THESIS

# WATERSHED CHARACTERISTICS THAT ARE RELATED TO THE OCCURRENCE OF IMPAIRED (CWA 303(d)) WATERS FOR PARK UNITS WITHIN THE PACIFIC WEST REGION OF THE NATIONAL PARK SERVICE

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# ABSTRACT

## WATERSHED CHARACTERISTICS THAT ARE RELATED TO THE OCCURRENCE OF IMPAIRED (CWA 303(d)) WATERS FOR PARK UNITS WITHIN THE PACIFIC WEST REGION OF THE NATIONAL PARK SERVICE

Since the establishment of the Clean Water Act (CWA) in 1972, the federal government has made significant strides toward improving the quality of U.S. water resources. The Total Maximum Daily Load (TMDL) program created from the federal CWA distributed the responsibility for improving water quality to states, territories, and authorized tribes, while appointing the U.S. Environmental Protection Agency (EPA) as the lead oversight. Over 43,500 TMDL plans have been developed according to the EPA's national summary of TMDL information. However, implementation of TMDLs is often delayed, which hinders improvement in water quality and may reduce the restoration potential of an impaired waterbody. The National Park Service (NPS) is an important stakeholder in the TMDL program because restoring and preserving water quality for future uses and enjoyment is a vital component of its mission. Therefore, the goal of this study is to identify watershed characteristics that are relevant to the occurrence of impaired waters within watersheds that intersect park units. This will assist NPS managers in evaluating waterbodies at risk and restoration potential.

An initial list of 25 watershed characteristics was identified to be included in this study. A survey was administered to NPS aquatic professionals to further reduce the number of characteristics and evaluate the most pertinent characteristics based on professional opinions. Eleven watershed characteristics were selected and quantified to examine their correlation to the occurrence of impaired waters. Watershed characteristics were chosen to represent each of the three categories: (1) land cover / use, (2) ecological / physical characteristics, and (3) social influences.

The study area was limited to HUC 12 polygons that intersect park units within the Pacific West Region of NPS. Watershed characteristics and impairments were measured for all intersecting HUC 12 polygons. Impairments were assessed based on state listings of CWA 303(d) waters and categories 4a, 4b, and 4c of CWA Section 305(b). Linear regression analysis was employed to investigate the correlation between each watershed characteristic to percent impairment. The results of the analyses revealed that average slope, amount of hydrography, agricultural land cover, and forest land cover were significant indicators of impaired waters at alpha 0.10 level. Although many of the watershed characteristics may have synergistic effects, multicollinearity was not considered in the design of this study. However, the results of this study may guide water quality professionals to hone their efforts on actively managing the significant watershed characteristics identified in this study.

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To my parents: I have such a profound appreciation for the sacrifices you have made as immigrants to the United States. You gave me the opportunity for a better education, career, and life. I am eternally grateful and would like to dedicate my thesis to you.

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Finally, to my late brother, Hao Ling, who fought the battle against Leukemia with the utmost valor: I dedicate this thesis, along with all my past and future accomplishments to you. Because of you, never will I squander another moment of my life.

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# INTRODUCTION

Since the enactment of the CWA of 1972, the federal government has made substantial efforts in remediating the ecological integrity of impaired waterbodies throughout the United States (Keller & Cavallaro, 2008). Two vital components of the CWA dealing with impaired waterbodies are section 303(d) and the TMDL program. Section 303(d) of the CWA obligates individual states, territories, and authorized tribes to develop a comprehensive list of impaired waterbodies biannually and to assign priority regarding restoration efforts. The purpose of the TMDL program is to develop plans that would lead to the gradual restoration of impaired waterbodies and attainment of water quality standards (WQS). WQS are defined by states and are unique to waterbodies and their designated uses (ex. coldwater habitat, fishing, swimming, etc). WQS are measurable thresholds set forth in order for a waterbody to be in compliance to the CWA. Waters that are 303(d) listed are considered to be impaired and failed to attain WQS (National Research Council, 2001). The TMDL program attempts to restore WQS by collecting water quality samples and assigning a pollution loading capacity for 303(d) listed waterbodies (USEPA, 2008). The general idea is to restrict the amount of pollutants entering the already impaired system and restore WQS using best management practices (ex. limiting the use of pesticides on local farms to reduce pesticide concentrations within streams) (USEPA, 2009).

Many recent studies have concluded that the success of the TMDL program is largely limited by the amount of financial resources available (VA Tech Center for TMDL & Watershed Studies, 2006; OIG, 2007). Despite funding allocation from the federal government and additional funds contributed by various agencies and stakeholders, state budgets for the TMDL program have remained the primary constraint to WQS attainment of impaired waterbodies (VA Tech Center for TMDL & Watershed Studies, 2006). Consequently, the EPA Office of Inspector

General (OIG) has criticized the TMDL program due to its excessive focus on TMDL development as opposed to the implementation of already developed TMDLs (OIG, 2007). The over-emphasis on development rather than implementation has largely depleted TMDL funding and delayed the execution of TMDL plans (Norton et al, 2009).

Federal land management agencies are mandated under the Government Performance and Results Act (GPRA) of 1993 to attain specified standards for all natural resources. Within the NPS, statistical reports of water quality are generated every year and reported to Congress for monitoring and budget purposes. Consequently, NPS is an important stakeholder in the TMDL program. As outlined by the Organic Act of 1916, the NPS strives to manage and *"leave* [our natural resources] *unimpaired for the enjoyment of future generations."* Therefore, it is imperative for the NPS to cooperate with state management agencies and other stakeholders to restore the quality of impaired waters within NPS lands.

This is a pilot study that aims to identify and assess the level of influence of various watershed characteristics on impaired waters. Past studies have mostly focused on single watershed characteristics within a smaller spatial scale. The purpose of this study is to determine watershed characteristics that are correlated with the occurrence of impaired waters in watersheds intersecting park units of the Pacific West Region (figure 1 appendix I). The Pacific West Region was selected based on the variety of ecosystems that exist within the region. Consequently, most source pollutants that affect surface waters within parks stem from outside the park boundary (Galvin, 2007). While some impairments may be caused by atmospheric deposition, several others are related to watershed characteristics that ultimately affect water quality within park lands. For example, local agricultural runoff into nearby streams may inevitably spike nutrient and pesticide levels in park waters. Similarly, heavy logging and urban sprawl within a watershed may trigger impairments such as sedimentation, metal contamination, etc. Therefore, it is imperative to understand the effects of watershed characteristics on surface water quality in order to improve management strategies and rehabilitate impaired waters.

This pilot study contains four objectives that are essential in evaluating the predictive power of each watershed characteristic to water impairments. The success of each objective is contingent upon the completion of the preceding objective(s). The objectives are ordered sequentially below to showcase the logical progression of this study.

**Objective 1**: Determine the areas of analysis (AOA) and quantify CWA impairments within each AOA.

a. Identify HUC 12 polygons that intersect the boundaries of park units within the Pacific West Region of NPS as AOAs.

b. Quantify total waterway meters and waterbody square meters in all AOAs.

c. Calculate percent impairment within all AOAs using a comprehensive review of state CWA publications and geographic information system (GIS) datasets.

**Goal:** There are two goals for the first objective. The first goal is to determine the study site, which is rudimentary to the data collection and measurement portion of this study. The second goal is to quantify the percent of impairments within the study areas. The percentage of impairment is necessary for the statistical analysis of watershed characteristics in the last objective.

**Objective 2:** Determine most relevant watershed characteristics to include in this study.

a. Characteristics include land cover/use variables, ecological/physical traits, and social influences on a watershed.

b. Identification of watershed characteristics of interest to this study was determined by NPS staff, who are considered to be experts in water quality management specific to parks.

**Goal:** Objective 2 aims to identify watershed characteristics that are associated to the occurrence and non-occurrence of impaired waters. An initial list of watershed characteristics was compiled based on a comprehensive literature review. Professional opinion was solicited by survey to further refine the number of watershed characteristics to be included in this study.

**Objective 3:** Compile datasets and reports that reflect watershed characteristics of interest to this study.

a. Emphasis was placed on geospatial datasets that have been previously created by other management agencies / stakeholders.

b. Reports and published literature were used in addition to geospatial information.

**Goal:** The third objective explores the data sources that are available to quantify watershed characteristics from the second objective. Certain watershed characteristics may be represented through a variety of datasets while others may lack representation. This objective helps identify which dataset to use and which watershed characteristic to exclude from analysis due to lack of data.

**Objective 4:** Quantify watershed characteristics in all AOAs and assess correlation to impairments.

a. Information on watershed characteristics were drawn from collected datasets and reports.

b. Watershed characteristics were quantified using the most appropriate units of measure (i.e. density, percentage, etc).

c. Statistical analyses were used to assess correlation between watershed characteristics to impairments.

**Goal:** The last objective measured the statistical significance of each watershed characteristic using linear regression analysis. The results will be used to evaluate the predictive power of each watershed characteristic to the occurrence/non-occurrence of impaired waters.

The results of this pilot study provide insights that will be useful to managers for assessing recovery potential of an impaired waterbody and for prioritizing/allocating restoration efforts. Watershed characteristics identified through this study consist of land cover/use variables, physical/ecological traits, and social impacts, which parallel the mission of NPS to manage lands based on a harmony of ecological and social values. The procedures and results of this pilot study have application potential, as other management agencies and stakeholders can adopt and/or expand on this project for their own unique goals and purposes. Results also provide managers with a method for assessing restoration potential of impaired waters and evaluate waterbodies at risk of impairment.

## LITERATURE REVIEW

The literature review is a comprehensive overview of the 25 watershed characteristics selected for this study (*Table 1*). Watershed characteristics were selected based on their prevalence in published studies. In this literature review, watershed characteristics are organized based on the three categories (i.e. land cover/use, ecological/physical, and social). The literature review uses several case studies to illustrate the correlation between each watershed characteristic and its influence on water impairments

*Table 1. Initial list of 25 watershed characteristics of interest in this study.*

| **Land Cover/Use** (7) | **Ecological/Physical** (10) | **Social Characteristics** (8) |
|---|---|---|
| Corridor/Road Density | Amount of Hydrography | Hydrological Alterations |
| Percent Agriculture | Bank Stability/Soil Types | Jurisdictional Complexity |
| Percent Forest | Biotic Integrity | Landownership Complexity |
| Percent Impervious Surface | Channelization | Legacy Land Use Effects |
| Percent Protected Lands | Climatic Variations | Number of NPDES Permits |
| Percent Urban Development | Presence of Endangered/Threatened Species | Recreational Opportunities |
| Residential Unit Density | Presence of Rare Taxa | Socioeconomic Stress |
| | Stream Order | Watershed Organizational Groups |
| | Topography (i.e. Slope & Elevation) | |
| | Watershed Size | |

### Land Cover / Use

Watershed characteristics within this category represent the physical landscape of the watershed. Often, land cover and land use are indicators of how humans have changed the physical structure of a watershed based on anthropogenic needs and values. For this study, seven watershed characteristics were chosen to represent this category (i.e. road density, percent agriculture, percent forest, percent impervious surface, percent protected lands, percent urban development, and residential unit density). Consequently, several published scientific reports have concluded a strong relationship between land cover/use and water quality within a watershed.

<u>Road Density</u>

Several studies have been published regarding the causal factors of impaired waters. For example, varying types of land cover/use may compromise water quality such as the road density, percent agriculture, forest, impervious surface, protected lands, urban development, and residential unit density. Extensive research indicated that the presence of roads may greatly impair watershed health. Godwin et al (2003) studied the implications of using road salt and its effects on the Mohawk River in New York from 1952 to 1998. The results of this study concluded that sodium ions within the Mohawk River have increased by 130% while chloride ions have spiked 243% throughout the 46 years. Aside from local impacts, the application of deicing salt may also lead to seasonal variations in water quality. Rodrigues et al (2010) stated that despite the largest application of salt occurred during the winter months, subsequent increase in water conductivity attributed to deicing salt may not appear until late spring season. However, water conductivity levels typically return to within normal range after July. Therefore, road salts cause both local and temporal variations in water quality (Godwin et al, 2006; Rodrigues et al, 2010).

In addition to the application of road salts, the existence of roads may have other harmful implications on water quality. Metals are emitted through the combustion engines of vehicles, which accumulate on road surfaces, parking lots, and the surrounding sediment. These metals are transported into nearby streams via road runoffs, especially during flood events (Eyles and Meriano, 2010). Contaminated sediments may also contribute to nutrient leaching and high levels of total suspended solids of nearby streams. Forsyth et al (2006) investigated the effects of forest roads (graveled vs. ungravelled) on water quality, primarily studying sediment and nutrient loss. Although there are measurable amounts of sediment and nutrient loss despite road types, this study concluded that the concentration of fine particles in road runoff is positively correlated with traffic loads. Therefore, roads contribute to elevated total suspended solids in nearby streams as well as other particles that may be entrained with surface runoff (Forsyth et al, 2006; Grayson et al, 1993).

Percent Agriculture

Surface runoff may contain elevated levels of nutrients due to the presence of nearby agriculture. The application of fertilizer to enhance growth of crops may have adverse effects on the overall water quality of the watershed (Schroder et al, 2004). Aside from nutrient leaching, grazing practices may also lead to a deterioration of riparian vegetation, thus resulting in heightened levels of sediments in nearby streams (Brainwood et al, 2004). The adverse relationship between agriculture and water quality is well-established and studied (Weber et al, 2001).

The application of fertilizer to enhance crop production is a common practice in agriculture. Specifically, nitrogen and phosphorus comprise a large percentage of the chemical composition in most fertilizers used today. However, nitrogen and phosphorus are often applied in excess and fail to be integrated in crop production. Therefore, much of the nutrients are lost from agricultural fields to nearby streams and lakes, producing changes in water chemistry and potential eutrophication (Nakano et al, 2008). A study by Foster et al (1989) researched the relationship between nitrate levels and agricultural intensity in various catchments within New Jersey. The results of this study concluded that elevated levels of nitrate were directly correlated to cultivation intensity and its application of fertilizer. Percent agricultural land cover within catchments was also an important predictor of nitrate exceedance in this study. Therefore, nutrient losses from agriculture may pose a great danger to aquatic ecosystems and the quality of drinking water (Shroder et al, 2004).

A study by Brainwood et al (2004) showcased the potential threat of agriculture on water quality in reservoirs. Three dams were studied with different primary source inputs: (1) agricultural runoff with frequent stock acesss (2) ground water from springs and no stock access, and (3) mixture of nearby urban creeks and agricultural runoff with stock access. The most distinct differences in water chemistry were showcased in the comparison of dams 1 & 2. Temperature, dissolved oxygen and pH were consistently higher in dam 1, especially during summer and winter seasons. In contrast, turbidity and conductivity levels were higher in dam 2 consistently throughout all seasons. Dam 3 produced very dissimilar water chemistries, which was attributed to urban stream input and factors that may affect its water quality. The results of this study demonstrated that the adverse effects of agriculture on freshwater supply are beyond that of nutrient loss. This is further accentuated by Bouma et al (2002), who examined the propensity of certain pesticides to percolate into groundwater. Although several laws have been enacted to regulate the application of pesticides, leaching of chemicals remains a problem. Percolation of pesticides into groundwater is often a function of soil type and its rate of absorption. Therefore, even low-risk pesticides may be problematic when absorbed into the soil in great concentrations.

Percent Forest

In addition to agricultural land cover, percent forest cover in a watershed is also a viable predictor of water quality. Specifically, forested watersheds typically have reduced runoff due to increased interception and absorption. Peterjohn and Correll (1984) studied the role of riparian forest in ameliorating the detrimental effects of agriculture on water quality. Annual sediment loads were reduced by 90% when riparian forests were located adjacent to agricultural fields. In addition, the results of this study demonstrated an 80% decrease of nitrate in surface runoff and 85% in groundwater nitrate. Other studies have also published similar findings and concluded that forest cover is an effective barrier to alleviate nutrient leaching stemming from agricultural practices (Jordan et al, 1993; Lowrance et al, 1984).

Riparian forests may also halt the transport of sediment, thus reducing total suspended solids in local streams (Norton & Fisher, 2000). Kreutzweiser et al (2009) investigated sedimentation patterns as a function of varying levels of logging within riparian forests. The results indicated that areas with the most intense logging led to an immediate rise in fine inorganic sediment within streams up to three to five times higher compared to pre-logging. By trapping sediments, riparian forests are also effectively reducing the amount of contaminants entering nearby streams. Furthermore, Ensign & Mallin (2001) documented several consequences associated with clearcuts including the occurrence of algal blooms, lower dissolved oxygen, and elevated levels of nitrogen, phosphorus, suspended solids, and fecal coliform. Therefore, riparian forests act as a buffer that protects and improves water quality (Norton & Fisher, 2000).

Percent Impervious Surface

Recent studies have suggested that percent impervious surface is a viable indicator of water quality (Conway, 2007; Pappas et al, 2008). Impervious surface is characteristic of developed/urbanized watersheds, which produce large amounts of stormwater runoff into the ecosystem (Eckley & Branfireun, 2009). Consequently, runoff from urbanized watersheds typically contain high concentrations of various pollutants due to impervious surfaces such as sediment, metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and more (Jartun et al, 2008). Stormwater runoff is eventually transported to surface waters, which contaminate and degrade water quality (Shaw et al, 2006).

Impervious surfaces are typically layered by a variety of pollutants, including atmospheric deposition of different metals. Sabin et al (2005) researched the concentration of metals from atmospheric deposition in stormwater within urbanized catchments. The results of this study suggested that atmospheric deposition (wet+dry) contributed 57% - 100% of the metals found in stormwater runoff. Impervious catchments have a higher propensity for retaining metals and other pollutants on the surface. Therefore, stormwater runoff may contain higher levels of contaminants and have harmful implications on local water quality.

Conway (2007) examined the susceptibility of water quality degradation based on percent impervious cover within coastal watersheds in New Jersey. The results of this study concluded that the percent impervious surface within a drainage area is highly correlated with specific conductance and pH. Also, based on the results of this study, Conway (2007) was able to determine an impervious surface threshold of 2.4% - 5.1%, after which water quality deteriorates greatly. This study also discovered a greater correlation between water quality and percent urban land cover. However, the greater correlation was attributed to the inclusion of impervious surfaces and other urban factors within percent urban cover.

Percent Urban Development & Residential Unit Density

Several studies have investigated the detrimental impacts of urban sprawl on water quality. Consequently, urban expansion has become a necessity to satisfy the social and economic demands associated with population growth (Yin et al, 2005). City development imposes severe stress on the surrounding aquatic environment, despite the implementation of sewage treatment plants (Beck, 2005; Mouri et al, 2011). Some primary sources of water pollution from urban areas include untreated effluents from sewage treatment plants, stormwater runoff, and air emissions (International Joint Commission, 2004). Factors associated to urban land cover may include population growth, impervious surface, road density, residential development, etc. Therefore, urban development may be an especially viable indicator of surface water quality within a watershed.

Although heavily urbanized watersheds typically include intricate wastewater infrastructures, anthropogenic effects on water quality may be reduced, but not eliminated (Beck, 2005; Fu et al, 2009). Urbanized watersheds typically experience fluctuations in biochemical oxygen demand, increased total nitrogen and phosphorus levels, elevated concentrations of suspended sediments, fecal contamination, and more (Cho et al, 2010; International Joint Commission, 2004; Mouri et al, 2011). Consequently, urban land cover may inhibit WQS attainment and engender violations in designated uses, resulting in more CWA 303(d) impaired waters (Gannon & Busse, 1989).

Percent Protected Lands

Contrary to urban land cover, little research has been done regarding the effectiveness of protected lands in the preservation of pristine water quality (Abell et al, 2007). Specifically to the context of this study, protected lands include those within the boundaries of federal and state land management agencies. In general, protected lands are designated with two primary goals in mind: 1.) to conserve the natural qualities of the area and 2.) to provide recreational opportunities to the public (McDonald et al, 2008). However, traditional methods for identifying conservation lands have largely focused on terrestrial resources and little attention have been given to conserving freshwater ecosystems (Nel et al, 2009). Nevertheless, past research seem to support both notions that protected areas may and may not be a viable predictor of impaired waters.

McDonald et al (2008) researched the propensity of bacterial contamination in natural waters within protected wilderness areas. Since the mid 1960s, the frequency of visitors recreating in wilderness areas within the United States has increased by approximately 400%. Consequently, this study concluded that increased visitor use is highly correlated with higher concentrations of *E. coli* and fecal coliform in nearby streams, and even in headwaters upstream of areas of frequent visitation. A more pertinent study by Silsbee and Larson (1982) showcased similar findings in Great Smoky Mountain National Park, where 98.6% of 367 samples tested positive for *E. coli*. Temporal variations of bacterial concentration were also found to support the correlation between visitor use and the degree of contamination. Concentrations were found to be significantly higher during weekends compared to weekdays. Similarly, bacterial densities during summer months were also higher than other seasons (McDonald et al, 2008). Since increased visitor use is characteristic of wilderness/protected areas, lands within the boundaries of state and federal land management agencies may be a viable predictor of impaired waters.

In contrast, other studies have discovered that protected areas are poor indicators of water quality. Roux et al (2008) explained that the designation of protected areas is rarely established with the conservation of freshwater resources in mind. In addition, it is uncommon for the extent of a protected area to encompass an entire catchment (i.e. to include both headwaters and the lower reaches). Finally, streams within protected areas are often managed based on designated uses (ex. impoundments for drinking water supply). Since protected areas are typically designated to conserve terrestrial resources, freshwater ecosystems within protected areas remain at risk for impairment (Abell et al, 2007; Nel et al, 2009). Therefore, protected areas may or may not be a viable predictor of impaired waters.

**Ecological / Physical Characteristics**

Watershed characteristics within this category represent the biotic and abiotic features of a watershed. While these watershed characteristics may be considered “natural,” they are still subject to human influences and change. For this study, ten watershed characteristics were selected to represent this category (i.e. amount of hydrography, biotic integrity, bank stability/soil types, channelization, climatic variations, presence of endangered/threatened species, presence of rare taxa, stream order, topography, and watershed size). These watershed characteristics may be used to evaluate aquatic ecosystem health and its susceptibility to water impairments.

<u>Amount of Hydrography</u>

The amount of hydrography, as related to water impairments, may be especially important in managing water resources in arid environments. In this study, the amount of hydrography is defined by the miles of waterways and acres of waterbodies within a watershed. Water feature classifications (i.e. perennial, intermittent, & ephemeral) may also affect the amount of hydrography within a watershed. Watersheds that receive plentiful rainfall and contain an abundance of perennial water features may be less susceptible to impairments due to dilution effects. Shuval (1967) studied the implications of wastewater disposal in semi-arid and arid environments. In dry areas, wastewater is typically disposed into river beds that are either intermittent or ephemeral. Consequently, the concentration of pollutants is more likely to exceed that of WQS due to limited dilution effects (McLeay et al, 1979; Environment Canada, 2010). In addition, a lack of hydrography may also reduce crucial riverine habitat, resulting in a loss of biodiversity (Boulton, 2003). For example, ecosystems that experience intense heat and drought conditions have higher evaporation rates. Fish communities in intermittent ponds become stressed due to increased concentrations of waste metabolites and oxygen depletion (Lewis, 2011). Therefore, the amount of hydrography in a watershed may have great implications on water quality.

Biotic Integrity

The biotic integrity of local fish communities may be indicative of stream health and water quality. As part of their fulfillment of the CWA 303(d) listing, the States of Maryland and Virginia have adopted biological criteria for identifying 303(d) waters in the Chesapeake Bay (Llanso et al, 2009). Although only applied for benthic macroinvertabrates, other researchers argue that an overall index of biotic integrity may provide great insights in assessing water impairments (Launois et al, 2011; Novotny et al, 2005). For example, Novotny et al (2005) explained that the presence of invasive and non-native biota degrades the local biological integrity, which may lead to a violation of WQS. It is a common assumption that biological integrity and diversity are reflective of environmental conditions (Stringfellow, 2008). Therefore, evaluating species diversity/composition may be a viable approach to evaluate water quality and health.

Bank Stability / Soil Types & Channelization

The pre-dominant physical soil properties within a watershed may have great implications on water quality. Studies have concluded that soil types may influence bank stability, erosion/sediment loading, channelization, and even the transport of various contaminants (Barrico et al, 2006; Merritts et al, 2010; North Carolina Cooperative Extension Service, 1997; Simon et al, 2011). As explained by Simon et al (2011), bank shear strength is affected by the cohesion of the soil particles. When evaluating bank cohesion, a negative correlation was determined between particle size and cohesiveness. Therefore, banks that are composed of a large percentage of sand are more vulnerable to streambank erosion than that of silt and clay. In contrast, most turbidity and total suspended solids impairments are attributed to finer soil particles such as silt and clay. Since heavier particles tend to settle out more quickly than finer particles, silt and clay may remain in suspension for longer periods of time (North Carolina Cooperative Extension Service, 1997). Suspended sediments may reduce fish spawning habitat and affect the density of organic matters, nutrients, and chemicals within streams (Barrico et al, 2006).

Climatic Variations

Environments that experience frequent wet-dry events may be even more susceptible to sediment loading. Merritts et al (2010) stated that despite the inherent compactness of finer sediment particles, constant wet-dry and freeze-thaw conditions may trigger an increase in mass failure and suspended sediments downstream. Climatic variations may have synergistic effects with other watershed characteristics that may ultimately affect water quality. As mentioned earlier, drought events inhibit dilution effects and soil permeability, thus leading to excess runoff and increased concentrations of contaminants (Weber et al, 2001). In contrast, flooding and sudden surges in flow can cause bank instability, erosion, and higher concentrations of total suspended solids (Environment Canada, 2010).

Seasonal variability in precipitation and climate may also affect water quality and how TMDLs are developed. Stow & Borsuk (2003) emphasized that load allocations calculated as part of a TMDL plan is inherently flawed due to its inability to capture weather variations. This study concluded that weather may influence variability in stream flow, which may result in both an over and under estimation for load allocation. Although an under estimation is not typically of concern (just a more conservative approach), an over estimation of load allocation may be detrimental to stream health. Therefore, weather and climate variability may be important predicators of water quality.

Presence of Endangered/Threatened Species & Presence of Rare Taxa

Species that are listed under the Federal Endangered Species Act (ESA) of 1973 receive extended protection due to their status. Although it is primarily the responsibility of the state to maintain WQS, federal agencies (i.e. USEPA and U.S. Fish & Wildlife Services) become involved when a specie is listed under the ESA (Marcus et al, 2010). In order to provide adequate protection, management strategies to preserve the natural populations of ESA species often include stressor remediation, habitat restoration, and species recovery/protection (Ryu et al, 2011). Additionally, TMDL priority for impaired waters that contain ESA species are typically given a higher ranking due to elevated risk of extinction (Lotus & Kraft, 2003). Pollutants/contaminants that adversely affect wildlife (including rare and listed species) may also affect the trophic interactions of the entire ecosystem due to bioaccumulation (Davis et al, 2007).

Therefore, the presence of endangered/threatened species may lead to more intensive management strategies to reduce to risk of water impairment.

The presence of rare species may also be indicative of local water quality. For example, generalist species are often more adaptive to stressful environments. As water quality deteriorates, generalists often outcompete the specialist species, causing a decline in biodiversity and the disappearance of the native fauna (Horn et al, 2004). Therefore, the presence of native rare species that are specialized in their respective habitat is a sign of healthy water quality.

### Stream Order

Stream order classifications are used to describe stream size and relative location of a stream within a catchment (West Virginia Conservation Agency, 2011). Although low stream orders are more sensitive to environmental stress, they are also more resilient and are more likely to meet WQS when restoration efforts are applied (USEPA, 2010). In contrast, higher stream orders have lower resilience and may be more susceptible to pollutants due to accumulation (Chen et al, 2009). Therefore, recovery potential for high stream orders is typically low and very costly (USEPA, 2010). Although the correlation between stream order classification and impairment may be vague, the restoration potential of higher stream orders may indicate its likelihood to remain impaired once it fails WQS.

### Topography

Topographic features are used to describe the physical characteristics of a landscape such as slope and elevation. Past studies have investigated the effects of slope on water quality and concluded that steeper slopes lead to increased erosion and transport of contaminated sediments into nearby streams (Silva & Williams, 2001). However, Chang (2008) published opposite results, and further explained that the effects of slope on water quality are misleading because slope is a secondary variable to land cover. Similar to slope, the effects of elevation on water quality may also be a product of other primary variables. Headwaters in higher elevations can serve as thermal refuges for certain fish species that are more suited for cold waters (Intergovernmental Panel on Climate Change, 2001). However, cooler water temperatures may also be attributed to percent forest, climatic variability, and stream order. Therefore, it is important to consider synergistic effects when assessing topographic features as a predictive variable for the occurrence/non-occurrence of impaired waters.

Watershed Size

Similar to topography, watershed size may be a secondary exploratory variable used to predict water impairments. According to the USEPA Water Recovery Potential Project, watershed size is directly related to jurisdictional, landownership, and ecosystem complexity (USEPA, 2010). Complex systems are often more difficult to manage and may have a lower restoration potential relative to smaller watersheds. In addition, increased jurisdictional and landownership complexity may complicate restoration efforts. Consequently, assuming that watershed size is positively correlated with system complexity, the occurrence of impaired waters is more likely to affect larger than smaller watersheds.

**Social Characteristics**

Watershed characteristics within this category represent the various ways humans rely, manage, and use a watershed. For this study, eight watershed characteristics were chosen to represent this category (i.e. hydrological alterations, jurisdictional complexity, landownership complexity, legacy land use effects, number of NPDES permits, recreational opportunities, socioeconomic stress, and watershed organizational groups). Although a watershed may provide several ecosystem services (i.e. recreational opportunities, drinking water, etc), extensive use and misuse may lead to poor water quality.

Hydrologic Alterations

Flow modification has become a necessity in order to meet the socioeconomic demands for water. Consequently, alterations in natural flow patterns may lead to detrimental changes in both the chemical and physical properties of surface waters (Connecticut Department of Environmental Protection, 2011; New Mexico Environment Department Surface Water Quality Bureau, 2006). For example, the presence of dams stops flow, minimize aeration, and can greatly impact dissolved oxygen levels and biotic communities (Tuckerman & Zawiski, 2007). Additionally, diversions for irrigated agriculture can often result in return flows that are contaminated with pollutants such as pesticides, nutrients, and sediment (Garuzabal & Causape, 2010). Although streams provide several essential ecosystem services, better management practices are required to ameliorate anthropogenic impacts on natural flow patterns and water quality.

The impounded Cuyahoga River in Ohio is affected by several water impairments. Tuckerman & Zawiski (2007) studied the implications of dams, specifically the Kent and Munroe Falls dams, on water quality in the Cuyahoga River. The results of this study concluded that the removal of Munroe Falls dam immediately led to improvements in dissolved oxygen levels. Kent Dam was modified to promote natural flow, which precipitated improvements to the local fish community in less than a year after modification.

Water withdrawals and diversions are a common practice for irrigated agriculture. Consequently, most current practices are not very environmentally sustainable and may cause problems in water quality (Garizabal & Causape, 2010). As discussed earlier, lower flows reduce dilution effects, which may lead to elevated concentrations of contaminants/ pollutants in the water (Environment Canada, 2010). Of even greater concern is the return flows from irrigated agricultural lands. Lee & Jones-Lee (2007) investigated agricultural discharges and its effects on water quality in the San Joaquin River in California. Nine of the twelve WQS violations in the San Joaquin River were attributed to agricultural runoff, including impairments such as selenium, boron, salinity, oxygen demand, nutrients, pesticides, fecal coliforms, and more. Diversions for irrigated agriculture may lead to higher concentrations of contaminants due to lack of dilution, which is then exacerbated by agricultural discharges.

Jurisdictional & Landownership Complexity

Watersheds typically span across several political jurisdictions, which forces multiple management entities to collaborate in restoration efforts. Within the context of this study, jurisdictional complexity is defined by the number of political jurisdictions within a watershed. Although more management agencies may result in more funding, cooperation to achieve a common goal becomes increasingly difficult. Since all jurisdictions are considered to be vital stakeholders to their residing watershed, it is important to include all management entities in the planning process (USEPA, 2010). Consequently, more jurisdictional involvement equates to increasing complexity, which may complicate restoration efforts and prevent the attainment of WQS (Norton et al, 2009).

Landownership complexity can also complicate restoration efforts by integrating the opinions and needs of all affected landowners within a management plan (USEPA, 2010). The number of private landowners within a watershed and their varying views on land management may convolute plans to restore impaired waters. Therefore, jurisdictional and landownership complexity have a negative correlation to the restoration potential of impaired waters (Norton et al, 2009).

Legacy Land Use Effects

Past land uses and practices can have lingering and harmful implications to local water quality. According to a TMDL report by Alabama Department of Environmental Management Water Quality Branch, Camp Branch has been listed on the Alabama 303(d) list since 1996 for metals, pH, siltation, and other habitat alterations. These impairments stem from legacy land uses, particularly from historical mining, mill tailings, and landfills. Similarly, Arizona Department of Environmental Quality (2004) has also attributed the mercury impairment in Alamo Lake to historical mining within the local area.

Past clearcuts may also contribute to current water quality challenges. A TMDL report by the Montana Department of Environmental Quality (2004) partially attributed sediment loading in Coal Creek to historical timber harvests. Due to reduced interception and root uptake, runoff in clearcut areas is particularly high. Therefore, past timber activities may have negative implications on current water quality.

Number of NPDES Permits

Section 402 of the CWA mandates the USEPA to implement the National Pollutant Discharge Elimination System (NPDES) permit program. The purpose of the NPDES program is to regulate point source effluents and its potential adverse effects on the receiving waters. Similar to Section 303(d) of the CWA, regulation and permitting responsibilities are delegated to the state management agencies while USEPA provides lead oversight of the NPDES program (Coker, 2008; USPEA 2009a). The number of NPDES permits within a watershed may indicate the susceptibility for 303(d) impairment within a watershed (Tuckerman & Zawiski, 2007). To the contrary, Chakraborti (2008) concluded that the NPDES program was effective in keeping receiving waters in compliance with WQS. Although more research is warranted in assessing the effectiveness of the NPDES program, the number of NPDES permits within a watershed may signify the management intensity for clean surface waters. Therefore, the number of NPDES permits within a watershed may be a predictor of the non-occurrence of impaired waters.

