Land Use Change in California, USA: Nonpoint Source Water Quality Impacts

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ABSTRACT / California's population increased 25% between 1980 and 1990, resulting in rapid and extensive urbanization. Of a total 123,000 ha urbanized in 42 of the state's 58 counties between 1984 and 1990, an estimated 13% occurred on irrigated prime farmland, and 48% on wildlands or fallow marginal farmlands. Sixty-six percent of all new irrigated farmland put into production between 1984 and 1990 was of lesser quality than the prime farmland taken out of production by urbanization. Factors dictating the agricultural development of marginal farmlands include the availability and price of water and land, agricultural commodity prices, and technical innovations such as drip irrigation systems that impact the feasibility and costs of production. The increasing amount of marginal farmland being put into production could have significant water quality consequences because marginal lands are generally steeper, have more erodible soils, poorer drainage, and require more fertilizer than prime farmlands. Although no data exist to test our hypothesis, and numerous variables preclude definitive predictions, the evidence suggests that new irrigated marginal lands can increase nonpoint source (NPS) pollution for a given size area by an order of magnitude in some cases.

Large-scale land use conversion can have significant impacts on both surface water and groundwater quality. These impacts are especially well illustrated in California, where rapid population increase has resulted in conversion of prime agricultural land and undeveloped wildlands to urban uses. Less obvious but more importantly, many marginal lands have been placed into agricultural production with serious water quality implications because the marginal lands are typically more erodible and require greater fertilizer application than prime farmlands.

In this study, we review the principal sources of water pollution in California, consider the probable long-term water quality impacts of land use conversion trends, and suggest possible water resource protection strategies.

KEY WORDS: Nonpoint source pollution; Water quality; Erosion; Prime farmland; Watershed management; Urbanization; Land use conversion; Best management practices

Sources of Water Pollution

Sources of water pollution can generally be classified as originating either from point sources or nonpoint sources. Nonpoint source (NPS) pollution is difficult to isolate and control because it does not originate from a single discharge point, but rather comes from surface runoff, percolation to groundwater, and atmospheric deposition or precipitation (EPA 1987). Point sources of water pollution, with the exception of leaking underground storage tanks, have been largely controlled over the last decade through the National Pollutant Discharge Elimination System (NPDES) wastewater permitting system administered by the California regional water quality control boards. On the other hand, diffuse landborne and airborne NPS pollution has not been controlled and is now the greatest contributor to surface and groundwater quality degradation (WRCB 1990). Nationwide, agriculture is the single largest contributor of NPS pollution, with sediment and nutrients most responsible for water quality degradation (EPA 1992).

Sources of Surface Water Pollution

Suspended sediment is the largest surface water NPS pollutant on a volumetric basis. In addition to the direct effects of increased turbidity, damage to hy-

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draulic structures, and reservoir sedimentation, fine sediment has secondary effects caused by adsorbed pollutants, and from trihalomethanes (THMs), which form when natural organic matter (derived from soils, decaying plant material and algae, and irrigation return flows) combines with chlorine used for disinfection of water supplies.

Nutrients (especially phosphorus and nitrogen) and pesticides are derived from agricultural soils in adsorbed or soluble form. Finer sediments have a higher capacity per unit of mass to adsorb nutrients and pesticides and tend to have a higher proportion of organic matter. In general, pollutants adsorbed onto sediment particles are not as readily bioavailable as more soluble forms, but will come into solution slowly over time (Kuhner 1980). Nutrients transported by sediment can cause eutrophication or nuisance algal growths that act as trihalomethane precursor material, increase turbidity, and cause taste and odor problems in water supplies. Adsorbed organic contaminants such as pesticides may also cause drinking water quality impairment. Soil erosion from urban areas is of concern because of heavy metal contamination. The costs of damages directly attributable to sediment and its associated pollutants has been estimated to exceed $3.5 billion dollars annually nationwide (Clark 1985).

