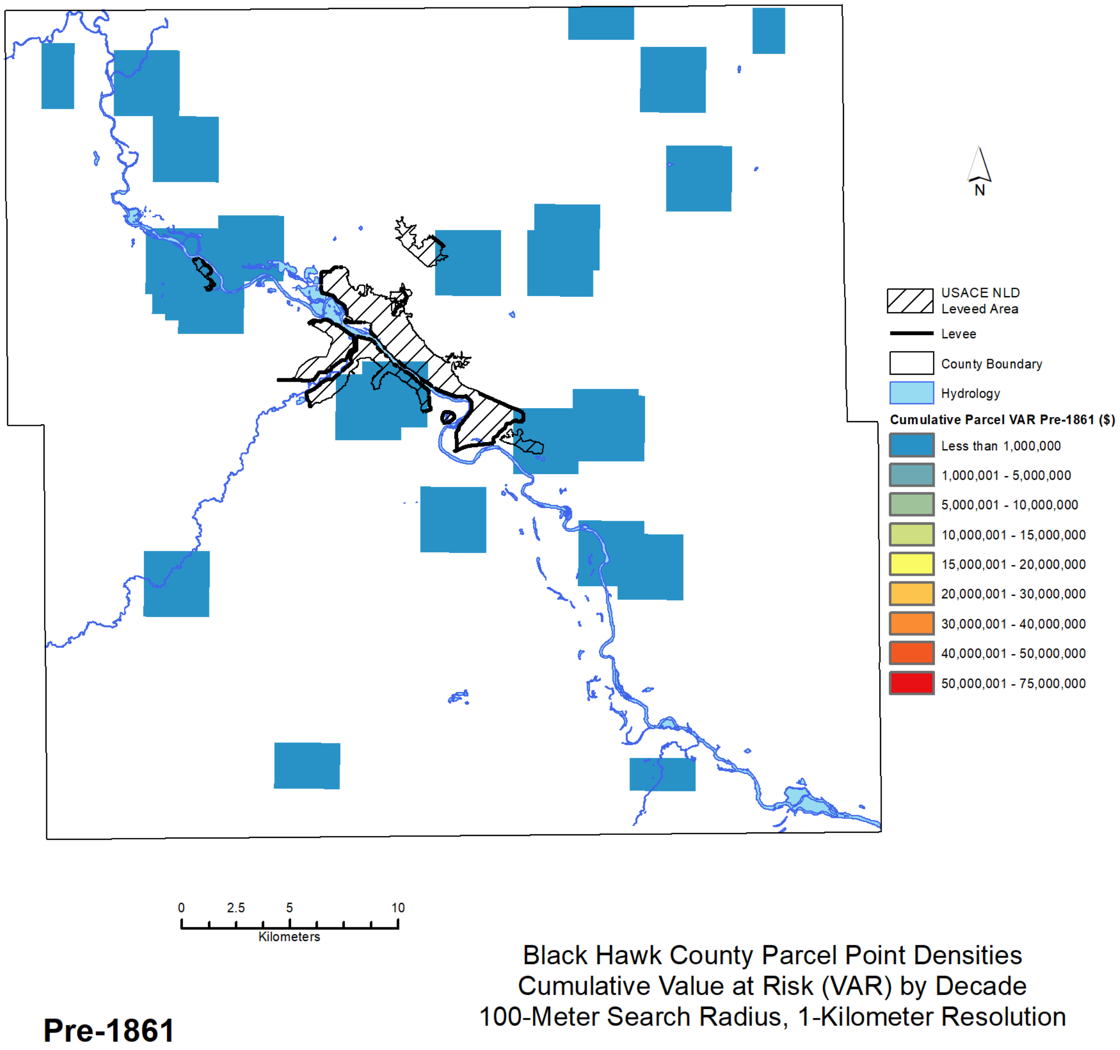
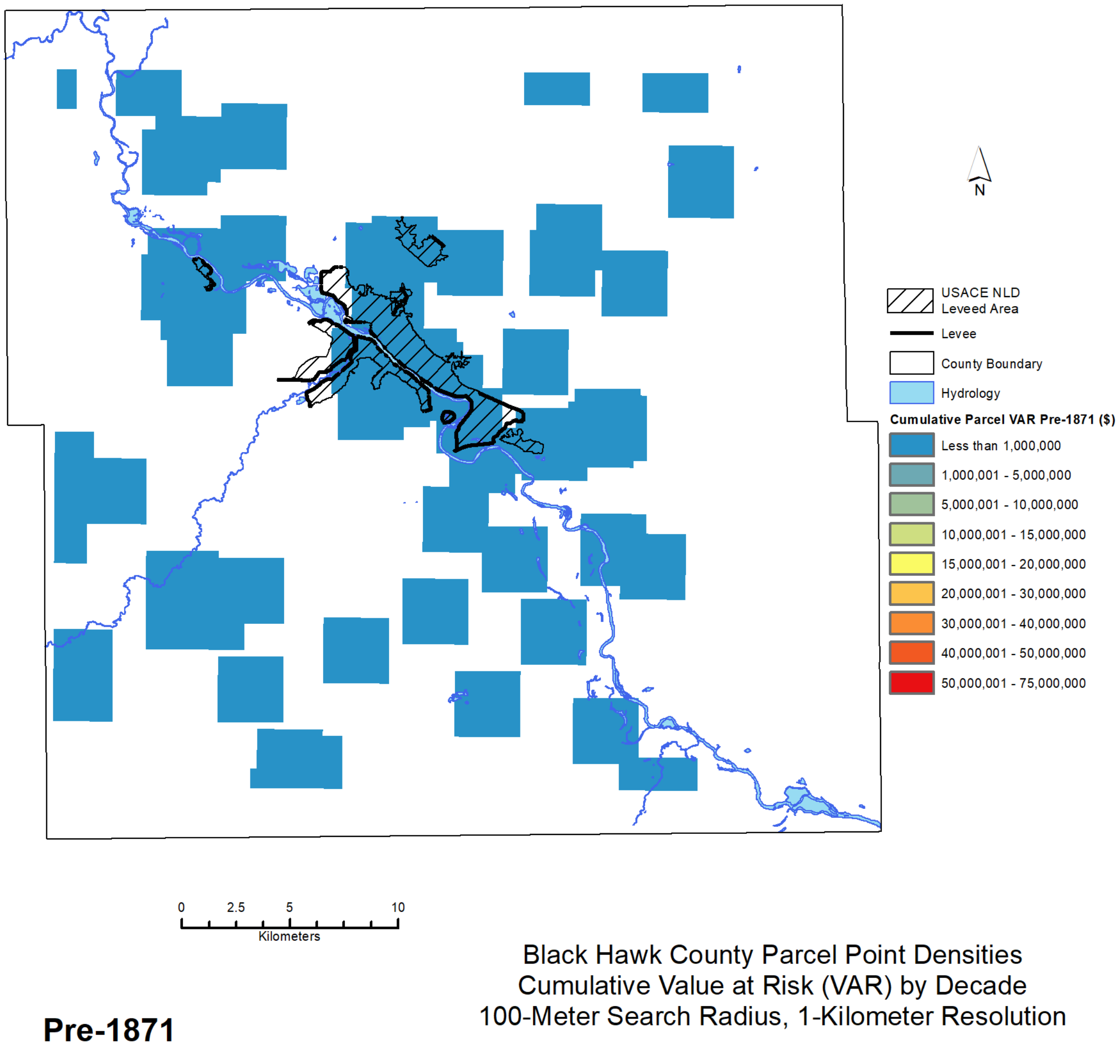


Figure C.25. Cumulative value at risk for Black Hawk County, Iowa, 1851-1860.



Black Hawk County Parcel Point Densities
Cumulative Value at Risk (VAR) by Decade
100-Meter Search Radius, 1-Kilometer Resolution

Pre-1871

Figure C.26. Cumulative value at risk for Black Hawk County, Iowa, 1851-1870.

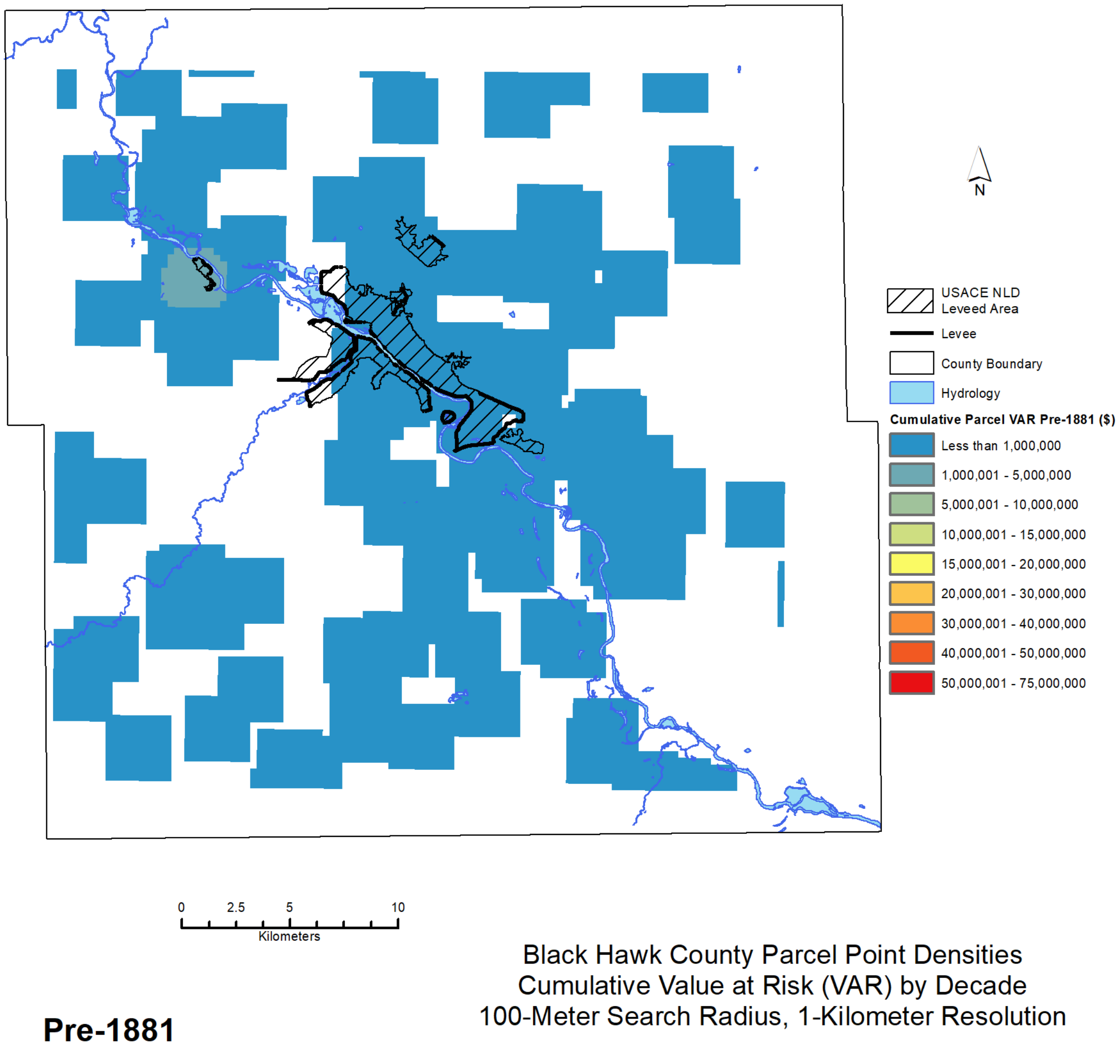
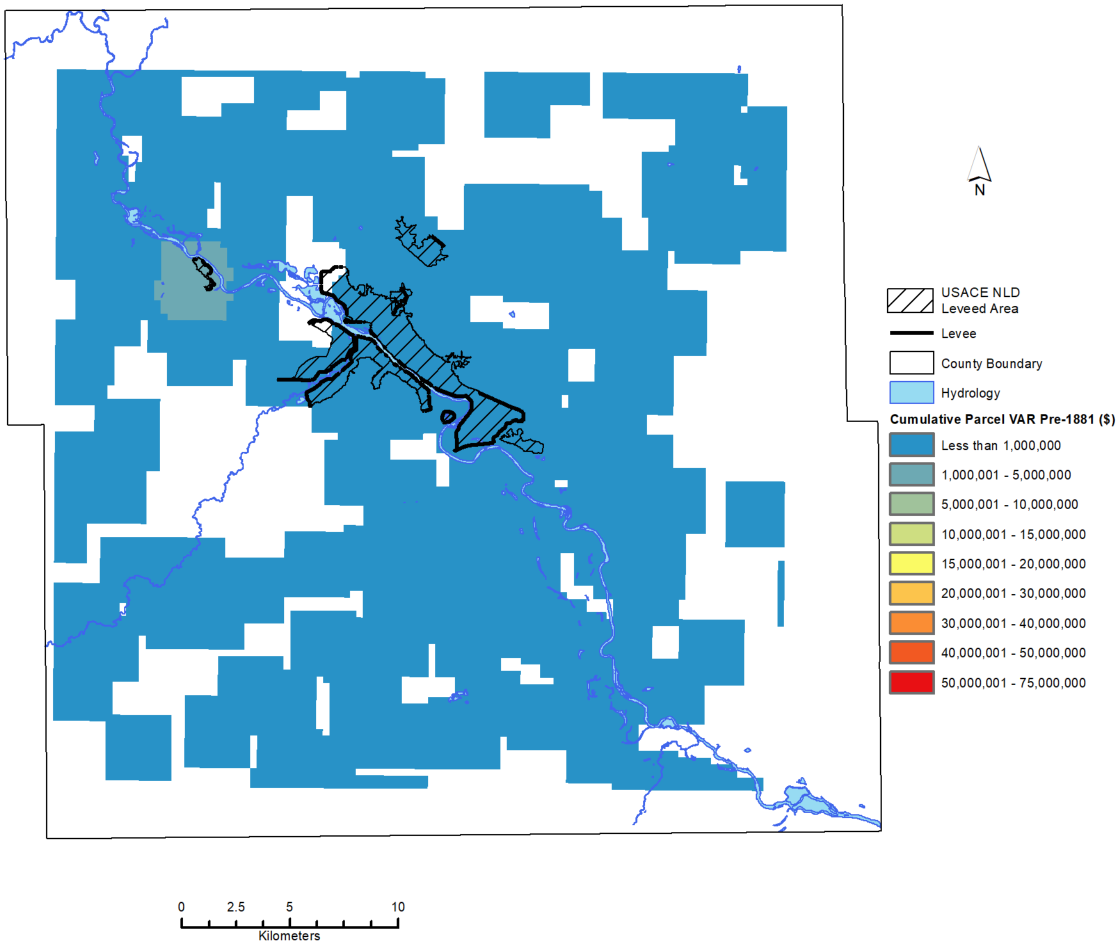


Figure C.27. Cumulative value at risk for Black Hawk County, Iowa, 1851-1880.



Black Hawk County Parcel Point Densities
Cumulative Value at Risk (VAR) by Decade
100-Meter Search Radius, 1-Kilometer Resolution

Pre-1891

Figure C.28. Cumulative value at risk for Black Hawk County, Iowa, 1851-1890.

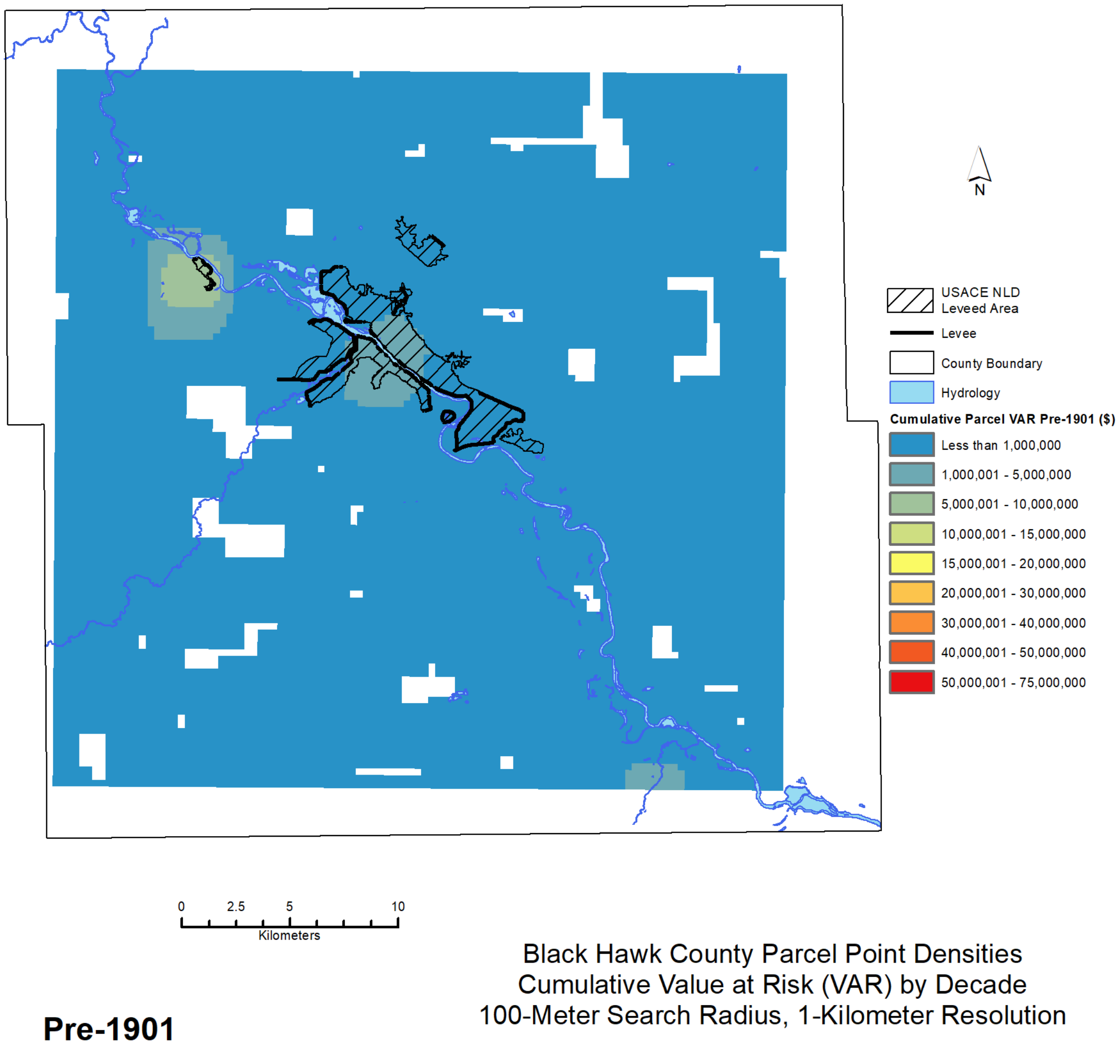


Figure C.29. Cumulative value at risk for Black Hawk County, Iowa, 1851-1900.

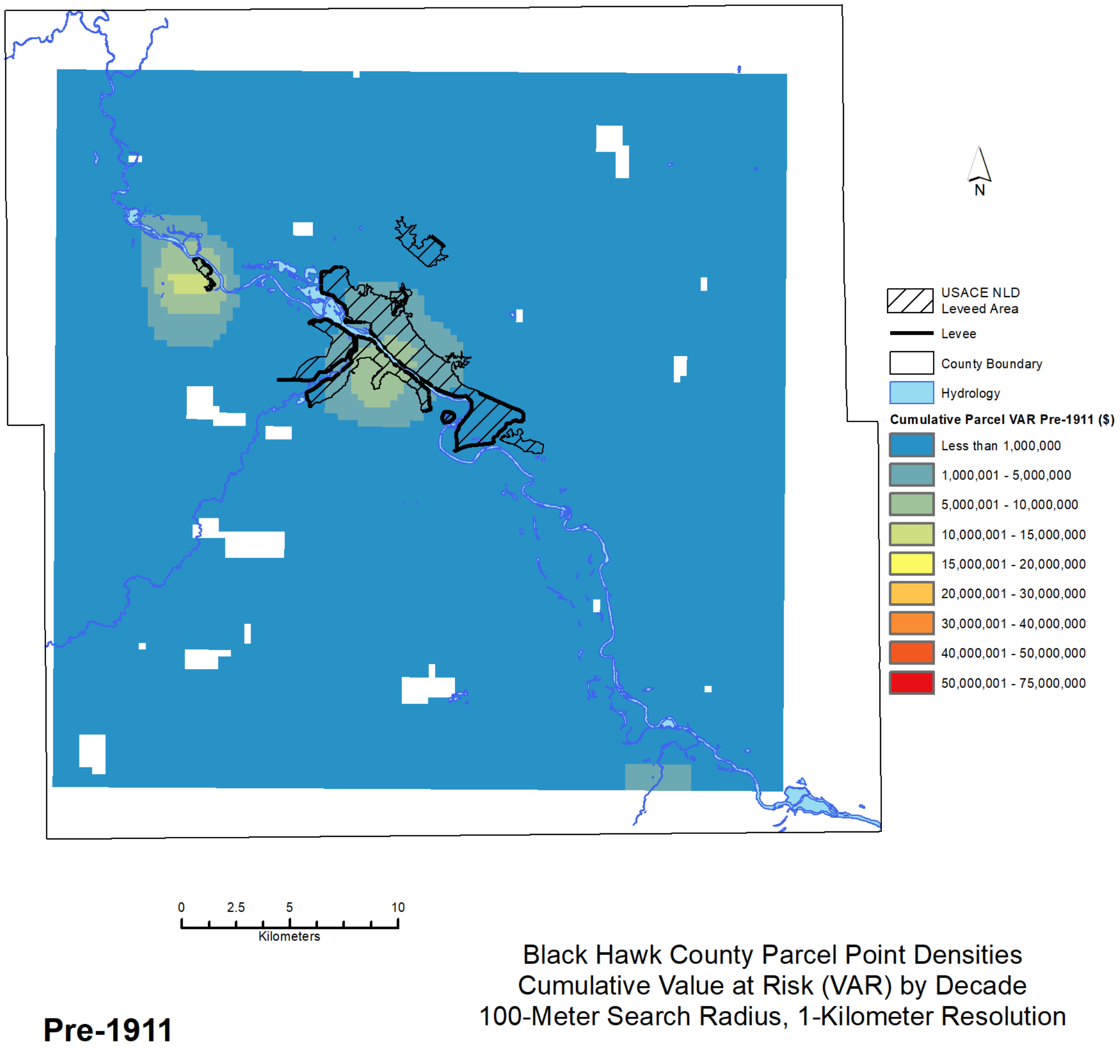


Figure C.30. Cumulative value at risk for Black Hawk County, Iowa, 1851-1910.

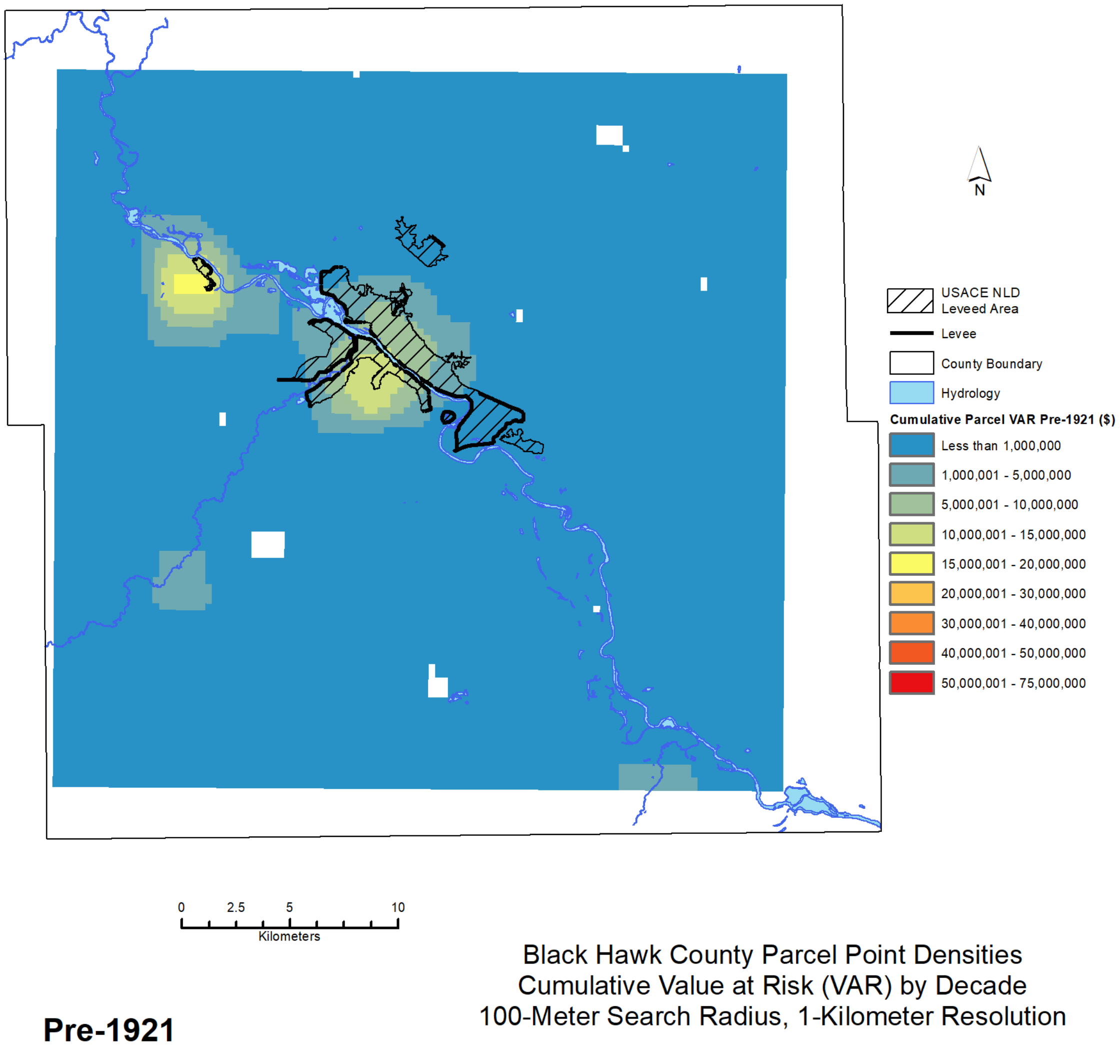


Figure C.31. Cumulative value at risk for Black Hawk County, Iowa, 1851-1920.

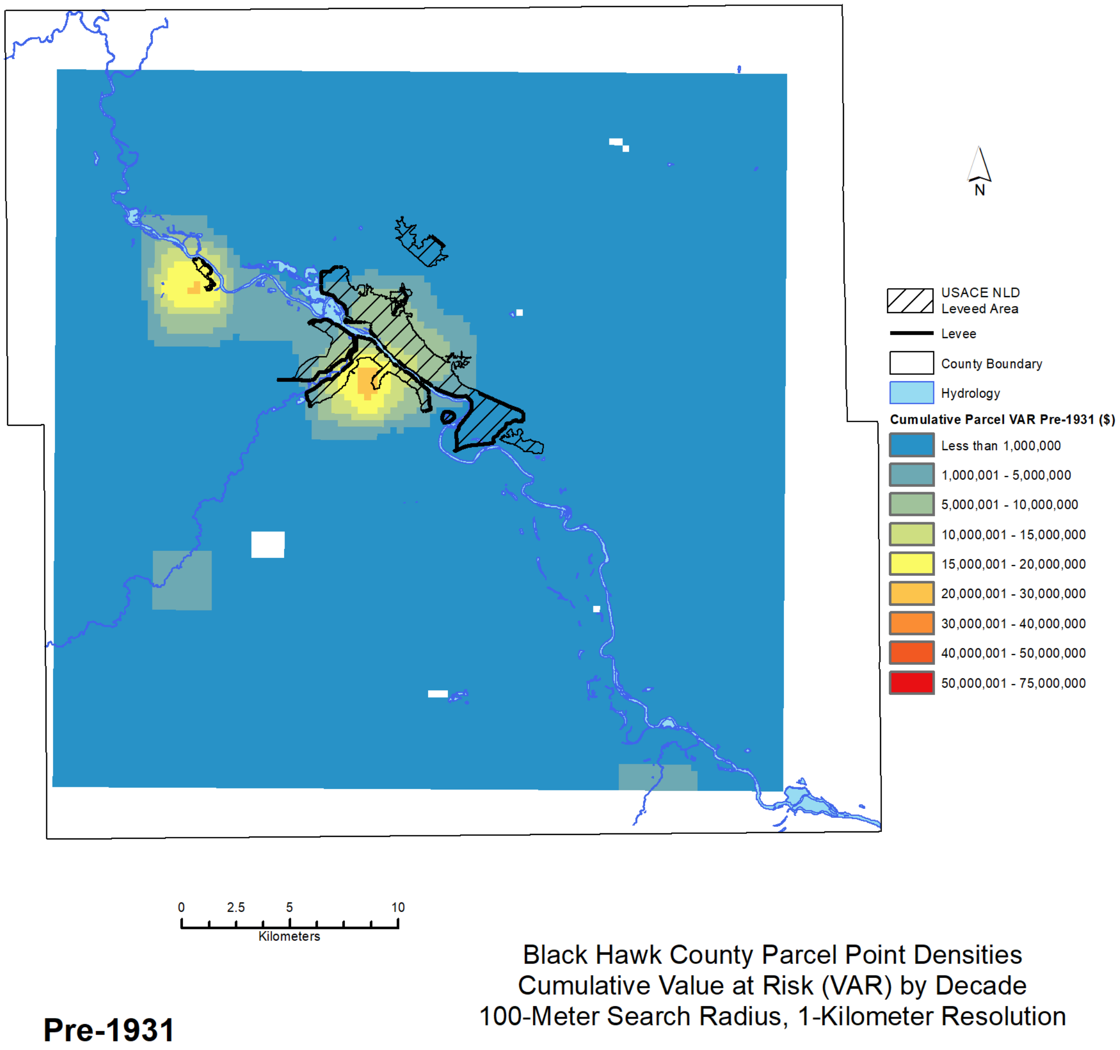


Figure C.32. Cumulative value at risk for Black Hawk County, Iowa, 1851-1930.

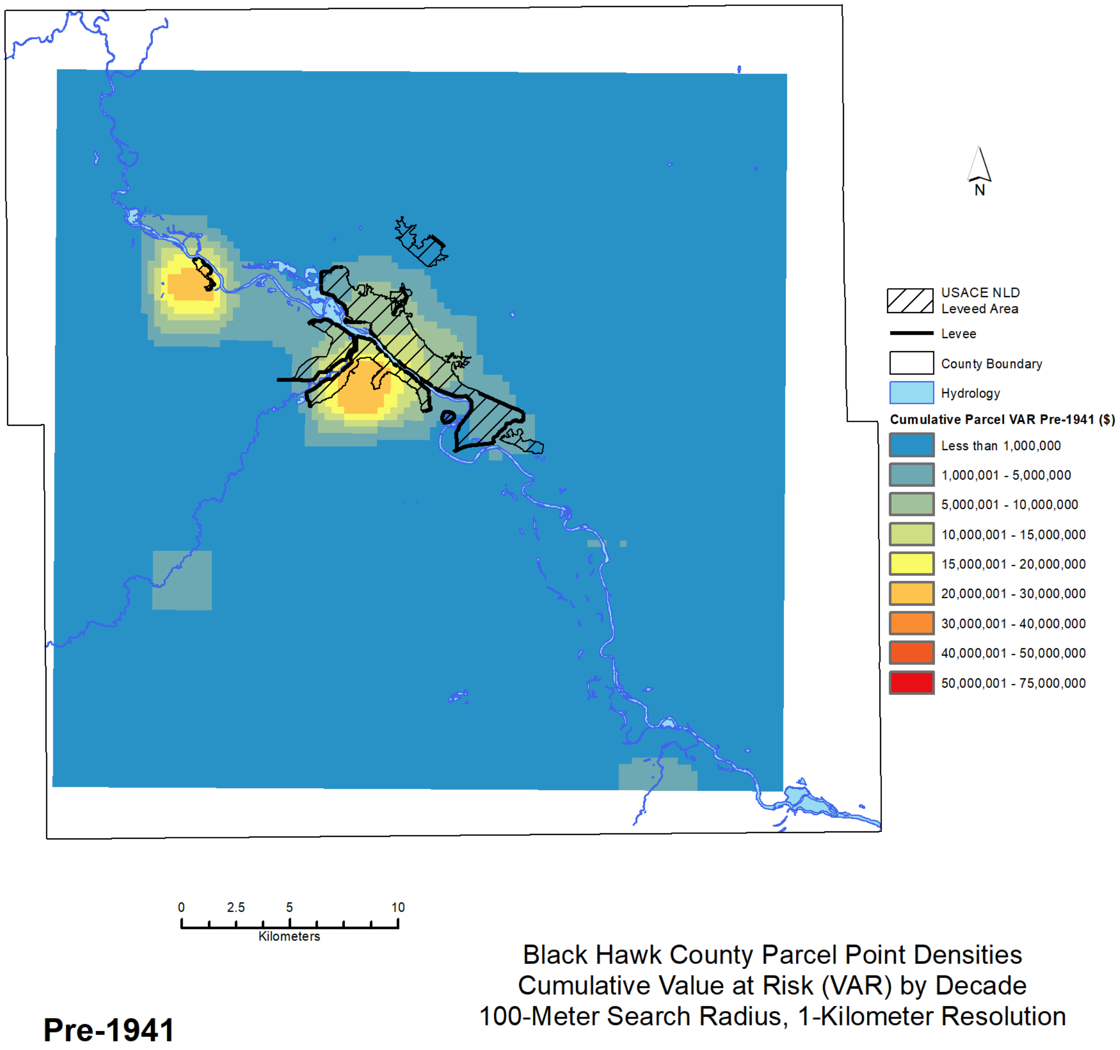


Figure C.33. Cumulative value at risk for Black Hawk County, Iowa, 1851-1940.

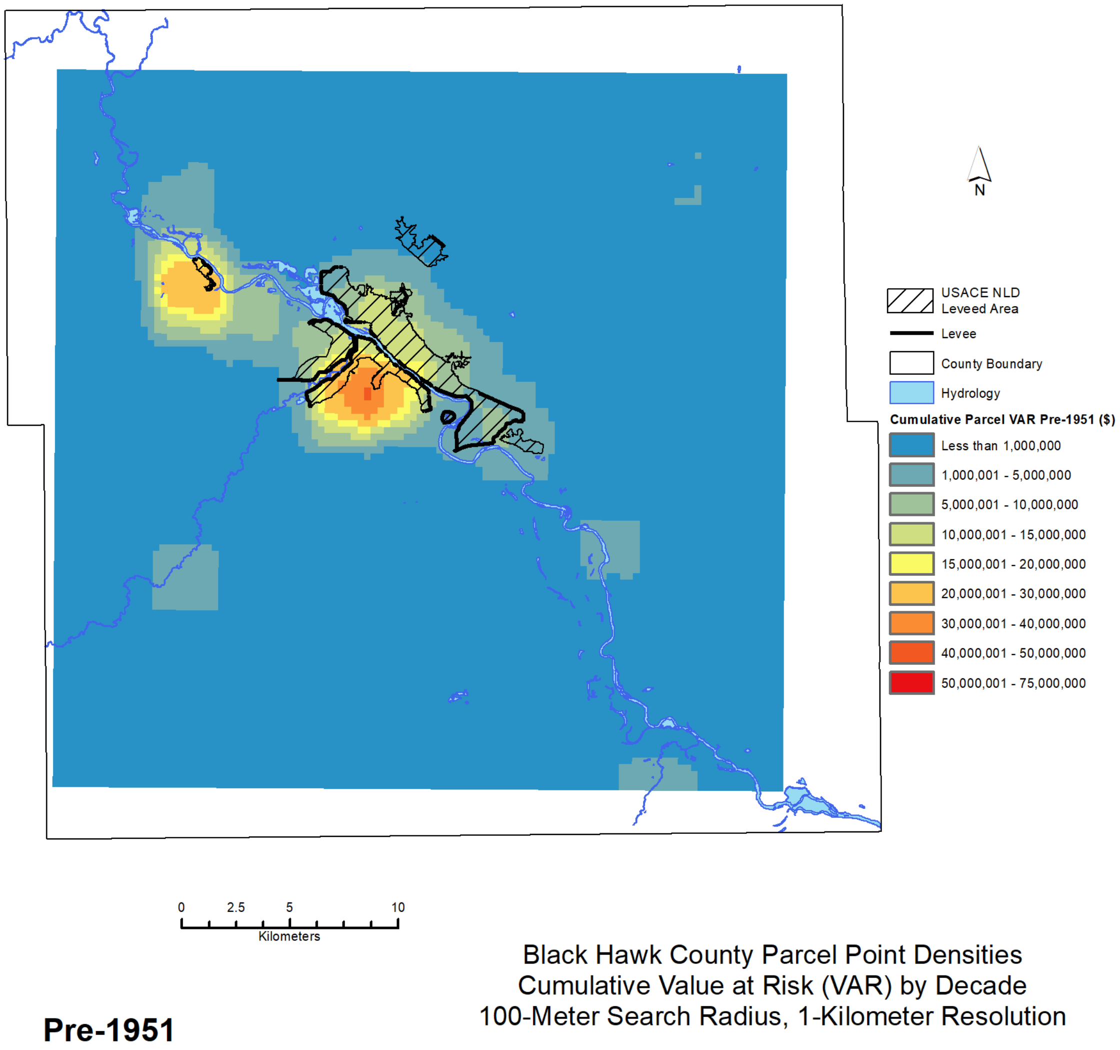


Figure C.34. Cumulative value at risk for Black Hawk County, Iowa, 1851-1950.

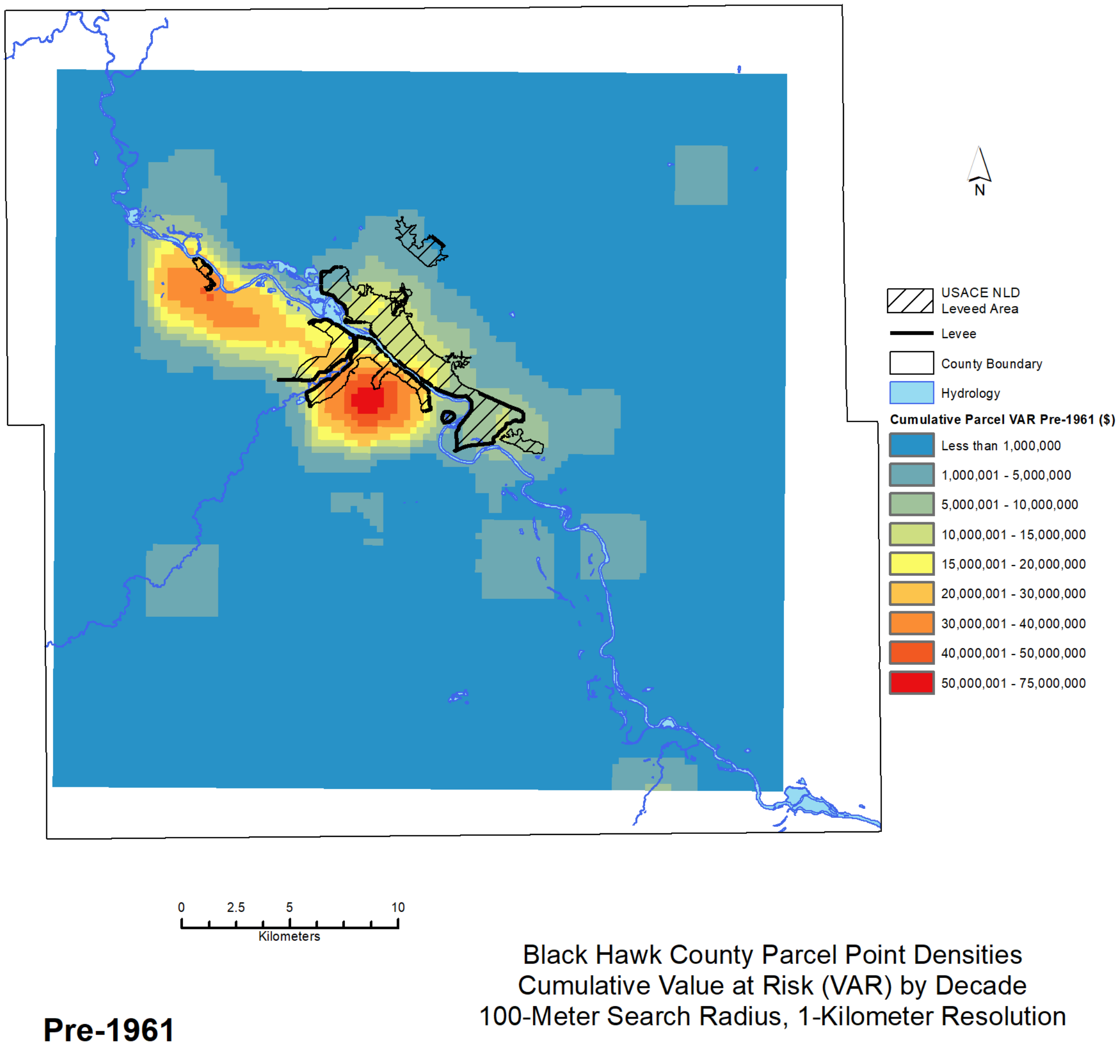


Figure C.35. Cumulative value at risk for Black Hawk County, Iowa, 1851-1960.

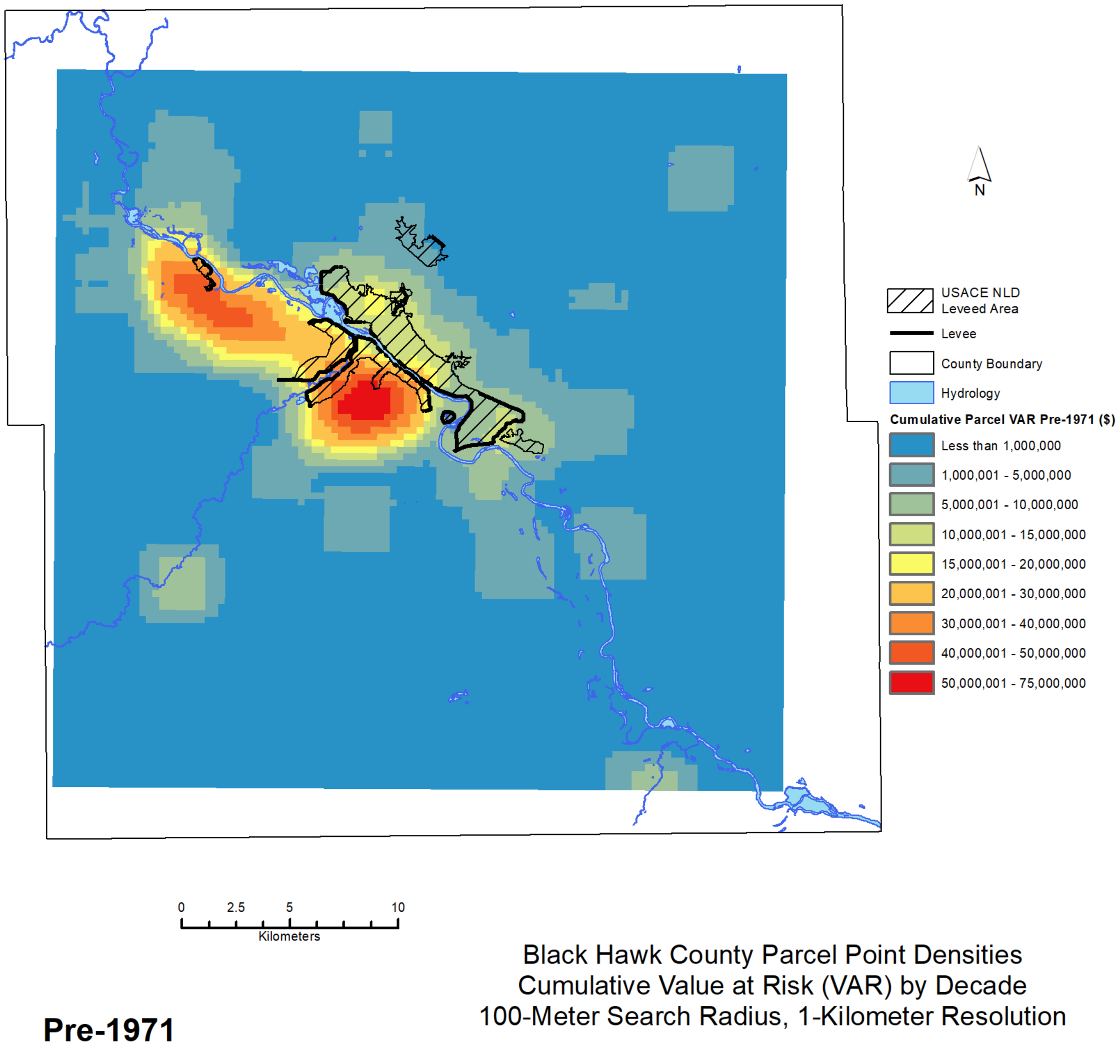


Figure C.36. Cumulative value at risk for Black Hawk County, Iowa, 1851-1970.

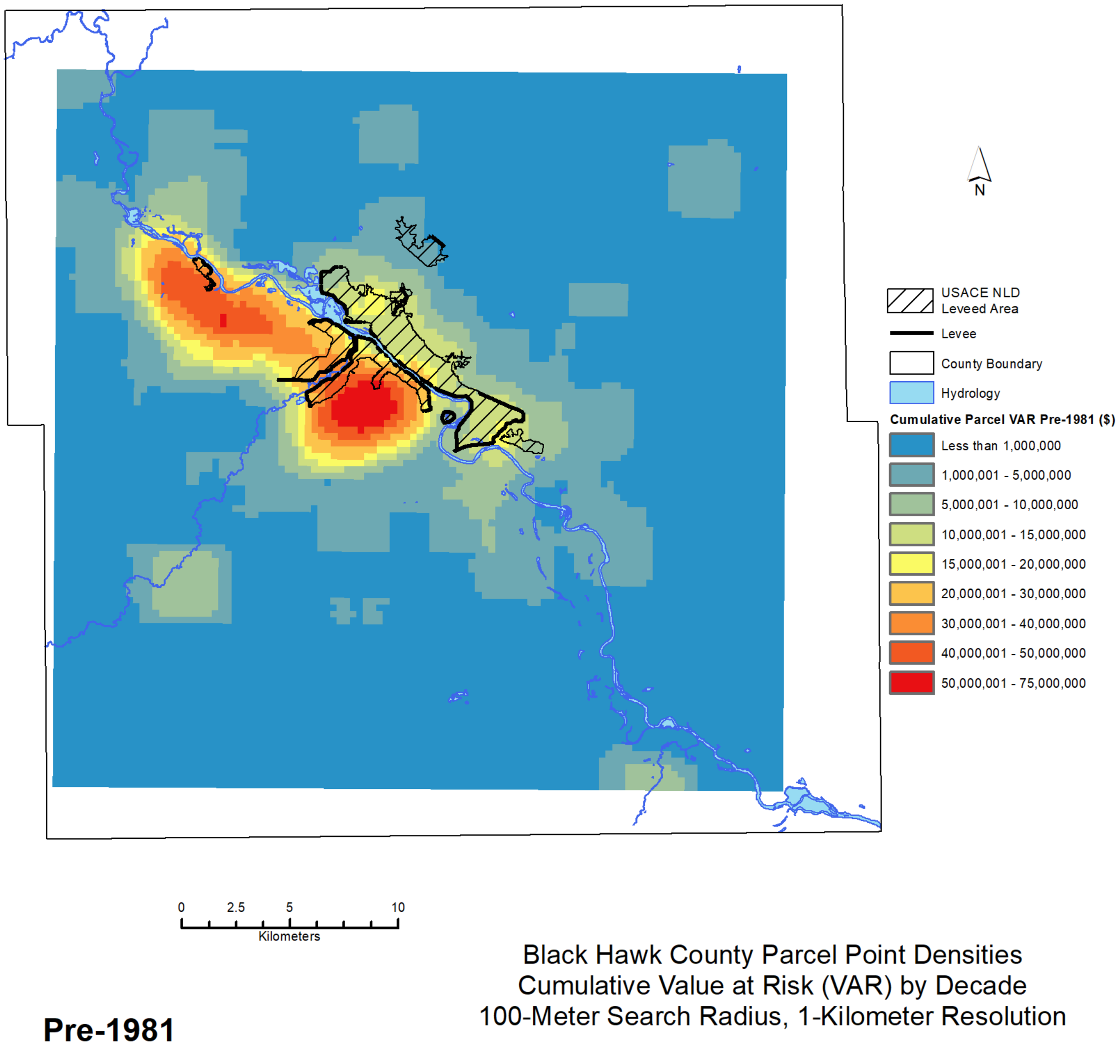


Figure C.37. Cumulative value at risk for Black Hawk County, Iowa, 1851-1980.

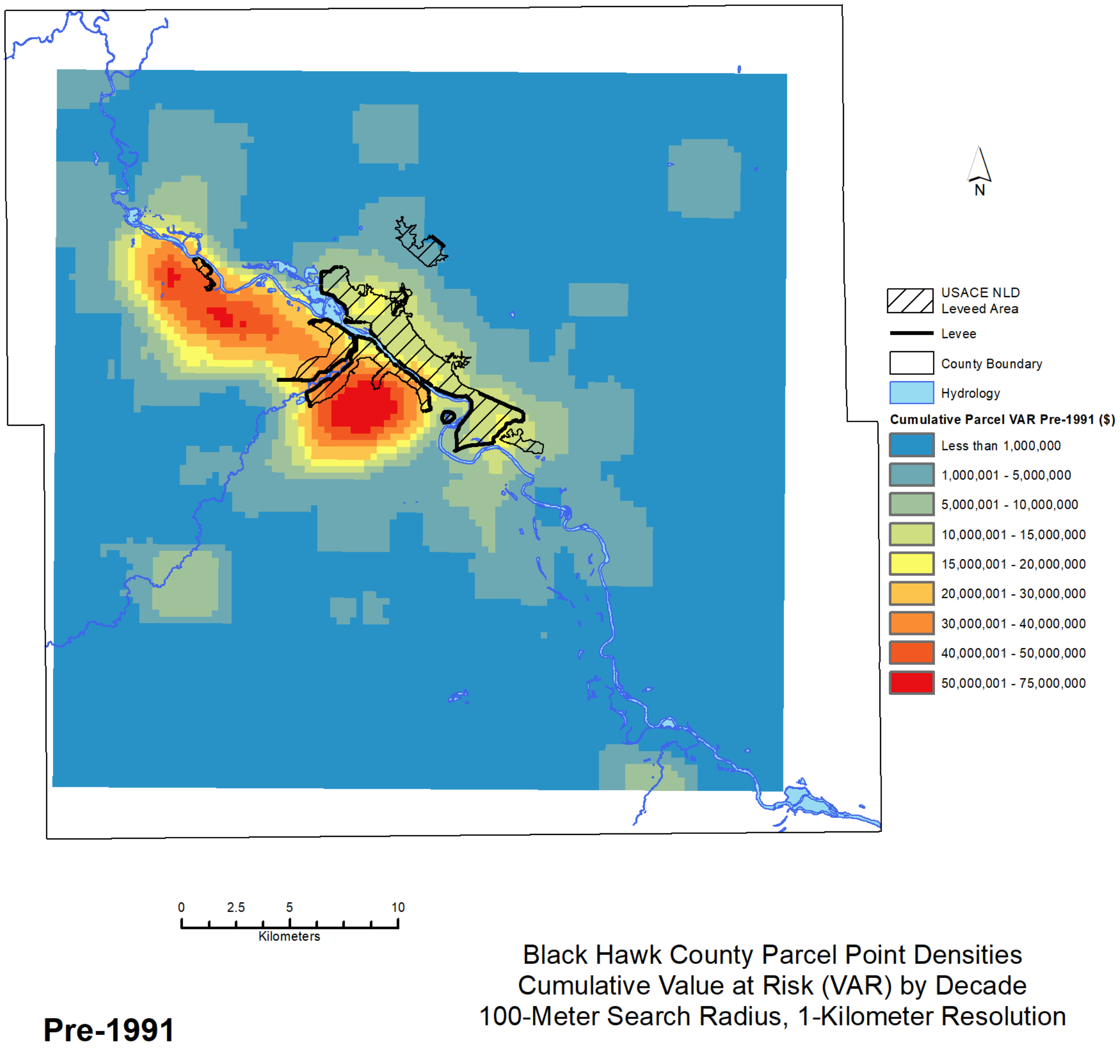


Figure C.38. Cumulative value at risk for Black Hawk County, Iowa, 1851-1990.

