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Socioeconomics, land use and coastal water quality in San Diego County

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Socioeconomics, land use and coastal water quality in San Diego County

A Thesis submitted in partial satisfaction of the requirements for the degree

Master of Science

in

Biology

by

Alberto Vasquez

Committee in charge:

Professor Jonathan Shurin, Chair
Professor Carolyn Kurle
Professor Scott Rifkin

2018

The thesis of Alberto Vasquez is approved and it is acceptable in quality and form for publication on microfilm:

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Chair

University of California San Diego

2018

DEDICATION

Dedicated to all the voiceless people in marginalized communities. To students that are parents, have little or no support and depend and God to help them balance life. Special thanks to my wife, Ana, who puts up with me and my beautiful kids, Albert, Alicia, Sammy and Daniel; who constantly have had to share me with school, work and my civic engagement. *Para toda la gente!*

-Alberto "Beto" Vasquez

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ABSTRACT OF THE THESIS

Socioeconomics, land use and coastal water quality in San Diego County

by

Alberto Vasquez

Master of Science in Biology

University of California San Diego, 2018

Professor Jonathan Shurin, Chair

San Diego is known for its temperate Mediterranean climate and beaches; however, human activities that compromise water quality degrade environmental conditions and impose economic and social costs. Urban runoff is one of the most serious threats to San Diego's coastal water quality, contributing to harmful algal blooms, low dissolved oxygen concentrations and impacts on economically important marine and estuarine taxa. Nutrients and toxins originate from residential, agricultural and industrial sources, and the land usage within watersheds determines their loadings. Economic development that improves human well being may either benefit water quality or further contamination of coastal ecosystems. The purpose of this study was to identify relationships between chemical and isotopic indicators of water quality and land usage and watershed socioeconomics composition. I found that areas with low socioeconomic status (SES), mostly in the southern watersheds, exhibited lower water quality scores based on composite indices. Interestingly, coverage of open, developed, impermeable or agricultural land uses was not directly correlated with water quality as I expected. Overall, water quality declined in southern watersheds where residents have the poorest socioeconomic status. My thesis suggests that anthropogenic activity and low socioeconomic status contribute to poor water quality and contamination of coastal environments. The role of economic development in transforming land use and affecting water quality needs to be evaluated in relation to other hydrologic factors that determine export of nutrients from watersheds to the ocean.

Introduction

With a population nearing 1.3 million and a growing development to suit the need, San Diego's regional watersheds receive excess anthropogenic nutrient inputs through runoff (SDCK, 2015). Excess nutrient pollution has led to degraded water quality in lagoons, ocean beaches and estuaries located downstream. High counts of fecal coliform bacteria as a result of nutrient overloading have repeatedly led to beach closures due water conditions that are unsafe for recreational activities. Close proximity to the Mexican International border and the Tijuana River, and its lack of effective wastewater treatment, explains the frequent incidence of water contamination events in south San Diego County. However, sources of contaminants on the U.S. side of the border, including septic systems, and agricultural and urban runoff (Hobbie et al., 2017) also contribute to elevated contaminant and nutrient levels regionally. Watershed characteristics (e.g., permeability, land composition/usage) that contribute to excess nutrients outputs are complicated and minimally understood.

Urban runoff is one of the most serious threats to San Diego County's coastal water quality (Bay et al. 2003; Schiff et al., 2003). With its Mediterranean climate, San Diego receives minimal precipitation through much of the year. As a result, precipitation events scour urban areas, removing accumulations of toxic compounds and nutrients and releasing them through an untreated storm drain system into the ocean. Anthropogenic sources provide as much as half or the nitrogen present in many coastal ecosystems globally (Vitousek et al., 1997; Reifel et al., 2009; Hobbie et al., 2017). In the Southern California Bight, human sources of nitrogen rival natural supplies in the near-shore coastal zone (Howard et al. 2014). Runoff of nutrients contributes to the global expansion of coastal oxygen minimum zones, with harmful impacts on marine life and important fisheries (Rabalais et al. 2010; Kurle et al., 2016). Legislative measures, such as the Clean Water Act, have been instrumental in identifying and limiting some of the main point sources of pollution such as agriculture and industry that contribute contaminants found in aquatic ecosystems. However, identifying non-point sources (NPS) contaminants is essential to design effective watershed management practices and curtail the amount of anthropogenic pollutants introduced to local water bodies via urban runoff (Carpenter et al. 1998; Herrick, 2010).

Contributing Factors to Water Quality

The fate of toxic contaminants and nutrients in runoff are determined by watershed characteristics (Carpenter et al. 1998 & Bay et al. 2003). Soil or ground absorption regulates the retention of different chemicals (via percolation) and the amount and chemical composition of runoff that an individual rain event can produce. Uptake by vegetation can also promote retention and prevent nutrient runoff. High flow rates and impervious surfaces such as pavement increase the export of compounds from terrestrial sources into the ocean (Shaver & Puddephatt, 2012). As development increases, so do impermeable surfaces, such as concrete, asphalt, and buildings, that both contribute non-point sources and prevent uptake and retention in the watershed (Bay et al., 2003). Stepenuck et al (2002) found that areas with <8% impermeable or concrete ground coverage typically show better stream quality than areas exceeding 12 to 20 percent imperviousness. In San Diego County, the Pueblo Watershed, the smallest, most populated, and the most heavily urbanized watershed in the county, and that includes downtown San Diego, Point Loma, and the greater Logan Heights area, is over 88% developed and contributes a substantial amount of accumulated toxic compounds into receiving waters (SWAMP, 2007). Open spaces such as public parks, golf ranges and agricultural spaces may also generate more nutrients and toxins than they remove due to fertilization and treatment with herbicides, pesticides and other chemicals (Blanchoud et al., 1997; Vasseur et al, 1997). Despite well-documented economic, environmental, and health-related costs of urban runoff (Stepenuck et al, 2002 & Hoxie et al, 1997), although some research has explored the relationship between land use and the coverage of different land cover types and stormwater quality – closer studies are required. Stormwater management is critical to minimizing anthropogenic impact on coastal water quality. Urban planning or zoning influence both volumes and quality of stormwater discharge. Stone & Bullen (2006) suggest that stormwater runoff volumes could be significantly mitigated with small changes in urban planning; particularly industrial and commercial land-development regulations.

Anthropogenic runoff not only degrades water quality and ecosystem services such as fishery production, but also contributes to the extirpation/extinction of marine species and poses health and economical risks for humans. Urban runoff has important consequences for economic value delivered by ecosystem services as well as human health and well-being. For example, degraded water quality can lead to increased costs in response to potential medical expenses associated with bacteria and raised water treatment costs. Additionally, San Diego's extensive tourism-based economy can also suffer from degraded aquatic ecosystems. Beach closures due to high bacteria counts prevent tourists and locals from visiting beaches and potentially keep visitors away from San Diego entirely, incurring lost revenue from tourism. According to the San Diego Tourism Authority, tourism revenue projections for 2015 were $9.9 billion, much of which is dependent on our climate and ecotourism (outdoors/coastal) activities. Preventing runoff of nutrients from the continental margins is likely to be much more effective than attempts at mitigating their impacts once they enter the marine environment.

Socioeconomics

Watershed characteristics are ultimately determined by economic and sociological forces that shape human land use. The distribution of industrial, agricultural, residential and commercial activities coupled with a community's culture, awareness and education can often shape environmental impacts. Socioeconomic statuses (SES) affect individuals' priorities, opportunities and activities in ways that affect their contribution to runoff (positively or negatively). According to the environmental Kuznet's Curve (EKC) hypothesis, there is a proportional relationship between income and an individuals' level of concern about or willingness to allocate resources to address the quality of their environment (Stern, 2004). Individuals of limited financial means are likely to prioritize immediate economic needs and well-being over aspects of quality of life like the condition of their environment (Wen et al., 2006; Farah, 2017). Here, SES refers to the accumulation of material wealth and includes noneconomic characteristics such as education and social prestige. SES is directly correlated to predictable differences in life stressors, neighborhood quality, physical and mental health and cognitive ability (Farah, 2017). The EKC implies that lack of economic development can have a detrimental impact on the environment, but that economic prosperity can eventually foster awareness and concern that can ultimately lead to effective mitigation efforts (Croizet & Claire, 1998). SES can be a predictor of landscape richness which influences an areas "greenness", making it proportional to income within those areas (Martin et al., 2003; Clarke et al., 2013). Affluent communities (which can afford to use water in irrigation) often contain higher concentrations of golf courses, public parks and lush gardens associated with the yards of homeowners, which can both be helpful for natural percolation of runoff and simultaneously harmful as a major source of pesticides and fertilizer. In addition, increased urban vegetation could increase quality of life by improving aesthetics and reducing energy costs by buffering extreme climate (Clarke et al., 2013). Therefore, the relationship between SES and water quality is therefore uncertain.

