Title
Flood Risk Management and the Levee Effect in West Sacramento, California

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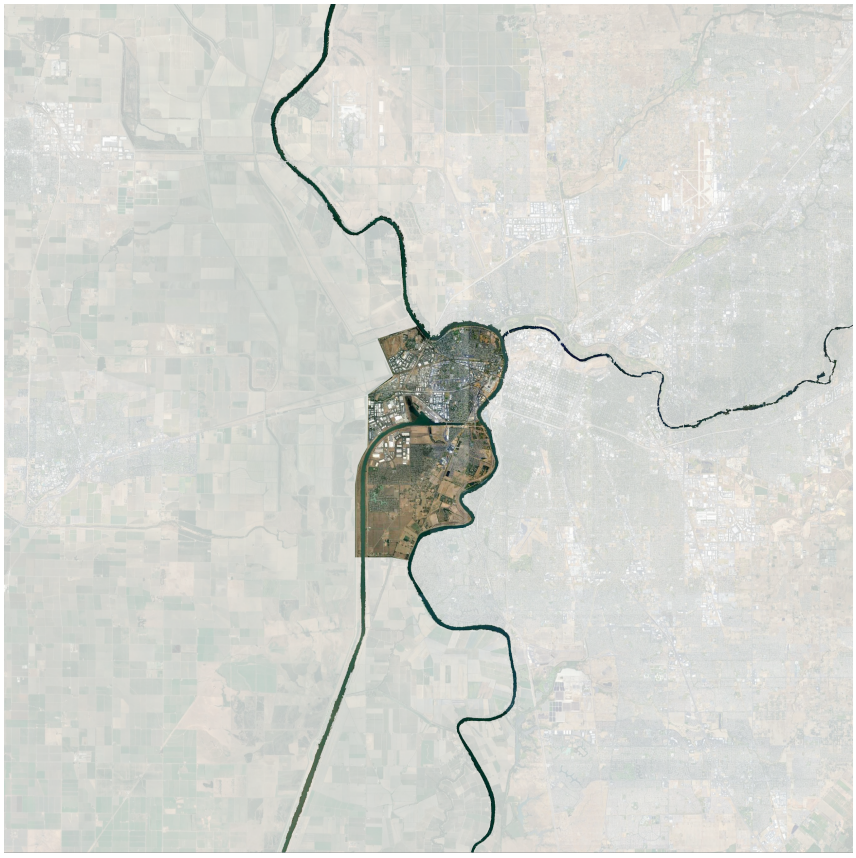


Flood Risk Management and the Levee Effect in West Sacramento, California

Abstract: This paper examines flood risk management and floodplain development in West Sacramento, a flood prone California city adjacent to the state capital. While Sest Sacramento participates in the National Flood Insurance Program, the Flood Insurance Rate Map for the city is outdated and does not adequately reflect actual flood risk. Analyses of US Census data, National Flood Insurance Program products, zoning ordinances, and remote sensing data indicate that development has continued in areas exposed to high flood hazard, increasing the risk of life and property to flooding.

Corey J. Ng
LA 254 - Rivers and Cities Term Paper
UC Berkeley, Spring 2021
Professor Matt Kondolf

1. Introduction

Flood risk management refers to the non-structural and structural methods for managing an existing flood risk situation, as well as the planning of a system that will reduce future flood risk (Plate 2002). Non-structural flood risk management tools in the US include flood insurance and land use planning, while structural methods include levees, bypasses, weirs, flood walls, channel modifications, dams and reservoirs (Kousky and Golnaraghi 2020). This paper focuses on flood risk management strategies used in West Sacramento, California.

The National Flood Insurance Program ("NFIP") is the primary non-engineering federal tool for flood risk management in the United States (Kousky and Golnaraghi 2020). The stated goals of the NFIP are to "promote the public interest by providing appropriate protection against the perils of flood losses and encourag[e] sound land use by minimizing exposure of property to flood losses" (42 U.S.C. 4001). The NFIP sets flood premiums and establishes floodplain regulations primarily using Flood Insurance Rate Maps ("FIRM"s). The success or failure of NFIP to achieve its stated goals for a given community depends largely on the ability of a FIRM to accurately document flood risk (Wilson and Kousky 2019).

The *levee effect*, a term coined by American geographer Gilbert White, describes the paradoxical tendency for large-scale flood mitigation projects to increase, instead of decrease, flood risk by exposing more people and property than likely would have been exposed absent such structural protection (Macdonald, Chester, Sangster, Todd, and Hooke 2011). Levee construction and improvement projects often encourage, rather than discourage, development in a floodplain, where short-term cost-benefit analyses often support building behind levees where there is a relatively low probability of failure or overtopping (Merz, Elmer, and Thieken 2009). The real estate and construction industries, as well as municipalities desiring to increase tax revenues through development, act in concert to encourage building behind levees (Knowles and Kunreuther 2014). The levee effect is well documented and actively occurring in

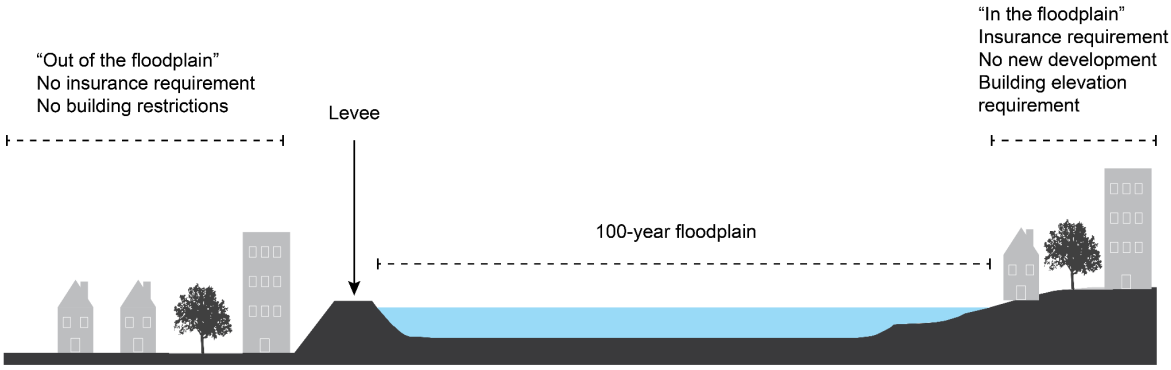
California's Central Valley, with several rapidly growing communities developing behind levees (Hutton, Tobin, and Montz 2018).