Recreational Opportunities

Recreational opportunities can damage local water quality in a variety of ways (Vesterinen et al, 2010). Consequently, water quality is often compromised to enhance recreational experiences and opportunities. While roads, trails, and campsites offer a wide selection of recreational activities, these artificial infrastructures adversely affect water quality, specifically through sedimentation. For example, campsites that are located nearby streams contain barren soil and lack of vegetative cover, which facilitates the transport of sediment into the adjacent stream.  In addition, exposed tree roots in riparian areas may compromise bank stability, further increasing the sediment load (Nelson Consulting Inc., 2008).

Aside from erosion, heavy campsite use may also increase nutrient levels. Organic waste deposits may elevate coliform bacteria and phosphate concentrations in the water, thus increasing the risk for eutrophication and 303(d) listing (King & Mace, 1974). When water quality is compromised, recreational experience also suffer, which may lead to a decline in use and visitation (Vesterinen et al, 2010). Therefore, recreational opportunities within a watershed may be a predictor of the occurrence of impaired waters.

Socioeconomic Stress

Socio-economic stress within a local community may negatively impact funding for management and restoration of impaired waters. According to the USEPA Water Recovery

Potential project, impoverished communities that experience socioeconomic distress are less inclined to divert dollars for restoration projects. Instead, local governments may wish to invest more funding to improve the overall socioeconomic status of the community. Also, restoration efforts may impose greater restrictions on water usage, thus negatively affecting residents' perception of restoration (USEPA, 2010).

Watershed Organizational Groups

Community involvement in water quality issues within respective local watersheds may enhance the restoration potential of impaired waters. According to the USEPA Water Recovery Potential project, collaboration with local watershed organizations increases the likelihood of restoration success. As evidenced by a sediment TMDL for the Van Duzen River and Yager Creek in California, valuable information were extracted from long-time landowners that possess extensive knowledge of the watershed. In addition, local watershed groups can bridge communication between management agencies and the public (USEPA, 1999). Often times, state agencies lack water quality data to make an informative CWA 305(b) listing. Community involvement and the cooperation of watershed organizational groups can fill missing informational gaps to improve monitoring for state agencies (Liu et al, 2008; VA Tech Center for TMDL & Watershed Studies, 2006; Voinov & Gaddis, 2008).

Watershed organizational groups may also assert pressure to federal, state, and local management agencies in order to maintain pristine water quality. This may lead to more active management, engage public involvement, and extra protection for waterbodies of interest. For example, Save the Poudre is a watershed organization that works to protect the water quality and ecosystem integrity of the Cache la Poudre River. It has posed great opposition to a recent proposal to further impound the Cache la Poudre River in order to meet the water supply demand of Northern Colorado. Save the Poudre has organized public meetings, presentations, and offered other viable alternatives that may alleviate any potential damage to the river (Save the Poudre: Poudre Waterkeeper, 2011). Although a decision has not been made, the presence of watershed organizational groups can certainly affect management decisions and help maintain healthy water quality.

Summary of Literature Review

There are several well-documented indicators/parameters related to water quality assessment. However, the degree to which they correlate with the occurrence of impaired waters that intersect NPS lands is still unknown. The aim of this study is to gain a better understanding of the watershed characteristics and how they may be used to predict the occurrence of impaired waters. These known characteristics are of utmost interest to this study and are expected to showcase high levels of correlation as opposed to less-documented parameters. Outcomes are assessed based on level of spatial co-occurrence and statistical analyses. The results of this study can potentially affect methods for prioritizing restoration efforts for all federal impaired waters.

# MATERIALS AND METHODS

The methods for this study were designed specific to the goals of each objective stated in the introduction. Each objective required different information and unique methodologies, and this chapter was organized based on the four objectives and their respective goals. Conceptual flowcharts are located at the beginning of each objective section to summarize the methodologies used. Finally, an overall conceptual flowchart for all methods in this study is provided in appendix II.

***Objective 1:*** *Determine the areas of analysis (AOA) and quantify CWA impairments within each AOA.*

<u>Identifying Areas of Analysis (AOAs)</u>

Since watershed characteristics were being examined and measured on the watershed level (HUC 12), the AOA must extend beyond the limits of park boundaries. Discrepancies in spatial scales may lead to erroneous statistical results and conclusions. Therefore, HUC 12 polygons that intersect park boundaries were identified as the AOAs for this study. Two GIS datasets were used to determine the AOAs: the NPS Current Administrative Park Boundaries dataset (including only the 55 park units of the Pacific West Region) and the Natural Resources Conservation Services (NRCS) Watershed Boundary Dataset (WBD). All HUC 12 polygons that were spatially coincident with park boundaries were identified as AOA (*Figure 1*). Two outputs were created in this step (both are spatially identical) in order to accommodate further data processing procedures. AOA1 refers to 55 individual HUC 12 shapefiles organized by park codes and AOA2 refers to a single shapefile that includes all HUC 12 polygons that intersect all park units. Detailed processing methods are located in appendix IX.

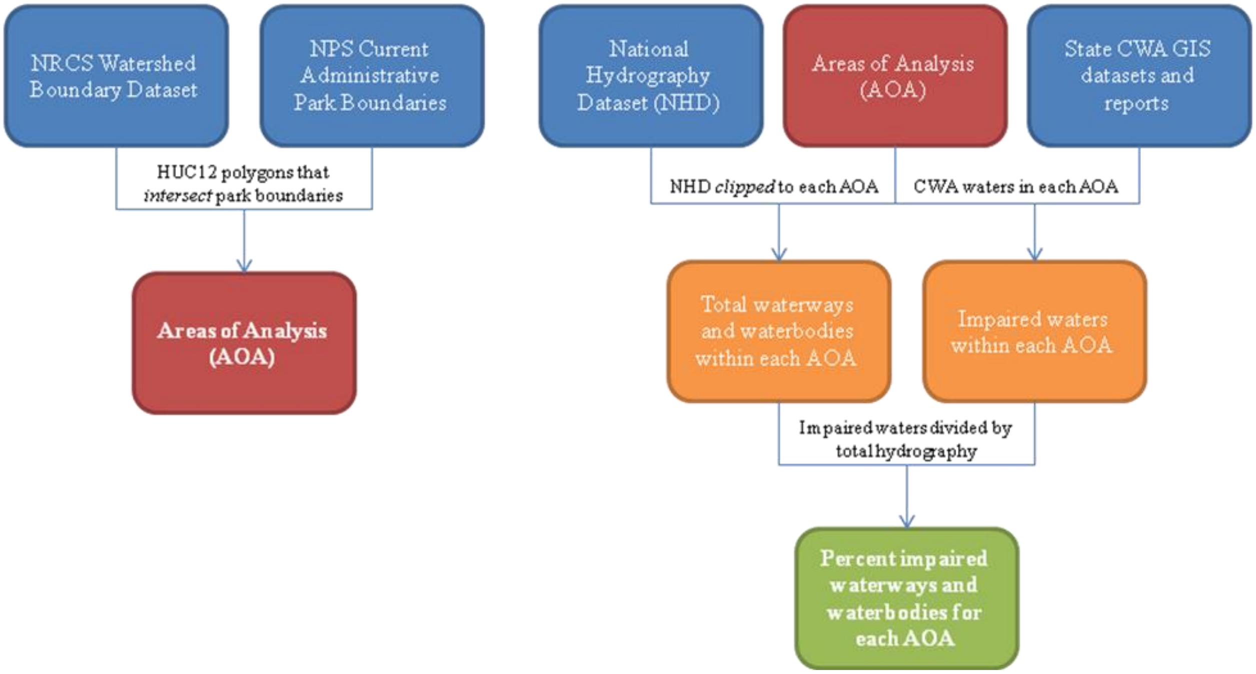


*Figure 1. Conceptual flowchart of methodologies for objective 1*

Quantifying CWA Impairments

Impairments within all AOAs were calculated as a percentage of total hydrography. Therefore, prior to measuring impairments, the summation of waterway meters and waterbody square meters must be calculated. The hydrographic statistics of AOAs were derived using the USGS National Hydrography Dataset (NHD) in high-resolution 1:24,000 scale. State CWA documents and GIS coverages were then employed to attribute the NHD features as impaired.

For this study, water impairments were not defined exclusively by CWA Section 303(d) waters. A thorough review of state 303(d) lists, 305(b) reports, and Integrated Reports were also used to assess impairments for this study. Under CWA Section 305(b), waters that are in categories 4a, 4b, and 4c are also failing in compliance to WQS. Therefore, this study included impairments that expand beyond the scope of CWA Section 303(d) (also known as category 5 of Section 305(b)). A description of all 305(b) categories used to assess water impairments for this study (as shown on the National Park Service Hydrographic and Impairment Statistics website [http://www.nature.nps.gov/water/HIS/index.cfm](http://www.nature.nps.gov/water/HIS/index.cfm)) is available in *table 2* below.

*Table 2. Description of all 305(b) categories used to assess water impairments for this study (as shown on the National Park Service Hydrographic and Impairment Statistics website).*

| | |
|---|---|
| ***Category 4a*** | *Waters within category 4a have USEPA approved TMDLs established for all applicable WQS. The USEPA advises that all approved TMDLs should be implemented as soon as practicable to ensure the attainment of WQS within the projected time stipulated in the TMDL.* |
| ***Category 4b*** | *Waters within category 4b require "other pollution control" to be set forth by the State rather than the development of a TMDL to attain all applicable WQS. States must demonstrate that best management practices can be applied to address all major pollutant sources and achieve WQS within a reasonable timeframe.* |
| ***Category 4c*** | *Waters within category 4c do not require the establishment of a TMDL because the impairment is not caused by a pollutant. Category 4c waters are impaired due to the presence of pollution, which is defined by the Clean Water Act as "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water" (Section 502(19)). Pollution occasioned by pollutants (and vice versa) does require the development of a TMDL to address the underlying pollutants. Examples of pollution that do not involve pollutants may include flow alterations and elevated temperatures.* |
| ***Category 5*** | *Only waters within category 5 are included in State 303(d) lists. These waters are impaired and do not meet specified designated uses due to the presence of one or more pollutants. Waters remain in category 5 until all violations of WQS and designated uses are addressed by a USEPA approved TMDL and/or some other delisting factor stipulated by the USEPA occurs.* |

The onus for meeting CWA reporting requirements falls to individual state management agencies. However, the time of reporting inevitably varies by state, which prevents a consistent temporal snapshot of water quality. Therefore, *table A4-1* of appendix IV depicts the status and cycle year for each state CWA report/dataset used for this study.

Baseline hydrographic statistics were calculated by including only waterways and waterbodies that intersect the AOA (*tableA5- 1* of appendix V). Quantification of impairments was also clipped to the extent of AOA. The percent of impairments was calculated by dividing the amount of impaired waters by the baseline hydrographic statistics. Detailed processing methods are located in appendix IX. Results of percent impairments are located in *table 3* below. Figure 2 illustrates all AOAs in this study and their respective impairment status.

*Table 3. Percent impaired waterways and waterbodies for AOAs containing impairments.*

| Park Unit | Park Name | % Impaired Waterways | % Impaired Waterbodies |
|---|---|---|---|
| BIHO | Big Hole National Battlefield | 12.936 | 2.229 |
| CIRO | City of Rocks National Reserve | 24.630 | 2.225 |
| CRLA | Crater Lake National Park | 8.483 | 0.000 |
| CRMO | Craters of the Moon National Monument | 22.848 | 1.450 |
| EBLA | Ebey's Landing National Historical Reserve | 6.362 | 2.842 |
| EUON | Eugene O'Neill National Historic Site | 0.002 | 0.000 |
| FOPO | Fort Point National Historic Site | 19.310 | 0.000 |
| FOVA | Fort Vancouver National Historic Site | 50.387 | 15.123 |
| GOGA | Golden Gate National Recreation Area | 9.584 | 28.996 |
| HAFO | Hagerman Fossil Beds National Monument | 35.387 | 11.712 |
| JODA | John Day Fossil Beds National Monument | 5.563 | 0.000 |
| JOTR | Joshua Tree National Park | 0.181 | 0.000 |
| LABE | Lava Beds National Monument | 63.353 | 99.677 |
| LAME | Lake Mead National Recreation Area | 1.184 | 2.405 |
| LARO | Lake Roosevelt National Recreation Area | 0.777 | 1.402 |
| LEWI | Lewis and Clark National Historical Park | 15.767 | 35.976 |
| MCHO | McLoughlin House National Historical Site | 76.927 | 0.000 |
| MIIN | Minidoka Internment National Monument | 17.690 | 5.574 |
| MORA | Mount Rainier National Park | 0.331 | 0.714 |
| NEPE | Nez Perce National Historical Park | 13.439 | 0.061 |
| NOCA | North Cascades National Park | 0.082 | 0.000 |
| OLYM | Olympic National Park | 1.609 | 2.485 |
| PORE | Point Reyes National Seashore | 6.968 | 0.000 |
| PRSF | Presidio of San Francisco | 0.244 | 0.000 |
| REDW | Redwood National Park and State Parks | 36.100 | 0.000 |
| ROLA | Ross Lake National Recreation Area | 0.331 | 0.000 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 0.978 | 0.000 |
| SAFR | San Francisco Maritime National Historical Park | 19.310 | 0.000 |
| SAJH | San Juan Island National Historical Park | 14.628 | 0.861 |
| SAMO | Santa Monica Mountains National Recreation Area | 15.130 | 20.778 |
| WHIS | Whiskeytown National Recreation Area | 5.618 | 6.127 |
| WHMI | Whitman Mission National Historic Site | 27.382 | 2.894 |
| YOSE | Yosemite National Park | 0.419 | 0.000 |

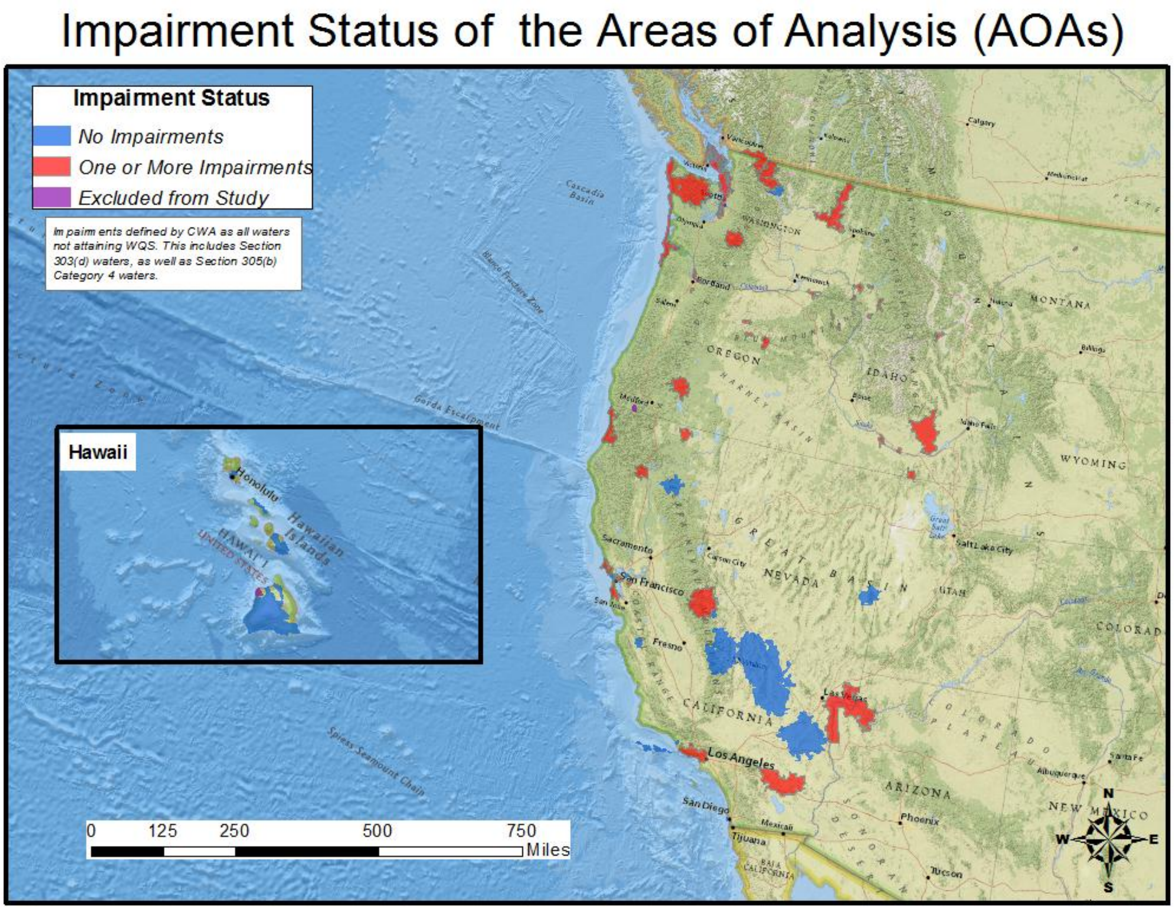


*Figure 2.Map of AOAs in this study and their impairment statuses.*

***Objective 2:*** *Determine most relevant watershed characteristics to include in this study.*

A comprehensive literature review was conducted to explore documented correlations between multiple watershed characteristics to the occurrences of impaired waters (*Figure 3*, part A). Through the Colorado State University library system (lib.colostate.edu), several scientific search engines (i.e. ScienceDirect, CAB Archives, Web of Science, Water Resources Abstracts, etc) were employed to query publications pertinent to this study. Specific keywords (i.e. TMDL, Clean Water Act, 303(d), Water Quality Standards, etc) were used to query pertinent journal articles. Several papers were reviewed in a wide array of scientific journals such as Biological Conservation, Chemosphere, Environmental Science & Policy, Agricultural Water Management, Journal of Hydrologic Engineering, Water Research, Journal of Environmental Management, etc.

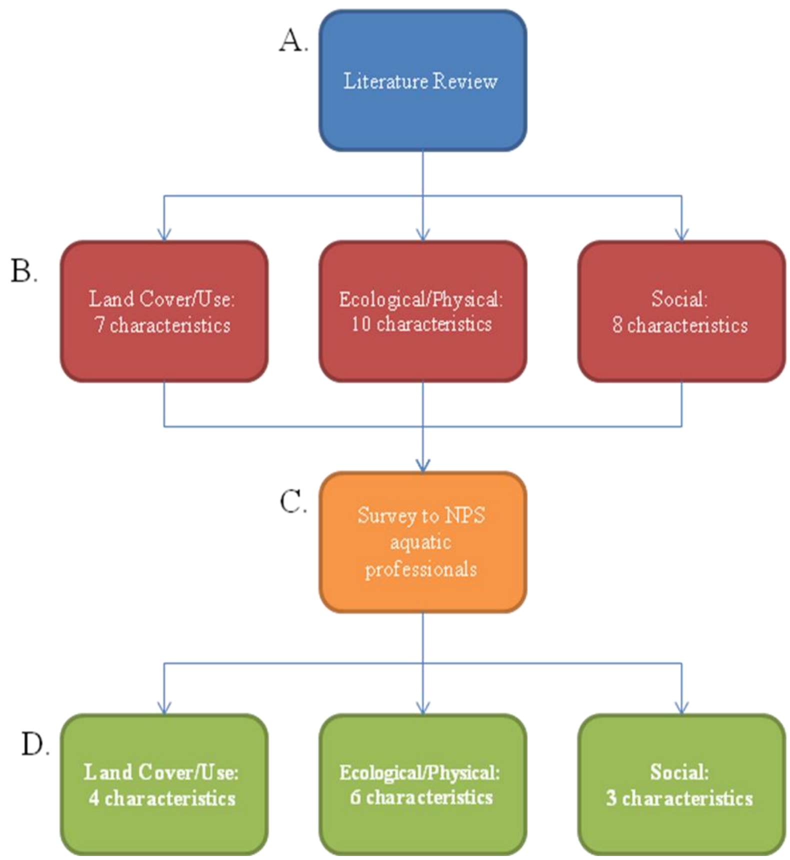


*Figure 3. Conceptual flowchart of methodologies for objective 2*

The result of the literature review was a list of watershed characteristics that are relevant to the occurrence of impaired waters (*table 1*in Literature Review section). This list was initially refined based on the amount of supporting evidence for each watershed characteristic. For example, there have been many published studies that focused on the implications of local agriculture on water quality. On the contrary, publications that document the relationship between the geometric shape of a watershed and water quality are scarce. Therefore, the initial list of watershed characteristics was inclusive of only characteristics that were deemed most prevalent in the literature review (*figure 3*, part B).

The initial list consisted of 25 watershed characteristics (*table 1*in Literature Review section). These characteristics were further assorted into three categories: (1) land cover/use, (2) ecological/physical, and (3) social. In order to reduce the complexity of this study, an additional filter was employed to reduce the number of watershed characteristics of interest to this study. A survey was administered in order to gather professional opinions regarding the predictive power of the 25 watershed characteristics to the occurrence and non-occurrence of impaired waters (*figure 3*, part C). The targeted audience consisted of aquatic professionals within and/or affiliated with the NPS. Recipients were selected from the NPS Wetnet Listserv (a listerv that allows NPS water professionals to broadcast news and reports to other like members) and attendees of the 2010 NPS Aquatic Professional Meeting in Fort Collins, Colorado.

The survey was designed to be completely anonymous and respondents were not required to answer each question. The survey was submitted and approved by the Colorado State University Institutional Review Board (IRB) on February 14, 2011. The letter of exemption from IRB can be found in appendix VI.

The survey was administered through Survey Monkey (an online interactive survey tool; www.surveymonkey.com). A copy of the survey can be found in the appendix VI. Recipients of the survey were asked to rate each watershed characteristic's ability to predict the occurrence/non-occurrence of impaired waters using a relative scale (i.e. Very Poor = 1, Poor = 2, Moderate = 3, Good = 4, Very Good = 5, Not Applicable = 0). Of the 236 e-mail addresses selected to partake in this survey, 9 e-mail addresses were retired (no longer existing on the NPS e-mail directory) and 17 e-mail addresses produced an automatic "out of office" reply. The first e-mail to solicit participation was sent on February 22, 2011. A reminder e-mail was sent approximately two weeks after the initial e-mail on March 8, 2011. The survey was closed on March 25, 2011 with 86 total respondents (≈ 38% response rate).

Ratings for each watershed characteristic were averaged. *Tables A7-1* thru *A7-6* in appendix VII showcase the results of the survey in both average rating and count responses. The average ratings were used in a preliminary analysis to observe watershed characteristics with high predictive power. However, statistical analyses of the survey results only utilized count responses. A two-way ANOVA multiple comparison with tukey adjustment analysis was used to compare watershed characteristics within each of the three categories. R v2.12.0 statistical program (http://www.r-project.org/) was used to execute the ANOVA analyses. An input text file was created for each category to reflect the count responses. Each watershed characteristic within a category was given a unique group letter. Scores for each watershed characteristic were assigned based on the count responses. For example, table 4 below illustrates the format of the input data for a characteristic with 2 counts of Very Poor, 1-Poor, 3-Moderate, 2-Good, 1-Very Good, and 1-N/A.

*Table 4. Input data format of survey results into R-Statistical program.*

| Group | Score |
|---|---|
| A | 1 |
| A | 1 |
| A | 2 |
| A | 3 |
| A | 3 |
| A | 3 |
| A | 4 |
| A | 4 |
| A | 5 |
| A | 0 |

The input data for each of the three categories were saved as individual text files and read into the R statistical program. R-program code (*code 1* of appendix III) was used to produce groupings of the characteristics that are significantly different from others. A table for each category was also produced to delineate significant differences (95% confidence level) in each ANOVA analysis.

Results from the two-way ANOVA multiple comparison analyses with tukey adjustment ($\alpha = 0.05$) are presented in the *tables 5-7* below. Means with the same letter in the tukey groupings were not significantly different.

*Table 5. Results of two-way ANOVA with tukey adjustment for Land Cover/Use Characteristics.*

| Tukey Grouping | | Means | # of Responses | Watershed Characteristic |
|---|---|---|---|---|
| | A | 4.1548 | 84 | Percent Urban Development |
| | A | 4.0833 | 84 | Percent Impervious Surface |
| B | A | 3.9405 | 84 | Percent Agriculture |
| B | A | 3.8214 | 84 | Percent Forest |
| B | | 3.5181 | 83 | Residential Unit Density |
| B | | 3.5122 | 82 | Corridor/Road Density |
| B | | 3.4881 | 84 | Percent Protected Lands |

*Table 6. Results of two-way ANOVA with tukey adjustment for Ecological/Physical Characteristics.*

| Tukey Grouping | | Means | # of Responses | Watershed Characteristic |
|---|---|---|---|---|
| | A | 4.0723 | 83 | Biotic Integrity |
| | B | 3.4167 | 84 | Bank Stability/Soil Types |
| | B | 3.241 | 83 | Channelization |
| C | B | 2.9375 | 80 | Watershed Size |
| C | B | 2.9286 | 84 | Presence of Rare Taxa |
| C | B | 2.9036 | 83 | Topography (i.e. elevation & slope) |
| C | | 2.6747 | 83 | Amount of Hydrography |
| C | | 2.6747 | 83 | Stream Order |
| C | | 2.6024 | 83 | Presence of Endangered/Threatened Species |
| C | | 2.4881 | 84 | Climatic Variations |

*Table 7. Results of two-way ANOVA with tukey adjustment for Social Characteristics.*

| Tukey Grouping | | Means | # of Responses | Watershed Characteristic |
|---|---|---|---|---|
| | A | 3.9643 | 84 | Legacy Land Use Effects |
| | A | 3.869 | 84 | Hydrological Alterations (i.e. dams, withdrawals) |
| | A | 3.5122 | 82 | Number of NPDES Permits |
| B | | 2.8313 | 83 | Landownership Complexity |
| B | | 2.7738 | 84 | Recreational Opportunities |
| B | | 2.5904 | 83 | Jurisdictional Complexity |
| B | | 2.5833 | 84 | Socioeconomic Stress |
| B | | 2.5301 | 83 | Watershed Organizational Groups |

The results of the ANOVA analyses were used to further refine the number of watershed characteristics that are included in the pilot study. Watershed characteristics in tukey groupings with high means were selected as characteristics of interest. Therefore, the initial list of 25 watershed characteristics was reduced to 13 for this study (*table 8*; *figure 3*, part D).

*Table 8. List of watershed characteristics of interest to this study after results of survey.*

| **Land Cover/Use** | **Ecological/Physical** | **Social** |
|---|---|---|
| Percent Urban Development | Biotic Integrity | Legacy Land Use Effects |
| Percent Impervious Surface | Bank Stability/Soil Types | Hydrological Alterations |
| Percent Agriculture | Channelization | Number of NPDES Permits |
| Percent Forest | Watershed Size | |
| | Presence of Rare Taxa | |
| | Topography | |

***Objective 3:*** *Compile datasets and reports that reflect watershed characteristics of interest to this study.*

Several sources were compiled for analyses. This section will identify the datasets used to represent the watershed characteristics of interest to this study. Metadata, general descriptions, and other pertinent information are located in appendix IV.

There were three general caveats developed during the data collection procedures. First, emphasis was placed on datasets that were geospatial. Data that were not georeferenced (i.e. exclusively tabular) were excluded from this study. Second, this study had to rely on the best information available. Essentially, data cannot be collected for every watershed characteristic due to lack of availability. Consequently, those characteristics were eliminated from analyses. Finally, certain watershed characteristics were excluded from the study due to scale effects. For example, Biotic Integrity and Presence of Rare Taxa were excluded from the study because the best data available were depicted in the HUC 8 scale. Consequently the difference in scales compared to the AOAs may cause erroneous results. In addition, Bank Stability/Soil Types were also excluded from the study because their effects are more relevant within riparian corridors. Therefore, their influence on impaired waters may not be detected at the assigned AOA scale. A comprehensive summary of the data collected for this study is provided in appendix IV (i.e. data used for determining AOAs, CWA impairments, and the three watershed characteristic groupings).

Datasets for Land Cover/Use Watershed Characteristics

Figure 4 identifies the datasets chosen to represent land cover/use watershed characteristics. Percent urban development, agriculture, and forest are calculated based on the National Land Cover Dataset (NLCD 2006). Percent impervious surface measurements are derived from the National Park Service NPScape dataset. A comprehensive summary of each dataset is available in appendix IV.

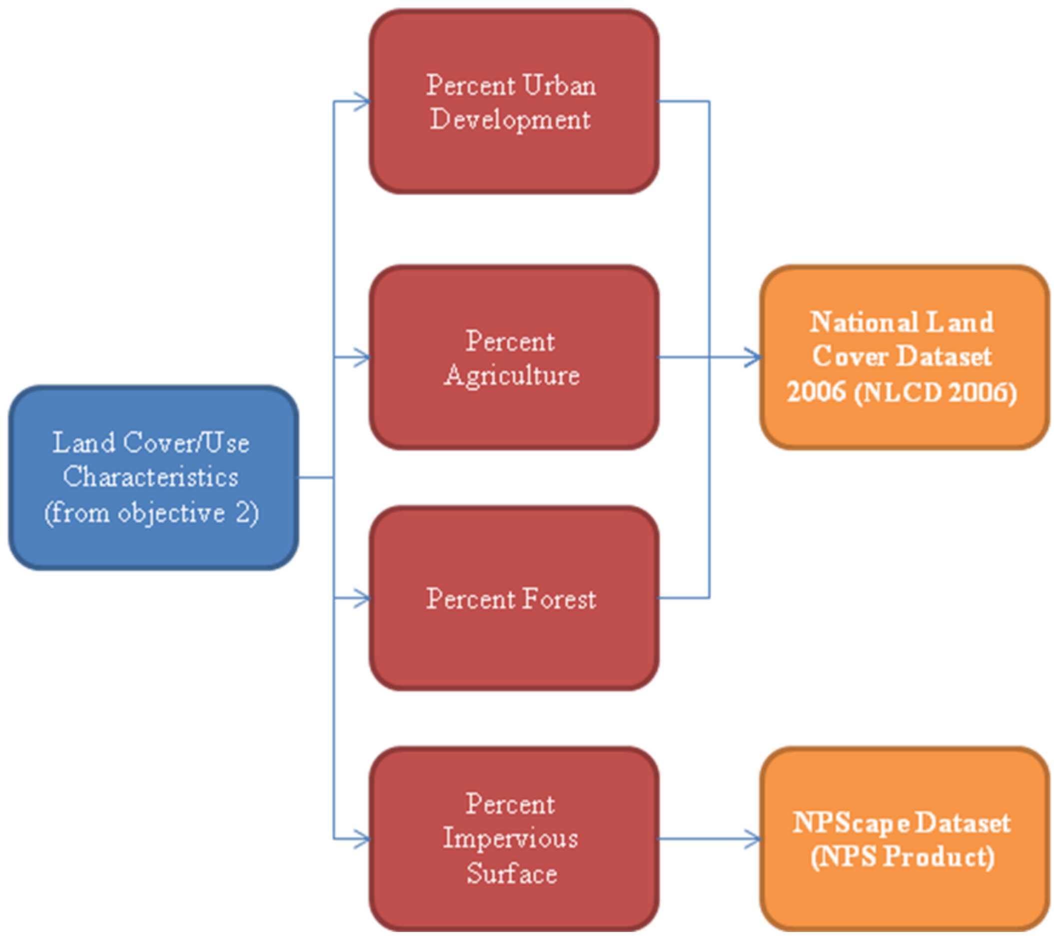


*Figure 4. Dataset chosen for each land cover/use watershed characteristic.*

Datasets for Ecological/Physical Watershed Characteristics

Figure 5 identifies the datasets chosen to represent ecological/physical watershed characteristics. Biotic integrity, presence of rare taxa, bank stability/soil types, and channelization were eliminated from this study due to either data availability or scale-dependent issues. The NRCS Watershed Boundary Dataset was used to calculate watershed size. Slope and elevation were derived using LANDFIRE EDNA dataset. Finally, the amount of hydrography was calculated using USGS NHD. A comprehensive summary of each dataset and the exclusion of specific watershed characteristics are detailed in appendix IV.

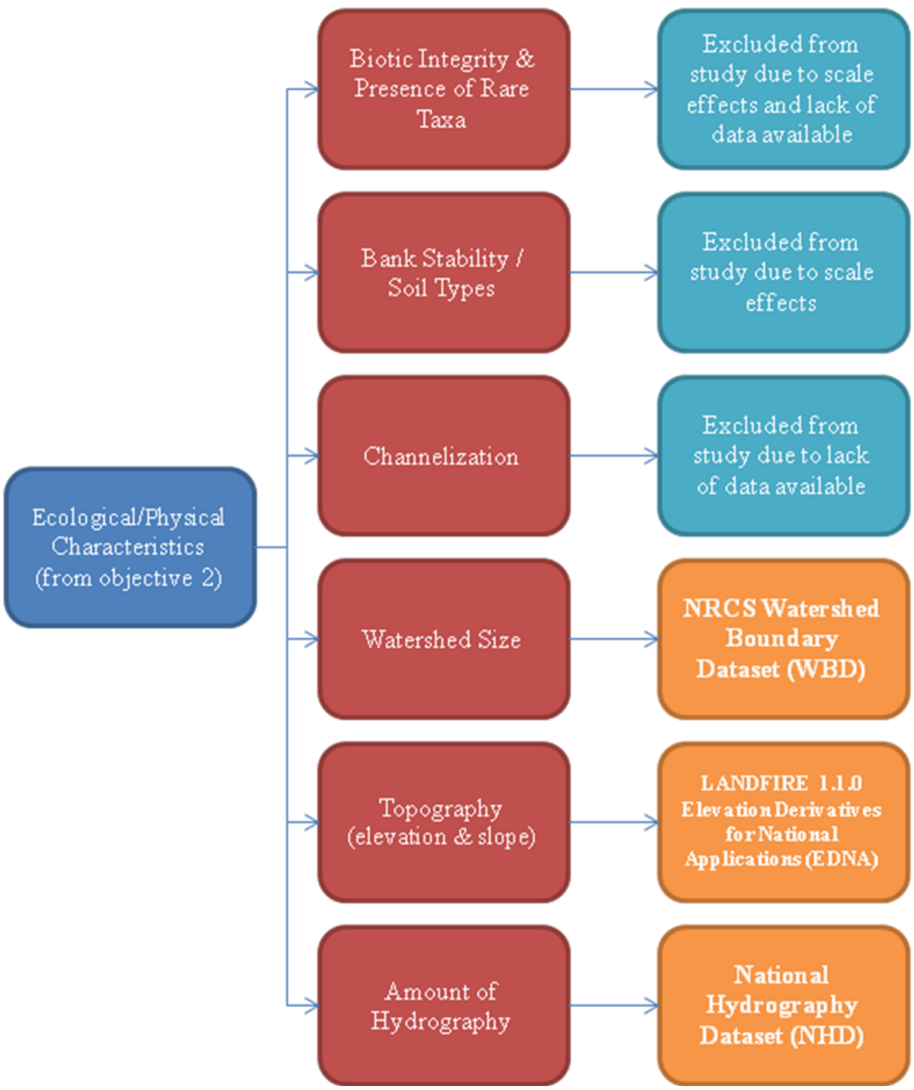


*Figure 5. Dataset chosen for each ecological/physical watershed characteristic.*

Datasets for Social Watershed Characteristics

Figure 6 identifies the datasets chosen to represent social watershed characteristics. Legacy land use effects were excluded from the study due to lack of data. The National Inventory of Dams (NID) was selected to represent the number of dams within a watershed (as part of hydrological alterations). The number of NPDES permits within a watershed was derived using EPA's GeoData Shape, which includes point location of NPDES permits. A comprehensive summary of each dataset and the exclusion of specific watershed characteristics are detailed in appendix IV.