Impacts

Nutrient loading can have adverse effects on water quality and services derived from aquatic ecosystems such as fishery yields. Elevated nitrogen levels often lead to excessive primary productivity in coastal surface waters (Bay et al., 2003; Carpenter et al., 1998). Decomposition of organic material in deeper waters can lead to depleted oxygen levels resulting in hypoxic, anoxic or oxygen minimum zones (OMZs) causing stress on organisms which can lead to negatively altered ecosystems (Carpenter et al., 1998). Increased productivity or toxic contaminants can often influence higher trophic level organisms like fishes or marine mammals (Bay et al., 2003; Reifel et al., 2006; Miller et al. 2010) or even scavenging birds like California Condors that acquire toxins via bioaccumulation after feeding on carcasses of marine mammals (Kurle et al. 2016). The chemistry of runoff water therefore has far reaching consequences for marine, freshwater and terrestrial ecosystems (Novotny & Witte, 1996).

I compared runoff waters among seven San Diego County watersheds and utilized water chemistry and stable isotope analysis to identify characteristics of land use and socioeconomics associated with loading of non-point contamination. My goal is to provide a regional perspective to improve management practices by accounting for contributions made by the variety of land usage within a watershed: agricultural, open space, and developed land. Watersheds varied in topography, land usage, community composition, and socioeconomic status. Some regions were deficient in vegetated open spaces such as parks that are beneficial for natural filtration and retention of nutrients, while others were largely comprised of undeveloped land. However, some areas exhibited more hardscaped ground coverage with little natural, permeable ground. Variation in human behaviors among watersheds was also apparent. Some sampling areas were redolent with trash and debris while others were more pristine. This could be indicative of residential indifference or lack of services provided by local municipalities; thus, underscoring the SES connection. All these variables contribute to the quality of urban runoff. Accounting for different sources of pollution will be instrumental in developing effective, localized watershed management strategies which could yield innovative alternative compliance solutions and lower environmental and economic impacts along with enhanced human wellbeing.

Materials and Methods

Study System

I sampled twenty-nine (29) sites within seven of 11 watersheds located in San Diego County, CA, USA (Map 1). These were, from North to South; Carlsbad, San Dieguito, Peñasquitos, San Diego River, Pueblo, Sweetwater and Otay watersheds. I did not include the Tijuana River, San Luis Rey and Santa Margarita watersheds in this investigation due to confounding variables, specifically low water flow during my sample period and limited access. Since the focus was on runoff entering receiving waters (San Diego Bay and Pacific Ocean), I chose sites were chosen at or near the mouths of waterways and various points upstream (where available). I sampled watersheds with multiple outlets at each of the different points where they entered the ocean, and I averaged the chemical variables measured within watersheds when comparing these values among watersheds. I selected sampling sites based on water availability and accessibility and most sites were within ten miles of the watershed mouths at the coast. Most sampling sites were characterized by chaparral and estuarine environments with light to heavy urban development.

Field Study

Each watershed was sampled at the mouth of each channel/creek and at one or more points upstream. Flow at collection sites varied from slight riffle to about .35 meters/second at some locations. Sites at the mouth consisted of brackish water while upstream sites were fresh water sources. Two of the seven areas included in this study had multiple outfalls which were sampled independently. These included Carlsbad, with four outfalls (San Elijo Lagoon, Batiquitos Lagoon, Agua Hedionda, and Buena Vista Creek) and Peñasquitos, with two outfalls (Peñasquitos and Rose Creek). Additionally, The San Dieguito watershed provided its own set of special circumstances with the implementation of the San Dieguito Lagoon created to the east of Interstate 5 which serves to mitigate runoff impacts discharged into receiving waters. Some sites were located within close proximity to potential nutrient sources (such as golf parks) that utilize fertilizers. Such sites were followed with sampling downstream (and upstream when possible) to determine differences in water chemistry above and below potential sources.

Sample Collection

Samples were collected during two periods (Map 1). The first (dry season of 215) samples were collected in summer between June 2015 – August 2015; the second collection (wet season 2015-2016) occurred in the winter between December 2015 – February 2016. Sampling dates were carefully selected with special consideration given to rainfall events resulting from the 2015-2016 storm season which had a higher than average rainfall due to the occurrence of an El Niño event (SDCWA, 2018). Sampling was only conducted in dry weather at least 36 hours after a rain event producing >.10 inch of precipitation.

Water Chemistry

Water samples were collected and analyzed for several chemical constituents. Field measurements included: pH, temperature, conductivity, dissolved oxygen (DO), and turbidity. Water samples for laboratory analysis were collected and placed in an insulated cooler with ice maintained at a temperature of ~ 4°C and processed for total nitrate and phosphate concentration analysis using Lachat's Quick Chem Autoanalyzer in the lab. Field equipment used included: Hanna (HI-98129) meter (pH, temperature, conductivity), HACH (HQ40D) & YSI meters (DO), and a Hanna (HI-93703) Microprocessor /Turbidity meter.

Water Quality Index Scores

To expand the temporal scope of my study, and because of the correlations among different water quality parameters, and seasonal and interannual environmental variability, I also used a water quality index (WQI) to classify overall water quality based on more extensive sampling than my own survey to compare among watersheds. Water quality index scores included the following constituents: bacteria, dissolved oxygen, turbidity, ammonia, phosphate, nitrate, pH, and frequency of surpassing thresholds. Water Quality Index Scores were derived by San Diego Coastkeeper using their 2015 data and water quality index (WQI) based on the Canadian Water Quality Index (CWQI). The CWQI was established by the Canadian Council of Ministers of the Environment (CCME) and adopted in 2007 by the Global Environmental Monitoring System (GEMS) / United Nations Environment Program (UNEP) to evaluate global water quality.

The San Diego Coastkeeper WQI (SDCWQI) scores were calculated based on the number of pollutants exceeding regional Basin Plan guidelines, and the degree to which variables exceed defined thresholds (Table 2). The definition and equations for scope, frequency, and amplitude are listed below* and can be modified to suit the amount of constituents being monitored.

Scope (F1) is the number of pollutant parameters within a single water collection site that exceed their respective guidelines over the total number of available parameters.

$$F1 = \left(\frac{\#\ failed\ parameters}{Total\ \#\ of\ parameters}\right) \times 100$$

Amplitude (F2) is the amount by which each pollutant parameter exceeds its Basin Plan guideline. The WQI is calculated in three steps. First, the excursion for individual tests is computed by the amount which a test value exceeds its Basin Plan guideline value.

$$Excursion = \left(\frac{failed\ test\ value}{guideline\ value}\right) - 1$$

Next, the normalized sum of excursions (NSE) within an individual site is calculated.

$$NSE = \left(\frac{\sum excursion}{Total\ \#\ of\ parameters}\right)$$

The last step is to transform the NSE so that it falls in the range of 0 to 100.

$$F2 = \left(\frac{nse}{0.01(nse) + 0.01}\right)$$

Together the scope and amplitude variables (F1 and F2) create a water collection site's WQI score. This score ranges from 0 (worst quality) to 100 (best quality).

$$WQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2}}{1.4142}\right)$$

Stable Isotope Analysis

Filters

Particular organic matter (POM) samples were collected using a Nalgene hand-pump vacuum with 47mm diameter Whatman GF/F filters for stable C and N isotope analysis. Prior to usage, 47mm GF/F filters were pre-combusted, weighed and wrapped in aluminum foil. All handling of filters was conducted with forceps and gloves to avoid contamination. Sample water was filtered directly through the pump in the field until filter coloration was evident and the volume was recorded. Filters were then carefully removed from the manifold, folded and placed into a foil package and placed in a cooler to maintain a low temperature of ~4°C. Upon arrival to lab, filters were placed in freezer until all sampling was completed. All filters were then processed together. Filters were oven-dried at 50-60°C overnight and weighed to determine the mass of particulate material collected on the filter. I sent the prepared filters to the Stable

Isotope Facility at UC Davis and they analyzed homogenized sub-samples of the POM for their stable carbon (ratio of $^{12}C/^{13}C$ or $\delta^{13}C$) and nitrogen ($^{14}N/^{15}N$ or $\delta^{15}N$) isotope values (reported in ‰).