Land uses that expose soil to erosion can increase NPS pollution. Rill, sheet, and gullying erosion are the most significant mechanisms; wind erosion is locally important. Agricultural row cropping, especially when augmented by irrigation, produces the highest soil erosion rates. Irrigation-induced erosion rates in the San Joaquin Valley have been estimated to range from 10,536 to 32,953 kg/ha (4.7–14.7 tons/acre), depending on the crop (SCS 1992). Chronic overgrazing is the other principal agent of agricultural soil erosion, with rangeland experiencing somewhat more erosion than pastureland (Myers and others 1985). Timber harvest leads to increased erosion, largely from construction of logging roads, although harvesting operations can also be a significant source, especially on steep slopes and sensitive soils (Reid and Dunne 1984). Loss of vegetation due to logging or wildfires will accelerate soil erosion, especially during wet winters following periods of drought.

Urbanization affects erosion rates directly and indirectly. Besides direct construction activity impacts, urbanization increases impervious surface area, increasing both the rate and volume of runoff, inducing stream channel downcutting and possible widening as the stream adjusts to the higher peak runoff (Leopold 1968). These physical impacts may have more significant water quality impacts than the chemical constituents of urban runoff (EPA 1983).

Sources of Groundwater Pollution

Nitrate contamination is responsible for most groundwater pollution in California, with water supply wells exceeding the strict drinking water standards (45 mg/liter as nitrate) in the central valley, central coast, and southern California regions, areas with presently and historically intensive agricultural uses. The Metropolitan Water District (which serves large areas of southern California) loses almost 4% of its water supply annually. Most groundwater in the agriculture-dominated Salinas Valley is expected to exceed nitrate standards by the year 2000 (Anton and others 1988).

Most nitrates in groundwater derive from the over 570 million kg of fertilizer applied annually to California farmlands, most of which eventually leaches to groundwater (Anton and others 1988). Other significant sources of nitrate contamination include confined animal operations such as dairies, feedlots, poultry farms, and septic systems, which typically leach 20–40 ppm of nitrate year-round to groundwater (Ellis 1982). As with pesticides, there is a variable latency period between the time chemicals are applied to the land surface and the time when groundwater contamination occurs. Soil acts as a reservoir for contaminants, which may persist for long periods of time until the chemicals are ultimately degraded, transported in association with sediment, or leached into groundwater.

Water Quality and Land Use Relationships

NPS pollution, the most significant source of surface and groundwater quality impairment, is directly related to land use. Agriculture is the greater contributor of NPS pollution, in part because of its large areal extent, and because of the extensive soil disturbance and application of fertilizers and pesticides. By contrast, despite a wide array of contaminants, urban storm runoff has not been implicated as a cause of significant degradation of water supplies, based on the results of two Nationwide Urban Runoff Program (NURP) studies and ongoing studies in Fresno and Sacramento, California (Archibald 1991). Similarly, timber harvest and construction activities are less important than agriculture because of their more limited areal extent and minimal groundwater impacts. Figure 1 summarizes the sources of water quality impairment and the corresponding long-term water quality impacts associated with agricultural, urban,

	Water Quality Impacts												
Sources of Pollution	Surface Water										Groundwater		
	Toxics Contam.	Eutrophication	Salinization	THM Precursors	Erosion/ Siltation	Bacterial Contam.	BOD/ Oxygen Depletion	Ammonia Toxicity	Turbidity	Acidification	Toxics Contam.	Nitrate Contam.	Salinization
A. Agricultural lands (cropland and livestock)													
Pesticide application	X										X		
Fertilizer application		X										X	
Irrigation return flows	X	X	X	X			X		X		X	X	X
Cultivation/Soil disturbance				X	X				X				
Animal confinement areas		X		X	X	X	X	X	X			X	
Overgrazing					X				X				
Airborne deposition	X	X							X	X			
B. Silvicultural lands (forestry/logging)													
Timber harvesting		X		X	X		X		X				
Access road construction					X				X				
Revegetation site preparation					X				X				
Pesticide application	X										X		
C. Urban lands (varied sources and contaminants)													
Urban runoff	X	X	X	X	X	X	X		X		X	X	X
Septic system leachate	X	X	X			X	X	X			X	X	X
Spills of hazardous materials	X						X				X		
Wastewater effluent	X	X	X	X		X	X	X	X	X	X	X	X
Transportation corridors	X	X	X			X	X		X		X		X
Solid waste disposal	X	X		X		X	X		X		X	X	X
Pesticide application	X										X		
Fertilizer application		X										X	
Air emissions/deposition	X	X							X	X	X		

Figure 1. Water quality impacts of various land uses.

and silvicultural land uses, as well as short-term construction activity impacts.