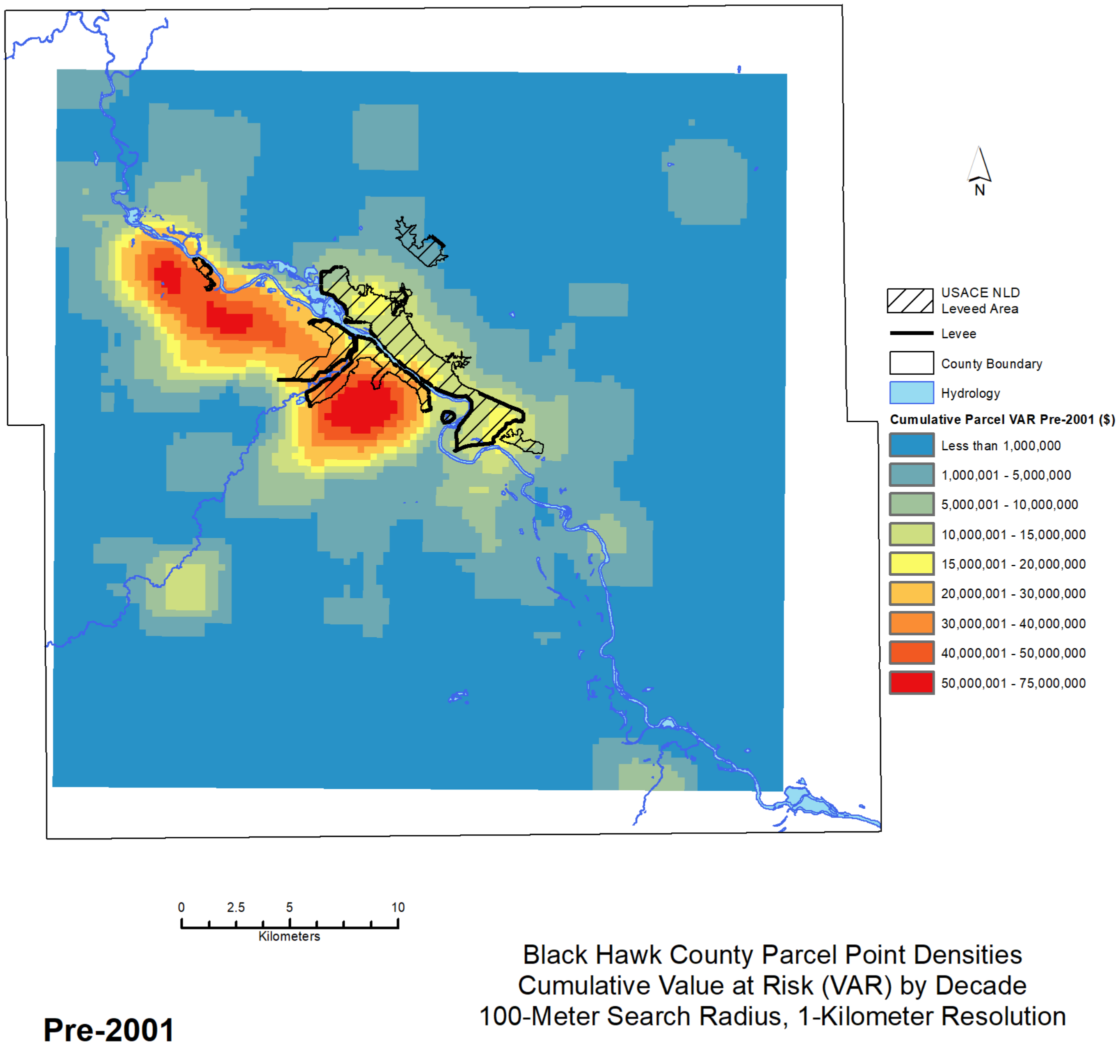


Figure C.39. Cumulative value at risk for Black Hawk County, Iowa, 1851-2000.

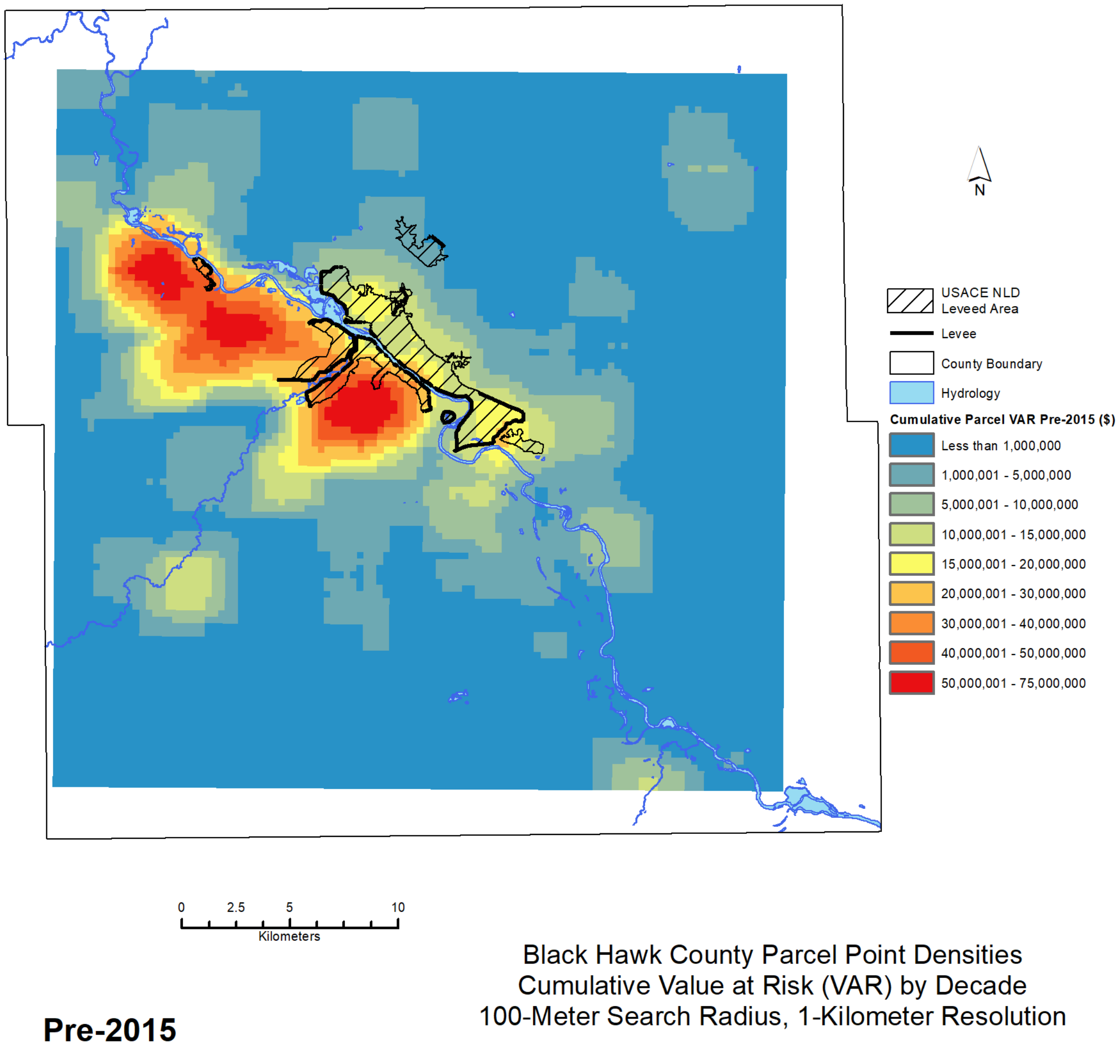


Figure C.40. Cumulative value at risk for Black Hawk County, Iowa, 1851-2015.

C.2.2 Black Hawk County, Iowa Decadal VAR Densities

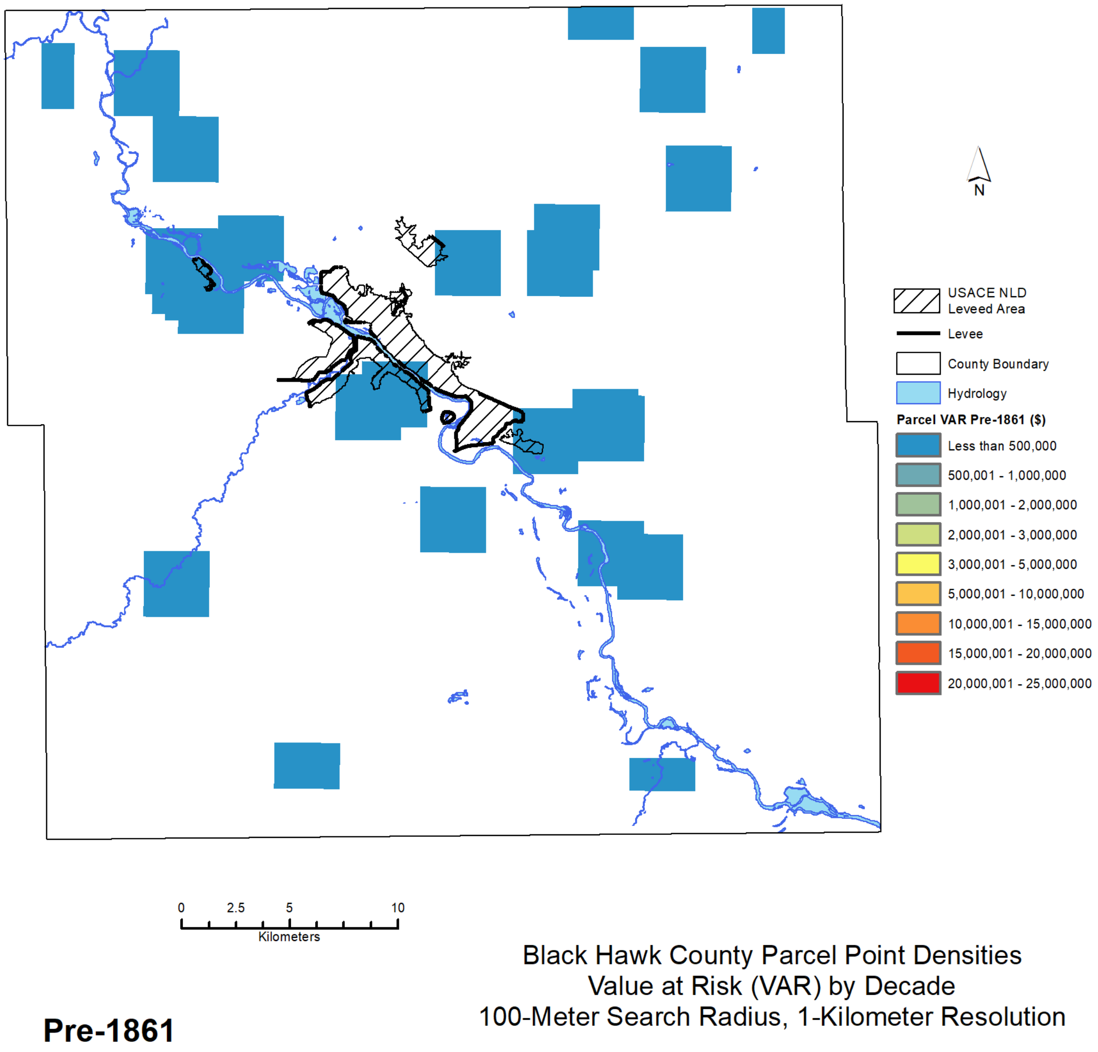


Figure C.41. Value at risk in Black Hawk County, Iowa, 1851-1860.

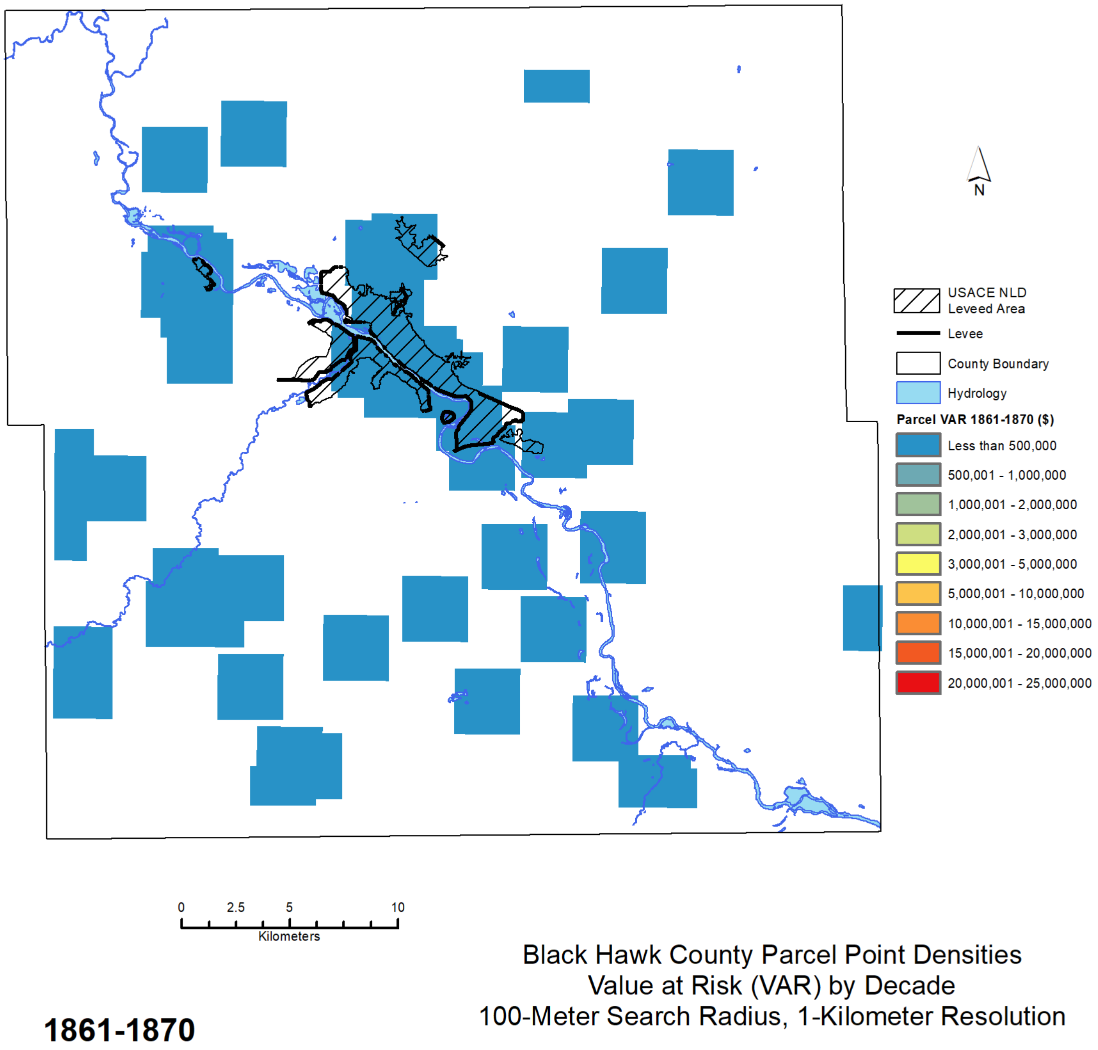


Figure C.42. Value at risk in Black Hawk County, Iowa, 1861-1870.

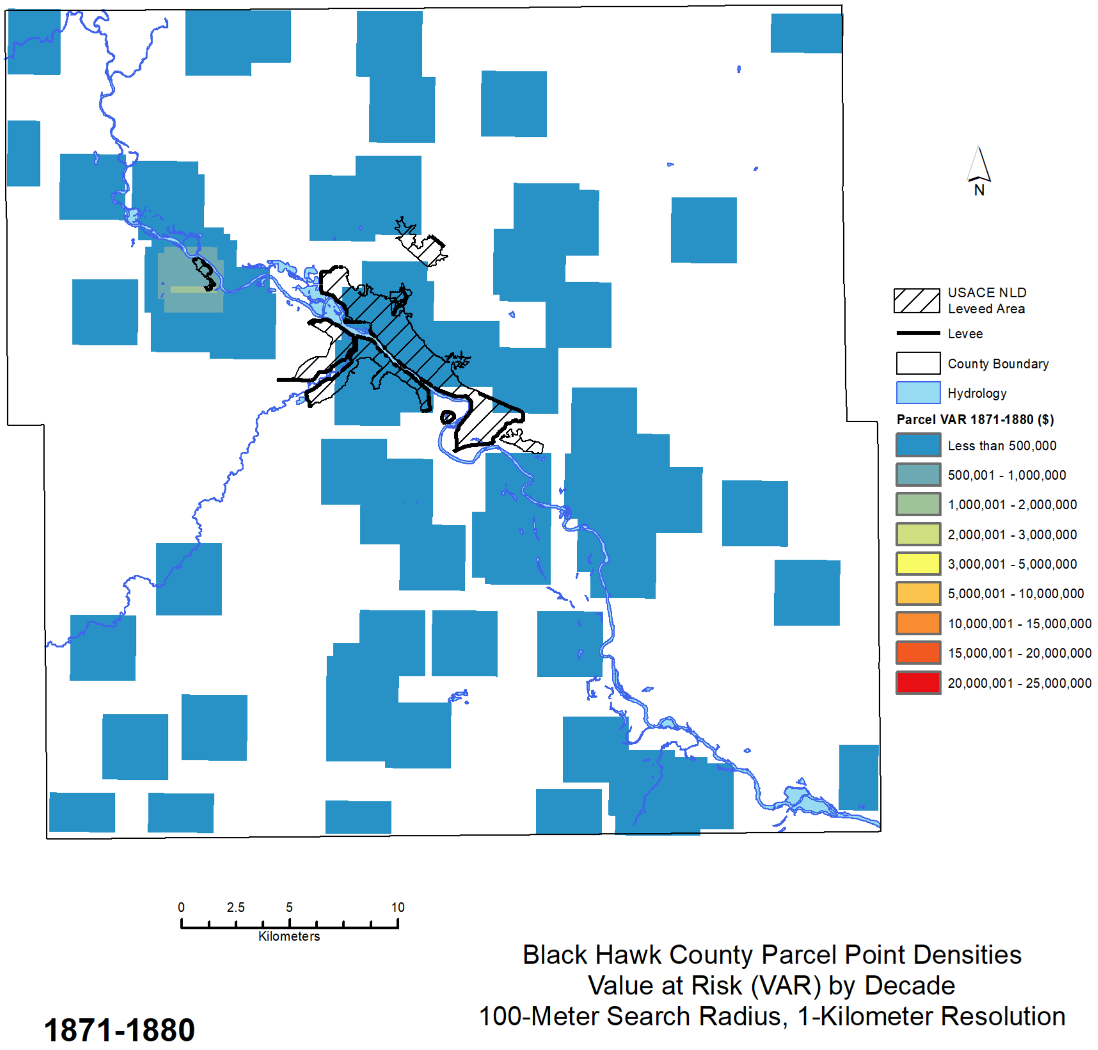


Figure C.43. Value at risk in Black Hawk County, Iowa, 1871-1880.

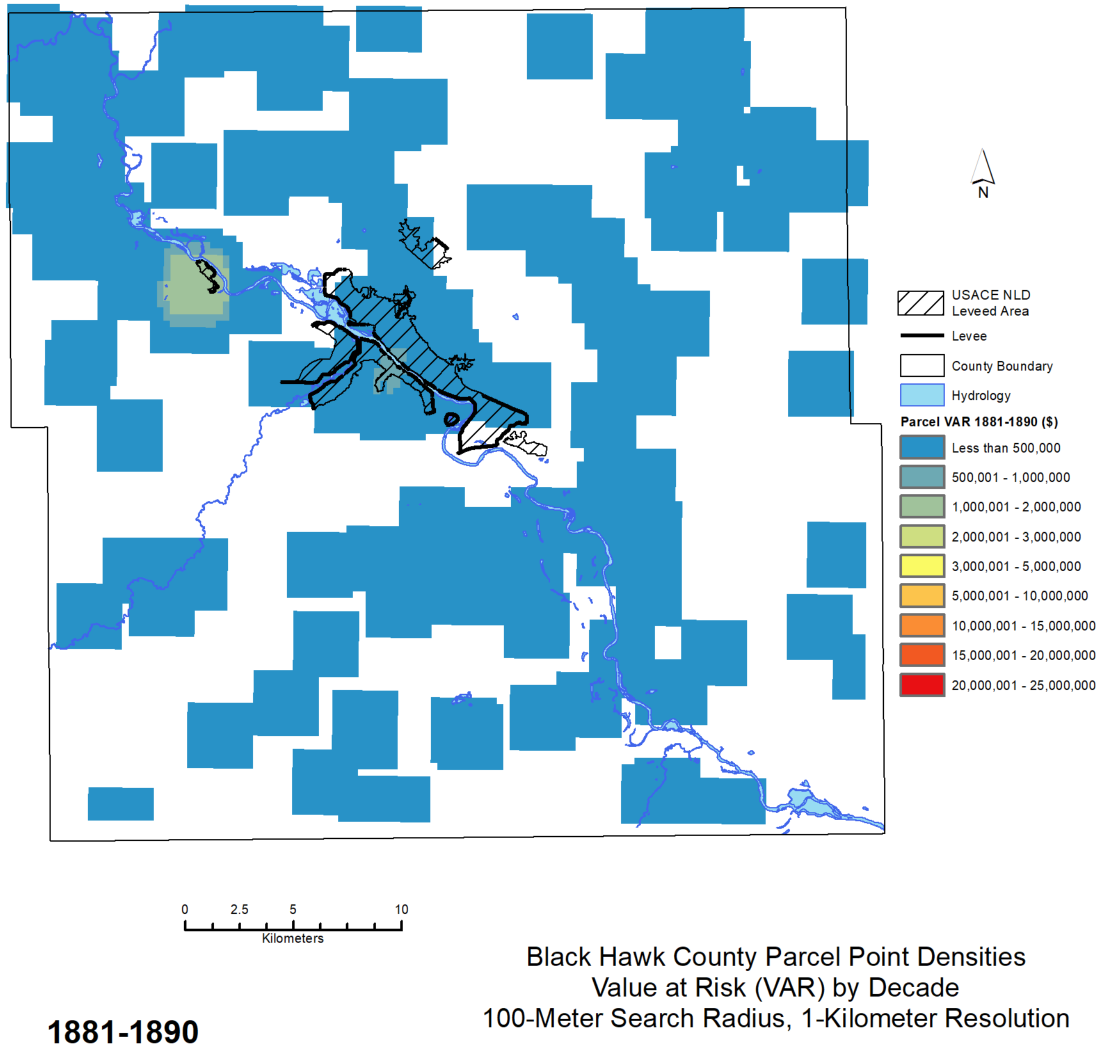


Figure C.44. Value at risk in Black Hawk County, Iowa, 1881-1890.

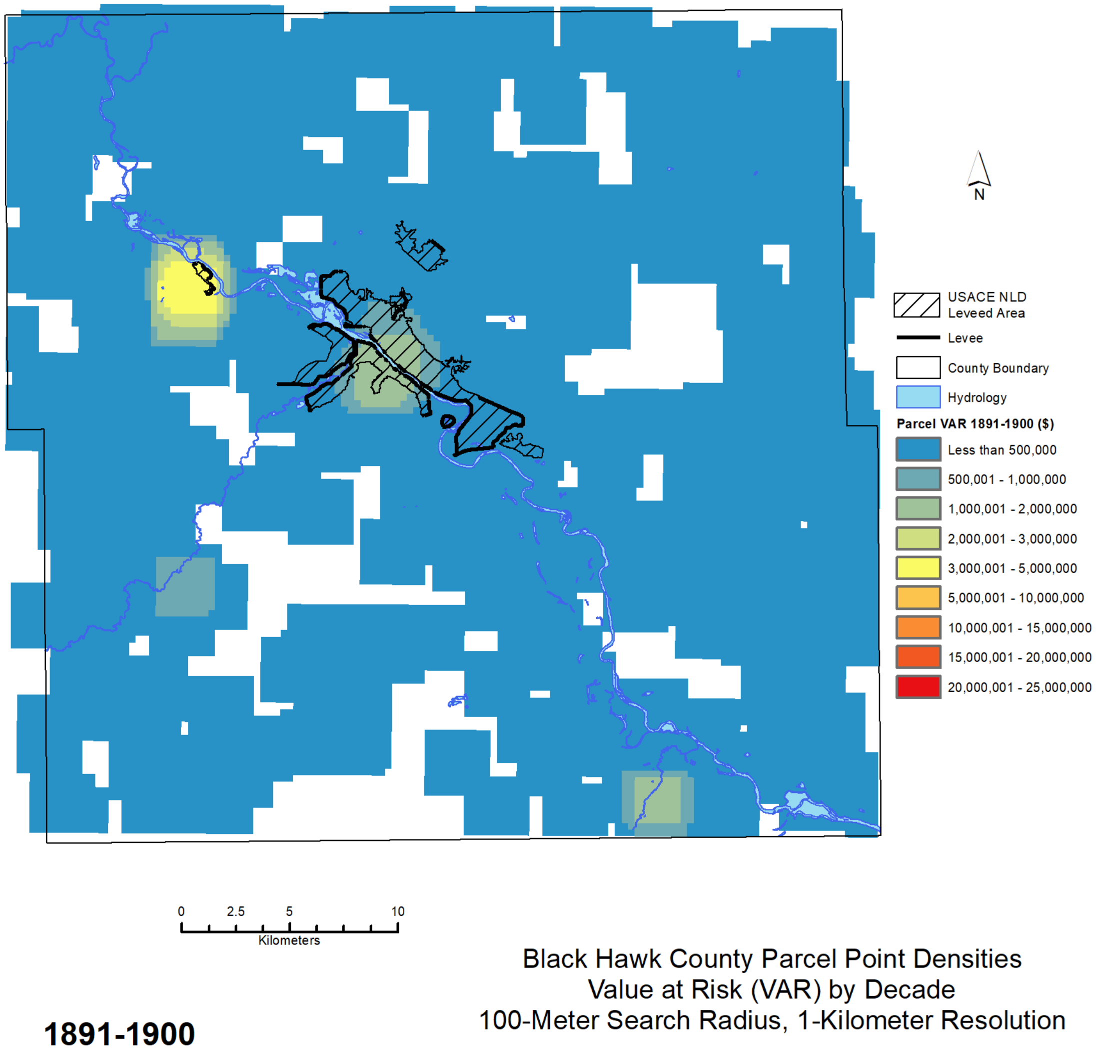


Figure C.45. Value at risk in Black Hawk County, Iowa, 1891-1900.

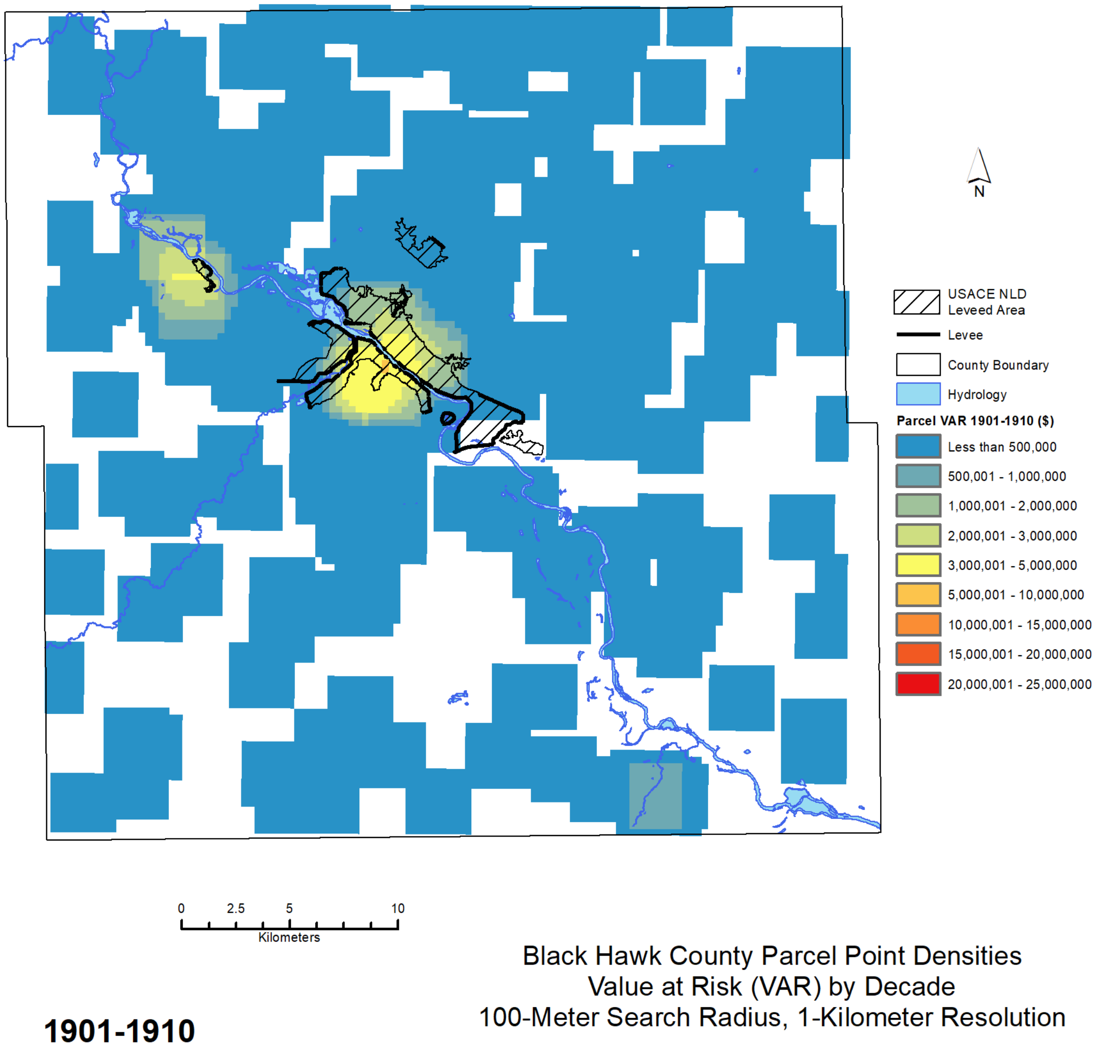


Figure C.46. Value at risk in Black Hawk County, Iowa, 1901-1910.

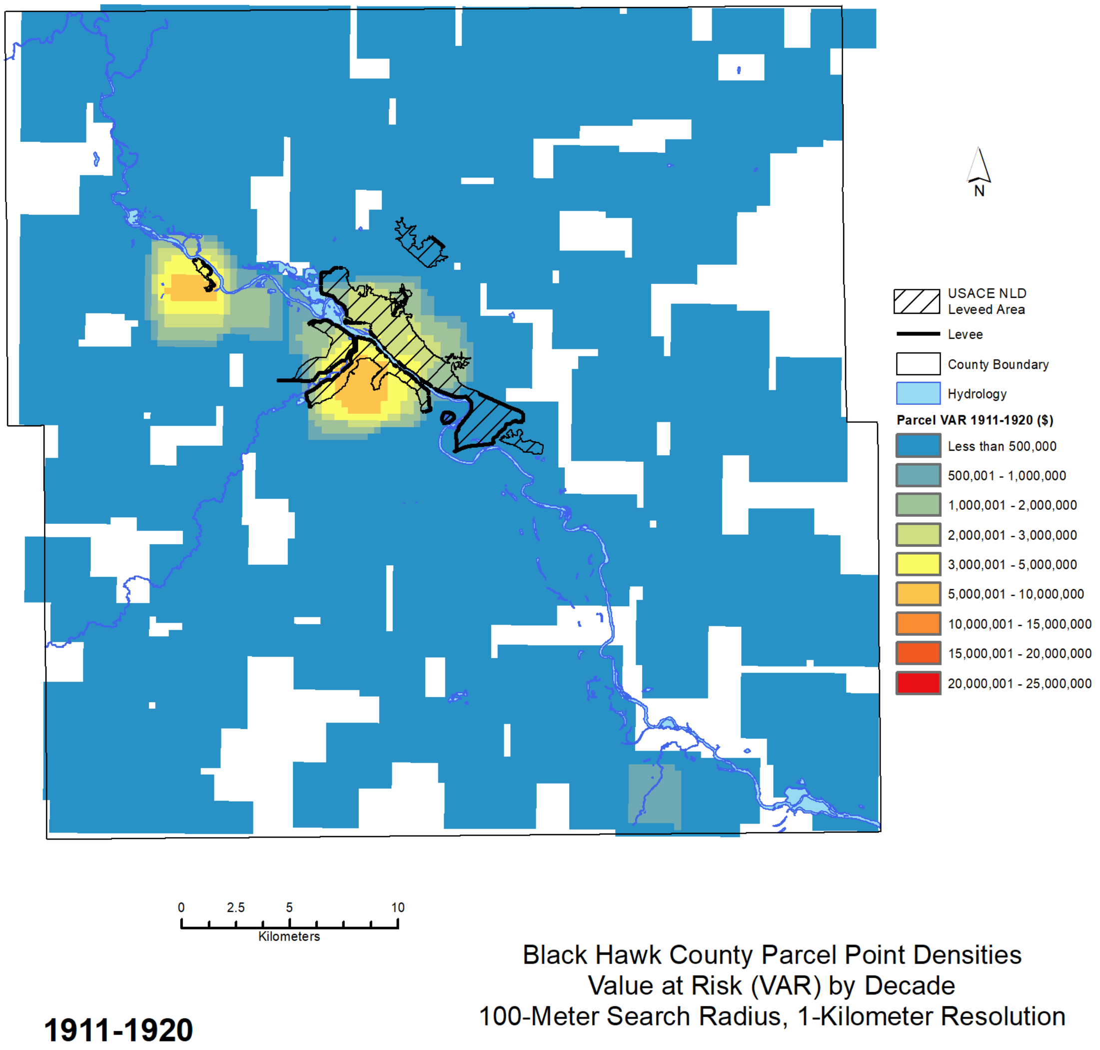


Figure C.47. Value at risk in Black Hawk County, Iowa, 1911-1920.

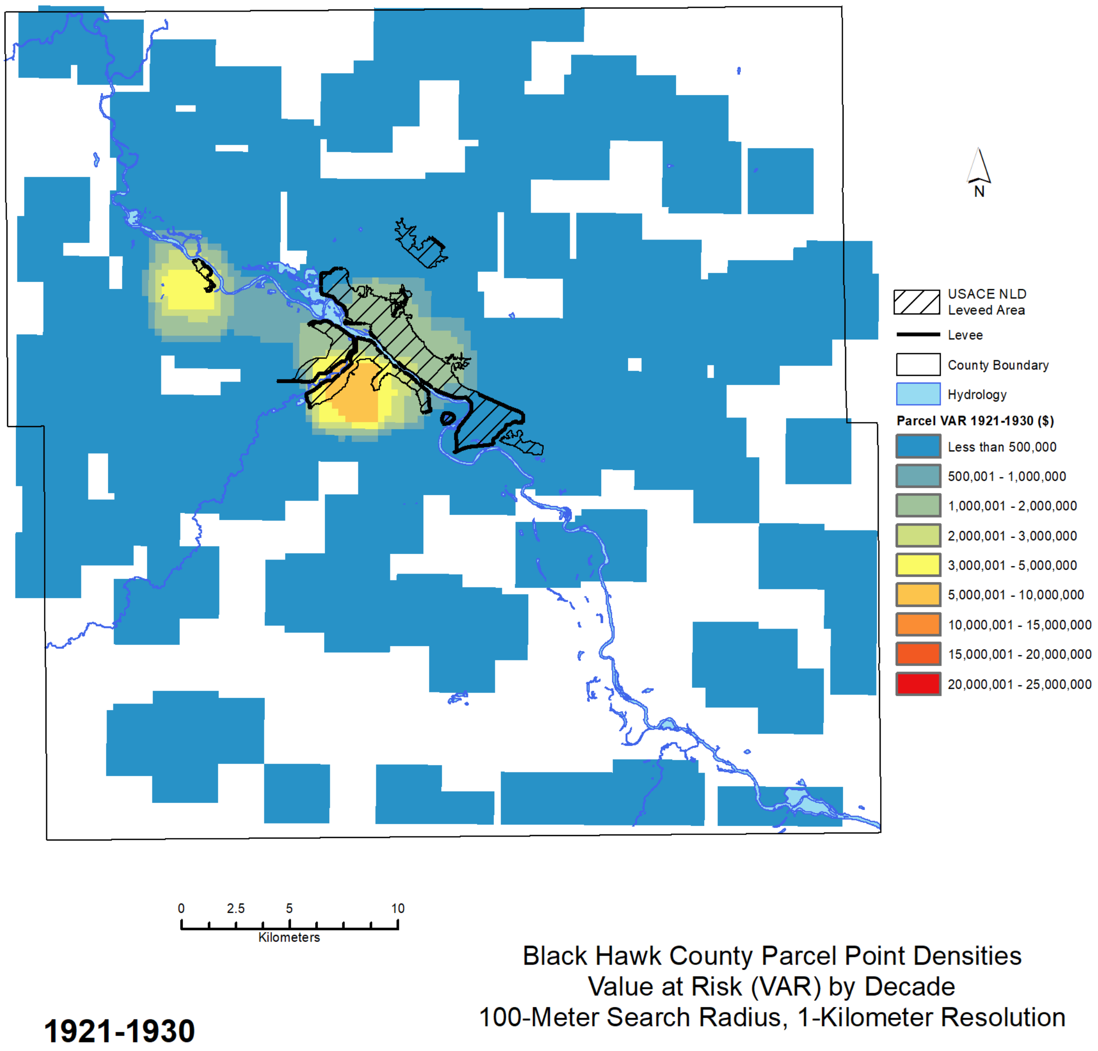


Figure C.48. Value at risk in Black Hawk County, Iowa, 1921-1930.

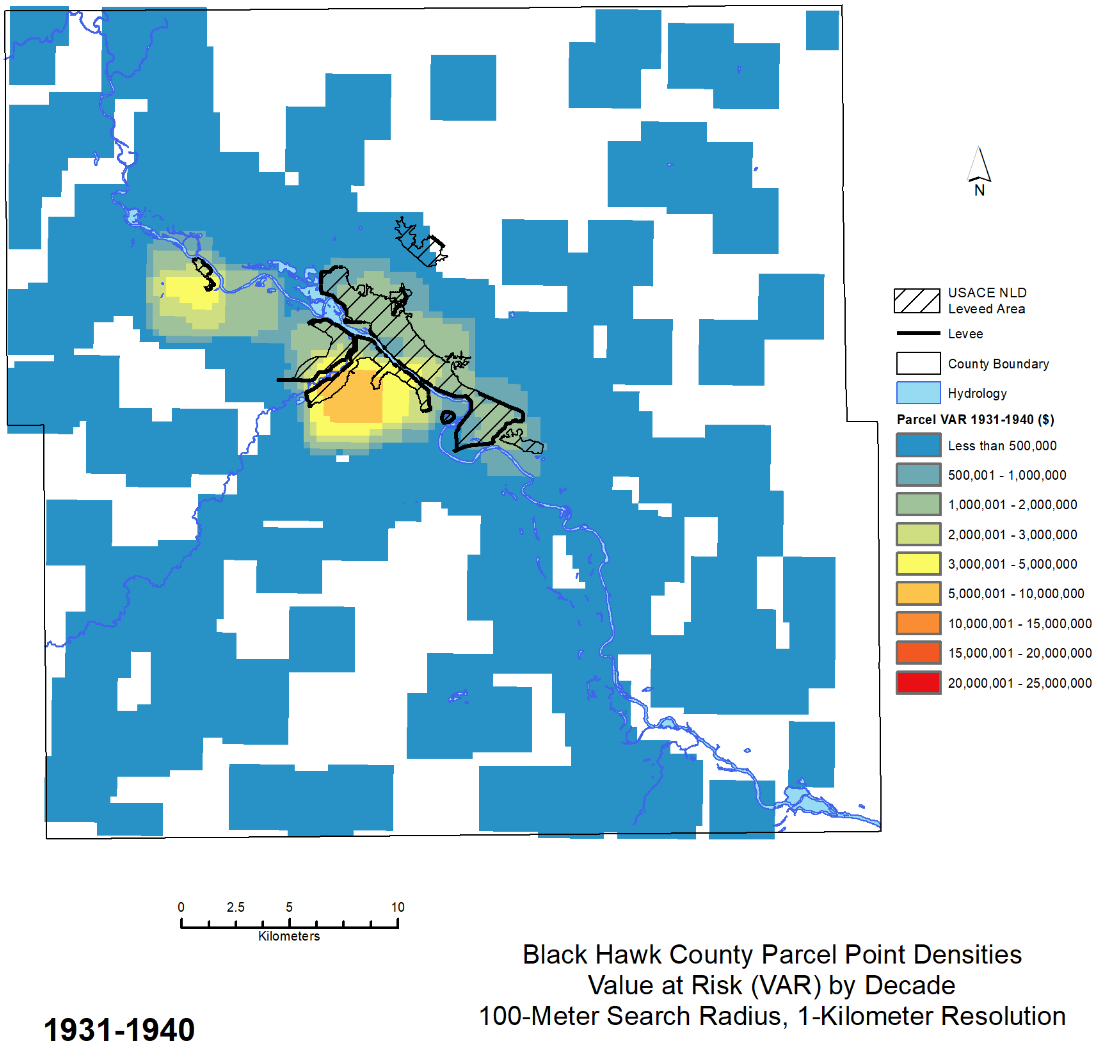
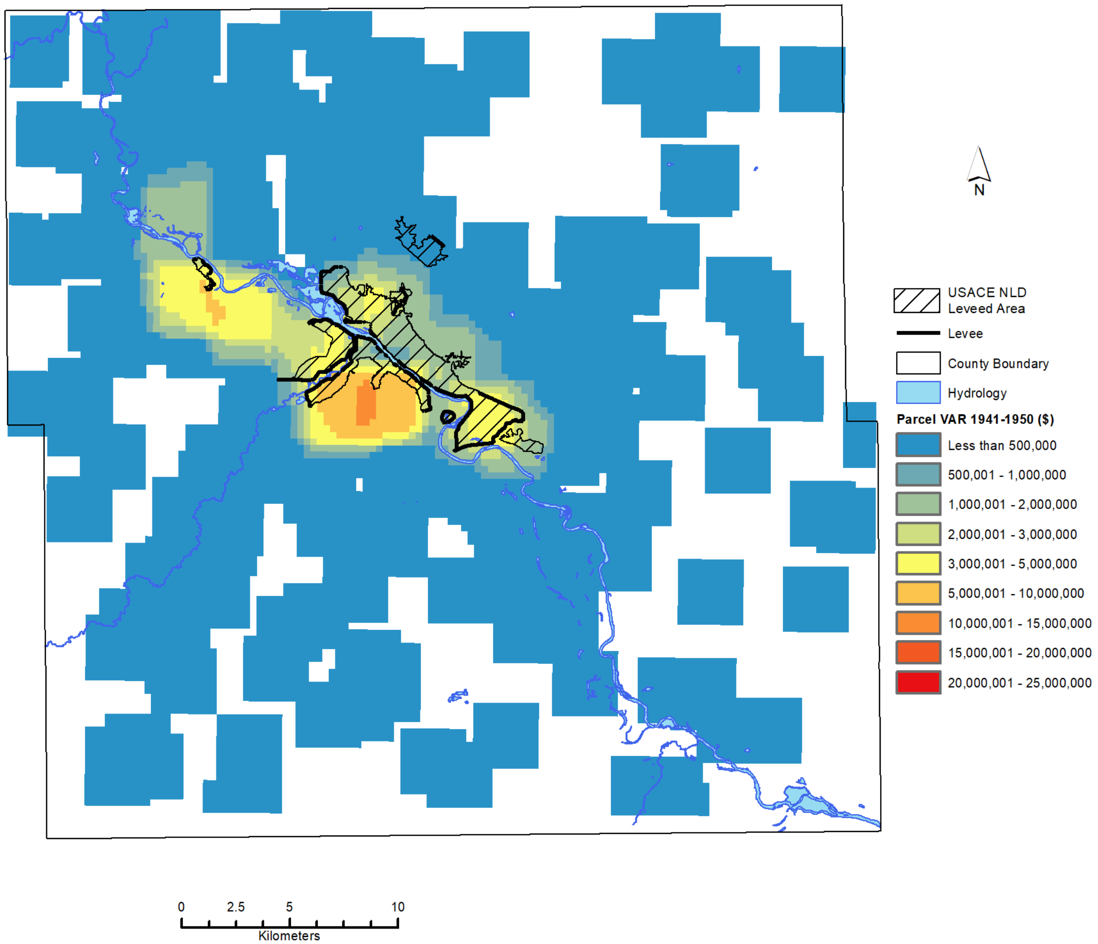


Figure C.49. Value at risk in Black Hawk County, Iowa, 1931-1940.



Black Hawk County Parcel Point Densities
Value at Risk (VAR) by Decade
100-Meter Search Radius, 1-Kilometer Resolution

1941-1950

Figure C.50. Value at risk in Black Hawk County, Iowa, 1941-1950.

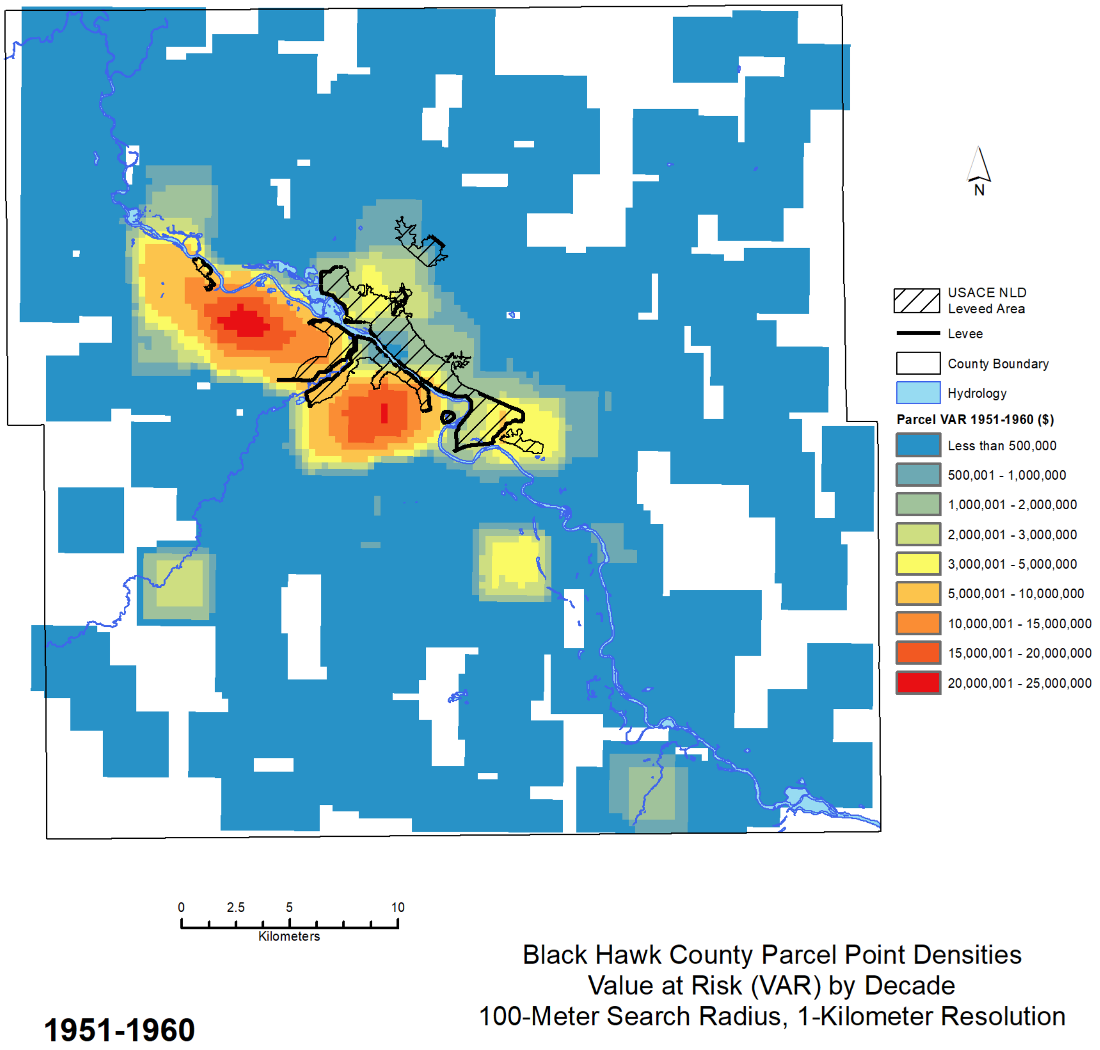


Figure C.51. Value at risk in Black Hawk County, Iowa, 1951-1960.

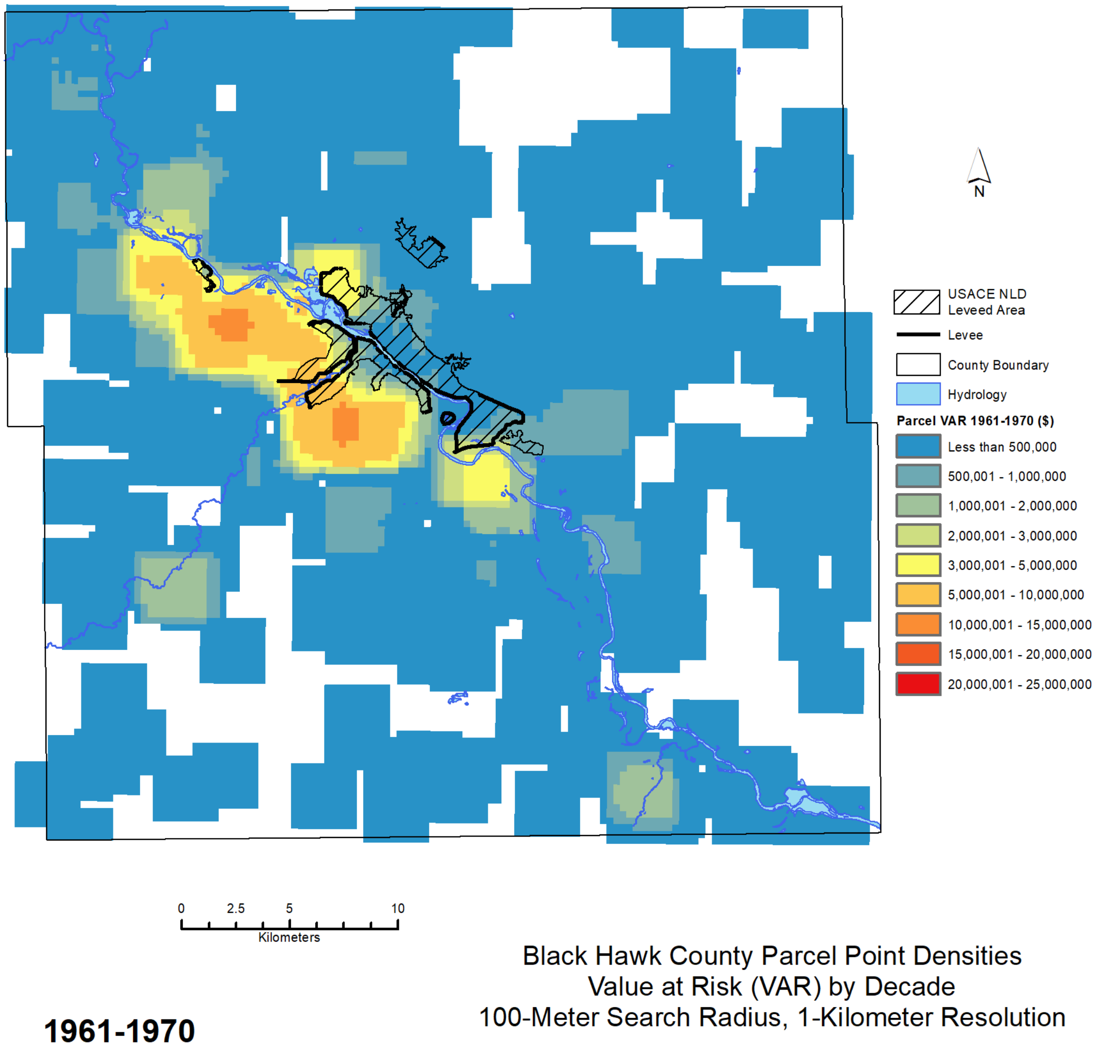


Figure C.52. Value at risk in Black Hawk County, Iowa, 1961-1970.

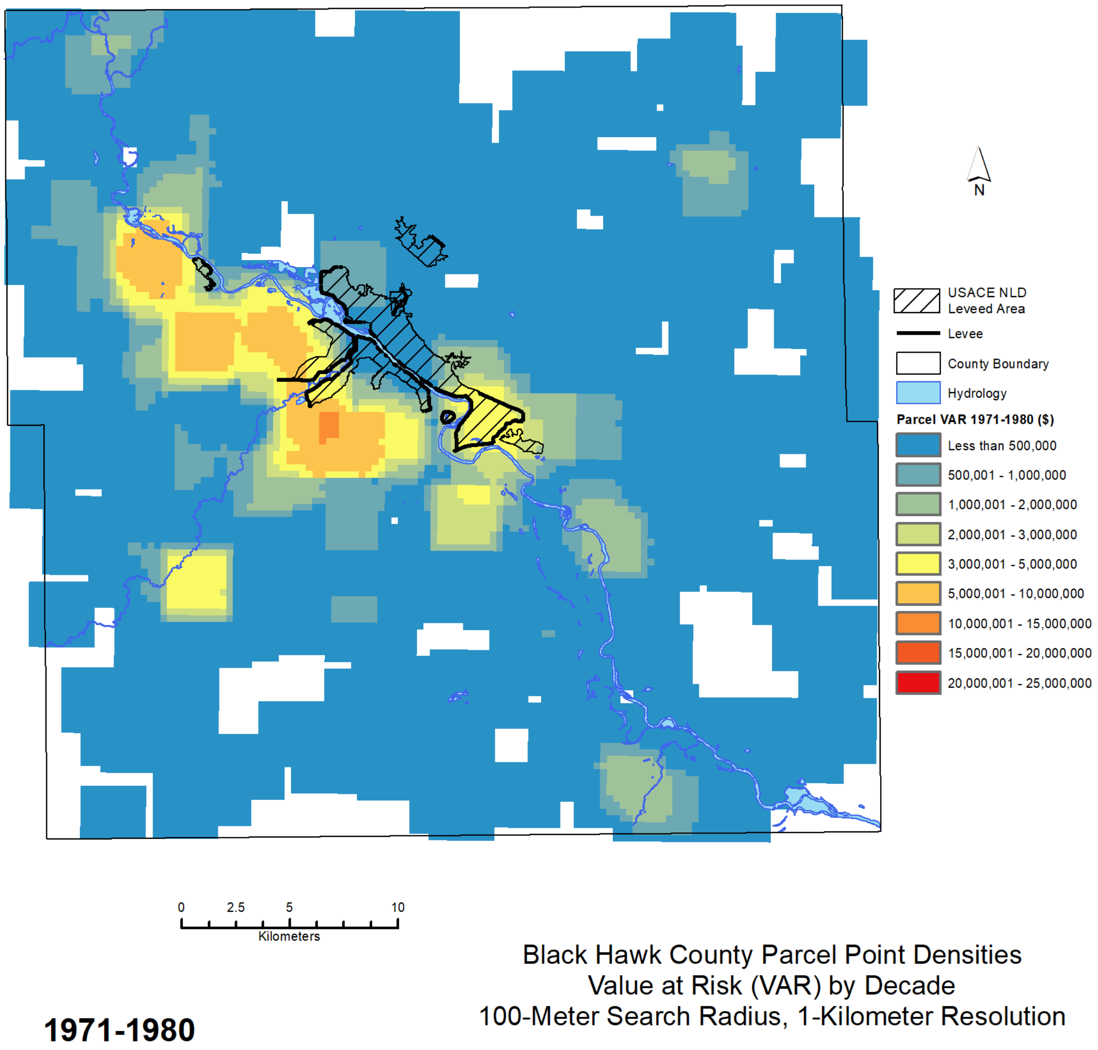


Figure C.53. Value at risk in Black Hawk County, Iowa, 1971-1980.