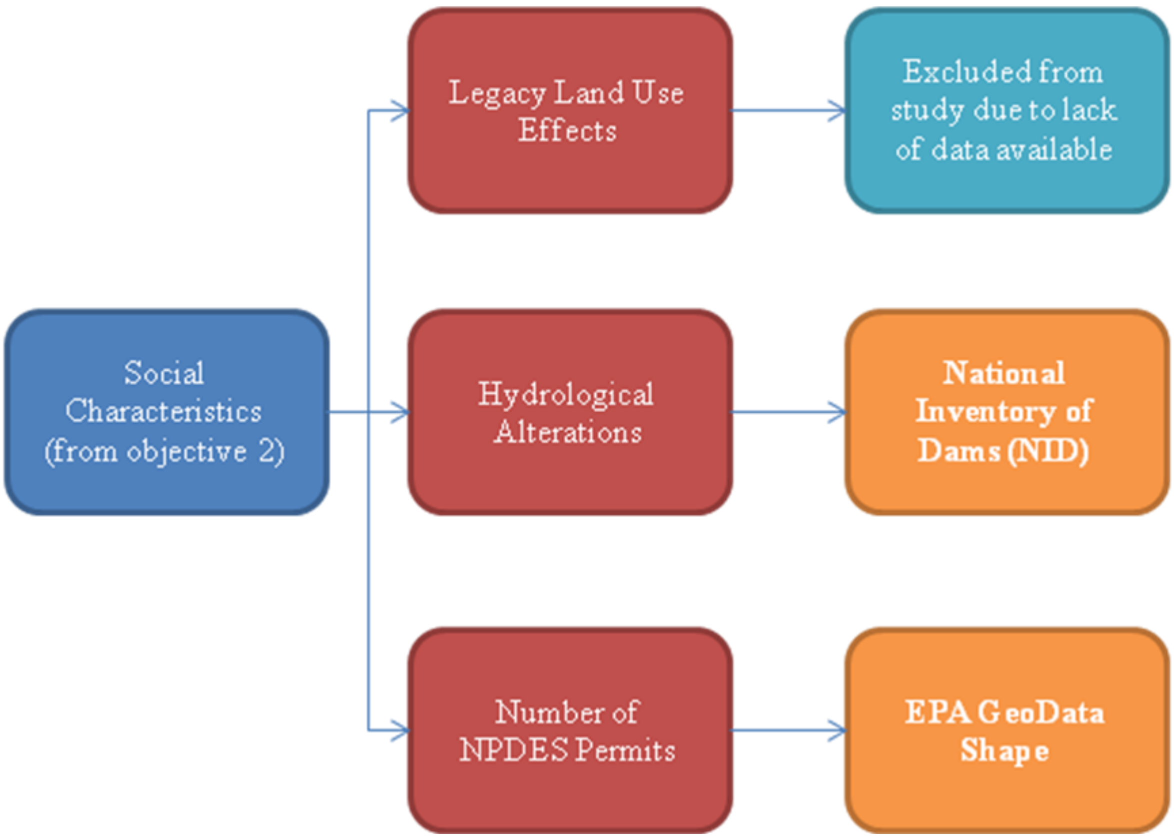


*Figure 6. Dataset chosen for each social watershed characteristic.*

***Objective 4:*** *Quantify watershed characteristics in all AOAs and assess correlation to impairments.*

This section provides a summary of the intensive processing steps required to quantify each watershed characteristic (*figure 7*, part A), as well as an overview of the statistical methods employed for this study (*figure 7*, part B). A comprehensive report of all processing methods for this objective is located in appendix IX.

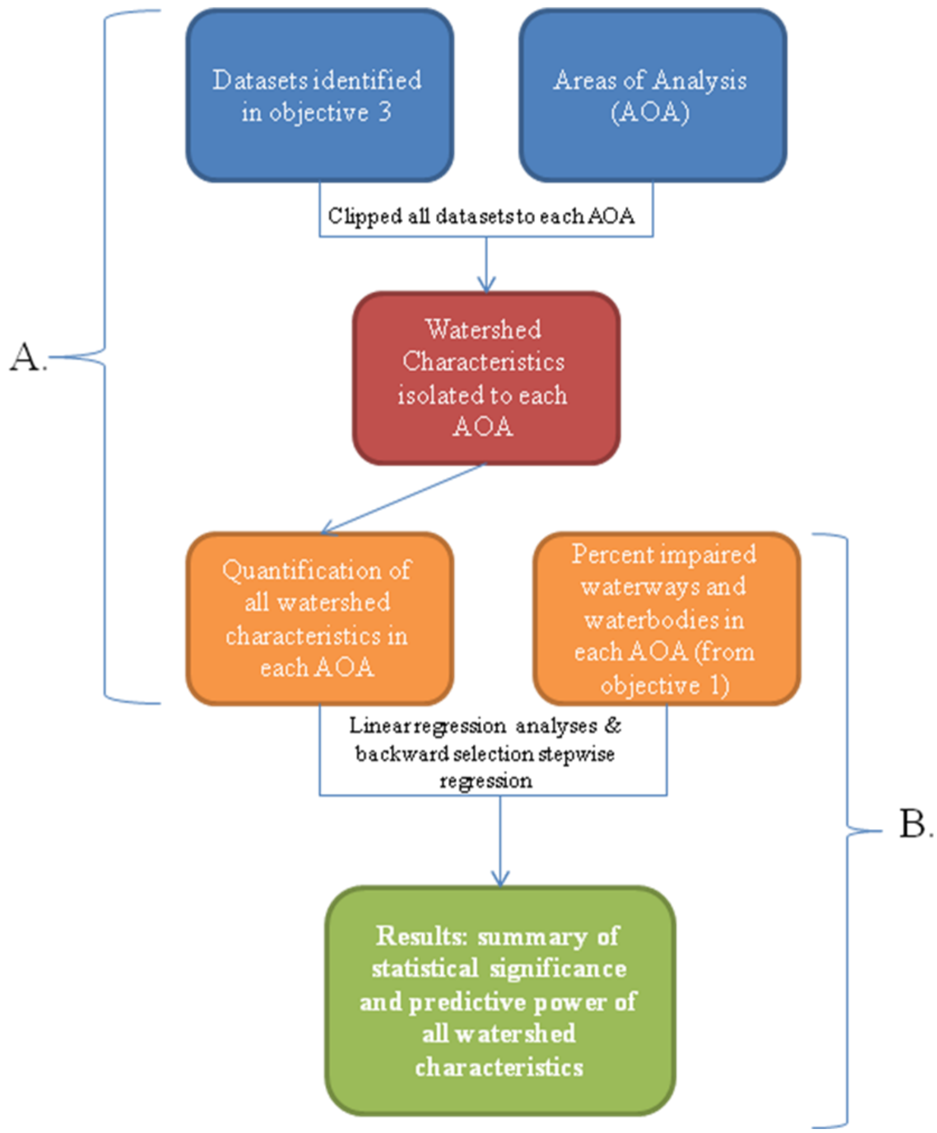


*Figure 7. Conceptual flowchart of methodologies for objective 4.*

Processing Methods for Data Collected

Several datasets were identified through the 3rd objective of this study. Datasets that represent the watershed characteristics were clipped to AOAs using ArcGIS geoprocessing tools. Comprehensive details of processing methods are located in appendix IX (under heading Objective 4). A combination of raster and vector datasets was used in this study. Information from raster datasets were derived using the value attribute table directly. Data collected from vector datasets were extracted by using either *calculate geometry* or count statistics in the attribute table. All data collected in this study are presented in tables located in appendix V.

**Statistical Analysis**

Linear regression analyses were used to study the correlation between each watershed characteristic of interest to impaired waters. In this study, impaired waters were defined by CWA as all waters not attaining WQS (this includes Sections 303(d) waters and Section 305(b) Category 4 waters). Each watershed characteristic was regressed against the percentage of impaired waterways and percent of impaired waterbodies to assess the degree of correlation. Twenty-two linear regression analyses were performed (11 watershed characteristics & 2 types of impairment quantifications) in this study.

Statistical analyses were computed using the R (v. 2.12.0) statistical programming platform. Inputs for analyses were organized based on watershed characteristic categories (land cover/use, ecological/physical, and social) and impairment types (waterway and waterbody). Compiled inputs were saved as comma-separated values (.csv) files. R-programming codes were employed to calculate the correlation and statistical significance of each watershed characteristic to percent impaired waterways and waterbodies (*codes 2-7* of appendix III).

Finally, stepwise regression analyses were performed for all watershed characteristics against percent impaired waterways and waterbodies. The two stepwise regression models used backward selection based on minimizing the Akaike's Information Criterion (AIC) value (an index that estimates the relative goodness of fit of a model; AIC is used for model selection when there are several parameters and a model is chosen based on minimizing the number of parameters while still achieving a specific degree of fit). *Codes 8 and 9* of appendix III was used to evaluate AIC values for various models within the backward selection process and to derive a final model that minimizes the number of parameters without compromising the fit of the model.

# RESULTS & DISCUSSION

The two most informative components of the results from the linear regression analyses were the correlation coefficient and the p-value.

(1) The correlation coefficient, specifically the sign, is indicative of the type of relationship that may exist between the watershed characteristic and the occurrence of impaired waters. For example, a negative correlation is observed in the linear regression analysis of forest land cover to impaired waterways (Norton & Fisher, 2000). This relationship (more forest, less impairment) is well documented in the literature review. The correlation coefficient ranges between +1 and -1. +/-1 implies the strongest positive/negative relationship between watershed characteristic and impaired waters. A correlation coefficient that is close to zero implies a weak relationship (0 = no relationship).

(2) The p-value is used to assess whether the watershed characteristic has a significant effect on impaired waters. The p-value is often used to test the null hypothesis ($H_o$ = watershed characteristic has no effect on impaired waters) at varying alpha levels. Lower p-values imply a more significant impact than higher p-values. In this study, p-values are estimates because they were derived using a non-rigorous sampling scheme. P-values are inherently more significant when calculated from a true probability sampling scheme. In this study, the p-values were calculated based on various established datasets. Therefore, the p-values are affected by errors propagated from the data sources and should not be regarded as p-values derived from a probability sampling scheme (i.e. interpretations of p-values from this study should be given less weight than p-values calculated from random sampling).

Results of each linear regression analysis are organized based on watershed characteristic of interest located in appendix VIII. Each analysis attempts to test the null hypothesis that each watershed characteristic has no significant impact on the occurrence or non-occurrence of impaired waters. Only significant findings are presented in this section.

Finally, the stepwise regression models are detailed in appendix VIII. Watershed characteristics were eliminated using the backward selection method based on minimizing the AIC value. The stepwise regression attempts to include the most relevant parameters in the model without compromising a significant amount of fit. The watershed characteristics retained in the final model post-selection process represent critical indicators of impaired waters in this study.

**Significant Findings**

Watershed characteristics excluded from this section did not produce any significant results and failed to reject their respective null hypotheses. The results of the impaired waterways analyses concluded significant p-values (alpha = 0.10) for the following watershed characteristics: average slope, total waterways, agricultural land cover, and forest land cover (*table 9)*. Average slope was the only significant watershed characteristic in the impaired waterbodies analyses at alpha = 0.10 level (*table 9)*. Finally, average slope and agricultural land cover were the only watershed characteristics included in the final models of both waterways and waterbodies stepwise regression analyses.

*Table 9. P-Values of all linear regression analyses of watershed characteristics to percent impaired waterways and waterbodies.*

| | | **% Impaired Waterways** | **% Impaired Waterbodies** |
|---|---|---|---|
| **Ecological / Pyhsical** | HUC 12 Area | 0.117 | 0.550 |
| | HUC 10 Area | 0.282 | 0.636 |
| | Average Elevation | 0.163 | 0.730 |
| | Average Slope | **0.004** | **0.067** |
| | Total Waterways / Waterbodies | **0.056** | 0.856 |
| **Land Cover/ Land Use** | Impervious Surface | 0.700 | 0.801 |
| | Urban Development | 0.193 | 0.847 |
| | Agriculture | **<0.001** | 0.311 |
| | Forest | **0.012** | 0.302 |
| **Social** | Dams | 0.695 | 0.457 |
| | NPDES Permits | 0.807 | 0.192 |

*__Bolded__ values were significant at $\alpha = 0.10$.

*Table 10. Correlation coefficients of all linear regression analyses of watershed characteristics to percent impaired waterways and waterbodies.*

| | | **% Impaired Waterways** | **% Impaired Waterbodies** |
|---|---|---|---|
| **Ecological / Pyhsical** | HUC 12 Area | -0.218 | -0.084 |
| | HUC 10 Area | -0.150 | -0.067 |
| | Average Elevation | -0.194 | -0.049 |
| | Average Slope | -0.394 | -0.254 |
| | Total Waterways / Waterbodies | -0.237 | -0.026 |
| **Land Cover/ Land Use** | Impervious Surface | 0.054 | -0.036 |
| | Urban Development | 0.182 | 0.027 |
| | Agriculture | 0.496 | 0.142 |
| | Forest | -0.344 | -0.145 |
| **Social** | Dams | -0.055 | 0.104 |
| | NPDES Permits | 0.034 | 0.182 |

***Average Slope (degrees) vs. Percent Impaired Waterways & Waterbodies***

The results of the linear regression analyses reject the null hypothesis that average slope has no effect on percent impaired waters. The effects of average slope may also interact with average elevation, land cover charactistics, and other confounding variables. In addition, watersheds with high slopes may have less development, which may reduce the exposure to pollutants and preserve the natural water quality. This relationship was accentuated by the negative correlation coefficients produced by the analyses (*table 10)*. Although the correlation coefficients were weak, the p-values produced from the regression analyses suggested that average slope may have significant impact on the percent of impaired waters in a watershed.

***Total Waterways vs. Percent Impaired Waterways***

The results of the waterway analysis reject the null hypothesis that total waterways have no effect on percent impaired waters. The negative correlation coefficient corresponds to the discussion pertaining to the dilution effect in the literature review (*table 10)*. Simply, a watershed with more hydrography is more capable of diluting pollutants. Therefore, concentration of pollutants may be reduced.

The various classifications of hydrography (i.e. perennial, intermittent, and ephemeral) were not considered in this study. This may have introduced a significant amount of error when attempting to measure the amount of hydrography within a watershed. Arid environments may have several miles of intermittent or ephemeral streams that were essentially given the same weight as perennial streams in this study (concept is also applied to waterbodies). Furthermore, since the NHD was produced based on a snapshot in time, hydrographic features may exist but were not accounted for in this measuremnt of total hydrography. Therefore, the results of the total waterways and waterbodies analyses may contain additional error.

***Percent Agricultural Land Cover vs. Percent Impaired Waterways***

The results of the waterway analysis rejected the null hypothesis that agricultural land cover has no effect on percent impaired waterways. Most notably, the coefficient correlation of approximately 0.5 (*table 10)* suggests that agricultural land cover may be an important indicator of impaired waters for all watersheds intersecting parks within the Pacific West Region of the National Park Service. Unlike the effects of urban development and impervious surface (where effects should be most evident in developed areas), the moderate correlation coefficient suggests that the effects of agricultural land cover may not be restricted to a specific landscape or ecosystem type. The correlation coefficient corresponds to the p-value, which also suggests that agricultural land cover has significant impacts on percent impaired waterways.

***Percent Forest Land Cover vs. Percent Impaired Waterways***

The results of waterway analysis rejected the null hypothesis that forest land cover has no effect on percent impaired waterways. The negative correlation coefficient suggests that increased forest land cover may reduce water impairments (*table 10)*. The effects of forest land cover may be collinear with other land cover variables in this study. Although the correlation coefficient is moderately weak, when performing a study that spans across several landscapes, a correlation coefficient of -0.344 may still be important. Relative to most other watershed characteristics of interest in this study, a correlation coefficient of -0.344 warrants more research in exploring the relationship between forest land cover and impairments.

***Backward Stepwise Regression Model for Percent Impaired Waterways***

The results of the stepwise regression analyses indicate that average slope and agricultural land cover were the two most important predictors of impaired waters in this study. The order of elimination during the selection process does not reflect the relative predictive power of each watershed characteristic. However, the remaining watershed characteristics in the final model do imply that average slope and agricultural land cover were the two strongest predictor for impairments in this study.

The stepwise regression models were used in order to account for a small degree of multicollinearity (typically if variables are collinear, significant variables may be eliminated because another collinear variable may explain similar variability in the impairment data).

Although each watershed characteristic was study singularly in the linear regression analyses, many have interactive effects with one another. Therefore, variations explained by one watershed characteristic may also be similar to another watershed characteristic. However, in order to truly assess interaction of these watershed characteristics, several interactive variables would have to be included in the stepwise regression analyses. In addition, some synergistic effects may be more influential than others, thus making interactive variables more difficult to assess. Since the varying levels of interactions cannot be standardized, interactive variables were not included in the stepwise regression analyses.

By using the backward selection method, watershed characteristics were eliminated because variation in impairments can be explained by remaining characteristics without compromising significant fit. For example, there is an evident positive relationship between impervious surface and urban land cover. In steps 7 and 8 in both stepwise regression analyses (pg 146 & 147), impervious surface was eliminated from the model while urban development was retained. Although both watershed characteristics may be important indicators, when coupled in the same model, urban development may also account for the effects of impervious surface. Therefore, in order to minimize the number of watershed characteristics in the model, impervious surface was excluded in step 7. Although the two characteristics were considered simultaneously, an interactive variable would be required to evaluate the significance of their interaction. Consequently, a comprehensive look at the effects of multicollinearity was not included in the stepwise regression analyses.

***Diagnostic Plots of Linear Regression Analyses***

Diagnostic plots were generated for each linear regression analysis. They are located in appendix VIII with a complete synopsis of all results for each statistical analysis from this study.

*Figure 8* is an example of the diagnostic plots produced using the R-program code in appendix III (*codes 2-7*). Similar to all other analyses in this study, the diagnostic plot showcased several abnormalities. First, the residual vs. fitted plot indicates that the residuals are high and suggests a non-linear relationship. As expected with most watershed characteristics, their relationships with water impairments are unlikely to be linear and simple. Therefore, transformation of the data may be necessary if using linear regression analysis to detect significance.

The Scale-Location plot in *figure 8* demonstrates non-equal variance in the data. A similar trend is evident throughout all of the linear regression analyses in this study. The erratic variances can be attributed to the nature of this study. When analyzing impairments and watershed characteristics within several AOAs that are different from one another (landscapes, ecology, urbanization, etc), unequal variance is almost inevitable.

The Normal Q-Q plot in *figure 8* showcases a non-normal distribution in the data. This is also a recurring trend throughout all of the linear regression analyses in this study. The right-skewed distribution in the Q-Q Plot may be attributed to some AOAs having more influence than others (ex. duplicate AOAs, which will be discussed in the conclusion section). This also parallels the Residuals vs. Leverage plot in *figure 8.* The Residual vs. Leverage plot shows two particular observations that are influential in the overall distribution of the data. It also indicates several outliers in the data. Therefore, according to the diagnostic plots, several improvements can be made to the data collection and statistical methods of this pilot study to improve the validity of the results.

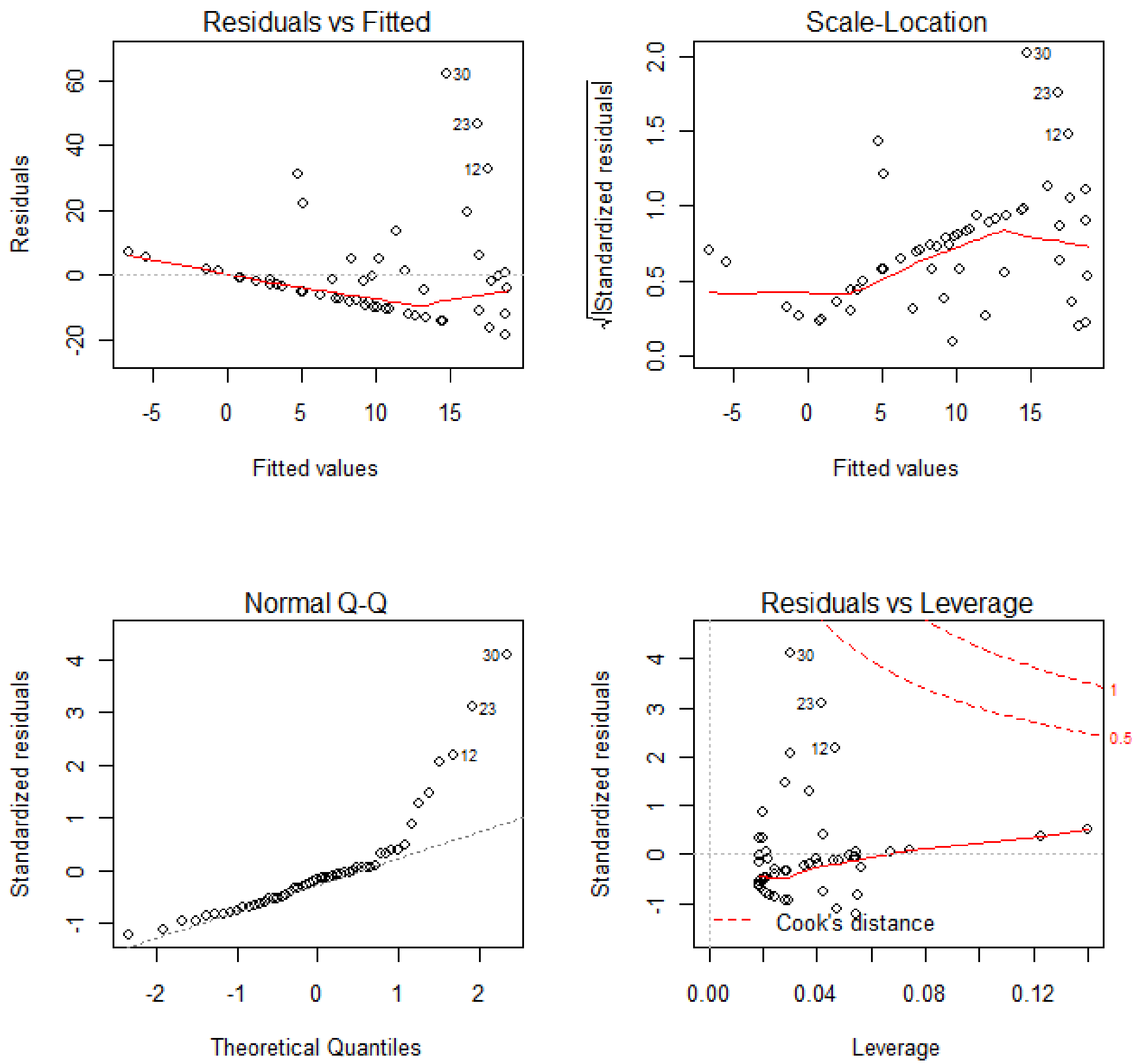


*Figure 8.Diagnostic plot of average slope vs. percent impaired waterways*

# CONCLUSION & RECOMMENDATIONS

Percent agricultural land cover and average slope have the most influence on the occurrence of impaired waters in this study. As illustrated in *table98* in the results section, p-values for percent agricultural land cover and average slope were both significant for predicting percent impaired waterways. Although p-value was insignificant for agricultural land cover in predicting percent impaired waterbodies, the correlation coefficients for both watershed characteristics were consistently high relative to other coefficients (*table 10 in the results section*). Therefore, this study concludes that agricultural land cover and slope were key indicators for predicting the occurrence of impaired waters within watersheds that intersect park units of the NPS Pacific West Region.

The results of this study will help water quality managers and stakeholders prioritize restoration efforts of impaired waters by focusing on specific watershed characteristics of high influence. As suggested by this study, water quality managers of parks within the Pacific West Region should place emphasis on surrounding agriculture and topography when assessing restoration potential. By replicating the methodologies of this study to specific areas of interest, managers can more effectively allocate funds and address impairments that are most worthy of restoration efforts. In turn, a systematic approach can be implemented for both TMDL development and implementation to maximize the attainment of WQS.

In addition, watershed characteristics of high influence may be valuable at predicting risk of WQS violations. According to the results of this study, priority should be given to monitor agricultural land cover and topography in order to evaluate risk of impairment for watersheds that intersect parks units in the Pacific West Region. Naturally, parks have a large stake in the quality of all waters that flow into their boundaries (Gavin, 2007). In order to effectively preserve pristine water quality and restore impaired waters within parks, managers are forced to participate in watershed level management. Therefore, park water quality managers are behooved to monitor/manage beyond the park level and cooperate in watershed level management with other stakeholders.

**Recommendations**

Several issues were encountered throughout the methodologies of this pilot study. The problems that emerged are listed below along with recommendations on addressing such issue.

1. **Spatial Scale-Dependence**: the initial intent of this study was to determine watershed characteristics that were important in predicting the occurrence and non-occurrence of impaired waters within park units of the Pacific West Region. However, the varying spatial scales (i.e. watershed characteristics vs. impaired waters within park units) would have most likely resulted in non-significant results (due to an under-estimation of impairments). Therefore, impairment was assessed in the watershed level in order to analyze watershed characteristics to impairments in the same spatial scale.

   **Recommendations**: some watershed characteristics were excluded from analysis due to its lack of influence in the watershed scale. In order to better assess predictors of impaired waters, we need to take into consideration the varying impacts each characteristic may have in different spatial scales. For example, soil types and bank stability are most relevant when analyzed within the riparian corridor. Therefore, data collection should be limited to within the riparian scale instead of the entire watershed.

2. **State CWA Listing Methodologies:** methods for identifying assessment units may differ between states. This may have contributed a significant amount of bias to this

study. For example, states such as Idaho and Utah identify assessment units on the watershed level. Therefore, impairment listings apply to all waters within the watershed. To the contrary, states such as California and Oregon identify assessment units based on specific reaches and locations. Therefore, their listings are more spatially precise and less liberal than Idaho and Utah. Finally, the state of Washington has adopted their own unique grid system based on sampling stations to identify assessment units. Therefore, the inconsistencies in state listing methodologies may drastically affect the assessment of impairments within this study.

**Recommendations**: there are currently no legal mandates to standardize listing methods between states. However, the USEPA has recently recommended that all states fulfill their CWA obligations by reporting on the watershed level. However, until a standardized listing methodology has been implemented, areas of analysis should be isolated based on state boundaries in order to minimize bias in impairment measurements.

3. **Temporal Variations in Data:** selected datasets used in this study represent a snapshot in time. Inevitably, some datasets may be more current than others and therefore, a temporal bias was inherent in this study. Although some watershed characteristics may not be as susceptible to change over time (ex. topographic features), other measured variables such as impairment and land cover may alter greatly in time.

   **Recommendations:** temporal variations in the data are inevitable in a study such as this one. Consequently, the only ways to limit temporal bias are to restrict the number of datasets used in a study and to ensure a small time gap between the datasets that are included in the study.

4. **Duplicate AOAs:** several park units within the Pacific West Region may share intersecting HUC 12 polygons due to their proximity to one another. A prime example of this would be the park units located in the San Francisco Bay area in California (Fort Point National Historic Site, Golden Gate National Recreation Area, Muir Woods National Monument, Point Reyes National Seashore, Presidio of San Francisco, San Francisco Maritime National Historical Park, and Rosie the Riveter / World War II Home Front National Historical Park). Consequently, the AOAs identified in this study may contain several duplicate HUC 12 polygons. Therefore, duplicate AOAs may have greater influence on the results of the analyses. **Recommendations**: duplicate HUC 12 polygons should be removed from the AOA. This may be accomplished by performing a dissolve in ArcMap on the AOA shapefiles. Similarly, a topology validation can be set up to identify overlapping polygons in ArcMap. Duplicate/overlapping AOAs need to be removed from the study to ensure each AOA has equal influence in the results of this study.
5. **Impairment Details:** as hinted in the literature review, several of the watershed characteristics examined in this study may be related to specific types of impairments. For example, agricultural runoff may precipitate in elevated levels of phosphorus and nitrogen in nearby waters. In addition, dams may hinder the natural flow of a stream, causing water temperatures to rise in reservoirs and oxygen levels to deplete. In this study, the quantification of impairments was general and did not include specific

impairment parameters. Therefore, such relationships between watershed characteristics and specific impairments were undetectable.

**Recommendations:** similar to analyzing watershed characteristics, impairments should be studied based on the different types of pollutants/pollution. This may allow the researcher to draw more concrete conclusions regarding the relationship between watershed characteristics and their associated impairments.

Similar to all pilot studies, the methodologies of this study will need to be improved upon to better understand the relationship between watershed characteristics and impaired waters. Although the methods for this pilot study can benefit greatly from some fine-tuning, the success of this study is inherent within its ability to test hypotheses and produce results. Future research may branch from this pilot study, mimic its methodologies, and/or benefit from the lessons learned in order to gain a more profound understanding of the correlation that may exists between watershed characteristics and water impairments.