This paper studies methods for flood risk management in West Sacramento, a flood prone city in Yolo County, California, and the relationship between flood insurance, levee proliferation, and floodplain development in the city. Specifically, this study analyzes the factors enabling floodplain development, and documents the spatial and temporal trends of development using various methods.

1.1 US National Flood Insurance Program

In 1967, Congress passed the National Flood Insurance Act, establishing a federally subsidized National Flood Insurance Program. Administered by the Federal Emergency Management Agency ("FEMA"), the NFIP produces FIRMs which provide the most comprehensive and authoritative information on community flood hazard. The 100-year floodplain is the essential demarcating feature of a FIRM and represents the area with a 1% chance of inundation each year.

Participation in NFIP by 'communities' (usually cities but also counties) is voluntary, and participating communities must adopt certain floodplain management practices in exchange for subsidized flood insurance (Wilson and Kousky 2019). These include limitations on further building in the 100-year floodplain. Houses that are already in the 100-year floodplain are eligible for subsidized flood insurance. Crucially, areas 'protected' by a levee with 100-year accreditation are excluded from the FIRM 100-year floodplain (Montz and Tobin 2008). Thus, developments can proceed in these areas 'protected' by levees and houses in these areas with federally-backed mortgages are not required to have flood insurance.



(adapted from Eisenstein et. al 2007)

FIGURE 1 The relationship between levees and the FEMA-designated 100-year floodplain

Despite the critical importance of having FIRMs that accurately communicate flood risk, FIRMs are often either outdated, do not accurately reflect recent development, or both (Keller, Rojanasakul, Ingold, Flavelle, & Harris 2017). As of 2014, only 52% of communities participating in NFIP had accurate FIRMs, with an additional 4-10% becoming out-of-date each year (Wilson 2014). In fact, according to a 2018 study, rather than the 13 million Americans living within a100-year floodplain, as determined by the FIRMs, there are 40 million Americans living in a 100-year floodplain (Wing, Paul, Smith, Sampson, Johnson, Fargione, & Morefield 2018).

2. Study Area

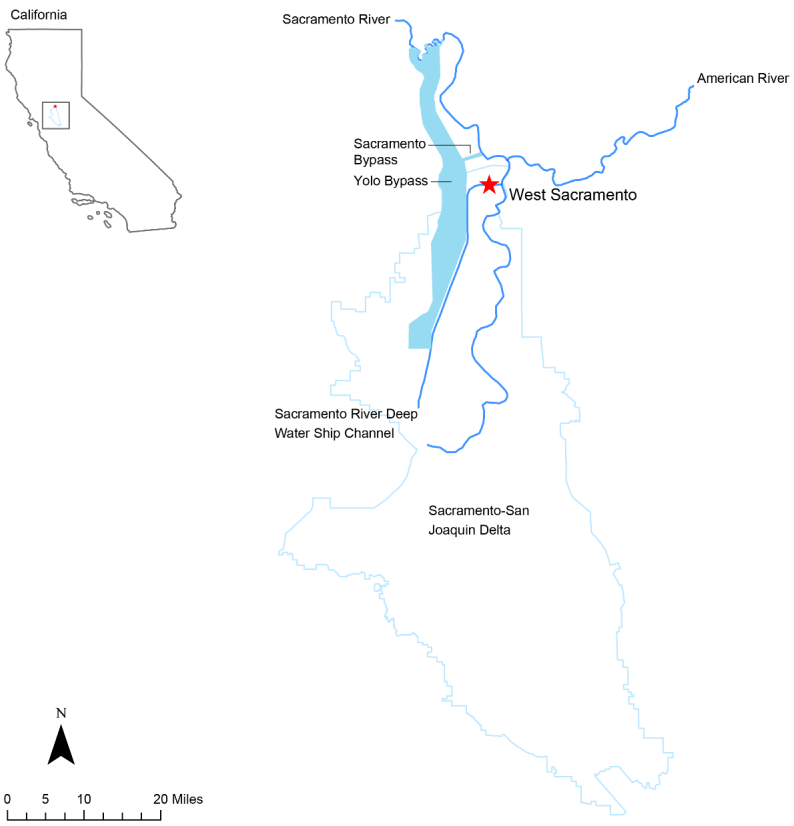


FIGURE 2 The study area

West Sacramento is a growing city (Table 1), located at the confluence of the American and Sacramento rivers in the Central Valley, a broad, mostly flat alluvial valley that drains into the Sacramento-San-Joaquin Delta. Prone to frequent, often severe floods, the Valley has a long history of flood risk management. The current system, the Sacramento River Flood Control Project, consists of 1,100 miles of levees and a series of bypasses and weirs, which route Sacramento River flows out of the main channel during flood events. This system is mostly adequate for limiting deep inundation, and has contributed to the perceptual fallacy that lands behind the levees are safe (James and Singer 2008).

Year	Population	% Change
1990	28,898	---
2000	31,615	9.40%
2010	48,744	54.18%
2019	53,519	9.80%

TABLE 1 Population growth in West Sacramento (source: US Census Decennial Data)

West Sacramento is almost entirely surrounded by floodways and levees and is bound by the Sacramento Bypass to the north, the Sacramento River to the east and the Yolo Bypass to the west. Bisected by the Deep Water Shipping Canal, the City comprises a North Basin and South Basin (Figure 2). According to Levee Protection Zone Maps created by the California Department of Water Resources, failure of any of the system's levees would result in nearly the entire area of West Sacramento being inundated with greater than 3 ft. of water (Figure 3).