Solid Samples

Because of its widespread presence and tolerance of alkaline and brackish waters, the amphipod *Hyalella azteca* was selected as a focal organism for stable isotope analysis. Amphipod coloration and size varied among collection locations. All solid sample collections were conducted on site, packaged and transported in a cooler to the lab where they were frozen until processing. In the two instances where amphipods were not found, other organisms (a worm and crustacean) were substituted for solid isotope sampling. Upon preparation for analysis, organism samples where thawed, sorted and analyzed under a dissecting microscope. Organisms were identified, photographed and packaged in labeled cryovials for freeze drying. Samples were freeze dried using the *Labconco Freezone 2.5* for 36 hours and packaged according to UC Davis' Stable Isotope Facility (SIF) specifications.

Data Analysis

Polar plots were used to illustrate interannual water quality among watersheds sampled in the San Diego Coast Keeper's data set throughout the region based on the metrics included in the watershed Quality Index (WQI) (Figure 4).

Variation among watersheds in measured water chemistry variables was assessed using an Analysis of Variance (ANOVA). All statistical analyses were performed using R. Associations among stable isotopes values, watershed constituents, seasons, sampling locations (coastal vs. inland) and land usage and socioeconomic status were assessed by correlations. A Principal

Components Analysis (PCA) was used to visualize the associations between different aspects of water chemistry and land cover types among the study watersheds.

Land Usage

Data collected by the Southern California Coastal Water Research Project (SCCWRP) as part of the Surface Water Ambient Monitoring Program (SWAMP) Reports provided a land usage breakdown by watershed. SWAMPs provided the following information for each of the seven San Diego watersheds within this study: total coverage area (mi^2), developed land (%), open area (%), and agricultural (%) (Table 3). For this study, land usage percentages are based on data acquired from 1998-2008 SWAMP studies and does not reflect the most current land composition.

Economics

Income-based information (average household income by census parcel) was provided by the 2010 US Census tract information. Incomes per area were determined and illustrated on an ArcGIS data map indicating high and low household income areas per census tract (where households under $30K/year were considered low). Household income tracts were then overlaid with a watershed scoring map indicating score in color (Map 2).

Land usage maps, an income spatial analysis map (depicting lower income communities throughout the county), and water quality scores (Map 2 - overlaid with income map) were compared to identify any trends (Maps 2 & 3).

Results

The $\delta^{13}C$ values of POM samples ranged from -39.35 to -17.6‰, and the $\delta^{15}N$ values ranged from 2.84 to 13.5‰. The $\delta^{15}N$ values varied significantly between watersheds in the wet season (winter) sampling and along coastal sites, with slightly higher values in the southern part of the county (Figure 3-B); there was less variation during the drier season (summer). The $\delta^{13}C$ and $\delta^{15}N$ values of amphipod samples ranged from -35.85 to -14.01‰, and from 3.86 – 18.76‰, respectively.

Results indicated strong significant differences in pH (Figure 1-A) among watersheds (P= <0.0001), sampling location (P=0.018) and season (P=0.016). We found no significant interactive effects of these predictor variables. Temperature was only influenced by season. Dissolved oxygen (DO) values (Figure 1-B) varied significantly among watersheds (P=0.004), with higher DO levels seen in the northern-most sites and DO decreasing to the south. Season also influenced DO (P=0.0003). Conductivity (Figure 1-C) was influenced by location (P=0.038) since coastal waters tended to be more saline than inland sites due to tidal influence. Interestingly, a significant watershed & season interaction (P=0.049) could be attributed to unique watershed characteristics, seasonal tides and/or distance of sampling locations from outfalls. Turbidity (Figure 1-D) was strongly influenced by sampling locations (P=<0.0001), with greater turbidity near the coast, as well as effects of watershed and location interactions (P=).002). This would be consistent with tidal influence and other sediment disturbances which yield turbidity.

Total Nitrogen (TN) (Figure 2-A) was influenced by watershed (P=0.001), location (P=0.0005), season (P=0.0001), and watershed & location interactions (P=0.008). TN increased toward the south in parallel with the trend in DO. Total Phosphorus (TP) (Figure 2-B) was significantly influenced by watershed (P=0.02) and season (P=0.03), and also tended to increase to the south. These results could be attributed to anthropogenic runoff, natural occurring deposits, and/or seasonal contributions from rainfall.

Stable isotope analysis (Figure 3: A-D) revealed significant variation in the $\delta^{13}C$ values of POM with season & location (P=0.05). The $\delta^{15}N$ values of POM (P=0.03) and amphipods (P=0.008) varied among watersheds, while amphipod $\delta^{15}N$ also varied with location (coastal vs. inland, P=0.003). A significant three-way interaction between watershed, season and location was also found for amphipods.

A Principal Component Analysis (PCA) of water chemistry and land usage indicated that watersheds showed distinct distributions of water chemistry descriptors in relation to land use (Fig. 4). The first principal axis (PC1, which explained 21% of the variation) was strongly correlated with land use, with positive values indicating more open land and negative values in more developed watersheds. This axis was also associated with nitrogen isotopic rations and nutrient concentrations. The second axis (PC2, which explained 14% of the variation) was associated mainly with agricultural land uses and conductivity. Southern watersheds (San Diego, Sweetwater and Otay) which are predominantly lower SES and have higher open land areas, exhibited lower WQI scores, higher $\delta^{15}N$ values, higher nutrient (TN and TP) concentrations and lower pH. Another group (Peñasquitos, Carlsbad and San Dieguito) consisted of mostly higher SES northern watersheds with some degree of agricultural activity. Interestingly, the Pueblo watershed, which is the smallest and most urbanized of all of the watersheds (with 88% impermeable ground and mixed zoning), stood apart from all other groups as having the second lowest WQ score, high conductivity but not higher nutrients or $\delta^{15}N$ values (Figures 4 & 5).

Socioeconomics

Lower water quality scores were predominantly observed in the southernmost areas of the county (Figure 5 & 6), which is also where most households living under San Diego's median income ($47,331/year) can be seen on Map 2 (US Census, 2010). Incidentally, these same areas are predominantly populated by minority groups and have minimal amount of park space (per 1000 people) in comparison to the rest of the county (City Project, 2016) (see Map 2: *Household Income and Watershed Quality* & Map 4: *The City Project: Park Poor, Income Poor, and People of Color*). The orange area in Map 2 illustrates areas with marginal water quality and the darker regions within it are indicative of lower-income density. These same areas are illustrated in Map 4 as park deficient, below median level income and as having more people of color than state average. Qualitative information was utilized in lieu of quantitative to assess potential connections between income (or SES) and water quality. Watersheds with low SES like Sweetwater, Otay and Pueblo also had degraded water quality. While watersheds with higher SES had better water quality comparatively.

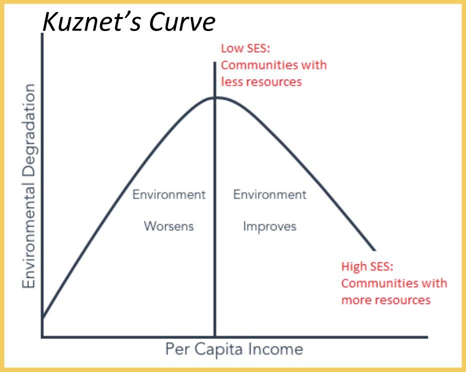
Land Usage

Watershed sizes are (in order from largest to smallest): San Diego River (440 mi^2), San Dieguito (346 mi^2), Sweetwater (230 mi^2), Carlsbad (211 mi^2), Los Peñasquitos (162 mi^2), Otay (154 mi^2), and Pueblo (56 mi^2) (see Table 3). Spatial representation map of watershed land usage have been provided as a supplemental visual tool (see Map 3). Areas such as the Pueblo watershed, which has the highest percentage of developed area (88%) and the smallest area (56 mi^2) did not have the worst water quality rating (score of 56) as would have been expected, but still scored among the lowest. Sweetwater watershed exhibited the worst WQ score (53), had among the higher $\delta^{15}N$ values, and interestingly has one of the lowest agricultural and developed area compositions. San Dieguito, which has the largest agricultural area (21%) also interestingly had the best WQ score (76). This could be attributed to the San Dieguito Lagoon which was created for habitat conservation/restoration and runoff mitigation. Overall, watershed size did not seem to directly correlate with WQI (Figure 4, PCA). Southernmost areas of the county mostly exhibited higher $\delta^{15}N$ values (Figure 3), although there were some exceptions in the north.