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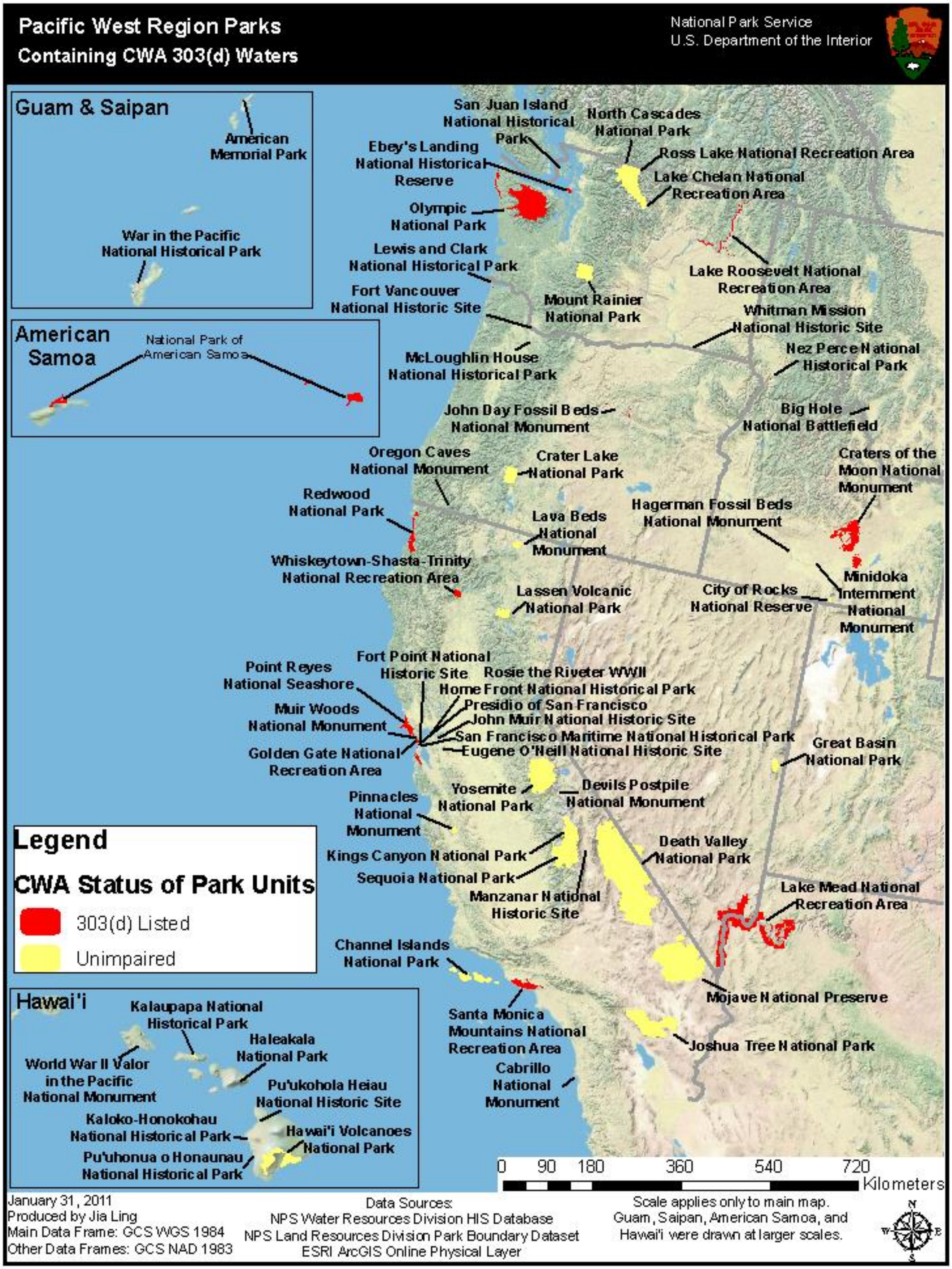
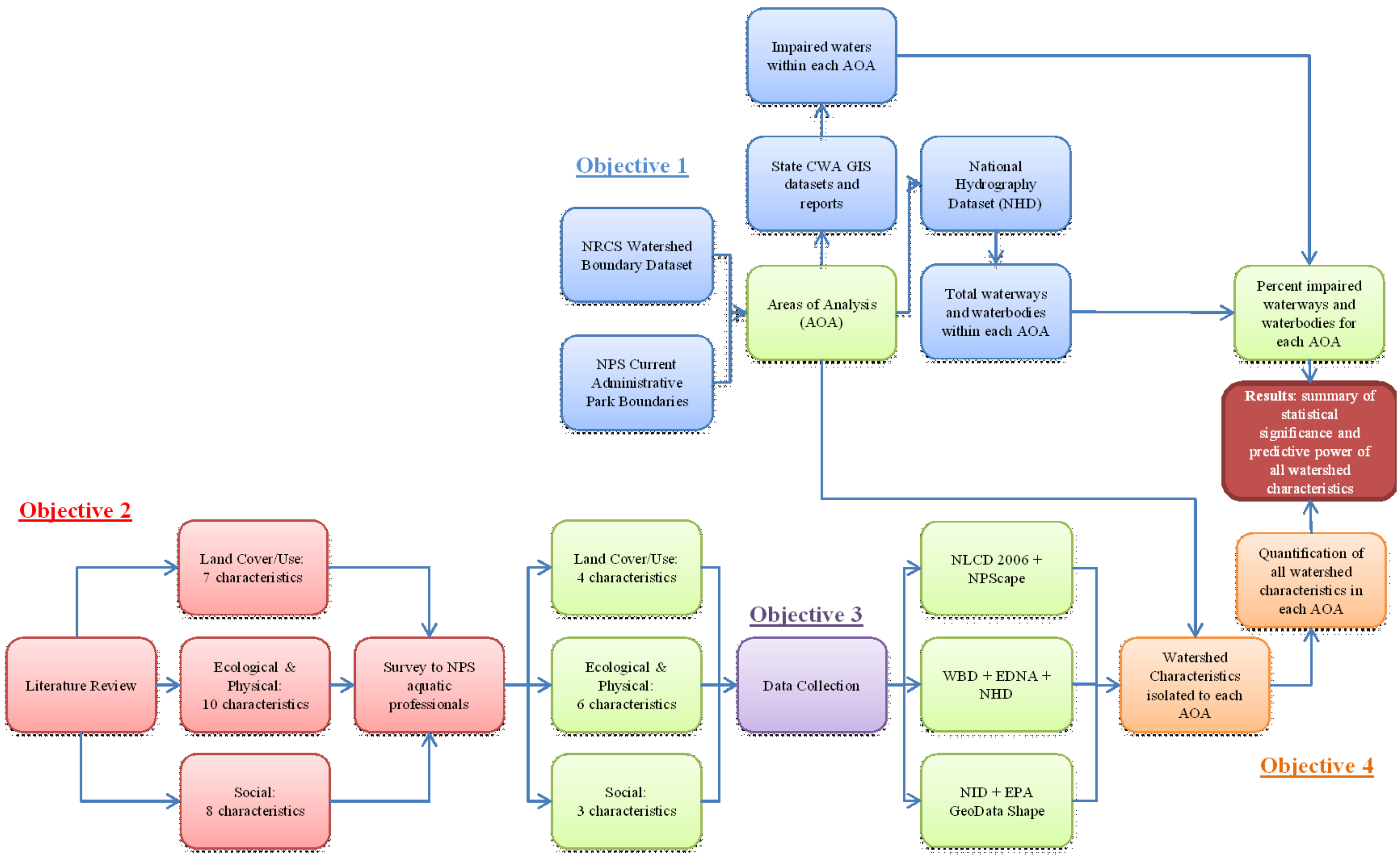
APPENDIX I: Study Site



Pacific West Region Parks
Containing CWA 303(d) Waters
National Park Service
U.S. Department of the Interior
Guam & Saipan
American Memorial Park
War in the Pacific National Historical Park
American Samoa
National Park of American Samoa
San Juan Island National Historical Park
North Cascades National Park
Ebey's Landing National Historical Reserve
Ross Lake National Recreation Area
Lake Chelan National Recreation Area
Olympic National Park
Lewis and Clark National Historical Park
Lake Roosevelt National Recreation Area
Fort Vancouver National Historic Site
Mount Rainier National Park
Whitman Mission National Historic Site
McLoughlin House National Historical Park
Nez Perce National Historical Park
John Day Fossil Beds National Monument
Big Hole National Battlefield
Oregon Caves National Monument
Crater Lake National Park
Craters of the Moon National Monument
Redwood National Park
Lava Beds National Monument
Hagerman Fossil Beds National Monument
Whiskeytown-Shasta-Trinity National Recreation Area
Minidoka Internment National Monument
Lassen Volcanic National Park
City of Rocks National Reserve
Point Reyes National Seashore
Fort Point National Historic Site
Rosie the Riveter WWII Home Front National Historical Park
Presidio of San Francisco
Muir Woods National Monument
John Muir National Historic Site
San Francisco Maritime National Historical Park
Eugene O'Neill National Historic Site
Golden Gate National Recreation Area
Great Basin National Park
Yosemite National Park
Devils Postpile National Monument
Pinnacles National Monument
Legend
CWA Status of Park Units
303(d) Listed
Unimpaired
Kings Canyon National Park
Death Valley National Park
Sequoia National Park
Manzanar National Historic Site
Lake Mead National Recreation Area
Channel Islands National Park
Mojave National Preserve
Hawai'i
Kalaupapa National Historical Park
Santa Monica Mountains National Recreation Area
Haleakala National Park
Joshua Tree National Park
World War II Valor in the Pacific National Monument
Cabrillo National Monument
Pu'ukohola Heiau National Historic Site
Kaloko-Honokohau National Historical Park
Hawai'i Volcanoes National Park
Pu'uhonua o Honaunau National Historical Park
0 90 180 360 540 720
Kilometers
January 31, 2011
Produced by Jia Ling
Main Data Frame: GCS WGS 1984
Other Data Frames: GCS NAD 1983
Data Sources:
NPS Water Resources Division HIS Database
NPS Land Resources Division Park Boundary Dataset
ESRI ArcGIS Online Physical Layer
Scale applies only to main map.
Guam, Saipan, American Samoa, and Hawai'i were drawn at larger scales.

APPENDIX II: Conceptual Flowchart of Methodologies




*Unique colors were used to highlight the methods for each objective.
(blue = objective 1, red = objective 2, purple = objective 3, orange = objective 4)
*Green was used to represent the goals for each objective.

APPENDIX III: Program Codes

*Code 1. R-program code used in ANOVA analysis for survey results.*

```
Social<-read.table("G://JL_Grad_Research//Survey//20110323_RInput_Social.txt",header=T)
Social.aov<-aov(score~group, data=Social)
summary(Social.aov)
Social.tk<-TukeyHSD(Social.aov)
Social.tk
plot(Social.tk)

EcoPhys<-read.table("G://JL_Grad_Research//Survey//20110323_RInput_EcoPhys.txt",header=T)
EcoPhys.aov<-aov(score~group, data=EcoPhys)
summary(EcoPhys.aov)
EcoPhys.tk<-TukeyHSD(EcoPhys.aov)
EcoPhys.tk
plot(EcoPhys.tk)

Land<-read.table("G://JL_Grad_Research//Survey//20110323_RInput_Land.txt",header=T)
Land.aov<-aov(score~group, data=Land)
summary(Land.aov)
Land.tk<-TukeyHSD(Land.aov)
Land.tk
plot(Land.tk)
```

*Code 2. Land Cover / Use Watershed Characteristics vs. Percent Impaired Waterways*

```
LCUWaterway = read.csv(file.choose(), header=T)

R_ImpSurf = lm(PercentImpaired ~ ImpSurf, data=LCUWaterway)
plot(LCUWaterway$ImpSurf, LCUWaterway$PercentImpaired, main="Relationship Between %
Impervious Surface \nLand Cover and % Impaired Waterways", xlab="% Land Cover >50 %Impervious
Surface (0.0-1.0)", ylab="% Impaired Waterways (0-100%)")
abline(R_ImpSurf, col="red")
cor(LCUWaterway$ImpSurf, LCUWaterway$PercentImpaired)
summary(R_ImpSurf)

R_UrbDev = lm(PercentImpaired ~ UrbDev, data=LCUWaterway)
plot(LCUWaterway$UrbDev, LCUWaterway$PercentImpaired, main="Relationship Between % Land
Cover w/ \nUrban Development and % Impaired Waterways", xlab="% Land Cover w/ Urban
Development (0.0-1.0)", ylab="% Impaired Waterways (0-100%)")
abline(R_UrbDev, col="red")
cor(LCUWaterway$UrbDev, LCUWaterway$PercentImpaired)
summary(R_UrbDev)

R_Ag = lm(PercentImpaired ~ Ag, data=LCUWaterway)
plot(LCUWaterway$Ag, LCUWaterway$PercentImpaired, main="Relationship Between % Agricultural
\nLand Cover and % Impaired Waterways", xlab="% Agricultural Land Cover (0.0-1.0)", ylab="%
Impaired Waterways (0-100%)")
abline(R_Ag, col="red")
cor(LCUWaterway$Ag, LCUWaterway$PercentImpaired)
summary(R_Ag)

R_Forest = lm(PercentImpaired ~ Forest, data=LCUWaterway)
plot(LCUWaterway$Forest, LCUWaterway$PercentImpaired, main="Relationship Between % Forest
Land Cover and % Impaired Waterways", xlab="% Forest Land Cover (0.0-1.0)", ylab="% Impaired
Waterways (0-100%)")
abline(R_Forest, col="red")
cor(LCUWaterway$Forest, LCUWaterway$PercentImpaired)
summary(R_Forest)
```

Y (Dependent Variable) = PercentImpaired = % of impaired waterway
X (Independent Variables) = ImpSurf = % land cover with >50% impervious surface
UrbDev = % urban development land cover
Ag = % agricultural land cover
Forest = % forest land cover

*Code 3. Ecological & Physical Watershed Characteristics vs. Percent Impaired Waterways*

```
EPWaterway = read.csv(file.choose(), header=T)

R_HUC12 = lm(PercentImpaired ~ HUC12, data=EPWaterway)
plot(EPWaterway$HUC12, EPWaterway$PercentImpaired, main="Relationship Between HUC12 Area
and % Impaired Waterways", xlab="HUC 12 Area (Square Meters)", ylab="% Impaired Waterways (0-
100%)")
abline(R_HUC12, col="red")
cor(EPWaterway$HUC12, EPWaterway$PercentImpaired)
summary(R_HUC12)

R_HUC10 = lm(PercentImpaired ~ HUC10, data=EPWaterway)
plot(EPWaterway$HUC10, EPWaterway$PercentImpaired, main="Relationship Between HUC10 Area
and % Impaired Waterways", xlab="HUC10 Area (Square Meters)", ylab="% Impaired Waterways (0-
100%)")
abline(R_HUC10, col="red")
cor(EPWaterway$HUC10, EPWaterway$PercentImpaired)
summary(R_HUC10)

R_AvgElev = lm(PercentImpaired ~ AvgElev, data=EPWaterway)
plot(EPWaterway$AvgElev, EPWaterway$PercentImpaired, main="Relationship Between Average
Elevation and % Impaired Waterways", xlab="Average Elevation (meters)", ylab="% Impaired
Waterways (0-100%)")
abline(R_AvgElev, col="red")
cor(EPWaterway$AvgElev, EPWaterway$PercentImpaired)
summary(R_AvgElev)

R_AvgSlop = lm(PercentImpaired ~ AvgSlop, data=EPWaterway)
plot(EPWaterway$AvgSlop, EPWaterway$PercentImpaired, main="Relationship Between Average Slope
and % Impaired Waterways", xlab="Average Slope (degrees)", ylab="% Impaired Waterways (0-100%)")
abline(R_AvgSlop, col="red")
cor(EPWaterway$AvgSlop, EPWaterway$PercentImpaired)
summary(R_AvgSlop)

R_WaterwayMeters = lm(PercentImpaired ~ WaterwayMeters, data=EPWaterway)
plot(EPWaterway$WaterwayMeters, EPWaterway$PercentImpaired, main="Relationship Between Total
Waterways and % Impaired Waterways", xlab="Total Waterways (meters)", ylab="% Impaired
Waterways (0-100%)")
abline(R_WaterwayMeters, col="red")
cor(EPWaterway$WaterwayMeters, EPWaterway$PercentImpaired)
summary(R_WaterwayMeters)
```

Y (Dependent Variable) = PercentImpaired = % of impaired waterway
X (Independent Variables) = HUC12 = total area (square meters)
HUC10 = total area (square meters)
AvgElev = average elevation (meters)
AvgSlop = average slope (degrees)
WaterwayMeters = total waterway length (meters)

*Code 4. Social Watershed Characteristics vs. Percent Impaired Waterways*

```
SocialWaterway = read.csv(file.choose(), header=T)

R_Dams = lm(PercentImpaired ~ Dams, data=SocialWaterway)
plot(SocialWaterway$Dams, SocialWaterway$PercentImpaired, main="Relationship Between Number of
Dams and % Impaired Waterways", xlab="Number of Dams", ylab="% Impaired Waterways (0-100%)")
abline(R_Dams, col="red")
cor(SocialWaterway$Dams, SocialWaterway$PercentImpaired)
summary(R_Dams)

R_NPDES = lm(PercentImpaired ~ NPDES, data=SocialWaterway)
plot(SocialWaterway$NPDES, SocialWaterway$PercentImpaired, main="Relationship Between Number
of NPDES Permits \nand % Impaired Waterways", xlab="Number of NPDES Permits", ylab="%
Impaired Waterways (0-100%)")
abline(R_NPDES, col="red")
cor(SocialWaterway$NPDES, SocialWaterway$PercentImpaired)
summary(R_NPDES)
```

Y (Dependent Variable) = PercentImpaired = % of impaired waterway
X (Independent Variables) = Dams = # of dams
NPDES = # of NPDES permits

*Code 5. Land Cover / Use Watershed Characteristics vs. Percent Impaired Waterbodies*

```
LCUWaterbody = read.csv(file.choose(), header=T)

R_ImpSurf = lm(PercentSqMeters ~ ImpSurf, data=LCUWaterbody)
plot(LCUWaterbody$ImpSurf, LCUWaterbody$PercentSqMeters, main="Relationship Between % Impervious Surface \nLand Cover and % Impaired Waterbodies", xlab="% Land Cover >50 %Impervious Surface (0.0-1.0)", ylab="% Impaired Waterbodies (0-100%)")
abline(R_ImpSurf, col="red")
cor(LCUWaterbody$ImpSurf, LCUWaterbody$PercentSqMeters)
summary(R_ImpSurf)

R_UrbDev = lm(PercentSqMeters ~ UrbDev, data=LCUWaterbody)
plot(LCUWaterbody$UrbDev, LCUWaterbody$PercentSqMeters, main="Relationship Between % Land Cover w/ \nUrban Development and % Impaired Waterbodies", xlab="% Land Cover w/ Urban Development (0.0-1.0)", ylab="% Impaired Waterbodies (0-100%)")
abline(R_UrbDev, col="red")
cor(LCUWaterbody$UrbDev, LCUWaterbody$PercentSqMeters)
summary(R_UrbDev)

R_Ag = lm(PercentSqMeters ~ Ag, data=LCUWaterbody)
plot(LCUWaterbody$Ag, LCUWaterbody$PercentSqMeters, main="Relationship Between % Agricultural \nLand Cover and % Impaired Waterbodies", xlab="% Agricultural Land Cover (0.0-1.0)", ylab="% Impaired Waterbodies (0-100%)")
abline(R_Ag, col="red")
cor(LCUWaterbody$Ag, LCUWaterbody$PercentSqMeters)
summary(R_Ag)

R_Forest = lm(PercentSqMeters ~ Forest, data=LCUWaterbody)
plot(LCUWaterbody$Forest, LCUWaterbody$PercentSqMeters, main="Relationship Between % Forest Land Cover \nand % Impaired Waterbodies", xlab="% Forest Land Cover (0.0-1.0)", ylab="% Impaired Waterbodies (0-100%)")
abline(R_Forest, col="red")
cor(LCUWaterbody$Forest, LCUWaterbody$PercentSqMeters)
summary(R_Forest)
```

Y (Dependent Variable) = PercentSqMeters = % of impaired waterbodies
X (Independent Variables) = ImpSurf = % land cover with >50% impervious surface
UrbDev = % urban development land cover
Ag = % agricultural land cover
Forest = % forest land cover

*Code 6. Ecological & Physical Watershed Characteristics vs. Percent Impaired Waterbodies*

```
EPWaterbody = read.csv(file.choose(), header=T)

R_HUC12 = lm(PercentSqMeters ~ HUC12, data=EPWaterbody)
plot(EPWaterbody$HUC12, EPWaterbody$PercentSqMeters, main="Relationship Between HUC12 Area
and % Impaired Waterbodies", xlab="HUC 12 Area (Square Meters)", ylab="% Impaired Waterbodies
(0-100%)")
abline(R_HUC12, col="red")
cor(EPWaterbody$HUC12, EPWaterbody$PercentSqMeters)
summary(R_HUC12)

R_HUC10 = lm(PercentSqMeters ~ HUC10, data=EPWaterbody)
plot(EPWaterbody$HUC10, EPWaterbody$PercentSqMeters, main="Relationship Between HUC10 Area
and % Impaired Waterbodies", xlab="HUC10 Area (Square Meters)", ylab="% Impaired Waterbodies (0-
100%)")
abline(R_HUC10, col="red")
cor(EPWaterbody$HUC10, EPWaterbody$PercentSqMeters)
summary(R_HUC10)

R_AvgElev = lm(PercentSqMeters ~ AvgElev, data=EPWaterbody)
plot(EPWaterbody$AvgElev, EPWaterbody$PercentSqMeters, main="Relationship Between Average
Elevation \nand % Impaired Waterbodies", xlab="Average Elevation (meters)", ylab="% Impaired
Waterbodies (0-100%)")
abline(R_AvgElev, col="red")
cor(EPWaterbody$AvgElev, EPWaterbody$PercentSqMeters)
summary(R_AvgElev)

R_AvgSlop = lm(PercentSqMeters ~ AvgSlop, data=EPWaterbody)
plot(EPWaterbody$AvgSlop, EPWaterbody$PercentSqMeters, main="Relationship Between Average
Slope and % Impaired Waterbodies", xlab="Average Slope (degrees)", ylab="% Impaired Waterbodies
(0-100%)")
abline(R_AvgSlop, col="red")
cor(EPWaterbody$AvgSlop, EPWaterbody$PercentSqMeters)
summary(R_AvgSlop)

R_WBSqMeters = lm(PercentSqMeters ~ WBSqMeters, data=EPWaterbody)
plot(EPWaterbody$WBSqMeters, EPWaterbody$PercentSqMeters, main="Relationship Between Total
Waterbodies \nand % Impaired Waterbodies", xlab="Total Waterbodies (square meters)", ylab="%
Impaired Waterbodies (0-100%)")
abline(R_WBSqMeters, col="red")
cor(EPWaterbody$WBSqMeters, EPWaterbody$PercentSqMeters)
summary(R_WBSqMeters)
```

Y (Dependent Variable) = PercentSqMeters = % of impaired waterbodies
X (Independent Variables) = HUC12 = total area (square meters)
HUC10 = total area (square meters)
AvgElev = average elevation (meters)
AvgSlop = average slope (degrees)
WBSqMeters = total waterbody area (square meters)

*Code 7. Social Watershed Characteristics vs. Percent Impaired Waterbodies*

```
SocialWaterbody = read.csv(file.choose(), header=T)

R_Dams = lm(PercentSqMeters ~ Dams, data=SocialWaterbody)
plot(SocialWaterbody$Dams, SocialWaterbody$PercentSqMeters, main="Relationship Between Number
of Dams and % Impaired Waterbodies", xlab="Number of Dams", ylab="% Impaired Waterbodies (0-
100%)")
abline(R_Dams, col="red")
cor(SocialWaterbody$Dams, SocialWaterbody$PercentSqMeters)
summary(R_Dams)

R_NPDES = lm(PercentSqMeters ~ NPDES, data=SocialWaterbody)
plot(SocialWaterbody$NPDES, SocialWaterbody$PercentSqMeters, main="Relationship Between
Number of NPDES Permits \nand % Impaired Waterbodies", xlab="Number of NPDES Permits",
ylab="% Impaired Waterbodies (0-100%)")
abline(R_NPDES, col="red")
cor(SocialWaterbody$NPDES, SocialWaterbody$PercentSqMeters)
summary(R_NPDES)
```

Y (Dependent Variable) = PercentSqMeters = % of impaired waterbodies
X (Independent Variables) = Dams = # of dams
NPDES = # of NPDES permits

*Code 8. Watershed Characteristics vs. Percent Impaired Waterways*

```
library(MASS)
ImpAll_Waterway = read.csv(file.choose(), header=T)
R_ImpAll_Waterway <-
lm(PercentImpaired~HUC12+HUC10+AvgElev+AvgSlop+WaterwayMeters+ImpSurf+UrbDev+Ag+For
est+Dams+NPDES, data=ImpAll_Waterway)
step <- stepAIC(R_ImpAll_Waterway, direction="backward")
step$anova # display results
```

*Code 9. Watershed Characteristics vs. Percent Impaired Waterbodies*

```
library(MASS)
ImpAll_Waterbody = read.csv(file.choose(), header=T)
R_ImpAll_Waterbody <-
lm(PercentImpaired~HUC12+HUC10+AvgElev+AvgSlop+WBSqMeters+ImpSurf+UrbDev+Ag+Forest
+Dams+NPDES,data=ImpAll_Waterbody)
step <- stepAIC(R_ImpAll_Waterbody, direction="backward")
step$anova # display results
```

*Code 10. ParkIntersectHUC.py*

```
# Created by Jia Ling March 8, 2011
# Clips HUC dataset based on a specified field within the park unit polygonal shapefile
# This script export the HUC(s) that intersect the polygons within a shapefile.

import sys, string, os, arcgisscripting
gp = arcgisscripting.create()
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.overwriteoutput = 1

#Define workspace for all outputs and temporary files
gp.workspace = "G:\\JL_Grad_Research\\Temp"

#Input data.
#PW_PrkBnd_Cont is the park unit shapefile and HUC## is the dataset to be clipped to the park unit.
PW_PrkBnd_Cont = "G:\\JL_Grad_Research\\Spatial_Data\\PW_PrkBnd_Cont.shp"
HUC12 = "G:\\JL_Grad_Research\\Spatial_Data\\NRCS_WBD\\PW_HUC12_a.shp"

#Saves the description and spatial reference of the study area as variables.
dscFC = gp.Describe(PW_PrkBnd_Cont)
sr = dscFC.SpatialReference

#Create a temp layer that will be used for the insert cursor later on...
Temp_Layer = "Temp_Layer.shp"
if not gp.Exists(Temp_Layer):
	gp.CreateFeatureClass_management(gp.workspace, Temp_Layer, "POLYGON", PW_PrkBnd_Cont, "", "", sr)

#Initiate search and insert cursor for the park unit shapefile
rows = gp.SearchCursor(PW_PrkBnd_Cont)
tempRows = gp.InsertCursor(Temp_Layer)
row = rows.Next()

#Search cursor will point to the first row of the park unit shapefile and insert cursor will copy that row into the temp layer.
#The data from Temp_Layer will then be converted into a shapefile on its own called Temp_Layer2
#Park_CODE is the field name within the park unit that will be used for the rename of the final output.
#HUC## is converted into a temporary shapefile, then selected based on intersection with Temp_Layer2 (which is determined by the search cursor)
#Copy selected features from temporary HUC shapefile and names output based on park code and HUC unit.
#Feature within the Temp_Layer.shp is deleted before looping.
```

*#All other temp layers are then deleted before looping over to the next row of the search cursor.*

```
while row:
	tempRows.InsertRow(row)
	unit = row.getvalue("Park_CODE")
	gp.MakeFeatureLayer(Temp_Layer, "Temp_Layer2.shp")
	gp.MakeFeatureLayer(HUC12, "Temp_Layer3.shp")
	gp.SelectLayerByLocation("Temp_Layer3.shp", "intersect", "Temp_Layer2.shp")
	gp.CopyFeatures("Temp_Layer3.shp", unit + "_HUC12.shp")
	if gp.Exists(Temp_Layer):
		gp.deletefeatures(Temp_Layer)
	if gp.Exists("Temp_Layer2.shp"):
		gp.Delete_management("Temp_Layer2.shp")
	if gp.Exists("Temp_Layer3.shp"):
		gp.Delete_management("Temp_Layer3.shp")
	row = rows.Next()
```

*#Delete/end search and insert cursors.*

```
del rows, tempRows, row
```

*#Since Temp_Layer was created outside the loop, it needs to be deleted after the cursors have ended. Cursors will place a schema lock on the Temp_Layer so it will not delete when it is within loop.*

```
gp.delete_management(Temp_Layer)
```

*Code 11. Clip_NLCD_to_AOA2.py*

```
# Created by Jia Ling March 8, 2011
import sys, string, os, arcgisscripting
gp = arcgisscripting.create()
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.overwriteoutput = 1

#Define workspace for all outputs and temporary files
gp.workspace = "G:\\JL_Grad_Research\\Temp"

#Input data.
#In this case, the AOA2 is the study area and NLCD2006 is the dataset to be clipped to the study
area.
AOA2 =
"G:\\JL_Grad_Research\\Spatial_Data\\NRCS_WBD\\Park_WBD\HUC12\PWPrk_HUC12Bnd_
Albers.shp"
NLCD2006 = "G:\\JL_Grad_Research\\Spatial_Data\\NLCD2006\\NLCD2006"

#Saves the description and spatial reference of the study area as variables.
dscFC = gp.Describe(AOA2)
sr = dscFC.SpatialReference

#Create a temp layer that will be used for the insert cursor later on...
Temp_Layer = "Temp_Layer.shp"
if not gp.Exists(Temp_Layer):
	gp.CreateFeatureClass_management(gp.workspace, Temp_Layer, "POLYGON", AOA2, "",
"", sr)

#Initiate search and insert cursor for AOA2
rows = gp.SearchCursor(AOA2)
tempRows = gp.InsertCursor(Temp_Layer)
row = rows.Next()
while row:
	tempRows.InsertRow(row)
	unit = row.getvalue("Park_CODE")
	gp.MakeFeatureLayer(Temp_Layer, "Temp_Layer2.shp")
	gp.ExtractByMask_sa(NLCD2006, "Temp_Layer2.shp", "NLCD_temp")
	gp.rename_management("G:\\JL_Grad_Research\\Temp\\NLCD_temp", "NLCD_" + unit)
	if gp.Exists(Temp_Layer):
		gp.deletefeatures(Temp_Layer)
	if gp.Exists("Temp_Layer2.shp"):
		gp.Delete_management("Temp_Layer2.shp")
	if gp.Exists("NLCD_temp"):
		gp.Delete_management("NLCD_Temp")
```

```
    row = rows.Next()

#Delete/end search and insert cursors.
del rows, tempRows, row

#Since Temp_Layer was created outside the loop, it needs to be deleted after the cursors have ended. Cursors will place a schema lock on the Temp_Layer so it will not delete when it is within loop.
gp.delete_management(Temp_Layer)
```

*Code 12. Clip_ImpSurf_to_AOA2.py*

```
# Created by Jia Ling March 8, 2011
import sys, string, os, arcgisscripting
gp = arcgisscripting.create()
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.overwriteoutput = 1

#Define workspace for all outputs and temporary files
gp.workspace = "G:\\JL_Grad_Research\\Temp"

#Input data.
#In this case, the AOA2 is the study area and ImpSurf is the dataset to be clipped to the study
area.
AOA2 =
"G:\\JL_Grad_Research\\Spatial_Data\\NRCS_WBD\\Park_WBD\HUC12\PWPrk_HUC12Bnd_
Albers.shp"
ImpSurf =
"G:\\JL_Grad_Research\\Spatial_Data\\NPScape\\Impervious_Surface\\LCC_Impervious_Surfac
e\\ImpSurf"

#Saves the description and spatial reference of the study area as variables.
dscFC = gp.Describe(AOA2)
sr = dscFC.SpatialReference

#Create a temp layer that will be used for the insert cursor later on...
Temp_Layer = "Temp_Layer.shp"
if not gp.Exists(Temp_Layer):
	gp.CreateFeatureClass_management(gp.workspace, Temp_Layer, "POLYGON", AOA2, "",
"", sr)

#Initiate search and insert cursor for the study area shp.
rows = gp.SearchCursor(AOA2)
tempRows = gp.InsertCursor(Temp_Layer)
row = rows.Next()
while row:
	tempRows.InsertRow(row)
	unit = row.getvalue("Park_CODE")
	gp.MakeFeatureLayer(Temp_Layer, "Temp_Layer2.shp")
	gp.ExtractByMask_sa(ImpSurf, "Temp_Layer2.shp", "ImpSurf_temp")
	gp.rename_management("G:\\JL_Grad_Research\\Temp\\ImpSurf_temp", "ImpSurf_" +
unit)
	if gp.Exists(Temp_Layer):
		gp.deletefeatures(Temp_Layer)
	if gp.Exists("Temp_Layer2.shp"):
```

```
        gp.Delete_management("Temp_Layer2.shp")
    if gp.Exists("ImpSurf_temp"):
        gp.Delete_management("ImpSurf_Temp")
    row = rows.Next()
```

*#Delete/end search and insert cursors.*

```
del rows, tempRows, row
```

*#Since Temp_Layer was created outside the loop, it needs to be deleted after the cursors have ended. Cursors will place a schema lock on the Temp_Layer so it will not delete when it is within loop.*

```
gp.delete_management(Temp_Layer)
```

*Code 13. Park_Intersect_HUC10.py*

```
# Created by Jia Ling March 8, 2011
# Clips HUC dataset based on a specified field within park unit polygonal shapefile
# This script export the HUC(s) that intersect the polygons within a shapefile.

import sys, string, os, arcgisscripting
gp = arcgisscripting.create()
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.overwriteoutput = 1

#Define workspace for all outputs and temporary files
gp.workspace = "G:\\JL_Grad_Research\\Temp"

#Input data.
#In this case, the PW_PrkBnd_Cont is the park unit polygon shapefile and HUC10 is the dataset
to be clipped to the park units.
PW_PrkBnd_Cont = "G:\\JL_Grad_Research\\Spatial_Data\\PW_PrkBnd_Cont.shp"
HUC10 =
"G:\\JL_Grad_Research\\Spatial_Data\\NRCS_WBD\\HUC10\\PWPrk_HUC10Bnd.shp"

#Saves the description and spatial reference of the park unit shapefile variables.
dscFC = gp.Describe(PW_PrkBnd_Cont)
sr = dscFC.SpatialReference

#Create a temp layer that will be used for the insert cursor later on...
Temp_Layer = "Temp_Layer.shp"
if not gp.Exists(Temp_Layer):
        gp.CreateFeatureClass_management(gp.workspace, Temp_Layer, "POLYGON",
PW_PrkBnd_Cont, "", "", sr)

#Initiate search and insert cursor for the park unit shapefile
rows = gp.SearchCursor(PW_PrkBnd_Cont)
tempRows = gp.InsertCursor(Temp_Layer)
row = rows.Next()

#Search cursor will point to the first row of the park unit shapefile and insert cursor will copy
that row into the temp layer.
#The data from Temp_Layer will then be converted into a shapefile on its own called
Temp_Layer2
#Park_CODE is the field name within the park unit shapefile that will be used for the rename of
the final output.
#HUC## is converted into a temporary shapefile, then selected based on intersection with
Temp_Layer2 (which is determined by the search cursor)
```

```
#Copy selected features from temporary HUC shapefile and names output based on park code
and HUC unit.
#Feature within the Temp_Layer.shp is deleted before looping.
#All other temp layers are then deleted before looping over to the next row of the search cursor.
while row:
    tempRows.InsertRow(row)
    unit = row.getvalue("Park_CODE")
    gp.MakeFeatureLayer(Temp_Layer, "Temp_Layer2.shp")
    gp.MakeFeatureLayer(HUC10, "Temp_Layer3.shp")
    gp.SelectLayerByLocation("Temp_Layer3.shp", "intersect", "Temp_Layer2.shp")
    gp.CopyFeatures("Temp_Layer3.shp", unit + "_HUC10.shp")
    if gp.Exists(Temp_Layer):
        gp.deletefeatures(Temp_Layer)
    if gp.Exists("Temp_Layer2.shp"):
        gp.Delete_management("Temp_Layer2.shp")
    if gp.Exists("Temp_Layer3.shp"):
        gp.Delete_management("Temp_Layer3.shp")
    row = rows.Next()

#Delete/end search and insert cursors.
del rows, tempRows, row

#Since Temp_Layer was created outside the loop, it needs to be deleted after the cursors have
ended. Cursors will place a schema lock on the Temp_Layer so it will not delete when it is within
loop.
gp.delete_management(Temp_Layer)
```

*Code 14. Clip_EDNA_to_AOA2.py*

```
# Created by Jia Ling March 8, 2011
import sys, string, os, arcgisscripting
gp = arcgisscripting.create()
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")
gp.AddToolbox("C:/ArcGIS/ArcToolbox/Toolboxes/Analysis Tools.tbx")
gp.overwriteoutput = 1

#Define workspace for all outputs and temporary files
gp.workspace = "G:\\JL_Grad_Research\\Temp"

#Input data.
#In this case, the AOA2 is the study area and EDNAis the dataset to be clipped to the study area.
AOA2 =
"G:\\JL_Grad_Research\\Spatial_Data\\NRCS_WBD\\Park_WBD\HUC12\PWPrk_HUC12Bnd_
Albers.shp"
EDNA = "G:\\JL_Grad_Research\\Spatial_Data\\USGS_DEM\\pw_dem30m"

#Saves the description and spatial reference of the study are as variables.
dscFC = gp.Describe(AOA2)
sr = dscFC.SpatialReference

#Create a temp layer that will be used for the insert cursor later on...
Temp_Layer = "Temp_Layer.shp"
if not gp.Exists(Temp_Layer):
	gp.CreateFeatureClass_management(gp.workspace, Temp_Layer, "POLYGON", AOA2, "",
"", sr)

#Initiate search and insert cursor for the study area shp.
rows = gp.SearchCursor(AOA2)
tempRows = gp.InsertCursor(Temp_Layer)
row = rows.Next()
while row:
	tempRows.InsertRow(row)
	unit = row.getvalue("Park_CODE")
	gp.MakeFeatureLayer(Temp_Layer, "Temp_Layer2.shp")
	gp.ExtractByMask_sa(EDNA, "Temp_Layer2.shp", "EDNA_temp")
	gp.rename_management("G:\\JL_Grad_Research\\Temp\\EDNA_temp", "EDNA_" + unit)
	if gp.Exists(Temp_Layer):
		gp.deletefeatures(Temp_Layer)
	if gp.Exists("Temp_Layer2.shp"):
		gp.Delete_management("Temp_Layer2.shp")
	if gp.Exists("EDNA_temp"):
		gp.Delete_management("EDNA_Temp")
	row = rows.Next()
```