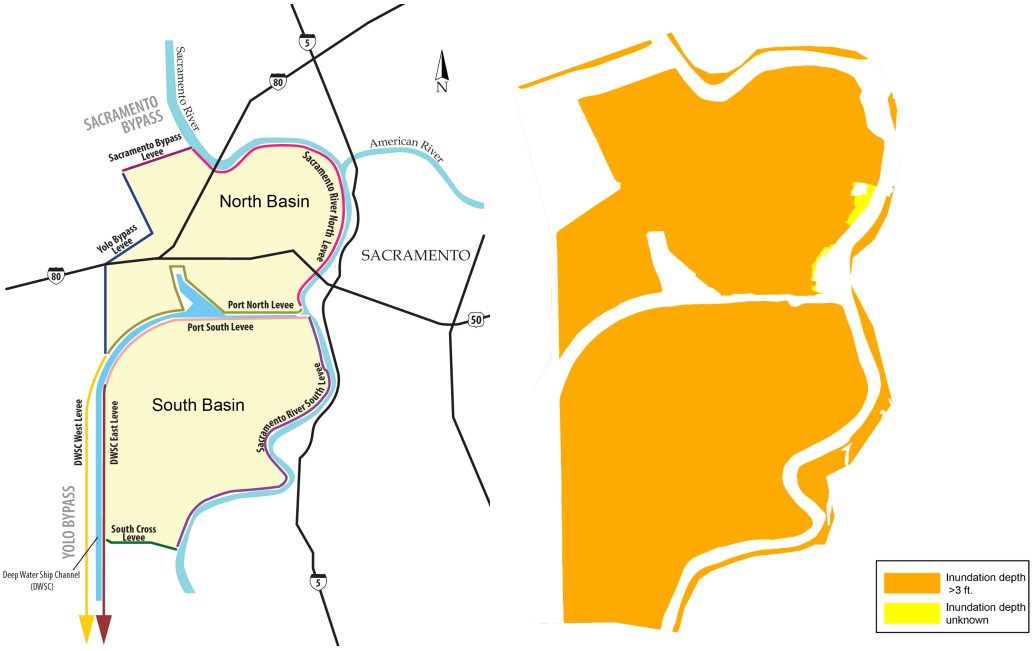


FIGURE 2 Levee system in West Sacramento (source: westsac.com)

FIGURE 3 CA Department of Water Resources Levee Flood Protection Zone Map (source: DWR)

In recent history there have been several significant flood events in West Sacramento, with the flood of record occurring in 1986. During this flood, the levee system sustained severe damages at several locations, prompting critical changes to the City's flood risk management strategy.

3. Methods

To assess flood insurance in West Sacramento, I analyze several products available at the FEMA Flood Map Service Center, including historical and effective FIRMs, Flood Insurance Studies, and National Flood Hazard Layers. I reviewed reports produced by the US Army Corps of Engineers to assess the level of protection of the West Sacramento levee system. Using historical zoning ordinances from the City of West Sacramento, US Census data, and remote sensing data from the National Landcover Database, I determine the spatial and temporal relationship between levee improvement projects and floodplain development in West Sacramento.

4. Results and Discussion

4.1 Flood Insurance in West Sacramento

West Sacramento joined NFIP with the publication of its first FIRM in March 1990. This historical FIRM placed much of the City within the 100-year floodplain (Figure 3). The remainder of the city was assigned to the 500-year floodplain. As a result, development in most of the city was subject to NFIP restrictions.

In response to the 1986 floods, the US Army Corps of Engineers recommended a series of levee improvements in the *Sacramento Metropolitan Area, California, Feasibility Report* that would bring West Sacramento’s flood control infrastructure to the 150-year level of protection

(US Army Corps of Engineers, 1992). These repairs were authorized in the Water Resources Development Act of 1992 (H.R. 6167, 102nd Congress), and in March 1995, FEMA remapped West Sacramento to incorporate these improvements (Figure 3). Under the new FIRM, most of the city was removed from the 100-year floodplain.

FIGURE 4 Historical and Effective FIRMs for West Sacramento (adapted from FEMA, 1990; FEMA, 1995)

FEMA is required to "assess the need to revise and update all floodplain areas and flood risk zones" every five years (42 U.S.C. §4101(e)). Despite the five year FIRM assessment requirement, the 1995 map remains effective today and has been in use for twenty-six years. According to a 2017 report from the Department of Homeland Security's Inspector General, maps older than five years require a new Flood Insurance Study to determine whether they reflect the current flood risk (Department of Homeland Security, 2017).

The effective Flood Insurance Rate Map in West Sacramento assumes the levees will provide protection for a 150-year flood (H.R. 6167, 102nd Congress). However, the most recent Flood Insurance Study for Yolo County (including West Sacramento) published in 2012 determined that several levees do not even provide 100-year protection: "During high

floodflows, the City of West Sacramento is not protected from flooding by the levees along the Sacramento River and the Yolo Bypass... Levees in Reclamation Districts (RDs) 811, 537, and 900 are not recognized as providing protection from the 1-percent annual chance flood." (FEMA, 2012). The referenced reclamation districts are special-purpose districts common in the Central Valley responsible for managing and maintaining levees, and constitute the entire area of West Sacramento.

4.2. Concurrent Levee and Floodplain Development

West Sacramento has invested heavily in levee improvement projects. Using local, state, and federal funds, the West Sacramento Flood Control Agency and the City of West Sacramento have spent $169,662,200 since 1992 on various projects to raise, expand, or repair its system of levees (Appendix Table 1).

Despite these efforts to improve the efficacy of the City's levee system, a 2015 US Army Corps of Engineers report found several vulnerabilities: "Based on analysis conducted as part of this investigation as well as other investigations by the State of California, the levee system for the West Sacramento area has a high probability of failure in multiple locations" (US Army Corps of Engineers, 2015). According to this report, a breach in the levee system during a 100-year storm event would result in inundation of nearly the entire city.

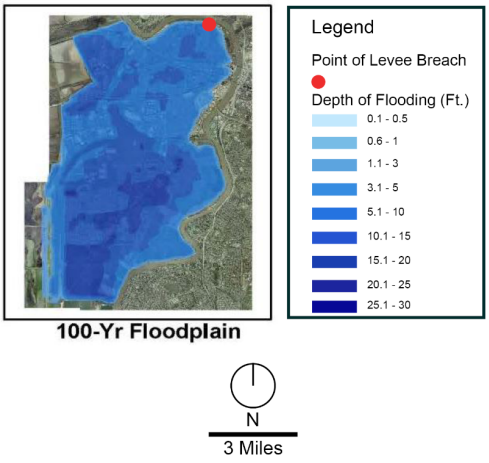


FIGURE 5 Extent of inundation in West Sacramento with levee failure and 100-year flood event (adapted from US Army Corps of Engineers, 2015)

The current Army Corps assessment of West Sacramento levees, published 16 July 2020 on the National Levee Database, gives the system the second highest possible risk rating (US Army Corps of Engineers, 7/6/2020).