Intensive construction activities can have significant localized impacts on water quality. Road cuts from highway construction can release natural metals and minerals, such as asbestos from serpentine rocks (DWR 1987). Construction site surface runoff rates have been reported to be as much as 100 times greater and sediment production 10–20 times higher than agricultural areas (Myers and others 1985). However, construction impacts are transient sources of NPS pollution and can be largely mitigated through good site planning and the implementation of best management practices (BMPs).

Land Use Conversion Trends in California

California encompasses about 40.5 million ha: 40% forest; 31% agricultural; 5% intensely developed urban land; and 24% desert and brushland as of 1990. The agricultural lands are predominantly rangeland or pasture (65%) and irrigated cropland (27%); dry cropland (5%) and irrigated pastureland (3%) constitute the remainder (AFT 1986, Pacific Data Research 1990). Urbanization is the principal driving force behind land use conversion in California, with a population increase of 25% from 1980 to 1990 to over 30 million people (DOF 1986, 1990). Not surprisingly, most land use conversion from urbanization occurs in counties with the greatest population growth, notably in southern California (OLC 1988, 1990, 1992). Over 123,000 ha were urbanized from 1984 to 1990 in the 42-county state Office of Land Conservation (OLC) farmland mapping study area, and as many as another 400,000 ha are expected to urbanize statewide by the year 2000 (OLC 1988, 1990, 1992; AFT 1986). Of all new urban lands developed in the OLC statewide study area between 1984 and 1990, 48% were formerly wildlands or marginal farmlands; 32% were grazing/dry farmlands; and 20% were irrigated farmlands, of which 63% were prime farmlands (OLC 1988, 1990, 1992).

Prime farmland has been extensively urbanized along the coastal plain from San Diego to San Francisco, and concentrated in the vicinity of major population centers in southern California, the San Joaquin Valley, and the San Francisco Bay area (Table 1). Despite this loss of prime agricultural land, the total

Table 1. Urbanization rates by county (1984–1990)[a]

Prime farmland[b]		Wildland/marginal farmland[c]	
County	Hectares (acres)	County	Hectares (acres)
Riverside	4593 (11350)	San Diego	9090 (22,461)
San Bernadino	1573 (3887)	Los Angeles	8950 (22,116)
Orange	1542 (3811)	San Bernadino	8266 (20,426)
Stanislaus	1154 (2852)	Orange	7949 (19,642)
Ventura	930 (2297)	Riverside	7268 (17,958)
Santa Clara	722 (1784)	Ventura	2204 (5447)
Fresno	673 (1663)	Contra Costa	1574 (3890)
Alameda	547 (1352)	Fresno	1420 (3510)
Yolo	457 (1130)	Solano	1364 (3370)
Contra Costa	412 (1018)	Alameda	1192 (2945)
Sonoma	386 (953)	Shasta	1093 (2700)
Kings	337 (832)	Placer	1044 (2581)
Monterey	303 (749)	Kern (4)	926 (2289)
Solano	290 (716)	El Dorado	912 (2254)
Kern[d]	271 (669)	Monterey	801 (1980)
San Benito	254 (627)	Santa Barbara	734 (1814)
Merced	249 (615)	Stanislaus	606 (1498)
Imperial	210 (519)	Sacramento[e]	534 (1319)
Los Angeles	205 (507)	Sonoma	444 (1096)
San Diego	177 (437)	Marin	412 (1017)
Total	15,285 (37,768)		56,783 (140,313)

[a] Top 20 counties based on California Office of Land Conservation data from 42 of 58 counties (does *not* include San Joaquin County).

[b] Prime farmland based on modified USDA Soil Conservation Service Land Inventory and Monitoring (LIM) system definition.

[c] Wildland/marginal farmland category includes a variety of rural land uses.

[d] Kern County data covers 1988–1990 only.