*#Delete/end search and insert cursors.*
del rows, tempRows, row

*#Since Temp_Layer was created outside the loop, it needs to be deleted after the cursors have ended. Cursors will place a schema lock on the Temp_Layer so it will not delete when it is within loop.*
gp.delete_management(Temp_Layer)

APPENDIX IV: Data Sources

*Table A4-1. State CWA source data used in this study.*

| State/Territory | Source | Source Author | Status | Cycle |
|---|---|---|---|---|
| Arizona | Status of Ambient Surface Water Quality in Arizona | Arizona Department of Environmental Quality | Final | 2008 |
| Arizona | Assessed Lakes / Streams GIS Shapefiles | Arizona Department of Environmental Quality | Final | 2008 |
| California | Integrated Report (303(d) List & 305(b) Report) | California EPA State Water Resources Control Board | Draft | 2010 |
| California | Statewide 303(d) GIS Shapefiles | California EPA State Water Resources Control Board | Final | 2006 |
| Hawaii | Water Quality Monitoring and Assessment Report: Integrated Report to the U.S. EPA | Hawaii State Department of Health | Final | 2006 |
| Hawaii | Statewide 303(d) Streams GIS Shapefiles | Hawaii State Department of Health | Final | 2006 |
| Idaho | Integrated Report | Idaho Department of Environmental Quality | Draft | 2010 |
| Idaho | Statewide 305(b) GIS Shapefiles | Idaho Department of Environmental Quality | Final | 2008 |
| Montana | Water Quality Integrated Report | Montana Department of Environmental Quality | Final | 2010 |
| Montana | Assessment Unit 305(b) GIS Coverages | Montana Department of Environmental Quality | Final | 2010 |
| Nevada | 303(d) List of Impaired Waters | Nevada Division of Environmental Protection: Bureau of Water Quality Planning | Final | 2006 |
| Nevada | Statewide 305(b) GIS Shapefiles | Nevada Division of Environmental Protection: Bureau of Water Quality Planning | Final | 2006 |
| Oregon | Integrated Report Database | Oregon Department of Environmental Quality | Final | 2010 |
| Oregon | Statewide 305(b) GIS Shapefiles | Oregon Department of Environmental Quality | Final | 2004-2006 |
| Utah | Utah Integrated Report | Utah Department of Environmental Quality: Division of Water Quality | Final | 2008 |
| Utah | Utah Division of Water Quality Assessment Units GIS Shapefiles | Utah Department of Environmental Quality: Division of Water Quality | Final | 2006 |
| Washington | Washington State Water Quality Assessment | State of Washington: Department of Ecology | Final | 2008 |
| Washington | Washington State CWA 303(d) GIS Shapefiles | State of Washington: Department of Ecology | Final | 2008 |

## NPS Current Administrative Park Boundaries Dataset

***Owner:*** National Park Service: Land Resources Division
***Source Link:*** http://landsnet.nps.gov; http://irma.nps.gov
***Scale*:** 1:200
***Projection*:** North American Datum of 1983; Geodetic Reference System 1980
***General Description*:** As described in the "NPS Boundary Update Process Flowchart" authored by the NPS Land Resources Division (http://landsnet.nps.gov/boundary_update_process.pdf):

*"The "Current Administrative Boundary" file that is available for download on the NPS Data Store* [*http://irma.nps.gov*] *contains boundary polygons in a shape file format that came from data from three different efforts. Boundaries digitized as part of the Horizon Project, boundaries collected from parks and regions by the GIS Division in 2001, and boundaries that the Lands Resources Division (LRD) has updated. The units LRD has updated are noted in metadata, attributed with the word "Lands" in the shape file, and listed in an email announcement that is sent out when any change to the "Current Administrative Boundary" file is posted."*

## NRCS Watershed Boundary Dataset

***Owner:*** Natural Resources Conservation Services
***Source Link:*** http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/ngmc
***Scale:*** 1:24,000
***Projection:*** Universal Transverse Mercator
***General Description:*** As described on the NRCS website:

*"Watershed boundaries define the aerial extent of surface water drainage to a point. The intent of defining hydrologic units (HU) for the Watershed Boundary Dataset is to establish a base-line drainage boundary framework, accounting for all land and surface areas. The selection and delineation of hydrologic boundaries are determined solely upon science-based hydrologic principles, not favoring any administrative or special projects nor particular program or agency. At a minimum, they are being delineated and georeferenced to the USGS 1:24,000 scale topographic base map meeting National Map Accuracy Standards (NMAS)."*

**State CWA Impairment Information**

*Arizona*

***Reports/Documents:*** 2006/2008 Status of Ambient Surface Water Quality in Arizona: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report [Final Version]
***Author:*** Arizona Department of Environmental Quality
***Source Link:*** http://www.azdeq.gov/environ/water/assessment/assess.html

*California*

***Reports/Documents:*** California 2010 Integrated Report (Clean Water Act Section 303(d) List / 305(b) Report [Draft Version]
***Author:*** California Environmental Protection Agency: State Water Resources Control Board
***Source Link:*** http://www.swrcb.ca.gov/water_issues/programs/tmdl/integrated2010.shtml

*Hawaii*

***Reports/Documents:*** 2006 State of Hawaii Water Quality Monitoring and Assessment Report: Integrated Report to the U.S. Environmental Protection Agency and the U.S. Congress Pursuant to Sections 303(D) and 305(B), Clean Water Act (P.L. 97-117) [Final Version]
***Author:*** The Hawaii State Department of Health
***Source Link:*** http://hawaii.gov/health/environmental/env-planning/wqm/wqm.html

*Idaho*

***Reports/Documents:*** Idaho 2010 Integrated Report [Draft Version]
***Author:*** Idaho Department of Environmental Quality
***Source Link:*** http://www.deq.idaho.gov/water-quality/surface-water/monitoring-assessment/integrated-report.aspx

*Montana*

***Reports/Documents:*** Montana 2010 Water Quality Integrated Report [Final Version]
***Author:*** Montana Department of Environmental Quality: Water Quality Planning Bureau
***Source Links:*** http://deq.mt.gov/default.mcpx ; http://cwaic.mt.gov/

*Nevada*

***Reports/Documents:*** Nevada's 2006 303(d) List of Impaired Waters [Final Version], Nevada's 2006 303(d) Delisted Waters [Final Version]
***Author:*** Nevada Division of Environmental Protection: Bureau of Water Quality Planning
***Source Links:*** http://ndep.nv.gov/bwqp/303dlist.htm

*Oregon*

***Reports/Documents:*** Oregon 2010 Integrated Report [Final Version], Oregon's 2010 Integrated Report – Assessment Database [Final Version]
***Author:*** Oregon Department of Environmental Quality
***Source Links:*** http://www.deq.state.or.us/wq/assessment/assessment.htm

*Utah*

***Reports/Documents:*** Utah 2008 Integrated Report [Final Version]
***Author:*** Utah Department of Environmental Quality: Division of Water Quality
***Source Links:*** http://www.waterquality.utah.gov/WQAssess/currentIR.htm

*Washington*

***Reports/Documents:*** Washington 2008 Water Quality Assessment 305(b) Report and 303(d) List [Final Version]

***Author:*** State of Washington Department of Ecology
***Source Links:*** http://www.ecy.wa.gov/programs/wq/303d/2008/index.html

## Land Cover/Use

*Percent Urban Development*

***Data Source:*** National Land Cover Dataset 2006 (NLCD2006)
***Owner:*** U.S. Geological Survey: Multi-Resolution Land Characteristics Consortium (MRLC)
***Source Link:*** http://www.mrlc.gov/nlcd2006.php
***Resolution:*** 30 meters
***Projection:*** Universal Transverse Mercator
***General Description:*** As described on the NLCD2006 main page:

> *"National Land Cover Dataset 2006 (NLCD2006) is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters. NLCD2006 is based primarily on the unsupervised classification of Landsat Enhanced Thematic Mapper+ (ETM+) circa 2006 satellite data. NLCD2006 also quantifies land cover change between the years 2001 to 2006. The NLCD2006 land cover change product was generated by comparing spectral characteristics of Landsat imagery between 2001 and 2006, on an individual path/row basis, using protocols to identify and label change based on the trajectory from NLCD2001 products. It represents the first time this type of 30 meter resolution land cover change product has been produced for the conterminous United States."*

***Caveat:*** During the data collection phase of this study, the NLCD dataset did not have 2006 updates prepared for the state of Hawaii. Therefore, NLCD 2001 was used for the state of Hawaii.

*Percent Impervious Surface*

***Data Source:*** NPScape – Monitoring Landscape Dynamics of US National Parks
***Owner:*** National Park Service, Natural Resource Program Center: Inventory & Monitoring Division
***Source Link:*** http://science.nature.nps.gov/im/monitor/npscape/index.cfm
***Resolution:*** 30 meters
***Projection:*** North American Datum 1983 Albers
***General Description:*** The impervious surface grids found within the NPScape project is a product of USGS NLCD 2006 dataset. Upon re-distribution, NPScape clipped the original coverage to a specified area of analysis. Furthermore, the NPScape project re-classified the original NLCD impervious surface classes. A general description of NLCD 2006 can be found in the *general description* section of *Percent Urban Development*. For more information regarding NPScape's methodologies, refer to the "NPScape Landcover Measure – Phase 1 Metrics Processing SOP" (https://irma.nps.gov/App/Reference/Profile?Code=2165449).

*Percent Agriculture*

***Data Source:*** National Land Cover Dataset 2006 (NLCD2006)
***Owner:*** U.S. Geological Survey: Multi-Resolution Land Characteristics Consortium (MRLC)
***Source Link:*** http://www.mrlc.gov/nlcd2006.php
***Resolution:*** 30 meters
***Projection:*** Universal Transverse Mercator
***General Description:*** A general description of NLCD 2006 can be found in the *general description* section of *Percent Urban Development*.
***Caveat:*** During the data collection phase of this study, the NLCD dataset did not have 2006 updates prepared for the state of Hawaii. Therefore, NLCD 2001 was used for the state of Hawaii.

*Percent Forest*

***Data Source:*** National Land Cover Dataset 2006 (NLCD2006)
***Owner:*** U.S. Geological Survey: Multi-Resolution Land Characteristics Consortium (MRLC)
***Source Link:*** http://www.mrlc.gov/nlcd2006.php
***Resolution:*** 30 meters
***Projection:*** Universal Transverse Mercator
***General Description:*** A general description of NLCD 2006 can be found in the *general description* section of *Percent Urban Development*.
***Caveat:*** During the data collection phase of this study, the NLCD dataset did not have 2006 updates prepared for the state of Hawaii. Therefore, NLCD 2001 was used for the state of Hawaii.

**Ecological/Physical**

*Biotic Integrity & Presence of Rare Taxa (excluded from analysis)*

***Data Source:*** Digital Distribution Maps of the Freshwater Fishes in the Conterminous United States (Version 3.0)
***Owner:*** NatureServe
***Source Link:*** http://www.natureserve.org/getData/fishMaps.jsp
***Scale:*** 1:24,000
***Projection:*** North American Datum of 1983; Geodetic Reference System 1980
***General Description:*** As described by the metadata (http://www.natureserve.org/getData/pdf/fishData.pdf):

> *"This data set contains current and historic distribution by small watershed (8-digit cataloging unit), as defined by the U.S. Geological Survey, of all native freshwater fishes of the United States, exclusive of Alaska and Hawaii. The goal of this project is to make this distributional information freely available to the public to inform conservation and other land-use decisions. The digital distribution maps are the result of a 12-year effort to produce, review, and revise a highly accurate database of fish distributions in the U.S."*

***Caveat:*** *Biotic integrity* and *presence of rare taxa* are most appropriately evaluated at a local scale. Although the distribution maps from NatureServe provided some valuable insight to information such as presence of invasive and endemic species within the 8-digit hydrological unit code (HUC) scale, the coverage was simply too coarse to include in the analysis of this study. In addition, the distribution of rare freshwater taxa, which may likely be listed under state and/or federal protection, are considered to be sensitive information. Therefore, both *biotic integrity* and *presence of rare taxa* were eliminated from the list of watershed characteristics of interest to this study.

*Bank Stability/Soil Types (excluded from analysis)*

***Data Source:*** STATSGO2
***Owner:*** Soil Survey Staff, Natural Resources Conservation Service
***Source Link:*** http://sdmdataaccess.nrcs.usda.gov
***Scale:*** 1- by 2- degree topographic quadrange / 1:250,000
***Projection:*** North American Datum of 1983
***General Description:*** As described by the metadata (http://soils.usda.gov/survey/geography/statsgo/description.html):

> *"The U.S. General Soil Map consists of general soil association units. It was developed by the National Cooperative Soil Survey and supersedes the State Soil Geographic (STATSGO) dataset published in 1994. It consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped."*

***Caveat:*** The effects of *bank stability/soil types* on water impairments are most evident when assessing characteristics of riparian habitat and their impact on water quality. Although sedimentation, erosion, and the transportation of various pollutants are primary concerns relating to *bank stability/soil types*, its effects are most effectively observed on a more local scale. Therefore, *bank stability/soil types* were excluded from the list of watershed characteristics of interest to this study.

*Channelization (excluded from analysis)*

***Data Source:*** National Hydrography Dataset (NHD)
***Owner:*** U.S. Geological Survey
***Source Link:*** http://nhd.usgs.gov/index.html
***Scale:*** 1:24,000
***Projection:*** North American Datum of 1983; Geodetic Reference System 1980
***General Description:*** As described by the metadata embedded with each NHD geodatabase download (more information at http://nhd.usgs.gov/nhd_faq.html#q101):

> *"The NHD is a national framework for assigning reach addresses to water-related entities, such as industrial discharges, drinking water supplies, fish habitat areas, wild and scenic rivers. Reach addresses establish the locations of these entities relative to one another within the NHD surface water drainage network, much like addresses on streets. Once linked to the NHD by their reach addresses, the upstream/downstream relationships of these water-related entities-*

*-and any associated information about them--can be analyzed using software tools ranging from spreadsheets to geographic information systems (GIS). GIS can also be used to combine NHD-based network analysis with other data layers, such as soils, land use and population, to help understand and display their respective effects upon one another. Furthermore, because the NHD provides a nationally consistent framework for addressing and analysis, water-related information linked to reach addresses by one organization (national, state, local) can be shared with other organizations and easily integrated into many different types of applications to the benefit of all."*

***Caveat:*** Several attempts were made to measure channelization for flowlines delineated in NHD. A promising method for measuring the fractal dimension of flowlines was the "Line Metrics Tool" in the Hawth's Analysis Tools program for ArcGIS (http://www.spatialecology.com/htools/linemetrics.php). This tool uses the equation:

$$\mathbf{D = Log(n) / (Log(n) + Log(d/L))}$$

D = Fractal Dimension
n = number of line segments that make up the line
d = distance between start and end points of the line
L = total length of the line (cumulative length of all line segments)

Consequently, there were several obstacles that made it impractical for the implementation of this tool. First, flowlines often extend beyond just one HUC unit (an apparent example being the Mississippi River). Therefore, measuring just the flowline segments that intersect the study area would not provide an accurate depiction of channelization. Second, the Line Metrics Tool cannot differentiate between a tributary and the mainstem of rivers. Therefore, its measure of total length is not accurate. Although the tool does successfully measure sinuosity of linear features, it was not designed to handle the topological complexities of NHD flowlines. Therefore, channelization was eliminated from the list of watershed characteristics of interest to this study.

*Watershed Size*

***Data Source:*** Watershed Boundary Dataset
***Owner:*** Natural Resources Conservation Services
***Source Link:*** http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/ngmc
***Scale:*** 1:24,000
***Projection:*** Universal Transverse Mercator
***General Description:*** A general description of the Watershed Boundary Dataset was provided earlier in this section.
***Caveat:*** *Watershed Size* was computed at HUC 10 and HUC 12 levels. Inclusion of *watershed size* as a watershed characteristic of interest may have been somewhat misleading. Although the survey clearly distinguished *watershed size* (actual area) and *amount of hydrography* (actual miles & acres) as two separate watershed characteristic, without reading the description, respondents may have interpreted the two characteristics

similarly. Therefore, both characteristics were included in the list of watershed characteristics of interest to this study.

*Topography*

***Data Source:*** LANDFIRE 1.1.0 Elevation Derivatives for National Applications (EDNA)
***Owner:*** U.S. Geological Survey
***Source Link:*** http://landfire.cr.usgs.gov/viewer/
***Resolution:*** 30 meters
***Projection:*** Albers Conical Equal Area
***General Description:*** As described by the metadata (http://landfire.cr.usgs.gov/distmeta/servlet/gov.usgs.edc.MetaBuilder?TYPE=html&DATASET=F0F):

> *"This file contains one of many raster grids of the Elevation Derivatives for National Applications (EDNA), a multi-layered database that provides systematic and consistent topographically-derived hydrologic derivatives. The filled DEM grid was created from the original elevation data by filling all of the depressions, or sinks, in the original DEM. To create this grid, an algorithm was used to locate and fill all depressions or sinks where there was no flow from pixel to pixel. During this process, efforts were made to maintain natural sink features…*
>
> *The Elevation Derivatives for National Applications (EDNA) was completed by a consortium of participants, including the USDOI Geological Survey for Earth Resources Observation and Science (USGS EROS) in Sioux Falls, South Dakota, the USGS National Mapping Division (USGS/NMD), the USGS Water Resources Division (USGS/WRD), the National Severe Storms Laboratory (NSSL), and the Environmental Protection Agency (EPA)…"*

## Social

*Legacy Land Use Effects (excluded from analysis)*

***Data Source:*** National Land Cover Datasets (NLCD): 1992, 2001, & 2006
***Owner:*** U.S. Geological Survey: Multi-Resolution Land Characteristics Consortium (MRLC)
***Source Link:*** http://www.mrlc.gov/index.php
***Resolution:*** 30 meters
***Projection:*** Universal Transverse Mercator
***General Description:*** General descriptions of each NLCD dataset can be found by following the *Source Link*. The website provides product descriptions that detail the attributes and development of each dataset (i.e. 1992, 2001, & 2006).
***Caveat:*** The *legacy land use effects* watershed characteristic was excluded from analysis because of lack of data. Although "legacy" may be a subjective term, a national coverage of land cover/use does not exist past 1992. Consequently, a 14 year span (compared to latest NLCD 2006) would be inadequate to determine significant changes on a landscape

level. Therefore, there was insufficient data to represent the *legacy land use effects* watershed characteristic.

*Hydrological Alterations*

***Data Source:*** National Inventory of Dams (NID)
***Owner:*** U.S. Army Corps of Engineers
***Source Link:*** http://nid.usace.army.mil
***Scale:*** unknown
***Projection:*** North American Datum 1983
***General Description:*** The National Inventory of Dams was downloaded using the *source link* above. The information was provided in a Microsoft access database format (.mdb). A table was uploaded into ArcGIS based on latitude and longitude coordinates, which were originally projected using North American Datum 1983. A general description of the NID was made available through the *source link*:

*"The goal of the NID is to include all dams in the U.S. that [specific] criteria, yet in reality, is limited to information that can be gathered and properly interpreted with the given funding. The Inventory initially consisted of approximately 45,000 dams, which were gathered from extensive record searches and some feature extraction from aerial imagery. Since continued and methodical updates have been conducted, data collection has been focused on the most reliable data sources, which are the various federal and state government dam construction and regulation offices. In most cases, dams within the NID criteria are regulated (construction permit, inspection, and/or enforcement) by federal or state agencies, who have basic information on the dams within their jurisdiction. Therein lies the biggest challenge, and most of the effort to maintain the NID; periodic collection of dam characteristics from 49 states (Alabama currently has no dam safety legislation or formal dam safety program), Puerto Rico, and 18 federal offices. Database management software is used by most state agencies to compile and export update information for the NID. With source agencies using such software, the Corps of Engineers receives data that can be parsed and has the proper NID codes. The Corps can then resolve duplicative and conflicting data from the 68 data sources, which helps obtain the more complete, accurate, and updated NID."*

***Caveat:*** *Hydrological Alterations* include a broad spectrum of watershed characteristics that may influence the natural flow regime and water depth of waterways and waterbodies. However, emphasis was given to specific watershed characteristics that have GIS representation. The National Inventory of Dams was used to represent *hydrological alterations* because of its GIS seamless national coverage. Consequently, other flow altering characteristics such as diversions, withdrawals, and hydroelectric power plants were excluded due to insufficient geospatial coverage.

*Number of NPDES Permits*

***Data Source:*** EPA GeoData Shape (Mar2011)
***Owner:*** U.S. Environmental Protection Agency
***Source Link:*** http://www.epa.gov/enviro/geo_data.html; http://cfpub.epa.gov/npdes/
***Scale:*** unknown

***Projection:*** North American Datum of 1983; Geodetic Reference System 1980
***General Description:*** As described by the USEPA National Pollutant Discharge Elimination System (NPDES) main page:

> *"Water pollution degrades surface waters making them unsafe for drinking, fishing, swimming, and other activities. As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. In most cases, the NPDES permit program is administered by authorized states. Since its introduction in 1972, the NPDES permit program is responsible for significant improvements to our Nation's water quality."*

APPENDIX V: Data Collected / Measured

*Table A5-1. Waterway meters and waterbody square meters for all AOAs.*

| Park Unit | Park Name | Waterway (Meters) | Waterbody (Square Meters) |
|---|---|---|---|
| BIHO | Big Hole National Battlefield | 511218 | 78146 |
| CABR | Cabrillo National Monument | 1342 | 7155 |
| CHIS | Channel Islands National Park | 1357110 | 114081 |
| CIRO | City of Rocks National Reserve | 566855 | 62821 |
| CRLA | Crater Lake National Park | 973328 | 54539678 |
| CRMO | Craters of the Moon National Monument | 1851008 | 5320175 |
| DEPO | Devils Postpile National Monument | 345588 | 4293609 |
| DEVA | Death Valley National Park | 31740767 | 394806915 |
| EBLA | Ebey's Landing National Historical Reserve | 211494 | 1642010348 |
| EUON | Eugene O'Neill National Historic Site | 207739 | 145529 |
| FOPO | Fort Point National Historic Site | 1305 | 149224 |
| FOVA | Fort Vancouver National Historic Site | 301980 | 14447632 |
| GOGA | Golden Gate National Recreation Area | 1306756 | 17412434 |
| GRBA | Great Basin National Park | 2106134 | 1025501 |
| HAFO | Hagerman Fossil Beds National Monument | 358183 | 1254248 |
| HALE | Haleakala National Park | 1039990 | 959632 |
| HAVO | Hawaii Volcanoes National Park | 786425 | 237961 |
| JODA | John Day Fossil Beds National Monument | 2786447 | 296839 |
| JOMU | John Muir National Historic Site | 72439 | 129734 |
| JOTR | Joshua Tree National Park | 7747180 | 26360650 |
| KALA | Kalaupapa National Historical Park | 241995 | 3552 |
| KICA | Kings Canyon National Park | 8069154 | 57606795 |
| LABE | Lava Beds National Monument | 481333 | 44956053 |
| LACH | Lake Chelan National Recreation Area | 996982 | 14078270 |
| LAME | Lake Mead National Recreation Area | 15662274 | 664521016 |
| LARO | Lake Roosevelt National Recreation Area | 9642805 | 326435928 |
| LAVO | Lassen Volcanic National Park | 1086478 | 10423105 |
| LEWI | Lewis and Clark National Historical Park | 932675 | 3253423 |
| MANZ | Manzanar National Historic Site | 321869 | 180644 |
| MCHO | McLoughlin House National Historical Site | 47770 | 189706 |
| MIIN | Minidoka Internment National Monument | 92091 | 461000 |
| MOJA | Mojave National Preserve | 15681044 | 133597956 |
| MORA | Mount Rainier National Park | 4821110 | 12206990 |
| MUWO | Muir Woods National Monument | 62624 | 178725 |
| NEPE | Nez Perce National Historical Park | 1770252 | 8134022 |
| NOCA | North Cascades National Park | 9796600 | 90805433 |
| OLYM | Olympic National Park | 18099034 | 91660697 |
| PINN | Pinnacles National Monument | 456610 | 317234 |
| PORE | Point Reyes National Seashore | 358246 | 2695750 |

| | | | |
|---|---|---|---|
| PRSF | Presidio of San Francisco | 103392 | 149224 |
| PUHE | Puukohola Heiau National Historic Site | 206782 | 133239 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 10474 | 3861 |
| REDW | Redwood National Park and State Parks | 2359231 | 20463540 |
| ROLA | Ross Lake National Recreation Area | 2423882 | 55492846 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 25773 | 554736 |
| SAFR | San Francisco Maritime National Historical Park | 1305 | 133905 |
| SAJH | San Juan Island National Historical Park | 123821 | 1929078 |
| SAMO | Santa Monica Mountains National Recreation Area | 2091793 | 7778088 |
| SEQU | Sequoia National Park | 3801626 | 19402017 |
| VALR | World War II Valor in the Pacific National Monument | 135503 | 39844 |
| WHIS | Whiskeytown National Recreation Area | 1816754 | 15356270 |
| WHMI | Whitman Mission National Historic Site | 445223 | 256386 |
| YOSE | Yosemite National Park | 10697659 | 68648191 |

*Table A5-2. Percent urban development, agriculture, and forest land cover.*

| Park Unit | Park Name | % Urban Development | % Agriculture | % Forest |
|---|---|---|---|---|
| BIHO | Big Hole National Battlefield | 1 | 1 | 50 |
| CABR | Cabrillo National Monument | 89 | 0 | 9 |
| CHIS | Channel Islands National Park | 4 | 0 | 53 |
| CIRO | City of Rocks National Reserve | 1 | 10 | 82 |
| CRLA | Crater Lake National Park | 1 | 6 | 86 |
| CRMO | Craters of the Moon National Monument | 1 | 6 | 58 |
| DEPO | Devils Postpile National Monument | 0 | 0 | 78 |
| DEVA | Death Valley National Park | 0 | 0 | 95 |
| EBLA | Ebey's Landing National Historical Reserve | 4 | 2 | 8 |
| EUON | Eugene O'Neill National Historic Site | 50 | 0 | 20 |
| FOPO | Fort Point National Historic Site | 11 | 0 | 1 |
| FOVA | Fort Vancouver National Historic Site | 35 | 17 | 15 |
| GOGA | Golden Gate National Recreation Area | 26 | 0 | 41 |
| GRBA | Great Basin National Park | 1 | 2 | 94 |
| HAFO | Hagerman Fossil Beds National Monument | 5 | 41 | 26 |
| HALE | Haleakala National Park | 9 | 14 | 52 |
| HAVO | Hawaii Volcanoes National Park | 4 | 2 | 56 |
| JODA | John Day Fossil Beds National Monument | 1 | 1 | 97 |
| JOMU | John Muir National Historic Site | 35 | 0 | 31 |
| JOTR | Joshua Tree National Park | 3 | 0 | 83 |
| KALA | Kalaupapa National Historical Park | 4 | 1 | 58 |
| KICA | Kings Canyon National Park | 0 | 0 | 66 |
| LABE | Lava Beds National Monument | 2 | 16 | 49 |
| LACH | Lake Chelan National Recreation Area | 0 | 0 | 72 |
| LAME | Lake Mead National Recreation Area | 2 | 0 | 87 |
| LARO | Lake Roosevelt National Recreation Area | 1 | 6 | 79 |
| LAVO | Lassen Volcanic National Park | 1 | 0 | 95 |
| LEWI | Lewis and Clark National Historical Park | 4 | 0 | 16 |
| MANZ | Manzanar National Historic Site | 1 | 0 | 93 |
| MCHO | McLoughlin House National Historical Site | 44 | 24 | 21 |
| MIIN | Minidoka Internment National Monument | 7 | 51 | 18 |
| MOJA | Mojave National Preserve | 1 | 0 | 90 |
| MORA | Mount Rainier National Park | 2 | 0 | 84 |
| MUWO | Muir Woods National Monument | 12 | 0 | 74 |
| NEPE | Nez Perce National Historical Park | 5 | 23 | 35 |
| NOCA | North Cascades National Park | 0 | 0 | 58 |
| OLYM | Olympic National Park | 2 | 0 | 75 |
| PINN | Pinnacles National Monument | 3 | 1 | 58 |
| PORE | Point Reyes National Seashore | 5 | 0 | 49 |
| PRSF | Presidio of San Francisco | 11 | 0 | 1 |

| | | | | |
|---|---|---|---|---|
| PUHE | Puukohola Heiau National Historic Site | 7 | 16 | 45 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 2 | 0 | 56 |
| REDW | Redwood National Park and State Parks | 5 | 2 | 87 |
| ROLA | Ross Lake National Recreation Area | 1 | 0 | 78 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 31 | 0 | 2 |
| SAFR | San Francisco Maritime National Historical Park | 11 | 0 | 1 |
| SAJH | San Juan Island National Historical Park | 1 | 1 | 4 |
| SAMO | Santa Monica Mountains National Recreation Area | 52 | 6 | 35 |
| SEQU | Sequoia National Park | 0 | 0 | 75 |
| VALR | World War II Valor in the Pacific National Monument | 33 | 0 | 66 |
| WHIS | Whiskeytown National Recreation Area | 8 | 0 | 82 |
| WHMI | Whitman Mission National Historic Site | 21 | 71 | 7 |
| YOSE | Yosemite National Park | 0 | 0 | 78 |

*Table A5-3. Percent land cover with >50% impervious surface.*

| **Park Unit** | **Park Name** | **% Impervious Surface** |
|---|---|---|
| BIHO | Big Hole National Battlefield | 0 |
| CABR | Cabrillo National Monument | 56 |
| CHIS | Channel Islands National Park | 2 |
| CIRO | City of Rocks National Reserve | 0 |
| CRLA | Crater Lake National Park | 0 |
| CRMO | Craters of the Moon National Monument | 0 |
| DEPO | Devils Postpile National Monument | 0 |
| DEVA | Death Valley National Park | 0 |
| EBLA | Ebey's Landing National Historical Reserve | 4 |
| EUON | Eugene O'Neill National Historic Site | 8 |
| FOPO | Fort Point National Historic Site | 30 |
| FOVA | Fort Vancouver National Historic Site | 15 |
| GOGA | Golden Gate National Recreation Area | 10 |
| GRBA | Great Basin National Park | 0 |
| HAFO | Hagerman Fossil Beds National Monument | 0 |
| HALE | Haleakala National Park | 1 |
| HAVO | Hawaii Volcanoes National Park | 0 |
| JODA | John Day Fossil Beds National Monument | 0 |
| JOMU | John Muir National Historic Site | 11 |
| JOTR | Joshua Tree National Park | 1 |
| KALA | Kalaupapa National Historical Park | 0 |
| KICA | Kings Canyon National Park | 0 |
| LABE | Lava Beds National Monument | 0 |
| LACH | Lake Chelan National Recreation Area | 0 |
| LAME | Lake Mead National Recreation Area | 1 |
| LARO | Lake Roosevelt National Recreation Area | 0 |
| LAVO | Lassen Volcanic National Park | 0 |
| LEWI | Lewis and Clark National Historical Park | 2 |
| MANZ | Manzanar National Historic Site | 0 |
| MCHO | McLoughlin House National Historical Site | 14 |
| MIIN | Minidoka Internment National Monument | 0 |
| MOJA | Mojave National Preserve | 0 |
| MORA | Mount Rainier National Park | 0 |
| MUWO | Muir Woods National Monument | 0 |
| NEPE | Nez Perce National Historical Park | 1 |
| NOCA | North Cascades National Park | 0 |
| OLYM | Olympic National Park | 0 |
| PINN | Pinnacles National Monument | 0 |
| PORE | Point Reyes National Seashore | 0 |
| PRSF | Presidio of San Francisco | 30 |

| | | |
|---|---|---|
| PUHE | Puukohola Heiau National Historic Site | 1 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 0 |
| REDW | Redwood National Park and State Parks | 0 |
| ROLA | Ross Lake National Recreation Area | 0 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 47 |
| SAFR | San Francisco Maritime National Historical Park | 30 |
| SAJH | San Juan Island National Historical Park | 1 |
| SAMO | Santa Monica Mountains National Recreation Area | 24 |
| SEQU | Sequoia National Park | 0 |
| VALR | World War II Valor in the Pacific National Monument | 26 |
| WHIS | Whiskeytown National Recreation Area | 1 |
| WHMI | Whitman Mission National Historic Site | 3 |
| YOSE | Yosemite National Park | 0 |