During this period of levee improvements, West Sacramento has undergone extensive floodplain development, concentrated in the South Basin. In May 1995, shortly after publication of the less development-restrictive FIRM, the City published its *Southport Framework Plan* which set forth its intention to add 14,050 residential units to the South Basin (City of West Sacramento, 1995). This land use change is documented in a comparison of zoning ordinances from 1988 and 1997 (Figure 4).

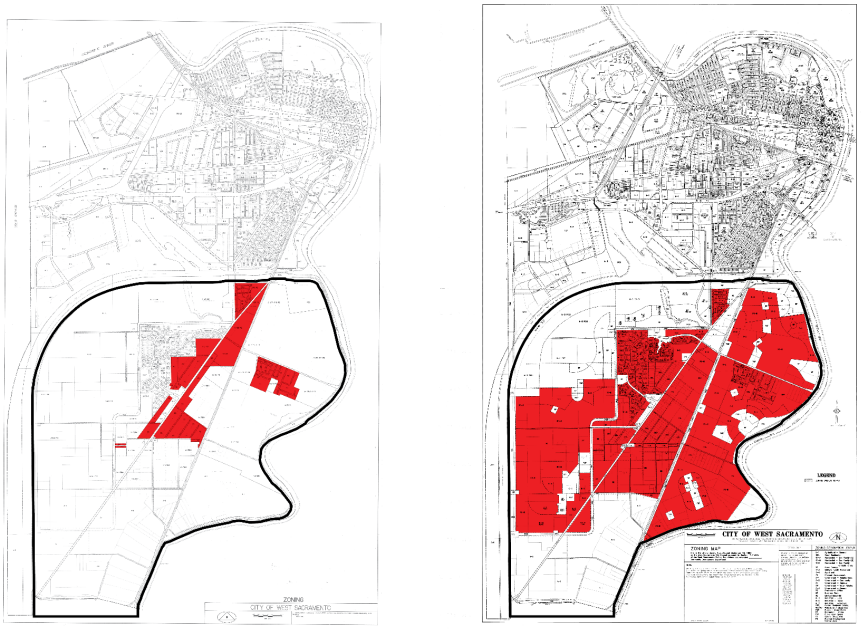


FIGURE 4 City of West Sacramento Zoning Ordinances; 1988 on left, 1997 on right. South Basin outlined in black; areas zoned “Rural Residential”, “Residential”, “Rural Estates”, “Multiple Family Residential”, or “Apartment” shaded in red (adapted from City of West Sacramento Planning Division, 1988 and 1997)

Analysis of US Census data reveals that a significant amount of the population and housing stock growth from 1990 has happened in the South Basin.

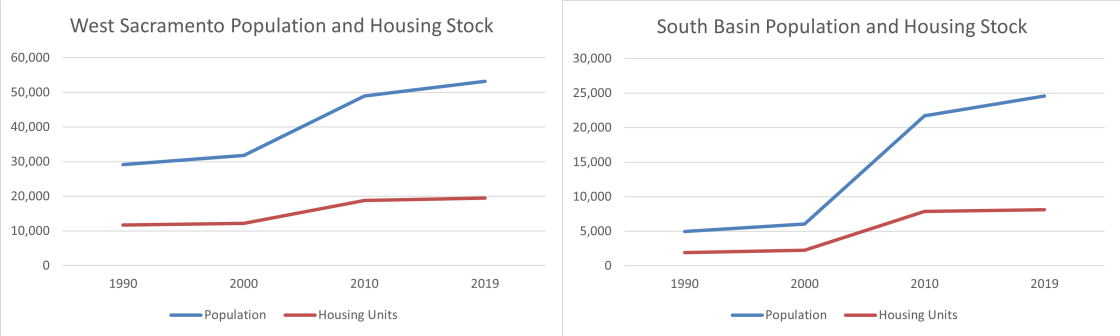


FIGURE 5 Population and housing stock growth in West Sacramento (left) and the South Basin of West Sacramento (right) (adapted from US Decennial Census data, prepared by Social Explorer).

An analysis of remote sensing data from the National Landcover Database (NLCD) for the years 2001-2016 documents development patterns following the zoning map (Figure 5). Notably, the medium- and high-intensity developed classes experienced growth rates above 20% while the grassland/herbaceous and cultivated crops classes shrank over 35% (Figure 6). These results indicate the predominant land change pattern during the period was conversion from open space landcover-types to developed landcover-types, increasing the amount of life and property within the West Sacramento floodplain. This urbanization of the floodplain has increased the potential consequences of flooding due to levee failure (Pinter 2005).