Watershed Index Scores

Based on the WQI scores provided by San Diego Coast Keeper, less affluent (southern) regions of San Diego County experienced a more degraded water quality. Overall scoring (lower numbers = worsened water quality) was as follows for the seven watersheds sampled within this study (Figure 6, from North to South): Carlsbad (66), San Dieguito (76), Los Peñasquitos (74), San Diego River (62), Pueblo (56), Sweetwater (53), and Otay (57). Watersheds with minimum agricultural presence (San Diego and Pueblo) had higher concentrations of phosphate and ammonia (Figure 5: Polar Plots). Interestingly, the $\delta^{15}N$ values did not consistently follow a trend (increasing or decreasing) with proximity to urbanized areas as would be expected if nutrient contributions were solely from runoff. Instead $\delta^{15}N$ ratios fluctuated or in some cases were higher at the further (upstream) sampling points (Figure 3). However, Pueblo watershed did stand out alone on the PCA (Figure 4), this could be due to its urbanization.

Discussion



My analysis indicates that water quality varies considerably among the seven watersheds I tested in San Diego County. Although on a smaller scale, my data supported the hypothesis of the environmental Kuznet's Curve that less affluent communities generally suffer greater environmental degradation, although this pattern had one notable exception (the Pueblo watershed). The southern watersheds with low SES all had lower water quality index scores (Figure 6). This could be due to lack of time and/or resources to develop strategies to mitigate contamination, or disproportionate coverage of land uses that contribute the most to water quality degradation. Low income communities are often zoned for mixed usage, placing heavy/light commercial, industrial or business properties next to residential ones, in contrast with higher income watersheds which are predominantly residential. Land acquisition within poorer communities has historically been available at low cost and therefore subjected to practices that would not be deemed acceptable in more affluent areas. It would be interesting to investigate water quality in this same area after the gentrification process it is currently undergoing.

Although research has indicated that increased impervious surfaces increase the export of terrestrial compounds into the ocean (Shaver et al., 2007; Vitousek et al., 1997; Reifel et al., 2009; Hobbie et al., 2017), this does not seem to be reflected in the $\delta^{15}N$ values of the POM or invertebrates (amphipods) I analyzed. Interestingly, the Pueblo watershed, a heavily urbanized area with a dense low-income population, which is 88% developed and the smallest of the seven watersheds, did not exhibit the worst water quality overall as expected. Although Pueblo did have the second worst WQ score, $\delta^{15}N$ values were not the highest there. Instead, $\delta^{15}N$ varied among watersheds but was not consistently attributable to land use. This pattern suggests that multiple land uses may contribute to variation in $\delta^{15}N$ such that residential, agricultural or industrial areas may all produce runoff of nitrogenous wastes.

The dominant source of nitrogen in most unimpacted terrestrial ecosystems is fixation from the atmosphere ($\delta^{15}N$ = 0 ‰) by plants and micro-organisms. Other additional sources of nitrogen include: fertilizers fixed from atmospheric nitrogen for industrial or agricultural purposes with compositions of 0 ± 3 ‰, and animal manure (including septic systems) with N isotope values generally in the range of +10 to +25‰ (USGS, 2004). Higher $\delta^{15}N$ values, possibly derived from animal waste, were evident in the northern and southernmost watersheds with respect to the solid (amphipod) $\delta^{15}N$ sample analysis conducted (Figure 7). High $\delta^{15}N$ values in POM (between 8 and 19‰) were observed in the southernmost watersheds (Figure 4) and in inland Peñasquitos and coastal San Diego sites. Figure 5 also support that watersheds with the lowest WQI scores also had higher frequencies of Enterococcus and coliform bacteria (specifically *E. coli*). The Water Quality Index (WQI) scores which are referenced, are calculated based on multiple factors, including the number of metrics exceeding prescribed thresholds and the degree to which thresholds were exceeded (Table 1 & 2). The relatively high $\delta^{15}N$ values observed in my survey indicate that anthropogenic sources make major contributions to both particulate matter and invertebrates and could be from a variety of sources, some of which introduce bacteria. Therefore, further and more detailed studies are necessary to determine the origins of coliform and Enterococcus within individual watersheds and respective isotope sources. Bacteria and other toxic compounds present risks to human health and can cause rippling effects ecosystems; identifying isotopic signatures help track contaminant sources.

These observations of compromised water quality could be attributed to multiple factors such as: heavily urbanized or impermeable ground coverage, usage of anthropogenic materials (agricultural, industrial, automotive, etc. discharges), and a lack of open spaces and parks (for natural filtration and removal of toxins and/or excess nutrients). This is especially true in lower income areas that are deficient in parks and other open spaces and lower in socioeconomic status.

According to data provided by the City Project - an organization which advocates for poor, park deficient communities - the areas identified within San Diego County as the most park deficient (Map 4), also happen to have the worst water quality and high presence of heavy nitrogen isotopes. Watersheds with higher SES (affluence), golf parks and residential areas whose “greenness” is proportional to their income, can likewise be responsible for nutrients and fertilizer deposition from landscaping. Likewise, agricultural presence within an area can also be a contributing factor as observed at the northernmost watersheds (Carlsbad and San Dieguito). However, further individualized studies are necessary to quantify the impact of watershed size, number of outfalls and mitigation ponds (such as the San Dieguito Lagoon) to better understand environmental and water quality impacts.

My study indicates that watersheds of San Diego County vary greatly in their impact in degrading coastal water quality. Many indicators of water quality, including DO and stable isotopes, decline toward the south where the lowest socioeconomic status populations are found. However, my data were not able to explain much of the variation among watersheds in water quality. Interestingly, land coverage types were not directly related to water quality as expected (Figure 4). Spatial variation within watersheds and seasonal and interannual fluctuations in time may produce the high degree of variation observed. Surprisingly, impermeable ground coverage did not seem to be a direct factor influencing water quality. Overall, water quality worsened the further south you went. Water chemistry may vary strongly in time with weather, and sampling over longer time periods may be necessary to detect consistent patterns of contamination among watersheds. My thesis is a first step toward drawing the link between economics, land use, and the contamination of coastal waters of San Diego County. I am hopeful that both the quantitative and qualitative observations will provide the information necessary to support strategic decision making by land managers and elected officials.