*Table A5-4. Area square meters of all intersecting HUC 10 and HUC 12 polygons.*

| Park Unit | Park Name | HUC 12 (Sq Meters) | HUC 10 (Sq Meters) |
|---|---|---|---|
| BIHO | Big Hole National Battlefield | 71359 | 180000 |
| CABR | Cabrillo National Monument | 1783 | 12175 |
| CHIS | Channel Islands National Park | 137920 | 250784 |
| CIRO | City of Rocks National Reserve | 114266 | 454853 |
| CRLA | Crater Lake National Park | 494692 | 1322916 |
| CRMO | Craters of the Moon National Monument | 1280805 | 1772331 |
| DEPO | Devils Postpile National Monument | 49766 | 100060 |
| DEVA | Death Valley National Park | 4967762 | 5969451 |
| EBLA | Ebey's Landing National Historical Reserve | 565759 | 631387 |
| EUON | Eugene O'Neill National Historic Site | 32844 | 92389 |
| FOPO | Fort Point National Historic Site | 60920 | 131240 |
| FOVA | Fort Vancouver National Historic Site | 63617 | 150072 |
| GOGA | Golden Gate National Recreation Area | 385011 | 673375 |
| GRBA | Great Basin National Park | 390124 | 886819 |
| HAFO | Hagerman Fossil Beds National Monument | 65472 | 264556 |
| HALE | Haleakala National Park | 200742 | 367486 |
| HAVO | Hawaii Volcanoes National Park | 1578461 | 1969727 |
| JODA | John Day Fossil Beds National Monument | 223865 | 702281 |
| JOMU | John Muir National Historic Site | 15238 | 58880 |
| JOTR | Joshua Tree National Park | 1441576 | 2173745 |
| KALA | Kalaupapa National Historical Park | 36061 | 76374 |
| KICA | Kings Canyon National Park | 1138816 | 2140161 |
| LABE | Lava Beds National Monument | 202533 | 558256 |
| LACH | Lake Chelan National Recreation Area | 222453 | 609531 |
| LAME | Lake Mead National Recreation Area | 2594403 | 3586009 |
| LARO | Lake Roosevelt National Recreation Area | 1103797 | 2168467 |
| LAVO | Lassen Volcanic National Park | 355046 | 955355 |
| LEWI | Lewis and Clark National Historical Park | 422987 | 611229 |
| MANZ | Manzanar National Historic Site | 51344 | 184671 |
| MCHO | McLoughlin House National Historical Site | 13206 | 87169 |
| MIIN | Minidoka Internment National Monument | 29852 | 241636 |
| MOJA | Mojave National Preserve | 2362095 | 3300515 |
| MORA | Mount Rainier National Park | 470970 | 1101645 |
| MUWO | Muir Woods National Monument | 12786 | 61981 |
| NEPE | Nez Perce National Historical Park | 287375 | 1215822 |
| NOCA | North Cascades National Park | 1163397 | 23694630 |
| OLYM | Olympic National Park | 2128558 | 2964254 |
| PINN | Pinnacles National Monument | 75763 | 205594 |
| PORE | Point Reyes National Seashore | 108167 | 172123 |
| PRSF | Presidio of San Francisco | 60915 | 131240 |

| | | | |
|---|---|---|---|
| PUHE | Puukohola Heiau National Historic Site | 49799 | 218622 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 149208 | 214733 |
| REDW | Redwood National Park and State Parks | 453952 | 839145 |
| ROLA | Ross Lake National Recreation Area | 406252 | 626492 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 81897 | 131240 |
| SAFR | San Francisco Maritime National Historical Park | 60987 | 131240 |
| SAJH | San Juan Island National Historical Park | 510001 | 513941 |
| SAMO | Santa Monica Mountains National Recreation Area | 503395 | 721524 |
| SEQU | Sequoia National Park | 859191 | 1934602 |
| VALR | World War II Valor in the Pacific National Monument | 20306 | 102279 |
| WHIS | Whiskeytown National Recreation Area | 252212 | 500964 |
| WHMI | Whitman Mission National Historic Site | 68498 | 290226 |
| YOSE | Yosemite National Park | 1259864 | 1847345 |

*Table A5-5. Average elevation and slope of each AOA.*

| Park Unit | Park Name | Average Elevation (Meters) | Average Slope (Degrees) |
|---|---|---|---|
| BIHO | Big Hole National Battlefield | 2020.89 | 8.37 |
| CABR | Cabrillo National Monument | 56.46 | 8.1 |
| CHIS | Channel Islands National Park | 183.16 | 16.13 |
| CIRO | City of Rocks National Reserve | 1898.84 | 8.99 |
| CRLA | Crater Lake National Park | 1605.78 | 6.86 |
| CRMO | Craters of the Moon National Monument | 1537.83 | 2.67 |
| DEPO | Devils Postpile National Monument | 2765.28 | 18.77 |
| DEVA | Death Valley National Park | 1076.08 | 10.77 |
| EBLA | Ebey's Landing National Historical Reserve | 9.32 | 0.65 |
| EUON | Eugene O'Neill National Historic Site | 224.73 | 11.4 |
| FOPO | Fort Point National Historic Site | 7.47 | 0.68 |
| FOVA | Fort Vancouver National Historic Site | 33.8 | 1.89 |
| GOGA | Golden Gate National Recreation Area | 135.22 | 10.87 |
| GRBA | Great Basin National Park | 2153.49 | 10.46 |
| HAFO | Hagerman Fossil Beds National Monument | 1001.87 | 3.6 |
| HALE | Haleakala National Park | 853.63 | 12.55 |
| HAVO | Hawaii Volcanoes National Park | 1371.35 | 5.39 |
| JODA | John Day Fossil Beds National Monument | 1023.34 | 13.93 |
| JOMU | John Muir National Historic Site | 135.65 | 13.62 |
| JOTR | Joshua Tree National Park | 714.31 | 9.47 |
| KALA | Kalaupapa National Historical Park | 288.85 | 16.33 |
| KICA | Kings Canyon National Park | 2628.92 | 20.97 |
| LABE | Lava Beds National Monument | 1370.91 | 2.79 |
| LACH | Lake Chelan National Recreation Area | 1538.39 | 28.26 |
| LAME | Lake Mead National Recreation Area | 814 | 11.15 |
| LARO | Lake Roosevelt National Recreation Area | 729.41 | 12 |
| LAVO | Lassen Volcanic National Park | 1784.4 | 9.8 |
| LEWI | Lewis and Clark National Historical Park | 15.27 | 1.71 |
| MANZ | Manzanar National Historic Site | 1697.6 | 13.35 |
| MCHO | McLoughlin House National Historical Site | 81.36 | 5.18 |
| MIIN | Minidoka Internment National Monument | 1196.39 | 1.12 |
| MOJA | Mojave National Preserve | 977.4 | 5.58 |
| MORA | Mount Rainier National Park | 1382.62 | 22.75 |
| MUWO | Muir Woods National Monument | 190.64 | 17.81 |
| NEPE | Nez Perce National Historical Park | 805.26 | 12.47 |
| NOCA | North Cascades National Park | 1036.2 | 23.61 |
| OLYM | Olympic National Park | 575.8 | 18.66 |
| PINN | Pinnacles National Monument | 465.94 | 14.82 |
| PORE | Point Reyes National Seashore | 105.1 | 11.46 |

| | | | |
|---|---|---|---|
| PRSF | Presidio of San Francisco | 7.47 | 0.68 |
| PUHE | Puukohola Heiau National Historic Site | 945.82 | 6.76 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 1863.88 | 7.52 |
| REDW | Redwood National Park and State Parks | 338.56 | 16.59 |
| ROLA | Ross Lake National Recreation Area | 1245.43 | 29.67 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 25.1 | 1.81 |
| SAFR | San Francisco Maritime National Historical Park | 7.46 | 0.68 |
| SAJH | San Juan Island National Historical Park | 4.59 | 0.45 |
| SAMO | Santa Monica Mountains National Recreation Area | 257.68 | 10.35 |
| SEQU | Sequoia National Park | 2487.03 | 21.1 |
| VALR | World War II Valor in the Pacific National Monument | 238.57 | 19.78 |
| WHIS | Whiskeytown National Recreation Area | 637.48 | 2.62 |
| WHMI | Whitman Mission National Historic Site | 272.36 | 16.15 |
| YOSE | Yosemite National Park | 2367.74 | 18.14 |

*Table A5-6. Number of dams and NPDES permits within each AOA.*

| Park Unit | Park Name | Number of Dams | Number of NPDES Permits |
|---|---|---|---|
| BIHO | Big Hole National Battlefield | 0 | 0 |
| CABR | Cabrillo National Monument | 0 | 1 |
| CHIS | Channel Islands National Park | 1 | 0 |
| CIRO | City of Rocks National Reserve | 0 | 0 |
| CRLA | Crater Lake National Park | 0 | 0 |
| CRMO | Craters of the Moon National Monument | 0 | 0 |
| DEPO | Devils Postpile National Monument | 0 | 0 |
| DEVA | Death Valley National Park | 12 | 0 |
| EBLA | Ebey's Landing National Historical Reserve | 6 | 0 |
| EUON | Eugene O'Neill National Historic Site | 1 | 0 |
| FOPO | Fort Point National Historic Site | 1 | 0 |
| FOVA | Fort Vancouver National Historic Site | 2 | 0 |
| GOGA | Golden Gate National Recreation Area | 25 | 5 |
| GRBA | Great Basin National Park | 0 | 0 |
| HAFO | Hagerman Fossil Beds National Monument | 1 | 3 |
| HALE | Haleakala National Park | 20 | 0 |
| HAVO | Hawaii Volcanoes National Park | 1 | 0 |
| JODA | John Day Fossil Beds National Monument | 1 | 0 |
| JOMU | John Muir National Historic Site | 1 | 2 |
| JOTR | Joshua Tree National Park | 4 | 1 |
| KALA | Kalaupapa National Historical Park | 0 | 0 |
| KICA | Kings Canyon National Park | 5 | 0 |
| LABE | Lava Beds National Monument | 0 | 0 |
| LACH | Lake Chelan National Recreation Area | 0 | 0 |
| LAME | Lake Mead National Recreation Area | 37 | 5 |
| LARO | Lake Roosevelt National Recreation Area | 9 | 0 |
| LAVO | Lassen Volcanic National Park | 1 | 0 |
| LEWI | Lewis and Clark National Historical Park | 2 | 0 |
| MANZ | Manzanar National Historic Site | 0 | 0 |
| MCHO | McLoughlin House National Historical Site | 4 | 0 |
| MIIN | Minidoka Internment National Monument | 0 | 0 |
| MOJA | Mojave National Preserve | 1 | 0 |
| MORA | Mount Rainier National Park | 1 | 0 |
| MUWO | Muir Woods National Monument | 0 | 0 |
| NEPE | Nez Perce National Historical Park | 5 | 2 |
| NOCA | North Cascades National Park | 4 | 0 |
| OLYM | Olympic National Park | 6 | 0 |
| PINN | Pinnacles National Monument | 1 | 0 |
| PORE | Point Reyes National Seashore | 3 | 0 |

| | | | |
|---|---|---|---|
| PRSF | Presidio of San Francisco | 1 | 0 |
| PUHE | Puukohola Heiau National Historic Site | 4 | 0 |
| PUHO | Pu'uhonua o Honaunau National Historical Park | 0 | 0 |
| REDW | Redwood National Park and State Parks | 3 | 1 |
| ROLA | Ross Lake National Recreation Area | 3 | 0 |
| RORI | Rosie the Riveter WWII Home Front National Historical Park | 4 | 1 |
| SAFR | San Francisco Maritime National Historical Park | 1 | 0 |
| SAJH | San Juan Island National Historical Park | 21 | 0 |
| SAMO | Santa Monica Mountains National Recreation Area | 43 | 8 |
| SEQU | Sequoia National Park | 3 | 0 |
| VALR | World War II Valor in the Pacific National Monument | 0 | 1 |
| WHIS | Whiskeytown National Recreation Area | 13 | 0 |
| WHMI | Whitman Mission National Historic Site | 3 | 0 |
| YOSE | Yosemite National Park | 15 | 1 |

APPENDIX VI: Survey

Colorado State University

**Research Integrity & Compliance Review Office**
Office of Vice President for Research
Fort Collins, CO 80523-2011
(970) 491-1553
FAX (970) 491-2293

| | | | |
|---|---|---|---|
| **DATE:** | February 14, 2011 | | |
| **TO:** | Dr. Melinda Laituri, NREL<br>Jia Ling, NREL | | |
| | Janell Barker | | |
| **FROM:** | Janell Barker, IRB Administrator<br>Research Integrity & Compliance Review Office | | |
| **TITLE:** | Identifying Watershed Characteristics that are Related to the Spatial Distribution of Impaired Waters for Park Units within the Pacific West Region of the National Park Service | | |
| **IRB ID:** | 020-12H | **Review Date:** | February 14, 2011 |

The Institutional Review Board (IRB) Administrator has reviewed this project and has declared the study exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b)(2): Research involving the use of educational tests.....survey procedures, interview procedures or observation of public behavior, unless: a) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects. The IRB determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as proposed in the Exempt application**, including obtaining and documenting (signed) informed consent if stated in your application or if required by the IRB.
- **Any modification of this research should be submitted to the IRB through an email to the IRB Administrator, prior to implementing any changes**, to determine if the project still meets the Federal criteria for exemption. If it is determined that exemption is no longer warranted, then an IRB proposal will need to be submitted and approved before proceeding with data collection.
- **Please notify the IRB if any problems or complaints of the research occur.**

Please note that you must submit all research involving human participants for review by the IRB. **Only the IRB may make the determination of exemption**, even if you conduct a similar study in the future.

## NPS Impaired Watersheds Project

Exit this survey >>

The NPS Water Resources Division, in cooperation with Colorado State University, is assessing the quantity and distribution of Clean Water Act impaired (303(d) listed) water resources within the National Park system. Part of this assessment entails an investigation of the relationships between watershed characteristics and the presence/absence and distribution of impaired waters. Of specific interest is identifying which watershed characteristics are most germane to assessing impaired waters. You are being asked to participate in this survey because of your expertise in the field of water resource management. Please take a couple minutes to help rate the following watershed characteristics based on your opinion of their ability to predict the occurrence/non-occurrence of impaired waters.

**1. In your opinion, please rate the following land cover/use characteristics on their ability to predict the occurrence/non-occurrence of impaired waters. A general description for each land cover/use characteristic is provided below the question.**

| | Very Poor | Poor | Moderate | Good | Very Good | Not Applicable |
|---|---|---|---|---|---|---|
| A. Corridor/Road Density | ○ | ○ | ○ | ○ | ○ | ○ |
| B. Percent Agriculture | ○ | ○ | ○ | ○ | ○ | ○ |
| C. Percent Forest | ○ | ○ | ○ | ○ | ○ | ○ |
| D. Percent Impervious Surface | ○ | ○ | ○ | ○ | ○ | ○ |
| E. Percent Protected Lands | ○ | ○ | ○ | ○ | ○ | ○ |
| F. Percent Urban Development | ○ | ○ | ○ | ○ | ○ | ○ |
| G. Residential Unit Density | ○ | ○ | ○ | ○ | ○ | ○ |

Other characteristics to consider:

A. Corridor/Road Density: Total road miles/watershed area
B. Percent Agriculture: Percent of agricultural area in a watershed
C. Percent Forest: Percent of forest cover in a watershed
D. Percent Impervious Surface: Percent impervious surface area in a watershed
E. Percent Protected Lands: Percent of protected land cover in a watershed
F. Percent Urban Development: Percent of urban area in a watershed
G. Residential Unit Density: Number of residential units/watershed area

**2. In your opinion, please rate the following ecological/physical characteristics on their ability to predict the occurrence/non-occurrence of impaired waters. A general description for each ecological/physical characteristic is provided below the question.**

| | Very Poor | Poor | Moderate | Good | Very Good | Not Applicable |
|---|---|---|---|---|---|---|
| A. Amount of Hydrography | ○ | ○ | ○ | ○ | ○ | ○ |
| B. Bank Stability/Soil Types | ○ | ○ | ○ | ○ | ○ | ○ |
| C. Biotic Integrity | ○ | ○ | ○ | ○ | ○ | ○ |
| D. Channelization | ○ | ○ | ○ | ○ | ○ | ○ |
| E. Climatic Variations | ○ | ○ | ○ | ○ | ○ | ○ |
| F. Presence of Endangered/Threatened Species | ○ | ○ | ○ | ○ | ○ | ○ |
| G. Presence of Rare Taxa | ○ | ○ | ○ | ○ | ○ | ○ |
| H. Stream Order | ○ | ○ | ○ | ○ | ○ | ○ |
| I. Topography (i.e. elevation, slope, etc.) | ○ | ○ | ○ | ○ | ○ | ○ |
| J. Watershed Size | ○ | ○ | ○ | ○ | ○ | ○ |

Other characteristics to consider:

A. Amount of Hydrography: Miles of waterways and acres of waterbodies
B. Bank Stability/Soil Types: Used to assess likelihood of erosion and sediment load
C. Biotic Integrity: Assessment of fish communities and its species composition
D. Channelization: Measure of sinuosity of a stream
E. Climatic Variations: The occurrence of drought, floods, and variations in climatic patterns
F. Presence of Endangered/Threatened Species: Presence of species listed as endangered or threatened under the Endangered Species Act
G. Presence of Rare Taxa: Presence of rare species as indicator of unimpaired waters
H. Stream Order: Used to describe size of streams from 1st to 12th order
I. Topography: Elevation, slope, etc.
J. Watershed Size: Total area of a watershed

**3. In your opinion, please rate the following social characteristics on their ability to predict the occurrence/non-occurrence of impaired waters. A general description for each social characteristic is provided below the question.**

| | Very Poor | Poor | Moderate | Good | Very Good | Not Applicable |
|---|---|---|---|---|---|---|
| A. Hydrological Alterations (i.e. dams or withdrawals) | ○ | ○ | ○ | ○ | ○ | ○ |
| B. Jurisdictional Complexity | ○ | ○ | ○ | ○ | ○ | ○ |
| C. Landownership Complexity | ○ | ○ | ○ | ○ | ○ | ○ |
| D. Legacy Land Use Effects | ○ | ○ | ○ | ○ | ○ | ○ |
| E. Number of NPDES Permits | ○ | ○ | ○ | ○ | ○ | ○ |
| F. Recreational Opportunities | ○ | ○ | ○ | ○ | ○ | ○ |
| G. Socioeconomic Stress | ○ | ○ | ○ | ○ | ○ | ○ |
| H. Watershed Organizational Groups | ○ | ○ | ○ | ○ | ○ | ○ |

Other characteristics to consider:

A. Hydrologic Alterations: Changes to natural flow regime due to dams and/or withdrawals
B. Jurisdictional Complexity: Number of local and state agencies with jurisdiction over a watershed
C. Landownership Complexity: Number of landowners along riparian corridors per mile of stream/river
D. Legacy Land Use Effects: Historical land uses and their potential effects on water quality today; e.g. mining, agriculture
E. Number of NPDES permits: Number of existing NPDES permits in a watershed
F. Recreational Opportunities: Presence/absence of federal/state/local conservation areas such as parks and forest lands
G. Socioeconomic Stress: Average residential income and home value within watershed
H. Watershed Organizational Groups: Number of groups that are involved in the aquatic management of a watershed

Thank you for your participation in this survey! All individual responses will be anonymous and private. Results of this survey will only be used within the scope of this NPS project.

APPENDIX VII: Survey Results

*Table A7-1. Survey Results: Percent Responses of Land Cover/Use Characteristics*

| Land Cover/Use Characteristics | Very Poor | Poor | Moderate | Good | Very Good | N/A | Total Responses | Avg Rating |
|---|---|---|---|---|---|---|---|---|
| Corridor/Road Density | 3.7 | 9.8 | 35.4 | 28 | 22 | 1.2 | 82 | 3.51 |
| Percent Agriculture | 4.8 | 3.6 | 14.3 | 35.7 | 40.5 | 1.2 | 84 | 4.00 |
| Percent Forest | 2.4 | 7.1 | 27.4 | 32.1 | 31 | 0 | 84 | 3.82 |
| Percent Impervious Surface | 3.6 | 3.6 | 14.3 | 32.1 | 45.2 | 1.2 | 84 | 4.08 |
| Percent Protected Lands | 2.4 | 8.3 | 38.1 | 34.5 | 15.5 | 1.2 | 84 | 3.49 |
| Percent Urban Development | 2.4 | 3.6 | 11.9 | 34.5 | 46.4 | 1.2 | 84 | 4.15 |
| Residential Unit Density | 2.4 | 13.3 | 31.3 | 30.1 | 21.7 | 1.2 | 83 | 3.52 |

*Table A7-2. Survey Results: Count Responses of Land Cover/Use Characteristics*

| Land Cover/Use Characteristics | Very Poor | Poor | Moderate | Good | Very Good | N/A | Total Responses |
|---|---|---|---|---|---|---|---|
| Corridor/Road Density | 3 | 8 | 29 | 23 | 18 | 1 | 82 |
| Percent Agriculture | 4 | 3 | 12 | 30 | 34 | 1 | 84 |
| Percent Forest | 2 | 6 | 23 | 27 | 26 | 0 | 84 |
| Percent Impervious Surface | 3 | 3 | 12 | 27 | 38 | 1 | 84 |
| Percent Protected Lands | 2 | 7 | 32 | 29 | 13 | 1 | 84 |
| Percent Urban Development | 2 | 3 | 10 | 29 | 39 | 1 | 84 |
| Residential Unit Density | 2 | 11 | 26 | 25 | 18 | 1 | 83 |

*Table A7-3. Survey Results: Percent Responses of Ecological/Physical Characteristics*

| **Ecological/ Physical Characteristics** | **Very Poor** | **Poor** | **Moderate** | **Good** | **Very Good** | **N/A** | **Total Responses** | **Avg Rating** |
|---|---|---|---|---|---|---|---|---|
| Amount of Hydrography | 6 | 32.5 | 38.6 | 9.6 | 9.6 | 3.6 | 83 | 2.73 |
| Bank Stability/Soil Types | 2.4 | 14.3 | 35.7 | 28.6 | 19 | 0 | 84 | 3.48 |
| Biotic Integrity | 2.4 | 3.6 | 13.3 | 45.8 | 34.9 | 0 | 83 | 4.07 |
| Channelization | 3.6 | 18.1 | 32.5 | 24.1 | 18.1 | 3.6 | 83 | 3.24 |
| Climatic Variations | 10.7 | 40.5 | 22.6 | 17.9 | 3.6 | 4.8 | 84 | 2.49 |
| Presence of Endangered/ Threatened Species | 10.8 | 33.7 | 32.5 | 12 | 7.2 | 3.6 | 83 | 2.60 |
| Presence of Rare Taxa | 8.3 | 28.6 | 25 | 26.2 | 9.5 | 2.4 | 84 | 2.93 |
| Stream Order | 10.8 | 25.3 | 44.6 | 12 | 4.8 | 2.4 | 83 | 2.67 |
| Topography (i.e. elevation, slope, etc.) | 8.4 | 22.9 | 42.2 | 16.9 | 8.4 | 1.2 | 83 | 2.90 |
| Watershed Size | 6.3 | 28.8 | 36.3 | 16.3 | 11.3 | 1.3 | 80 | 2.94 |

*Table A7-4. Survey Results: Count Responses of Ecological/Physical Characteristics*

| Ecological/ Physical Characteristics | Very Poor | Poor | Moderate | Good | Very Good | N/A | Total Responses |
|---|---|---|---|---|---|---|---|
| Amount of Hydrography | 5 | 27 | 32 | 8 | 8 | 3 | 83 |
| Bank Stability/Soil Types | 2 | 12 | 30 | 24 | 16 | 0 | 84 |
| Biotic Integrity | 2 | 3 | 11 | 38 | 29 | 0 | 83 |
| Channelization | 3 | 15 | 27 | 20 | 15 | 3 | 83 |
| Climatic Variations | 9 | 34 | 19 | 15 | 3 | 4 | 84 |
| Presence of Endangered/ Threatened Species | 9 | 28 | 27 | 10 | 6 | 3 | 83 |
| Presence of Rare Taxa | 7 | 24 | 21 | 22 | 8 | 2 | 84 |
| Stream Order | 9 | 21 | 37 | 10 | 4 | 2 | 83 |
| Topography (i.e. elevation, slope, etc.) | 7 | 19 | 35 | 14 | 7 | 1 | 83 |
| Watershed Size | 5 | 23 | 29 | 13 | 9 | 1 | 80 |

*Table A7-5. Survey Results: Percent Responses of Social Characteristics*

| Social Characteristics | Very Poor | Poor | Moderate | Good | Very Good | N/A | Total Responses | Avg Rating |
|---|---|---|---|---|---|---|---|---|
| Hydrological Alterations (i.e. dams & withdrawals) | 1.2 | 8.3 | 20.2 | 42.9 | 27.4 | 0 | 84 | 3.87 |
| Jurisdictional Complexity | 10.8 | 31.3 | 39.8 | 12 | 3.6 | 2.4 | 83 | 2.59 |
| Landownership Complexity | 6 | 24.1 | 44.6 | 19.3 | 4.8 | 1.2 | 83 | 2.89 |
| Legacy Land Use Effects | 1.2 | 6 | 20.2 | 40.5 | 32.1 | 0 | 84 | 3.96 |
| Number of NPDES Permits | 3.7 | 11 | 24.4 | 40.2 | 18.3 | 2.4 | 82 | 3.51 |
| Recreational Opportunities | 9.5 | 27.4 | 41.7 | 13.1 | 7.1 | 1.2 | 84 | 2.77 |
| Socioeconomic Stress | 9.5 | 32.1 | 35.7 | 11.9 | 6 | 4.8 | 84 | 2.58 |
| Watershed Organizational Groups | 13.3 | 30.1 | 39.8 | 12 | 2.4 | 2.4 | 83 | 2.53 |

*Table A7-6. Survey Results: Count Responses of Social Characteristics*

| Social Characteristics | Very Poor | Poor | Moderate | Good | Very Good | N/A | Total Responses |
|---|---|---|---|---|---|---|---|
| Hydrological Alterations (i.e. dams & withdrawals) | 1 | 7 | 17 | 36 | 23 | 0 | 84 |
| Jurisdictional Complexity | 9 | 26 | 33 | 10 | 3 | 2 | 83 |
| Landownership Complexity | 5 | 20 | 37 | 16 | 4 | 1 | 83 |
| Legacy Land Use Effects | 1 | 5 | 17 | 34 | 27 | 0 | 84 |
| Number of NPDES Permits | 3 | 9 | 20 | 33 | 15 | 2 | 82 |
| Recreational Opportunities | 8 | 23 | 35 | 11 | 6 | 1 | 84 |
| Socioeconomic Stress | 8 | 27 | 30 | 10 | 5 | 4 | 84 |
| Watershed Organizational Groups | 11 | 25 | 33 | 10 | 2 | 2 | 83 |

APPENDIX VIII: Results from Linear and Stepwise Regression Analyses

*HUC 12 (square meters) vs. Percent Impaired Waterways & Waterbodies*

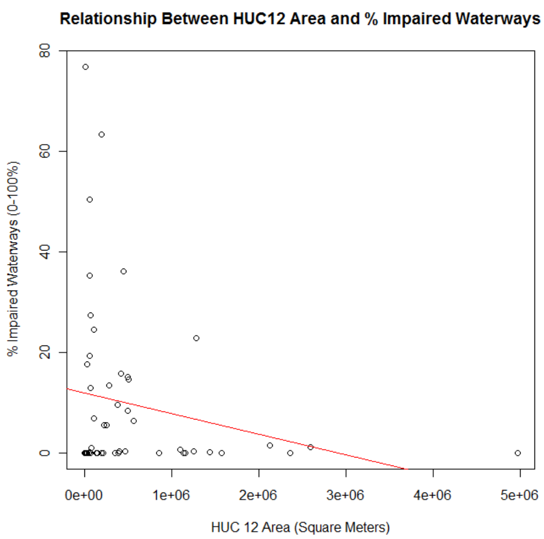
$H_o$: HUC12 (square meters) has no effect on percent impaired waterways / waterbodies.
$H_a$: HUC12 (square meters) has an effect on percent impaired waterways / waterbodies.

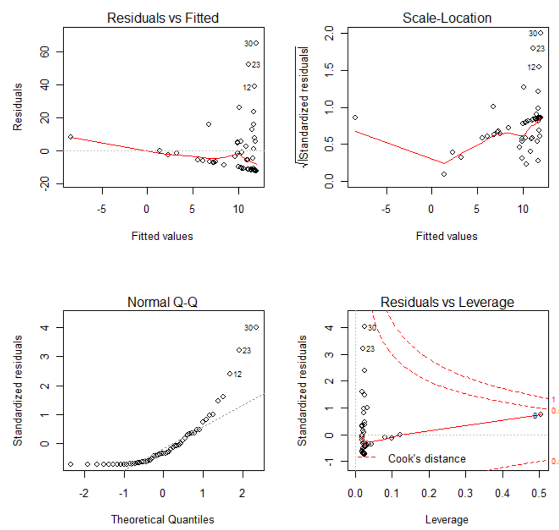
**<u>R Outputs: Percent Impaired Waterways</u>**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 1.200e+01 | 2.674e+00 | 4.489 | 4.11e-05 |
| HUC12 | -4.118e-06 | 2.586e-06 | -1.593 | 0.117 |

Residual standard error: 16.37 on 51 degrees of freedom
Multiple R-squared: 0.04737, Adjusted R-squared: 0.02869
F-statistic: 2.536 on 1 and 51 DF, p-value: 0.1175

cor(EPWaterway$HUC12, EPWaterway$PercentImpaired)
[1] -0.2176495




Correlation Coefficient = -0.218: a weak negative correlation was observed when regressing HUC12 to percent impaired waterways.

P-Value = 0.117: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.
Scale-Location Plot: implies unequal variance in the data.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

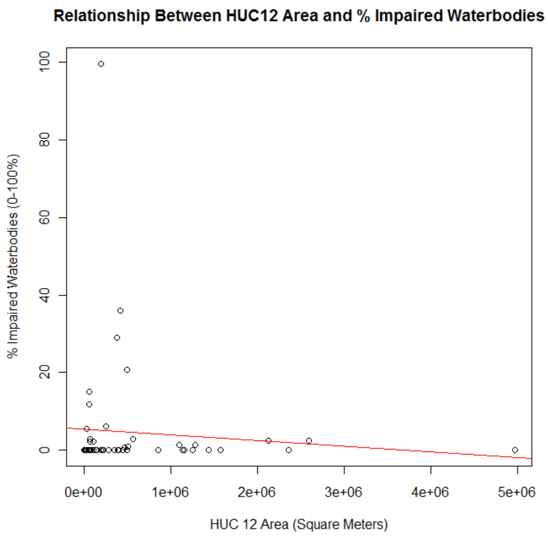
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

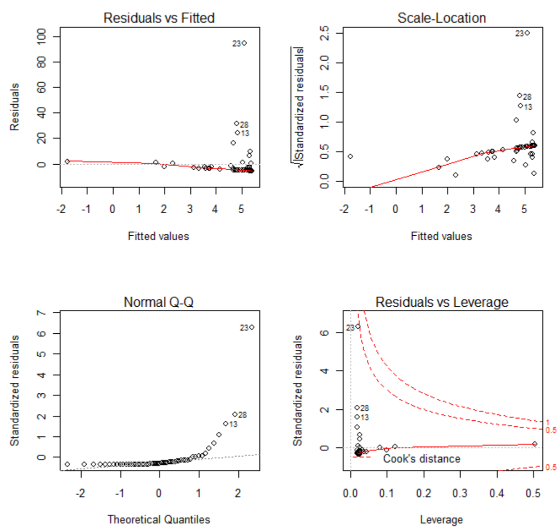
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 5.403e+00 | 2.483e+00 | 2.177 | 0.0342 |
| HUC12 | -1.445e-06 | 2.401e-06 | -0.602 | 0.5501 |

Residual standard error: 15.2 on 51 degrees of freedom
Multiple R-squared: 0.007047, Adjusted R-squared: -0.01242
F-statistic: 0.362 on 1 and 51 DF, p-value: 0.5501

cor(EPWaterbody$HUC12, EPWaterbody$PercentSqMeters)
[1] -0.08394814




Correlation Coefficient = -0.084: a very weak negative correlation was observed when regressing HUC12 to percent impaired waterbodies.

P-Value = 0.550: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*HUC 10 (square meters) vs. Percent Impaired Waterways & Waterbodies*

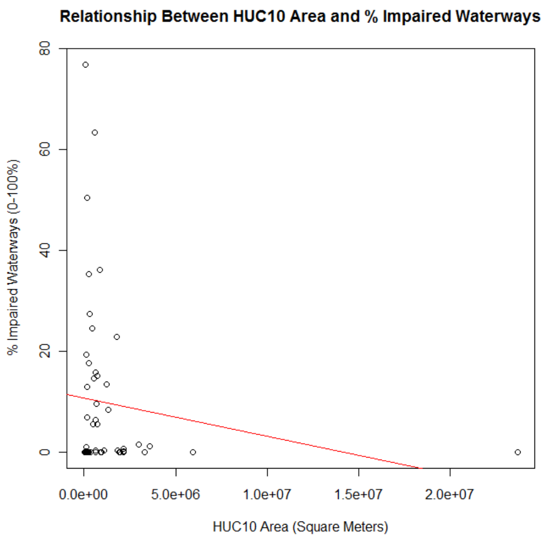
$H_o$: HUC10 (square meters) has no effect on percent impaired waterways / waterbodies.
$H_a$: HUC10 (square meters) has an effect on percent impaired waterways / waterbodies.

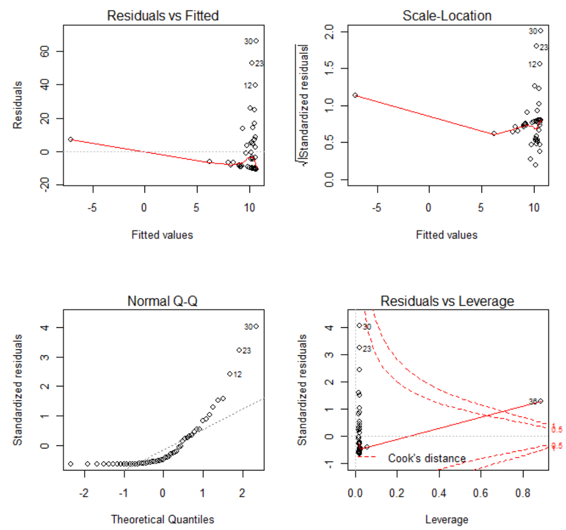
**R Outputs: Percent Impaired Waterways**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 1.069e+01 | 2.454e+00 | 4.357 | 6.4e-05 |
| HUC10 | -7.507e-07 | 6.906e-07 | -1.087 | 0.282 |

Residual standard error: 16.58 on 51 degrees of freedom
Multiple R-squared: 0.02265, Adjusted R-squared: 0.003482
F-statistic: 1.182 on 1 and 51 DF, p-value: 0.2821

cor(EPWaterway$HUC10, EPWaterway$PercentImpaired)
[1] -0.1504838




Correlation Coefficient = -0.150: a weak negative correlation was observed when regressing HUC10 to percent impaired waterways

P-Value = 0.282: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data

Normal Q-Q- Plot: implies non-normal distribution and data is rght-skewed.