[e] Sacramento County data covers 1988–1990 only.

amount of irrigated cropland has remained nearly constant because many new marginal farmlands have been placed into production in southern California and the San Joaquin Valley, and, to a lesser extent in the bay area, central coast, and Sacramento Valley regions (Table 2). Total irrigated cropland has changed little since 1980 and is unlikely to increase because of environmental and water availability constraints as well as speculation on anticipated urban development (AFT 1986; CDF 1988).

Geographical shifts in agricultural production have occurred as a result of urbanization. The expansion of San Jose into the fertile Santa Clara Valley displaced orchards over the coastal hills into the San Joaquin Valley. Ironically, nearly all recent urbanization in the northern San Joaquin Valley has been on prime farmlands. New farmland production has been focused on the rolling foothills at the eastern and western margins of the valley (Jones and Stokes 1991). New irrigated marginal lands do not have the same production potential or crop commodity options as the prime lands that have been urbanized. Recent trends on marginal lands have been toward higher value commodities such as avocados, vineyards, and horticultural crops.

Of the 7191 ha newly placed into irrigation in San Diego County (Table 2), 10% is considered prime farmland, 66% is marginal farmland, and 24% intermediate (OLC 1988, 1990, 1992). Based on data from 42 counties, 66% of all new irrigated farmland placed into production between 1984 and 1990 (76,910 ha) was of lesser quality than the prime farmland taken out of production by urbanization; only 34% of the new irrigated lands was prime farmland (OLC 1988, 1990, 1992).

Factors dictating the rate of new irrigated marginal farmland being placed into production include the availability and price of land; availability (including reliability and quality) and price of water; agricultural commodity prices; and technology costs and innovations (Singer and others 1990). Urbanization is competing directly with agriculture for finite land and water resources. The placing of marginal land into production may not continue indefinitely, mainly because of water availability, causing the total amount of statewide irrigated cropland to decrease in the future.

Table 2. New irrigated farmland (hectares; 1984–1990)[a]

County	Prime[b]	Intermediate[c]	Marginal[d]	Total
San Diego	761	1702	4728	7191
San Luis Obispo	3119	968	2403	6490
Riverside	2833	985	2446	6264
Stanislaus	392	4737	959	6088
Glenn	2256	1086	1193	4535
Yolo	1783	371	1435	3589
Santa Barbara	1727	528	1283	3538
Fresno	1011	824	1653	3488
Napa	1264	845	1306	3415
Imperial	1791	1548	17	3356
San Bernadino	1334	1634	260	3228
Sonoma	639	498	2042	3179
Kings	585	1629	459	2673
Kern[e]	1604	571	372	2547
Placer	160	276	1778	2214
Merced	480	304	1320	2104
Siskiyou[f]	339	569	759	1667
Solano	871	148	594	1613
Tehama	677	197	572	1446
Shasta	1016	283	35	1334
Total	24,642	19,703	25,614	69,959

[a] Top 20 counties based on total new irrigated acreage from California Office of Land Conservation data from 42 of 58 counties (does not include San Joaquin County).

[b] Prime farmland based on modified USDA Land Inventory and Monitoring system definition.

[c] Intermediate defined as USDA LIM "farmland of statewide importance" category which is between "prime farmland" and "unique farmland" in the classification system.

[d] Marginal defined as USDA LIM "unique farmland" category. It does not meet criteria for "prime farmland" or "farmland of statewide importance" and is the lowest quality category of irrigated farmland included in this classification system.

[e] Kern County data covers 1988–1990 only.

[f] Siskiyou County data covers 1986–1990 only.

In southern California especially, large areas of irrigated farmland are now left fallow, evidently in anticipation of urban development (CDF 1988).

Urbanization of wildlands and marginal fallow farmlands has accounted for most of the lands converted to urban use (Table 1). As land values increase, large parcels are subdivided, attracting new residents and further driving up land prices. Six California counties (Riverside, San Bernadino, Calaveras, Amador, Nevada, and El Dorado) experienced population growth rates in excess of 50% from 1980 to 1990. Much of this development occurred as "ranchettes," small low-density semiagricultural parcels (typically 1–20 ha), which now cover almost 800,000 ha in California. There has also been some conversion of wildlands to new agricultural uses, such as the conversion of wildland to orchards in southern California.

