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ORIGINAL ARTICLE

The levee effect revisited: Processes and policies enabling development in Yuba County, California

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Prolonged, heavy rain in Northern California led to the evacuation of over 180,000 residents on February 12, 2017 after the capacity of the Oroville Dam, which spills into the Feather River, came into question. This paper examines the development of the floodplain along the Yuba and Feather rivers and identifies changes in risk distribution resulting from increased urbanisation. The levee system in this area was extended, and additional embankments were erected between 2004 and 2011. Olivehurst has particularly experienced high population growth and increased housing values despite a history of flooding, partly due to failed mitigation structures. Increased development stemming from a false sense of security associated with mitigation projects, termed the *levee effect*, has been well documented. Analyses of census data, land cover change, Federal Emergency Management Agency (FEMA) flood zone designations, and county development plans indicate that several factors other than available land have precipitated expansion: (a) population pressure, (b) recertification of the levees that now confine the official floodplain, and (c) the fact that flood insurance is no longer a requirement for homeowners. Development trends from 1980 to 2015 put communities built in anticipation of the upgraded levee system that are completely reliant upon it for flood protection at risk.

KEYWORDS

floodplain management, levees, mitigation, urban development

1 | INTRODUCTION

Population pressure, often combined with escalating housing demand in some regions, has led to development in hazardous areas and to investment in protective measures to reduce the risk (Blaikie, Cannon, Davis, & Wisner, 2014; Interagency Floodplain Management Review Committee, 1994; Smith, 2013). While some of these mitigation measures, such as elevating structures above base flood elevations, are quite effective, others such as sea walls and levees can create a false sense of security. The levee effect has been well documented since Gilbert White coined the term in 1947 (see, for example, Burton, Kates, & White, 1968; Pielke Jr, 2000; Tobin, 1995). As early as 1937, Segoe (1937, p. 55) pointed out the fallacy associated with large-scale mitigation projects:

> "…there is a danger that by reason of increased occupancy and values in the areas subject to floods after construction of the system of headwater reservoirs, the damages over a long period of years might be greater rather than less, in spite of the 300-, 400-, 500-million dollar expenditure that these works might cost."

Unfortunately, such knowledge has not translated into wise land use decisions, especially in the face of significant development pressures and the economic benefits that accompany increased development (Collenteur, de Moel, Jongman, & Di Baldassarre, 2015; Montz & Tobin, 2008). Often, simple cost–benefit analysis supports increased development given the low probability of failure or over-topping (Merz, Elmer, & Thieken, 2009). Yet, it is such low-probability but high-consequence events that create disasters and too often leave those in the "protected" area entirely unprepared (Ciullo, Viglione, Castellarin, Crisci, & Di Baldassarre, 2017). As stated by Di Baldassarre et al. (2013), drivers of development in the floodplain involve a complex interplay of social reactions to flood events, technological capacity to contain waterways, and economic and political interests in the area.

Despite what is known about the levee effect and in spite of the fact that approximately 33% of flood losses in the United States can be attributed to levee failure or overtopping (Committee on Risk-Based Analysis for Flood Damage Reduction 2000), levees are sometimes used to encourage development. Technologically driven development alters the number of individuals exposed to flood risk, as well as the overall community's interpretation of and behavioural reaction to risk (Aerts et al., 2018; Ciullo, Viglione, & Castellarin, 2016). The Sacramento Valley, as described by Kelley (1998), features an ongoing example of the flood control battle in an area converted from swamp areas of large rivers for mining, agriculture, and—most recently—urban developments. This project presents a specific case study that evaluates some underlying forces, processes, and potential impacts of levee construction in a particularly flood-prone region—Yuba County, California. Specifically, this study identifies the temporal and spatial characteristics of development plans, including population pressure, mitigation efforts, and economic response, providing a means to assess the impact of the confluence of priorities as they relate to flood risk, with implications for many other areas.

2 | FLOOD HISTORY OF THE STUDY AREA

Yuba County is located in north central California, USA. The county's western boundary is the Feather River, with the Bear River at its southern boundary. The Yuba River is a tributary of the Feather, joining it at Marysville (Figure 1). The region has a long history of flooding, owing in part to the topography of the area and to the anthropogenic activities within the watershed. Specifically, historic hydraulic gold mining in the nearby foothills of the Sierra Nevada Mountains led to large quantities of silt being deposited in the rivers. To combat the floods resulting from the reduced river capacities, levees were built but in a piecemeal fashion (James & Singer, 2008). This, in turn, exacerbated flooding even more as (a) silt continued to build up in the riverbeds because of the levees, and (b) rivers were further manipulated by the construction of things such as debris dams and by-passes. Floods occurred in 1852 and 1853 along the Feather and Yuba rivers, after which levees were constructed to protect Marysville. Campbell (1996) lists 31 major flood events in the Sacramento Valley between 1805 and 1986, and others have documented the continuing flood events of the last 30 years or so (Fridirici & Shelton, 2000; James & Singer, 2008; Kelley, 1998).

Levees have been a major part of the flood response strategies in California's Central Valley since the mid-19th century (Foley & Morley, 1949; Stiles 1957) and now extend over 10,500 km (Army Corps of Engineers, 2013). After flooding in 1907 and 1909, an integrated flood plan was proposed, and the Flood Control Act in 1917 established the Sacramento River Flood Control Project to provide unified management of the area's rivers (see James & Singer, 2008 for details). Nevertheless, flooding continued to devastate communities located in the floodplains of the Yuba and Feather rivers; in some places, these floodplains now have a lower elevation than the riverbed due to continued silt accumulation within the channels. Seasonal snow melt and prolonged rains contributed to subsequent floods on the Feather River recorded in 1937, 1940, 1942, 1944, 1948, and 1950 (Stiles 1957). The largest flood on record on the Feather River occurred in 1955 when a levee broke at Yuba City, killing 38 and causing $20 million in damages. In both 1986 and 1997, levees broke along the Yuba, Feather, and Bear Rivers, leading to extensive flooding in Linda and Olivehurst (Figure 2). Linda was affected the most by the 1986 flood and Olivehurst by the 1997 floods, and some areas of each community were flooded in both years (Montz & Tobin, 1988; Tobin & Montz, 1988). Furthermore, there were two floods in 1997, within 2 weeks of one another, and some people were cleaning up from the first flood when they were hit a second time (Tobin & Montz, 1997). The 1997 floods renewed debates amongst residents and policymakers regarding the potential for maintaining communities behind the levees, but cost–benefit analysis suggested that improved levees would be more effective than planned retreat (Kelley, 1998).