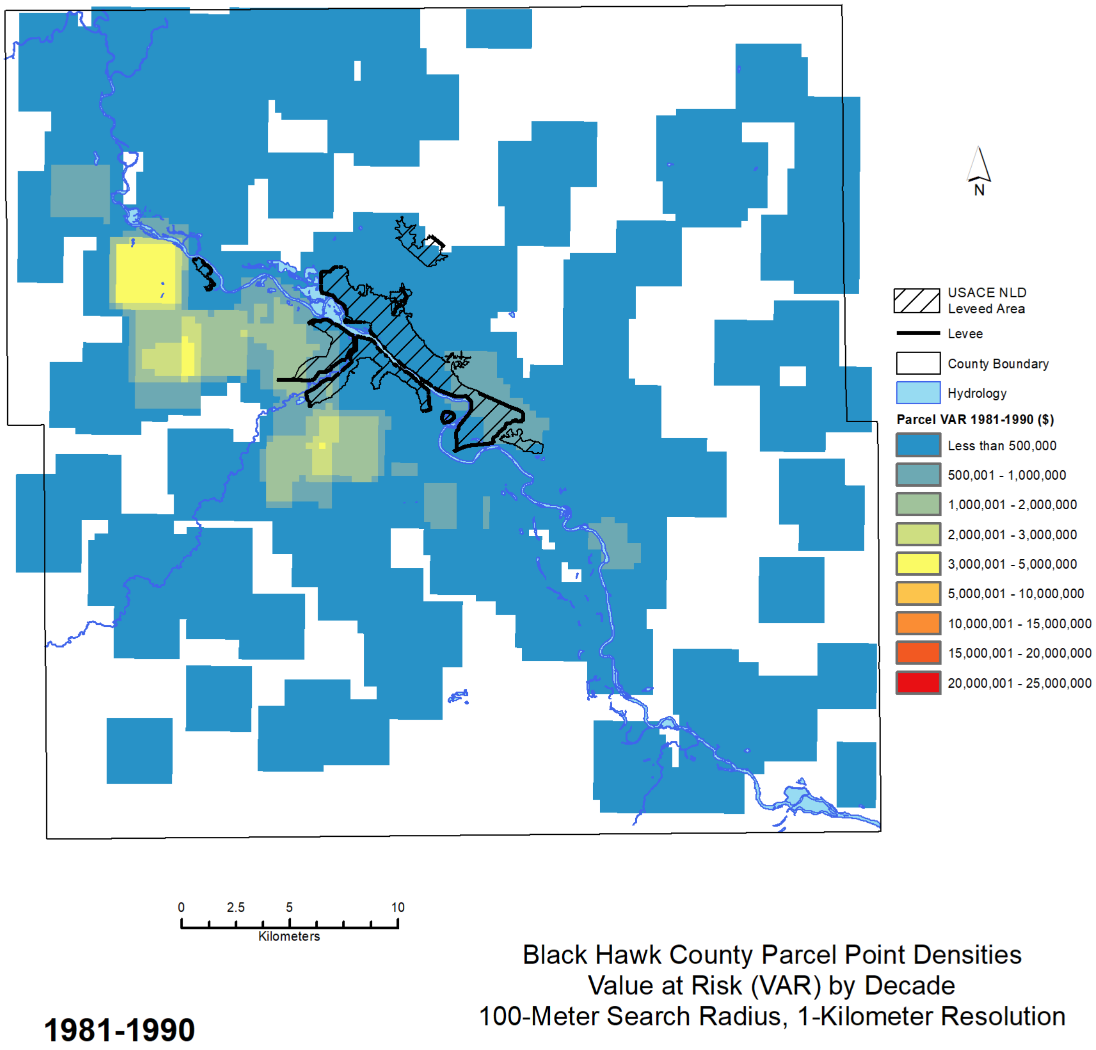


Figure C.54. Value at risk in Black Hawk County, Iowa, 1981-1990.

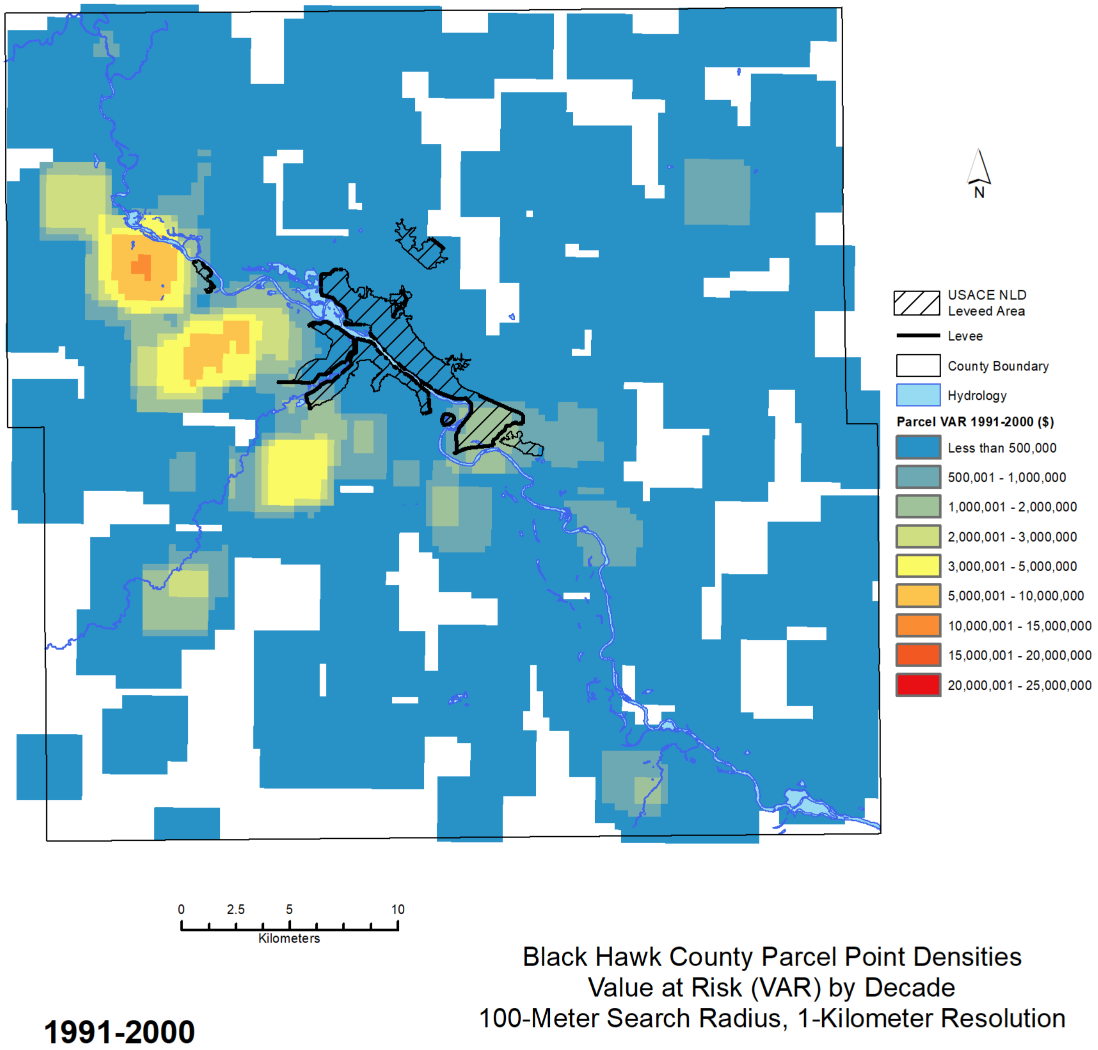


Figure C.55. Value at risk in Black Hawk County, Iowa, 1991-2000.

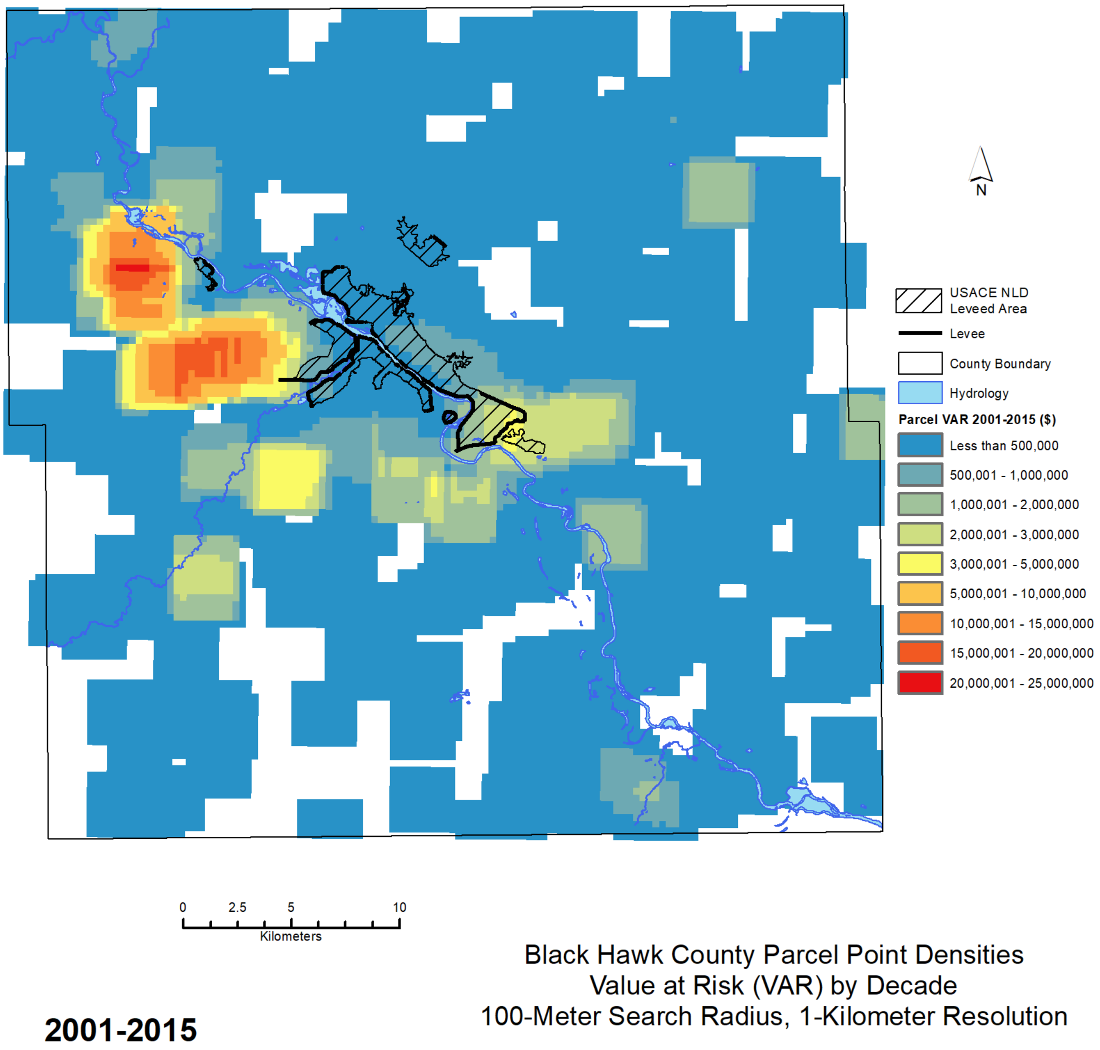


Figure C.56. Value at risk in Black Hawk County, Iowa, 2001-2015.

C.3.1 Des Moines County, Iowa Decadal Cumulative VAR Densities

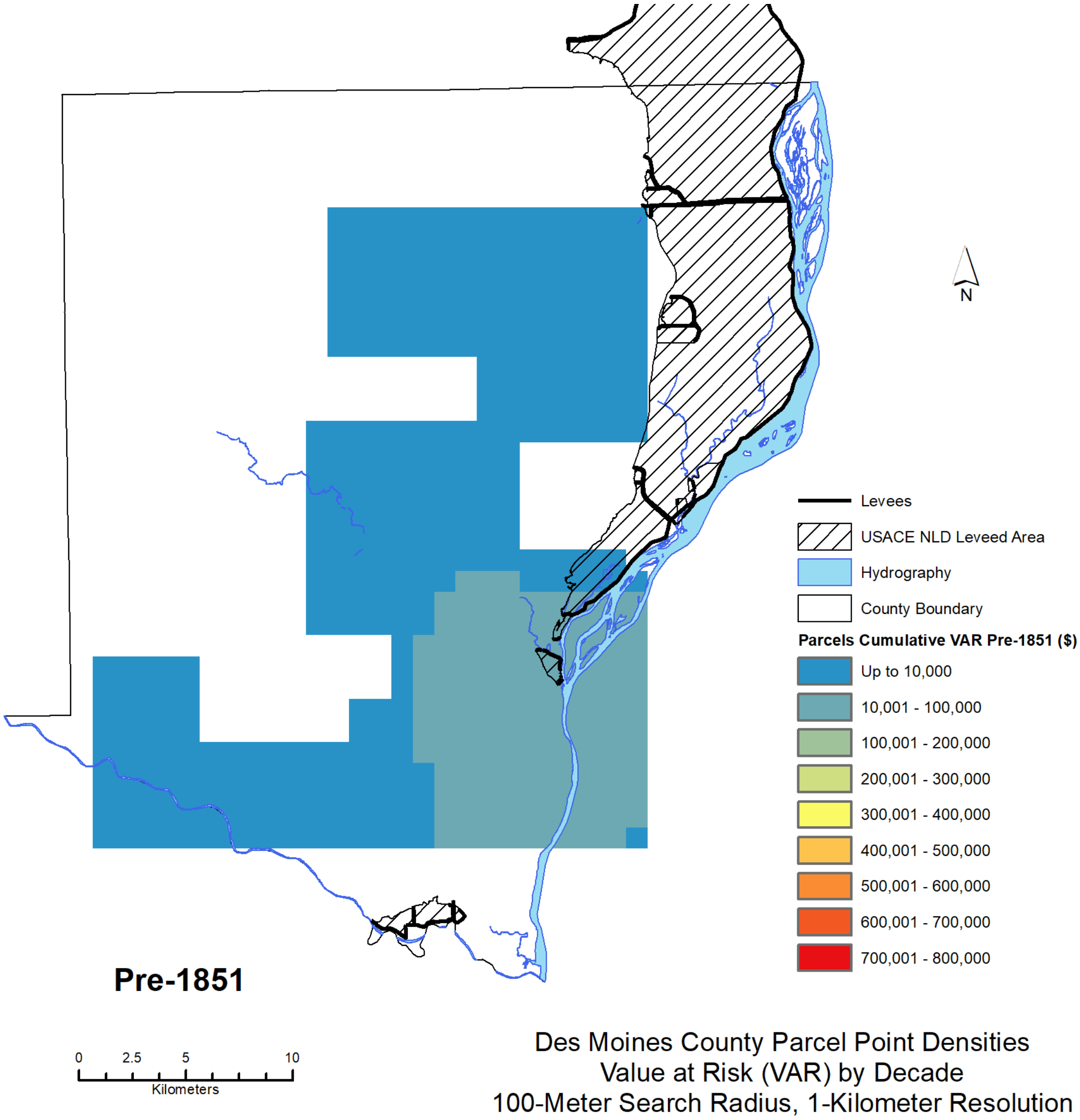


Figure C.57. Cumulative value at risk for Des Moines County, Iowa, Pre-1851.

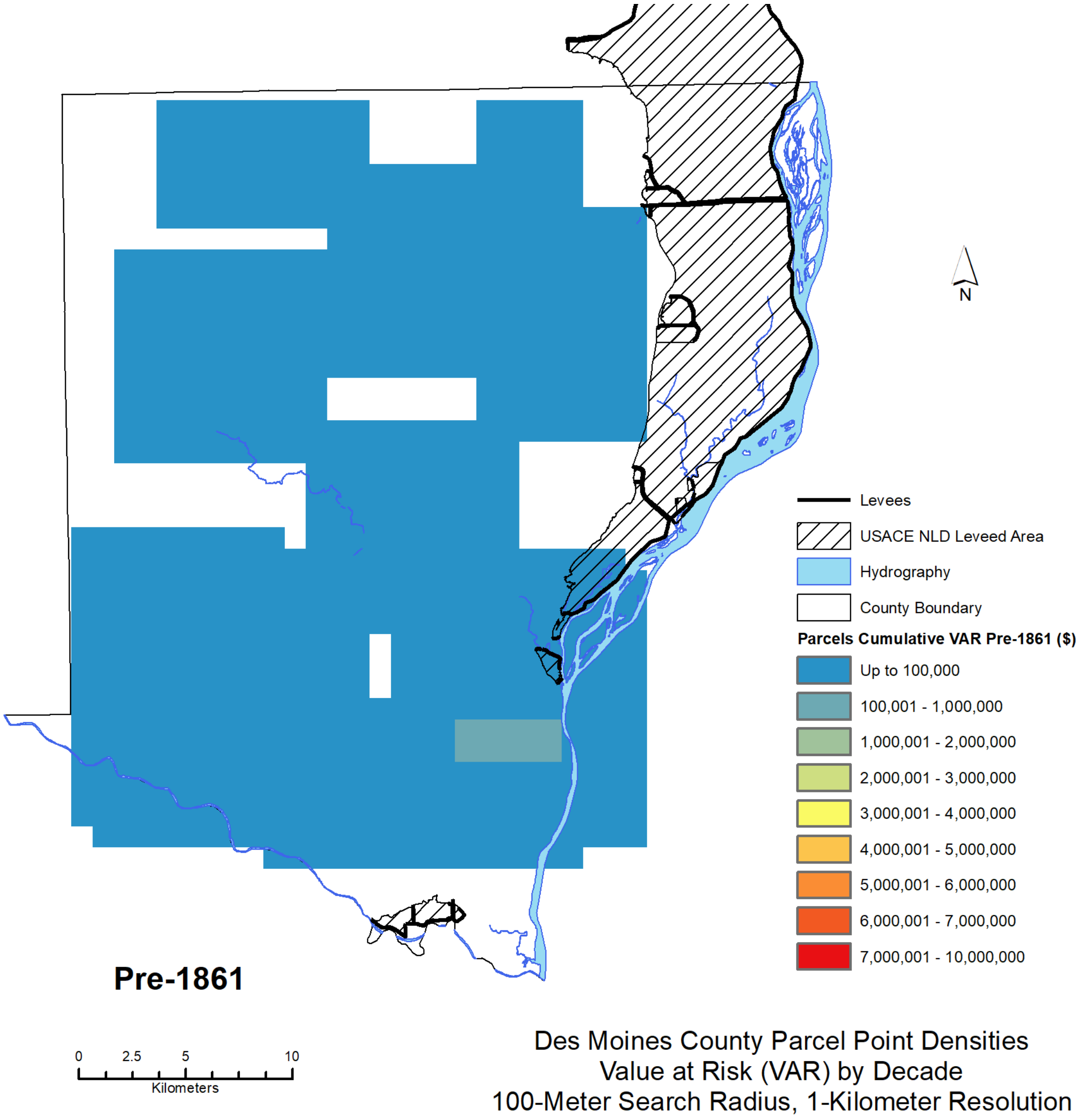


Figure C.58. Cumulative value at risk for Des Moines County, Iowa, 1851-1860.

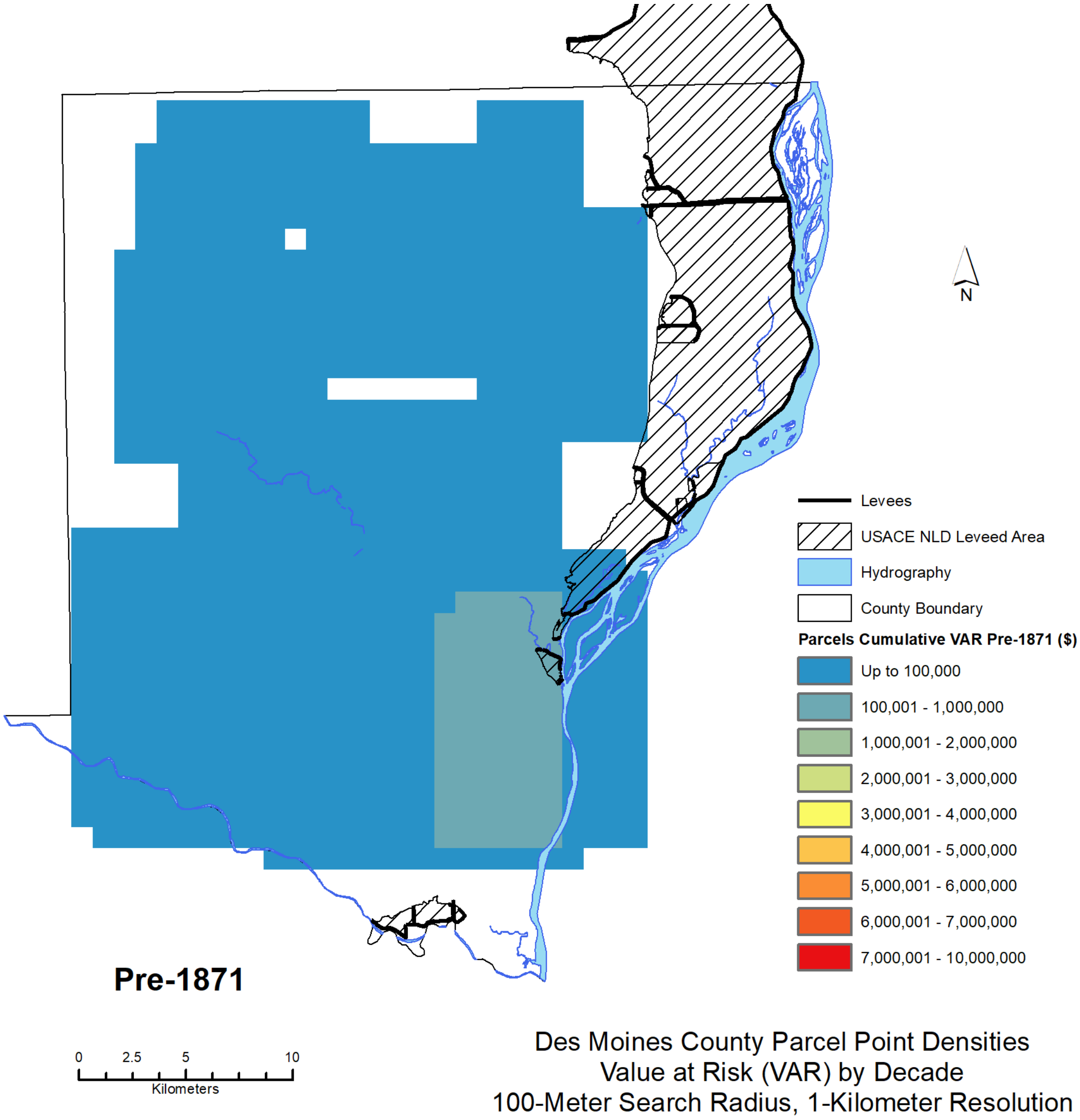


Figure C.59. Cumulative value at risk for Des Moines County, Iowa, 1851-1870.

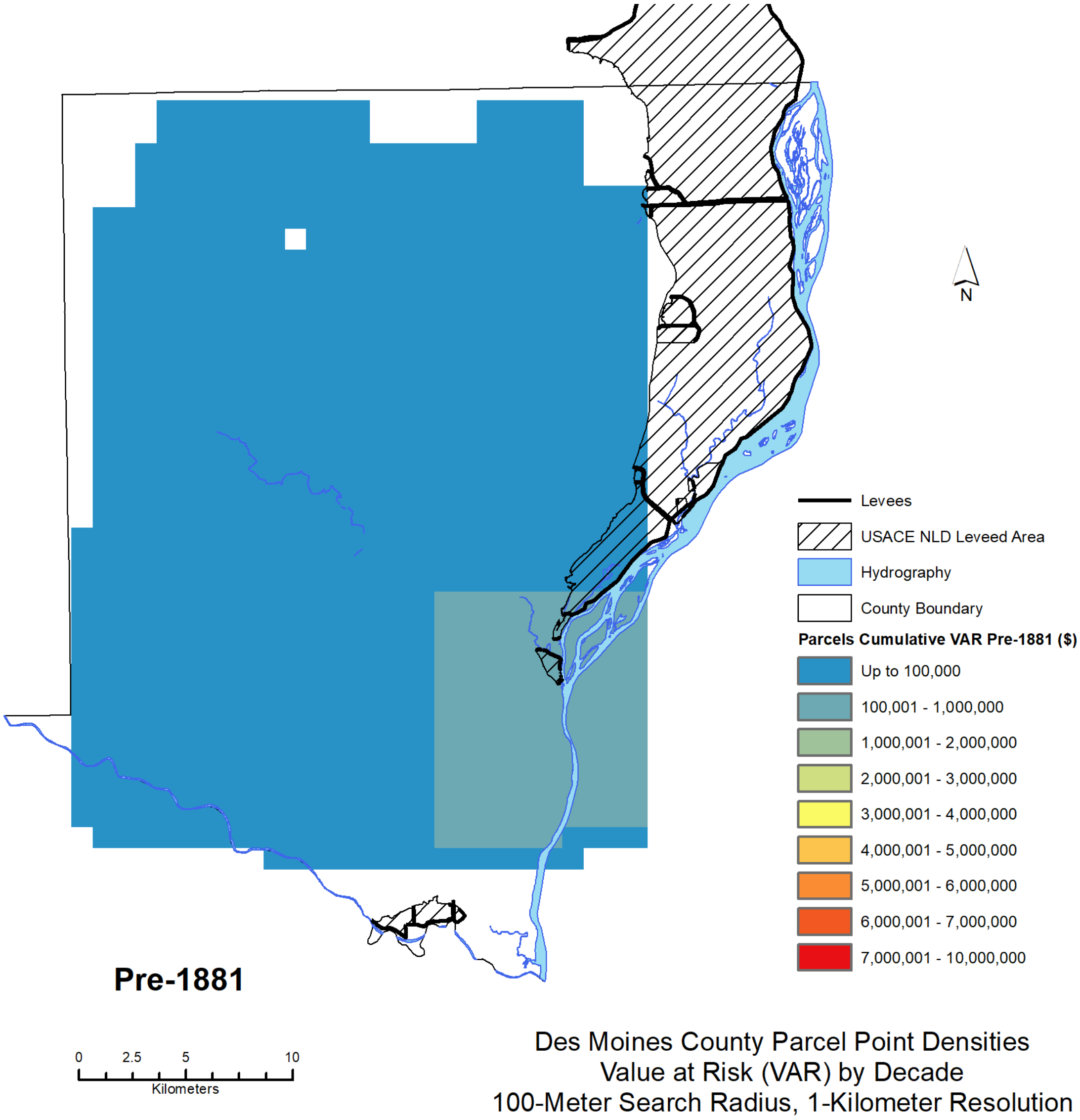


Figure C.60. Cumulative value at risk for Des Moines County, Iowa, 1851-1880.

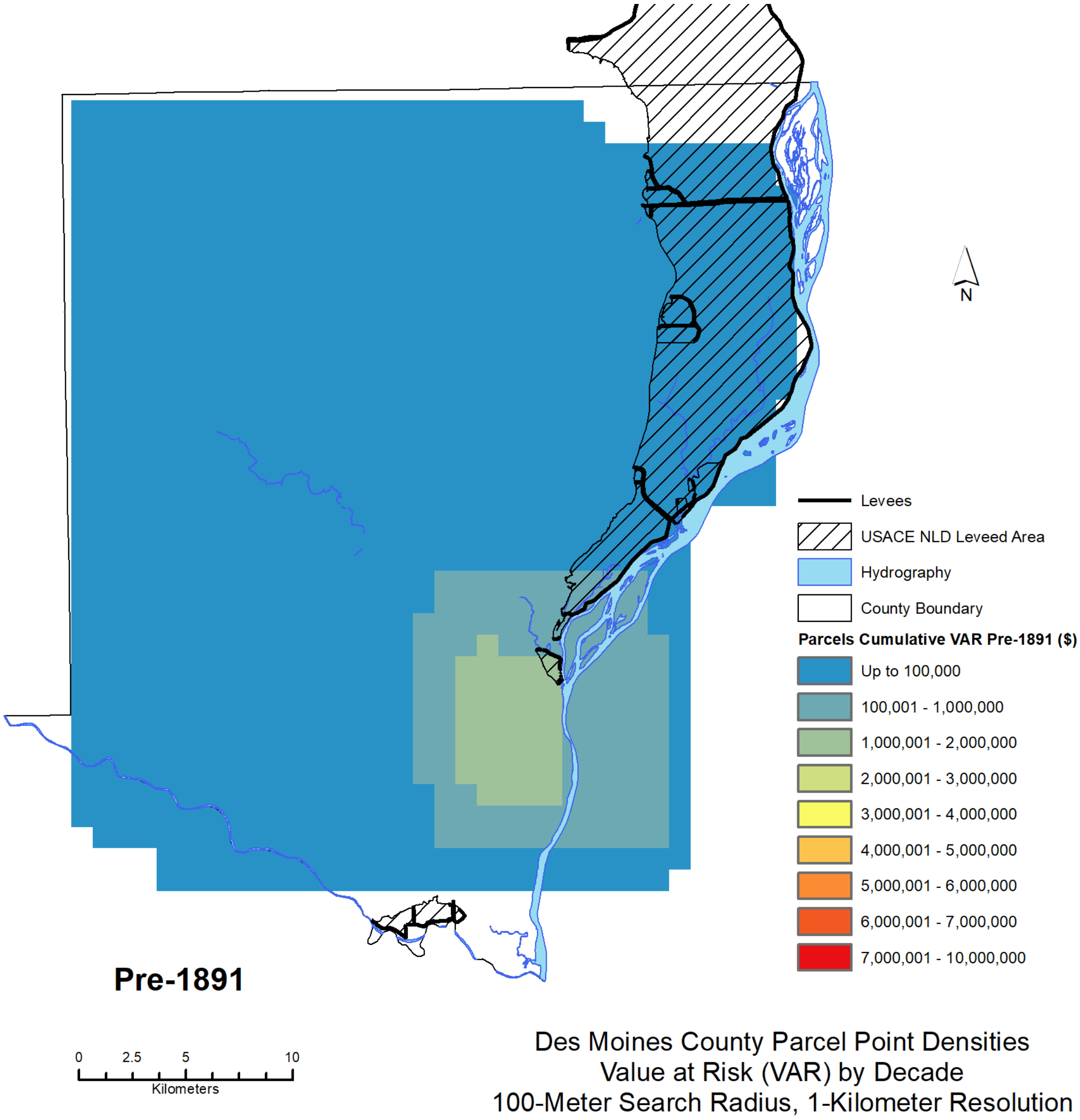


Figure C.61. Cumulative value at risk for Des Moines County, Iowa, 1851-1890.

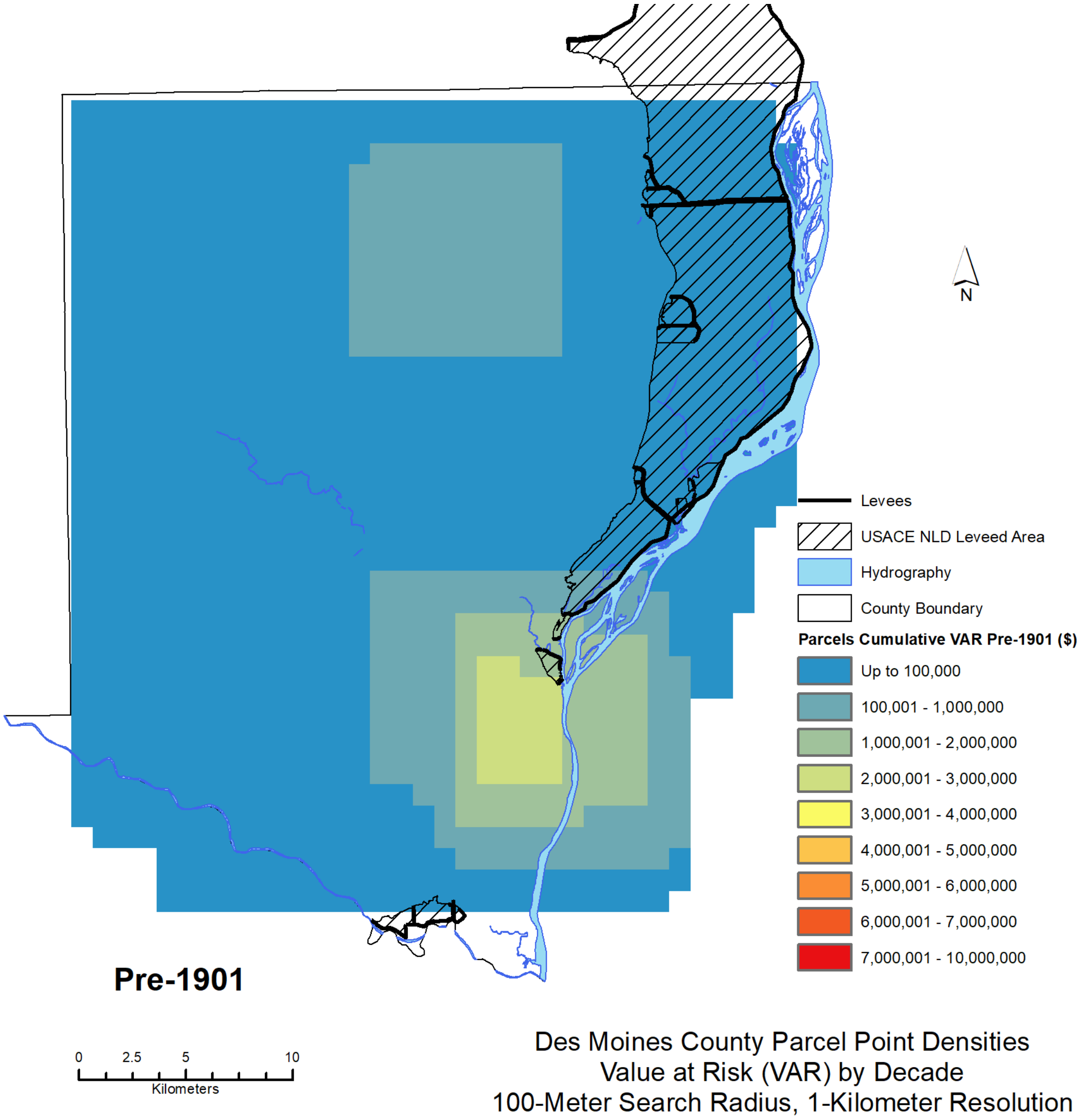


Figure C.62. Cumulative value at risk for Des Moines County, Iowa, 1851-1900.

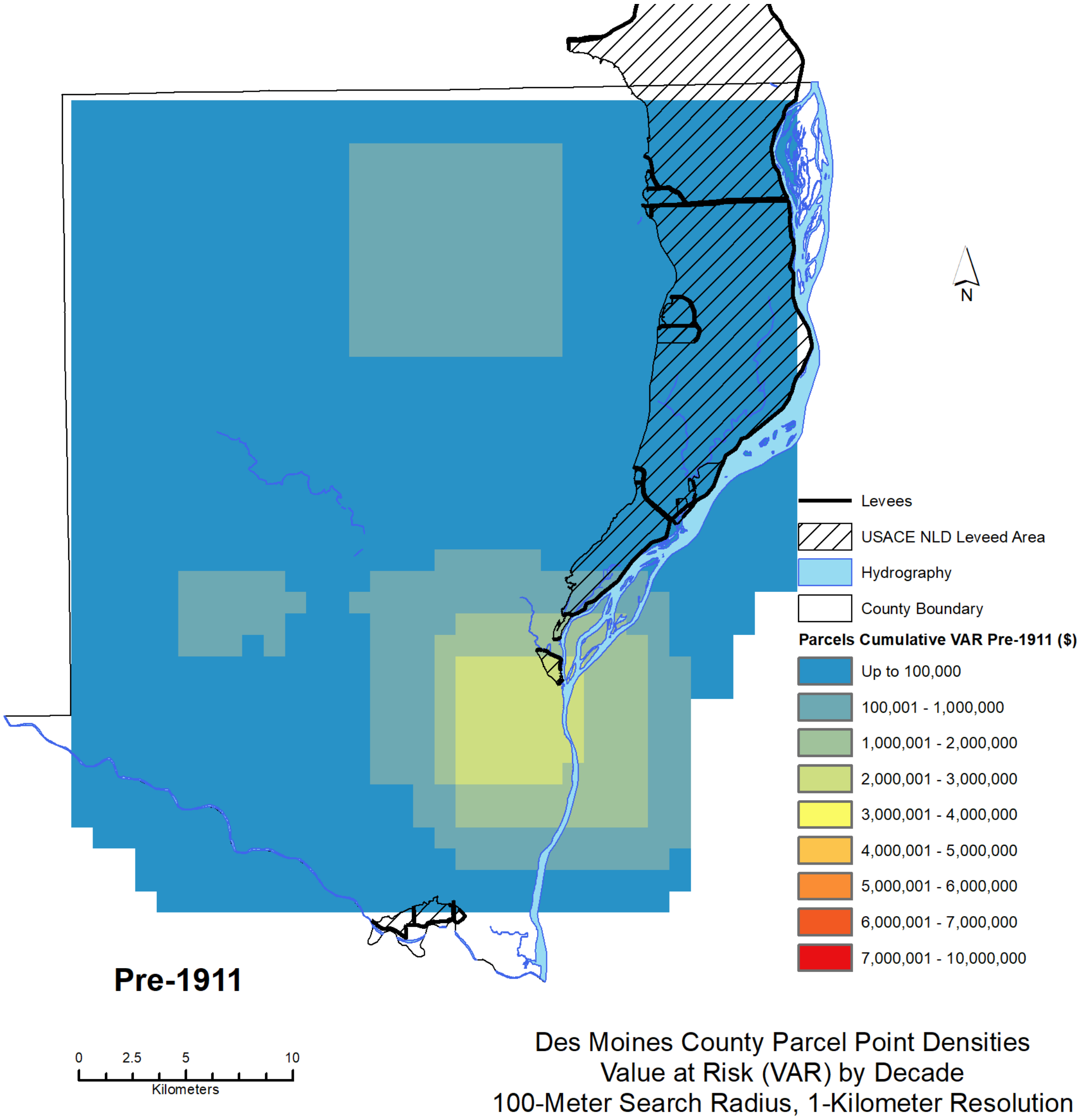


Figure C.63. Cumulative value at risk for Des Moines County, Iowa, 1851-1910.

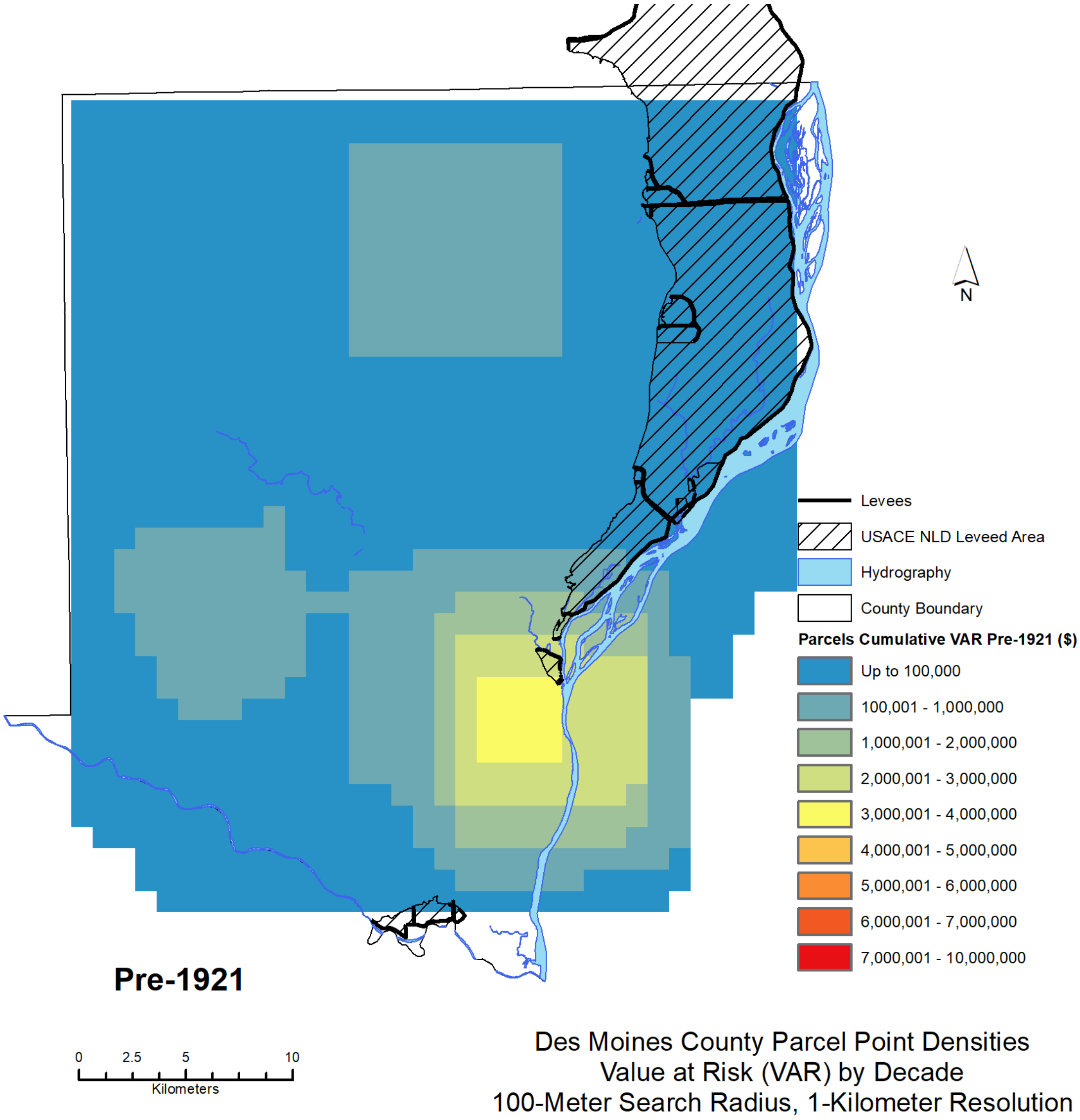


Figure C.64. Cumulative value at risk for Des Moines County, Iowa, 1851-1920.

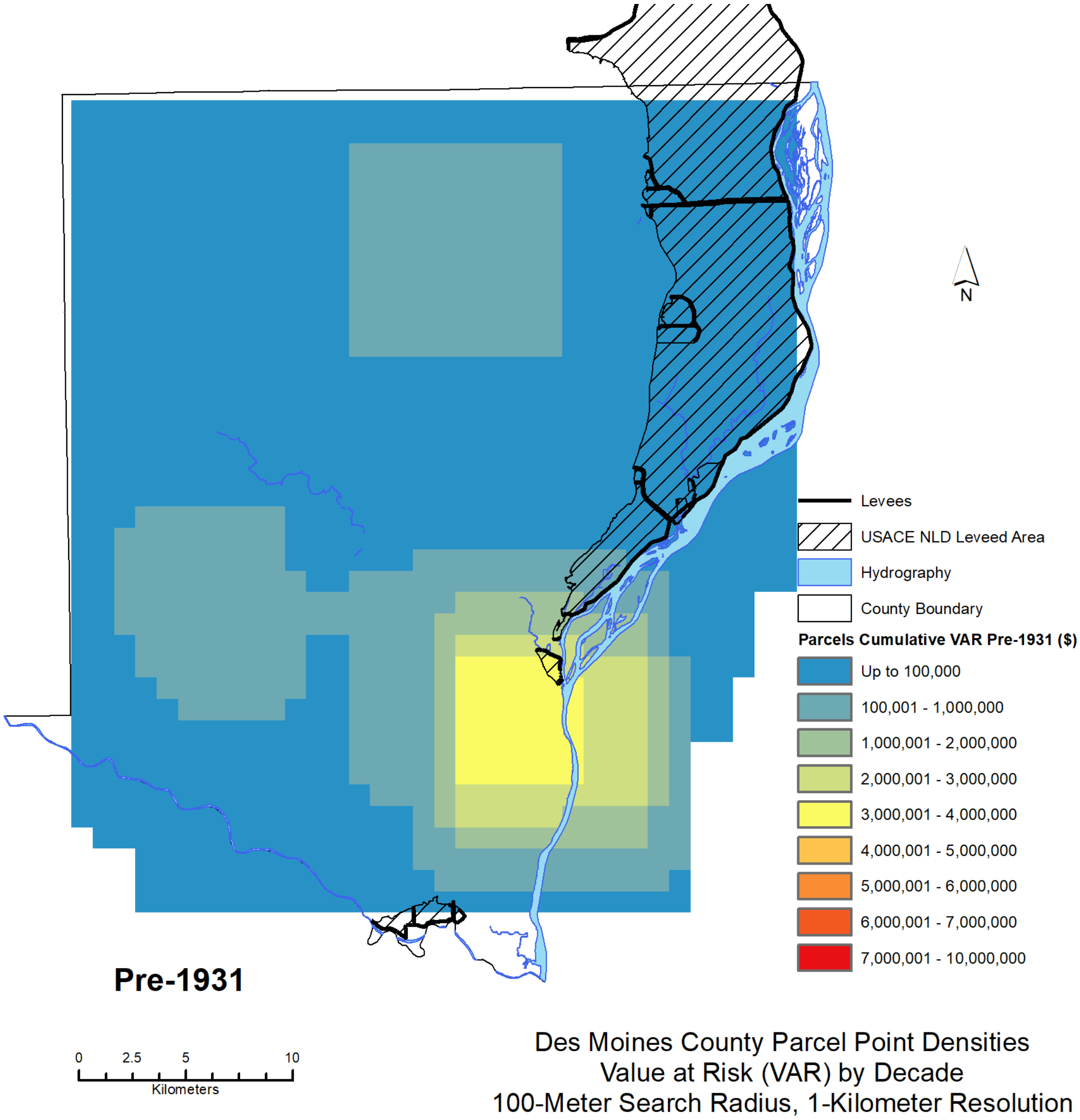


Figure C.65. Cumulative value at risk for Des Moines County, Iowa, 1851-1930.

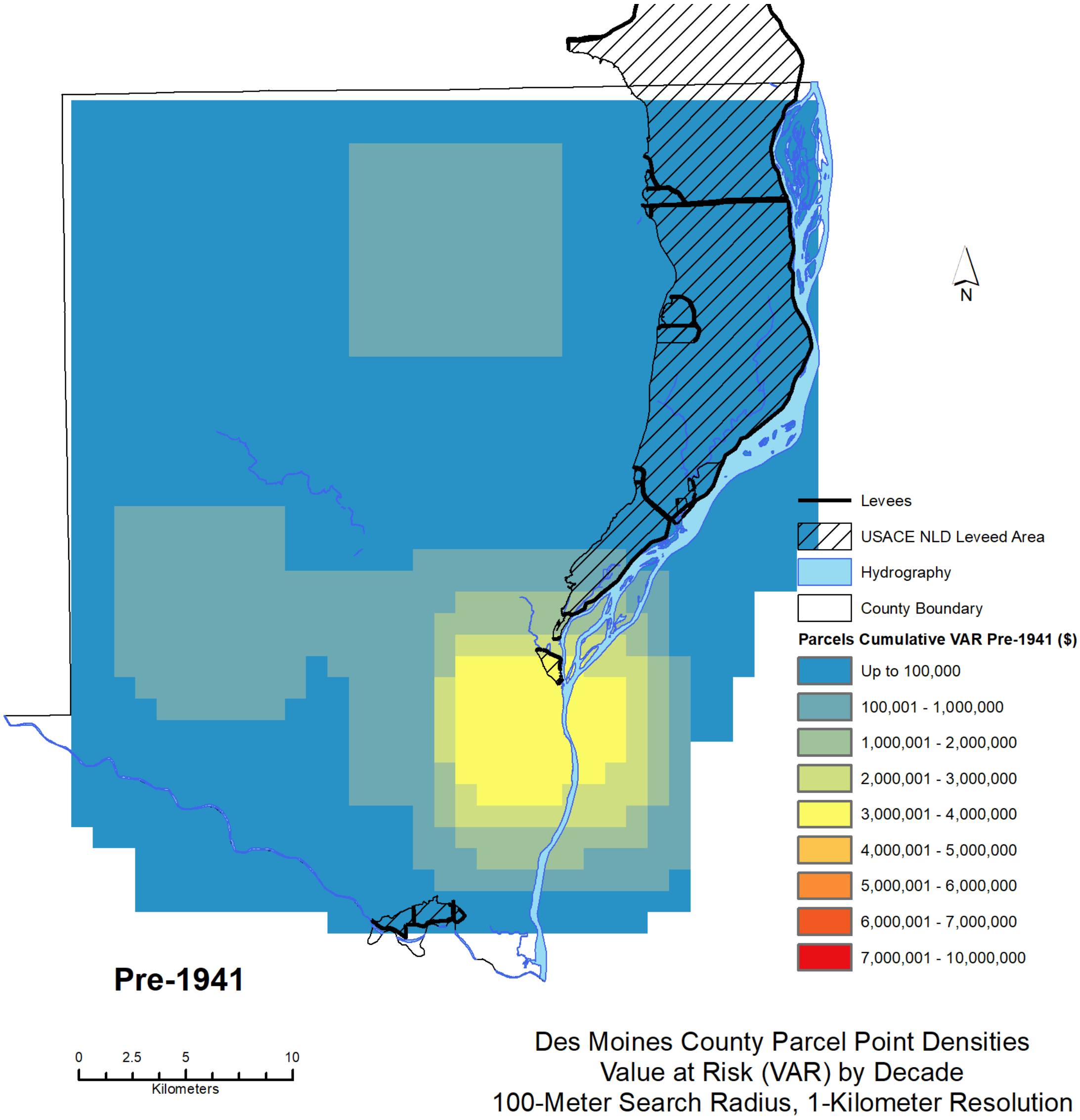


Figure C.66. Cumulative value at risk for Des Moines County, Iowa, 1851-1940.

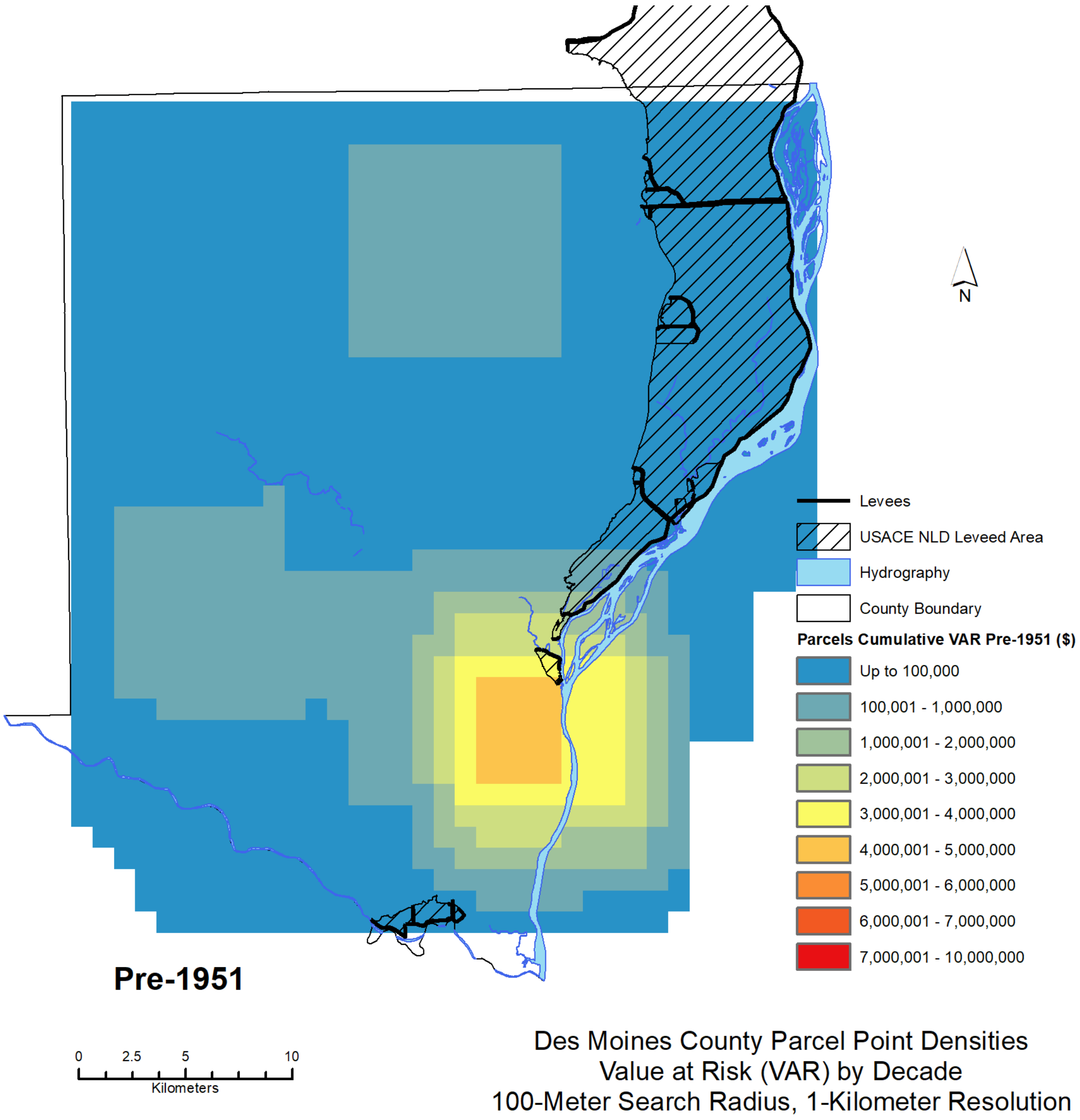


Figure C.67. Cumulative value at risk for Des Moines County, Iowa, 1851-1950.