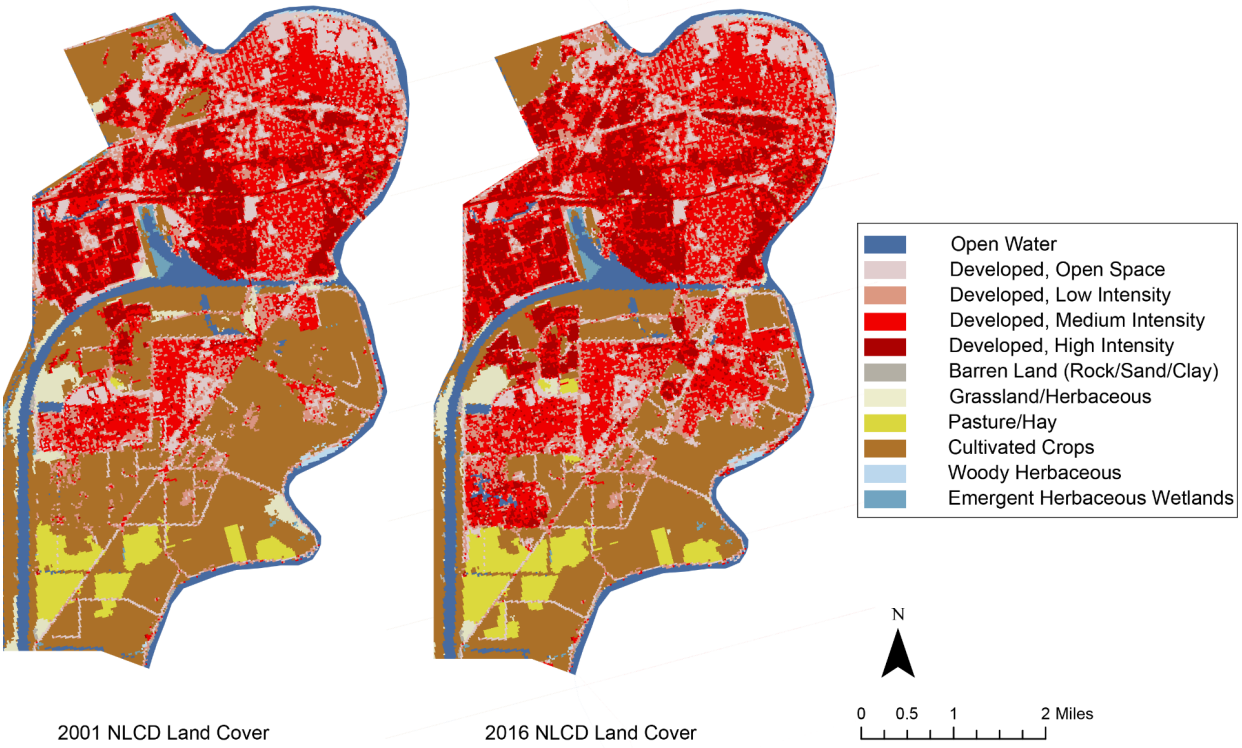


FIGURE 5 Land cover change in West Sacramento, 2001-2016 (adapted from NLCD 2001; NLCD 2016)

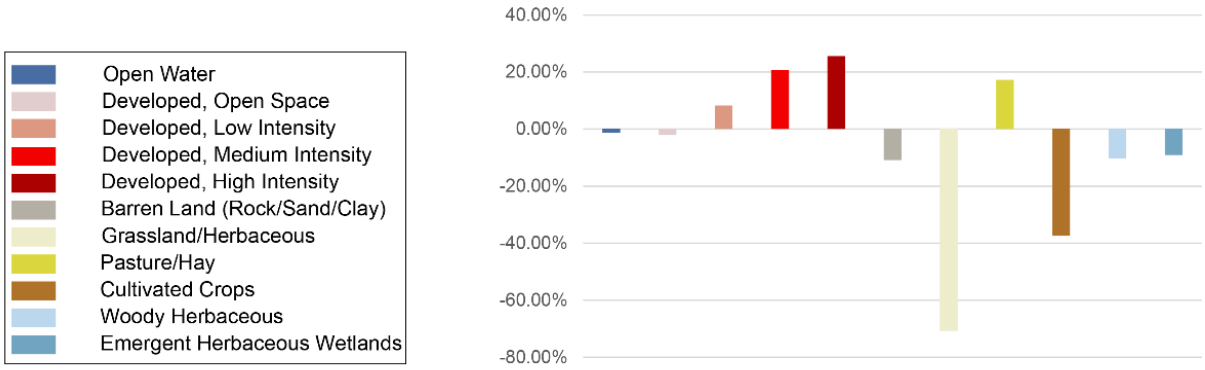


FIGURE 6 Percent land cover change in West Sacramento, 2001-2016 (adapted from NLCD 2001; NLCD 2016)

5. Conclusions and Future Research

> *"A flood insurance program is a tool that should be used expertly or not at all. Correctly applied, it could promote wise use of flood plains. Incorrectly applied, it could exacerbate the whole problem of flood losses"*
>
> - Gilbert White, 1966. *A Unified National Program for Managing Flood Losses*

The use of outdated, less development-restrictive Flood Insurance Rate Maps, proliferation of levee improvement projects, and zoning floodplain lands for residential development have all contributed to putting more lives and property at risk in West Sacramento, a classic illustration of the 'levee effect'. NFIP rules require that flood maps be updated every 5 years, so it is unclear how the city of West Sacramento could continue to use the 1995 FIRM (showing almost the entire city to be out of the floodplain) when more recent flood studies unequivocally state that these lands are vulnerable to flooding from the 100-year flood and from levee failures.

All of this recent development in West Sacramento is dependent upon a levee system that is at "high risk" of failure according to the US Army Corps of Engineers. According to the Central Valley Flood Protection Act of 2008, urban levees in the Central Valley must be upgraded to provide 200-year flood protection (Central Valley Flood Protection Act of 2008). However, several sections of the West Sacramento levee system do not provide protection from the 100-year flood (US Army Corps of Engineers 2020; FEMA 2012). Given these discrepancies, it is unclear how the city of West Sacramento could continue to use the 1995 FIRM, which assumes the levees provide 150-year flood protection.

FEMA is currently in the process of overhauling its FIRM mapping procedures under the Risk Rating 2.0 initiative. It is expected that West Sacramento will be issued a new FIRM under this initiative. Once an updated FIRM is published, an analysis of the flood risk of recent floodplain development can be done following the framework established by Hutton, Tobin, and Montz (2018).

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Appendix A

Year Completed	Project Name	Cost

1992	Sacramento Urban Area Levee Reconstruction Project	$ 8,000,000
1992, 1999	West Sacramento Project	$ 32,000,000
2008	I St. Bridge Early Implementation Project	$ 640,000
2009	Yolo Bypass South Slip 1	$ 3,500,000
2011	Yolo Bypass South Slip 2	$ 2,400,000
2011	Bridge District Levee Maintenance Road Project	$ 3,122,200
2011	The Rivers Early Implementation Project	$ 17,000,000
2011	CHP Academy Early Implementation Project	$ 10,000,000
2015	Sacramento Bank Project - South River Road	$ 8,000,000
2018	Southport Sacramento Early River Implementation Project: Phase 1&2	$ 85,000,000
Planned	Southport Sacramento Early River Implementation Project: Phase 3	To be determined
Planned	Yolo Bypass East Levee Project	To be determined

TABLE A-1 Major levee projects in West Sacramento from 1993 (Source: West Sacramento Area Flood Control Agency, 2021).

APPENDIX B

PEER REVIEWER'S COMMENT FORM

Complete this 2-page form (and submit a copy with your paper) for full class credit.
Title Flood Risk Management and the Levee Effect in West Sacramento, California
Author Corey Ng Date in 4/12/21
Your name Dana Tinio Date out 4/12/21

Instructions for Peer Reviewers:
In addition to answering the questions posed below, identify portions of the text that are unclear or where the author's arguments seem fuzzy. At several points throughout, perform the "paramedic" revision on sentences. Don't do this revision throughout, but you do it at a few points to help the author see where and how it could be done.