Water Quality Impacts of Current Land Use Trends

Drawing upon the information presented above, we can now consider the water quality impacts expected from the three major types of land use conversion occurring in California: urbanization of prime farmland; urbanization of wildland/marginal farmland; and the conversion of wildland/marginal farmland to new irrigated agricultural production. For water quality, conversion of wildland/marginal farmland to new irrigated cropland is the most significant because of the potential for increased NPS pollution (especially sediment and nutrients) from these new irrigated farmlands.

Urbanization of Prime Farmland

When prime farmland is urbanized, a localized decrease in NPS pollution typically results because urban areas generally have lower NPS loading rates than agricultural lands. Table 3 compares NPS suspended sediment and nutrient concentrations from urban and agricultural drainage in the San Joaquin Valley. Urbanization will also add various point sources (septic systems, underground storage tanks, industrial and municipal wastewater effluent), but these point sources, with the exception of septic systems, have been heavily regulated through either the NPDES

Table 3. Nonpoint source suspended sediment and nutrient concentrations, San Joaquin Valley, California[a]

NPS contaminant	Urban runoff—Fresno, California[b] Residential	Commercial	Industrial	Agricultural drainage, San Joaquin Valley[c]
Total suspended sediment[d] (TSS)	243 (N = 65) [9–1540]	264 (N = 94) [2–3720]	683 (N = 100) [51–2770]	698 (N = 143) [23–7800]
Nitrate + nitrite (dissolved, as N)	0.9 (N = 66) [0.1–4.7]	2.1 (N = 87) [0.1–22.0]	1.8 (N = 81) [0.1–5.5]	23.3 (N = 242) [0.5–120.0]
Total phosphorus (as P)	0.63 (N = 66) [0.10–2.40]	0.63 (N = 87) [0.05–9.10]	6.6 (N = 90) [0.92–20.00]	0.45 (N = 414) [0.01–3.60]

[a] Mean values are in milligrams per liter based on the number of discrete samples listed (N); range of values is given in brackets [ ].

[b] Urban runoff data from USGS Open File report 84–718; data based on sampling from October 1981 to April 1983; residential catchment based on single-family residential land use.

[c] Agricultural drainage nutrient data from California DWR San Joaquin Valley Drainage Monitoring program based on sampling of between 24 and 32 subsurface drains in the central and southern parts of the San Joaquin Valley from 1985 to 1987.

[d] Total suspended sediment agricultural data based on USDA Soil Conservation Service field data collected from 17 agricultural drains and creeks in Western Stanislaus County, northern San Joaquin Valley, during 1988.

permitting process or by extensive underground storage tank regulations. On the other hand, NPS pollution has remained largely unchecked.

The long-term water quality impacts of urbanizing agricultural land will depend upon the type of urban use, its density, and whether it is sewered. Industrial land uses often produce significantly higher concentrations of contaminants than commercial or residential areas (Gunther and others 1991). High-density unsewered developments that rely on septic systems can contaminate shallow groundwater with nitrates. On the other hand, replacing rural septic systems with sanitary sewers may improve groundwater quality. Construction activities can produce significant localized transient NPS pollution, but sediment yields will generally decrease as the process of development is completed (Wolman 1967). Thus, site specific hydrogeological and geomorphic characteristics, as well as cumulative watershed effects, influence the magnitude of water quality impacts caused by urbanization on a local basis.

Urbanization of Wildlands/Marginal Farmlands

Whereas urbanization of active agricultural land would likely decrease NPS pollution, this benefit is largely absent when urbanizing wildlands. However, marginal farmlands may be actively contributing NPS pollution or have residual soils contamination as a result of past chemical application practices. New impervious surfaces may potentially decrease the rate of contaminant leaching to groundwater. Urbanization of marginal farmlands may actually mitigate more adverse NPS pollution. Many of the same factors influencing urbanization impacts on prime farmland also apply to this scenario. Conversely, urbanization of undeveloped wildlands will likely result in water quality degradation caused by urban runoff and short-term construction impacts.