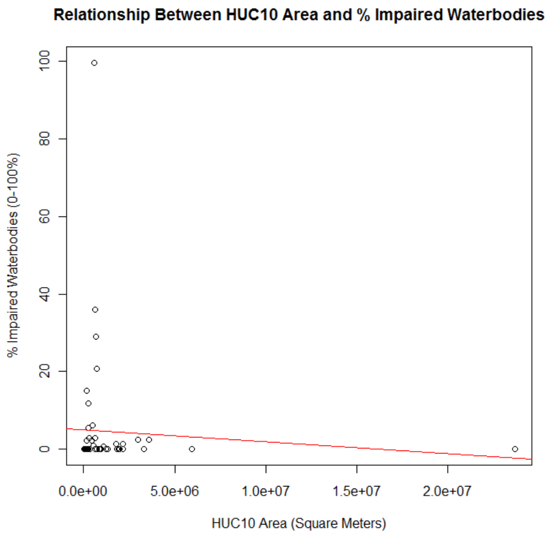
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

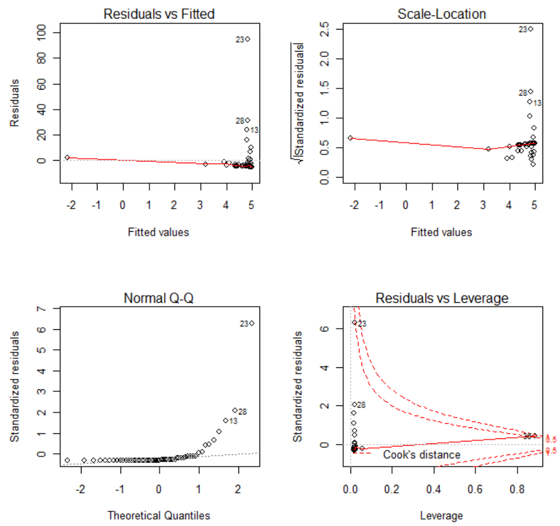
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 4.996e+00 | 2.253e+00 | 2.217 | 0.0311 |
| HUC10 | -3.022e-07 | 6.339e-07 | -0.477 | 0.6356 |

Residual standard error: 15.22 on 51 degrees of freedom
Multiple R-squared: 0.004438, Adjusted R-squared: -0.01508
F-statistic: 0.2273 on 1 and 51 DF, p-value: 0.6356

cor(EPWaterbody$HUC10, EPWaterbody$PercentSqMeters)
[1] -0.06661507




Correlation Coefficient = -0.067: a very weak negative correlation was observed when regressing HUC10 to percent impaired waterbodies

P-Value = 0.636: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*Average Elevation (meters) vs. Percent Impaired Waterways & Waterbodies*

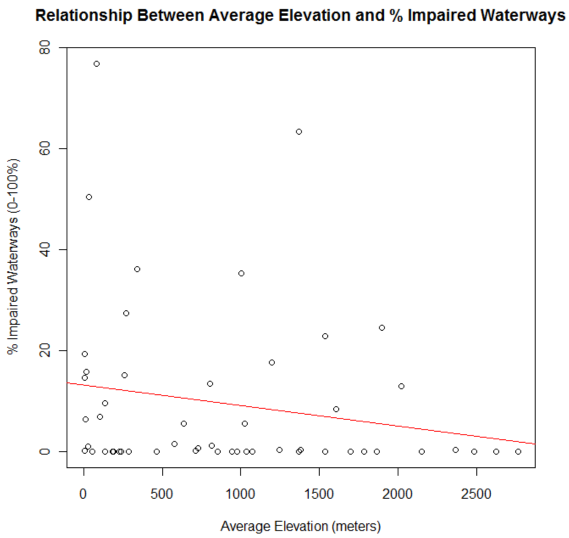
$H_o$: Average Elevation (meters) has no effect on percent impaired waterways / waterbodies.
$H_a$: Average Elevation (meters) has an effect on percent impaired waterways / waterbodies.

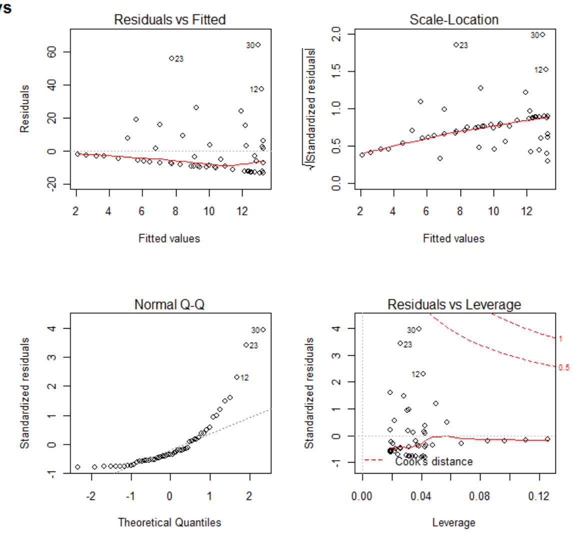
**<u>R Outputs: Percent Impaired Waterways</u>**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 13.312366 | 3.409276 | 3.905 | 0.000278 |
| AvgElev | -0.004060 | 0.002867 | -1.416 | 0.162843 |

Residual standard error: 16.45 on 51 degrees of freedom
Multiple R-squared: 0.03783, Adjusted R-squared: 0.01896
F-statistic: 2.005 on 1 and 51 DF, p-value: 0.1628

cor(EPWaterway$AvgElev, EPWaterway$PercentImpaired)
[1] -0.1944985




Correlation Coefficient = -0.194: a weak negative correlation was observed when regressing average elevation to percent impaired waterways

P-Value = 0.163: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data

Normal Q-Q Plot: implies non-normal distribution and data is right-skewed.

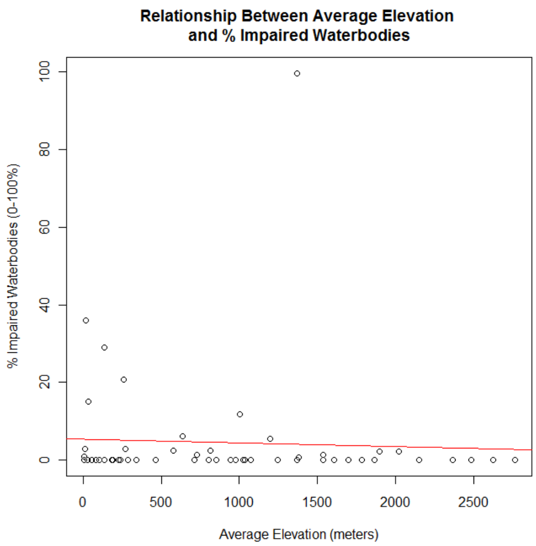
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows multiple observations that are influential in the overall distribution of the data.

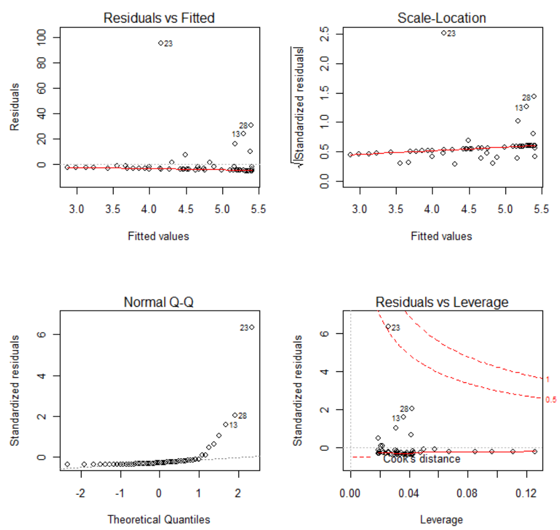
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 5.4155428 | 3.1572952 | 1.715 | 0.0924 . |
| AvgElev | -0.0009216 | 0.0026554 | -0.347 | 0.7300 |

Residual standard error: 15.23 on 51 degrees of freedom
Multiple R-squared: 0.002356, Adjusted R-squared: -0.01721
F-statistic: 0.1205 on 1 and 51 DF, p-value: 0.73

cor(EPWaterbody$AvgElev, EPWaterbody$PercentSqMeters)
[1] -0.04854139




Correlation Coefficient = -0.049: a very weak negative correlation was observed when regressing average elevation to percent impaired waterways

P-Value = 0.730: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship

Scale-Location Plot: unequal variance in the data

Normal Q-Q Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows multiple observations that are influential in the overall distribution of the data.

*Average Slope (degrees) vs. Percent Impaired Waterways & Waterbodies*

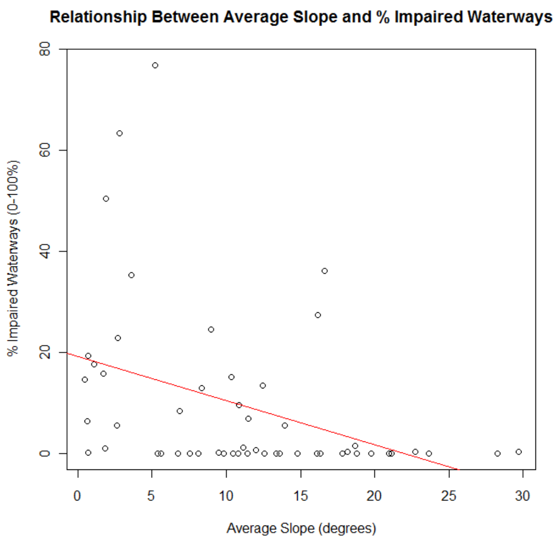
$H_o$: Average Slope (degrees) has no effect on percent impaired waterways / waterbodies.
$H_a$: Average Slope (degrees) has an effect on percent impaired waterways / waterbodies.

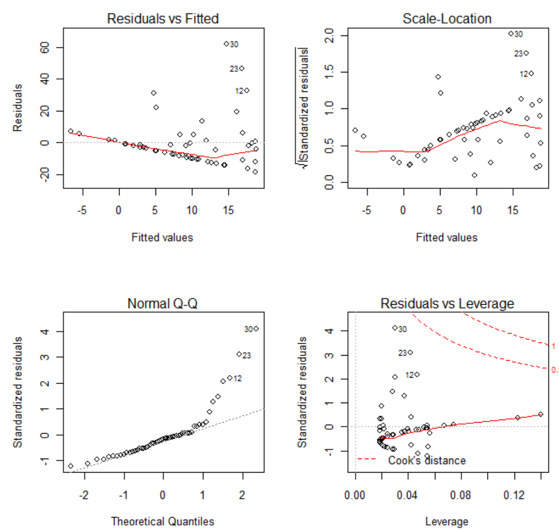
## R Outputs: Percent Impaired Waterways

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 19.2188 | 3.7648 | 5.105 | 4.96e-06 |
| AvgSlop | -0.8742 | 0.2858 | -3.059 | 0.00354 |

Residual standard error: 15.41 on 51 degrees of freedom
Multiple R-squared: 0.155, Adjusted R-squared: 0.1384
F-statistic: 9.356 on 1 and 51 DF, p-value: 0.003537

cor(EPWaterway$AvgSlop, EPWaterway$PercentImpaired)
[1] -0.3937173




Correlation Coefficient = -0.394: a weak negative correlation was observed when regressing average slope to percent impaired waterways.

P-Value = 0.004: significant at alpha = 0.10 level; the results of this linear regression analysis rejected the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data

Normal Q-Q Plot: implies non-normal distribution and data is right-skewed.

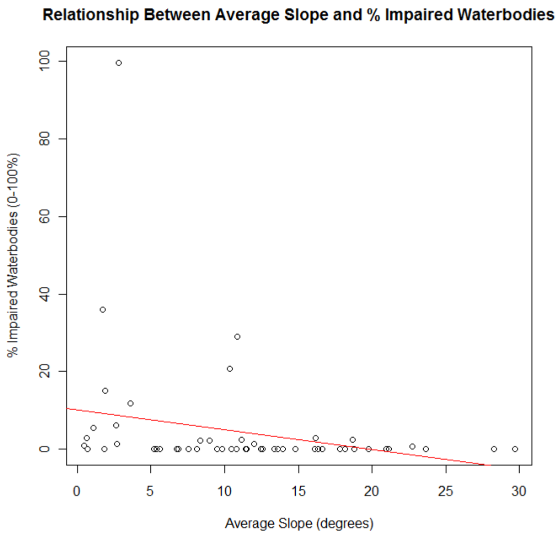
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

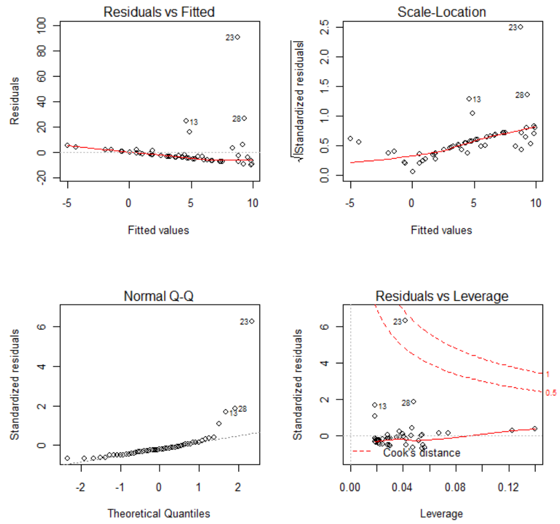
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 10.1788 | 3.6028 | 2.825 | 0.00673 |
| AvgSlop | -0.5126 | 0.2735 | -1.874 | 0.06661 |

Residual standard error: 14.75 on 51 degrees of freedom
Multiple R-squared: 0.06445, Adjusted R-squared: 0.0461
F-statistic: 3.513 on 1 and 51 DF, p-value: 0.06661

cor(EPWaterbody$AvgSlop, EPWaterbody$PercentSqMeters)
[1] -0.2538676




Correlation Coefficient = -0.254: a weak negative correlation was observed when regressing average slope to percent impaired waterbodies.

P-Value = 0.067: significant at alpha = 0.10 level; the results of this linear regression analysis rejected the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

*Amount of Hydrography vs. Percent Impaired Waterways & Waterbodies*

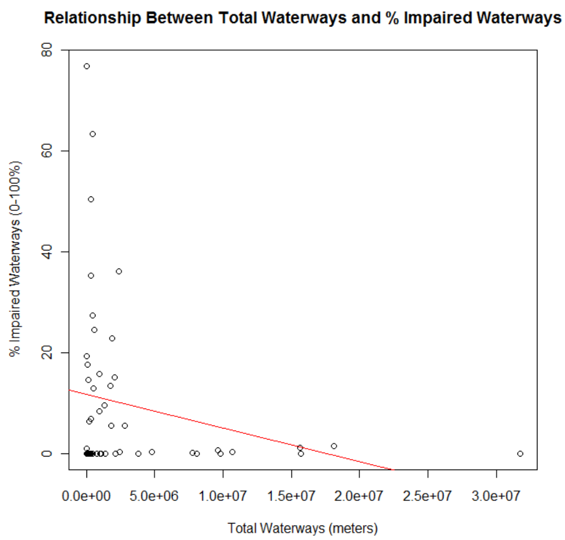
$H_o$: Total Waterways (meters) has no effect on percent impaired waterways / waterbodies.
$H_a$: Total Waterways (meters) has an effect on percent impaired waterways / waterbodies.

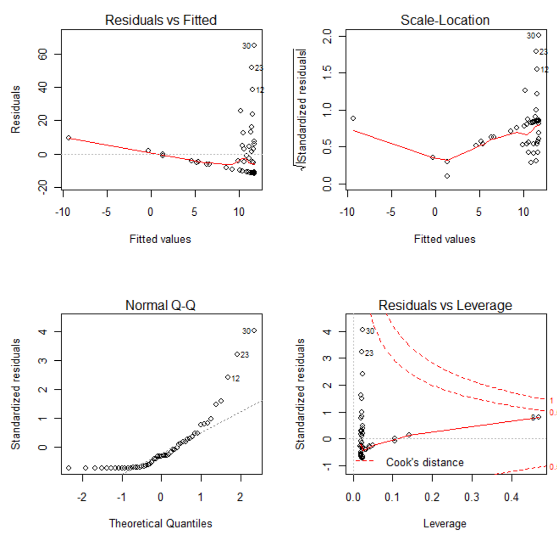
**<u>R Outputs: Percent Impaired Waterways</u>**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 1.180e+01 | .542e+00 | 4.642 | 2.45e-05 |
| WaterwayMeters | -6.669e-07 | 3.824e-07 | -1.744 | 0.0872 . |

Residual standard error: 16.29 on 51 degrees of freedom
Multiple R-squared: 0.05628, Adjusted R-squared: 0.03778
F-statistic: 3.042 on 1 and 51 DF, p-value: 0.08718

cor(EPWaterway$WaterwayMeters, EPWaterway$PercentImpaired)
[1] -0.2372436




Correlation Coefficient = -0.237: a weak negative correlation was observed when regressing total waterway meters to percent impaired waterways.

P-Value = 0.087: significant at alpha = 0.10 level; the results of this linear regression analysis rejected the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

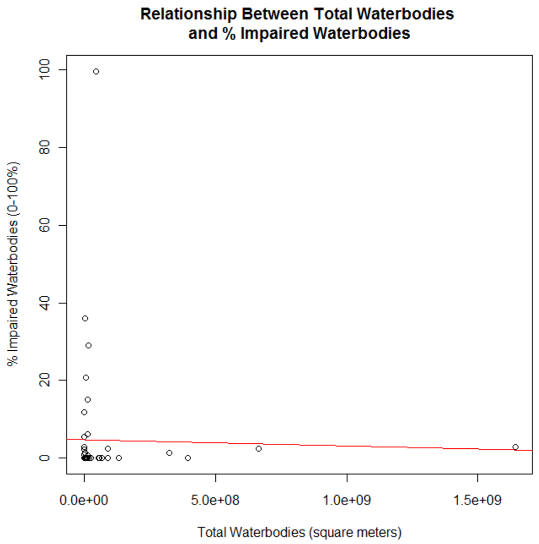
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also one particular observation that is influential in the overall distribution of the data.

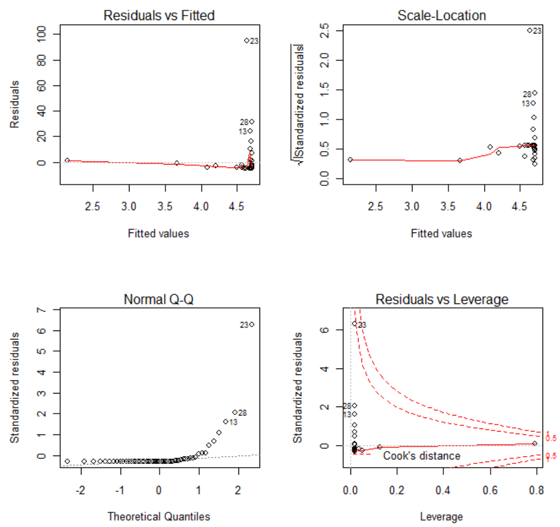
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 4.707e+00 | 2.183e+00 | 2.157 | 0.0358 |
| WBSqMeters | -1.563e-09 | 8.551e-09 | -0.183 | 0.8557 |

Residual standard error: 15.25 on 51 degrees of freedom
Multiple R-squared: 0.0006548, Adjusted R-squared: -0.01894
F-statistic: 0.03342 on 1 and 51 DF, p-value: 0.8557

cor(EPWaterbody$WBSqMeters, EPWaterbody$PercentSqMeters)
[1] -0.02558957




Correlation Coefficient = -0.026: a very weak negative correlation is observed when regressing total waterbody square meters to percent impaired waterbodies.

P-Value = 0.856: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*Percent Impervious Surface vs. Percent Impaired Waterways & Waterbodies*

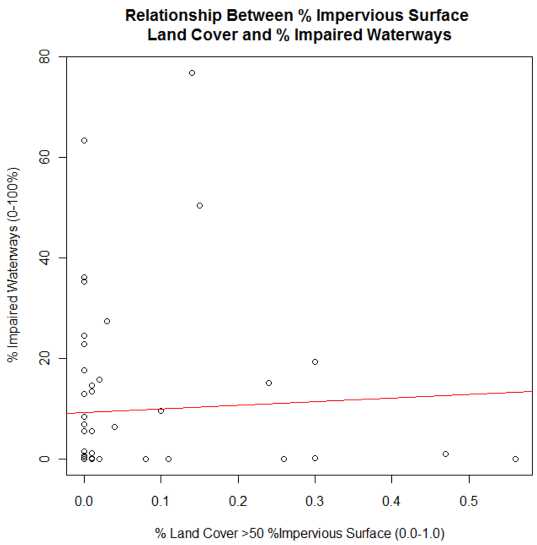
$H_o$: Percent Impervious Surface has no effect on percent impaired waterways / waterbodies.
$H_a$: Percent Impervious Surface has an effect on percent impaired waterways / waterbodies.

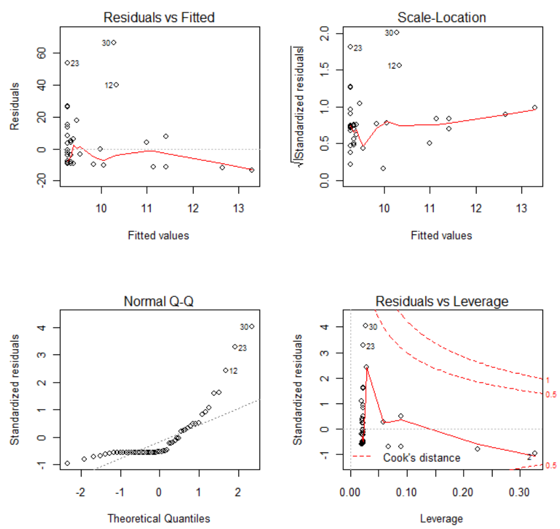
## R Outputs: Percent Impaired Waterways

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 9.264 | 2.557 | 3.622 | 0.000672 |
| ImpSurf | 7.196 | 18.578 | 0.387 | 0.700129 |

Residual standard error: 16.74 on 51 degrees of freedom
Multiple R-squared: 0.002933, Adjusted R-squared: -0.01662
F-statistic: 0.15 on 1 and 51 DF, p-value: 0.7001

cor(LCUWaterway$ImpSurf, LCUWaterway$PercentImpaired)
[1] 0.05415648




Correlation Coefficient = 0.054: a very weak positive correlation was observed when regressing impervious surface to percent impaired waterways.

P-Value = 0.700: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

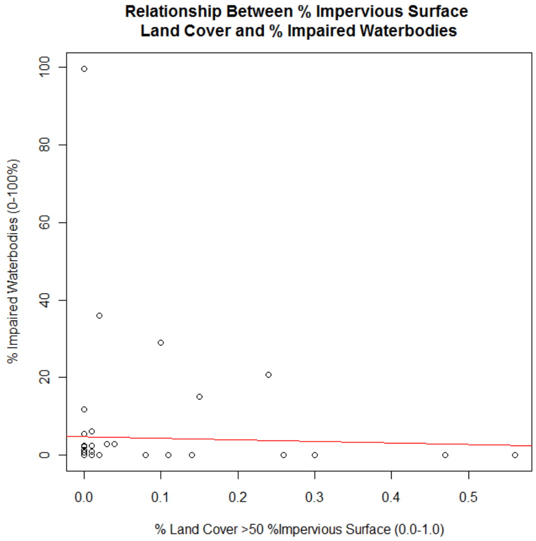
Residuals Vs. Leverage Plot: shows few outliers in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

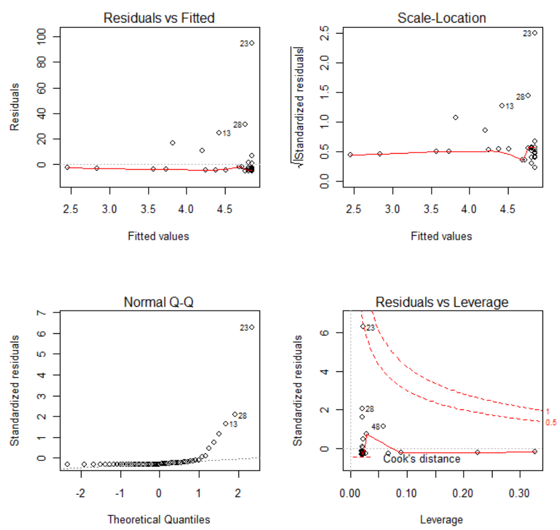
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 4.853 | 2.328 | 2.085 | 0.0421 |
| ImpSurf | -4.295 | 16.910 | -0.254 | 0.8005 |

Residual standard error: 15.24 on 51 degrees of freedom
Multiple R-squared: 0.001263, Adjusted R-squared: -0.01832
F-statistic: 0.0645 on 1 and 51 DF, p-value: 0.8005

cor(LCUWaterbody$ImpSurf, LCUWaterbody$PercentSqMeters)
[1] -0.03554008




Correlation Coefficient = -0.036: a very weak negative correlation is observed when regressing impervious surface to percent impaired waterbodies.

P-Value = 0.801: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

*Percent Urban Development vs. Percent Impaired Waterways & Waterbodies*

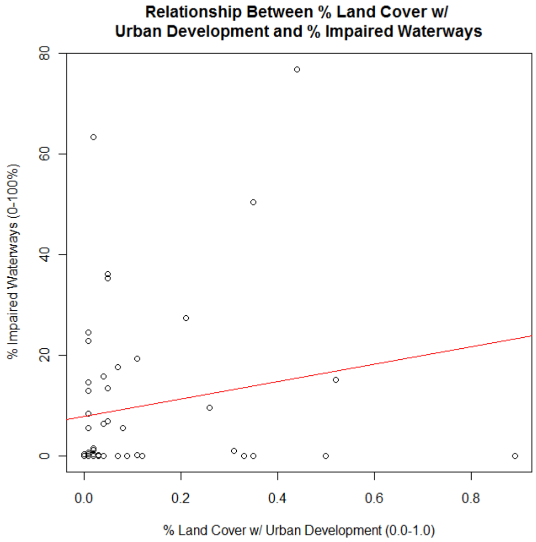
$H_o$: Percent Urban Development has no effect on percent impaired waterways / waterbodies.
$H_a$: Percent Urban Development has an effect on percent impaired waterways / waterbodies.

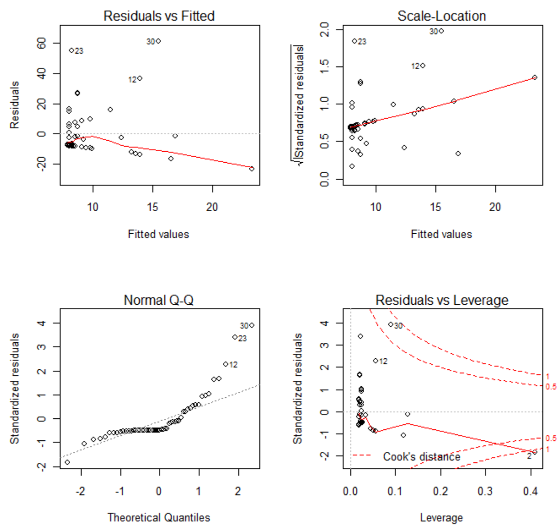
**R Outputs: Percent Impaired Waterways**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 7.866 | 2.657 | 2.961 | 0.00465 |
| UrbDev | 17.327 | 13.143 | 1.318 | 0.19329 |

Residual standard error: 16.49 on 51 degrees of freedom
Multiple R-squared: 0.03295, Adjusted R-squared: 0.01399
F-statistic: 1.738 on 1 and 51 DF, p-value: 0.1933

cor(LCUWaterway$UrbDev, LCUWaterway$PercentImpaired)
[1] 0.1815333




Correlation Coefficient = 0.182: a weak positive correlation was observed when regressing urban development to percent impaired waterways.

P-Value = 0.1933: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

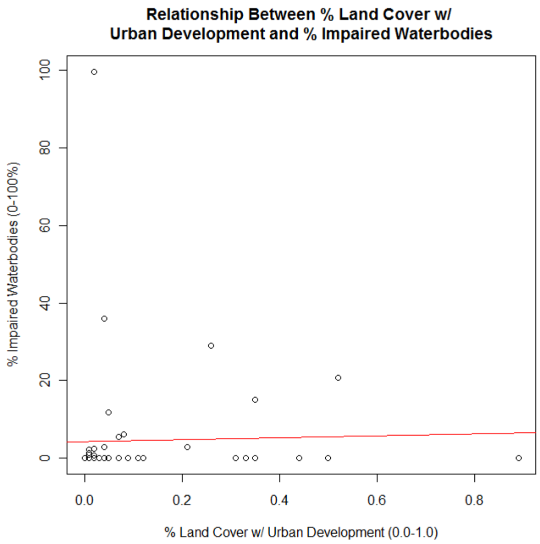
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

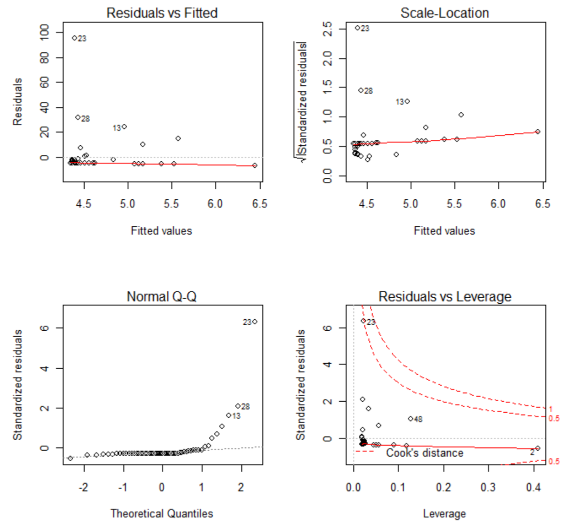
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 4.345 | 2.456 | 1.769 | 0.0829 |
| UrbDev | 2.364 | 12.151 | 0.195 | 0.8465 |

Residual standard error: 15.24 on 51 degrees of freedom
Multiple R-squared: 0.0007419, Adjusted R-squared: -0.01885
F-statistic: 0.03786 on 1 and 51 DF, p-value: 0.8465

cor(LCUWaterbody$UrbDev, LCUWaterbody$PercentSqMeters)
[1] 0.02723716




Correlation Coefficient = 0.027: a very weak positive correlation is observed when regressing urban development to percent impaired waterbodies.

P-Value = 0.847: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*Percent Agricultural Land Cover vs. Percent Impaired Waterways & Waterbodies*

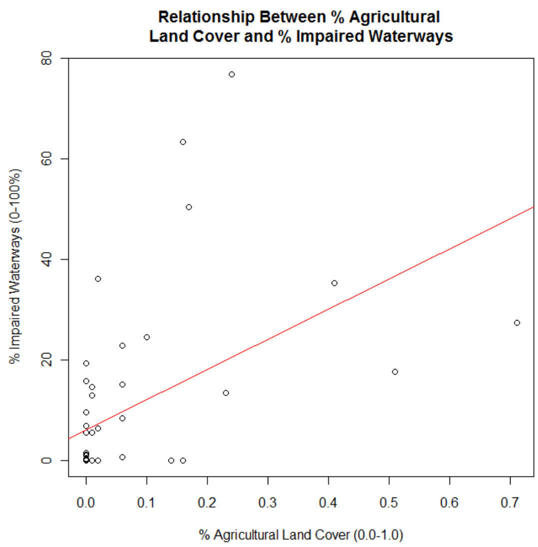
$H_o$: Percent Agricultural Land Cover has no effect on percent impaired waterways / waterbodies.
$H_a$: Percent Agricultural Land Cover has an effect on percent impaired waterways / waterbodies.

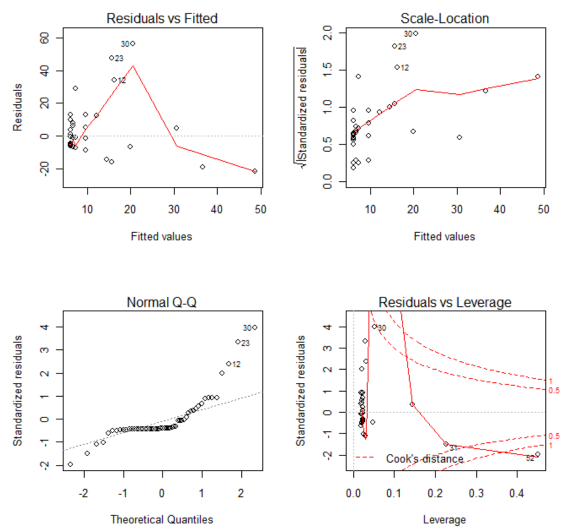
**R Outputs: Percent Impaired Waterways**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 6.066 | 2.189 | 2.771 | 0.007774 |
| Ag | 60.131 | 14.740 | 4.080 | 0.000159 |

Residual standard error: 14.56 on 51 degrees of freedom
Multiple R-squared: 0.246,  Adjusted R-squared: 0.2313
F-statistic: 16.64 on 1 and 51 DF,  p-value: 0.0001587

cor(LCUWaterway$Ag, LCUWaterway$PercentImpaired)
[1] 0.4960226




Correlation Coefficient = 0.496: a moderate positive correlation was observed when regressing agricultural land cover to percent impaired waterways.

P-Value = 0.00016: significant at alpha = 0.10 level; the results of this linear regression analysis rejected the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

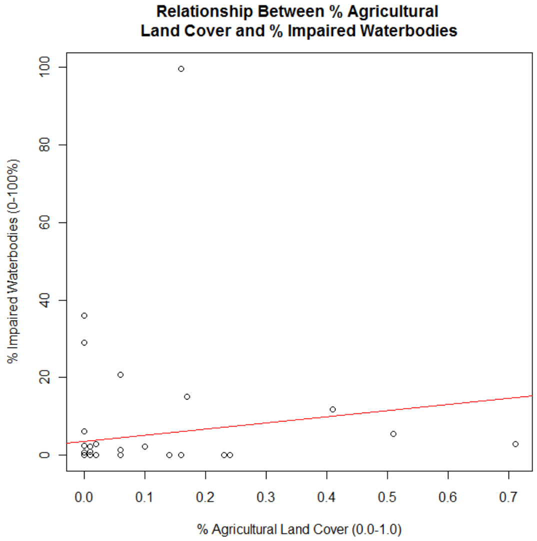
Residuals Vs. Leverage Plot: shows few outliers in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

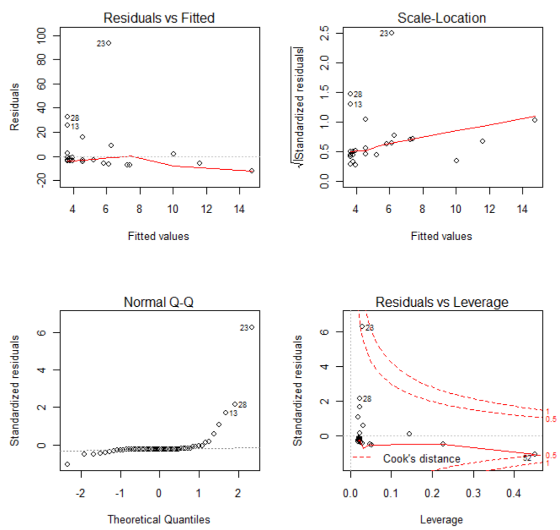
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 3.651 | 2.270 | 1.609 | 0.114 |
| Ag | 15.636 | 15.282 | 1.023 | 0.311 |

Residual standard error: 15.1 on 51 degrees of freedom
Multiple R-squared: 0.02011,  Adjusted R-squared: 0.0008992
F-statistic: 1.047 on 1 and 51 DF, p-value: 0.3111

cor(LCUWaterbody$Ag, LCUWaterbody$PercentSqMeters)
[1] 0.1418191




Correlation Coefficient = 0.142: a weak positive correlation is observed when regressing agricultural land cover to percent impaired waterbodies.