LOGICAL STRUCTURE AND MANUSCRIPT ORGANIZATION
What are the main points of the manuscript? Is the problem clearly stated?
Yes, the problem is clearly stated. The main point is that West Sacramento's Flood Insurance Rate Map is outdated and has led to a proliferation of development in the floodplain, which heightens flood risk for people living in the floodplain.

Does the ms make explicit what the authors did, distinct from what others had done before?
Yes, it properly cites others' work. Since this topic is relatively specific (investigating West Sacramento in particular), there seems to be less of a need to "distinguish" itself from past works. Rather, it draws on other literature to analyze a novel topic.

Are statements clearly supported by evidence? Give an example of one that is and one that
isn't if possible.
Yes. Good example: During this period of population growth and levee improvements, West Sacramento has undergone extensive floodplain development.
This statement is followed by cited statistics. I could not find unsubstantiated statements.

Diagram the author's argument, identifying unsupported assumptions:
FIRM is outdated, which heightens risk in the floodplain
- Has not been updated since 1995
- City/developers have taken advantage of outdated mapping to increase development in the floodplain
- This has in turn led to more spending on levee projects, which creates a false sense of security

Are calculations clearly shown or described so that they can be checked? Are the calculations correct?
n/a but maps and diagrams are very good.

Does the title accurately reflect the content of the manuscript?
Yes, it is very straightforward.

Is the text adequately divided by section headings for ease of reading?
Yes.

Do the section headings correctly reflect the content of the sections? Indicate suggested changes.
Yes.

Is the material presented in the most readily comprehensible order? How can the manuscript organization be improved?
Yes, and it follows the guidelines for the project.

What portions of the manuscript do not contribute directly to the author's argument and can be deleted?
Rather than suggesting deletions, I would recommend building on a few areas (e.g. conclusions, consequences of levee failures, political gain of developing in the floodplain).

PROSE
What is the intended audience? Are style and tone suitable?
This manuscript reads with a technical tone and holds the purpose of identifying a problem. While perhaps it is not meant for the general public, it is informative and accessible to those with some familiarity around flood risk management and flood insurance. It could potentially be used to inform policy decisions on this matter.

Is the writing clear and concise? Suggest changes in text to clarify writing.

For the most part, the writing is clear. I left suggested edits in the document. There may be opportunities to make more powerful, pointed statements with “active voice” language.

Appendix C

Second Draft

1. Introduction

Flood risk management refers to the non-structural and structural methods for managing an existing flood risk situation, as well as the planning of a system that will reduce future flood risk (Plate 2002). The primary non-structural flood risk management tool in the US is flood insurance, while structural methods include levees, bypasses, flood walls, channel modifica-tions, dams and reservoirs (Kousky and Golnaraghi 2020). A successful flood risk management regime employs an appropriate and complementary combination of policy and engineering strategies.

The *levee effect*, a term coined by seminal American geographer Gilbert White, describes the paradoxical tendency for large-scale flood mitigation projects to increase, instead of decrease, flood risk by exposing more people and property than likely would have been exposed absent such structural protection (Macdonald, Chester, Sangster, Todd, and Hooke 2011). Similarly, levee construction and improvement projects often encourage, rather than discourage, development in a floodplain, where short-term cost-benefit analyses often support building behind levees where there is a relatively low probability of failure or overtopping (Merz, Elmer, and Thieken 2009). The real estate and construction industries, as well as municipalities desiring to increase tax revenues through development, act in concert to encourage building behind levees (Knowles and Kunreuther 2014).

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1.1 US National Flood Insurance Program

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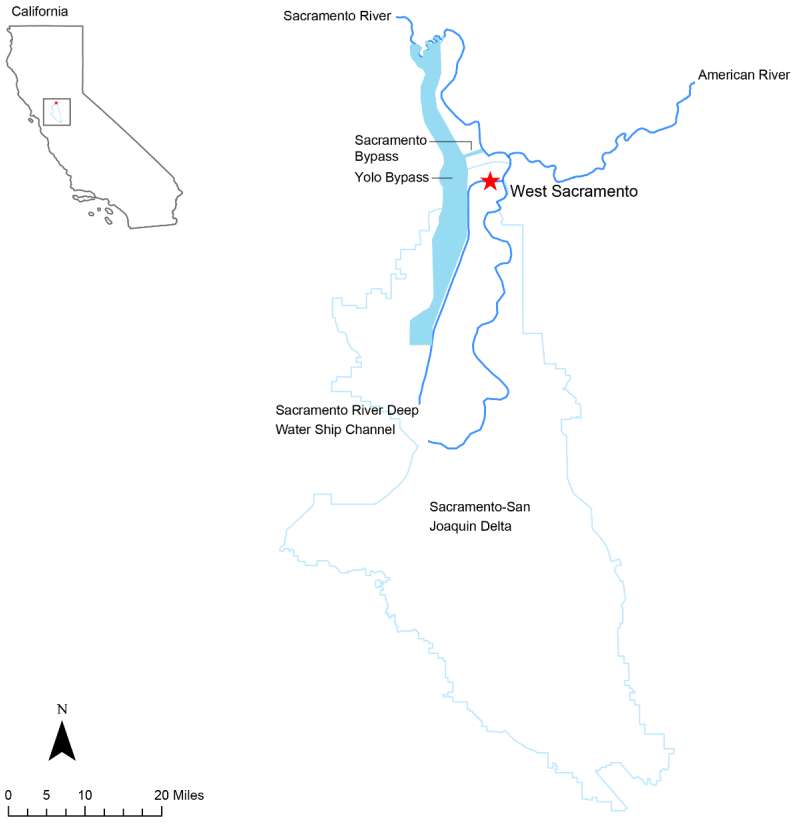

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West Sacramento is almost entirely surrounded by floodways and levees and is bound by the Sacramento Bypass to the north, the Sacramento River to the east and the Yolo Bypass to the west. Bisected by the Deep Water Shipping Canal, the City comprises a North Basin and South Basin (Figure 2). In recent history there have been several significant flood events in West Sacramento, with the flood of record occurring in 1986. During this flood, the levee system

sustained severe damages at several locations, prompting critical changes to the City's flood risk management strategy.