Most recently, the county was in a state of emergency in February 2017 when the Oroville Dam, approximately 70 km upstream, was at risk of failure due to prolonged rains. Over 180,000 residents in Yuba and Butte counties were evacuated on February 12 to clear the dam's floodplain (Park & McLaughlin, 2017). The Oroville region received 50–150 cm of rain over 45 days leading up to this event; the average return interval ranged between 10 and 250 years (Crow, 2017). The dam's capacity was threatened because the main and emergency spillways had been compromised by water releases earlier in the year. One such release was 2,831 cm, which remained within manageable limitations of the Feather and Yuba River levees downstream (CBEC Industries, 2012; Stork et al., 2017).

Since the Oroville Dam's completion in 1968, releases into the Feather River have caused devastating floods at the confluence with the Yuba River in 2 years. In 1986, a release

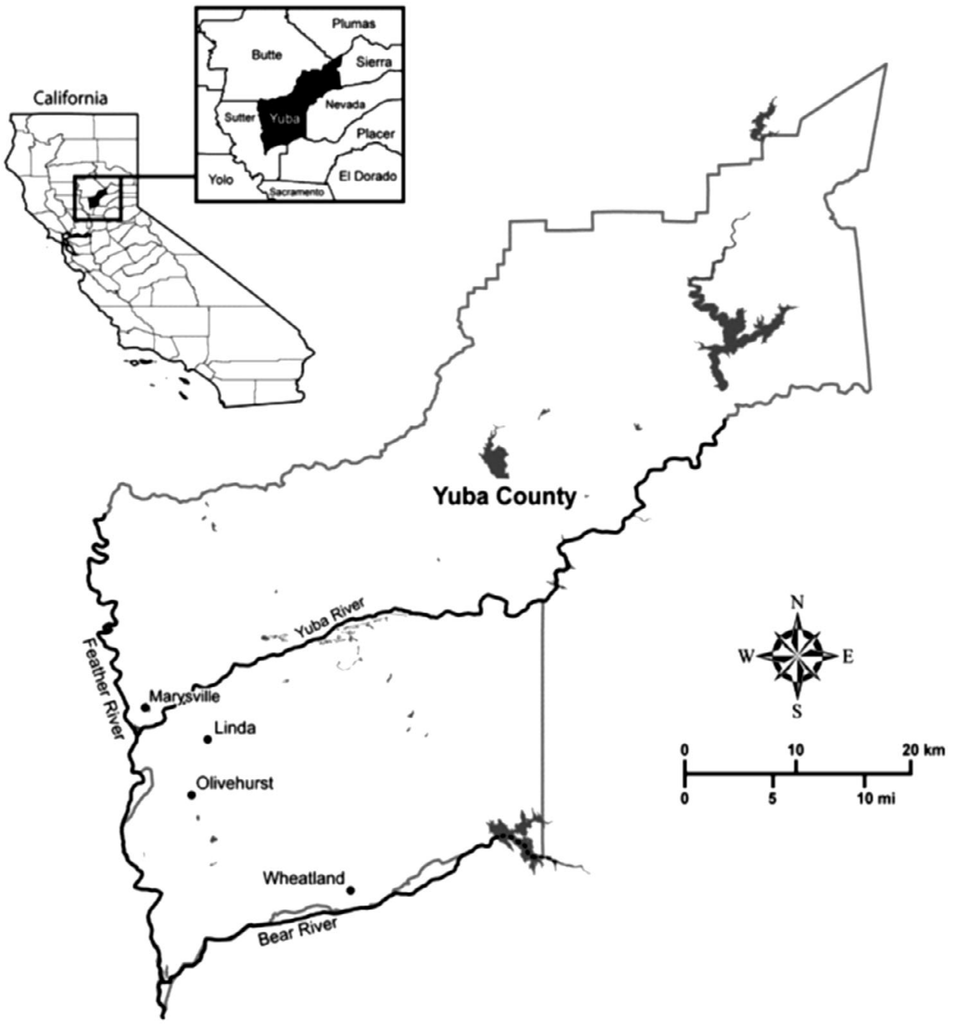

FIGURE 1 The study area

of 4,247 cm resulted in a levee break (Stork et al., 2017). A second 4,247 cm release contributed to the highest recorded rate of flow, 4,559 cm, in January 1997, causing the evacuation of 85,000 residents south of Marysville and Yuba City (USA Today 2017; Williams, 1997). The 1997 event exceeded the 100-year recurrence interval (CBEC Industries, 2012).

3 | DEMOGRAPHICS AND DEVELOPMENT OF THE STUDY AREA

Although flood routes are considered in risk analyses regarding dam failure (Zhang, Peng, Chang, & Xu, 2016), population change inevitably complicates the picture. In this instance, Yuba County has seen significant population growth, thus exacerbating risk potential. Between 2000 and 2010, the population of Yuba County increased by almost 20% (Figure 3), from 60,219 to 72,155 (Table 1). Much of this growth is probably the result of the county's relative proximity to Sacramento, which is approximately 54 km south. To keep up with the demand for housing, several developments have been created. One such estate, Plumas Lake, comprises an additional 12,000 homes in Olivehurst, although that capacity may be raised to 15,500 under the 2021 housing update, which calls for up to 4,000 additional units by the termination of the Yuba County General Plan for urban development (Yuba County, 2014). Other planned estates include East Linda and additional parts of Olivehurst, where overcrowding is high and revitalisation is needed (Yuba County, 2014). These plans were approved under the assumption that increased housing will not only draw higher-income residents as commuters from Sacramento but will also stimulate the local economy.