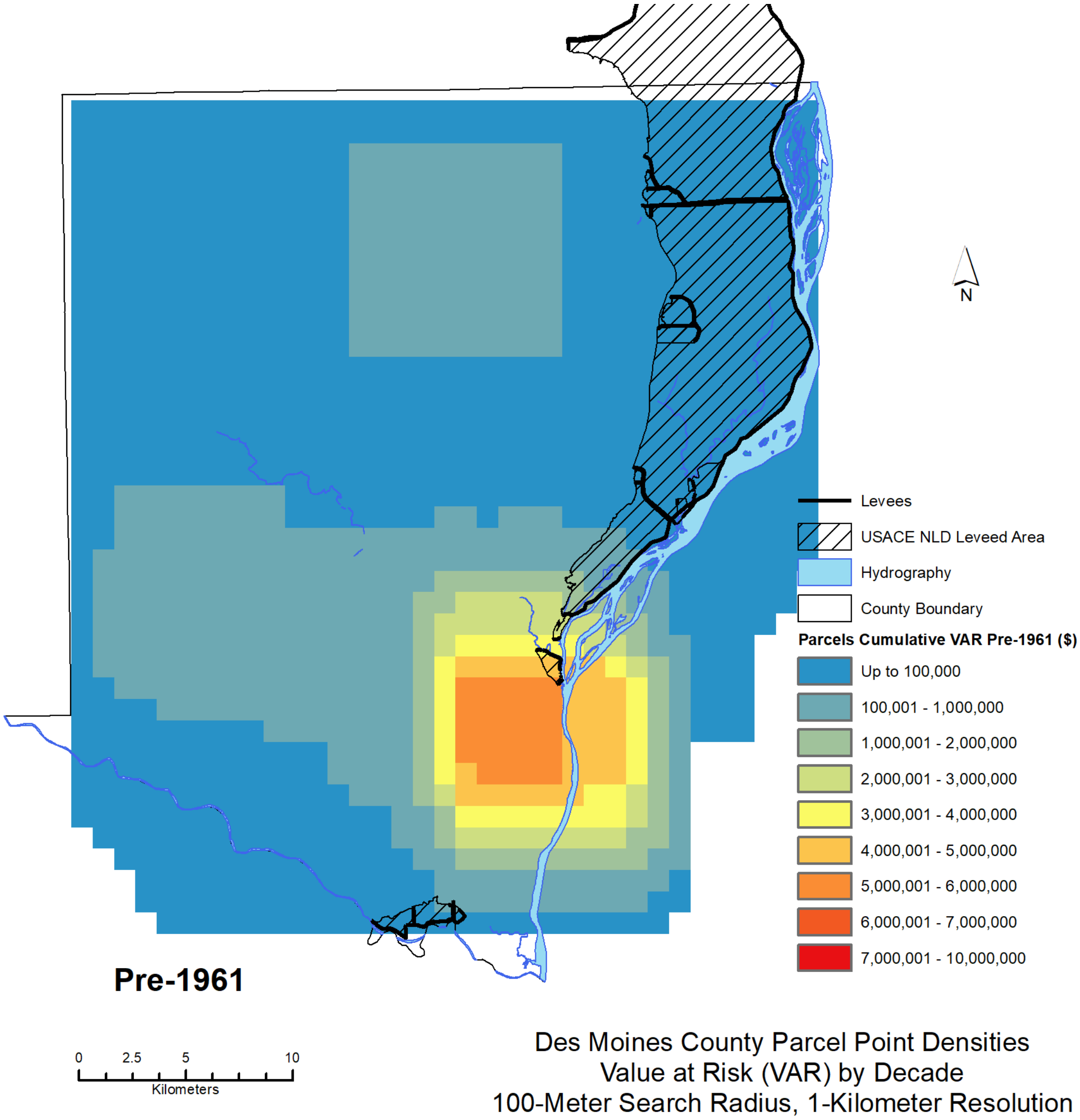


Figure C.68. Cumulative value at risk for Des Moines County, Iowa, 1851-1960.

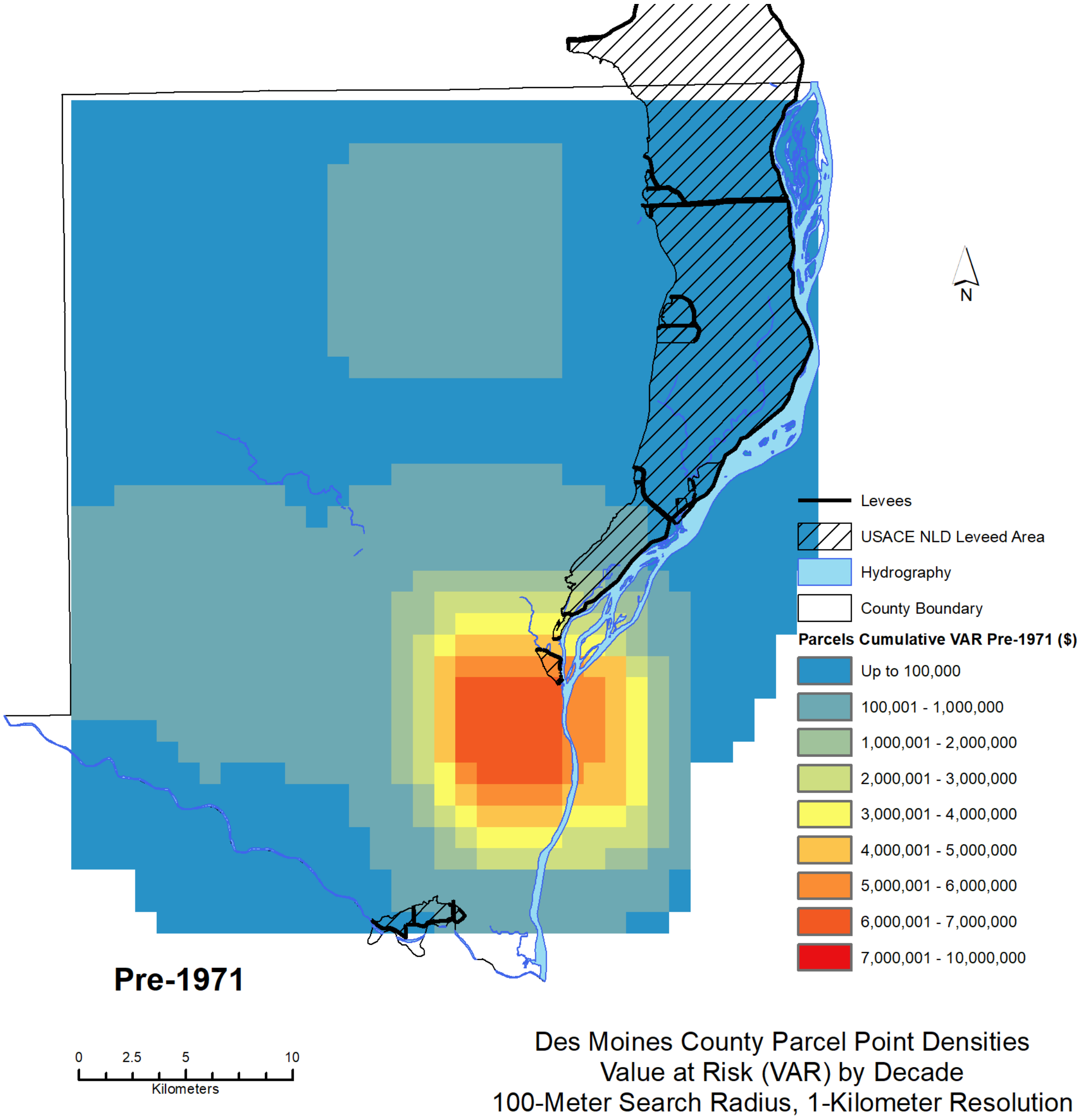


Figure C.69. Cumulative value at risk for Des Moines County, Iowa, 1851-1970.

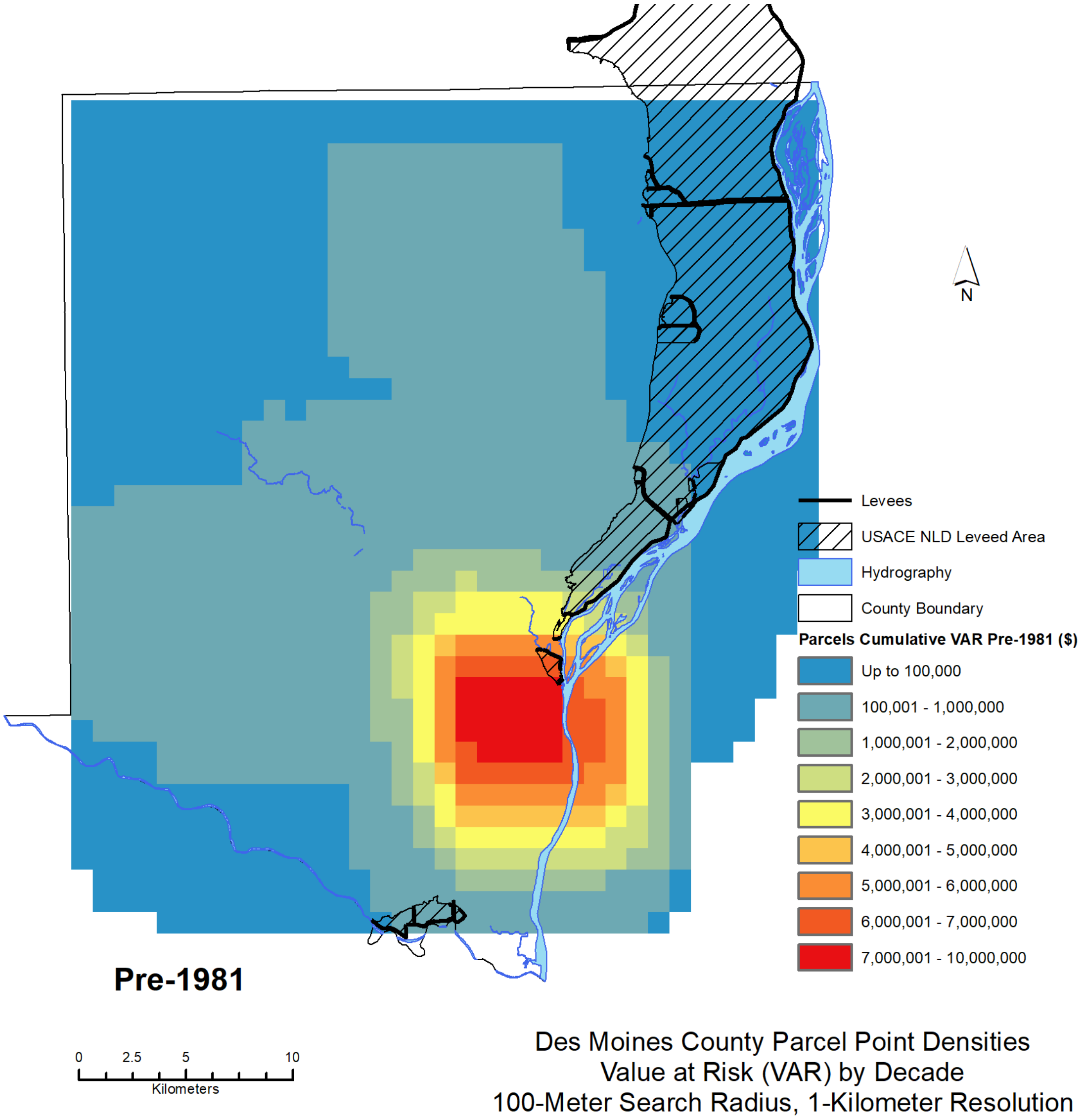


Figure C.70. Cumulative value at risk for Des Moines County, Iowa, 1851-1980.

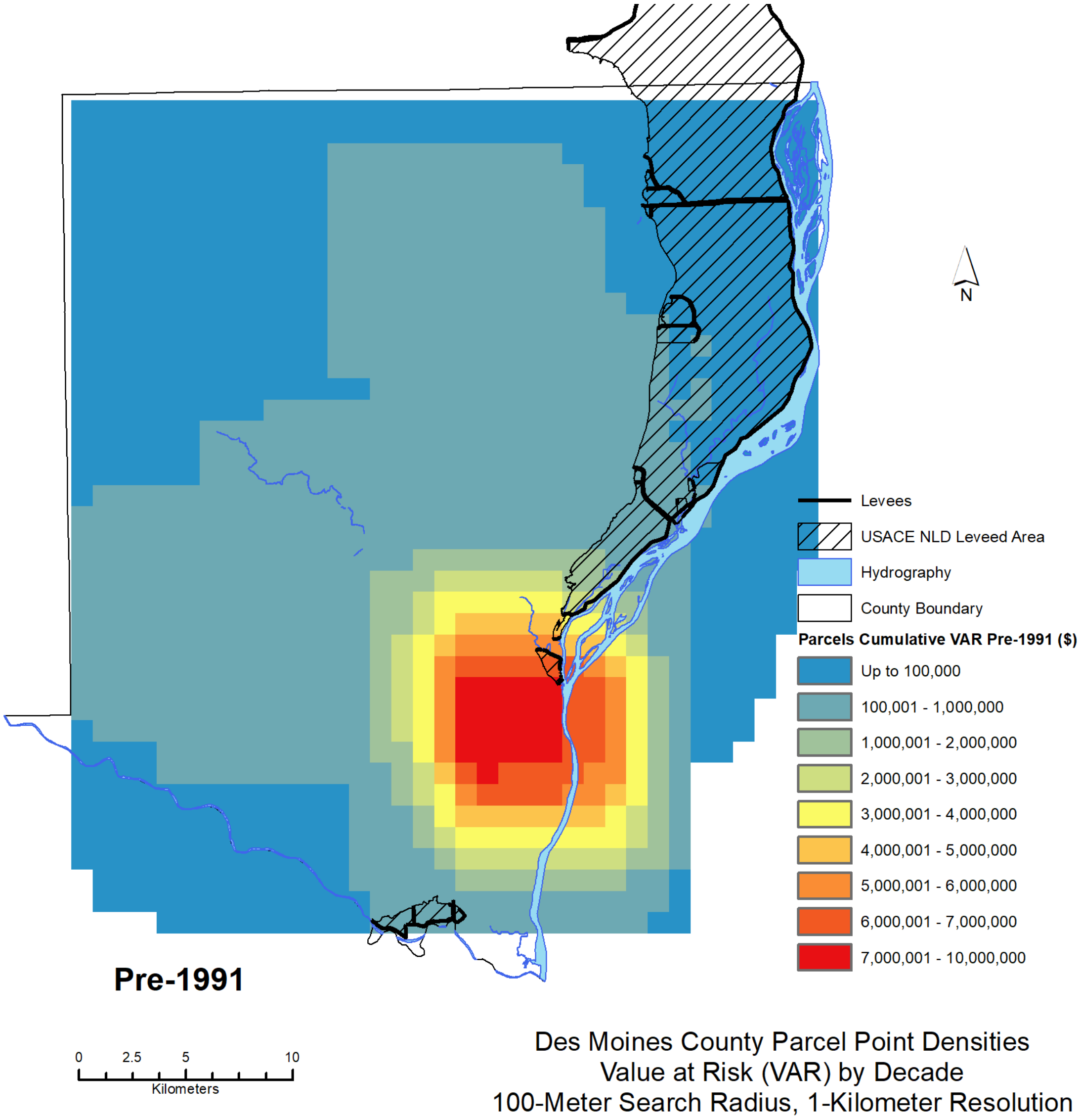


Figure C.71. Cumulative value at risk for Des Moines County, Iowa, 1851-1990.

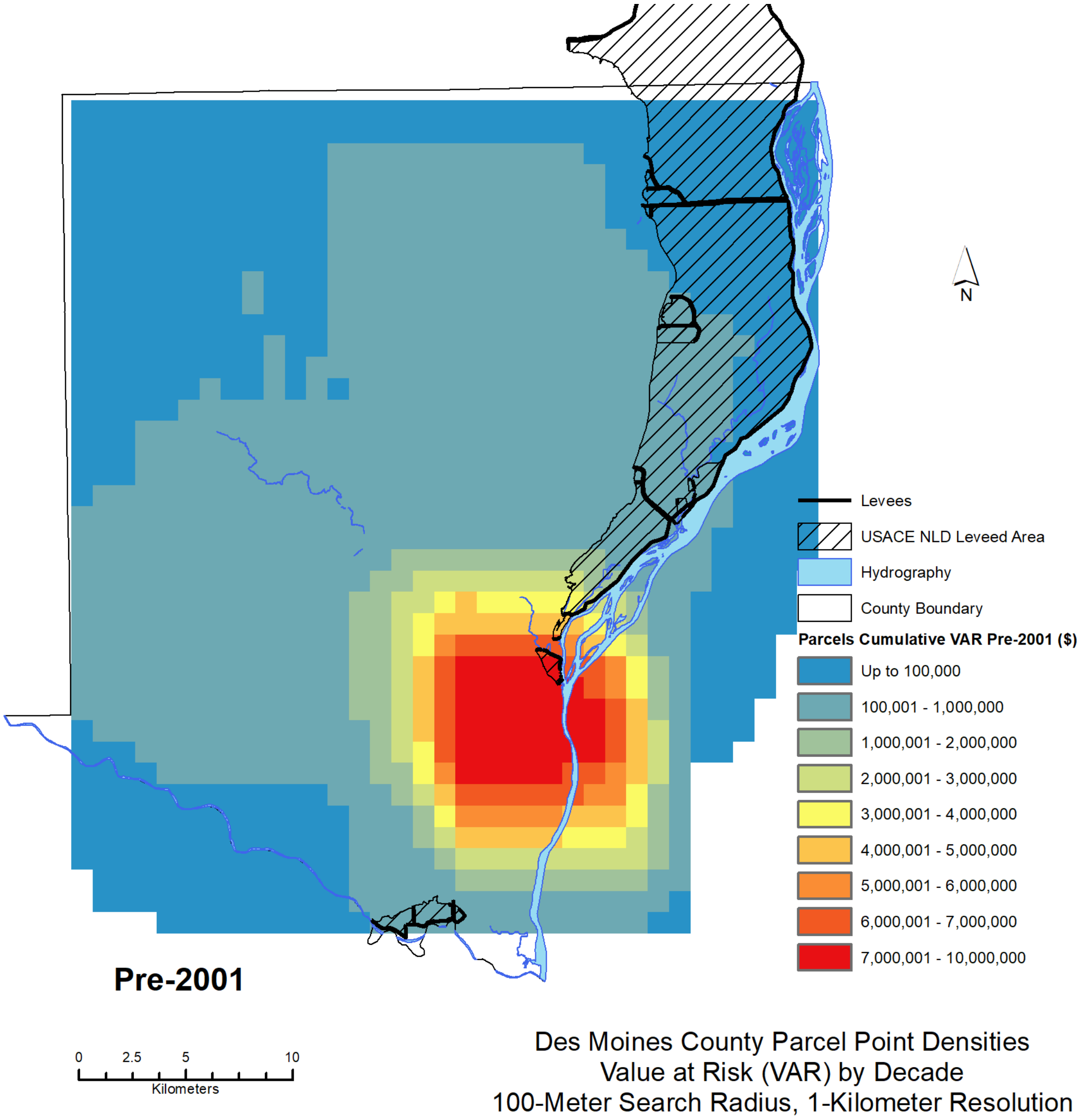


Figure C.72. Cumulative value at risk for Des Moines County, Iowa, 1851-2000.

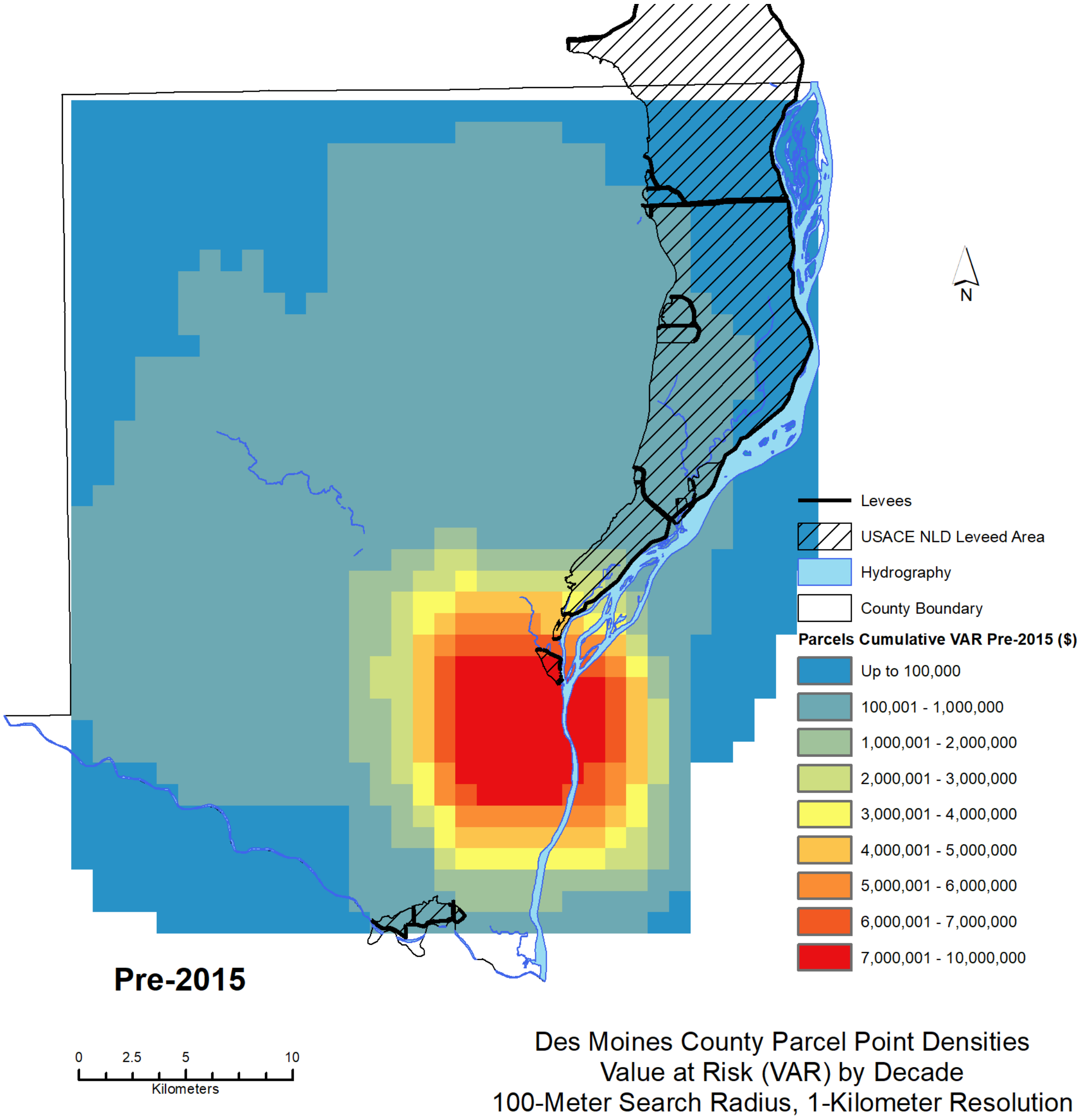


Figure C.73. Cumulative value at risk for Des Moines County, Iowa, 1851-2015.

C.3.2 Des Moines County, Iowa Decadal VAR Densities

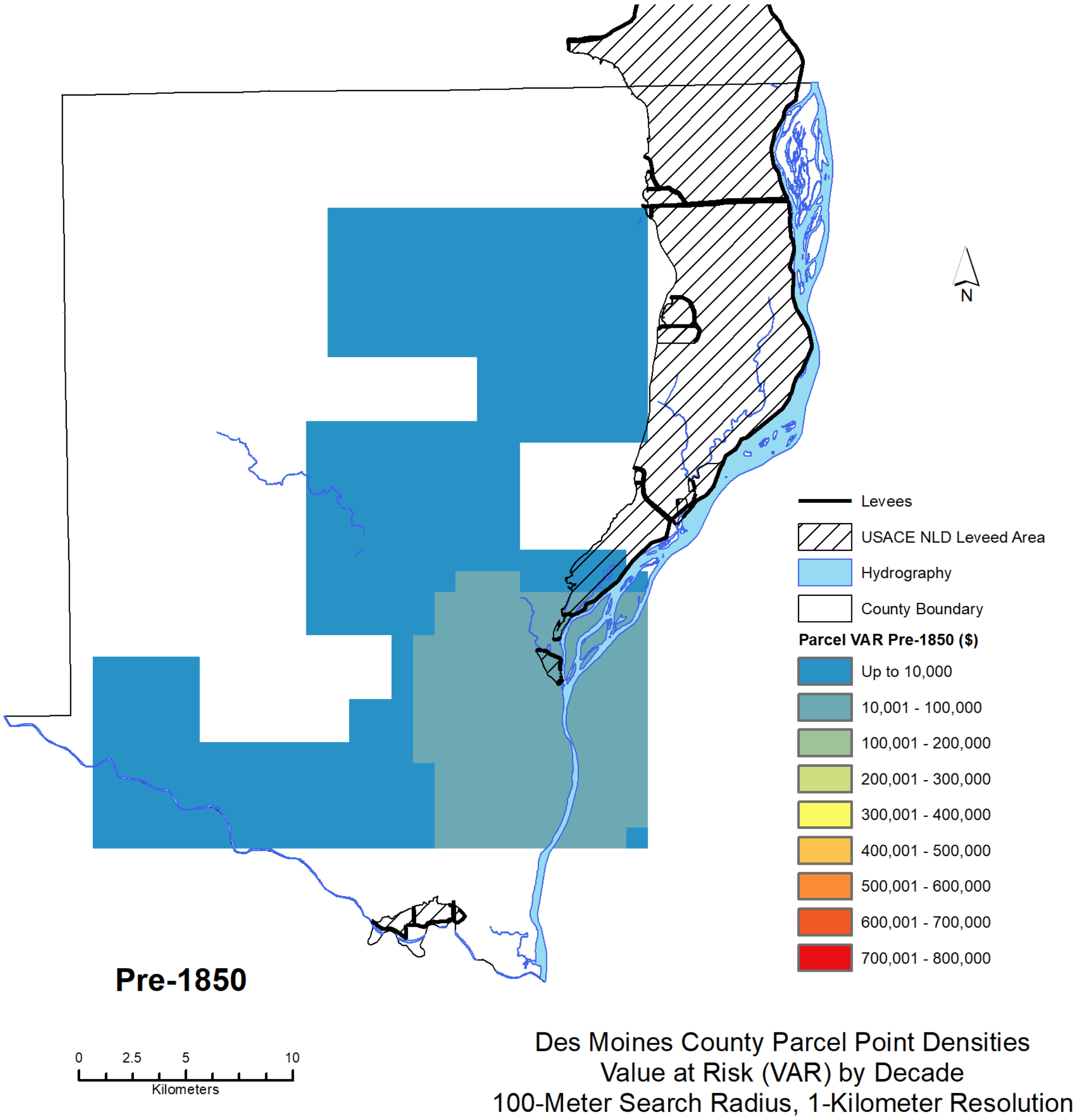


Figure C.74. Value at risk in Des Moines County, Iowa, Pre-1850.

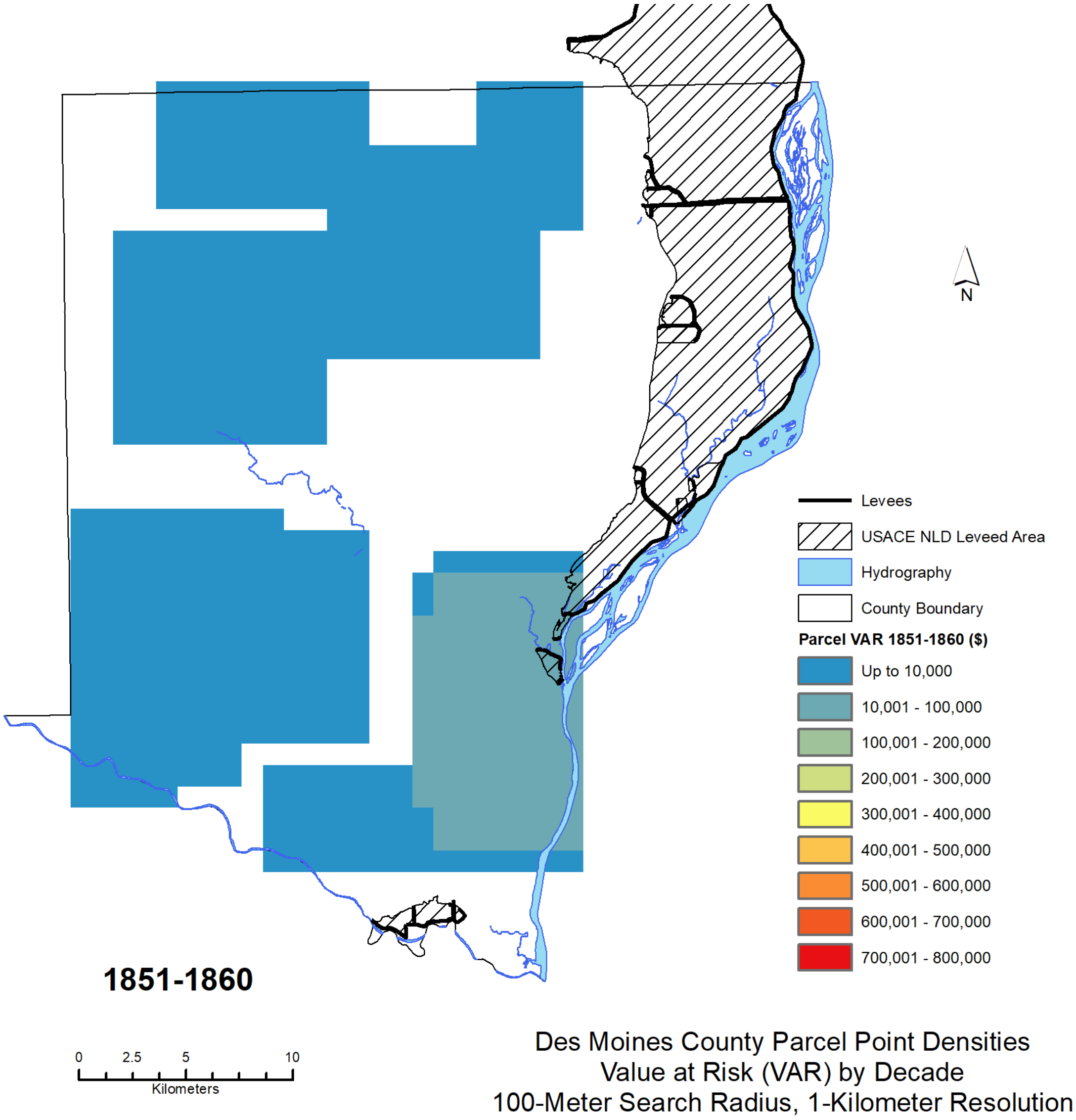


Figure C.75. Value at risk in Black Hawk County, Iowa, 1851-1860.

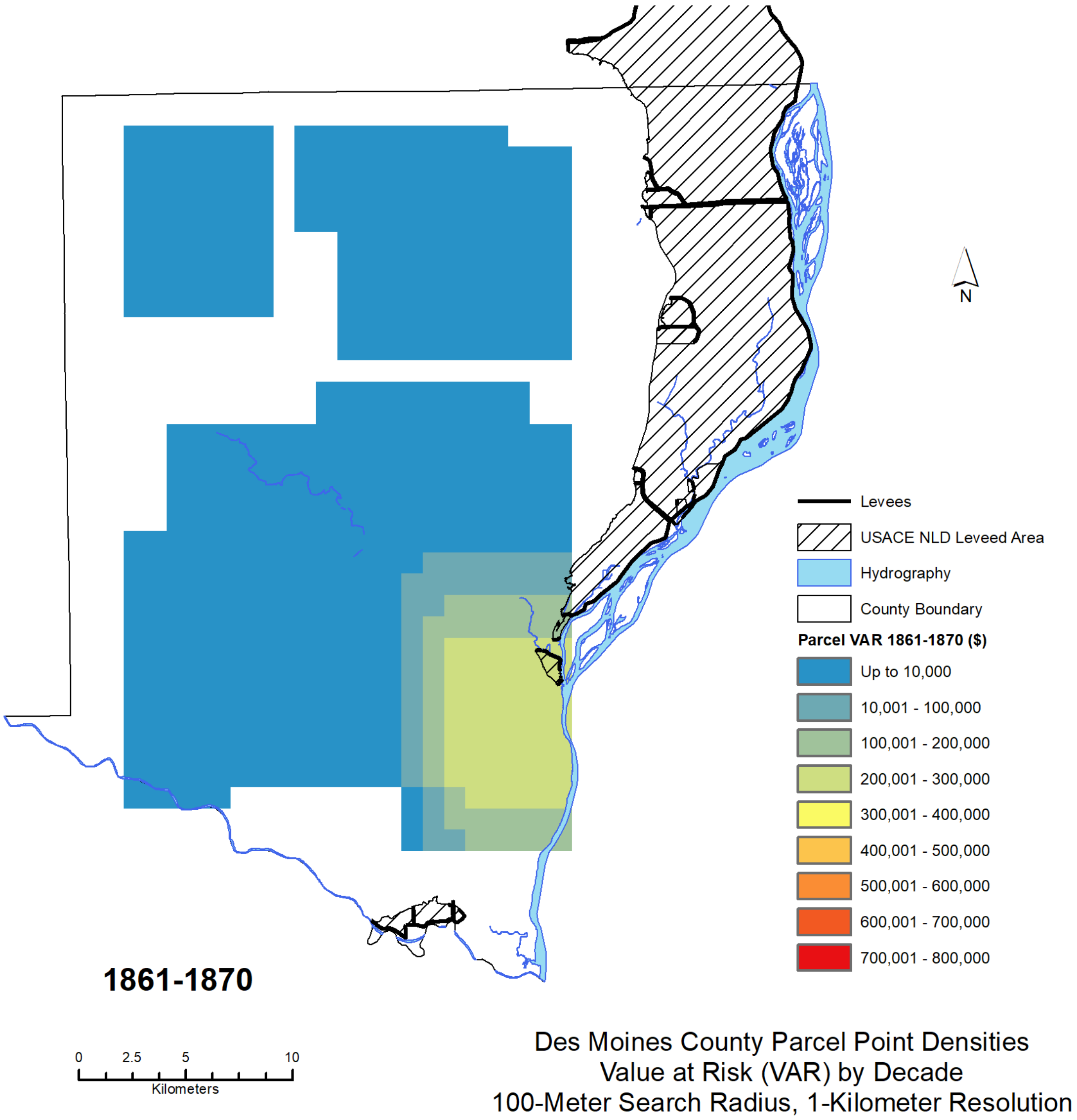


Figure C.76. Value at risk in Black Hawk County, Iowa, 1861-1870.

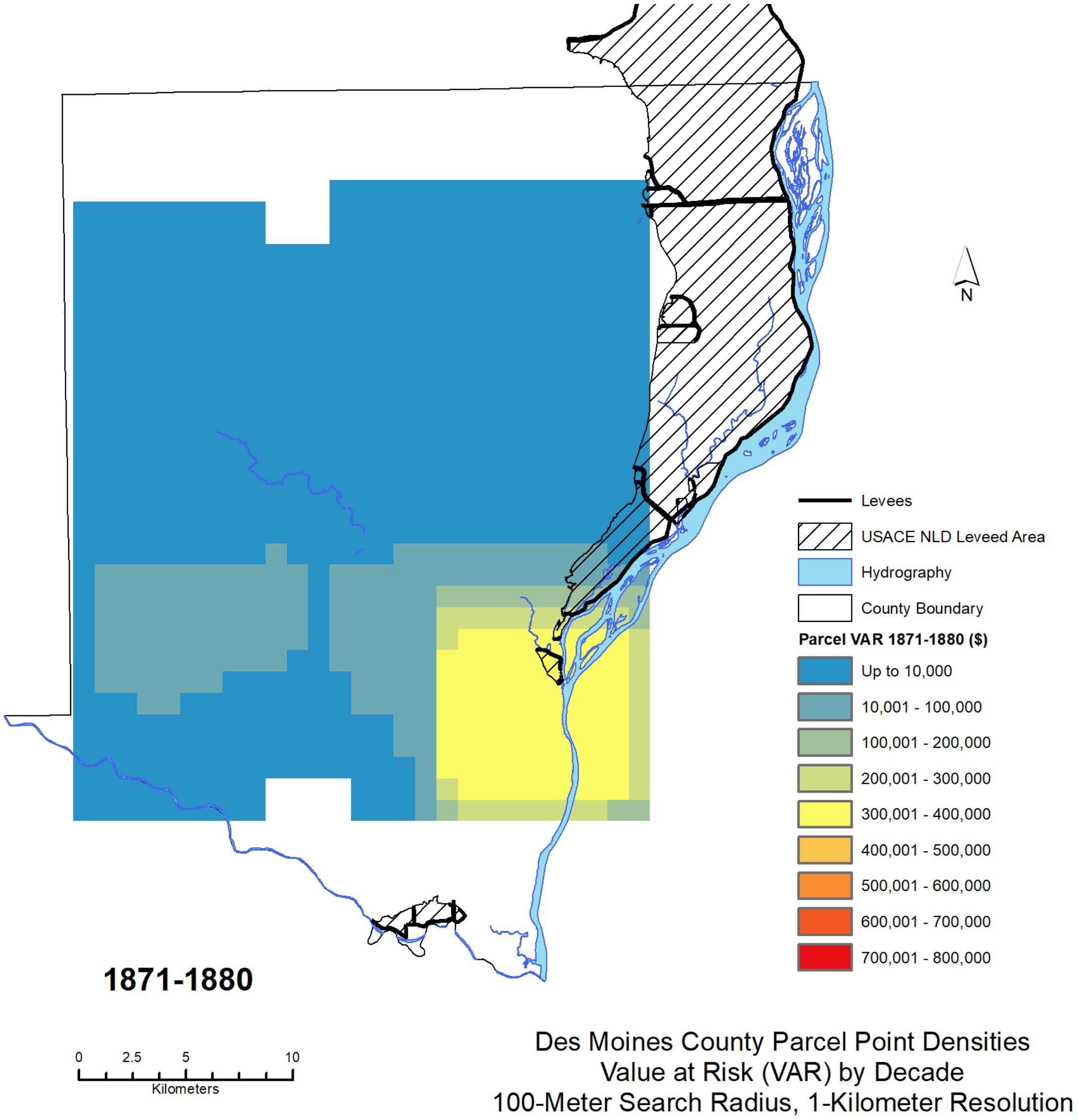


Figure C.77. Value at risk in Black Hawk County, Iowa, 1871-1880.

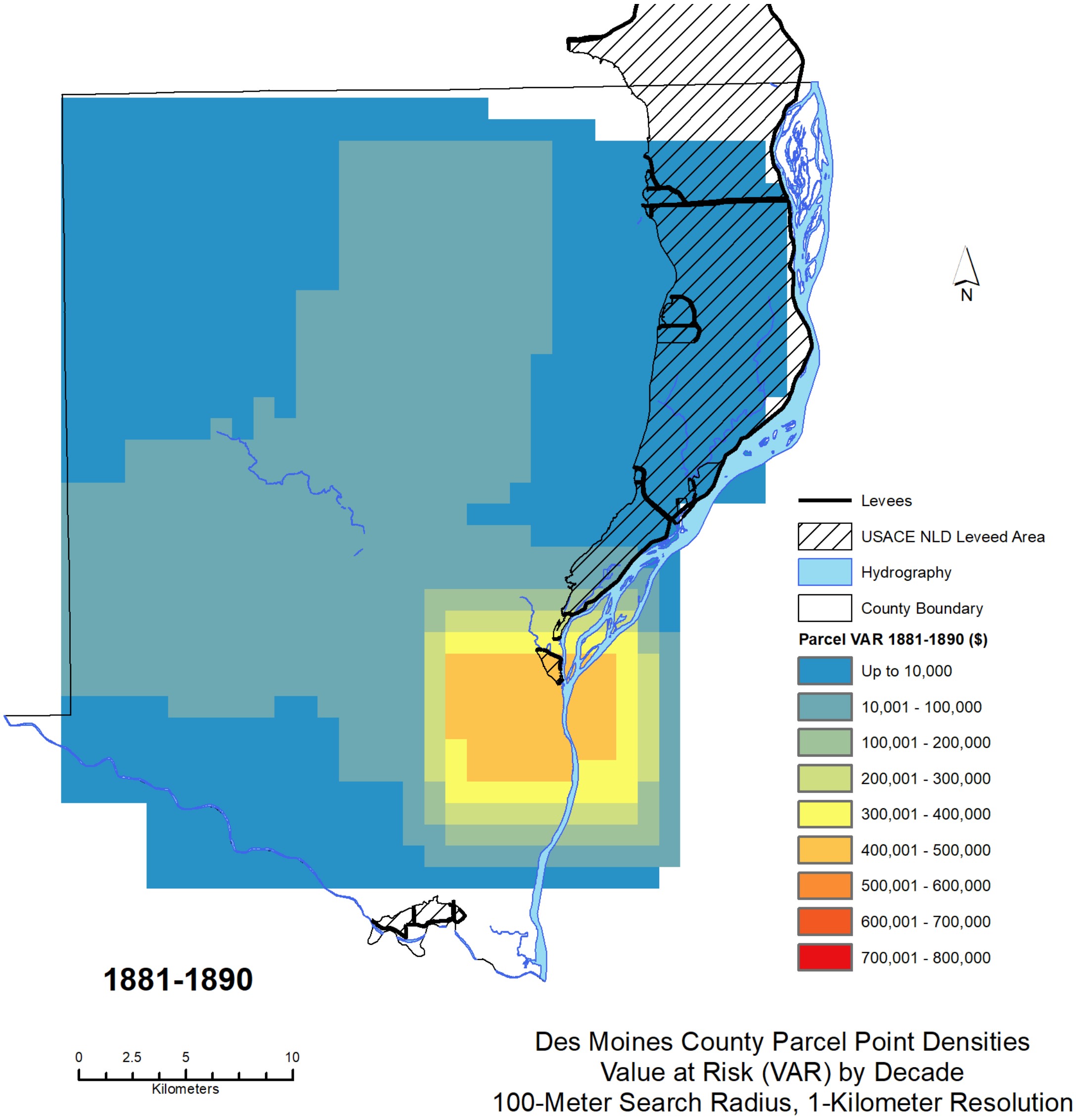


Figure C.78. Value at risk in Black Hawk County, Iowa, 1881-1890.

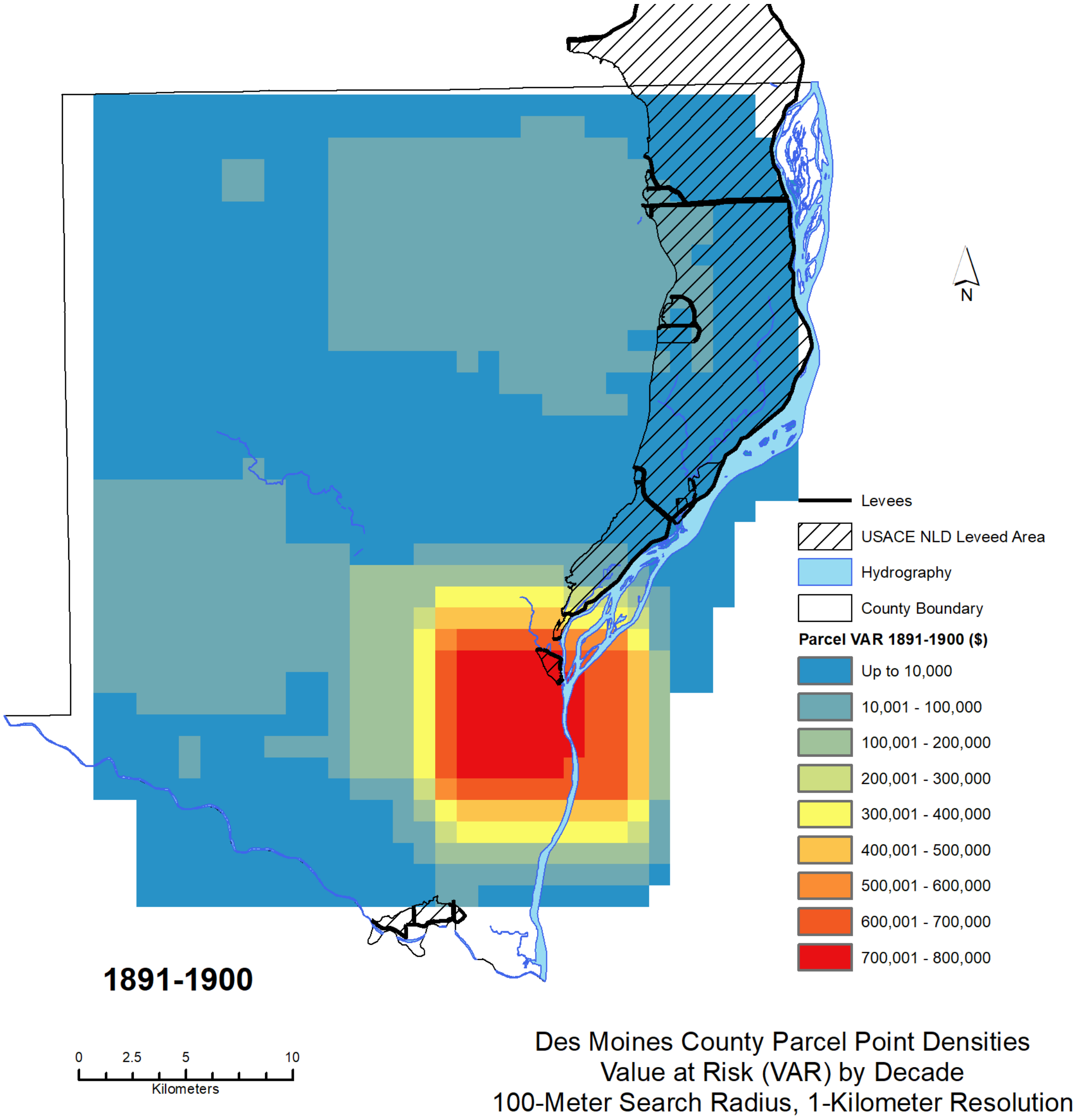


Figure C.79. Value at risk in Black Hawk County, Iowa, 1891-1900.

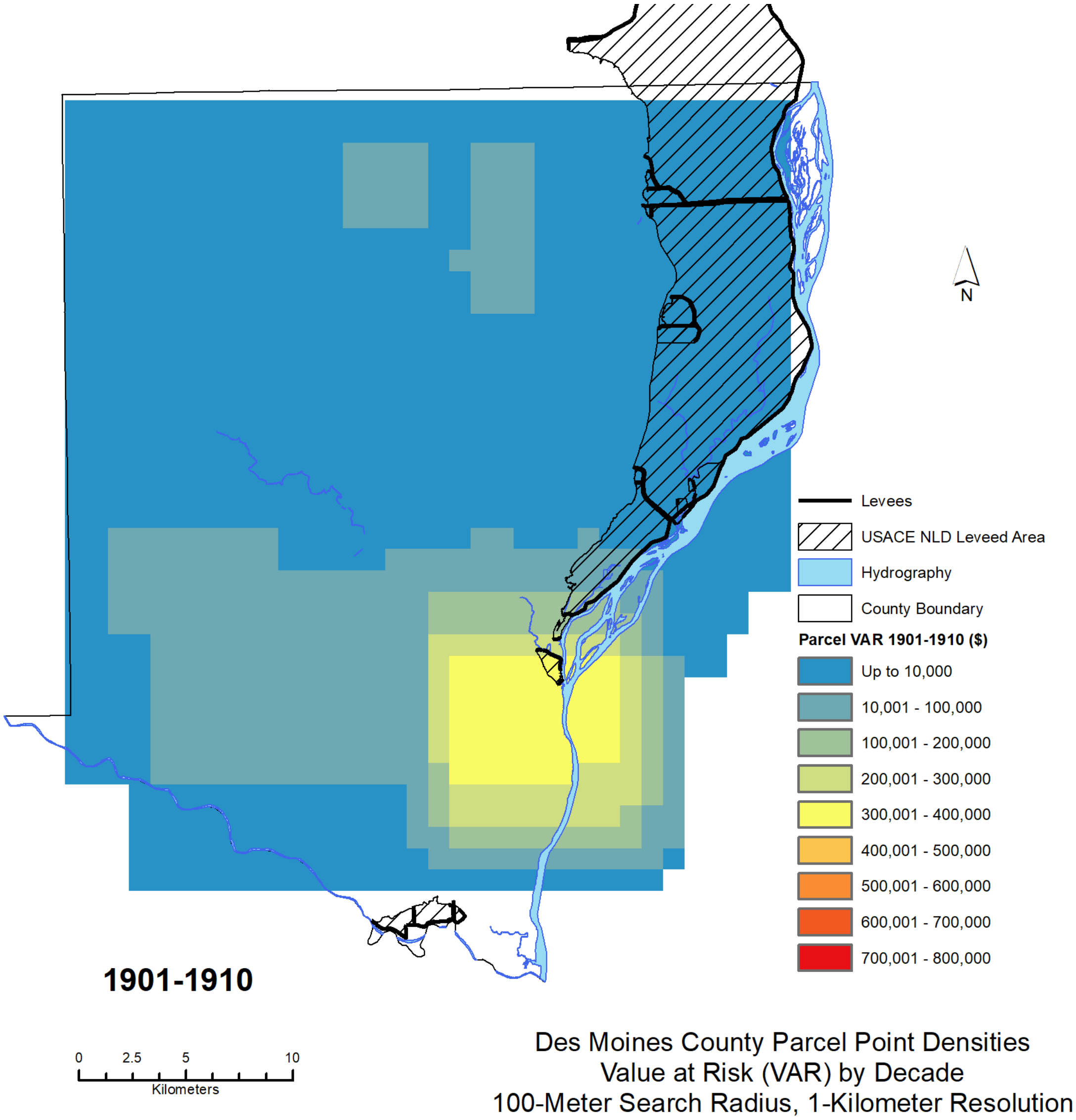


Figure C.80. Value at risk in Black Hawk County, Iowa, 1901-1910.

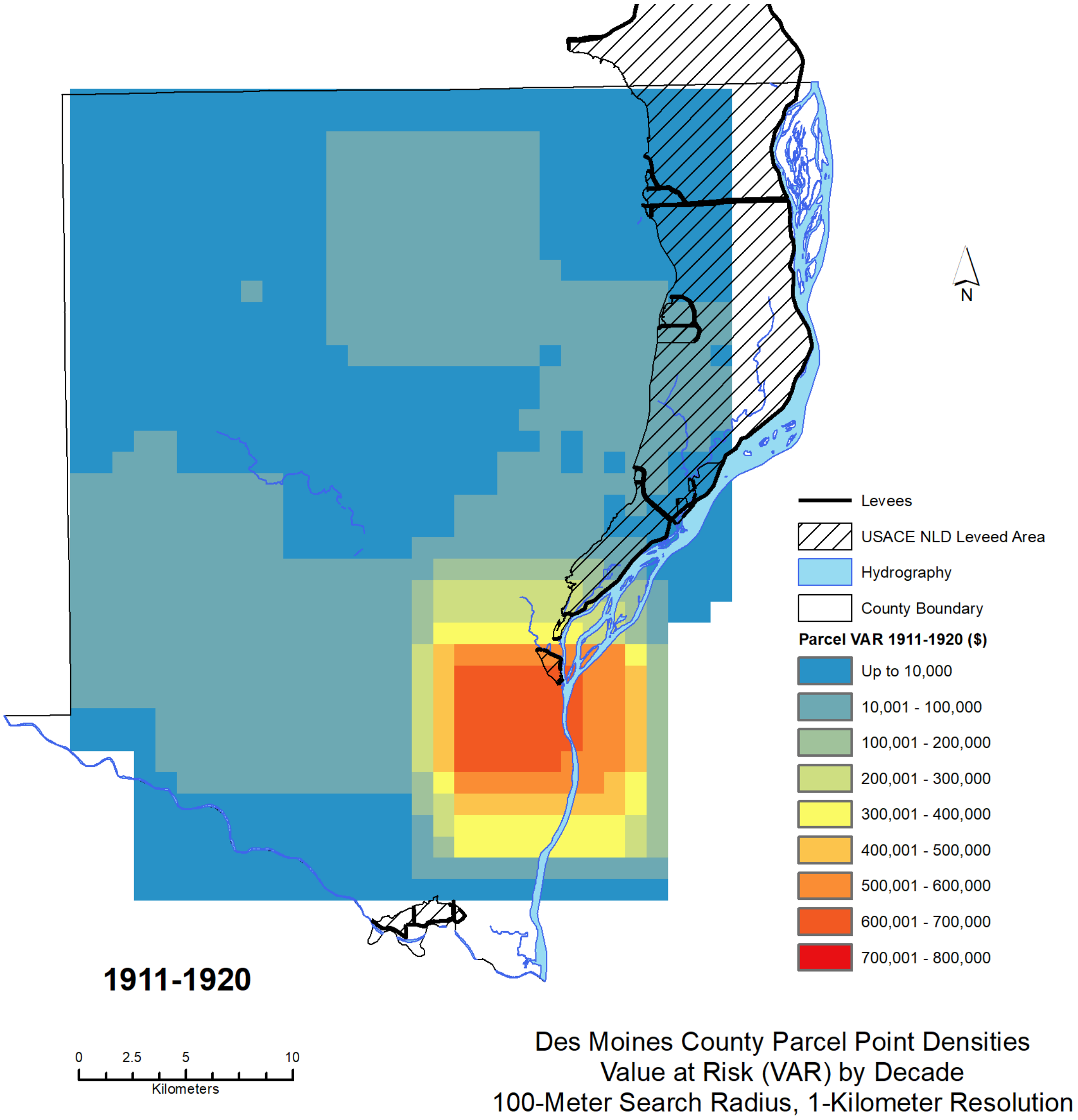


Figure C.81. Value at risk in Black Hawk County, Iowa, 1911-1920.