P-Value = 0.311: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed..

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*Percent Forest Land Cover vs. Percent Impaired Waterways & Waterbodies*

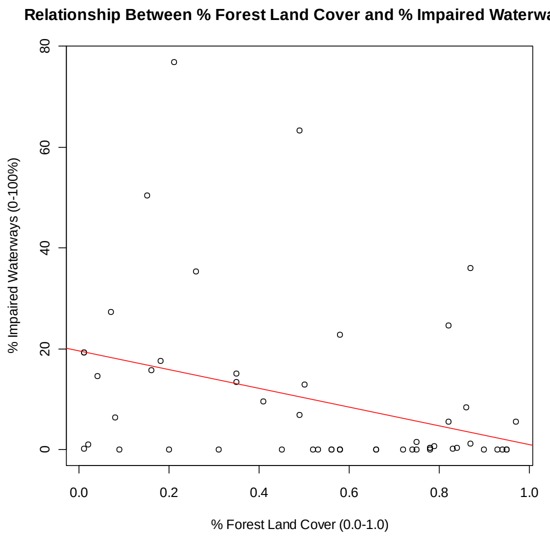
$H_o$: Percent Forest Land Cover has no effect on percent impaired waterways / waterbodies.
$H_a$: Percent Forest Land Cover has an effect on percent impaired waterways / waterbodies.

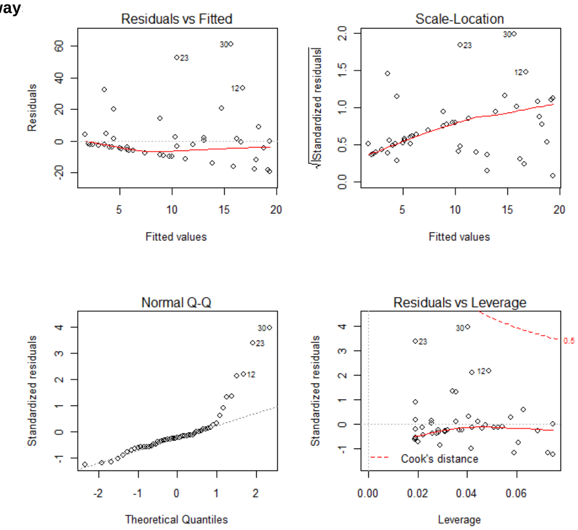
## R Outputs: Percent Impaired Waterways

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 19.594 | 4.361 | 4.493 | 4.05e-05 |
| Forest | -18.541 | 7.093 | -2.614 | 0.0117 |

Residual standard error: 15.75 on 51 degrees of freedom
Multiple R-squared: 0.1181, Adjusted R-squared: 0.1008
F-statistic: 6.832 on 1 and 51 DF, p-value: 0.01174

cor(LCUWaterway$Forest, LCUWaterway$PercentImpaired)
[1] -0.3437099




Correlation Coefficient = -0.344: a moderately weak negative correlation was observed when regressing forest land cover to percent impaired waterways.

P-Value = 0.012: significant at alpha = 0.10 level; the results of this linear regression analysis rejected the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

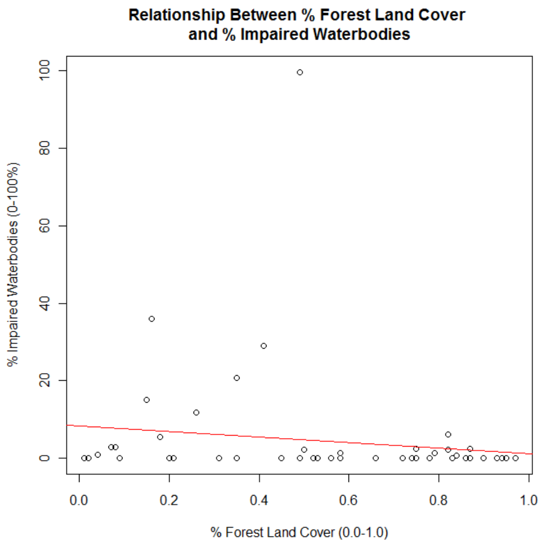
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows several observations that are influential in the overall distribution of the data.

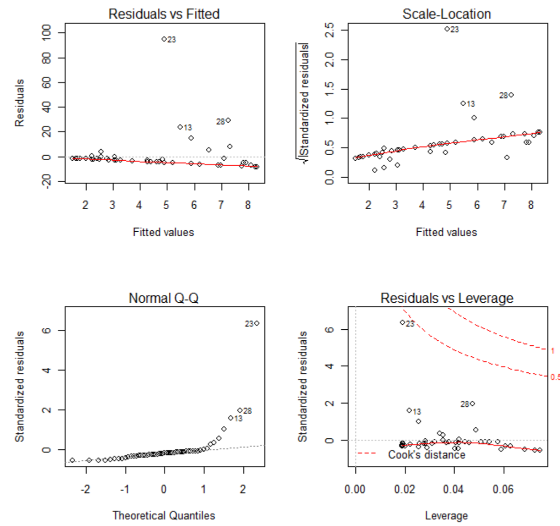
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 8.382 | 4.179 | 2.006 | 0.0502 |
| Forest | -7.094 | 6.798 | -1.044 | 0.3016 |

Residual standard error: 15.09 on 51 degrees of freedom
Multiple R-squared: 0.02091, Adjusted R-squared: 0.001713
F-statistic: 1.089 on 1 and 51 DF, p-value: 0.3016

cor(LCUWaterbody$Forest, LCUWaterbody$PercentSqMeters)
[1] -0.1446058




Correlation Coefficient = -0.145: a weak negative correlation was observed when regressing forest land cover to percent impaired waterbodies.

P-Value = 0.302: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows several observations that are influential in the overall distribution of the data.

*Number of Dams vs. Percent Impaired Waterways & Waterbodies*

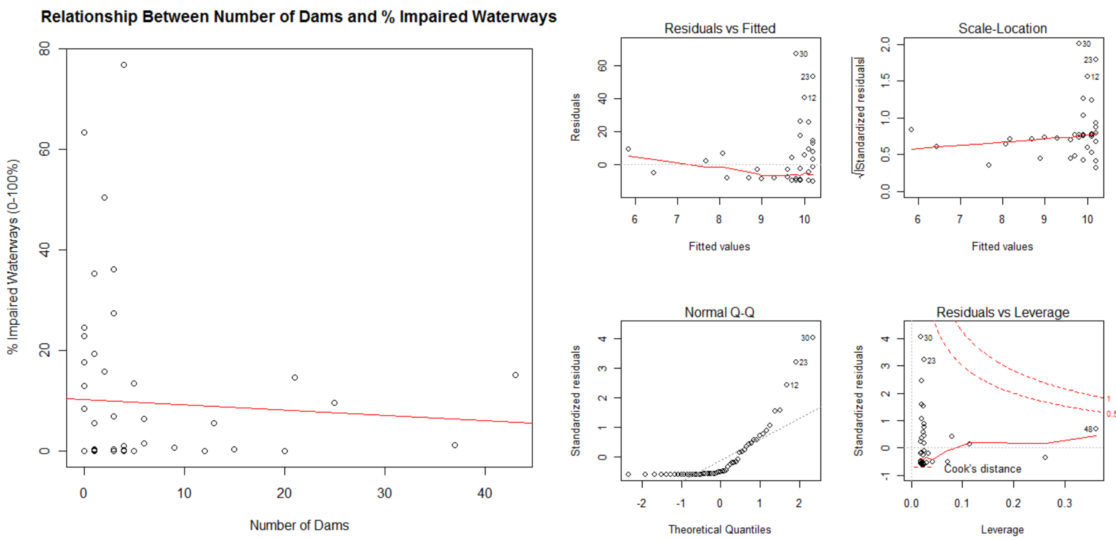
$H_o$: Number of Dams has no effect on percent impaired waterways / waterbodies.
$H_a$: Number of Dams has an effect on percent impaired waterways / waterbodies.

**R Outputs: Percent Impaired Waterways**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 10.2141 | 2.6469 | 3.859 | 0.000322 |
| Dams | -0.1019 | 0.2582 | -0.395 | 0.694774 |

Residual standard error: 16.74 on 51 degrees of freedom
Multiple R-squared: 0.003044, Adjusted R-squared: -0.0165
F-statistic: 0.1557 on 1 and 51 DF, p-value: 0.6948

cor(SocialWaterway$Dams, SocialWaterway$PercentImpaired)
[1] -0.0551727




Correlation Coefficient = -0.055: a very weak negative correlation was observed when regressing number of dams to percent impaired waterways.

P-Value = 0.695: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

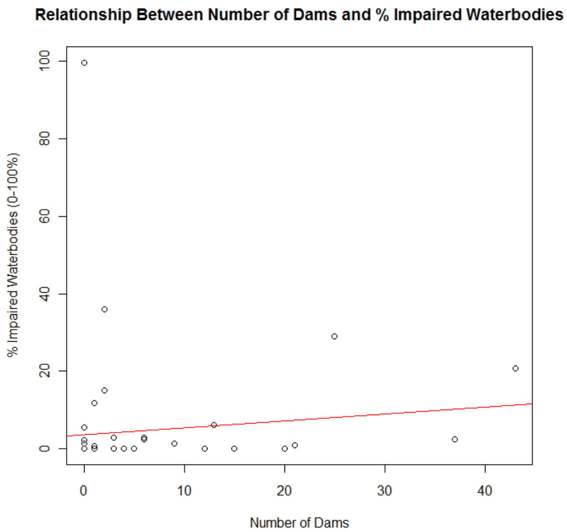
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

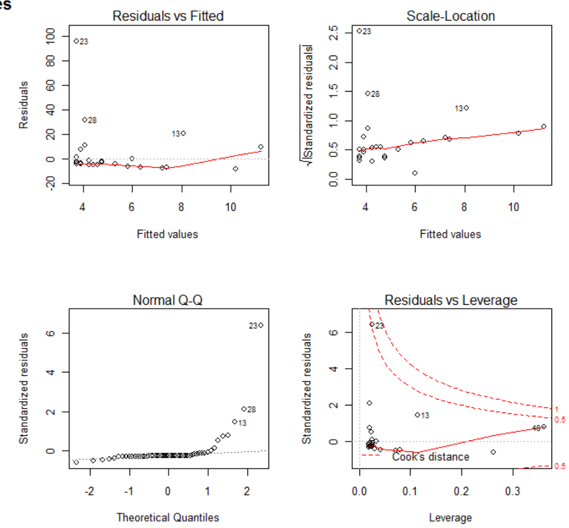
## R Outputs: Percent Impaired Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 3.7052 | 2.3978 | 1.545 | 0.128 |
| Dams | 0.1753 | 0.2339 | 0.750 | 0.457 |

Residual standard error: 15.17 on 51 degrees of freedom
Multiple R-squared: 0.01089, Adjusted R-squared: -0.008499
F-statistic: 0.5618 on 1 and 51 DF, p-value: 0.457

cor(SocialWaterbody$Dams, SocialWaterbody$PercentSqMeters)
[1] 0.1043786




Correlation Coefficient = 0.104: a very weak positive correlation was observed when regressing number of dams to percent impaired waterbodies.

P-Value = 0.457: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows two particular observations that are influential in the overall distribution of the data.

*Number of NPDES Permits vs. Percent Impaired Waterways & Waterbodies*

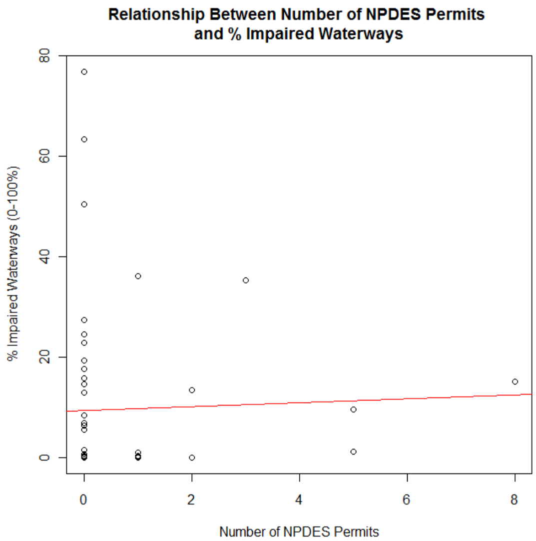
$H_o$: Number of NPDES Permits has no effect on percent impaired waterways / waterbodies.
$H_a$: Number of NPDES Permits has an effect on percent impaired waterways / waterbodies.

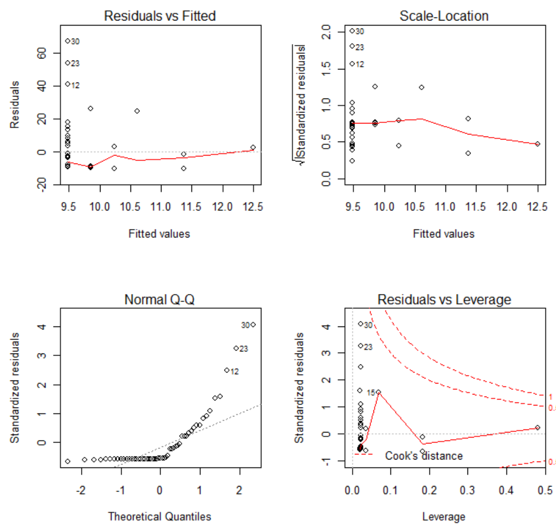
**R Outputs: Impaired Percent Waterways**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 9.4756 | 2.4713 | 3.834 | 0.000348 |
| NPDES | 0.3785 | 1.5371 | 0.246 | 0.806463 |

Residual standard error: 16.76 on 51 degrees of freedom
Multiple R-squared: 0.001188,   Adjusted R-squared: -0.0184
F-statistic: 0.06065 on 1 and 51 DF,  p-value: 0.8065

cor(SocialWaterway$NPDES, SocialWaterway$PercentImpaired)
[1] 0.03446401




Correlation Coefficient = 0.034: a very weak positive correlation was observed when regressing number of NPDES permits to percent impaired waterways.

P-Value = 0.807: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

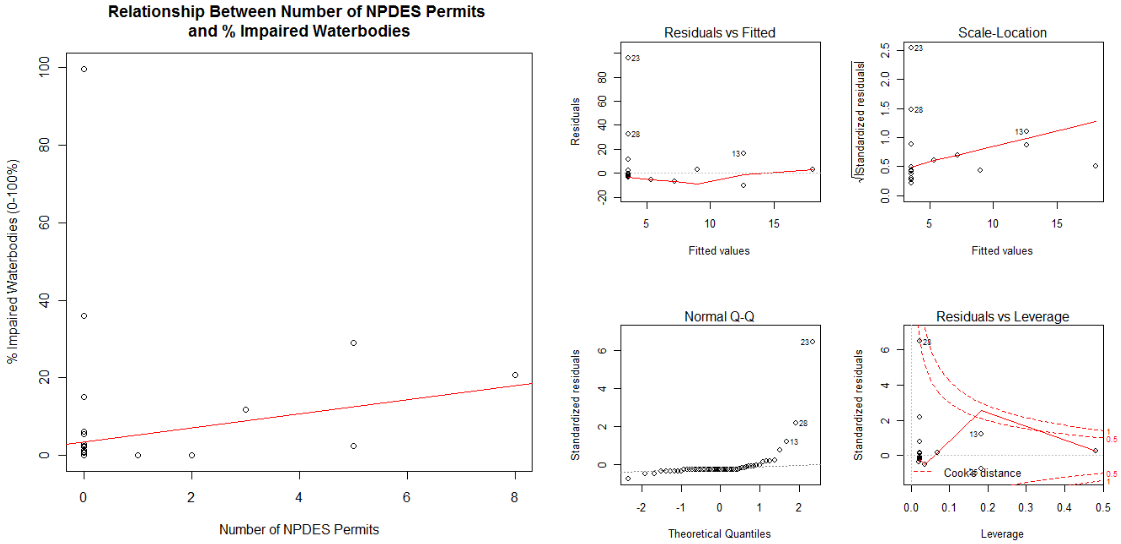
Residuals Vs. Leverage Plot: shows several outliers in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

## R Outputs: Impaired Percent Waterbodies

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 3.532 | 2.211 | 1.597 | 0.116 |
| NPDES | 1.818 | 1.375 | 1.321 | 0.192 |

Residual standard error: 15 on 51 degrees of freedom
Multiple R-squared: 0.0331, Adjusted R-squared: 0.01415
F-statistic: 1.746 on 1 and 51 DF, p-value: 0.1923

cor(SocialWaterbody$NPDES, SocialWaterbody$PercentSqMeters)
[1] 0.1819465




Correlation Coefficient = 0.182: a very weak positive correlation was observed when regressing number of NPDES permits to percent impaired waterbodies.

P-Value = 0.192: insignificant at alpha = 0.10 level; the results of this linear regression analysis failed to reject the null hypothesis.

Residual vs. Fitted Plot: residuals are high and suggest non-linear relationship.

Scale-Location Plot: unequal variance in the data.

Normal Q-Q- Plot: implies non-normal distribution and data is right-skewed.

Residuals Vs. Leverage Plot: shows one outlier in the data. The leverage plot also shows one particular observation that is influential in the overall distribution of the data.

*Backward Stepwise Regression Model for Percent Impaired Waterways*

Start: AIC=295.36
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag + Forest + Dams + NPDES

Step 1: AIC=293.37
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag + Dams + NPDES

Step 2: AIC=291.45
PercentImpaired ~ HUC12 + HUC10 + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag + Dams + NPDES

Step 3: AIC=289.58
PercentImpaired ~ HUC12 + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag + Dams + NPDES

Step 4: AIC=287.72
PercentImpaired ~ HUC12 + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag + Dams

Step 5: AIC=285.84
PercentImpaired ~ HUC12 + AvgSlop + WaterwayMeters + ImpSurf + UrbDev + Ag

Step 6: AIC=284
PercentImpaired ~ HUC12 + AvgSlop + ImpSurf + UrbDev + Ag

Step 7: AIC=282.84
PercentImpaired ~ AvgSlop + ImpSurf + UrbDev + Ag

Step 8: AIC=281.92
PercentImpaired ~ AvgSlop + UrbDev + Ag

Final: AIC=280.67
PercentImpaired ~ AvgSlop + Ag

*Backward Stepwise Regression Model for Percent Impaired Waterbodies*

Start: AIC=295.11
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag + Forest + Dams + NPDES

Step 1: AIC=293.12
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag + Dams + NPDES

Step 2: AIC=291.23
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag + Dams

Step 3: AIC=289.31
PercentImpaired ~ HUC12 + HUC10 + AvgElev + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag

Step 4: AIC=287.45
PercentImpaired ~ HUC12 + HUC10 + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag

Step 5: AIC=285.62
PercentImpaired ~ HUC12 + AvgSlop + WBSqMeters + ImpSurf + UrbDev + Ag

Step 6: AIC=284
PercentImpaired ~ HUC12 + AvgSlop + ImpSurf + UrbDev + Ag

Step 7: AIC=282.84
PercentImpaired ~ AvgSlop + ImpSurf + UrbDev + Ag

Step 8: AIC=281.92
PercentImpaired ~ AvgSlop + UrbDev + Ag

Final: AIC=280.67
PercentImpaired ~ AvgSlop + Ag

# Appendix IX: Processing Methods

**Objective 1**

Identifying Areas of Analysis (AOAs)

The NRCS WBD and NPS Current Administrative Park Boundaries dataset were re-projected to Albers Equal-Area Conic projection (a North American continent projection). A python script was produced in order to automatically export the intersecting HUC 12 polygons (this required modules imported from ArcGIS 9.3.1). The HUC 12 polygons were saved as individual shapefiles using their corresponding park code within the naming convention (ex. BIHO_HUC12.shp; 55 shapefiles in total). Python script *ParkIntersectHuc.py* is located in the appendix III (*code 10).*

A second coverage was created by merging (ArcToolBox > Data Management Tools > General > Merge) the individual Park_HUC12 shapefiles into a single shapefile. The output from the merge geoprocess was dissolved (ArcToolBox > Data Management Tools > Generalization > Dissolve) by park code. The resulting output is a shapefile that includes one feature (intersecting HUC 12 polygons dissolved into single polygon) for each park.

To minimize confusion, the individual HUC 12 shapefiles by park codes (55 individual shapefiles) will be referred to as AOA1 and the dissolved HUC 12 shapefile (one shapefile with 55 park-HUC12 boundaries) will be referred to as AOA2. The abbreviation AOA will be a general term used to describe the areas of analysis for this study.

**Objective 1**

Quantifying CWA Impairments: Calculating Baseline Hydrographic Statistics

Pre-staged NHD was downloaded from nhd.usgs.gov by state. NHD data was obtained for the states of Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, and Washington in file geodatabase format (.gdb extension). Within each geodatabase was a dataset that contained five feature classes: NHDPoint, NHDLine, NHDWaterbody, NHDArea, and NHDFlowline. A thorough description of each feature class is provided in the help documentation located on the NHD website (nhd.usgs.gov). Since this study is primarily focused on waterways and waterbodies, only NHDFlowline and NHDWaterbody feature classes were included in the data collection. During the time of data collection, NHD for AOAs associated with Kaloko-Honokōhau National Historical Park and Oregon Caves National Monument were unavailable. Therefore, the number of AOAs was reduced from 55 to 53 for this study.

The NHDFlowline feature classes (one from each state, seven in total) were merged into one feature class. The merged feature class was reprojected into Albers Equal-Area Conic projection and added into an ArcMap session with AOA2. The split tool (ArcToolBox > Analysis Tools > Extract > Split) was used in order to clip the merged NHDFlowline feature class to each AOA. The same methods were applied to the NHDWaterbody feature classes. The results were 53 feature classes that contained flowlines for each AOA and another 53 feature classes for waterbodies.

Area square meters of waterbodies were calculated using the *calculate geometry* tool for the 53 NHDWaterbody feature classes. Only select waterbody types were included in the summation of total square meters for each AOA. Using the NHD FTYPE classifications, features that were attributed with an FTYPE of 390 (lake/pond), 436 (reservoir), and 361 (playa) were included in the summation for total square meters.

Meters of waterways were calculated using the *calculate geometry* tool for the 53 NHDFlowline feature classes. However, not all flowlines were included in the summation for each AOA. *Select by Location* was used in order to identify flowlines that were within waterbodies with the specific FTYPES listed above. Selected features were excluded from the summation of meters for each AOA to ensure features were not being counted in both waterbody and waterway statistics. The total meters of waterways and square meters for waterbodies were summed for each AOA and recorded in *table A5-1* of appendix V.

**Objective 1**

Quantifying CWA Impairments: Calculating Percent Impaired Waterways & Waterbodies

Percent impaired waterways were calculated using state GIS delineations of assessment units and water quality reports. A commonality amongst state listings of impairments is the use of unique identifiers (sometimes referred to as the Entity ID) for each assessment unit. When an assessment unit is listed as impaired within state 303(d) list or in categories 4a, 4b, or 4c in state 305(b) report, the spatially-coinciding flowline features to the assessment unit is tagged with the corresponding Entity ID. Only flowlines that contribute to the total waterway meters summations were included in the attribution of Entity IDs. Impaired waterway meters were totaled for each AOA by including only featrures with an Entity ID in the summation. Impaired waterways were reported as a percentage by evaluating ([meters of impaired waterways] / [total waterway meters]) for each AOA. *Table 3* contains the percent of impaired waterways for each AOA.

The same processing methods for measuring percent impaired waterways were applied to percent impaired waterbodies. Only waterbody features that contributed to the total waterbody square meters were included in the attribution of Entity IDs. Percent impaired waterbodies were calculated for each AOA by evaluating ([square meters of impaired waterbodies] / [total waterbody square meters]). *Table 3* (pg 29) contains the percent of impaired waterbodies for each AOA.

**Objective 4**

Land Cover/Use Watershed Characteristics

*Percent Urban Development, Percent Agriculture, Percent Forest*

Measurements for *percent urban development, percent agriculture,* and *percent forest* were derived using the 2006 NLCD. The legend/classification that describes the value attribute table within the NLCD dataset is provided on the USGS NLCD 2006 webpage (http://www.mrlc.gov/nlcd06_leg.php). The values listed in table A9-1 were used to quantify percent cover of urban development, agriculture, and forest within each AOA. The data collected are shown in *table A5-2* of appendix V. Comprehensive processing methods for measuring *percent urban development, agriculture, and forest* are located in appendix IX

*Table A9-1. NLCD values included in this this study.*

| **Watershed Characteristic** | **Value** | **Description** |
|---|---|---|
| Percent Urban Development | 21 | **Developed, Open Space** – areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. |
| Percent Urban Development | 22 | **Developed, Low Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units. |
| Percent Urban Development | 23 | **Developed, Medium Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units. |
| Percent Urban Development | 24 | **Developed High Intensity** – highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover. |
| Percent Agriculture | 81 | **Pasture/Hay** – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for |

| | | |
|---|---|---|
| | | greater than 20% of total vegetation. |
| Percent Agriculture | 82 | **Cultivated Crops** – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled. |
| Percent Forest | 41 | **Deciduous Forest** – areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change. |
| Percent Forest | 42 | **Evergreen Forest** – areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage. |
| Percent Forest | 43 | **Mixed Forest** – areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover. |
| Percent Forest | 52 | **Shrub/Scrub** – areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. |
| Percent Forest | 90 | **Woody Wetlands** – areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |

The NLCD 2006 dataset was downloaded via the NRCS GeoSpatial Data Gateway (http://datagateway.nrcs.usda.gov/). NLCD data was obtained for the states of Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, and Washington. State coverages of NLCD were mosaicked into one NLCD raster. Prior to further processing, the mosaicked NLCD raster was re-projected to Albers Equal-Area Conic projection. Finally, a script was produced to clip the mosaicked NLCD raster to AOA2 (*Clip_NLCD_to_AOA2.py* located in appendix III, *code 11*). The outputs were individual raster files (53 total; one for each AOA) with the following naming convention: NLCD_BIHO12 (NLCD = source dataset, BIHO = park code, 12 = HUC level).

The 53 NLCD rasters were added to an ArcMap session. Values were extracted from individual value attribute tables. For example, in order to derive percent forest cover, the counts for 41, 42, 43, 52, and 90 were summed and recorded. The total counts for all values were also summed in order to calculate a percent cover (ex. [summed counts for 41, 52, 43, 52, & 90] / total counts). This step was repeated to estimate percent agriculture (81 & 82) and percent urban development (21, 22, 23, & 24). The data collected are shown in *table A5-2* of appendix V.

*Percent Impervious Surface*

Data collected to estimate impervious surface are from NPScape, an ongoing monitoring project of landscape variables that is of interest to the National Park Service (http://science.nature.nps.gov/im/monitor/npscape/). NPScape serves impervious surface rasters based on Landscape Conservation Cooperative (LCC) units. Impervious surface rasters were downloaded for the following LCC's: Plains and Prairie Potholes, Southern Great Plains, Desert, Southern Rockies, Great Northern, Great Basin, North Pacific, South Pacific, and Pacific Islands. The processing methods for *percent impervious surface* were similar to those for processing *percent agriculture, percent forest*, and *percent urban development*. Rasters from all LCC's were mosaicked into one raster coverage. The mosaicked raster was reprojected into Albers Equal-Area Conic projection. Finally, a script was produced to clip the mosaicked impervious surface raster to AOA2 (*Clip_ImpSurf_to_AOA2.py* located in appendix III, *code 12*). The outputs were individual raster files (53 total; one for each AOA) with the following naming convention: ImpSurf_BIHO12 (ImpSurf = impervious surface, BIHO = park code, 12 = HUC level).

The 53 impervious surface grids were added to an ArcMap session. Values were extracted from individual raster's value attribute tables. Unlike NLCD classification, NPScape has assigned a "Class Name" to each value (ranging from 1 – 9):

| Value | Class Name |
|---|---|
| 1 | 0-2% |
| 2 | 2-4% |
| 3 | 4-6% |
| 4 | 6-8% |
| 5 | 8-10% |
| 6 | 10-15% |
| 7 | 15-25% |
| 8 | 25-50% |
| 9 | 50-100% |

For this study, only counts that pertain to the Value 9 were included in the data collection. Therefore, collected data represent percent land cover within a watershed that is >50% impervious surface. The total counts were also recorded to calculate the percent impervious surface cover (i.e. [counts from Value 9] / total counts). The data collected are located in *table A5-3* of appendix V.

**Objective 4**

Ecological/Physical Watershed Characteristics

*Watershed Size*

The NRCS WBD was downloaded via the NRCS GeoSpatial Data Gateway (http://datagateway.nrcs.usda.gov/) in shapefile format. WBD data was obtained for the states of California, Hawaii, Idaho, Montana, Nevada, Oregon, and Washington. WBD shapefiles (one from each state) were merged into a single shapefile. The merged shapefile was reprojected into Albers Equal-Area Conic projection. The reprojected shapefile and the NPS park boundaries were uploaded into an ArcMap session. All WBD polygons that intersected park boundaries were selected using the "Select by Location" spatial query tool. The selected features were exported as a shapefile titled "Prk_WBD.shp."

The WBD utilizes the USGS HUC classification system. HUC information is embedded within the attribute table. Therefore, Prk_WBD.shp was dissolved by HUC10 and HUC12 to produce two outputs (PWPrk_HUC12Bnd.shp & PWPrk_HUC10Bnd.shp). Since this study was premised around the AOAs identified in *objective 1*, further processing for HUC 12 WBD polygons was moot (AOAs = HUC 12 polygons that intersected the 53 park units of interest).

A python script titled "Park_Intersect_HUC10.py" was produced to export intersecting HUC 10 polygons to the 53 park boundaries. The resulting 53 shapefiles were saved using the naming convention BIHO_HUC10.shp. "Park_Intersect_HUC10.py" is located in appendix III (*code 13*).

The 53-HUC 10 shapefiles and AOA1 were added to an ArcMap session. The dataframe was projected to Albers Equal-Area Conic projection. The calculate geometry tool was used to measure the total square meters for each shapefile (106 total shapefiles). The data collected are located in *table A5-4* of appendix V.

*Topography (Average Elevation & Slope)*

EDNA data was downloaded from the LANDFIRE homepage (http://landfire.cr.usgs.gov/viewer/) for the states of Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, and Washington. 30m rasters were obtained for each state and mosaicked into a single grid. A script was produced to clip the single grid to AOA2, which resulted in a grid for each 53 AOAs (*Clip_EDNA_to_AOA2.py* is located in appendix III, *code 14*).

Average elevation was calculated for each AOA by opening the value attribute table and calculating the mean for all counts. The elevation grids were then used to produce slope grids (one for each AOA). Each elevation grid was added into an ArcMap session. The spatial analyst extension was enabled to access the Spatial Analyst Tools. The slope tool (ArcToolBox > Spatial Analyst Tools > Surface > Slope) was used for each grid in order to produce 53 slope grids (calculated in degrees). Average slope was calculated for each grid by opening the value attribute table and calculating the mean for all counts. The data collected are located in *table A5-5* of appendix V.

**Objective 4**

Social Watershed Characteristics

*Hydrological Alterations (Number of Dams)*

The National Inventory of Dams was downloaded in a personal geodatabase format (extension .mdb). A table within the geodatabase titled “NIDSTATEFEDERAL” contained latitude and longitude coordinates for all dams within the database. In addition, the table also contained other pertinent information such as the dam name, county location, river name, and ownership information. However, this study was only interested in the number of dams that intersect each AOA.

“NIDSTATEFEDERAL” table was uploaded into an ArcMap session. By specifying the latitude and longitude fields, ArcMap was able to georeference the location of each dam. By using *display xy data*, an intermediate layer was created that graphically displayed each latitude-longitude coordinates with a point. This intermediate layer was exported as a point shapefile and saved as “NID2009.shp.”

“NID2009.shp” and AOA2 were added to an ArcMap session. First, “NID2009.shp” was reprojected into Albers Equal-Area Conic projection to match the projection of AOA2. The split tool was used to clip the “NID2009.shp” to AOA2 using park codes as the split field. The outputs were 53 point shapefiles of “NID2009.shp” clipped to each AOA (using the naming convention “NID_BIHO_HUC12.shp”). Finally, all 53 outputs were added into an ArcMap session. The number of features within each point shapefile equaled the number of dams within each AOA. The data collected are located in *table A5-6* of appendix V.

*Number of NPDES Permits*

The USEPA national GIS coverage of NPDES permits is a point shapefile with details such as coordinates, zip code, and facility location embedded within the attribute table. The point shapefile was reprojected into Albers Equal-Area Conic projection and given the name "NPDES_201103.shp." Similar to studying potential correlation between the number of dams to water impairments, this study was only interested in the number of NPDES permits that exists within each AOA.

The processing methods for the *number of NPDES permits* were similar to those of *hydrological alterations*. "NPDES_201103.shp" and AOA2 were uploaded into an ArcMap session. The split tool was used to clip "NPDES_201103.shp" to AOA2 using park codes as the split field. The outputs were 53 point shapefiles of "NPDES_201103.shp" clipped to each AOA (using the naming convention "NPDES_BIHO12.shp"). The 53 outputs were added into ArcMap and the number of features within each shapefile corresponded to the number of NPDES permits that exists within each AOA. The data collected are located in *table A5-6* of appendix V.