All this development is entirely reliant on an extensive levee system. Levee improvements on the Bear, Feather, and Yuba rivers have been undertaken for more than 30 years, although the levee breaks in 1986 and 1997 suggest that continuous maintenance is needed to ensure that the system restricts seasonal high-flow events to the floodway. Since those failures, the levees have been improved and expanded, with most recent work occurring between 2004 and 2011 (Three Rivers Levee Improvement Authority, 2016). These improvements included not only the reinforcement of earthen levees but the inclusion of set backs, which allow the rivers to meander slightly before reaching the levee. The

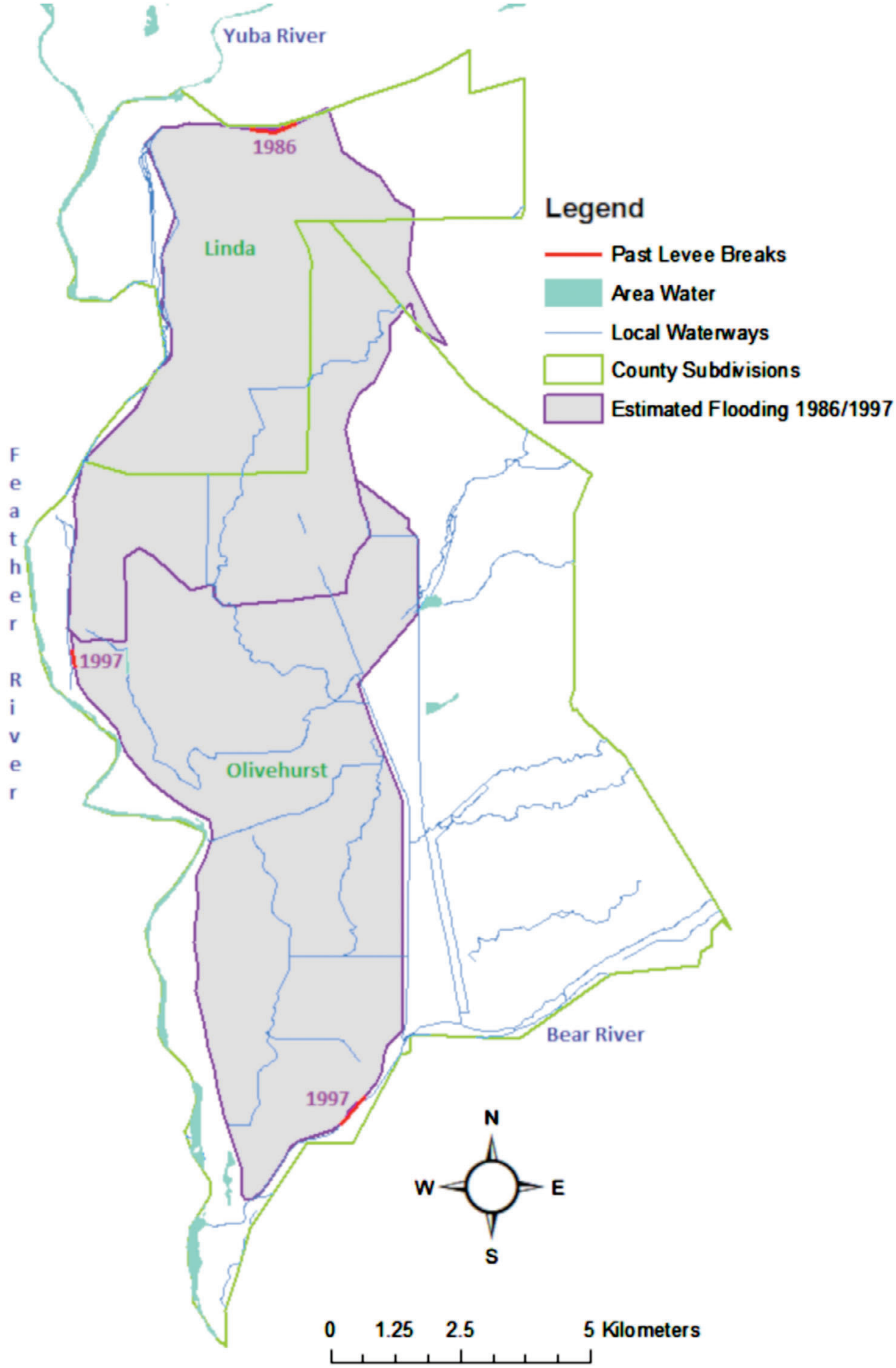

FIGURE 2 Prior flood extent estimates and levee breaks (adapted by authors from Montz & Tobin, 2008 and United States Census Bureau, 2012a, United States Census Bureau, 2012b)*. *Overlap in flood events not shown

Plumas Lake development plan exemplifies reliance on the levees. Construction started in 2002 but was abruptly halted when the US Army Corps of Engineers found that the area was at higher risk than originally thought, and the levees could not be certified at the traditional 100-year level. This meant that the requirements of the National Flood Insurance Program (NFIP) would be in effect, including mandatory flood insurance (Figure 4) (Montz & Tobin, 2008). Efforts were then mounted to improve the urban levees to the 200-year protection level, which is now required by state law for urban areas in the Sacramento–San Joaquin Valley to protect against "future rare events" (Department of Water Resources, 2012). Some developers of the Plumas Lake area helped to fund parts of the project. In addition, some developers promised to pay the flood insurance premiums for anyone living in the development until the levees were certified or until 2010, whichever came first. In February 2011, the Federal Emergency Management Agency (FEMA) certified

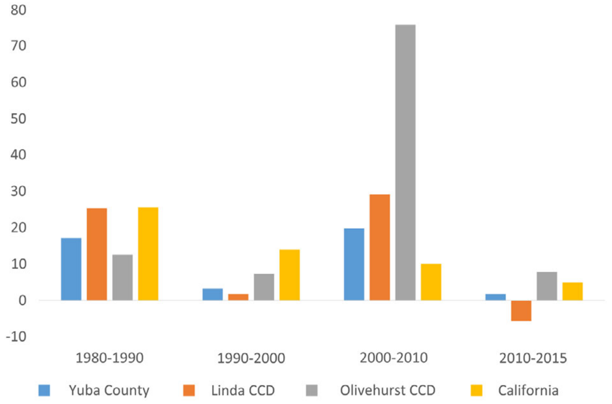

FIGURE 3 Percentage population growth in California, Yuba County, and county subdivisions, 1980–2010 (adapted from United States Census Bureau, 2003; United States Census Bureau, 2012c; United States Census Bureau, 2016)

the urban levee improvements to the 200-year flood design level. However, earlier that year, the Army Corps of Engineers rated the levees around Linda and Olivehurst as minimally acceptable due to the encroachment of structures, increase of pests, and deterioration of embankments (Army Corps of Engineers, 2013; Federal Emergency Management Agency, 2011).