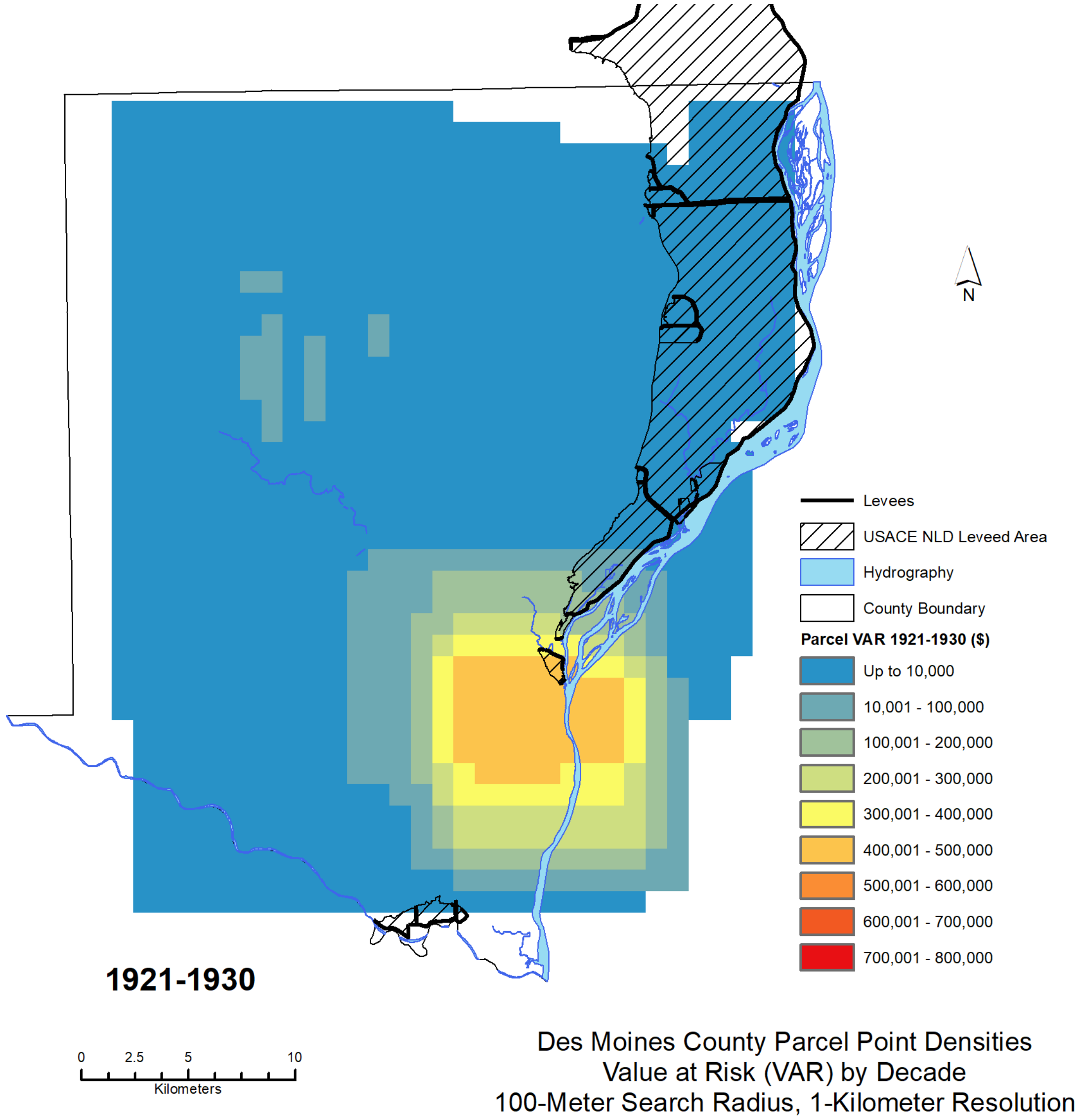


Figure C.82. Value at risk in Black Hawk County, Iowa, 1921-1930.

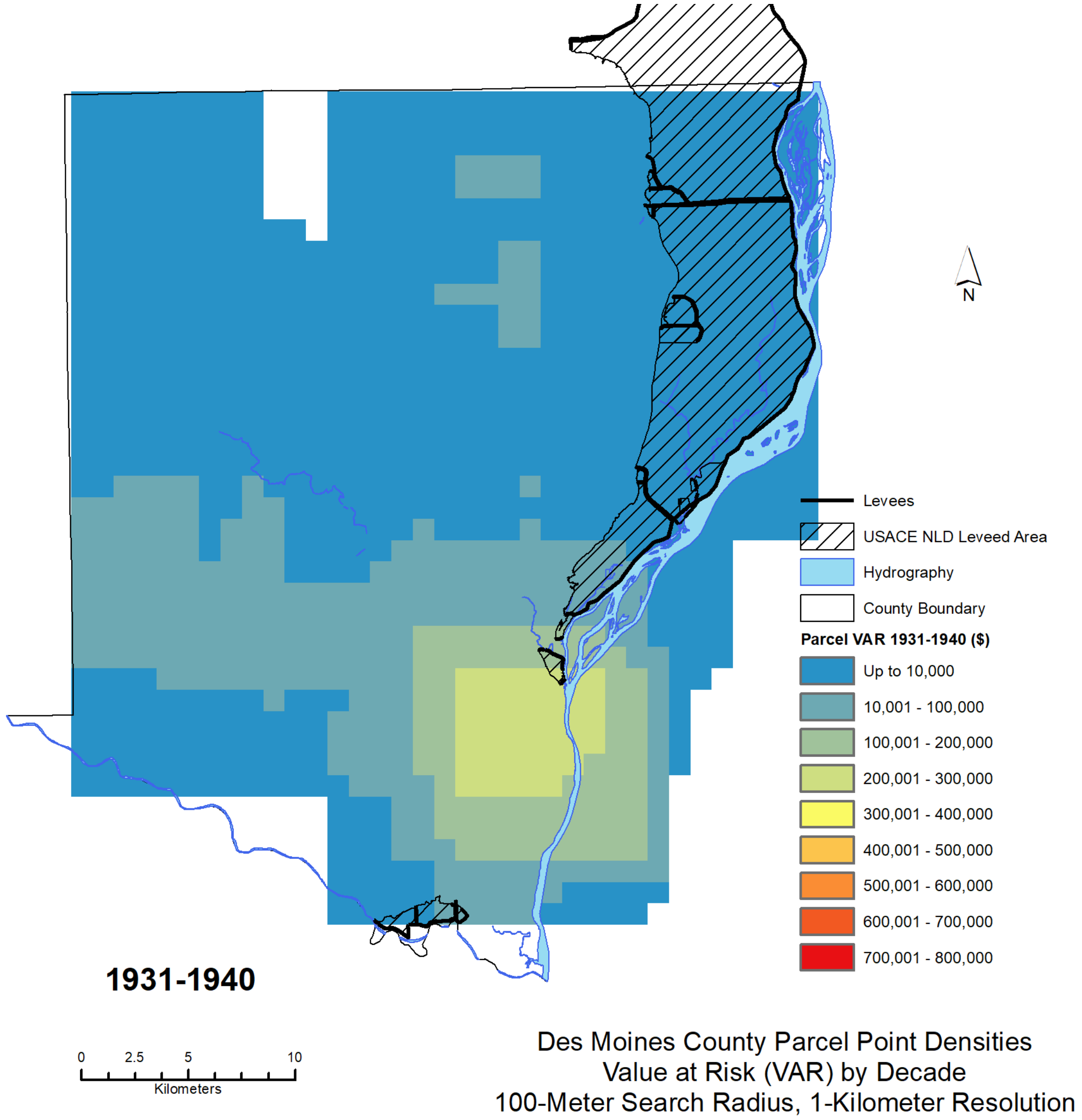


Figure C.83. Value at risk in Black Hawk County, Iowa, 1931-1940.

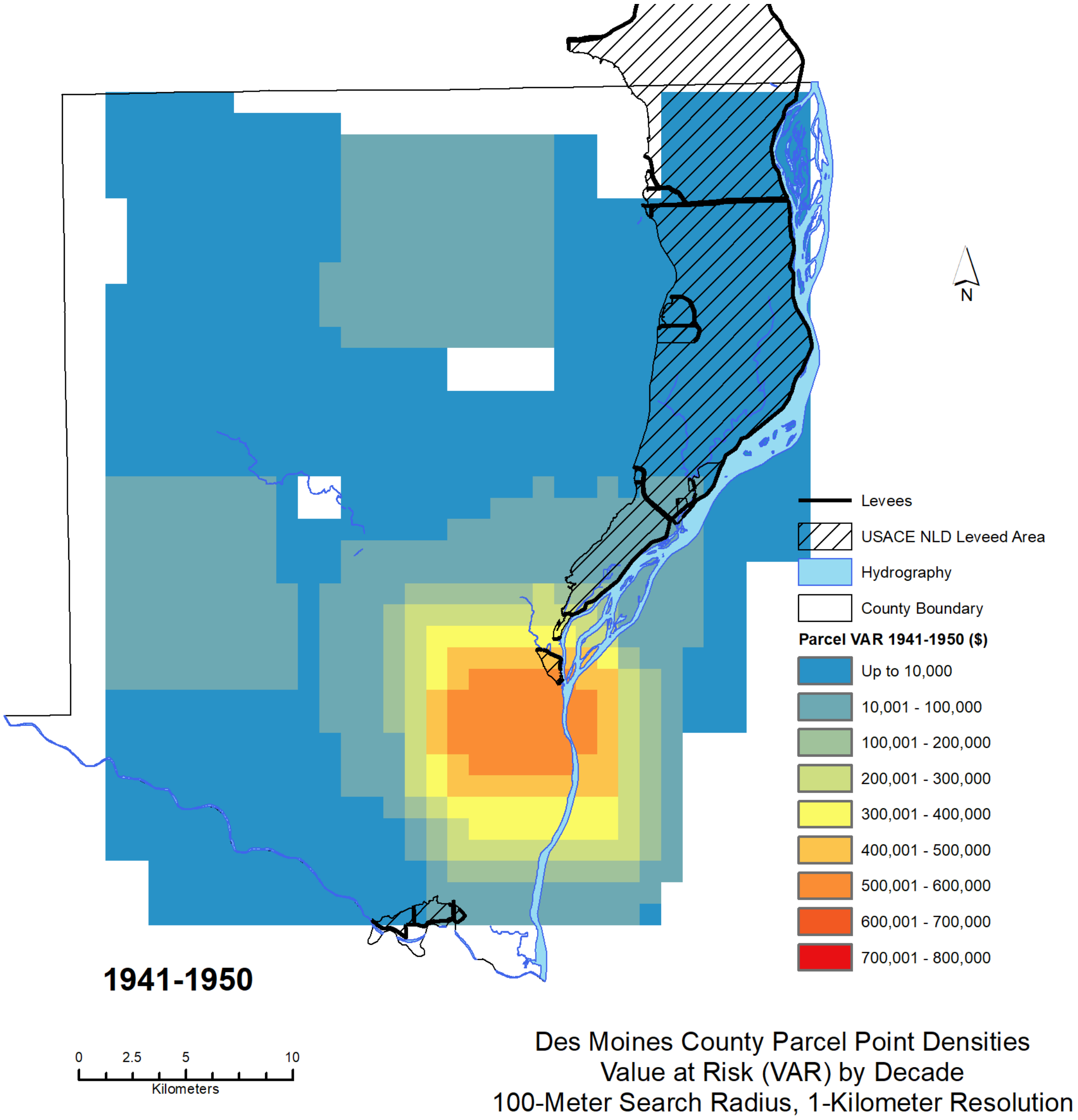


Figure C.84. Value at risk in Black Hawk County, Iowa, 1941-1950.

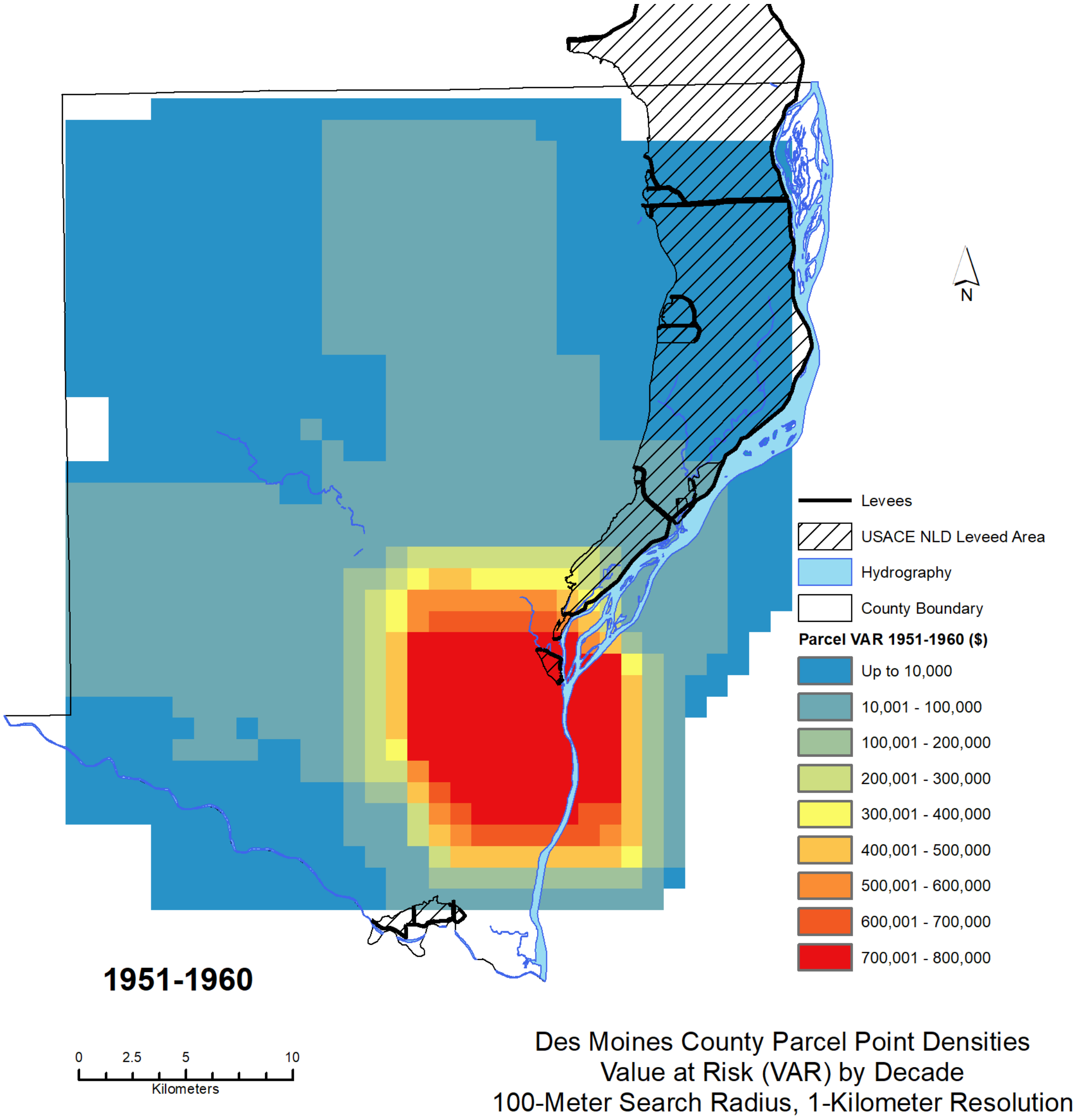


Figure C.85. Value at risk in Black Hawk County, Iowa, 1951-1960.

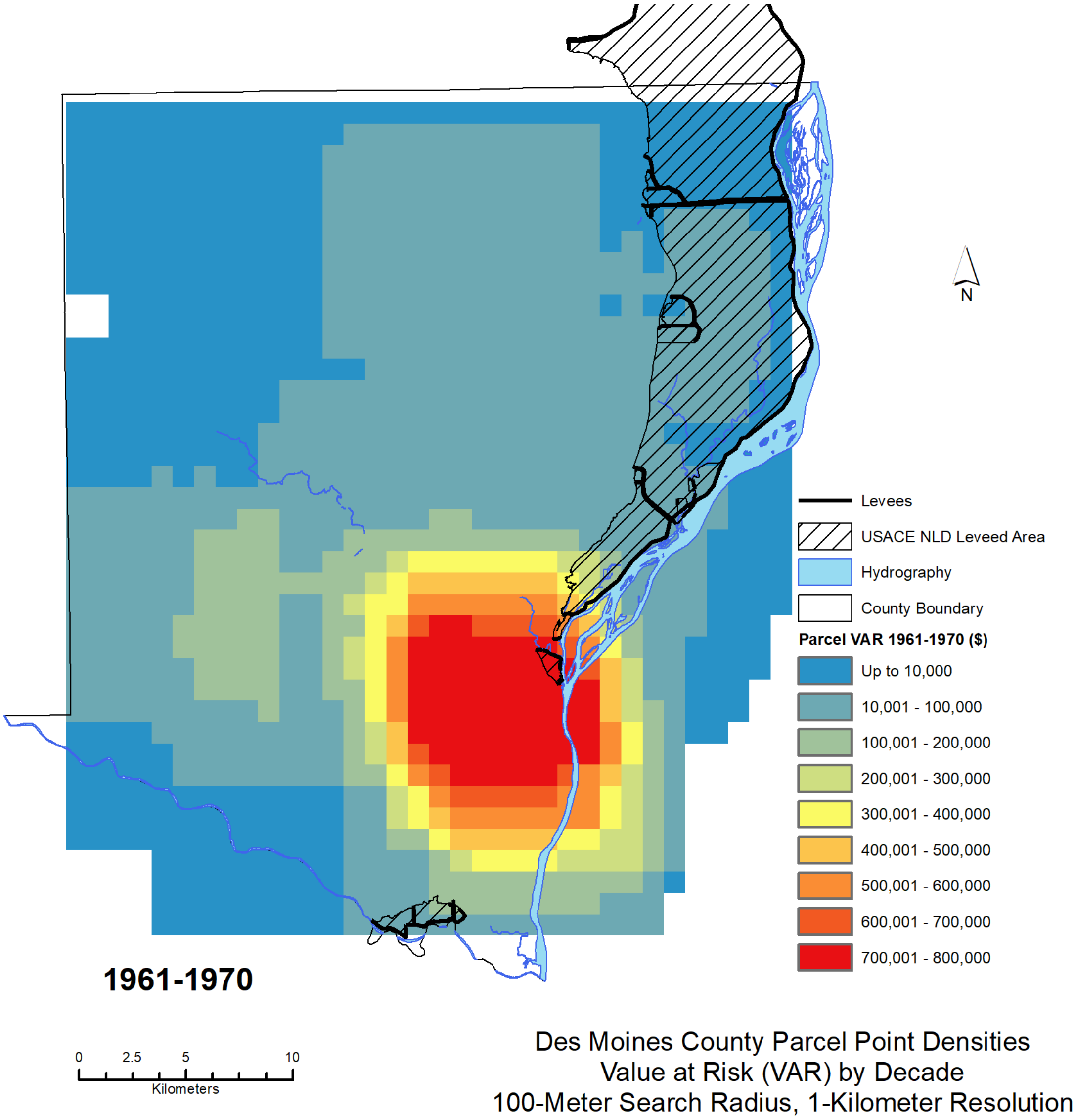


Figure C.86. Value at risk in Black Hawk County, Iowa, 1961-1970.

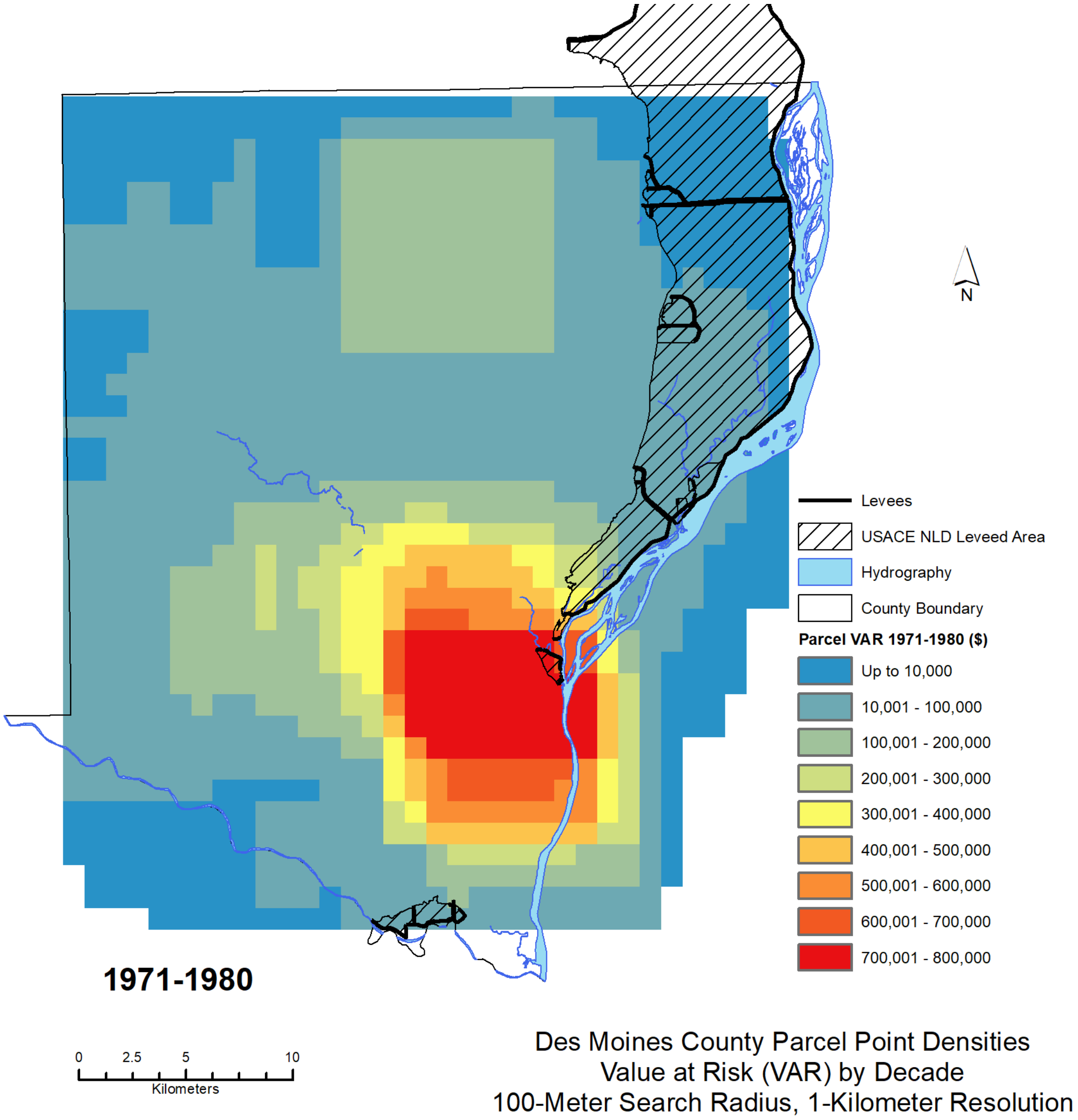


Figure C.87. Value at risk in Black Hawk County, Iowa, 1971-1980.

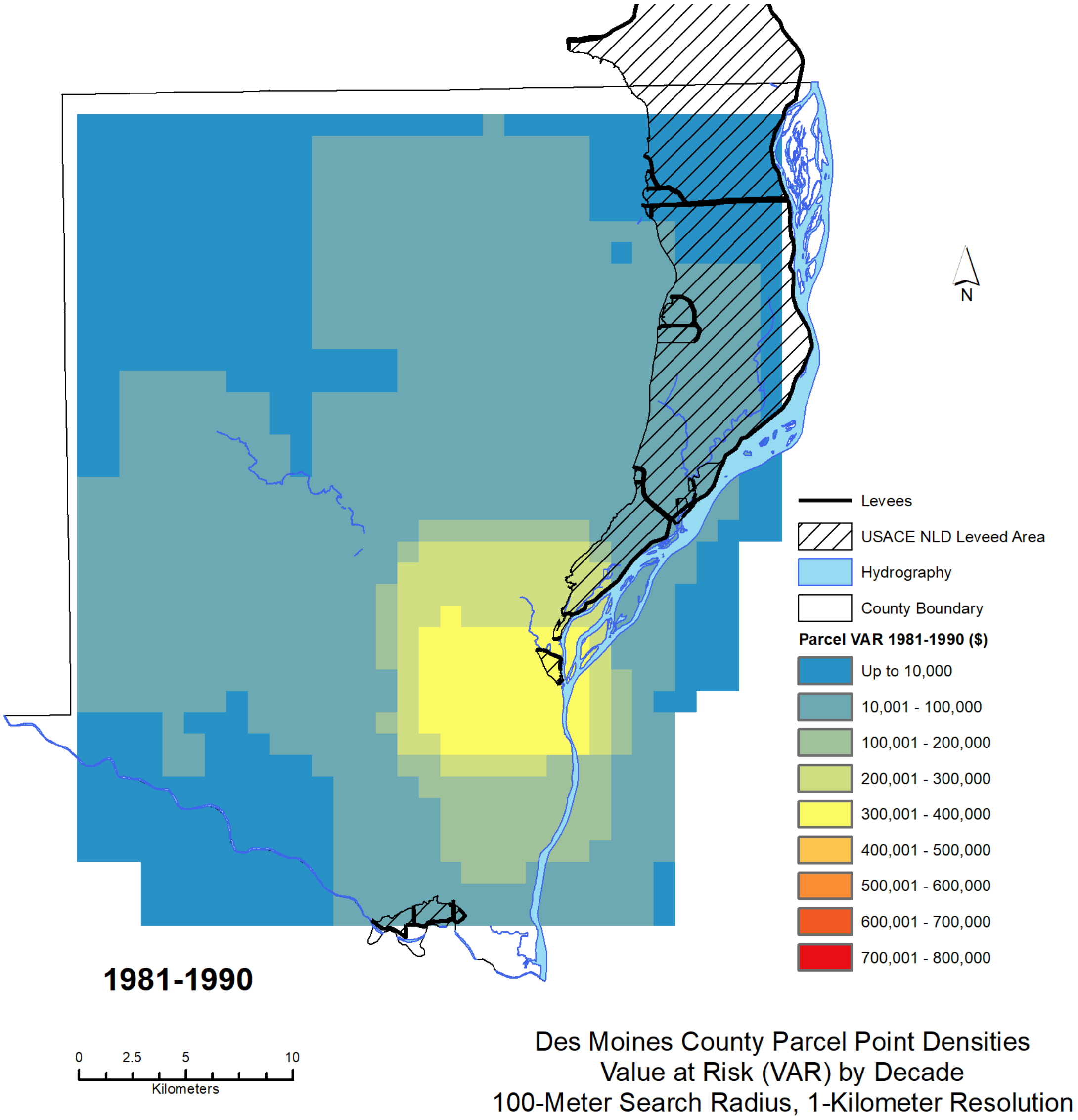


Figure C.88. Value at risk in Black Hawk County, Iowa, 1981-1990.

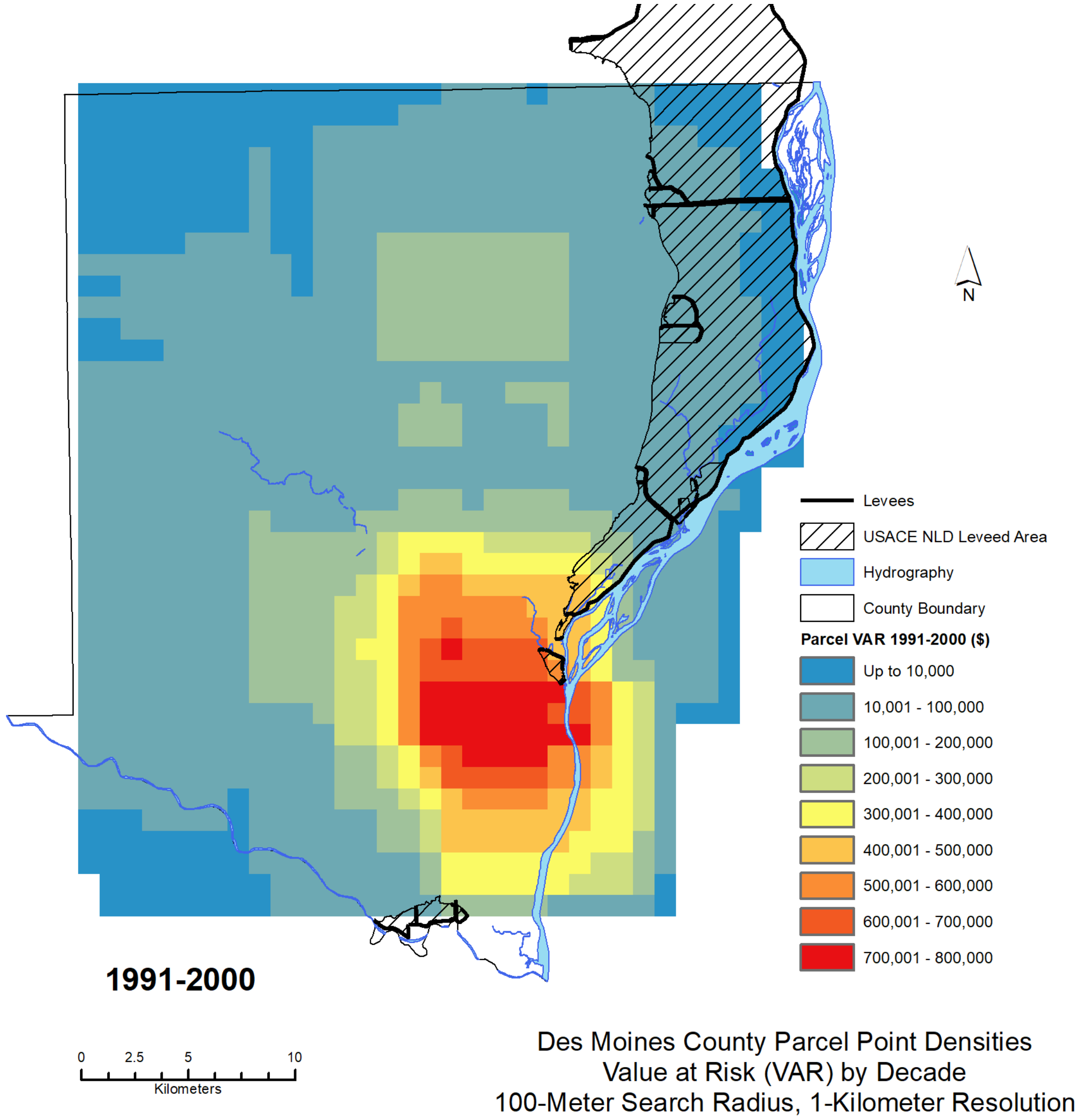


Figure C.89. Value at risk in Black Hawk County, Iowa, 1991-2000.

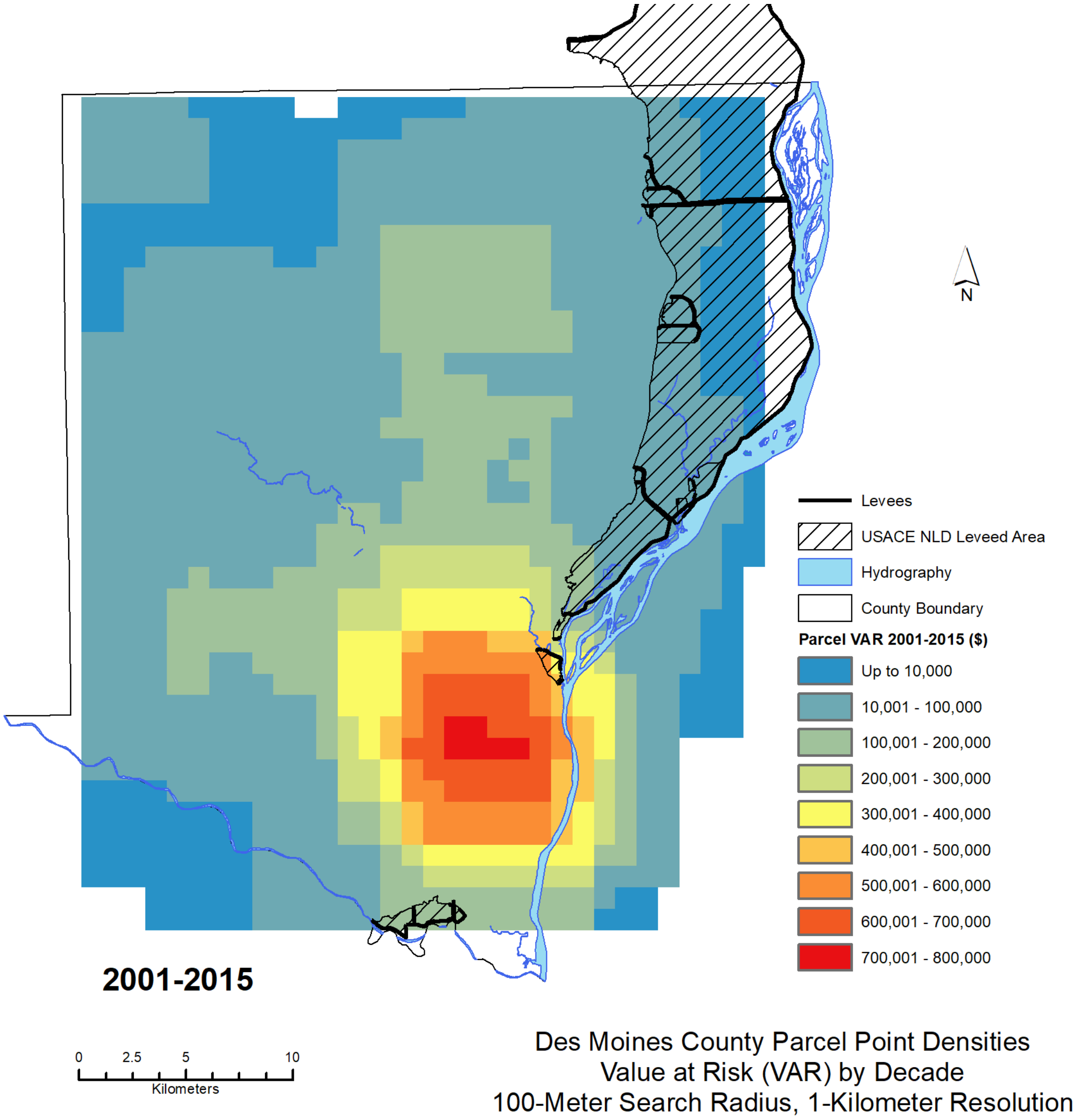


Figure C.90. Value at risk in Black Hawk County, Iowa, 2001-2015.

C.4.1 Tulsa County, Oklahoma Decadal Cumulative VAR Densities

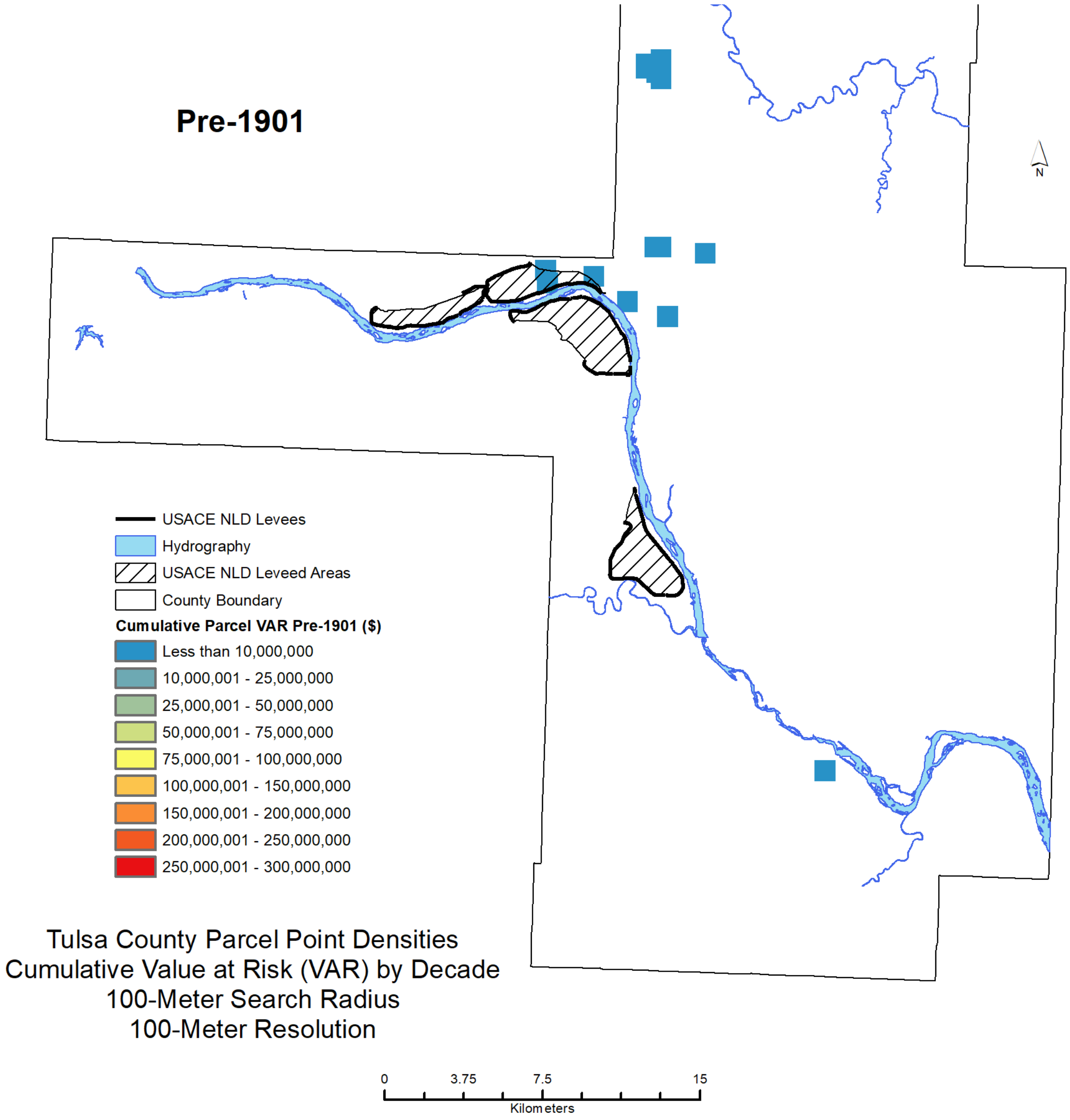


Figure C.91. Cumulative value at risk for Tulsa County, Oklahoma, Pre-1901.

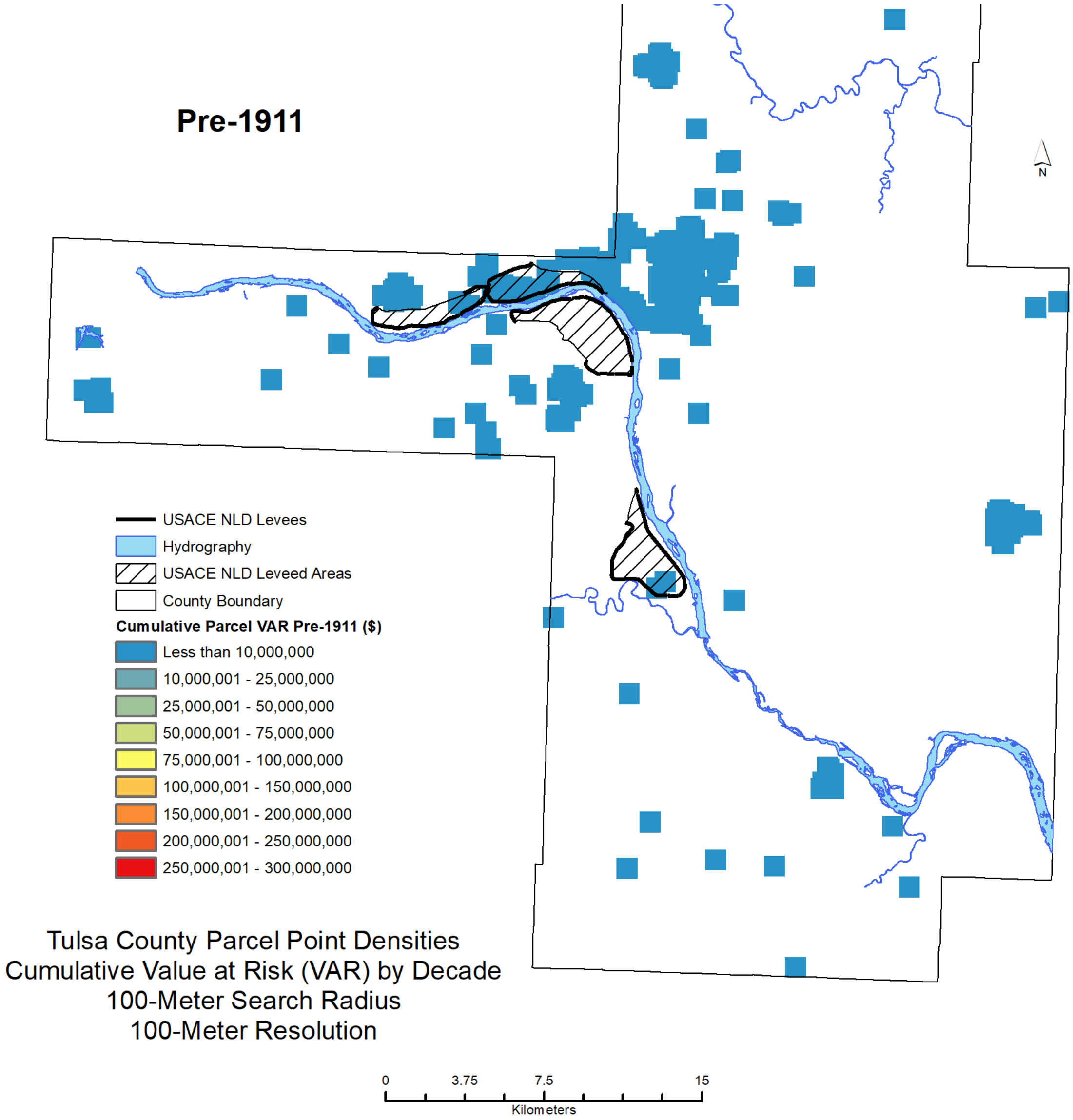


Figure C.92. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1910.

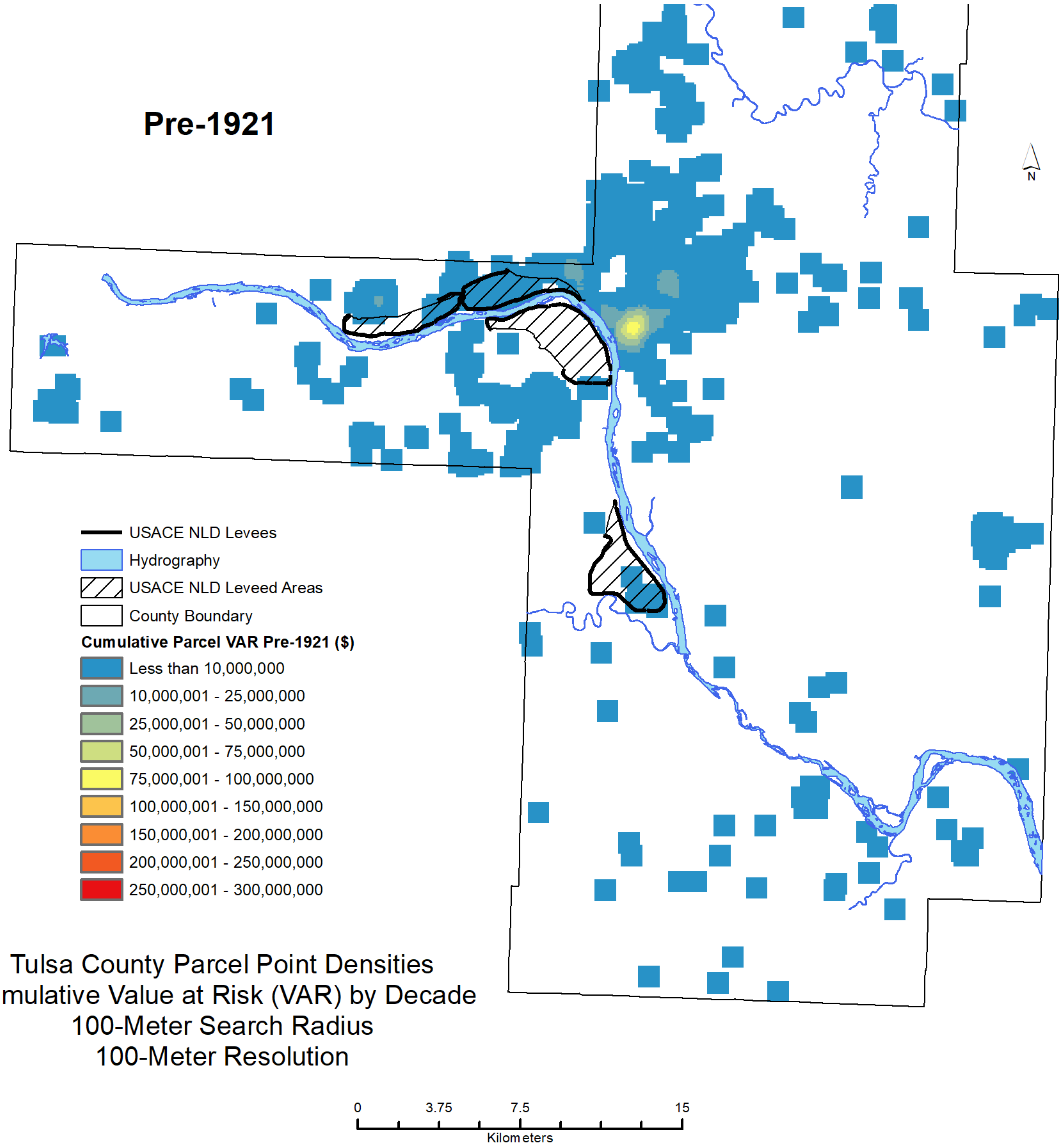


Figure C.93. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1920.

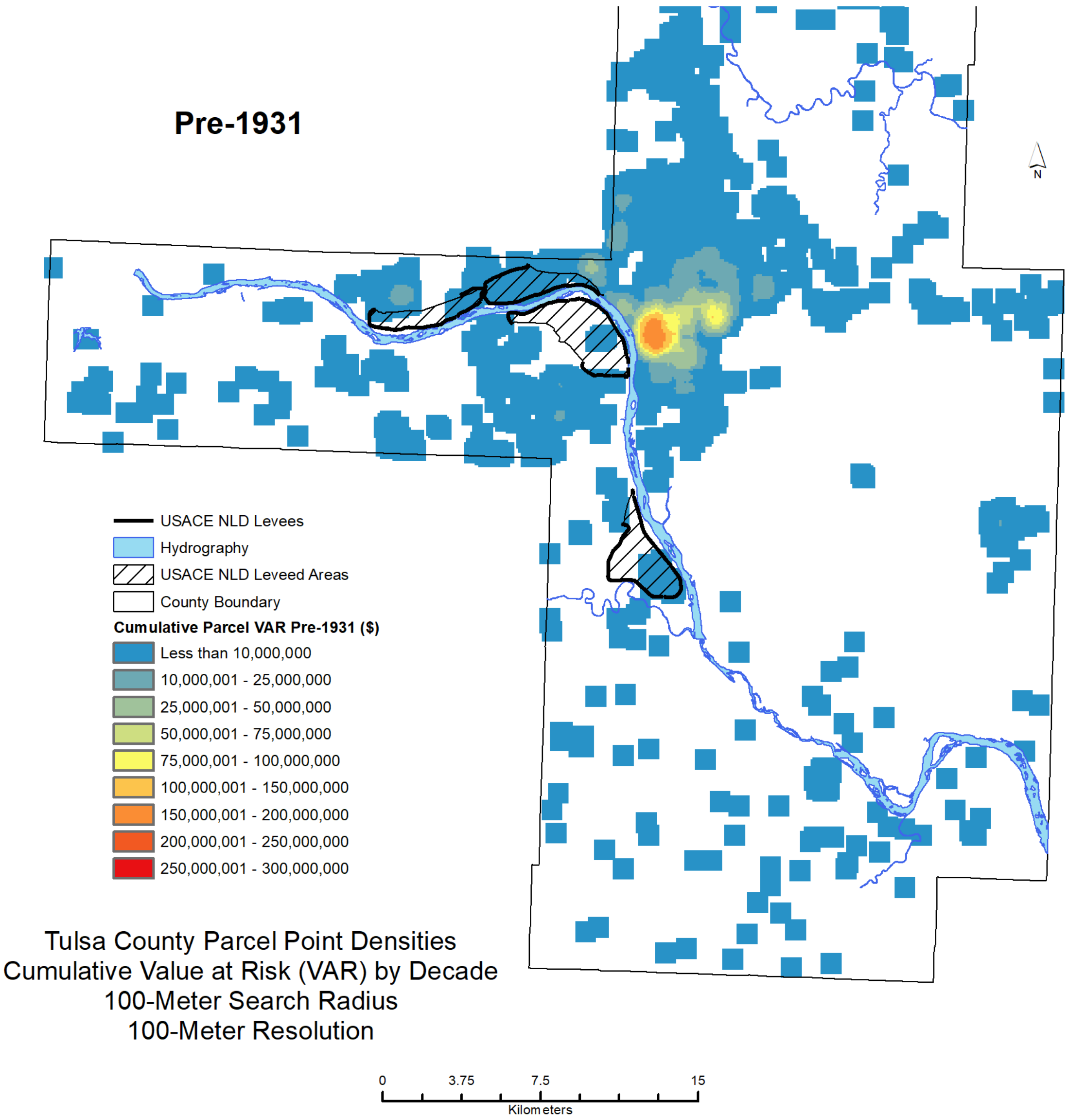


Figure C.94. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1930.