FIGURES

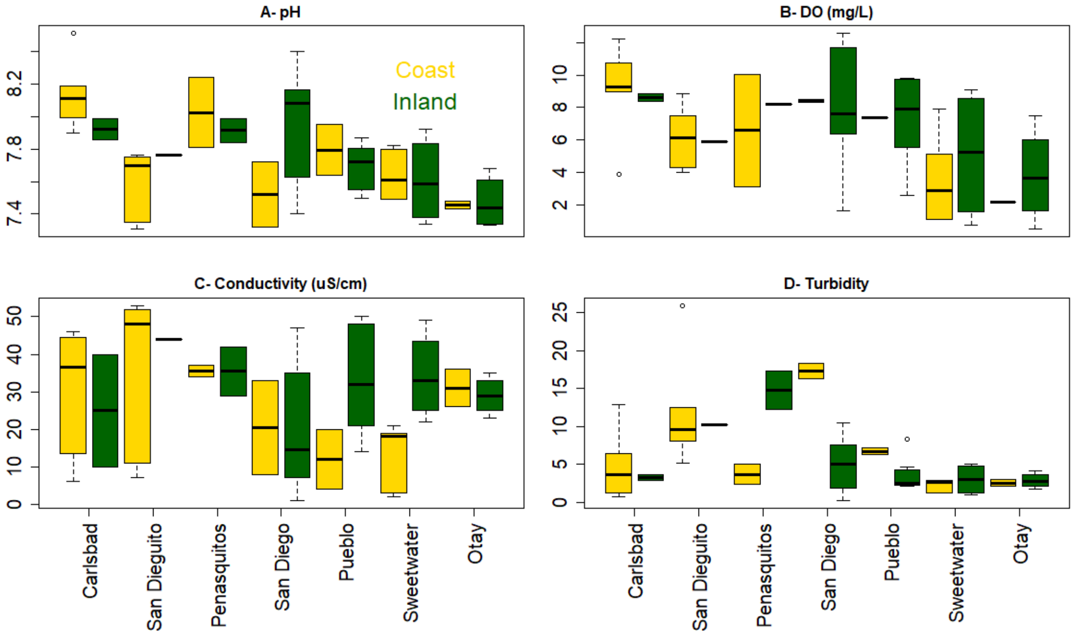


Figure 1 (A-D): Investigation Results

(pH, DO, Conductivity & Turbidity among sampled watersheds)

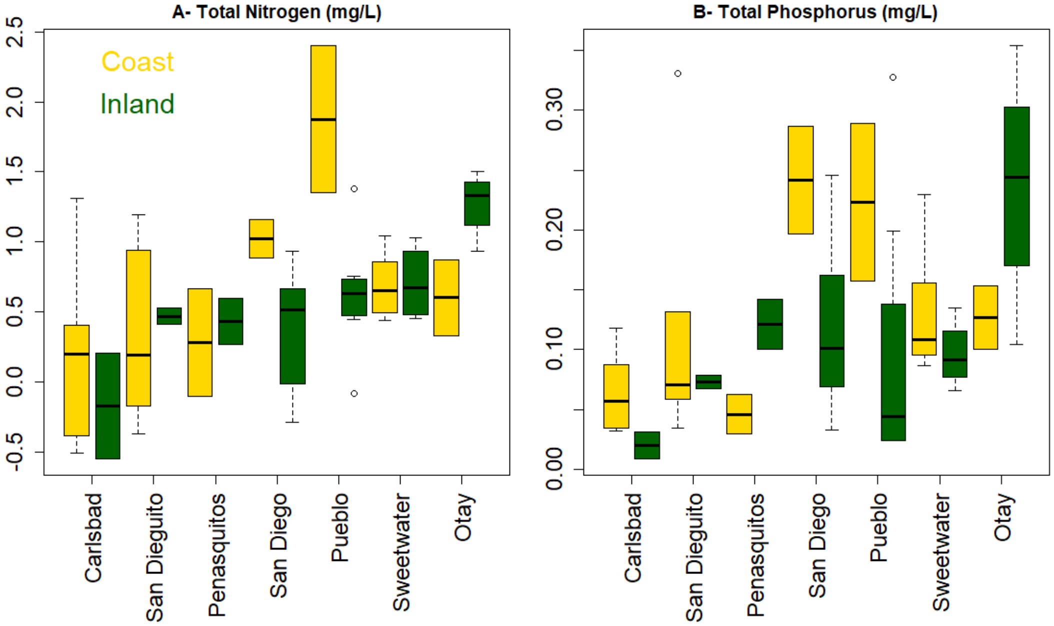


Figure 2 (A-B): Total Nitrogen (TN) and Total Phosphorus (TP) among sampled watersheds

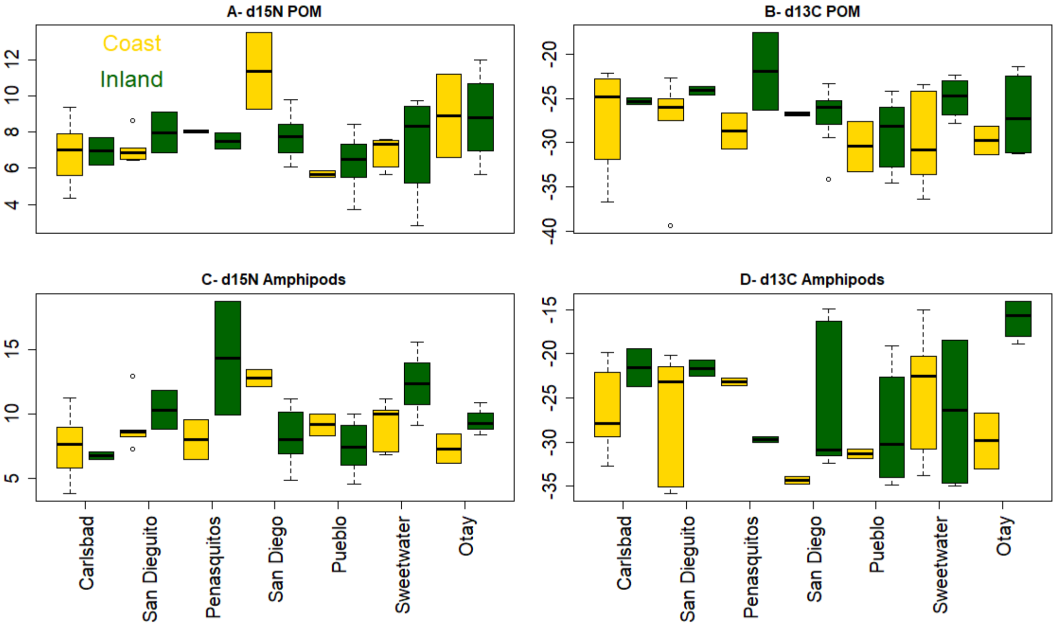


Figure 3 (A-D): Isotope Analysis

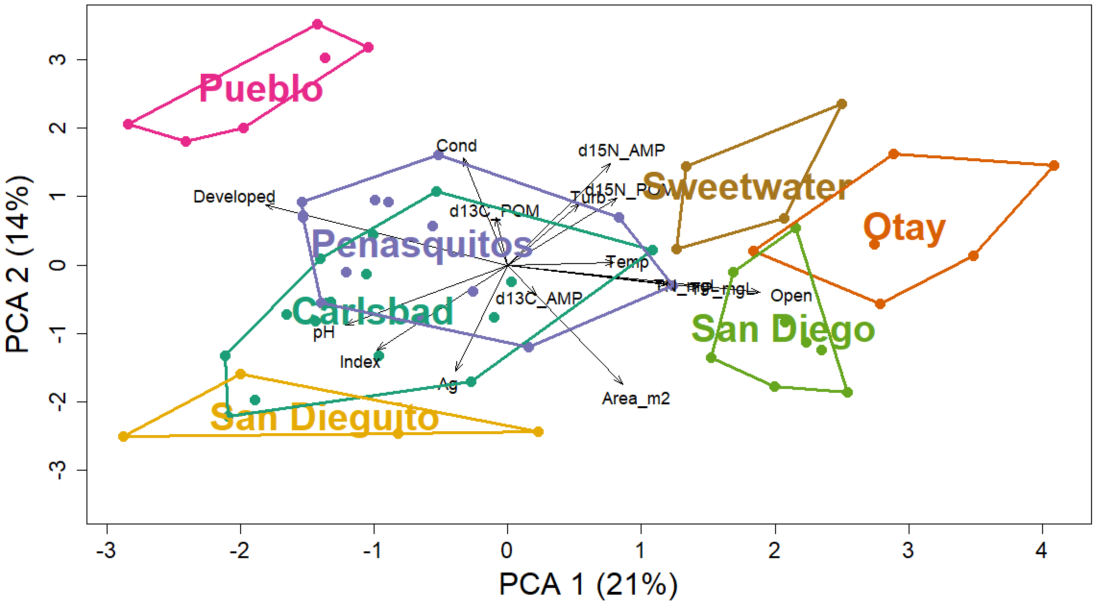
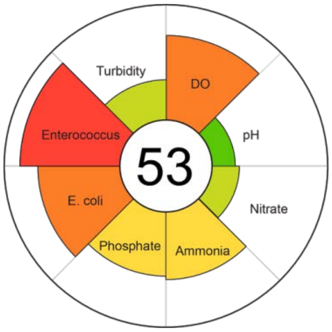
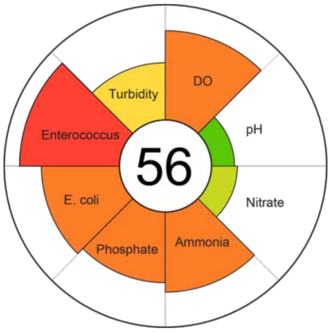