Although the Sacramento Valley features many large-scale levees, flood waters move through low-lying basins whenever levees are overtopped or fail (James & Singer, 2008). As residential developments are removed from flood insurance requirements by increased levee certification, awareness of the risk tends to decrease (Harling, 2011; Ludy & Kondolf, 2012), and urban planners and emergency managers take on overlapping roles to ensure the resilience of their communities. This situation was further complicated in California by court decisions following the 1986 flood in Yuba County when some residents sought compensation for their losses. Specifically, the Paterno v. State of California, 113 Cal. App. 4th 998 (2003) case found that "the state should have known the fragile nature of the levee and had 'ample opportunity' to monitor it and effect necessary improvements" (Pitzer 2004). A further modification, Assembly Bill No. 70, which became effective in 2008, shifted some of the liability for property damage to cities and counties when these entities have "…increased the state's exposure for property damage by unreasonably approving…new development in a previously undeveloped area…that is protected by a state flood control project… unless specific requirements are met" (California State Senate, 2007). Assembly Bill 70 clearly addresses the levee effect, yet development continues, and it is quite likely that a litigious battle will ensue following future flooding of these newly developed areas, including the new developments in Linda and Olivehurst. This area offers an extreme example of the levee effect. The objectives of this case study are to spatially and temporally assess the continued development of flood-prone areas and identify changes in risk resulting from increased urbanisation.

4 | METHODS

In order to determine the patterns of risk and exposure identifiable due to the levee effect, spatial and temporal trends of the changes in development in the floodplain of Yuba County were examined. This case addresses gaps in the literature regarding the concurrent human–environment interactions within floodplains (Ciullo et al., 2016; Di Baldassarre et al., 2013). Following the theoretical framework established by Ciullo et al. (2016), population density, past floods, and technological fixes were assessed within the floodplain to identify increased risk from 1980 to 2015.

4.1 | Datasets

Analyses of census data, land cover change, FEMA flood zone designations, and county development plans were conducted. Spatial analysis included three levels: (a) populated areas, (b) levee improvements, and (c) insurance zonation changes. Regional divisions from the United States Census Bureau for the year 2010 indicated population distribution. Levee improvements as certified in 2011 were obtained from Be Prepared Yuba (2012). FEMA flood zones from 2011 that included 1% risk and consequently continued to require insurance after the levee recertification were accessed from the Yuba County California Department of Public Works (2011). Temporal analysis included changes on two levels: (a) population density and (b) land use. County-level data from the United States Census Bureau were used to calculate percentage change from 1980, 1990, 2000, and 2010. Data for 2015 were also presented from the American Community Survey, which provides population data collected by the US Census Bureau between 10-year surveys. National Land Cover Database files from 2000 to 2011, both before and after completion of the levee recertification, provide visual documentation of the urbanisation in the southwest part of the county over time.

4.2 | Data analysis

County-level US Census Bureau population data from Yuba County, the Linda Census County Division (CCD), and the Olivehurst CCD were included. The CCDs, which include county-level data collected by the US Census Bureau, were used for spatial analysis instead of the more detailed census tracts because the boundaries are most consistent with prior

TABLE 1 Population in Yuba County and census county divisions (CCDs)

	1980	1990	2000	2010	2015 (Est.)
Yuba County	49,733	58,288	60,219	72,155	73,437
Linda CCD	10,682	13,386	13,626	17,602	16,615
Olivehurst CCD	9,935	11,191	12,016	21,120	22,770