Bringing Marginal Land into Production

Potential long-term NPS pollution for specific tracts of newly irrigated marginal land will depend upon the extent of new cropland, type of crop, and tillage and management practices. The amount of fertilizer and type of pesticide applied vary with the crop. Row cropping generally results in the greatest soil disturbance and requires high rates of both pesticide and fertilizer applications. The method and volume of water application for irrigation will affect surface runoff, leaching, and erosion potential. Site-specific characteristics including soil and hydrogeologic conditions, aquifer properties, landform slope, and proximity of surface receiving waters all affect the potential for NPS pollutant generation and impact. Construction of drainage systems for new irrigated land may cause short-term impacts that will depend mainly on site-specific characteristics and the implementation of runoff and erosion controls during the construction period.

Overall, the conversion of marginal lands or wildlands to new irrigated cropland can result in increased NPS pollution because of greater soil erosion from frequently steeper marginal lands; more intensive fertilizer and pesticide usage usually required; and surface runoff contaminants and toxic or saline leachate from poorly drained marginal soils. Marginal farmlands often have poor phosphorus retention characteristics, necessitating greater fertilization than prime farmlands. A study of the northern San Joaquin Valley found that additional phosphorus and twice as much nitrogen was normally applied to marginal hillside vineyards compared to prime valley vineyards (Jones and Stokes 1991). Phosphorus is often the limiting nutrient for surface water algae blooms, and its release through surface runoff can cause accelerated eutrophication of receiving waterbodies.

Unfortunately, no data exist to directly support our hypothesis of increased NPS pollution from new marginal farmlands. However, the general nature of the NPS impacts can be modeled by employing the universal soil loss equation (USLE), commonly used to estimate sheet and rill erosion from agricultural lands (Wischmeier and Smith 1965). In this model, soil erosion is directly related to a soil-erodability factor, K (a function of soil properties), and to a slope length/gradient factor, LS. Values of K range over an order of magnitude, from 0.05 to 0.69, so a marginal soil can experience substantially greater soil loss than prime farmland. For a large range of slope and length factors, soil erosion is nearly directly proportional to slope (Goldman and others 1986). For example, in San Diego County, avocados have historically been grown on soils with 5% slopes, but more recently avocado orchards have been developed on hillsides with slopes exceeding 15% (G. Bender, San Diego County Cooperative Extension, personal communication 1991). This increase in slope alone would result in a sevenfold increase in predicted soil erosion. Thus, if other factors are held constant, the higher K values and increased slopes of marginal farmland suggest that erosion rates on marginal lands may exceed prime lands by an order of magnitude in many cases.

In Ventura County, avocados are grown on slopes as high as 75%. Accelerated erosion caused by such steep hillside cultivation led to the adoption of a hillside erosion ordinance that requires farmers in Ventura County to prepare and implement erosion control plans in consultation with the county resource conservation district and USDA Soil Conservation Service. Implementation of the ordinance has substantially reduced hillside erosion (Jones and Stokes 1991).

Strategies for Minimizing NPS Pollution

One strategy to minimize the NPS impacts of land use conversion is to eliminate the incentives for placing California marginal farmlands into production. These include government subsidies of some agricultural commodities and water prices. Undesirable secondary effects may include rising food prices, however. Because prime farmland is very productive, some localities have implemented local land use controls for preserving prime farmland. However, these are generally ineffective because they only shift urban development beyond their spheres of influence to nearby jurisdictions not similarly regulated. Regional land use planning is essential for setting and holding defined urban limits and encouraging increased urban densities and infill in order to preserve prime farmland in urbanizing areas. Reform of government incentive programs and a comprehensive land use regulatory system administered on a regional or statewide scale are needed to control the spread of agriculture onto marginal lands and urbanization of prime farmland over such a large area as California.

Another approach to minimizing NPS pollution from a given area is implementation of best management practices (BMPs). Rates of NPS pollution from irrigated marginal lands can be mitigated through implementation of sound agricultural soil conservation practices and erosion/sediment controls, and irrigation management measures such as installation of drip systems. Full implementation of BMPs will also increase costs of production, making marginal lands less economically attractive.

The greatest opportunities for implementation of a full range of water resource protection strategies are in rural developing areas where most land use conversion is occurring. Mechanisms to protect both groundwater and surface water should be integrated into the land use planning and permitting processes in order to achieve the highest level of implementation. "Hot spots" responsible for the most NPS pollution should be targeted by local agencies for implementation of cost-effective BMPs at the watershed level.

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