SECTION 404 PERMITTING IN COASTAL TEXAS FROM 1996 - 2003:

PATTERNS AND EFFECTS ON STREAMFLOW

A Dissertation

by

WESLEY E. HIGHFIELD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2008

Major Subject: Urban and Regional Sciences

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Approved by:

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ABSTRACT

Section 404 Permitting in Coastal Texas from 1996 – 2003:
Patterns and Effects on Streamflow. (August 2008)

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Chair of Advisory Committee: Dr. Samuel D. Brody

This study explores the spatial-temporal patterns of Section 404 permitting program under the Clean Water Act and examines its impact on mean and peak annual streamflow. The study area consists of 47 sub-basins that are delineated based on USGS streamflow gauges. These sub-basins span from the southern portion of coastal Texas to the easternmost portion of coastal Texas. Descriptive, spatial and spatial-temporal statistical methods are used to explore patterns in Section 404 permitting between 1996 and 2003. The effects of Section 404 permit types on mean and peak annual streamflow over the same 8 year period are also statistically modeled with a host of other relevant control variables.

Exploratory analyses of Section 404 permits demonstrated characteristics that were indicative of suburban and, to a larger extent, exurban development. Explanatory analyses of the effects of Section 404 permitting on mean and peak streamflow showed that Section 404 permits increase both measures. These increases were minimal on a per-permit basis but have the ability to accumulate over time and result in much larger increases. Section 404 permits also displayed an ordered effect based on the permit type. Permit types that represent larger impacts had larger effects. The effects of permits of streamflow followed a descending pattern of Individual permits, Letters of Permission, Nationwide permits, and General permits. This "type of permit impact" supports the use of this measure as an indicator of wetland impact and loss and corroborates previous studies that have incorporated this measure.

DEDICATION

This work is dedicated to my son,

Jacob Forest.

ACKNOWLEDGEMENTS

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I would like to thank my committee chair, Sam Brody for his constant guidance, support and friendship. You have been a great chair and mentor. You have always been driven me to do my best, and are a great friend. You've finally gotten rid of your first graduate student. I would also like to thank Walt Peacock for his constant advice, academic and otherwise, often over fermented beverages. I'm also grateful to Mike Lindell, who always had time to answer questions and let me seek his advice. Thanks for all of your help and guidance over the past six years. Thanks also to Patti Smith, who offered her hydrologic expertise and assistance for this undertaking.

I would also like to thank my mother, who instilled the importance of education in me at a young age. As a result of her encouragement I have discovered that I will always seek out and enjoy learning, even if it didn't appear that way for quite a while.

Finally, I'm indebted to the love and support of my wife Linda. Somehow we have managed to obtain far more education than either of us ever dreamed, and done it at a time when most people would have had a hard time juggling the rest of life. Without your constant support and motivation, I would have never completed this dissertation, at least not in this decade. Thanks for believing in me.

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1. INTRODUCTION

1.1 Background of the Study

As early as the passage of the 1972 Federal Water Pollution Control Act the U.S. government has sought to protect the nation's water resources. Even more stringent controls were put in place following a U.S. Congressional goal to have "no overall net loss of wetlands" (National Research Council, 2001). The U.S. Army Corps of Engineers (USACE) was charged with implementing Section 404 of the Clean Water Act (CWA), an environmental permitting program that regulates activities which discharge dredge or fill material into waters of the United States. However, wetland losses and impacts continue despite ongoing federal attempts to curb activities that result in wetland degradation, alteration, or loss. For example, from the mid 1950s to the early 1990s the Texas coast alone lost an estimated 210,600 acres of wetlands (Moulton, Dahl & Dall, 1997).

Also during late 1970s onward, there was an increasing recognition of the functional importance of wetlands. These functions include biodiversity support, water quality improvement, flood attenuation, and carbon sequestration; all of which are central landscape functions that are impaired when wetlands are lost or degraded (Zedler & Kercher, 2005). Large amounts of research have been conducted regarding several areas of wetland science, including their effects on streamflow and flooding. The general consensus of the literature on wetland loss and streamflows is that wetlands typically have an attenuating effect on streamflow, reducing overall flow, peak flow, and short return period floods. However, the vast majority of empirical research concerning wetland loss and its effects is focused on small areas over a single period or short periods of time. Very few studies have addressed the effect of *cumulative* wetland *loss* on streamflow over time in a large geographic area.

This dissertation follows the style of *Journal of the American Planning Association*.

Research on the Section 404 program is also somewhat limited in scope. One area of Section 404 research is focused on wetland mitigation that may be required as a result of permitted wetland development. Studies based on this characteristic of Section 404 generally find that mitigation projects are unsuccessful or never undertaken. Additionally, wetlands created as a result of compensatory mitigation are often found in watersheds far from the original developed wetland. A second area of research on Section 404 which focuses on its impacts, finds measurable and detrimental loss of wetlands and their functions through this environmental permitting program. Although there is a full record of wetland permitting activity available through the Section 404 program, there are very few empirical analyses that have explored or used this data to better understand the patterns and hydrologic effects of wetland alteration and loss.