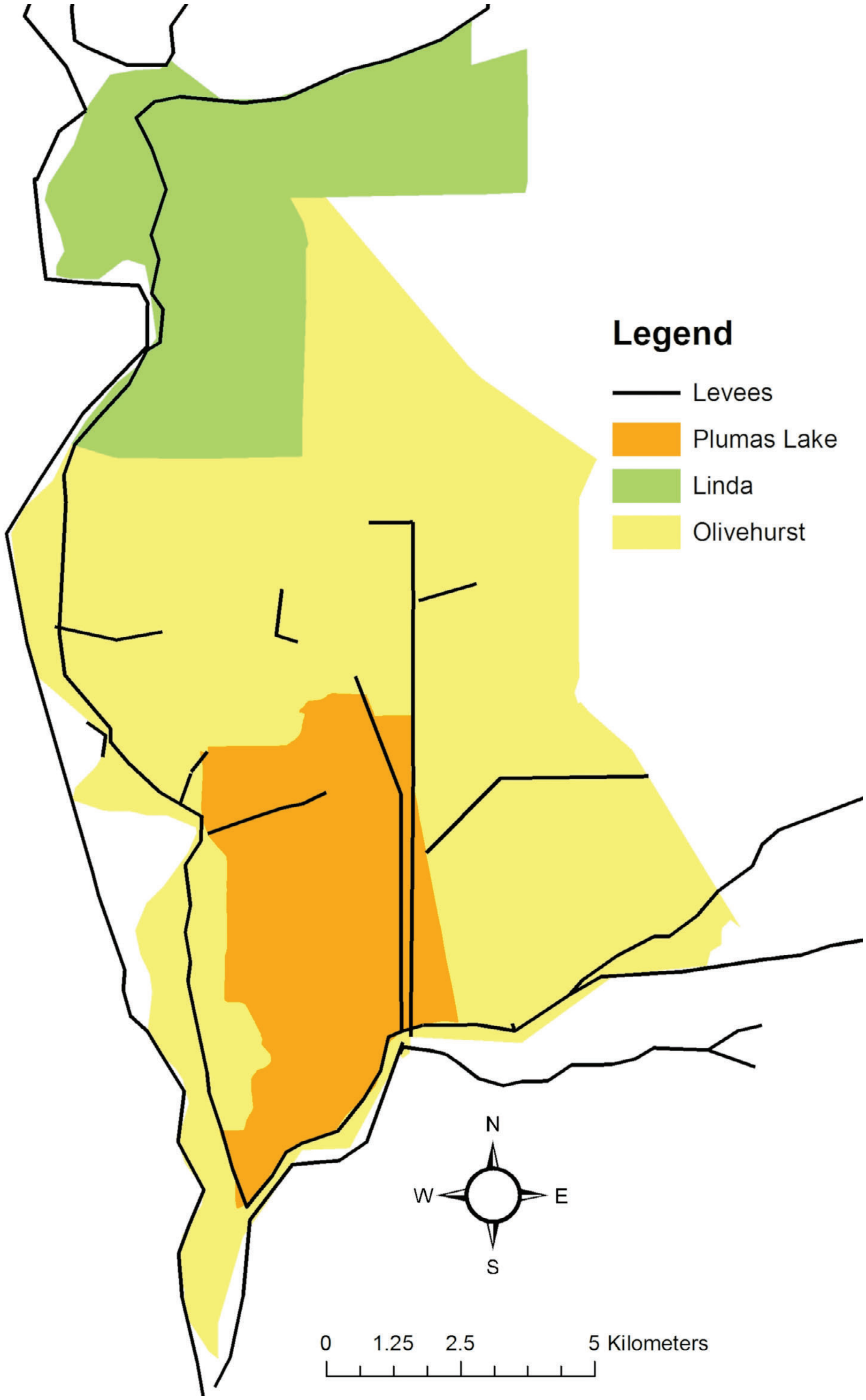

FIGURE 4 Recertified levees in the study area (generated by authors from Be Prepared Yuba, 2012 and United States Census Bureau, 2012a, United States Census Bureau, 2012b)

flood boundaries. A census designated place (CDP) for Plumas Lake was also included to reflect its emerging high concentration of population. Tigerline Shapefiles of regional divisions from the US Census Bureau were used to delineate population concentrations and create a base map for the study area (Figure 5).

The reduced flood insurance designations were manually digitised from the Yuba County California Department of Public Works (2011). The 1% flood zones from FEMA beyond the 200-year flood-certified levee capacities include: A - areas without detailed base flood elevations, as well as areas with detailed analysis of hydraulic flows; AE – known base flood elevations; AH - ponding; and AO - high-velocity flow potential. These areas are particularly pertinent to mortgage holders because they also indicate a 26% chance of a 1–3 ft flood over a 30-year period, which is typically the

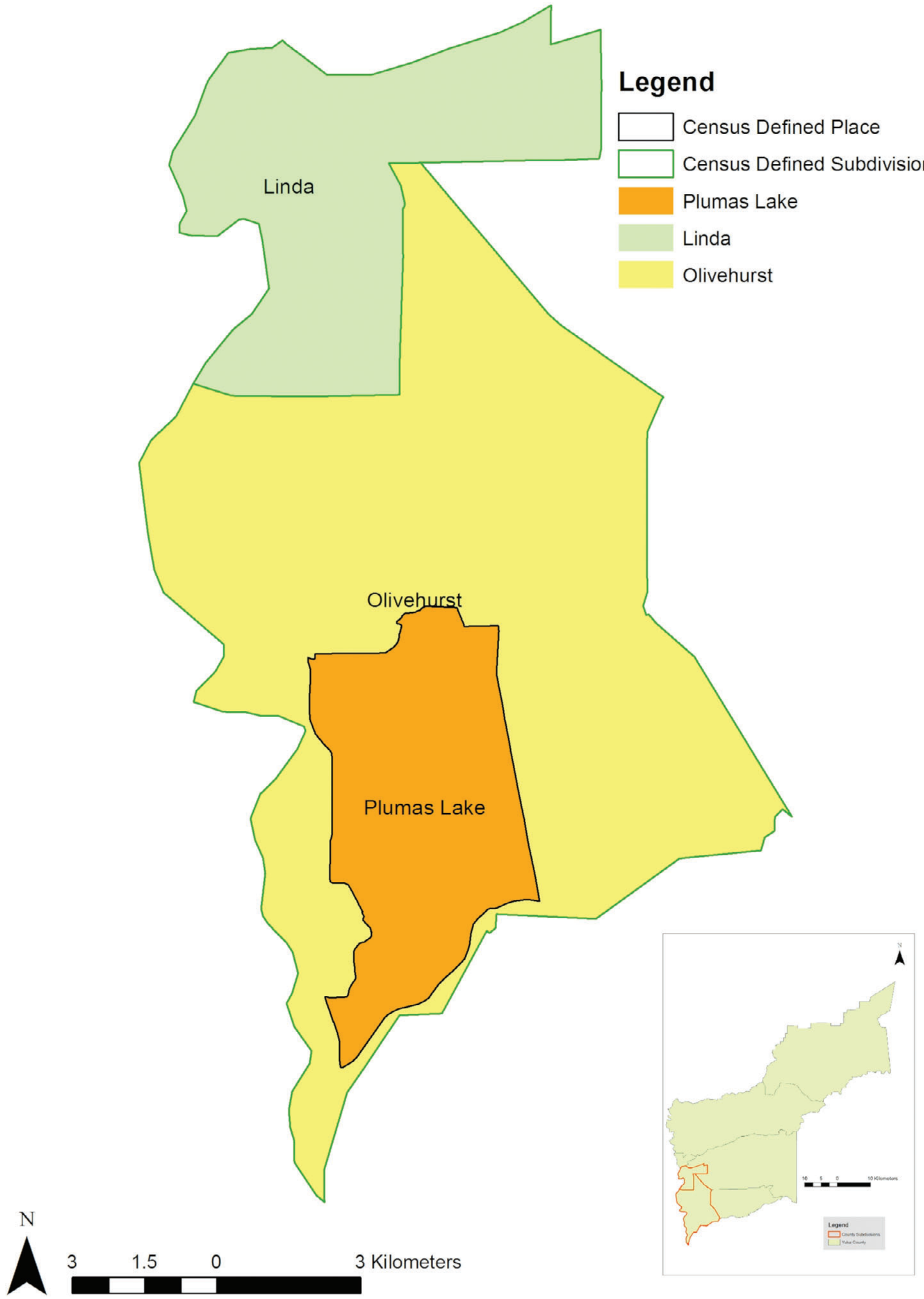

FIGURE 5 Census designations* (generated by authors from United States Census Bureau, 2012a, United States Census Bureau, 2012b). *Location of inset map is shown in Figure 1

time for repayment of their home loan. Less frequent events, such as the 200-year flood, were not used due to the difficulty in estimating their extent from sparse historic records. The proximity of new development to the areas with reduced flood insurance requirements was determined based on map overlays of flood zone designations and census divisions.

Temporal trends in population- and housing-related census data were analysed to ascertain relationships between past flood events, hazard mitigation, and residential development. Decadal trends are presented from as early as 1980 when possible to incorporate the first flood in the study area after the construction of the Oroville Dam. Estimates from the 2015 American Community Survey were also used to track variation in trends leading up to and following the levees' recertification. Longitudinal data were not available for Plumas Lake because population for such a designation was not present until 2010; before 2010, the population was incorporated in the Olivehurst CCD (Figure 3). Finally, National Land Cover Database files from 2000 to 2011 were compared to confirm development patterns suggested by the increase in population density reflected in census designation changes and called for in county development plans.