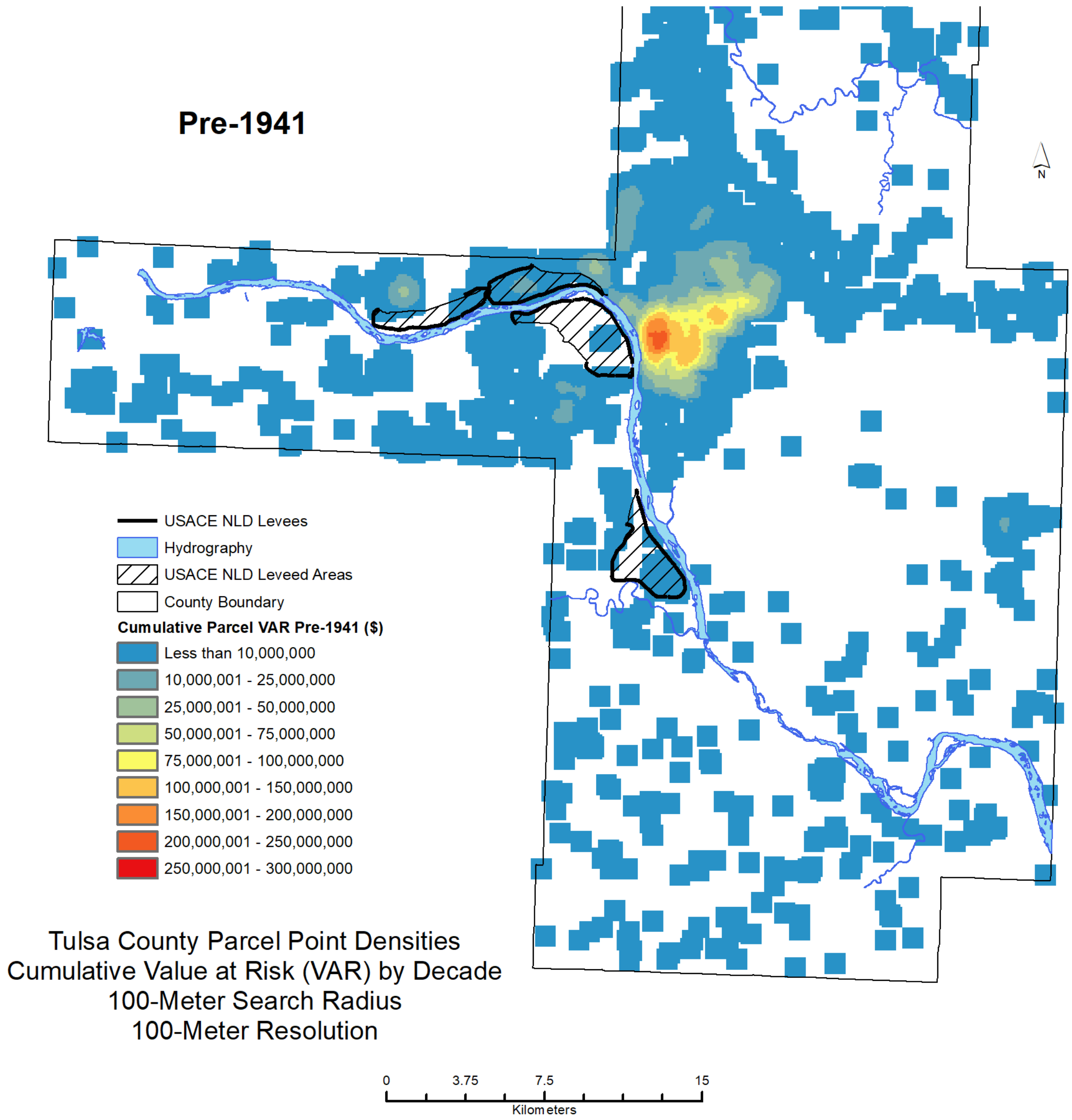


Figure C.95. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1940.

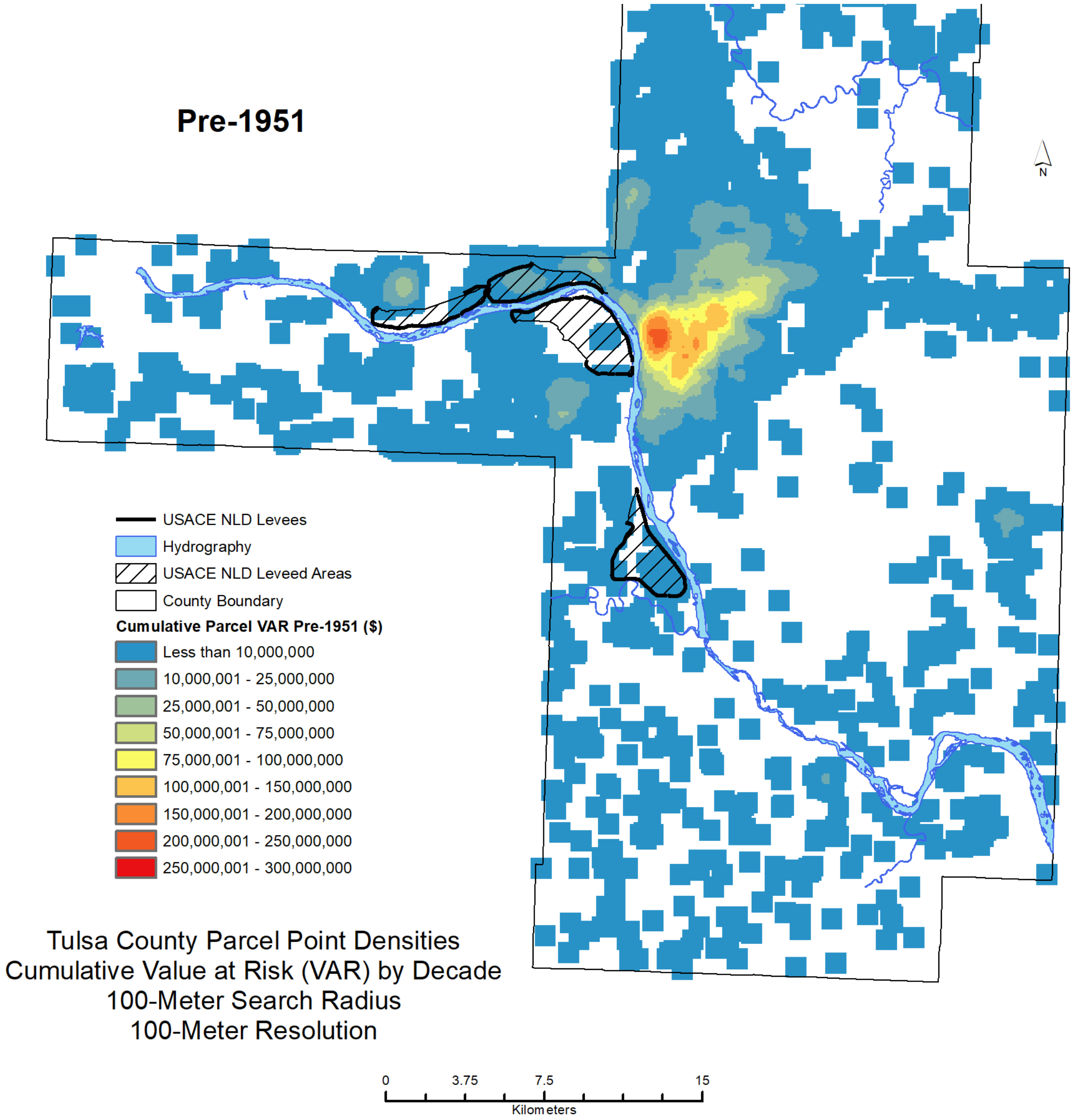


Figure C.96. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1950.

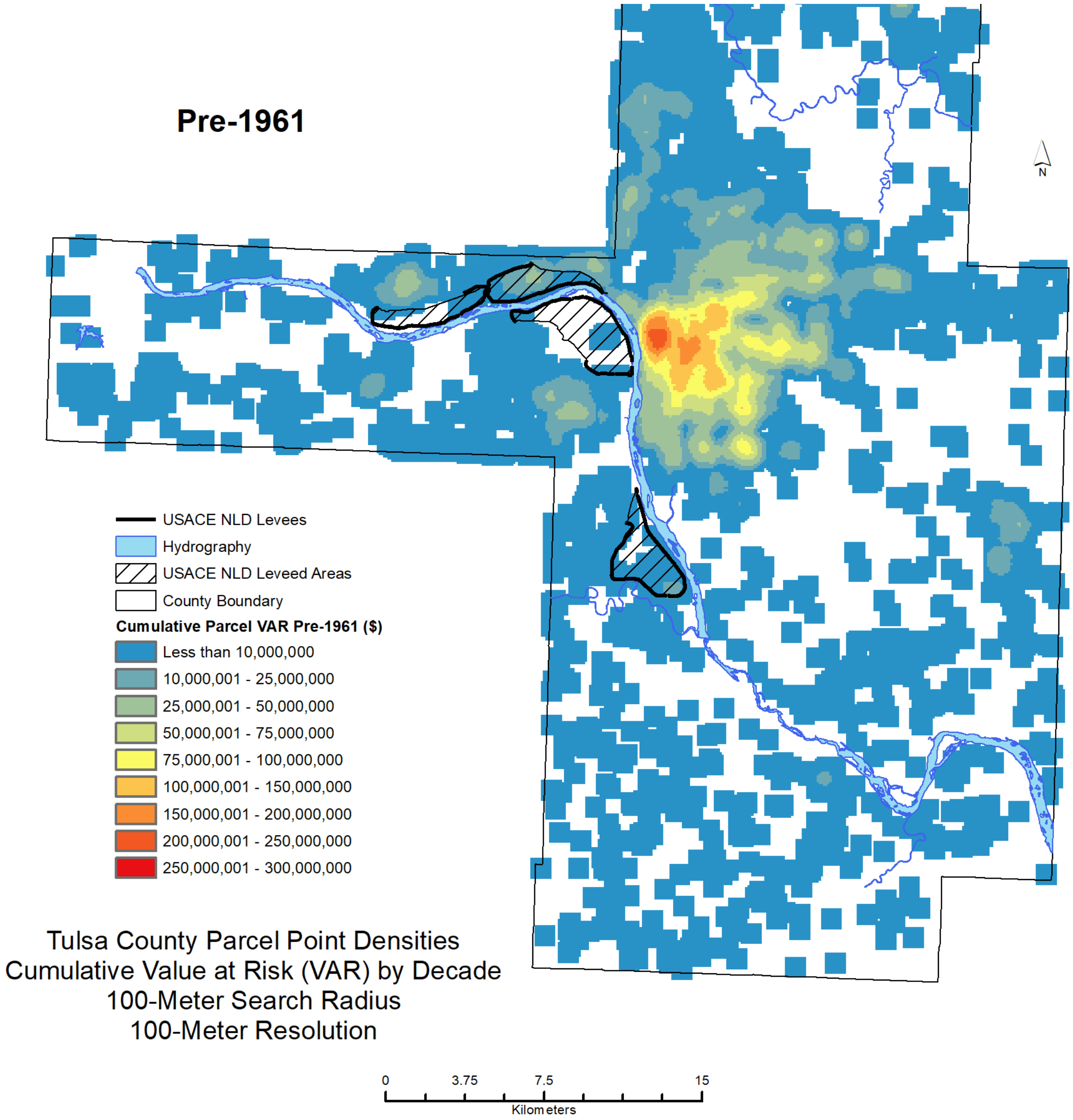


Figure C.97. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1960.

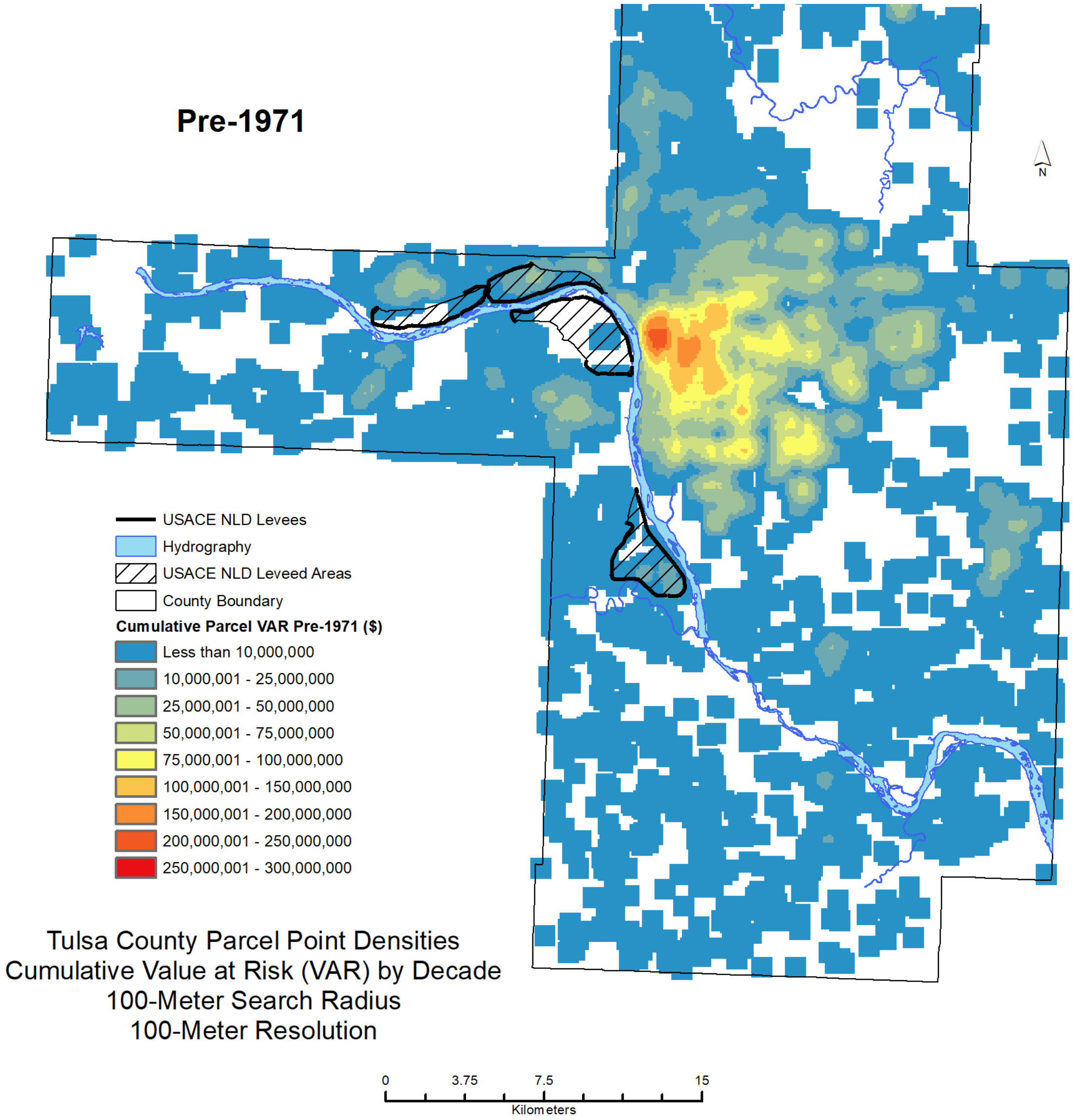


Figure C.98. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1970.

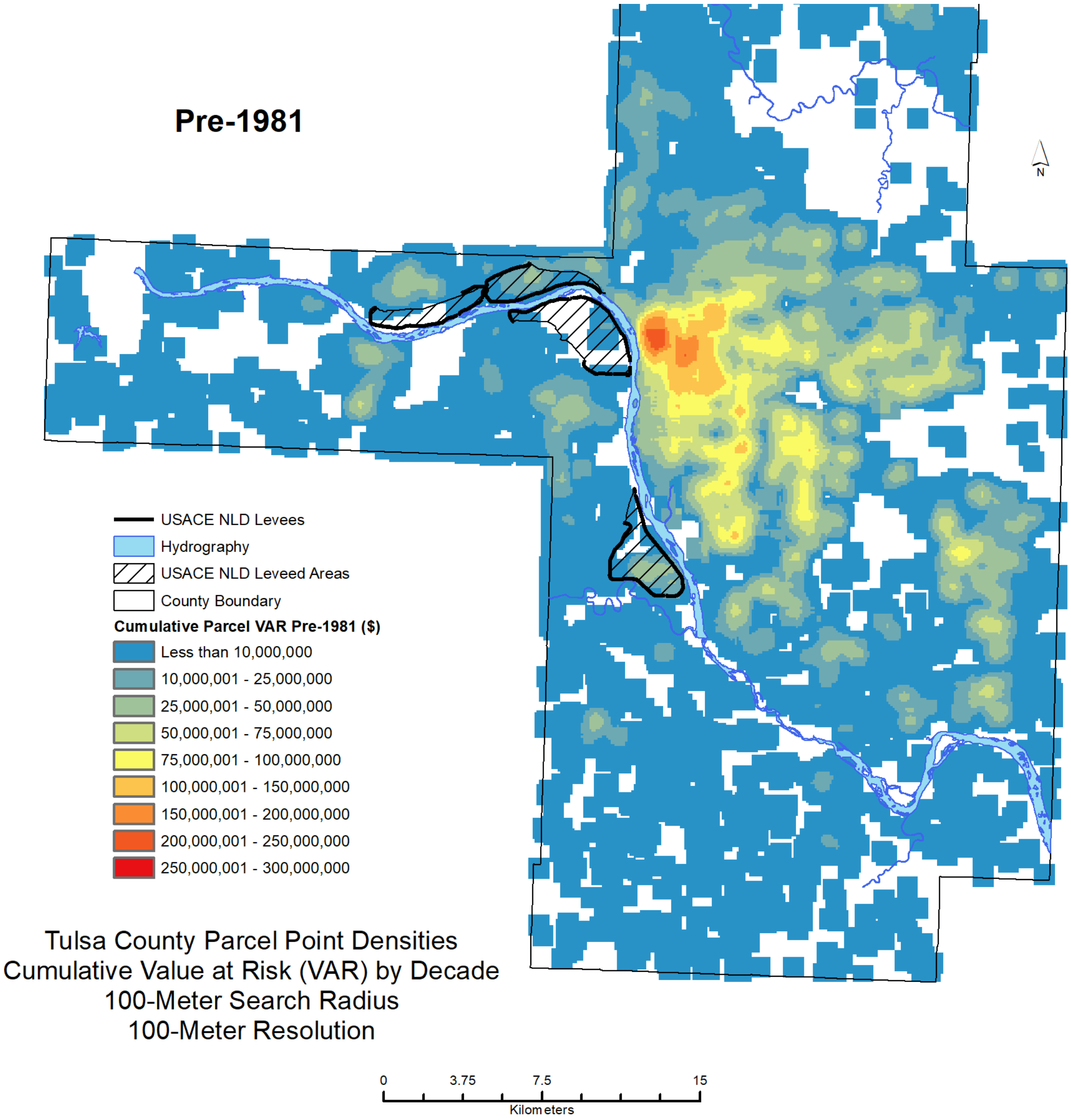


Figure C.99. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1980.

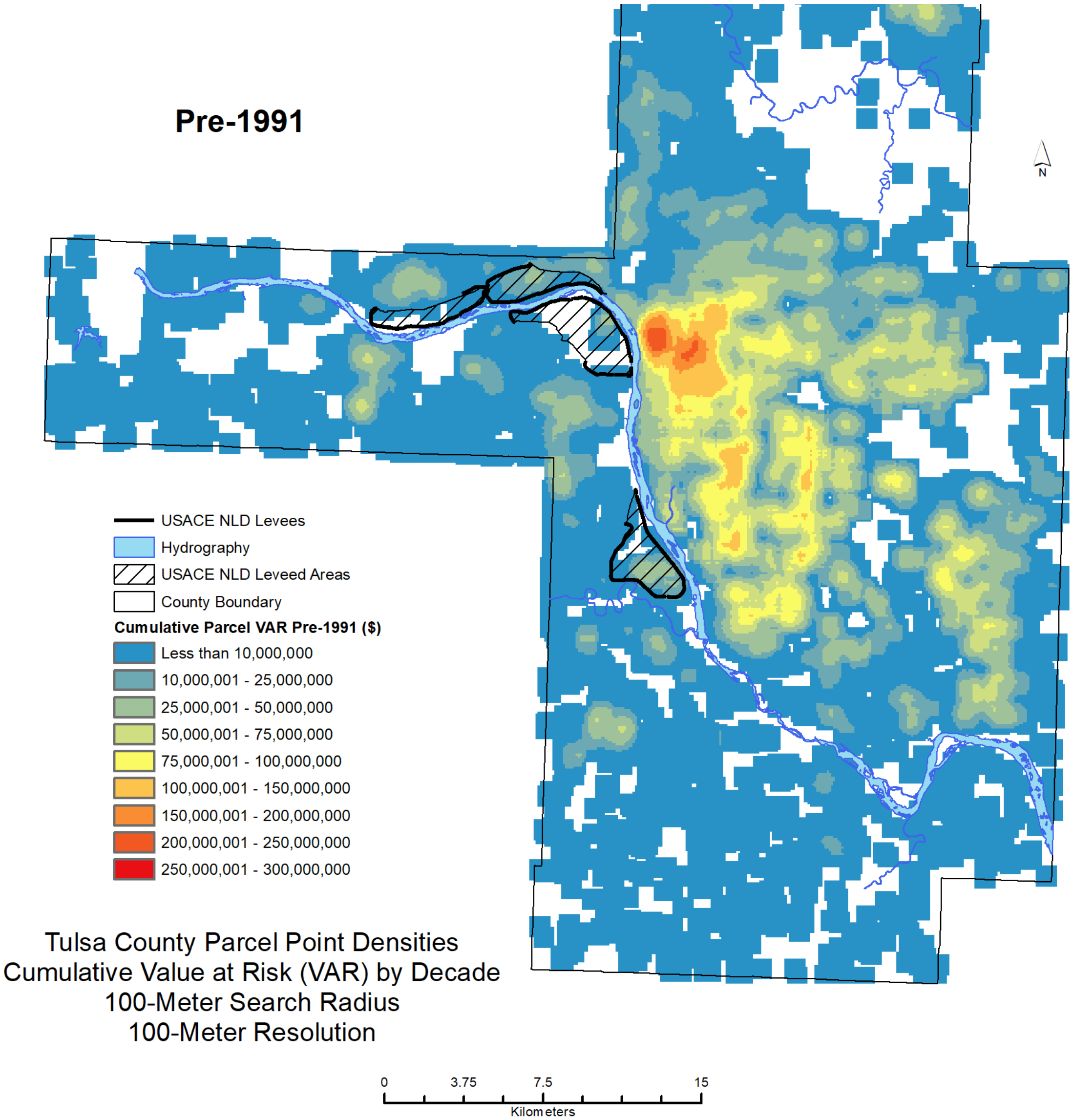


Figure C.100. Cumulative value at risk for Tulsa County, Oklahoma, 1901-1990.

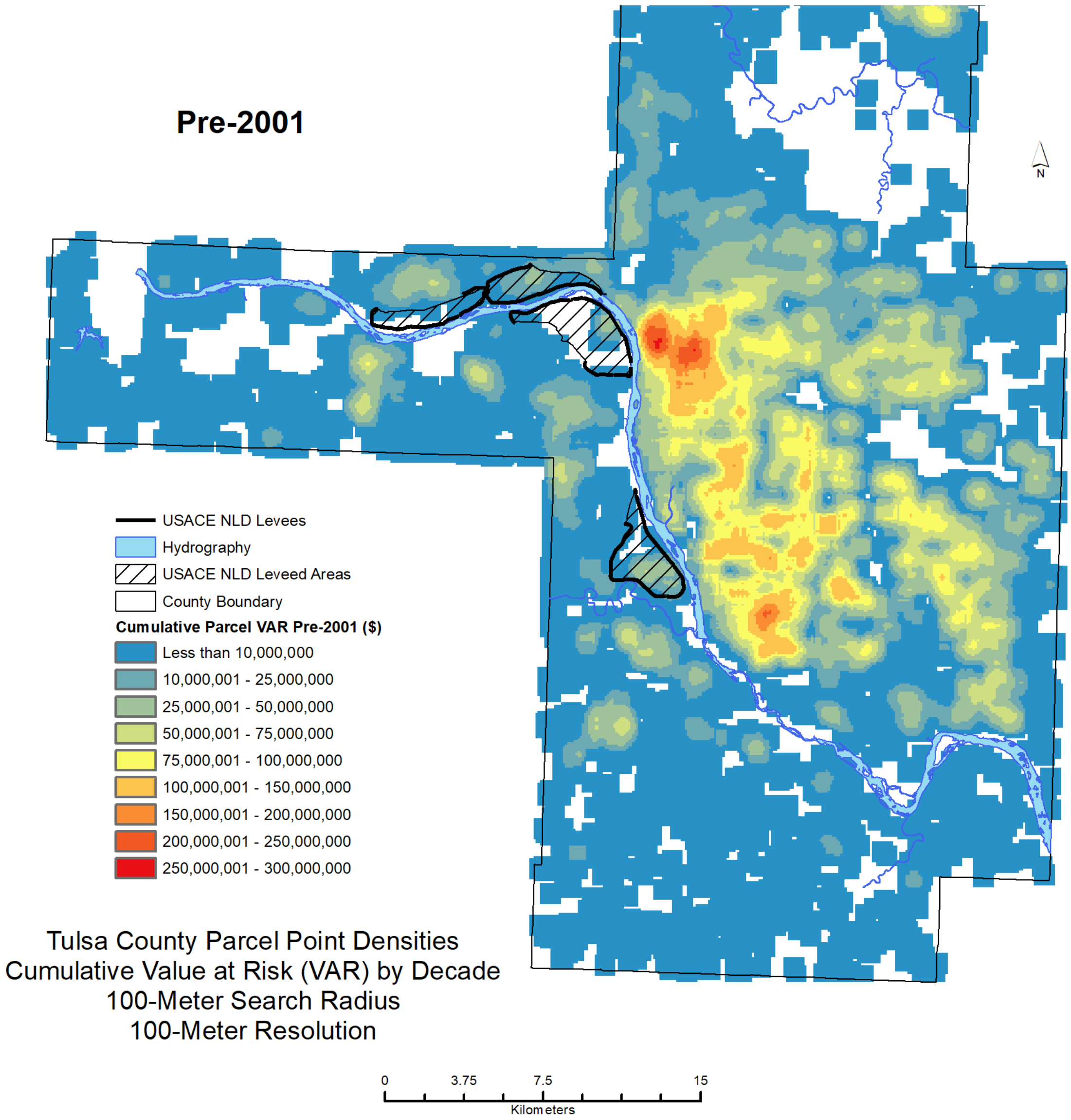


Figure C.101. Cumulative value at risk for Tulsa County, Oklahoma, 1901-2000.

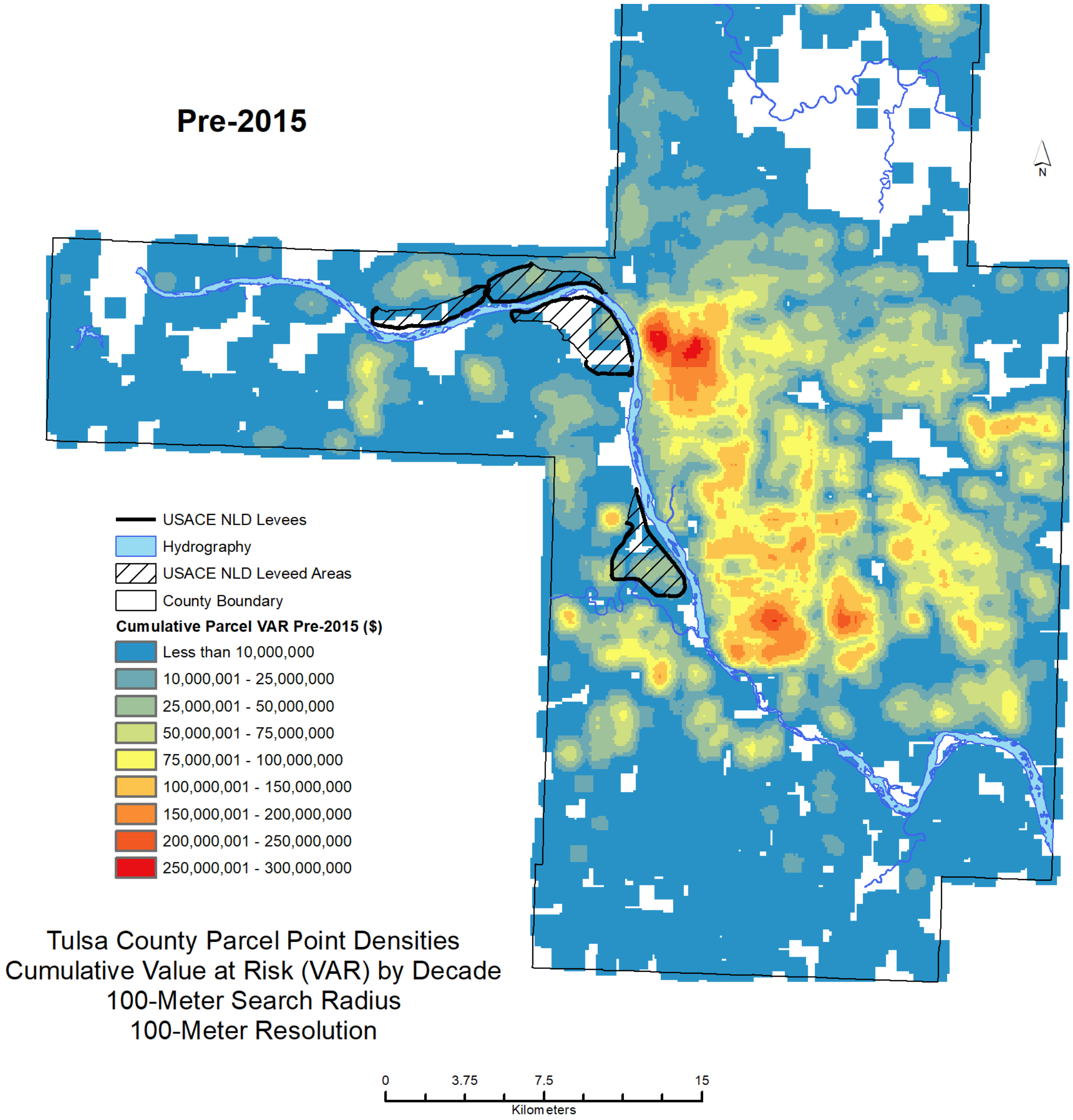


Figure C.102. Cumulative value at risk for Tulsa County, Oklahoma, 1901-2015.

C.4.2 Tulsa County, Oklahoma Decadal VAR Densities

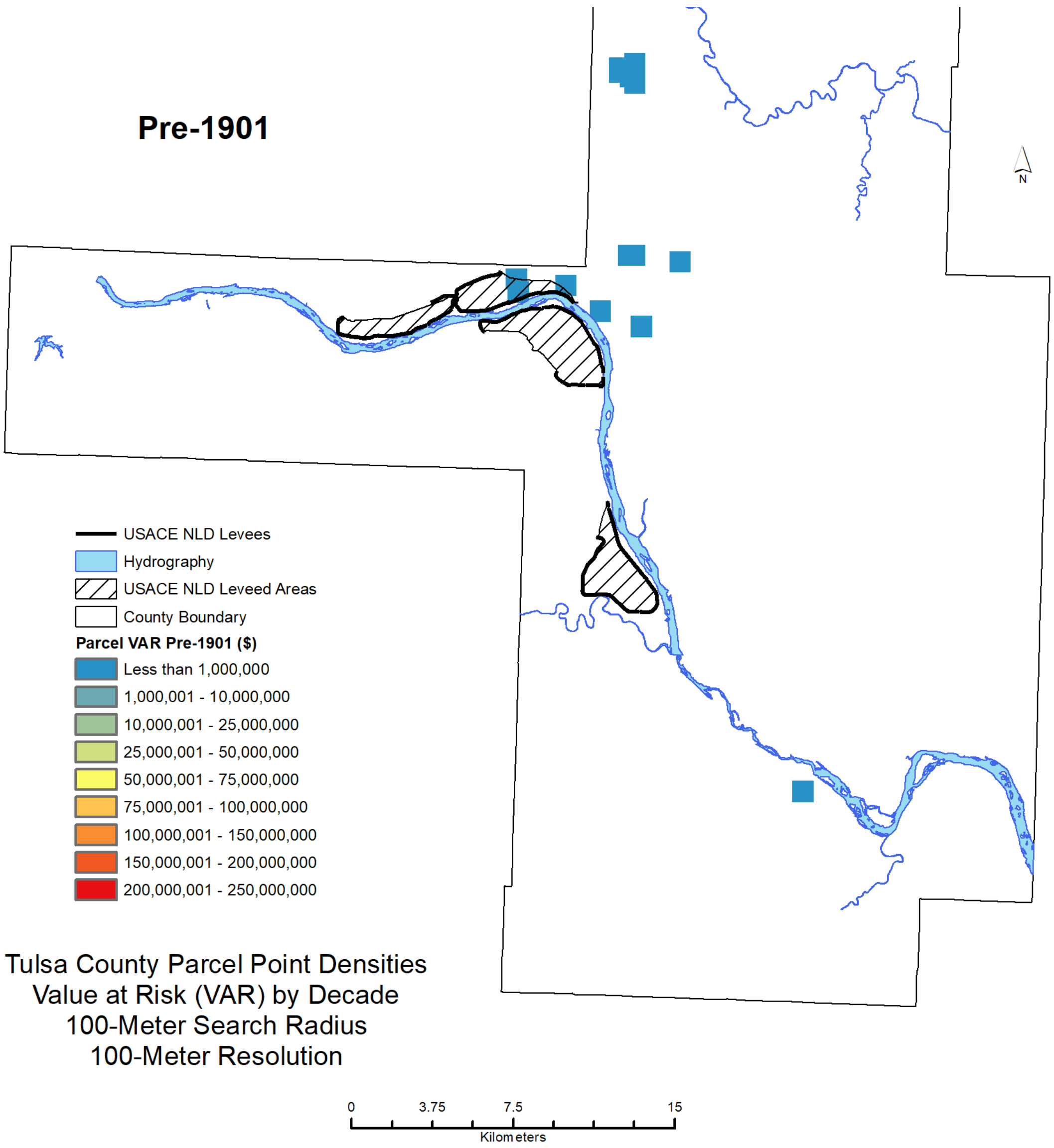


Figure C.103. Value at risk in Tulsa County, Oklahoma, Pre-1901.

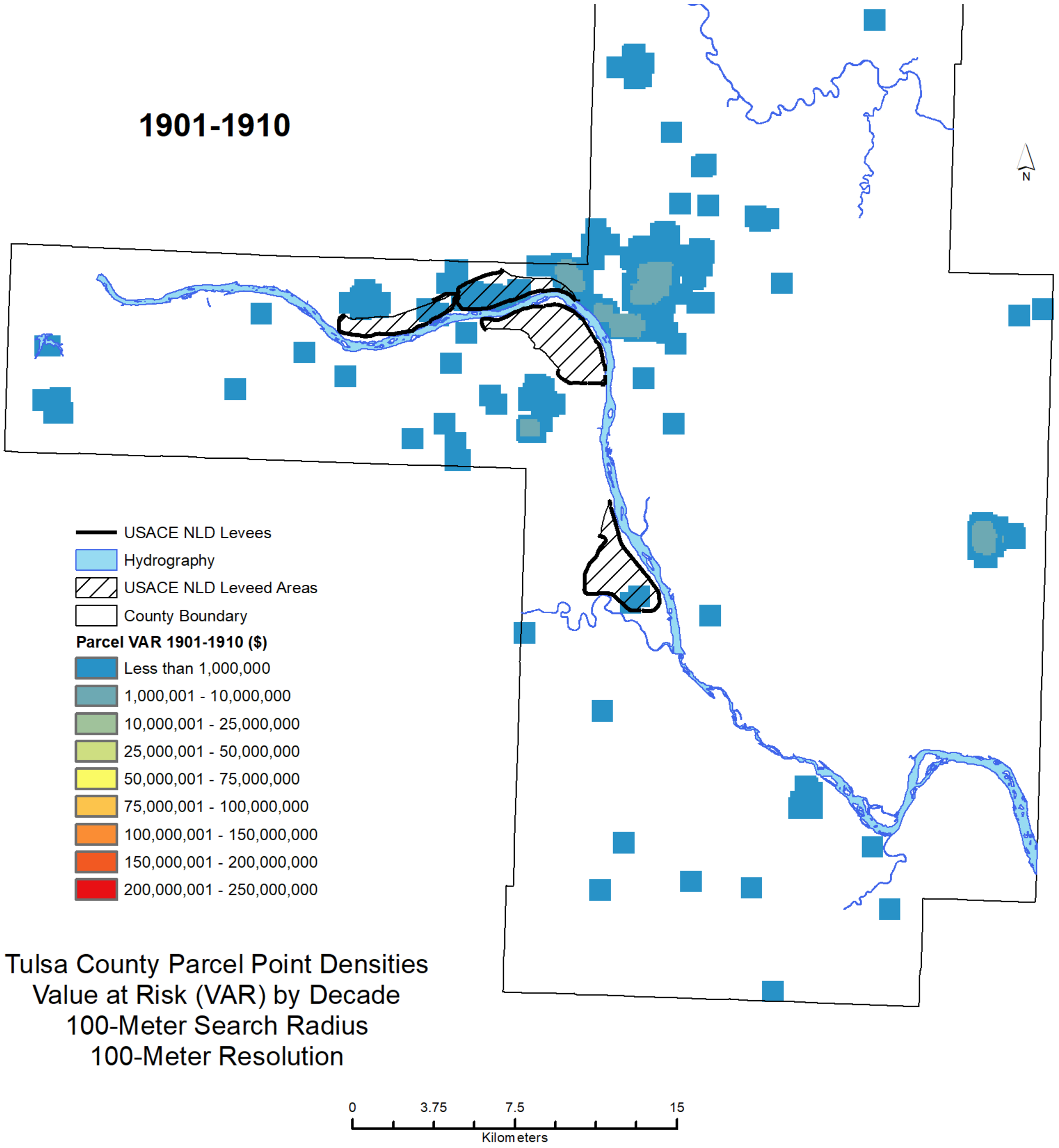


Figure C.104. Value at risk in Tulsa County, Oklahoma, 1901-1910.

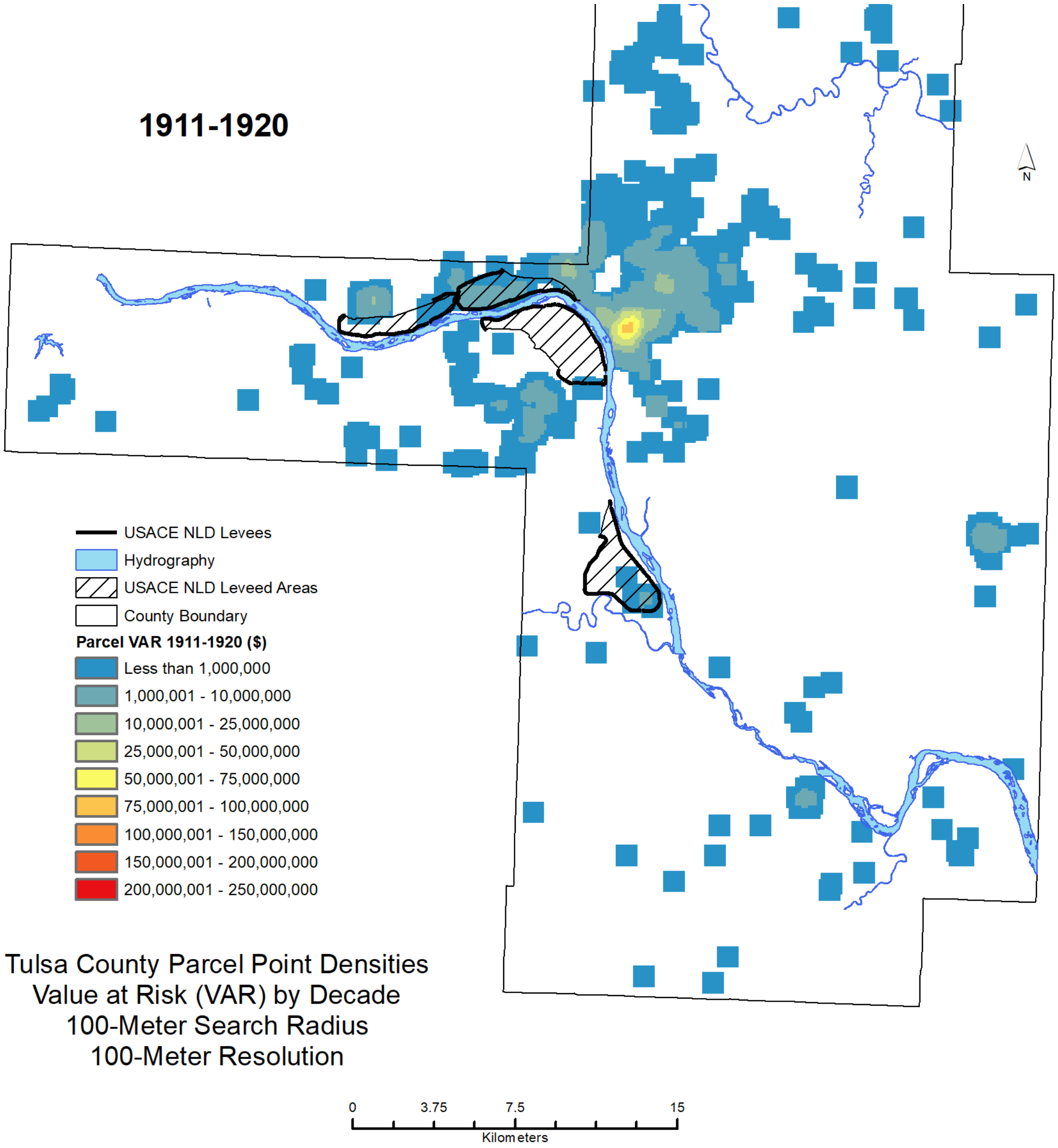


Figure C.105. Value at risk in Tulsa County, Oklahoma, 1911-1920.

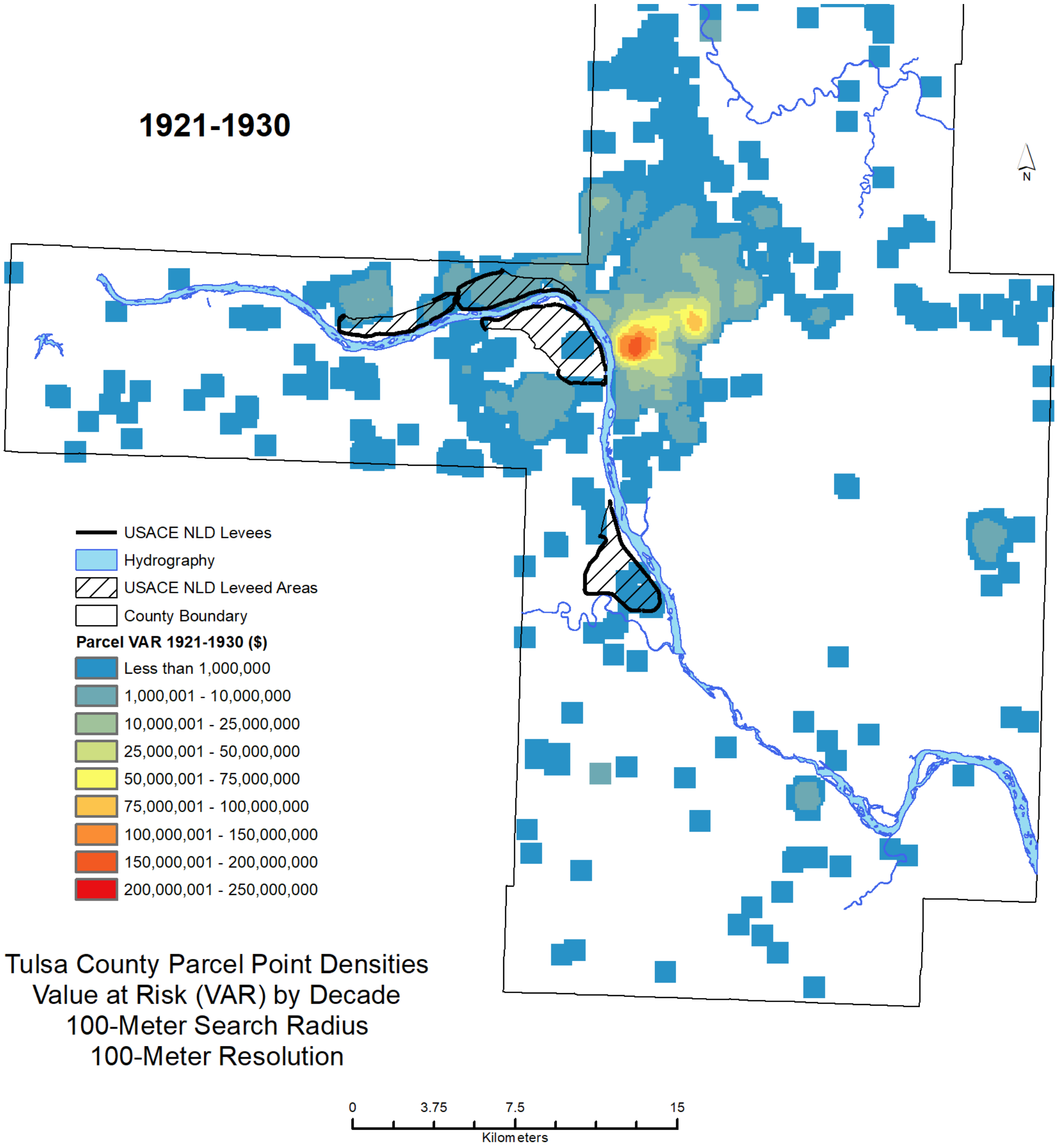


Figure C.106. Value at risk in Tulsa County, Oklahoma, 1921-1930.

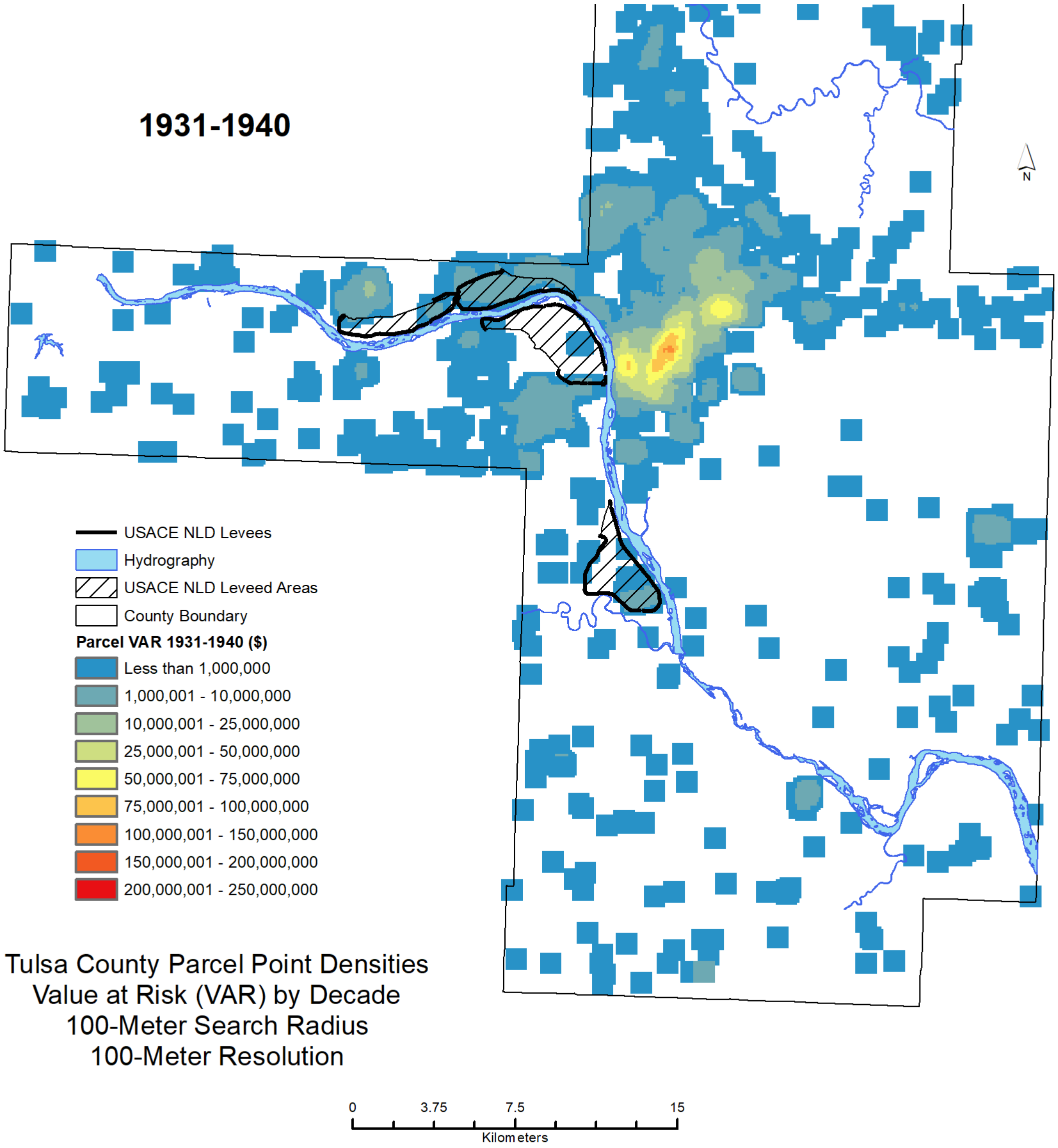


Figure C.107. Value at risk in Tulsa County, Oklahoma, 1931-1940.

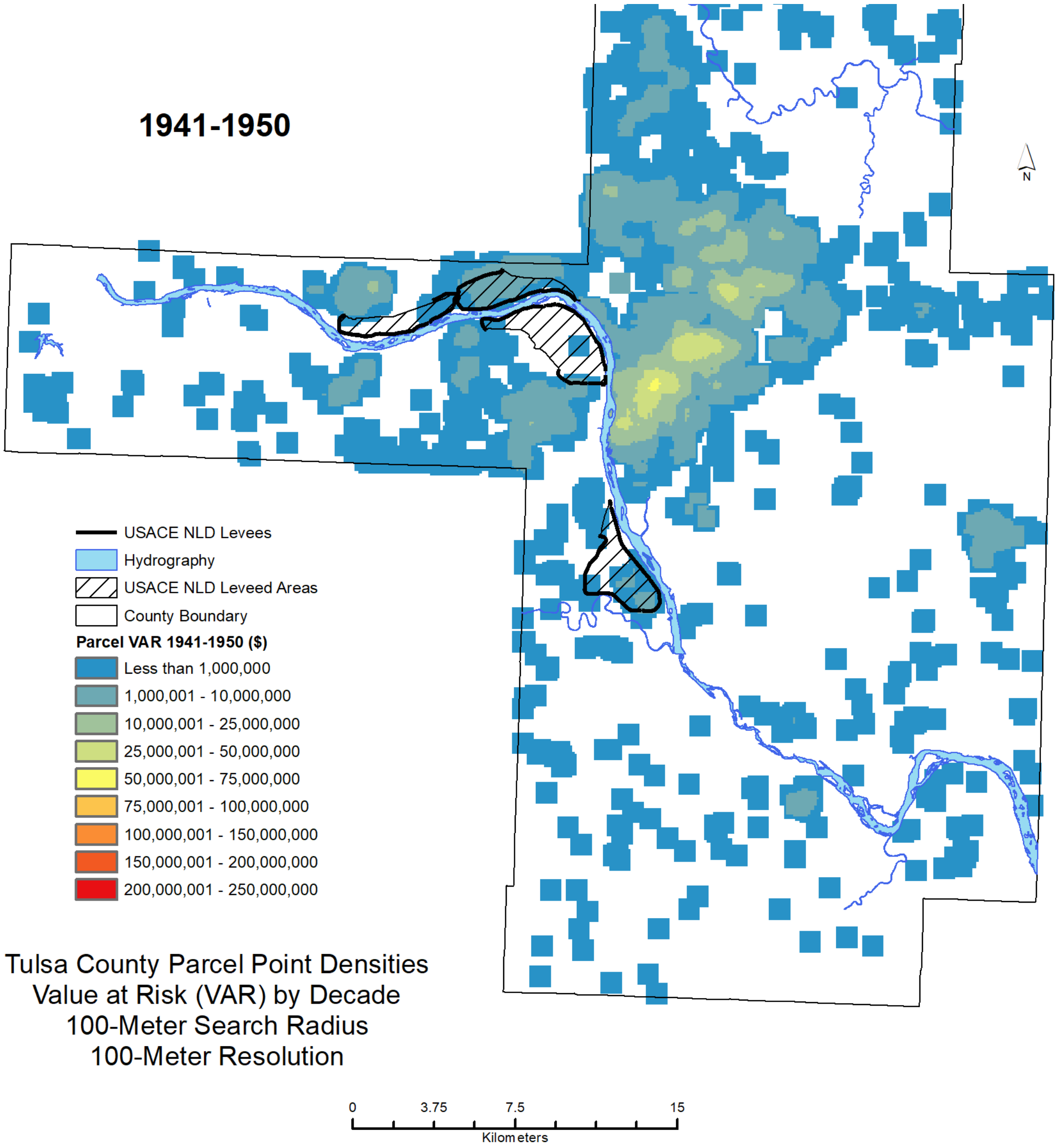


Figure C.108. Value at risk in Tulsa County, Oklahoma, 1941-1950.