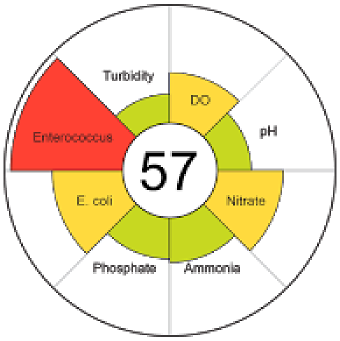
Figure 4: Principal Component Analysis (PCA) of Water Chemistry & Land Usage



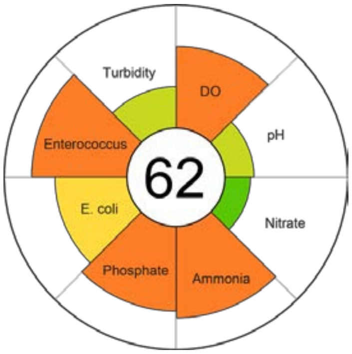
Sweetwater



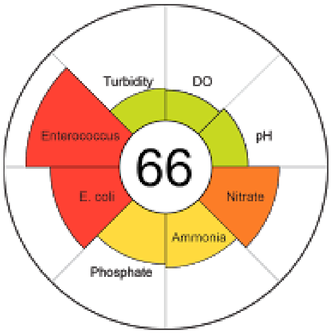
Pueblo



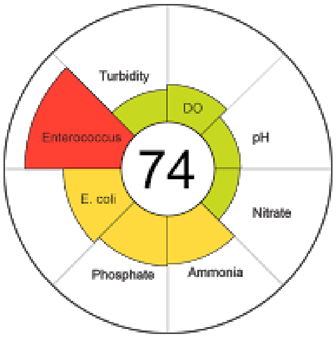
Otay



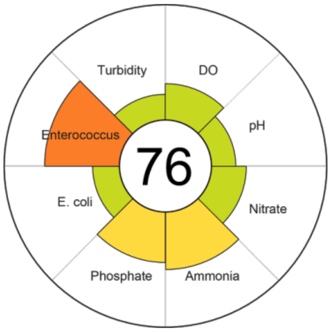
San Diego



Carlsbad



Peñasquitos



San Dieguito

Figure 5: Polar Plots: SDCK Water Quality Index Scores

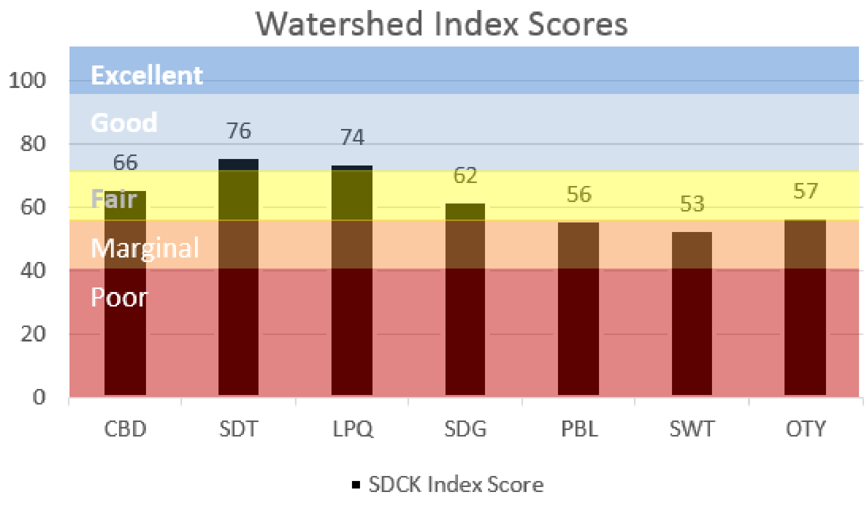


Figure 6: Overall Water Quality Index (WQI) Scores

TABLES

Table 1: Water Quality Index (WQI) Score Categories. The Gems/UNEP provides a grading chart that ranks WQI scores into five distinct categories. These categories, their scoring range, and a brief description are in the table below.

Designation	Index Value	Description
Excellent	95-100	All measurements are within objectives virtually all of the time
Good	80-94	Conditions rarely depart from natural or desirable levels
Fair	65-79	Conditions sometimes depart from natural or desirable levels
Marginal	45-64	Conditions often depart from natural or desirable levels
Poor	0-44	Conditions usually depart from natural or desirable levels

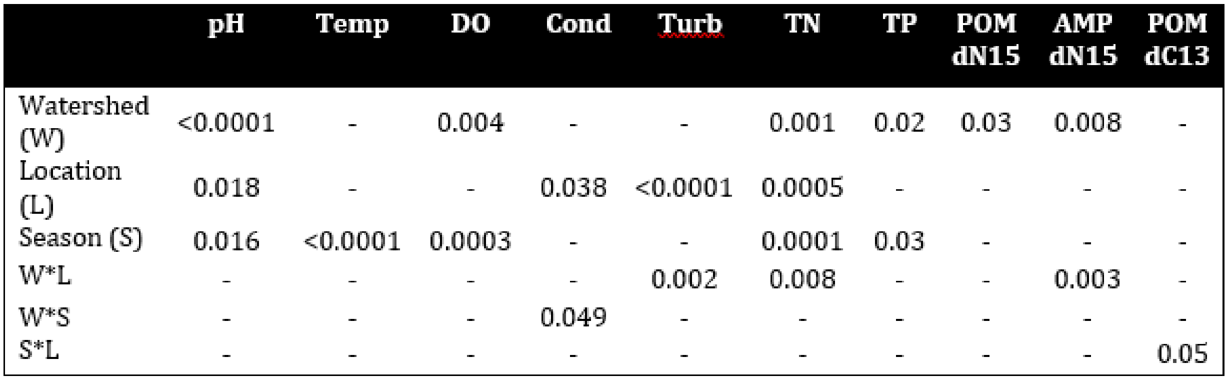
Table 2: SDCK Water Quality Parameters. The table below lists the water quality parameters included in the calculation of San Diego Coastkeeper WQI scores. Water quality guideline set by the Basin Plan for each parameter are included.

Water Parameter	**Basin Plan Guideline Value**
Dissolved Oxygen	<5.0 mg/L
pH	<6.5 or >8.5
Nitrate	>1 mg/L
Ammonia	>0.025 mg/L
Total Phosphorus	>0.1 mg/L
E. Coli	>406 MPN/100 mL
Enteroccocus	>108 MPN/100 mL
Turbidity	>5 units
Cadmium	>2.0 µg/L
Chromium	>16 µg/L
Copper	>80 µg/L
Lead	>65 µg/L
Nickel	>470 µg/L
Zinc	>120 µg/L

Table 3: San Diego County Watershed Land Usage. Land usage composition of San Diego watersheds included in this study. Information from 2009 SWAMP reports.