5 | RESULTS AND DISCUSSION

The series of mitigation measures deployed to prevent flooding in Olivehurst and Linda following the 1997 floods has

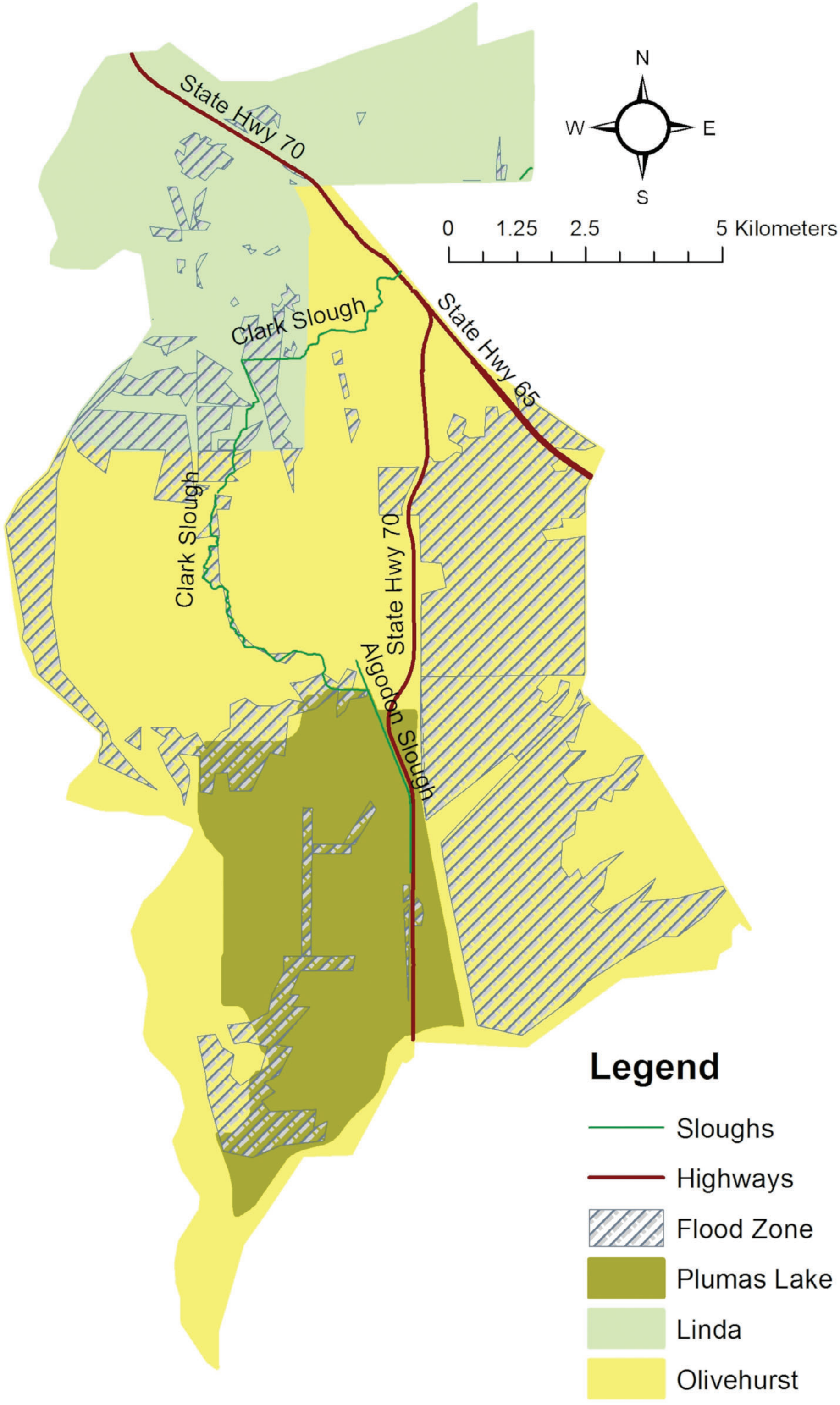

FIGURE 6 Flood zones and local features of the study area (generated by authors from Yuba County Department of Public Works, 2011 and United States Census Bureau, 2012a, United States Census Bureau, 2012b)

not changed the elevation of the basin but rather provided what has been traditionally described as the structural response or technological fix (White, 1961). The majority of the newly developed areas of Plumas Lake are within the extent of the 1997 flood. However, the recertification of levees on the Bear River to the south (Figure 4) and Algodon Slough to the east (Figure 6) reduced the FEMA-designated floodplain and thus also reduced the flood insurance requirement. The 1% flood zone now encompasses the generally less-developed southwest and northern areas of Plumas Lake, with the exception of a vein that runs along a portion of Highway 70 (Figure 6).

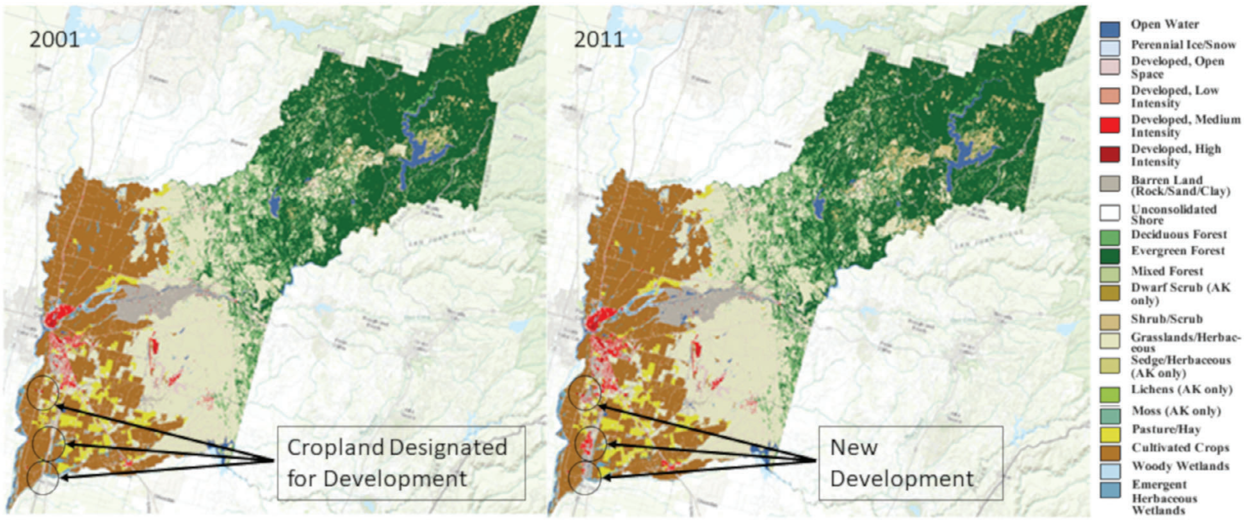

FIGURE 7 Land cover change in Yuba County, 2001–2011 (adapted by authors from MRLC, 2016a, MRLC, 2016b)