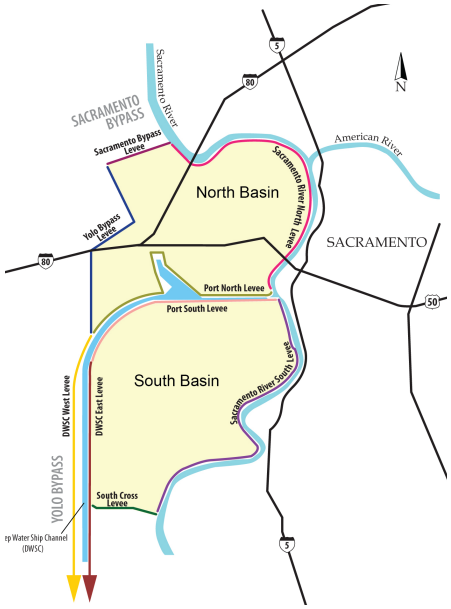

FIGURE 2 Levee system in West Sacramento (source: westsac.com)

3. Methods

To assess the flood insurance protocol in West Sacramento, I analyze FEMA flood insurance products, including historical and effective FIRMs and Flood Insurance Studies. Using historical zoning ordinances from the City of West Sacramento and remote sensing data from the National Landcover Database, I determine the spatial and temporal relationship between levee improvement projects and floodplain development in West Sacramento.

4. Results and Discussion

4.1 Flood Insurance in West Sacramento

West Sacramento joined NFIP with the publication of its first FIRM in March 1990. This historical FIRM placed much of the City within the 100-year floodplain. The remainder of the city was

assigned to the 500-year floodplain. As a result, development in most of the city was subject to NFIP restrictions.

In response to the 1986 floods, the US Army Corps of Engineers recommended a series of levee improvements in the *Sacramento Metropolitan Area, California, Feasibility Report* that would bring West Sacramento's flood control infrastructure to the 150-year level of protection (US Army Corps of Engineers, 1992). These repairs were authorized in the Water Resources Development Act of 1992 (H.R. 6167, 102nd Congress), and in March 1995, FEMA remapped West Sacramento to incorporate these improvements (Figure 3). Under the new FIRM, most of the city was removed from the 100-year floodplain.

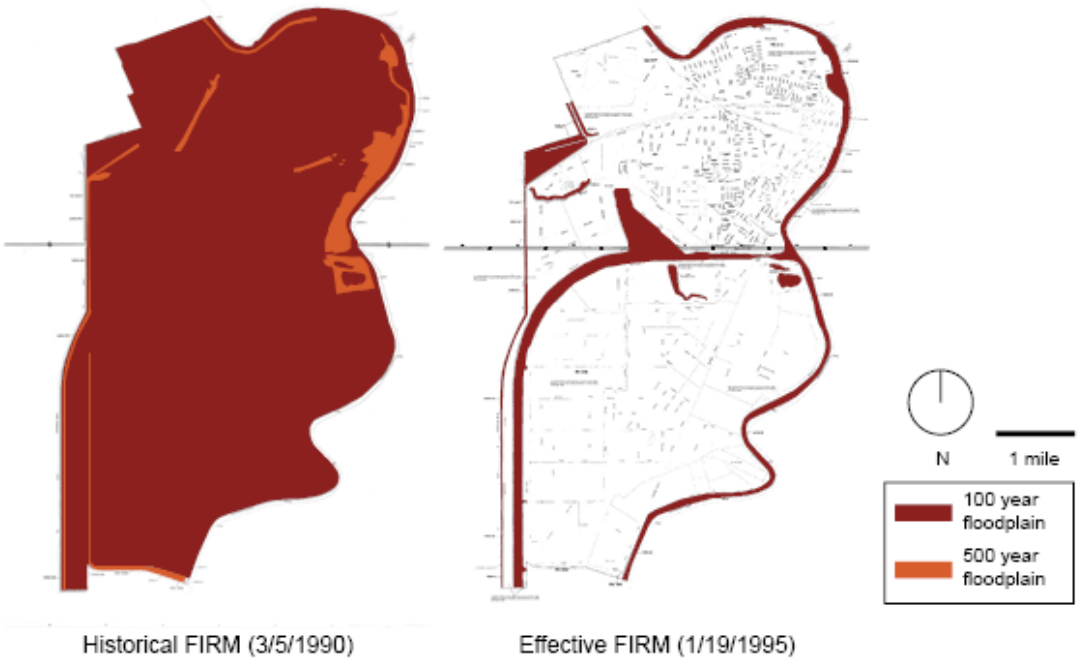

FIGURE 3 Historical and Effective FIRMs for West Sacramento (adapted from FEMA, 1990; FEMA, 1995)

FEMA is required to "assess the need to revise and update all floodplain areas and flood risk zones" every five years (42 U.S.C. §4101(e)). Despite the five year FIRM assessment requirement, the 1995 map remains effective today and has been in use for twenty-six years.

According to a 2017 report from the Department of Homeland Security's Inspector General, maps older than five years require a new Flood Insurance Study to determine whether they reflect the current flood risk (Department of Homeland Security, 2017). The most recent Flood Insurance Study for Yolo County (including West Sacramento) was published in 2012 and determined that several levees do not provide the 100-year protection the effective FIRM suggests: "During high floodflows, the City of West Sacramento is not protected from flooding by the levees along the Sacramento River and the Yolo Bypass... Levees in Reclamation Districts (RDs) 811, 537, and 900 are not recognized as providing protection from the 1-percent annual chance flood." (FEMA, 2012). The referenced reclamation districts are special-purpose districts common in the Central Valley responsible for managing and maintaining levees, and constitute the entire area of West Sacramento.

4.2. Concurrent Levee and Floodplain Development

West Sacramento has invested heavily in levee improvement projects. Together with the US Army Corps of Engineers, the City has spent $169,662,200 since 1992 on various projects to raise, expand, or repair its system of levees (Table 2).

Year Completed	Project Name	Cost
1992	Sacramento Urban Area Levee Reconstruction Project	$ 8,000,000
1992, 1999	West Sacramento Project	$ 32,000,000
2008	I St. Bridge Early Implementation Project	$ 640,000
2009	Yolo Bypass South Slip 1	$ 3,500,000
2011	Yolo Bypass South Slip 2	$ 2,400,000

2011	Bridge District Levee Maintenance Road Project	$ 3,122,200
2011	The Rivers Early Implementation Project	$ 17,000,000
2011	CHP Academy Early Implementation Project	$ 10,000,000
2015	Sacramento Bank Project - South River Road	$ 8,000,000
2018	Southport Sacramento Early River Implementation Project: Phase 1&2	$ 85,000,000
Planned	Southport Sacramento Early River Implementation Project: Phase 3	To be determined
Planned	Yolo Bypass East Levee Project	To be determined

TABLE 2 Major levee projects in West Sacramento from 1993 (Source: West Sacramento Area Flood Control Agency, 2021).