WATERSHED	ABBREVIATION	AREA (MI^2)	%OPEN	%DEVELOPED	%AGRICULTURE
CARLSBAD	CBD	211	38	50	12
SAN DIEGUITO	SDT	346	18	61	21
LOS PENASQUITOS	LPQ	162	43	53	4
SAN DIEGO	SDG	440	72	26	2
PUEBLO	PBL	56	12	88	0
SWEETWATER	SWT	230	67	29	4
OTAY	OTY	154	70	20	10

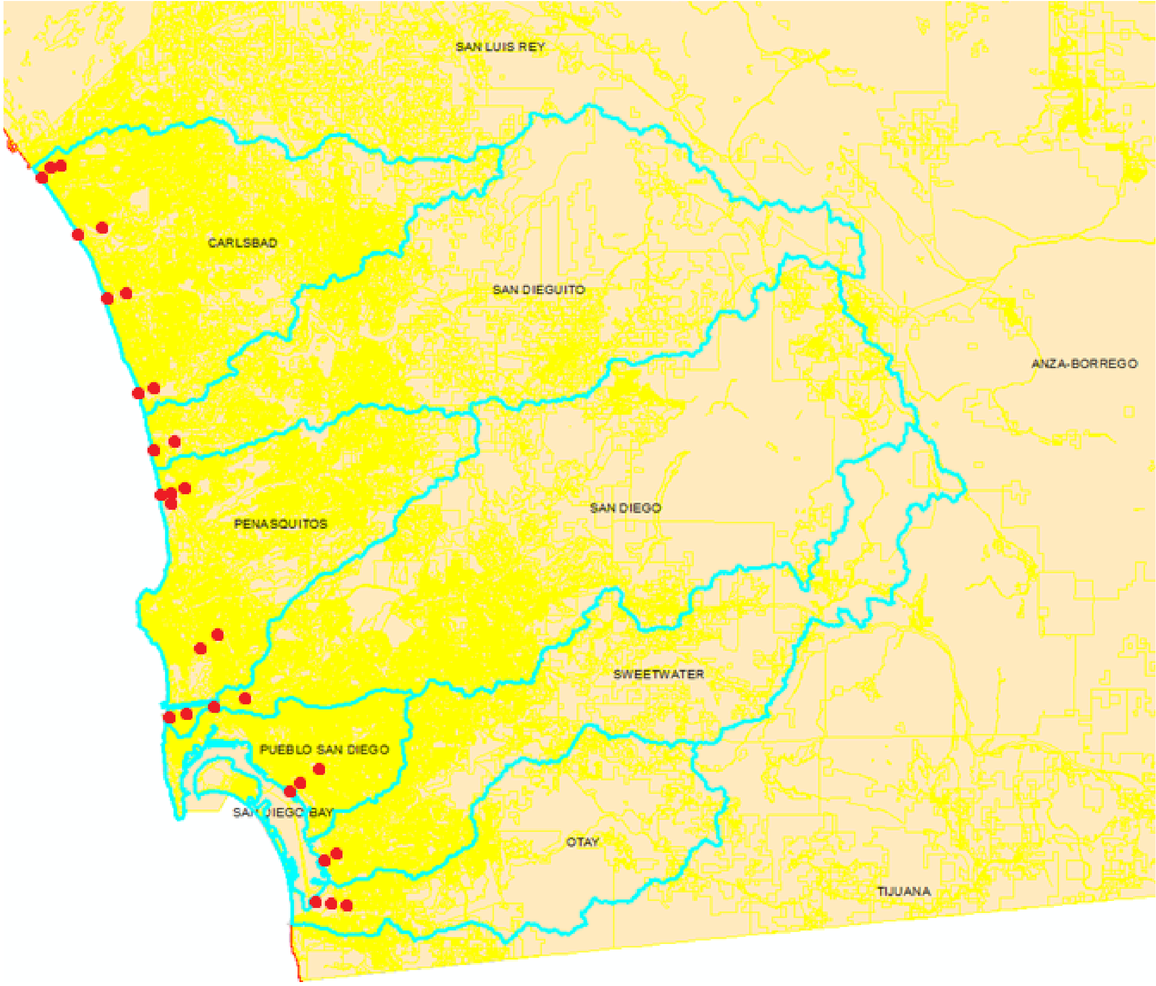
Table 4: ANOVA Results. Significant values from ANOVA analysis.



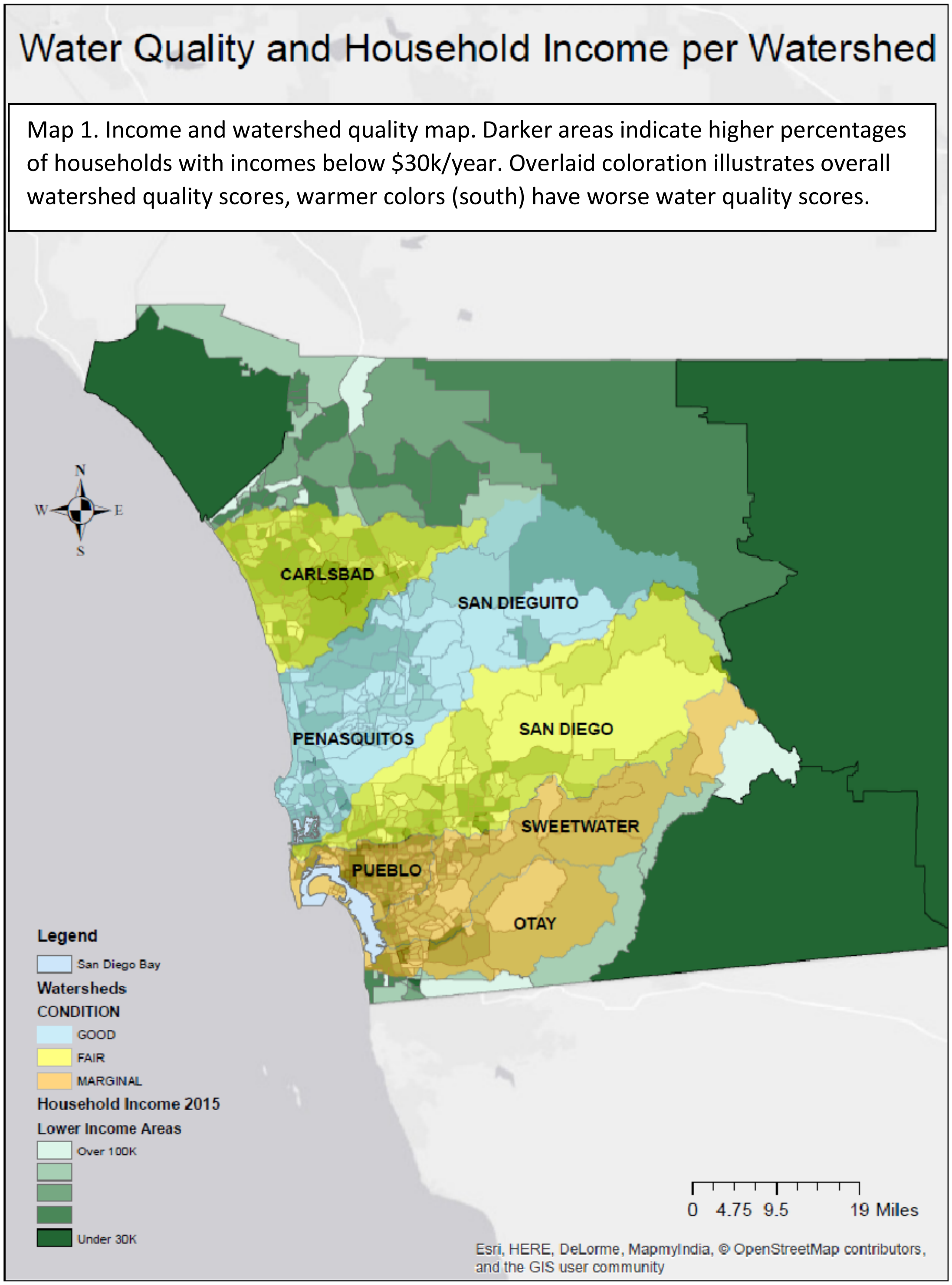
	pH	Temp	DO	Cond	Turb	TN	TP	POM dN15	AMP dN15	POM dC13
Watershed (W)	<0.0001	-	0.004	-	-	0.001	0.02	0.03	0.008	-
Location (L)	0.018	-	-	0.038	<0.0001	0.0005	-	-	-	-
Season (S)	0.016	<0.0001	0.0003	-	-	0.0001	0.03	-	-	-
W*L	-	-	-	-	0.002	0.008	-	-	0.003	-
W*S	-	-	-	0.049	-	-	-	-	-	-
S*L	-	-	-	-	-	-	-	-	-	0.05

MAPS

Map 1: San Diego County Watershed Sampling Sites (7 watersheds , 29 sites)