The flow of water is not constrained by political designations; consequently, some flood zones cross districts. Areas to the south of Olivehurst, including outlying areas within Plumas Lake where residential development transitions to cropland, are at risk of flooding from both the Feather and Bear Rivers, although this is partially protected by the Feather River set back. East of Plumas Lake, less-densely populated areas of Olivehurst fall within the 1% flood zone, including parts adjacent to highways 70 and 65. Although this area did not flood in 1986 or 1997, it remains under crop or livestock production, as was much of the Plumas Lake area prior to the proposed improvements to the levee system, which, as noted earlier, removed the insurance requirement and promoted its development (Figure 7). The central portion of Olivehurst CCD, although not inclusive of extensive housing infrastructure, is also at risk of flooding along its boundaries with Linda and Plumas Lake. This flood risk carries through a narrow swath of the area along Clark Slough (Figure 6). Less-densely developed areas to the west, which experienced significant flooding from both the 1986 and 1997 floods, are protected to some extent by the Feather River levee set back (Figure 4).

Areas in east Linda and north Olivehurst that did not flood in the last 32 years remain largely outside the 1% flood zone and continue to be populated. However, several sections of the southern part of Linda extend through the 1% flood zone (Figure 6). On the one hand, portions of west Linda that flooded in 1986 are protected by levees that are set back (Figure 4). On the other hand, despite the levee improvements, central areas of the district still have a 1% annual risk of flooding.

Given that some portions of all the levees along the Bear, Feather, and Yuba rivers have all failed since 1986 (Figure 2), flood hazard awareness should remain a concern of planners and residents alike. Other built-up areas that are seeking future development opportunities by converting farmland, such as Wheatland farther east on the Bear River (Figure 7), would include sections with a 1% flood risk (Yuba County California Department of Public Works, 2011). Proximity to past breaks, however, has not deterred revitalisation and development. Areas in north Linda and south Olivehurst, including Plumas Lake, have maintained and increased housing infrastructure as a result of population and economic development pressures.

Population has increased throughout the county, although the rates of such change have varied. Figure 7 shows that Maryville to the north is reaching capacity, whereas mountainous areas to the northeast remain largely undeveloped. The entire county experienced low growth in the decade between 1990 and 2000 due, at least in part perhaps, to the mini recession that California experienced in the early 1990s (Bancroft Library, 2011). Overall, the state has grown by 14% during the decade, but Yuba County has grown at a much lower rate, with the Olivehurst CCD having the highest rate of growth at just over 7% (Figure 3). This is lower than the growth rate from 1980 to 1990, which included the 1986 flood that affected Linda. However,

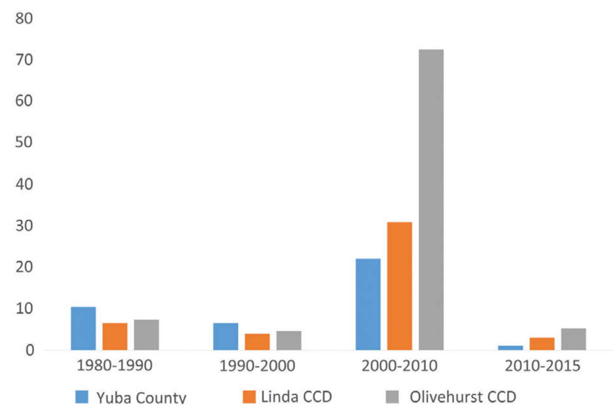

FIGURE 8 Percentage change of housing stock in Yuba County, and county subdivisions, 1980–2010 (adapted from United States Census Bureau, 2003; United States Census Bureau, 2012c; United States Census Bureau, 2016)

TABLE 2 Housing numbers in Yuba County and census county divisions (CCDs)

	1980	1990	2000	2010	2015 (Est.)
Yuba County	19,246	21,245	22,636	27,635	27,930
Linda CCD	4,163	4,433	4,608	6,029	6,207
Olivehurst CCD	3,613	3,877	4,054	6,989	7,349

population growth rates remained above those of the county from 1980 to 1990 in Linda. Olivehurst and Linda both experienced reduced population growth from 1990 to 2000. The build up of damage entropy in the area from the 1997 floods could have deterred residents from relocating to or remaining in the areas; however, without more detailed analysis, the direct correlation between these events and population trends cannot be determined (Montz & Tobin, 1988). Nevertheless, from 2000 to 2010, Yuba County and its subdivisions experienced quite different trends compared to the state as a whole, which has seen declining growth rates since the 1990s. Yuba County, Linda, and Olivehurst all rebounded from the slow growth in the 1990s, with Linda and Olivehurst experiencing greater increases than Yuba County, despite these communities' flood histories. Olivehurst's extraordinary growth at more than 75% can be attributed largely to the Plumas Lake development. This high growth rate has not been sustained from 2010 to 2015; in fact, Linda has decreased in population since the completion of the recertified levee system in 2011.