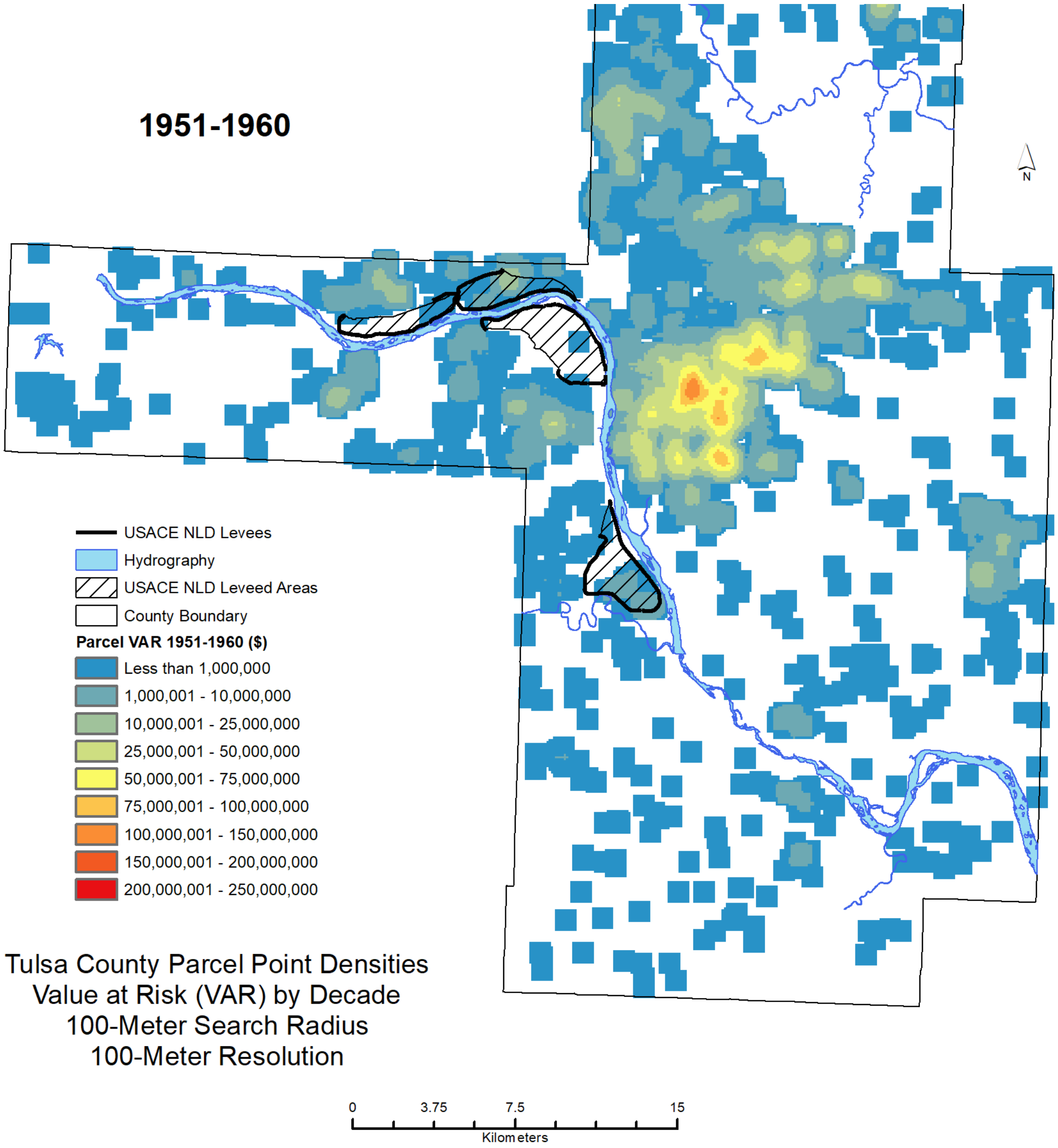


Figure C.109. Value at risk in Tulsa County, Oklahoma, 1951-1960.

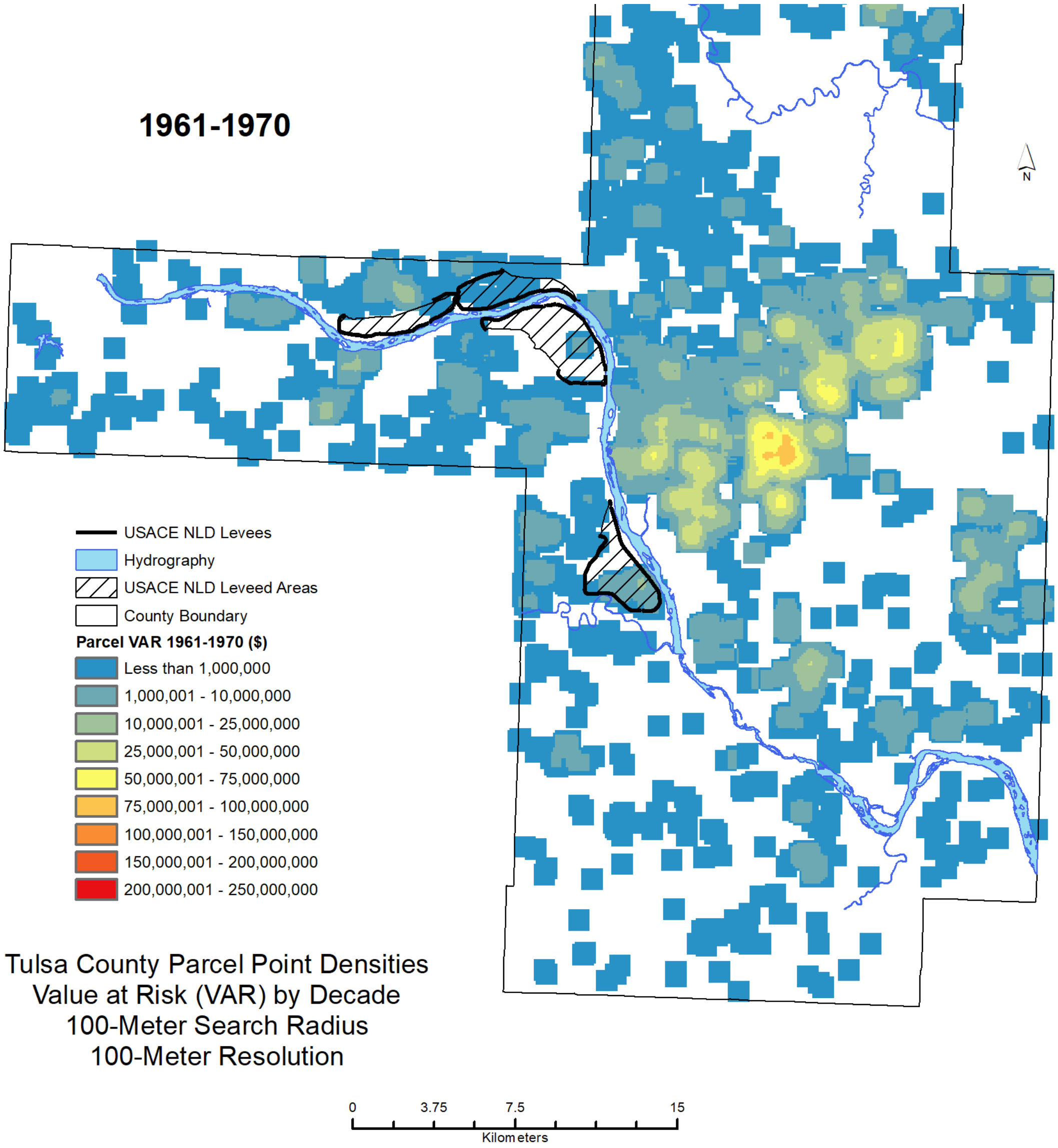


Figure C.110. Value at risk in Tulsa County, Oklahoma, 1961-1970.

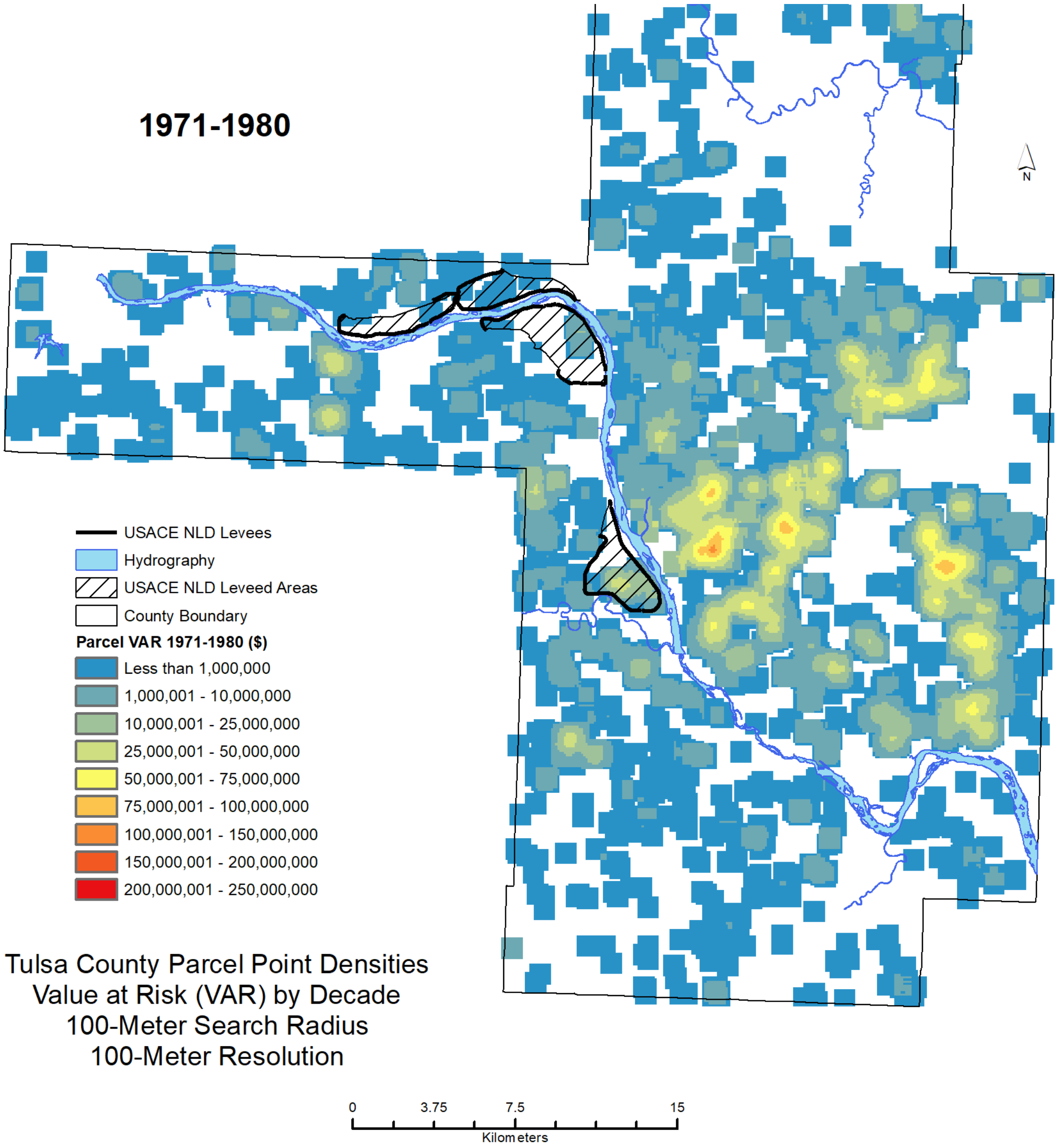


Figure C.111. Value at risk in Tulsa County, Oklahoma, 1971-1980.

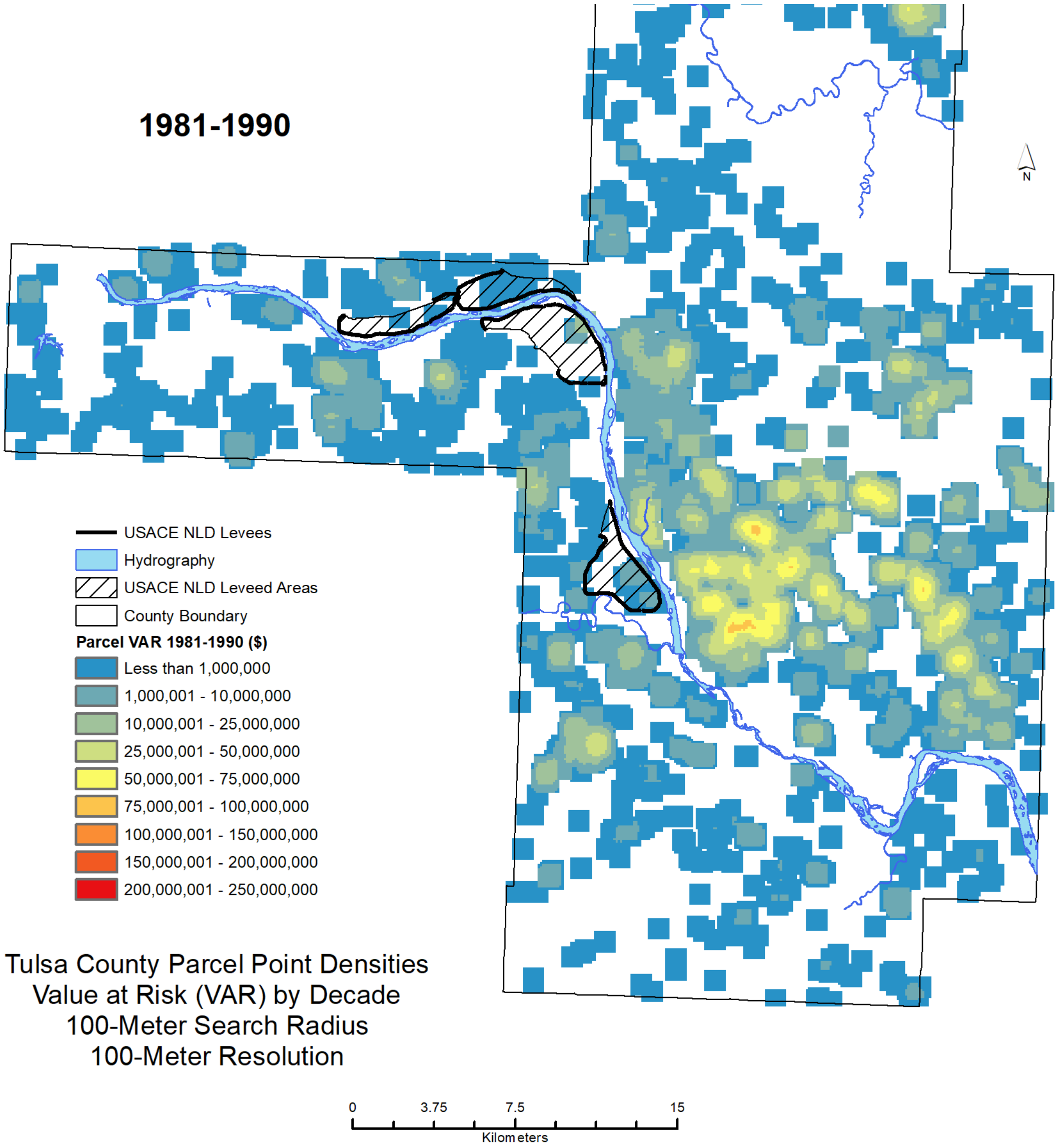


Figure C.112. Value at risk in Tulsa County, Oklahoma, 1981-1990.

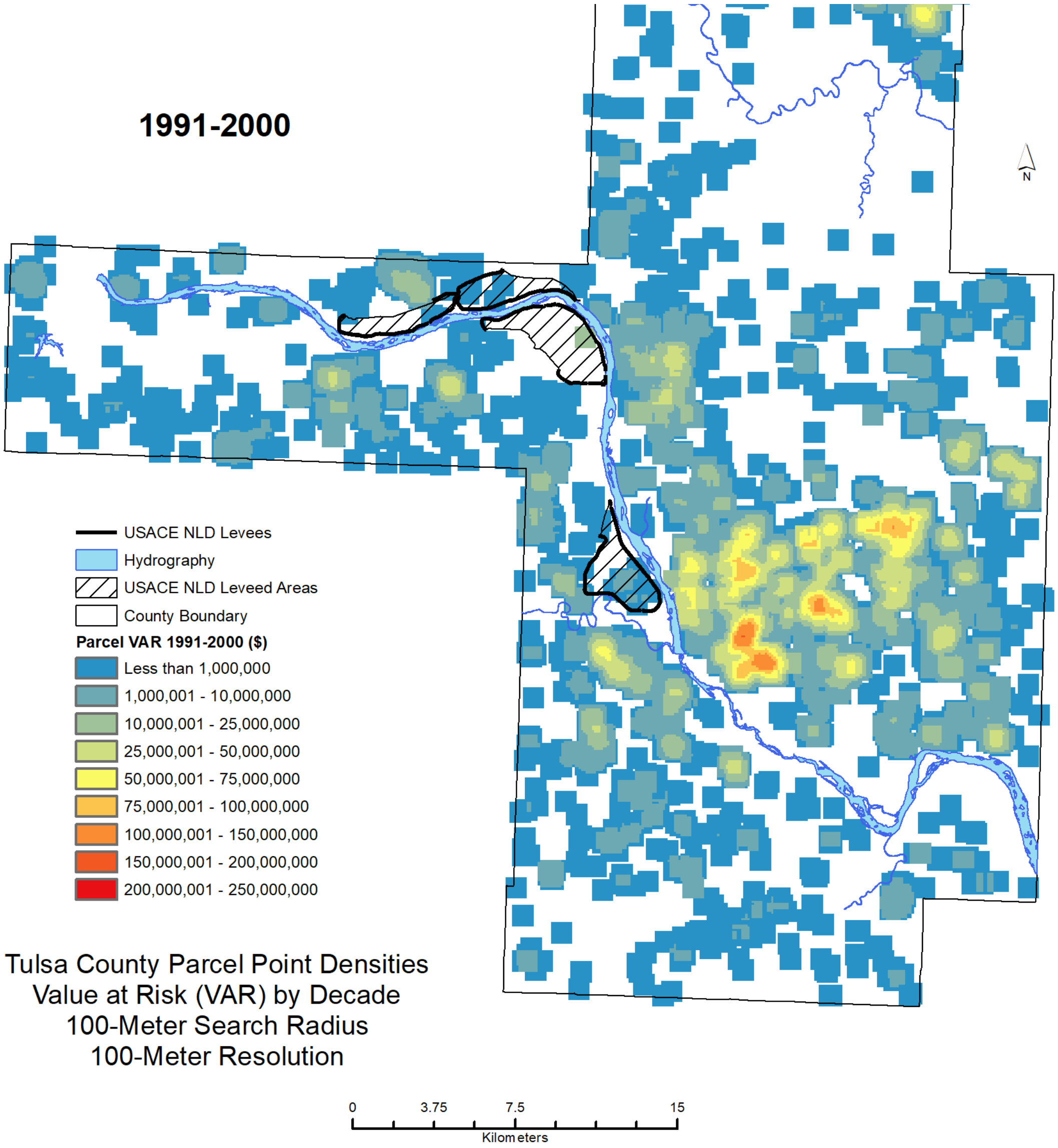


Figure C.113. Value at risk in Tulsa County, Oklahoma, 1991-2000.

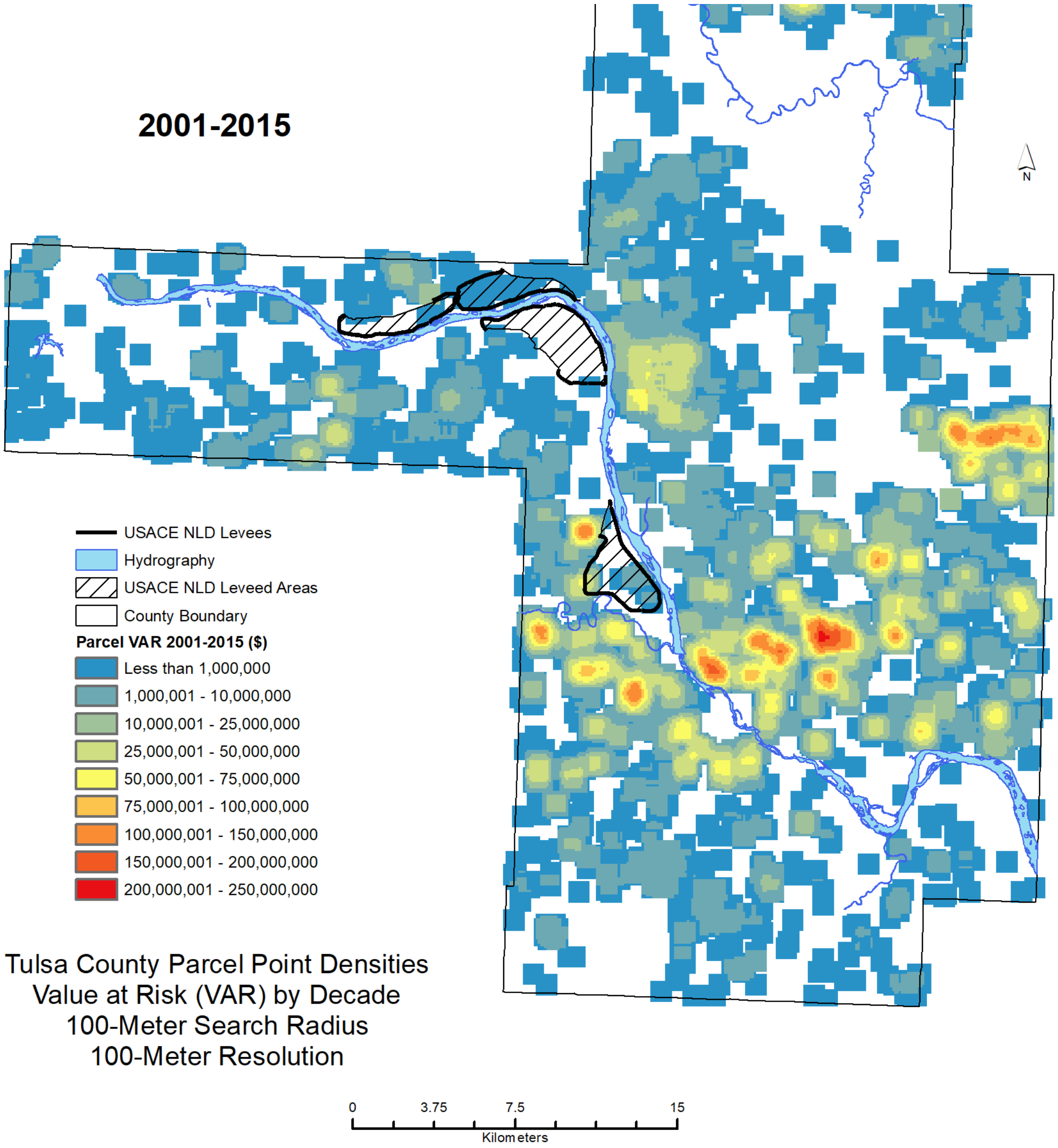


Figure C.114. Value at risk in Tulsa County, Oklahoma, 2001-2015.

C.5.1 Sacramento County, California Decadal Cumulative VAR Densities

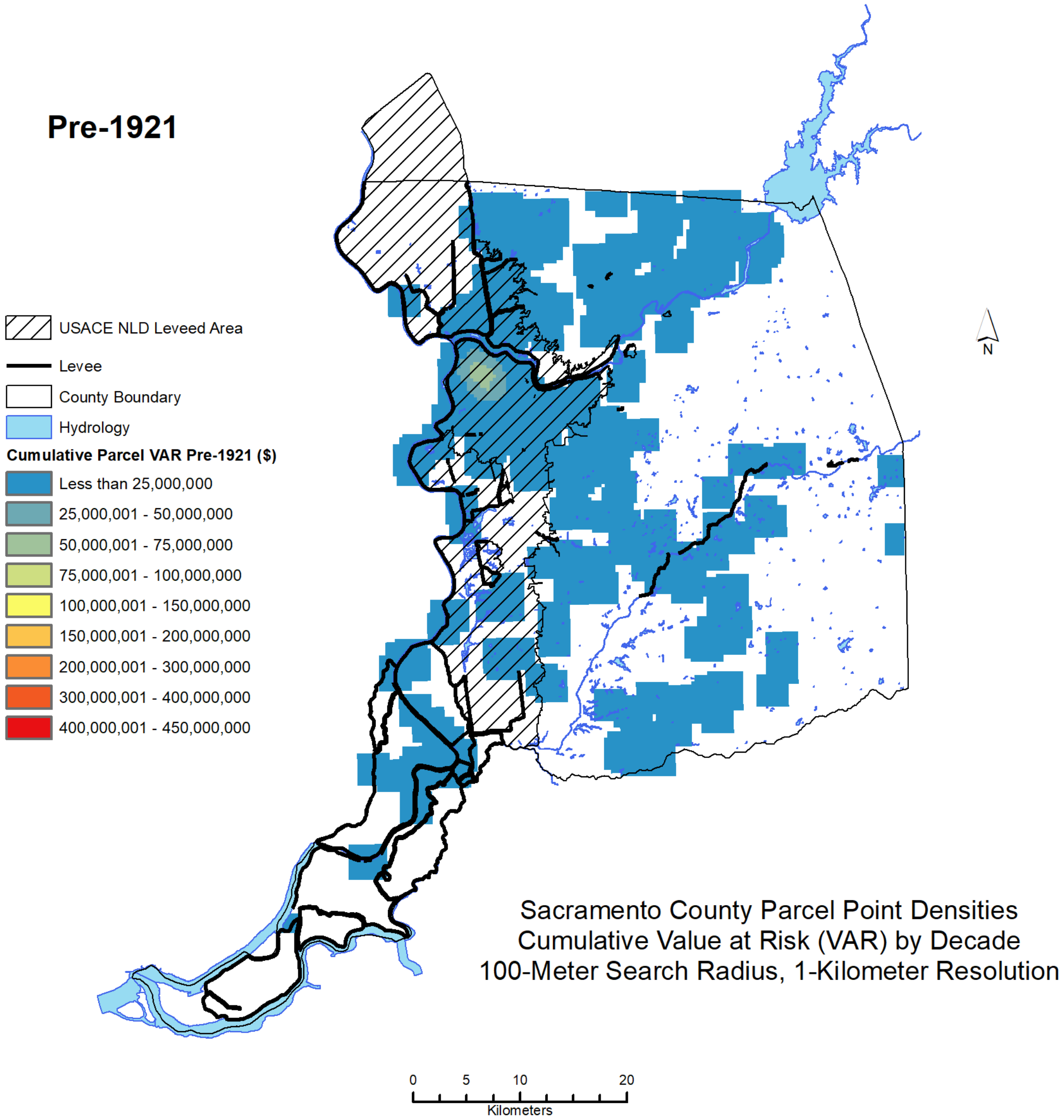


Figure C.115. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1920.

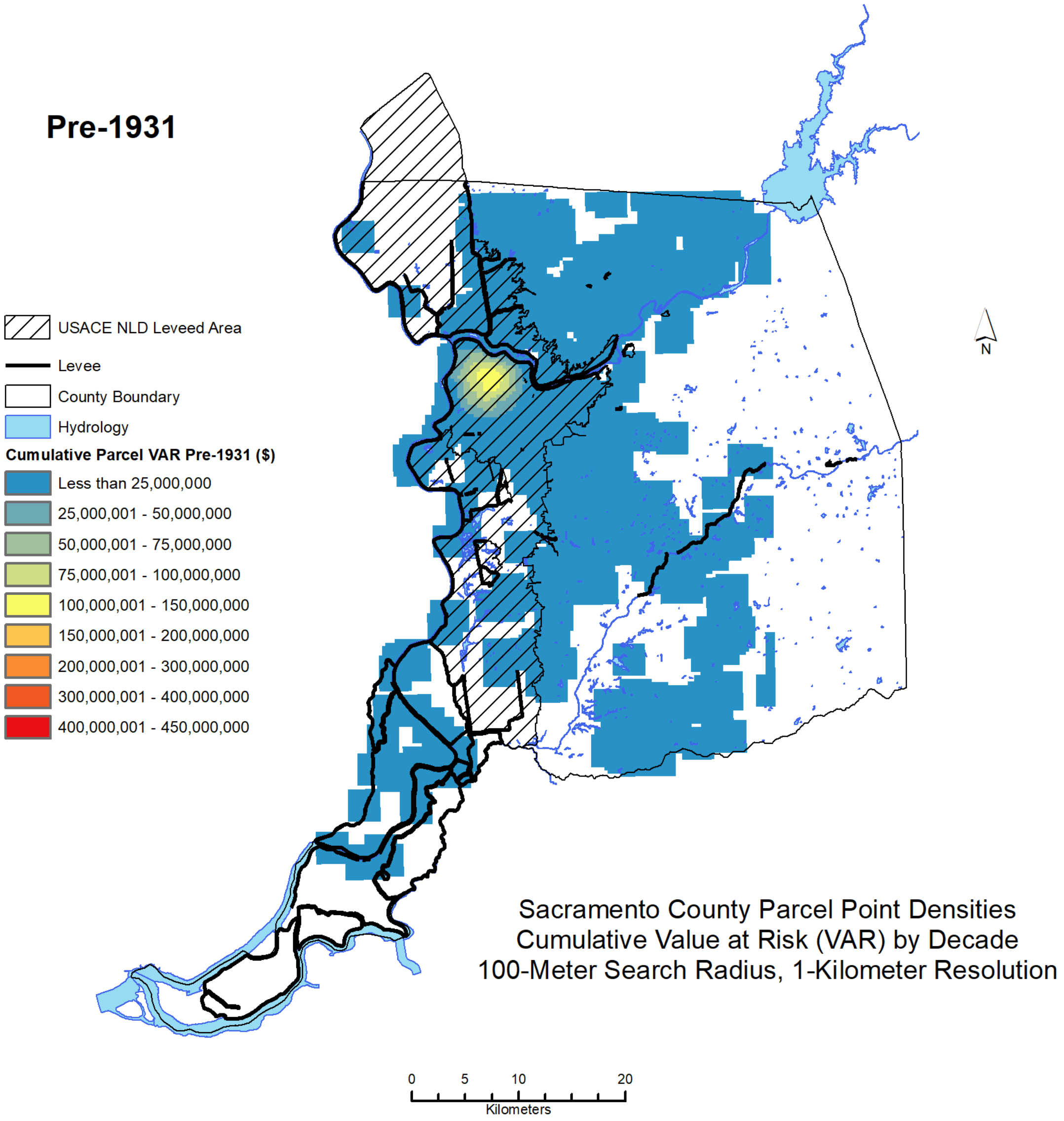


Figure C.116. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1930.

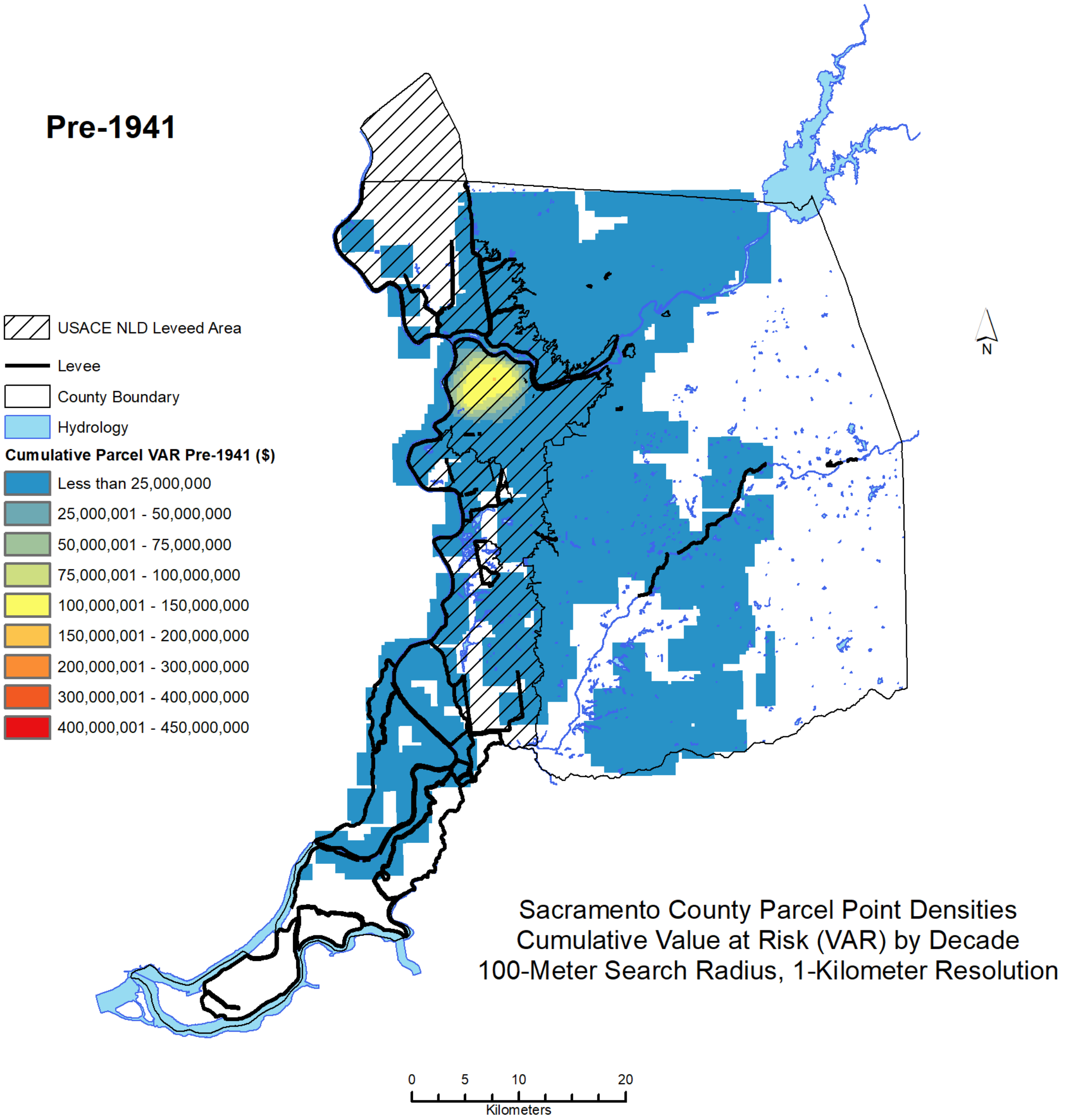


Figure C.117. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1940.

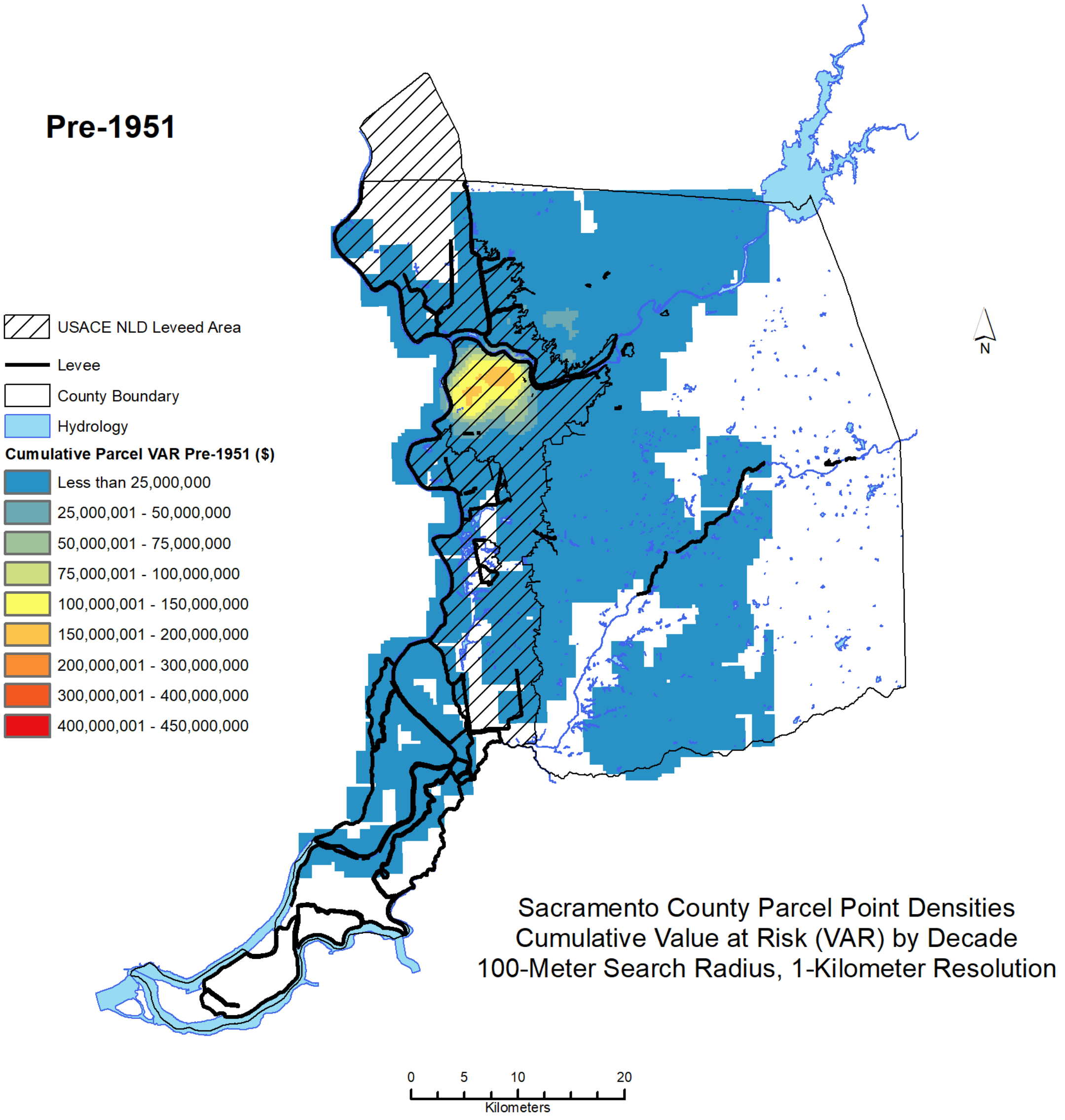


Figure C.118. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1950.

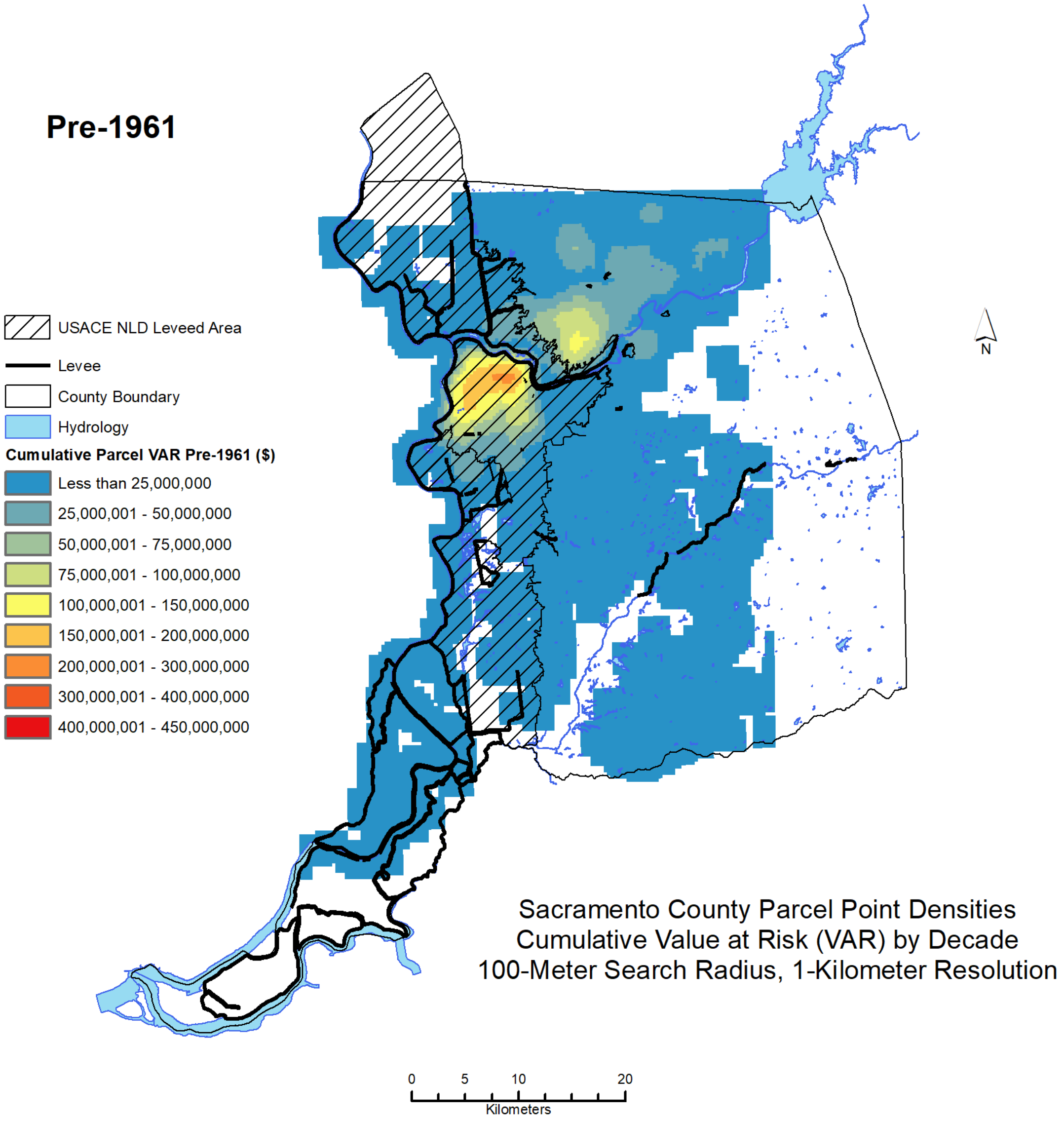


Figure C.119. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1960.

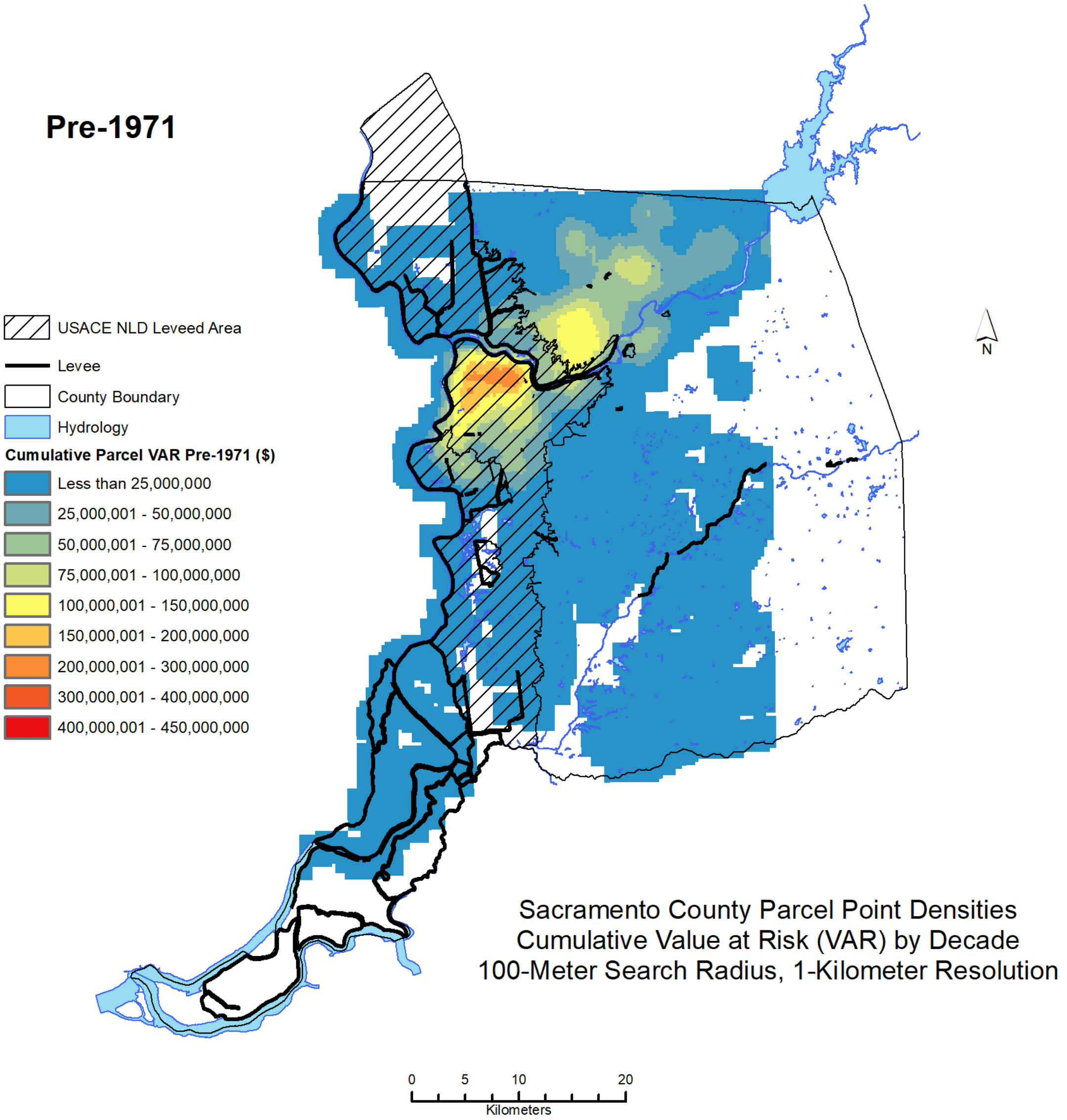


Figure C.120. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1970.

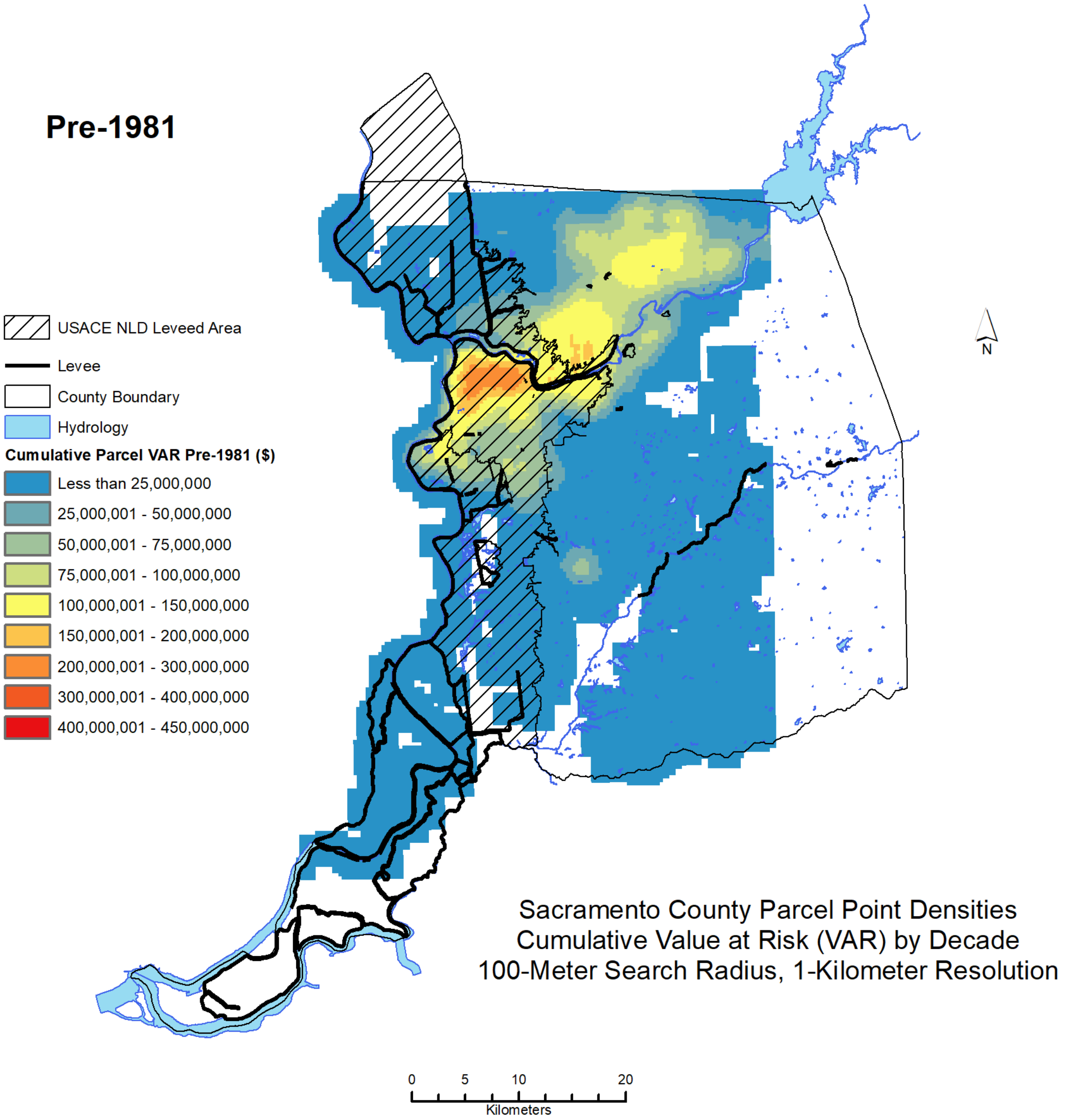


Figure C.121. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1980.

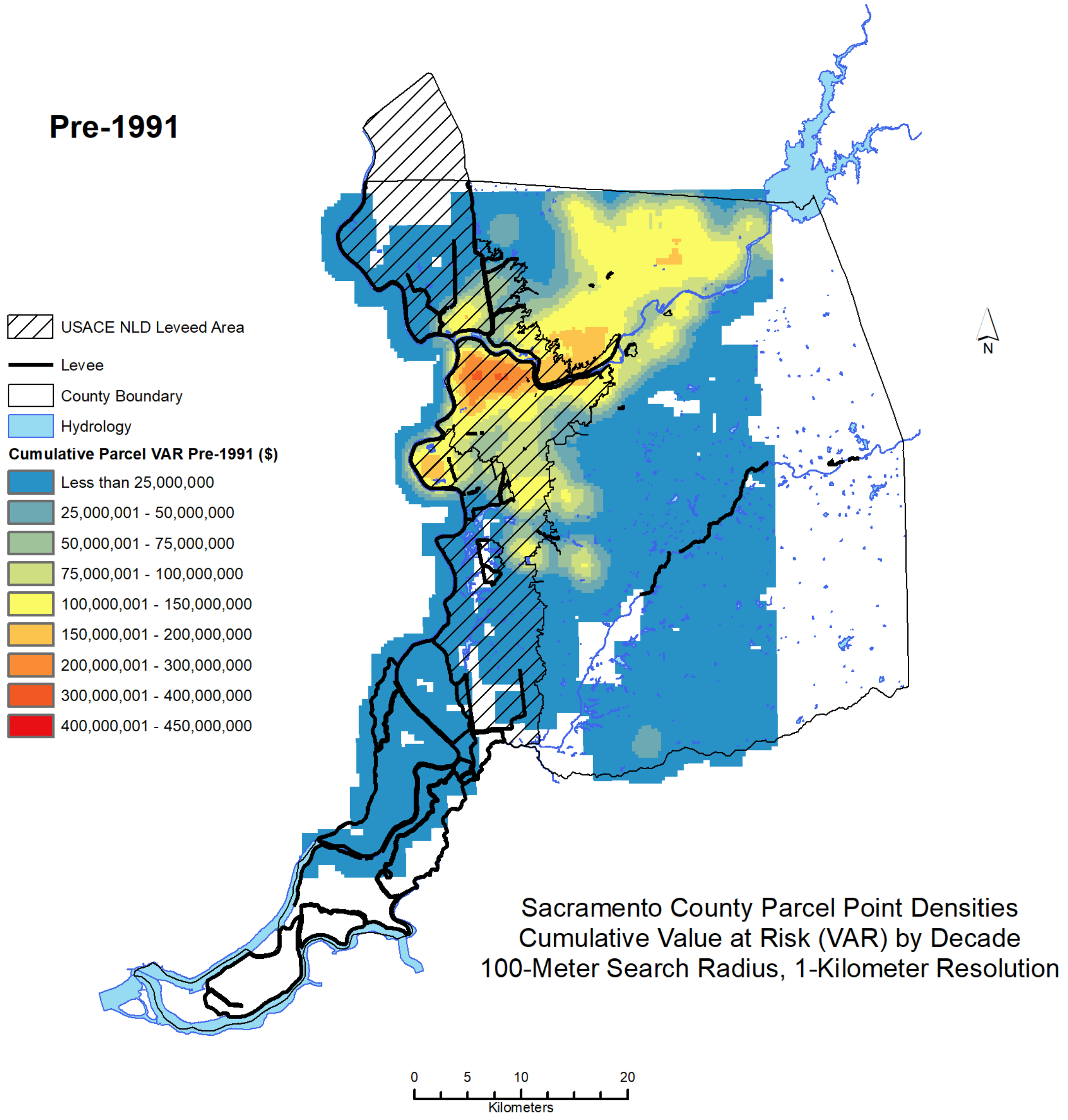


Figure C.122. Cumulative value at risk for Sacramento County, Oklahoma, 1851-1990.