Map 2: Household Incomes and Watershed Quality



Water Quality and Household Income per Watershed

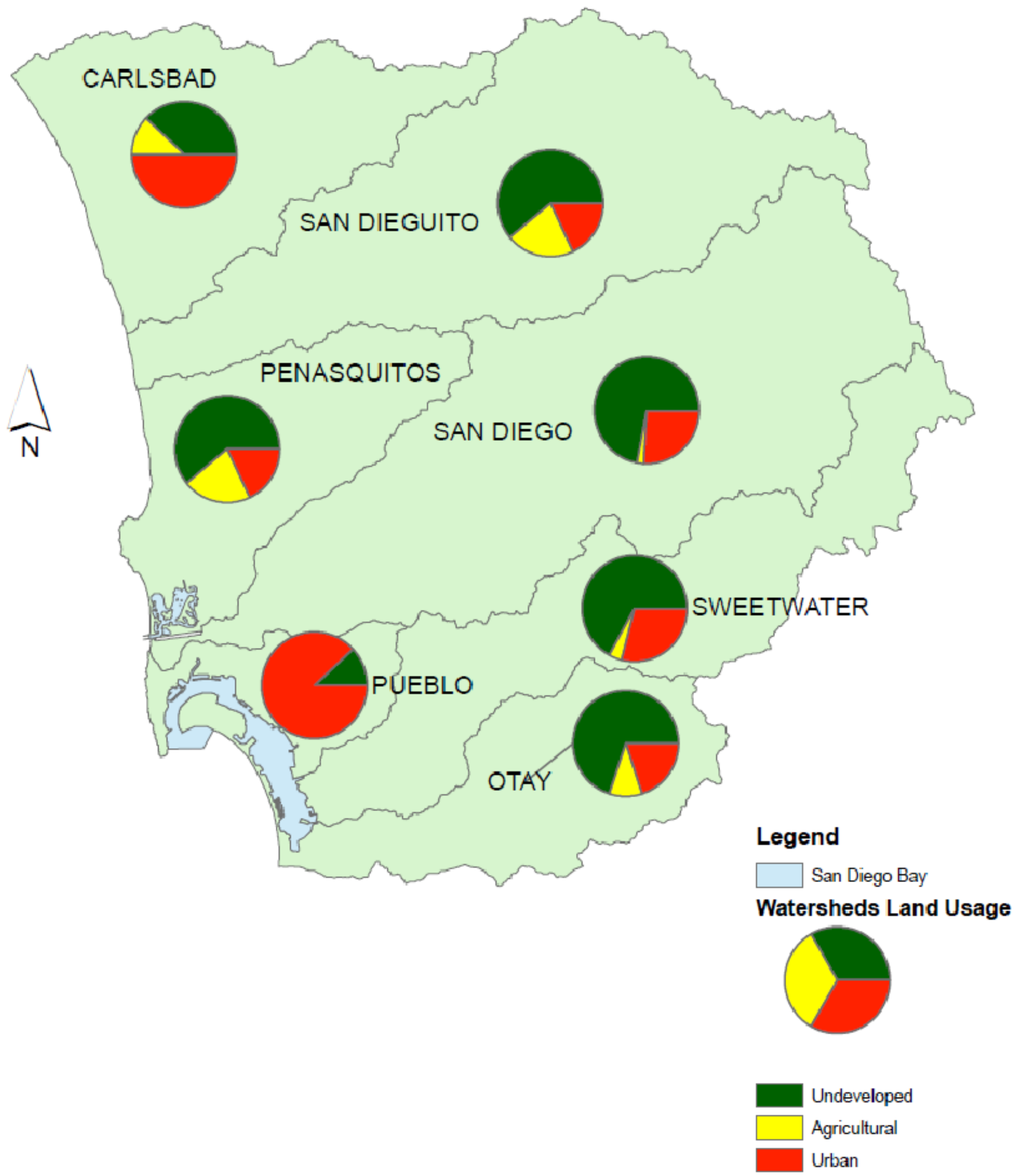
Map 1. Income and watershed quality map. Darker areas indicate higher percentages of households with incomes below $30k/year. Overlaid coloration illustrates overall watershed quality scores, warmer colors (south) have worse water quality scores.

Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

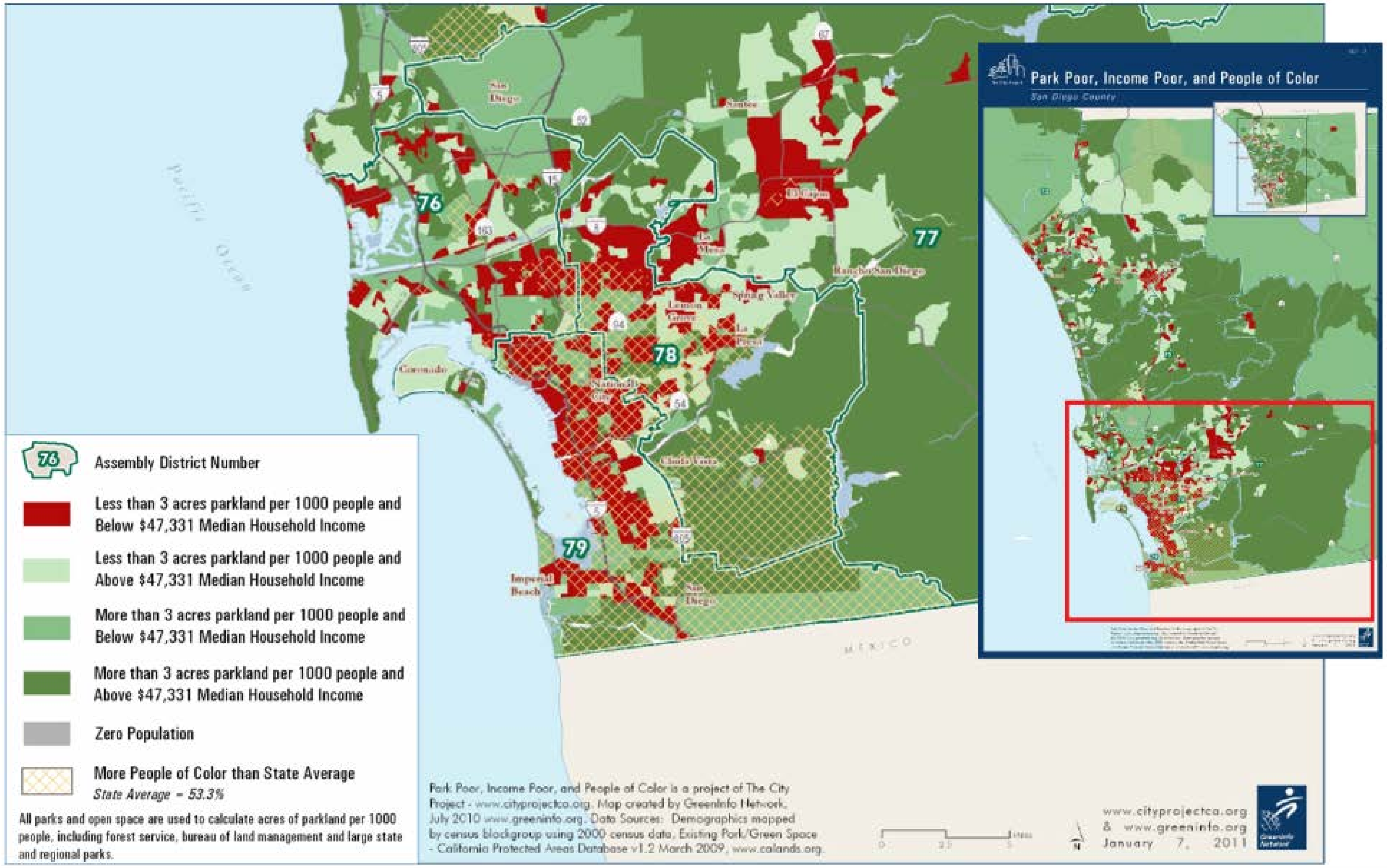
Map 3: San Diego County Watershed Land Usage

Sampled Watershed Land Usage

Map 2. Map of San Diego County outlining watersheds included in this study. Watershed land usage composition is illustrated in respective graphs.



Map 4: The City Project: Park Poor, Income and People of Color



Park Poor, Income Poor, and People of Color is a project of The City Project - www.cityprojectca.org. Map created by GreenInfo Network, July 2010 www.greeninfo.org. Data Sources: Demographics mapped by census blockgroup using 2000 census data, Existing Park/Green Space - California Protected Areas Database v1.2 March 2009, www.calands.org.

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