The housing stock increased throughout the county over the study period. In 1980, Linda and Olivehurst accounted for about 40% of the county's housing, and by 2010, this had increased to just over 47% (Figure 8). Olivehurst had fewer houses than the Linda CCD until it surpassed Linda by the time of the 2010 census, again owing to the Plumas Lake development. The rates of growth in the housing stock show important differences (Table 2). Both Linda and Olivehurst show smaller proportional increases than Yuba County in both the 1980s and 1990s, perhaps relating to the floods during those decades. Yet, the 2000s tell a very different story,

FIGURE 9 New development in Plumas Lake (photo by authors)

FIGURE 10 Redeveloped area of Olivehurst (photo by authors)

with greater increases in Linda and Olivehurst than in the county. These continuous, if variable, housing development increases at the county and district levels are in line with long-term trends for the state of California, which increased urban development from 1975 to 2010 in part by reducing agricultural land area by 1% (Sleeter, Wilson, Soulard, & Liu, 2011). Although converted land in Olivehurst was primarily agricultural (Figure 7), housing did expand into a variety of land use types in the study area, set to be released from flood insurance requirements in 2011 (Figure 6). Clearly, the development and revitalisation efforts of the county are paying off in the targeted areas, and it is only through the levee improvements that this development is possible without the extra NFIP requirements.

Since 2010, the rate of housing unit increase has significantly declined in Yuba County to 1.1% from 2010 to 2015. Even the fastest growing area saw only a 5% increase. Soulard and Wilson (2015) identify a drought between 2005 and 2010 across the Central Valley that may have facilitated the conversion of agricultural land to urban housing. In Yuba County, however, this decline in growth coincides with reports of uncertainty in the newly certified levees (Army Corps of Engineers, 2013). When the drought eases across the Sacramento area, the levees protecting the residents who flocked to flood-prone areas will be tested, as demonstrated by the events of early 2017.

Figure 9 shows new housing units in Pumas Lake, which, in addition to having some of the highest population and housing growth rates, also commands new home prices of $40,000 more than the older homes in other revitalised parts of the study areas (United States Census Bureau, 2016). These homes back onto low-lying areas in the 1% flood zone but are not themselves included in the designated floodplain. Revitalised housing in Linda and Olivehurst seen in Figure 10 is still sited in low-lying areas. The extent to which reduced insurance requirements altered social memory and awareness of floods was beyond the scope of this study. However, reliance on the technological fix to ameliorate flooding in these areas has put more residents and increasingly valuable housing assets at risk.

6 | CONCLUSIONS AND FUTURE RESEARCH

Development on the floodplain has improved the amount and quality of the housing stock in Olivehurst and Linda, although the addition of Plumas Lake to an area that historically floods requires complete reliance on the levee system. Although many current neighbourhoods are outside the FEMA-designated high flood-risk area, which means residents can avoid increased costs related to flood insurance, Linda and Plumas Lake both feature communities with boundaries on or within the 1% annual flood zone. Furthermore, Plumas Lake is located in an area accessible to the interstate highway, which increases economic opportunity for the residents' commuting to Sacramento; at the same time, other parts of Olivehurst and Linda may be cut off on occasions due to flooding near the highways.

In the event of a levee break, such as those that led to the 1986 and 1997 floods, properties and lives in the floodplain remain vulnerable. The data show only a minor drop in the population growth of affected districts during the study period, which temporally correspond to floods in the 1980s and 1990s. Potential impacts from the floods are more evident in the decreased housing stock available from 1990 to 2000. The substantial increase in population and housing from 2000 to 2010 coincides with the promise of improved levees as well as recovery and isolation from economic issues experienced across the state.

Declining and even negative rates of population and housing stock growth appeared in 2015 estimates following the recertification of the levees. Given the reports of embankment deterioration shortly after the completion of improvements to the levees, developments outside of the designated 1% flood zone may well be at risk. The economic opportunity brought to Yuba County through replacement and expansion on the floodplain may be eradicated by future disaster costs.

It is beyond the scope of this study to make direct correlations between flood events or levee certification and shifting risk profiles. Annual analyses of population shifts at finer scales would bolster evidence of change in development trends associated with specific events. Furthermore, research involving surveys of flood memory and risk perception could expand upon the role of social reactions in floodplain development. Comparative studies are also needed to determine the likelihood of such extreme change in other urbanising floodplains.

7 | RECOMMENDATIONS

The levee effect is alive and well in Yuba County, California. Indeed, the improvement of levees was sought to allow for development, and it has taken place. The areas that experienced the greatest growth are those that flooded in 1986 or 1997 but are now "protected" by the levees. Both population and housing growth rates between 1980 and 2010 in Linda and Olivehurst have outpaced those of the county despite the ongoing experiences with floods from levee failures in these communities. Economic growth and development pressures have been substantial in the county, and the county has responded. To date, Yuba County plans have been highly successful from a development perspective. Furthermore, there is little doubt that we know more now, and we have the technology to build stronger levees than in the past. Yuba County, and indeed the State of California, are relying on that—as are many other communities throughout the world.

Others question the wisdom of such an approach. The Federal Interagency Levee Policy Review Committee (2006) made it clear that levees should be viewed as risk reduction measures, not as flood protection measures. This is even more important in the face of a dynamic hydrological system. Conditions in the Yuba and Feather watersheds have been changing over time, due in part to human activities including the history of hydraulic gold mining, the construction of by-passes, and piecemeal levee development (James & Singer, 2008). To this must be added the spectre of climate change, which will alter the seasonal flows and storage potential of the valley (Ciullo et al., 2016; VanRheenen, Wood, Palmer, & Lettenmaier, 2004). Many of the levees are now certified to the 200-year flood level, but that is based on past events, not what might be seen in the future. This short sightedness, which is not by any means unique to Yuba County, also ignores the region's flood history, which has been lengthy and devastating, despite many efforts to control the rivers. Enlightened flood risk managers are needed to provide development alternatives and overcome the false sense of security from the levee effect now that more people and property are at risk.

In areas recovering from disasters, considerations for rebuilding and expanding housing should include not only the structural mitigation potential of levees but should also address underlying features of the landscape and economic sustainability of developments. Hence, comprehensive planning would seem essential. Neighbourhoods of Yuba County that were recently evacuated due to potential flooding from dam failures feeding into the Feather River are left to re-evaluate the likelihood of levee failure, the results of which will flood well beyond the 1% flood zone.

Although Yuba County is an extreme example of growth and demographic changes associated with the levee effect, floodplain managers everywhere should be wary of implications for areas with levee systems that are experiencing rampant development. These outcomes may be slower to develop in many areas or influence other vulnerable populations; however, population pressure is almost a universal concern. Subtle changes in urban planning and disaster preparation have the potential to reduce risk if policymakers recognise the potential long-term consequences of increased population concentration in floodplains. Finally, the dynamic conditions associated with global climate change may further compromise ongoing risk analyses, especially those related to flood frequencies and probabilities.

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