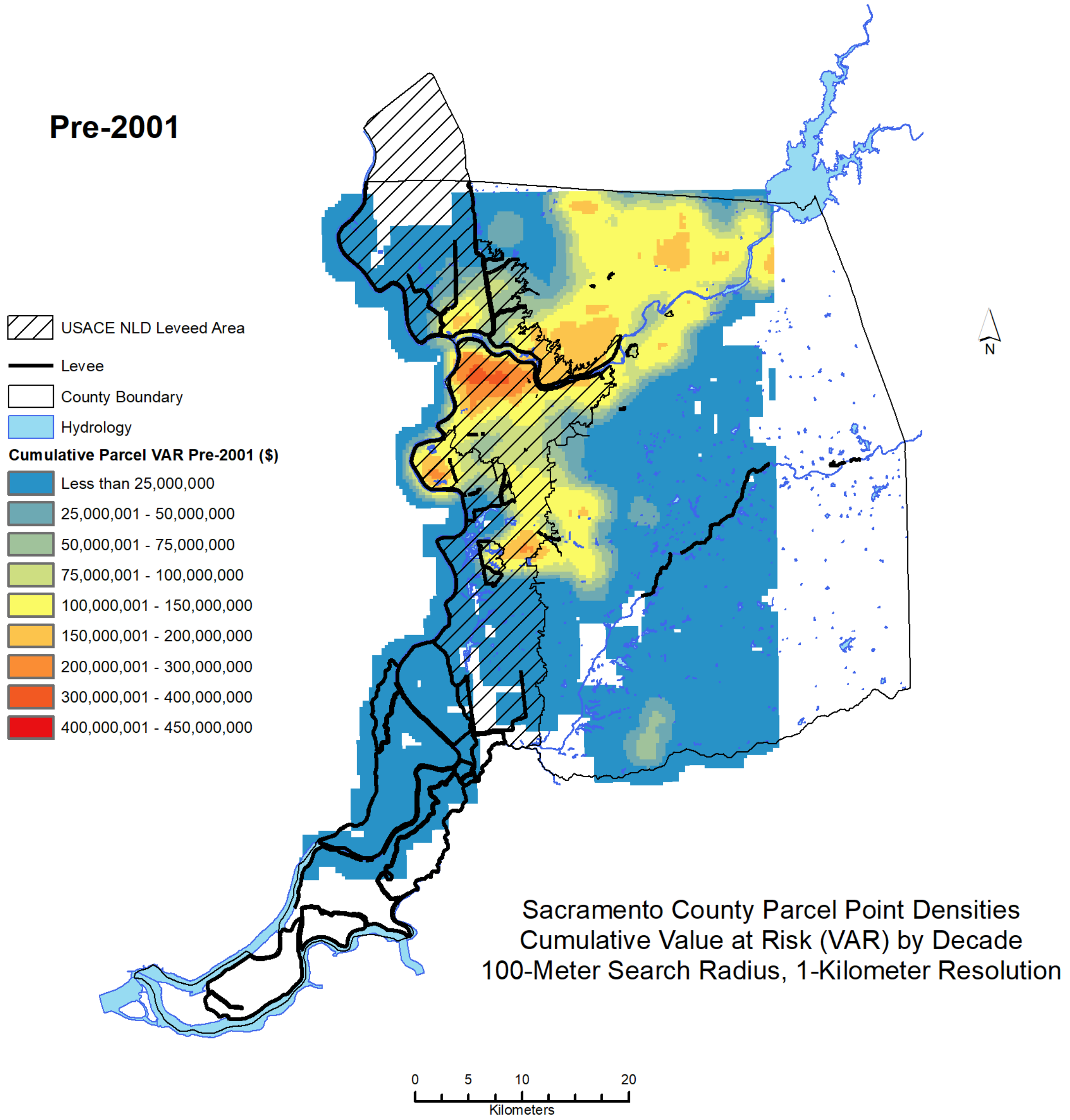


Figure C.123. Cumulative value at risk for Sacramento County, Oklahoma, 1851-2000.

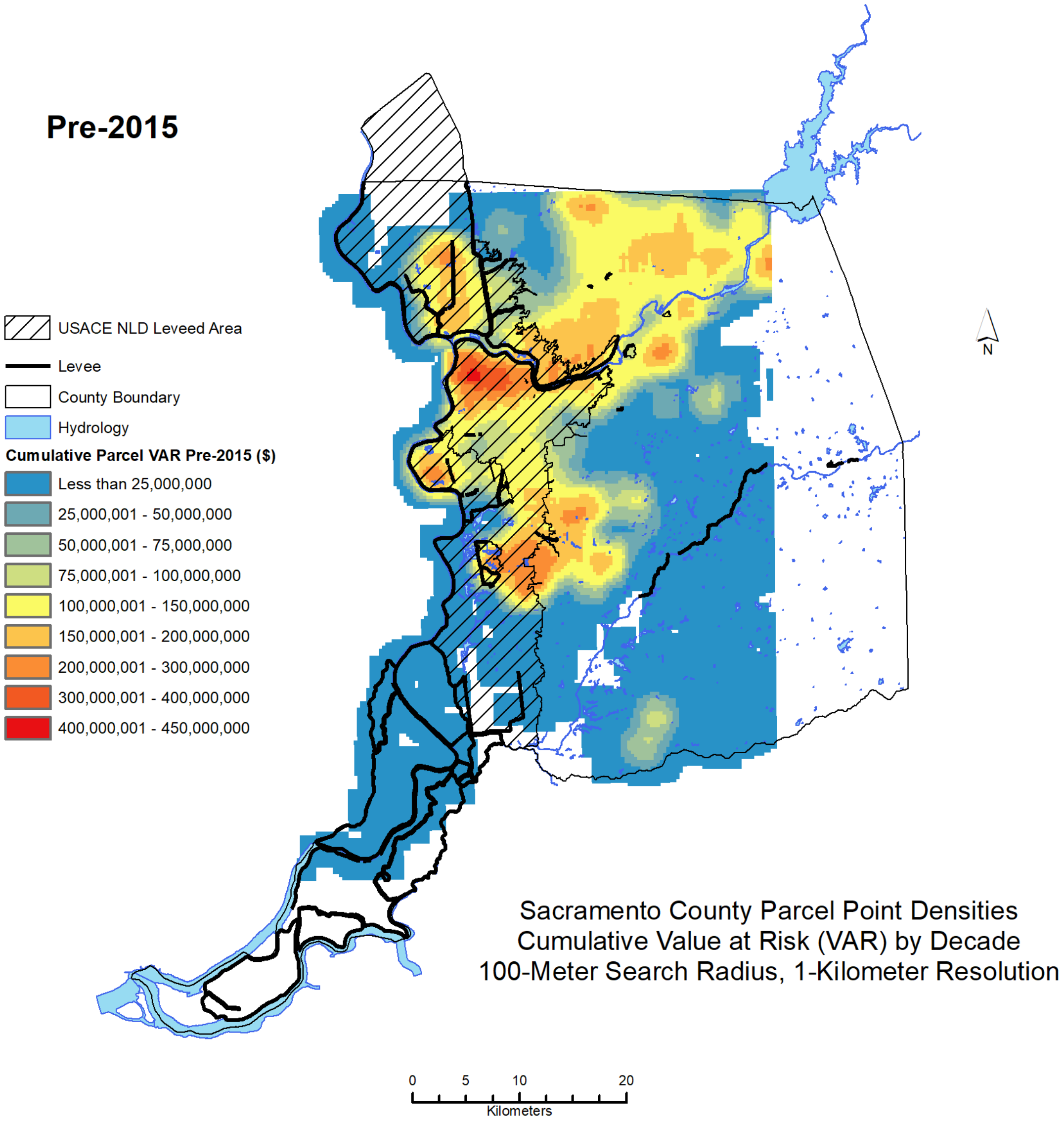


Figure C.124. Cumulative value at risk for Sacramento County, Oklahoma, 1851-2015.

C.5.2 Sacramento County, California Decadal VAR Densities

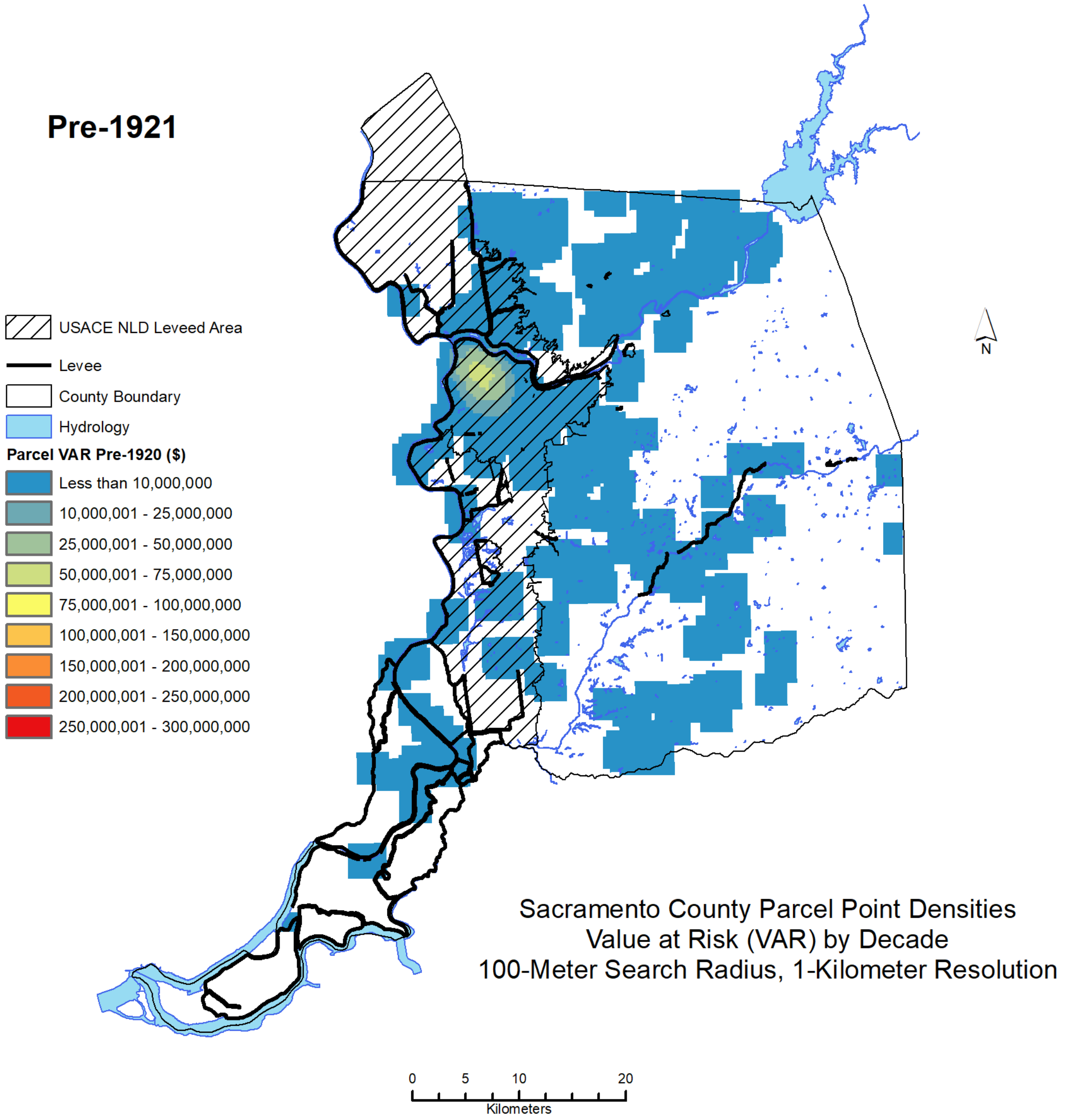


Figure C.125. Value at risk in Sacramento County, California, 1851-1920.

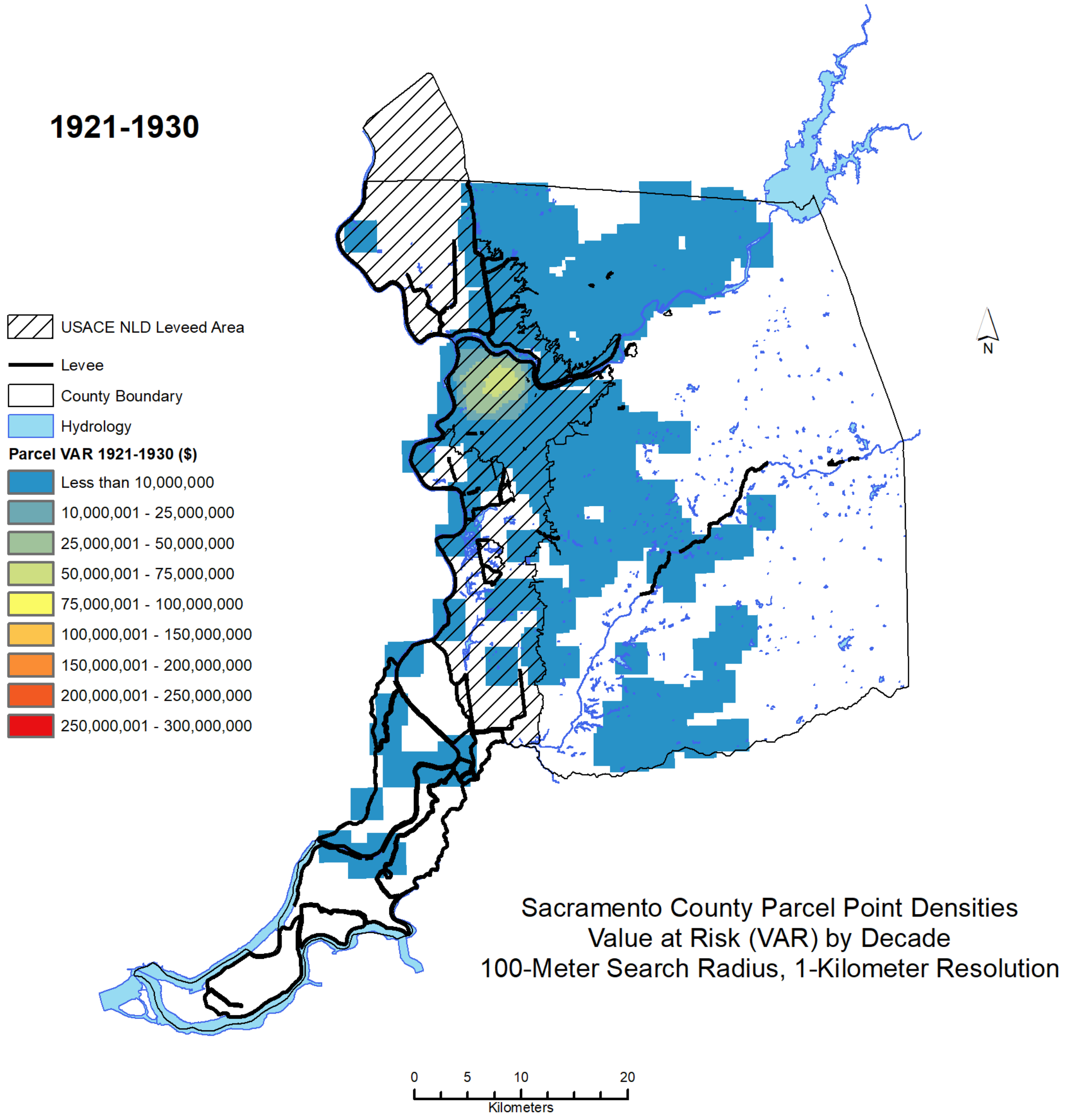


Figure C.126. Value at risk in Sacramento County, California, 1921-1930.

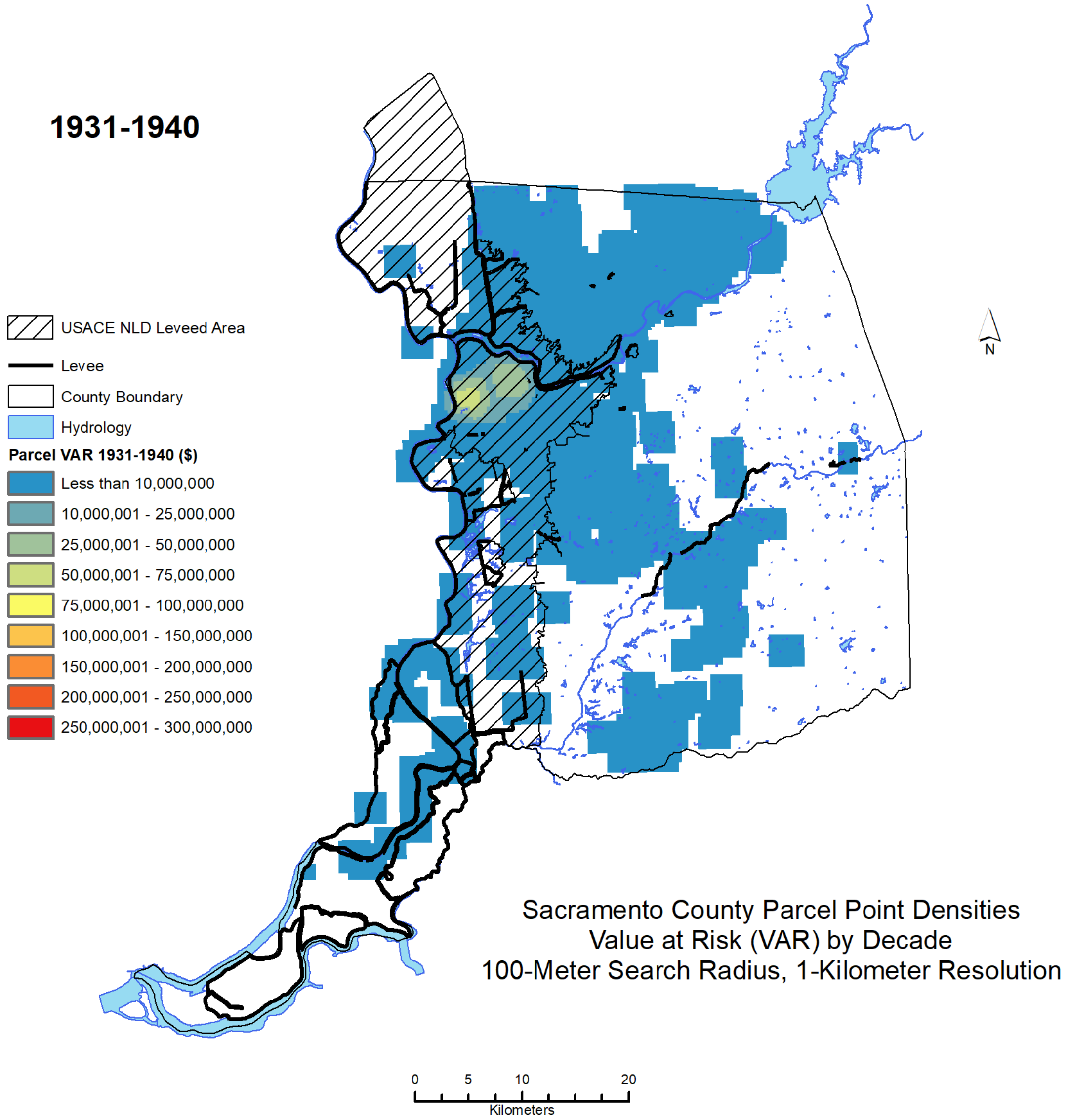


Figure C.127. Value at risk in Sacramento County, California, 1931-1940.

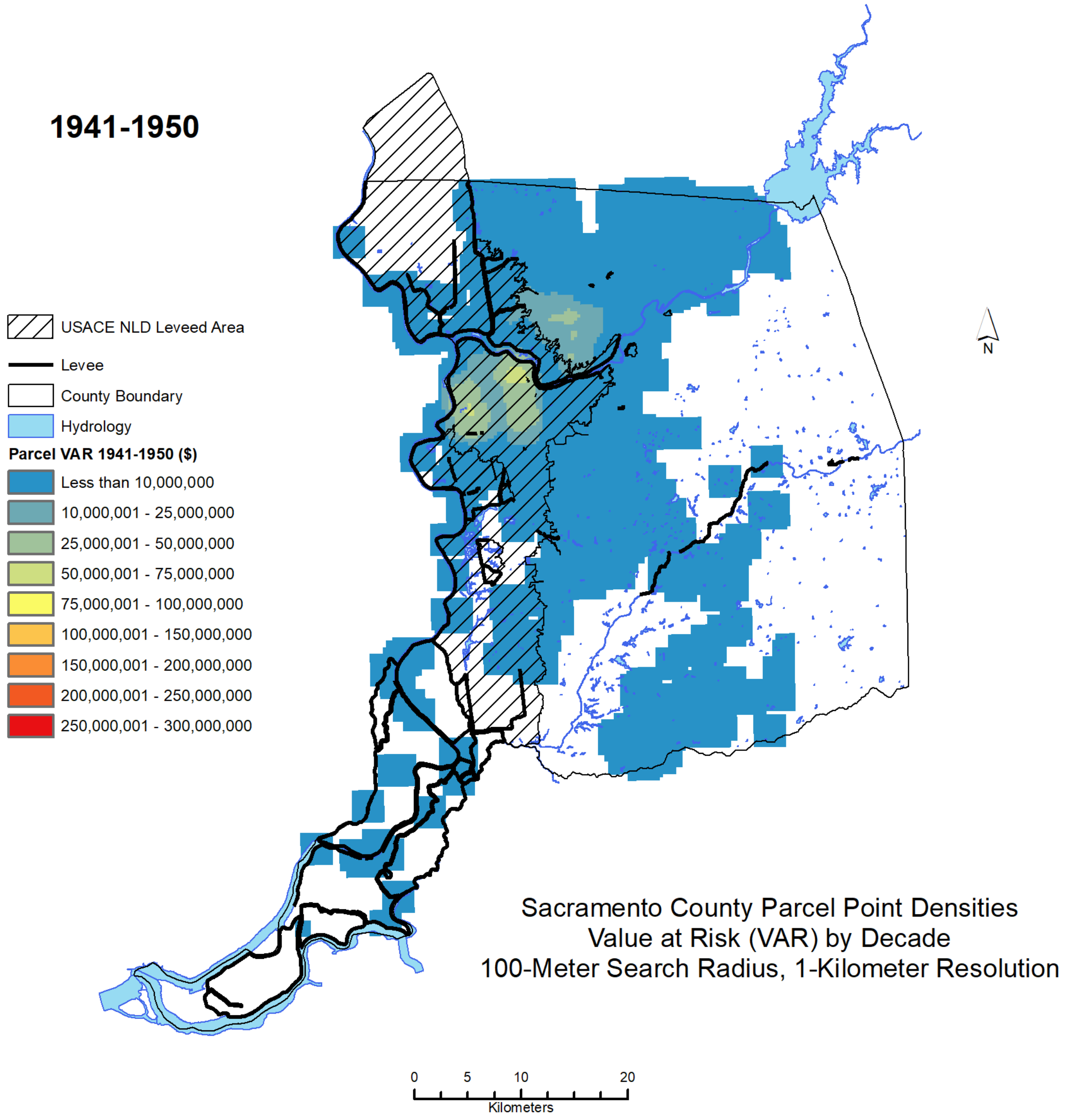


Figure C.128. Value at risk in Sacramento County, California, 1941-1950.

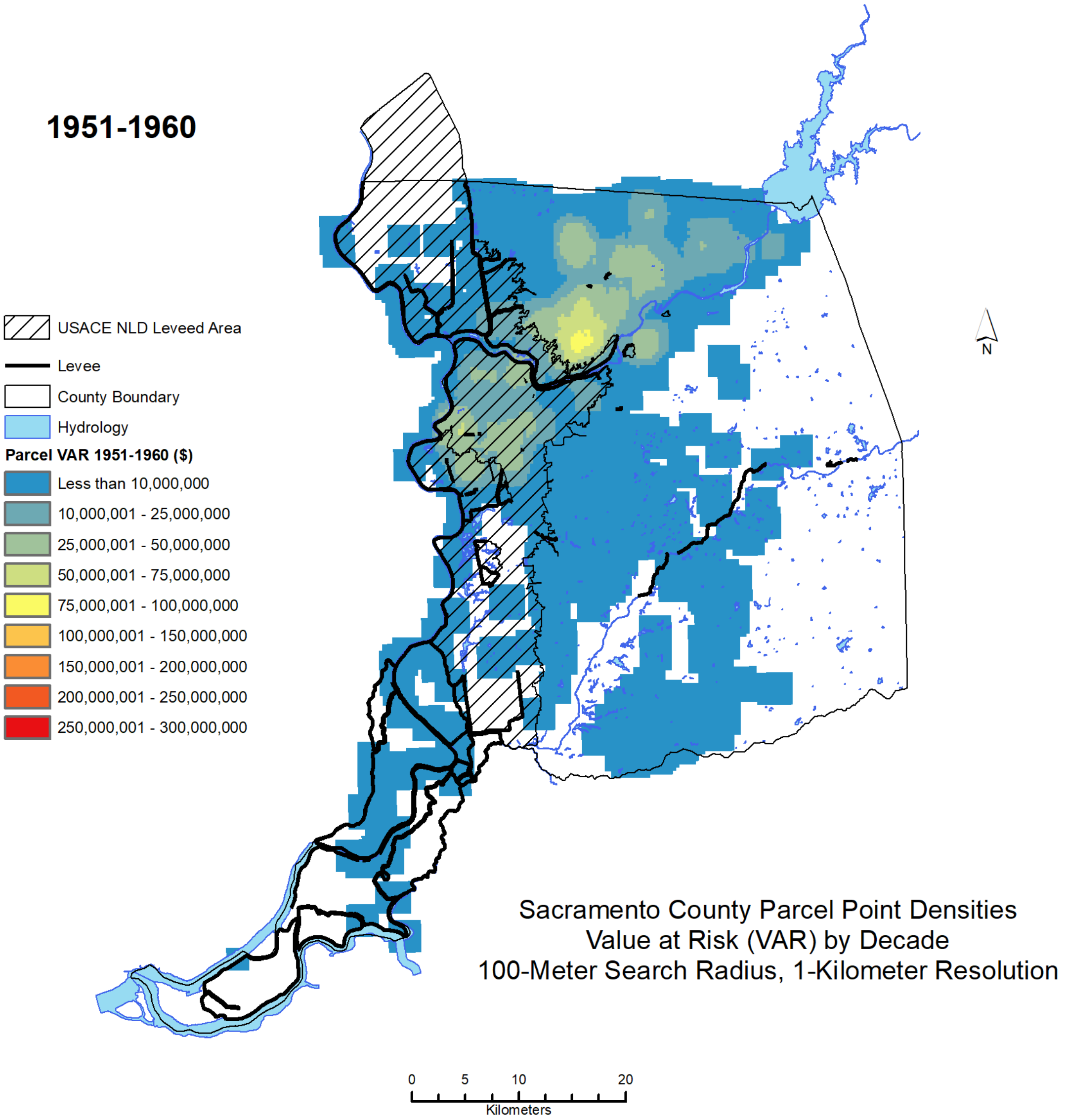


Figure C.129. Value at risk in Sacramento County, California, 1951-1960.

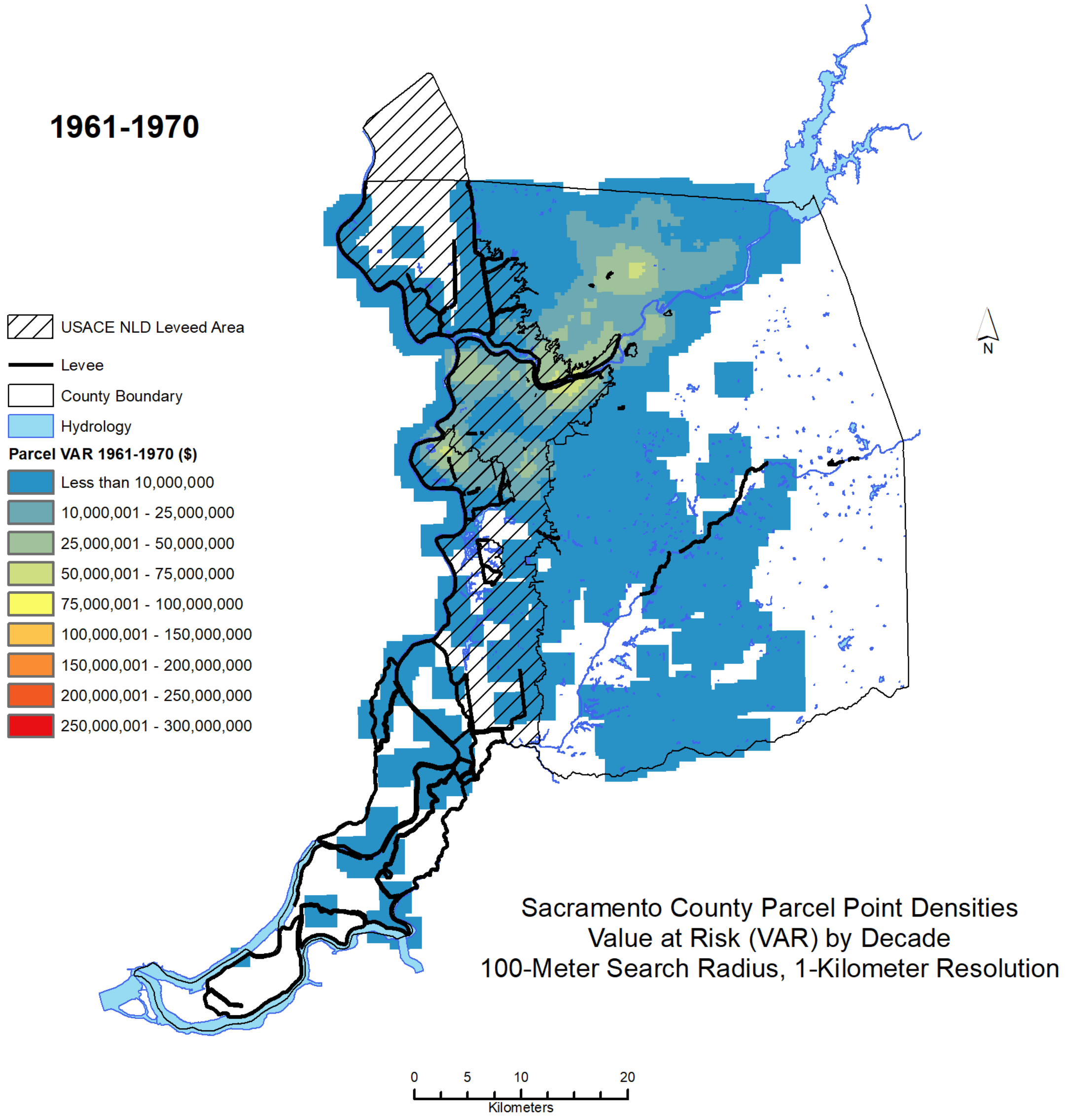


Figure C.130. Value at risk in Sacramento County, California, 1961-1970.

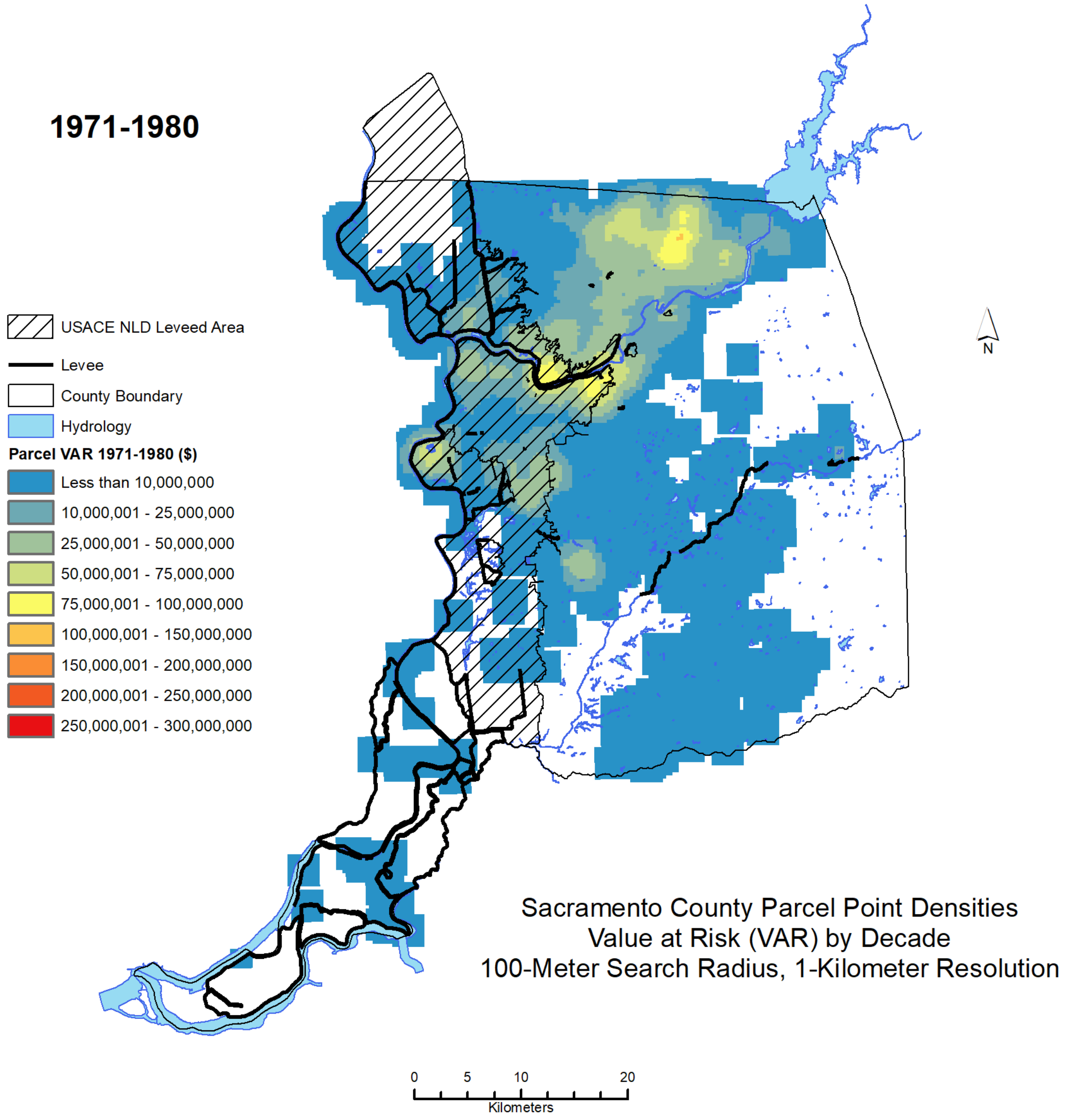


Figure C.131. Value at risk in Sacramento County, California, 1971-1980.

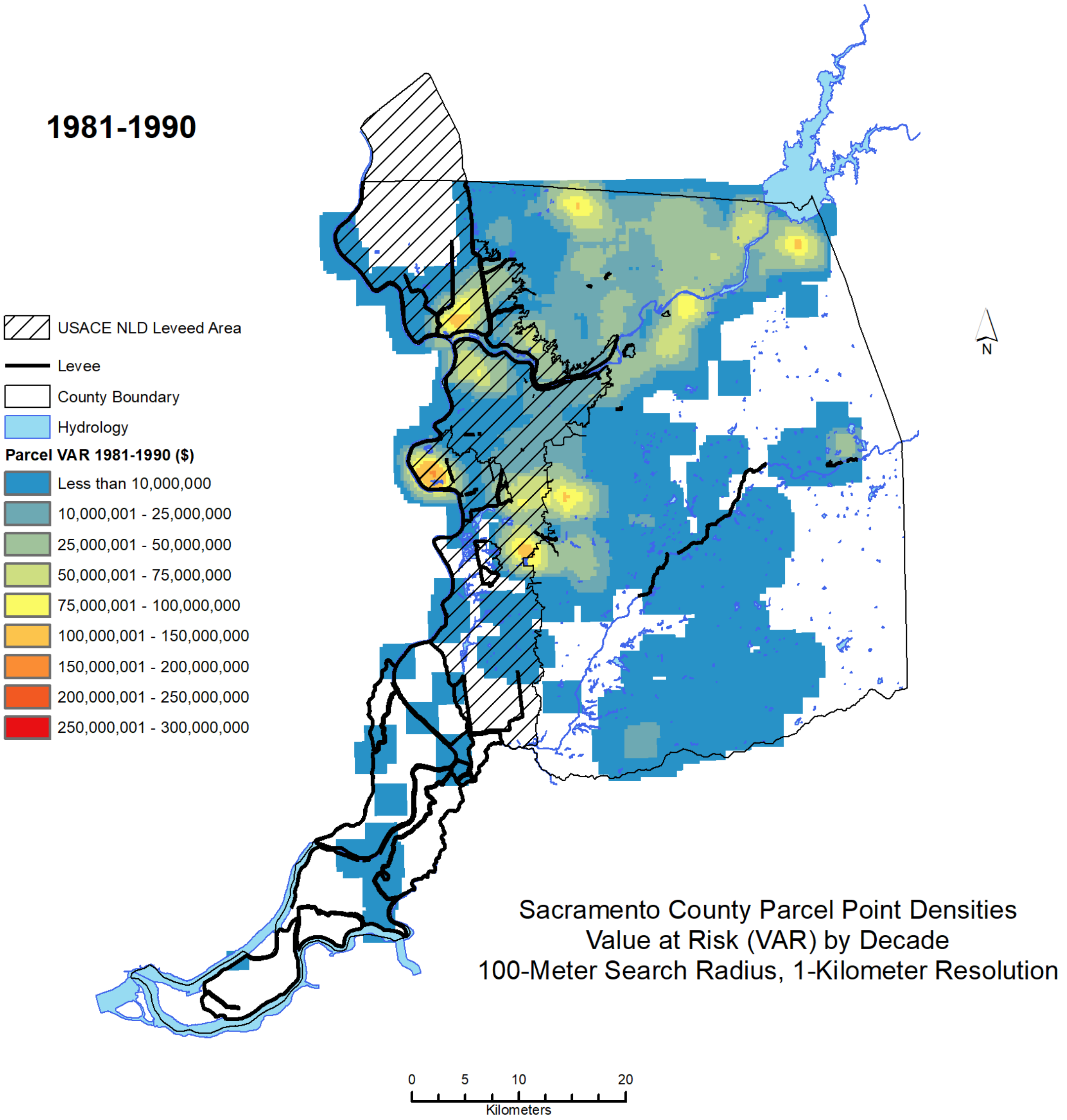


Figure C.132. Value at risk in Sacramento County, California, 1981-1990.

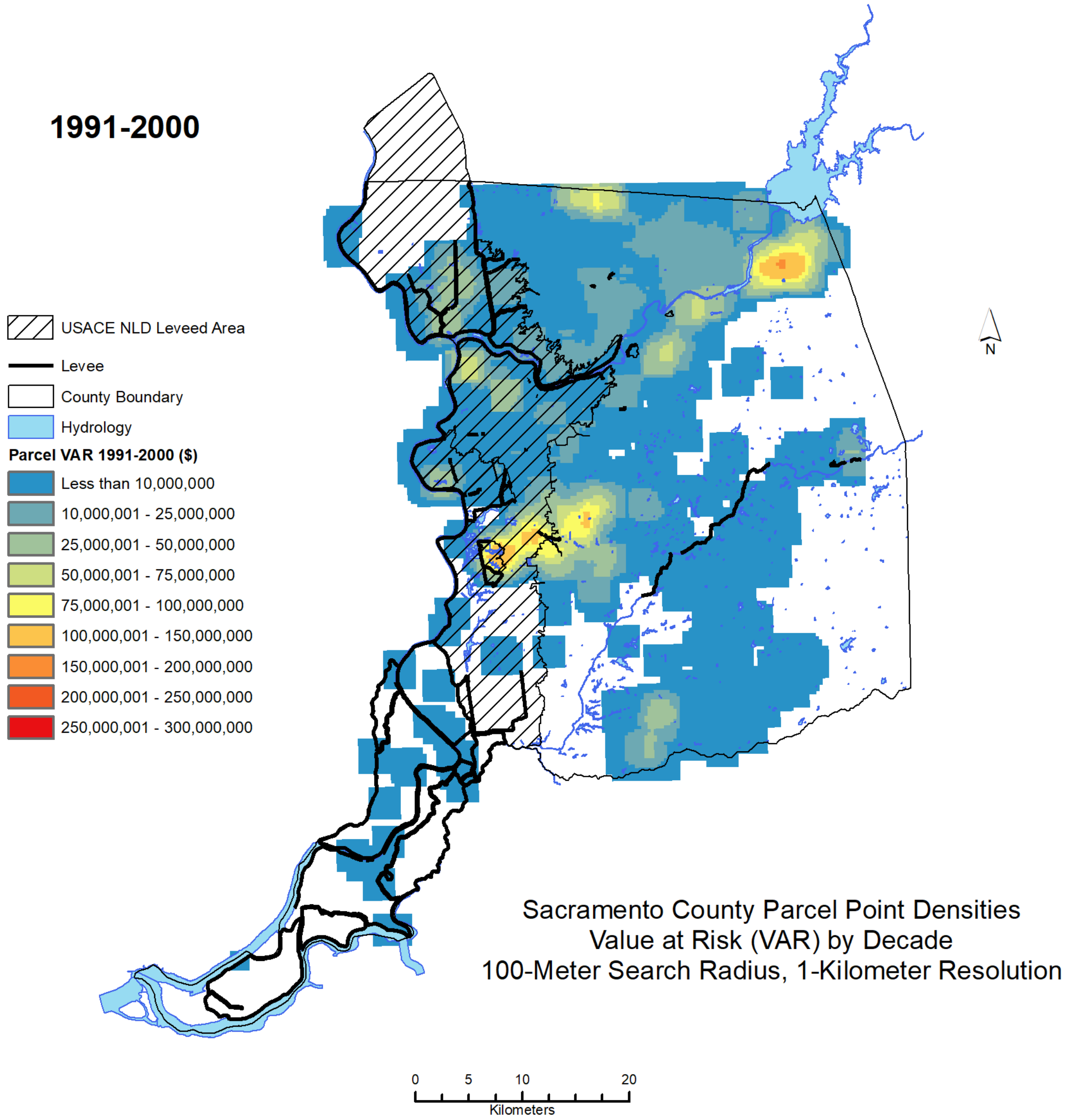


Figure C.133. Value at risk in Sacramento County, California, 1991-2000.

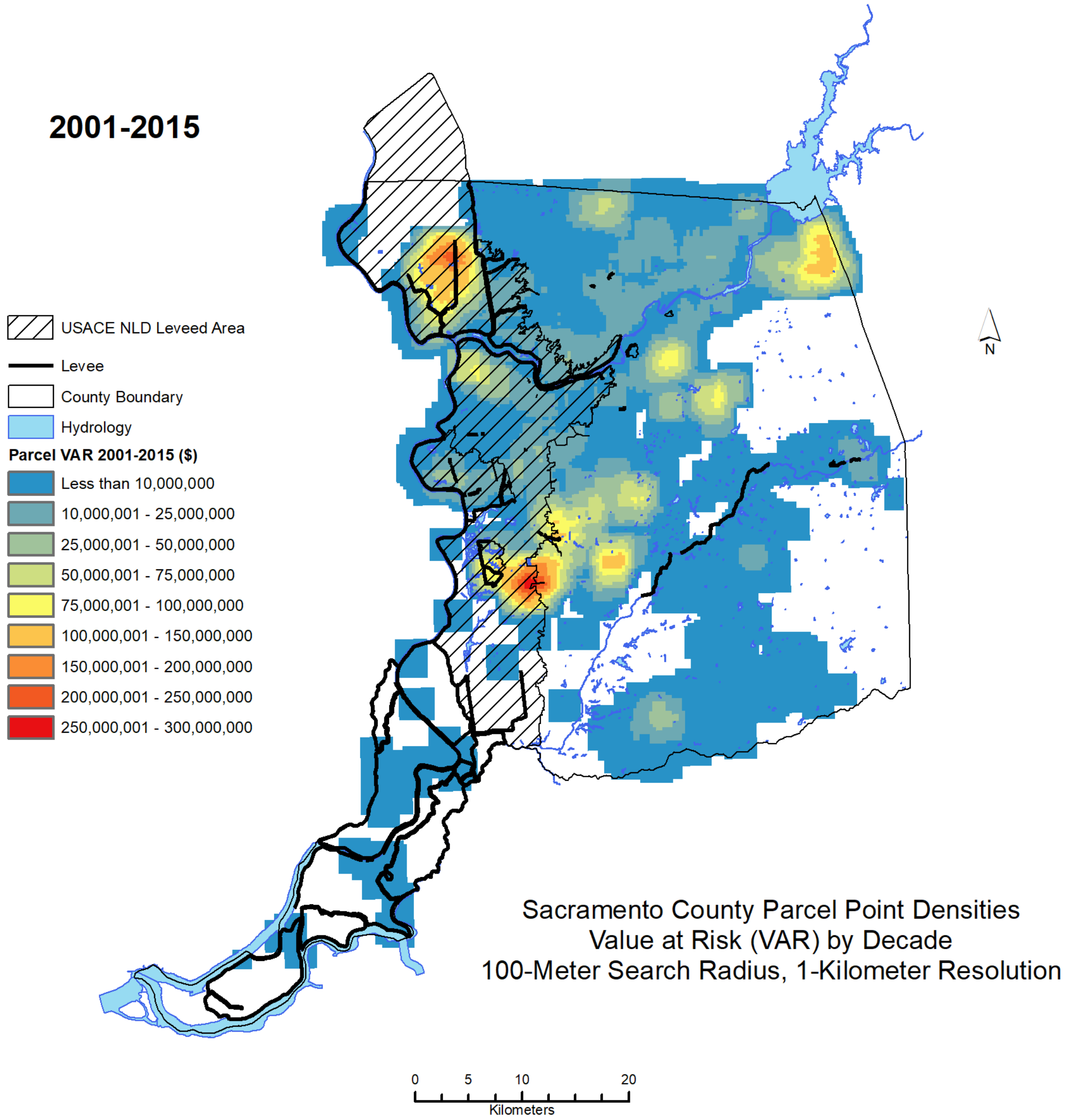


Figure C.134. Value at risk in Sacramento County, California, 2001-2015.

FLOOD ZONE REQUIREMENTS

ZONE	DEFINITION	RESIDENTIAL CONSTRUCTION (Includes all single / multi. family dwelling units)	COMMERCIAL CONSTRUCTION (Excludes all residential dwelling units)
A	No base flood elevations determined (base flood elevation to be determined by Department of Utilities).	NEW CONSTRUCTION AND SUBSTANTIAL IMPROVEMENT: ☐ Elevate lowest floor, including basement, a minimum of one foot (1') above the base flood elevation or depth number. If no depth is specified for the zone AO, elevate two feet (2') above the highest adjacent grade. ☐ Hold Harmless Agreement regarding Risk of Flooding ☐ Elevation Certificate	NEW CONSTRUCTION AND SUBSTANTIAL IMPROVEMENT: ☐ Elevate lowest floor, including basement or floodproof the building to a minimum of one foot (1') above the base flood elevation or depth number. If no depth is specified for the zone AO, elevate two feet (2') above the highest adjacent grade. ☐ Hold Harmless Agreement regarding Risk of Flooding ☐ Elevation Certificate ☐ Floodproofing Certificate (when floodproofing provided)
AE	Base flood elevations determined [Example ZONE AE (EL 33)].		
AH	Flood depths of 1 to 3 feet (Usually areas of ponding); base flood elevations determined [Example ZONE AH (EL 17)].		
AO	Flood depths of 1 to 3 feet (Usually sheet flow on sloping terrain; average depths determined. For areas of alluvial fan flooding; velocities determined [Example ZONE AO (DEPTH 2)].		
Magpie Creek 100yr	See Magpie Creek Floodplain Map (Local Floodplain not FEMA)		
A99	To be protected from 100-year flood by Federal protection system under construction; no base flood elevations determined.	NEW CONSTRUCTION AND SUBSTANTIAL IMPROVEMENT: ☐ Hold Harmless Agreement Regarding Risk of Flooding on Property	
AR	Area of special flood hazard which results from the decertification of a previously accredited flood protection system which is determined to be in the process of being restored to provide 100-year or greater level of flood protection [Examples ZONE AR, ZONE AR (EL 18), ZONE AR (DEPTH 2)].	NEW CONSTRUCTION: ☐ Elevate lowest floor, including basement, to the lower of the following: a. Three feet(3') above the highest adjacent grade b. Base flood elevation or depth number ☐ Hold Harmless Agreement regarding the Risk of Flooding ☐ Elevation Certificate SUBSTANTIAL IMPROVEMENT: ☐ Hold Harmless Agreement regarding the Risk of Flooding on Property	NEW CONSTRUCTION: ☐ Elevate lowest floor, including basement, or floodproof the building to the lower of the following: a. Three feet(3') above the highest adjacent grade b. Base flood elevation or depth number ☐ Hold Harmless Agreement regarding the Risk of Flooding ☐ Elevation Certificate SUBSTANTIAL IMPROVEMENT: ☐ Hold Harmless Agreement regarding the Risk of Flooding on Property
X (SHADED	Areas of 500-year flood: areas of 100-year flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 100-year flood.	None	
X	Areas determined to be outside the 500-year floodplain.	None	

City of
SACRAMENTO
Community Development

300 Richards Blvd., 3rd Floor
Sacramento, CA 95811
Help Line: 916-264-5011
CityofSacramento.org/dsd

HOLD HARMLESS AGREEMENT REGARDING THE RISK OF FLOODING TO REAL PROPERTY

(New Construction or Substantial Improvements in Special Flood Hazard Area)

RECITALS

A. The undersigned have filed for a building permit to construct a new structure or to substantially improve an existing structure (the "New Construction") located at ______________________________________, APN _____________ (the "Property"). The New Construction is described in the undersigned's construction plans submitted to the City of Sacramento and incorporated herein by this reference.

B. The New Construction may be subject to flooding hazards due to its location in a 100-year floodplain, as described in a Flood Insurance Rate Map (FIRM) prepared by the Federal Emergency Management Agency (FEMA).

C. Despite the potential for flood-related property damage, and with full knowledge of the potential for flood-related property damage, the undersigned intend to construct the New Construction.

D. Section 15.108.040 of the Sacramento City Code requires the undersigned to execute this Agreement acknowledging and assuming the risk that the New Construction may be subject to flood-related property damage.

AGREEMENT

In consideration of the issuance of a building permit for the New Construction, the undersigned agree as follows:

1. Recitals Incorporated. The foregoing Recitals are incorporated by this reference as if fully set forth at this place.

2. Flood-Related Property Damage. For purposes of this Agreement, the term "flood- related property damage" shall mean any damage to real or personal property of any kind, including but not limited to vehicles, due to flooding resulting from water flowing in or from the channels or tributaries of the Sacramento River, American River, Dry Creek, Arcade Creek, Morrison Creek or Natomas East Main Drainage Canal levee systems.

3. Acknowledgment and Assumption of Risk. The undersigned understand and acknowledge and expressly assume the risk that the New Construction may be subject to flood-related property damage, and the undersigned hereby elect to voluntarily proceed with the New Construction with full knowledge that this may be hazardous to the undersigned, the New Construction and the Property. The undersigned voluntarily assume full responsibility for any risk of flood-related property damage arising from the undersigned proceeding with the New Construction.

4. <u>Waiver of Property Damage Claims.</u> The undersigned unconditionally waive any and all flood-related property damage claims asserting liability on the part of the City, or its officers, agents or employees premised on the issuance of a permit for the New Construction, whether or not the issuance of this permit is due to the negligence of the City or its officers, agents or employees.

5. <u>Notice.</u> In the event the undersigned convey the Property or New Construction to a third party, or grant a possessory interest in the New Construction to a third party, the undersigned expressly agree to include the following notice provision in the purchase agreement or lease (Note: the blanks shown below should not be filled in now, but must be filled in with the applicable references in the actual notice provision that is included in the purchase agreement):

> [Transferee/Lessee] expressly acknowledges and assumes the risk that the property located at ____________, APN _______________, may be subject to flooding due to its location in a 100-year floodplain.
>
> [Transferee/Lessee] unconditionally waives any and all flood-related property damage claims asserting liability on the part of the City of Sacramento or its officers, agents or employees premised on the issuance of a permit for construction of the New Construction, whether or not the issuance of this permit is due to the negligence of the City or its officers, agents or employees. As used herein, the term “flood-related property damage” means any damage to real or personal property of any kind, including but not limited to vehicles, due to flooding resulting from water flowing in or from the channels or tributaries of the Sacramento River, American River, Dry Creek, Arcade Creek, Morrison Creek or Natomas East Main Drainage Canal levee systems. As used herein, the term “New Construction” means the “New Construction” identified in the “Hold Harmless Agreement Regarding the Risk of Flooding to Real Property” dated______________ and recorded at ________________________ in the Office of the Sacramento County Recorder.

Notwithstanding the foregoing, the above notice shall not be required if, as a result of future flood control improvements and subsequent remapping by FEMA to remove the Property that includes the New Construction from the 100-year floodplain, the Property no longer is located in a 100-year floodplain designated on a FIRM at the time the Property or New Construction is conveyed.

6. <u>Hold Harmless.</u> The undersigned agree to defend, hold harmless and indemnify the City and its officers, employees and agents from and against any and all flood-related property damage claims premised on the issuance of a building permit for the New Construction.

The undersigned intend that the City be indemnified to the fullest extent permitted by law and, specifically, that any negligence on the part of the City shall not bar indemnity, unless such negligence is found to have been the sole cause of the damage.

The term “claims,” as used in this Agreement, includes all direct or class actions or subrogation or inverse condemnation lawsuits brought by any person, entity or governmental agency in connection with the City's issuance of a building permit for the New Construction.

Notwithstanding the foregoing, the above obligation to defend, hold harmless and indemnify the City, its officers, employees and agents from and against any and all flood - related property damage claims premised on the issuance of a building permit for the New Construction shall not apply to any flood-related property damage that occurs when the Property no longer is located in a 100-year floodplain designated on a FIRM, as a result of future flood control improvements and remapping by FEMA to remove the Property that includes the New Construction from the 100-year floodplain.

7. Release From Indemnification. The undersigned shall be released from any obligation to indemnify the City as set forth in Section 6, above, if, at such time as the City seeks to enforce the provisions of Section 6, the undersigned demonstrate that they have conveyed all of the undersigned’s’ interests in the New Construction to a third party and have fully complied with the provisions of Section 5, above.

8. Severability. The undersigned expressly intend that if any provision of this Agreement is held by a court of competent jurisdiction to be void or unenforceable, the remaining provisions shall not be affected and shall remain in full force and effect.

9. Attorney’s Fees. The undersigned agree that if any legal action is brought to enforce the provisions of this Agreement, the prevailing party shall be entitled to recover reasonable attorney’s fees and costs from the non-prevailing party.

10. Insurance. The undersigned acknowledge that the City highly recommends obtaining flood insurance for the New Construction and the Property.

11. Succession; Recording. The undersigned expressly agree and intend that the obligations contained herein are covenants that benefit and run with the Property and the New Construction, in accordance with Section 1468 of the Civil Code, and the burden thereof shall be binding upon their respective constituents, heirs, assignees and successors in interest. The City may record this Agreement in the Office of the Sacramento County Recorder.

Dated:________________

____
SIGNATURE

Title of Signatory (if Signing for an Entity)

____
Name of Entity (if applicable)

____
Print Name

____
Address

____

SIGNATURE

\---
Title of Signatory (if Signing for an Entity)

Name of Entity (if applicable)

Print Name

Address