Despite these efforts to improve the efficacy of the City's levee system, a 2015 US Army Corps of Engineers report found several vulnerabilities: "Based on analysis conducted as part of this investigation as well as other investigations by the State of California, the levee system for the West Sacramento area has a high probability of failure in multiple locations" (US Army Corps of Engineers, 2015).

During this period of levee improvements, West Sacramento has undergone extensive floodplain development, concentrated in the South Basin. In May 1995, shortly after publication of the less development-restrictive FIRM, the City published its *Southport Framework Plan* which set forth its intention to add 14,050 residential units to the South Basin (City of West Sacramento, 1995). This land use change is documented in a comparison of zoning ordinances from 1988 and 1997 (Figure 4).

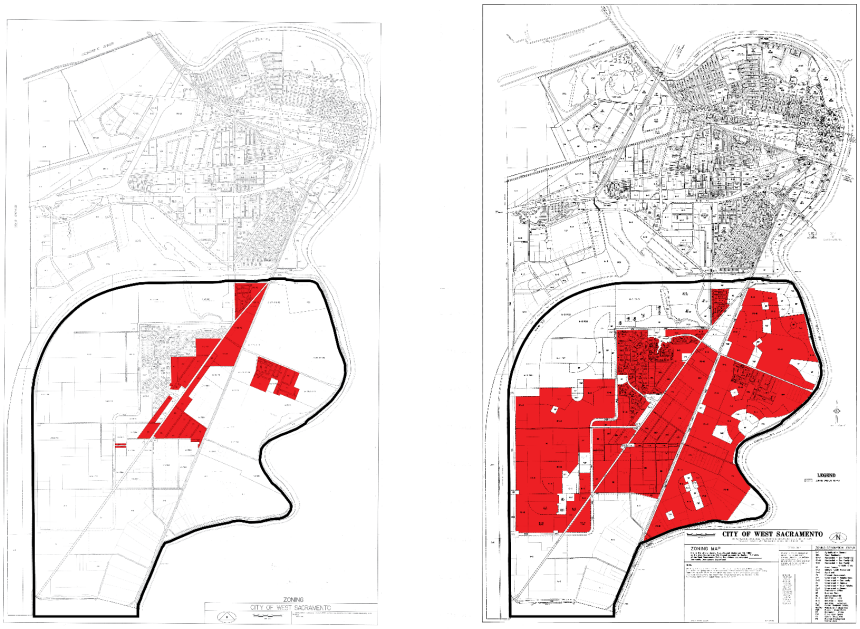

FIGURE 4 City of West Sacramento Zoning Ordinances; 1988 on left, 1997 on right. South Basin outlined in black; areas zoned “Rural Residential”, “Residential”, “Rural Estates”, “Multiple Family Residential”, or “Apartment” shaded in red (adapted from City of West Sacramento Planning Division, 1988 and 1997)

An analysis of remote sensing data from the National Landcover Database (NLCD) for the years 2001-2016 verifies these development trends (Figure 5). Notably, the medium- and high-intensity developed classes experienced growth rates above 20% while the grassland/herbaceous and cultivated crops classes shrank over 35%. These results indicate the predominant land change pattern during the period was conversion from lower density, more permeable land cover types to higher density, less permeable ones. This urbanization of the floodplain has increased the potential consequences of flooding due to levee failure (Pinter 2005).

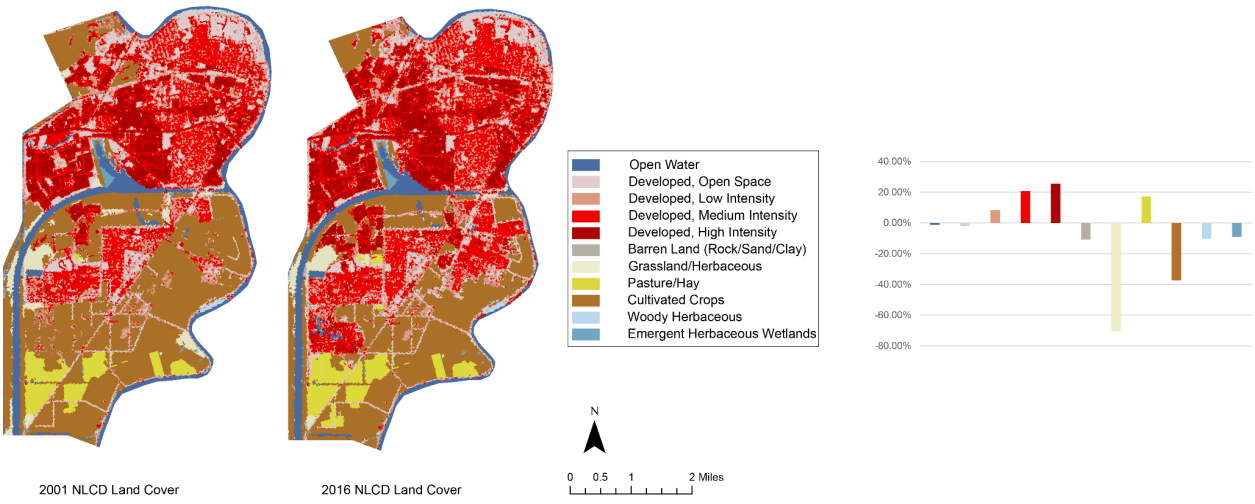

FIGURE 5 Land cover change in West Sacramento, 2001-2016 (adapted from NLCD 2001; NLCD 2016)

5. Conclusions and Future Research

The use of outdated, less development-restrictive Flood Insurance Rate Maps, proliferation of levee improvement projects, and pro-development zoning ordinances have all contributed to the levee effect in West Sacramento. In the event of a levee failure, more lives and property are at risk due to this development.

According to the 1990 FIRM, all of the recent development has taken place within the 100-year floodplain. However, in the absence of a FIRM showing the current flood risk to West Sacramento, further research is needed to document how much of the recent development is at high risk of flooding due to levee failure. Once an updated FIRM is published, an analysis of the flood risk of floodplain structures can be done following the framework established by Hutton, Tobin, and Montz (2018).