1.2 Research Purpose and Objectives

The overall aim of this dissertation was to better understand the spatial and temporal patterns and potential streamflow effects of permitting activity under Section 404 of the CWA. Because a comprehensive record of permits exists through the Section 404 program, an under-utilized indicator of wetland loss and alteration is available. The overarching research question for this study was *what are the cumulative effects of Section 404 permitting on mean and peak streamflow?* The specific objectives of this study were to:

1. Gain a better understanding of Section 404 permit implementation at a regional level by quantifying the spatial-temporal patterns of permitting activity through Exploratory Space-Time Data Analysis;
2. Determine the effect of Section 404 permitting activity on mean and peak streamflow at a regional scale by utilizing empirical data and longitudinal statistical modeling;
3. Identify the policy implications of the potential consequences of wetland alteration through the Section 404 permitting program based on regional-scale, long term, empirical data.

1.3 Research Justification

This research is timely for several reasons. First, population increases along the Texas coast are some of the highest amongst U.S. coastal counties and are projected to increase into areas that have been historically undeveloped. For example, population growth in Harris County between 1980 and 2003 was second only to Los Angeles County. Several coastal Texas counties are projected to see 10% to 15% percent population increases by 2008; population by shoreline mile is expected to double between 1960 and 2010 to 1,216 people per km (Culliton, Warren, Goodspeed, Remer, Blackwell & McDonough, 1990).

Second, the study area has also historically been an area of wetland losses. From the mid 1950s to the early 1990s the Texas coast lost an estimated 210,600 acres of wetlands to both agriculture and, increasingly, urban land uses (Moulton et. al., 1997). In other words, as the population increases along the Texas coast with its associated development, wetlands will continue to be lost.

Third, there is a paucity of research regarding wetland loss through the Section 404 program that evaluates the potential effects of streamflow at a regional scale and incorporates the inherent temporal aspects of the issue. This lack of research comes during a time when the importance of numerous wetland functions is increasingly recognized. This is especially true of the often cited wetland function of attenuating peak streamflow, the focus of this research.

1.4 Dissertation Structure

This dissertation consists of eight Sections. Section 1 gives a brief background of the research, presents research purposes and objectives, and provides a justification for conducting the research. Section 2 reviews the wetlands research literature that pertains directly to the research questions and builds a foundation for later Sections. The first part of Section 2 presents a historical account of wetland policy including primary legal findings, the types of wetland permits available under Section 404 of the Clean Water Act, and previous research based upon wetland permits. The second part of

Section 2 reviews research concerning the effects of wetlands and wetland loss on streamflow. This section of the review is divided into three parts, each representing the methodological approach used in the study. A summary of the research is provided at the end of each part of Section 2.

Section 3 addresses the research framework of the dissertation. This section assembles the framework necessary to further understand the potential effects of wetland loss and/or alteration through Section 404 permitting activity on streamflow. It identifies and discusses measurable variables for explanatory analysis, submits specific research hypotheses for Section 404 permit types, and presents the control variables necessary for later analyses. Section 4 contains a description of the study area, the procedures followed for sample selection and the approaches to variable measurement. The specific statistical methods used in exploratory and explanatory analyses are described. These are followed by the potential validity threats of the study design.

Section 5 presents the results of descriptive and spatial-temporal statistics conducted on Section 404 permits. A summary of the exploratory analyses for the descriptive and spatial-temporal statistics is provided after each section; an overall summary of the exploratory analyses concludes Section 5. Section 6 contains the explanatory results that examine the effect of Section 404 permits on two measures of streamflow. Results are presented and summarized first by each dependent variable. An overall synthesis of the explanatory results ends Section 6.

Section 7 contains a discussion of the exploratory and explanatory analyses. It also addresses potential policy implications based on the research results. Finally, Section 8 summarizes the key findings of the dissertation, presents overall conclusions and addresses the research limitations and suggestions for future research.

2. LITERATURE REVIEW

This Section outlines and reviews the critical areas of research literature necessary to build an understanding of the policy surrounding wetland loss and the effects of wetland loss and alteration on streamflow. Specifically, the first part of this section covers the evolution of federal wetland policy under Section 404 of the CWA, the Section 404 permitting process and previous research on the impacts of this environmental permitting program. The second part of this section reviews the empirical research pertaining to the effects of wetland loss and alteration on streamflow and flooding. A summary of the research findings and limitations concludes this Section.

2.1. Wetland Policy in the United States

2.1.1. The Clean Water Act

True federal wetlands protection, at least in some capacity, began with the passage of the Federal Water Pollution Control Act of 1972. This act initially did not include any references to wetlands and was primarily geared towards wastewater treatment. However, in debating the Federal Water Pollution Control Act, Congress recognized that the protection of water quality must reach beyond point sources (Lewis, 2001). This ongoing debate brought about several changes and an expansion to the legislation, eventually resulting in what is commonly referred to as the Clean Water Act of 1977. The passage of the Clean Water Act (CWA) included the principal statute that regulates wetland alterations: Section 404. Section 404 gave the United States Army Corps of Engineers (USACE) the primary responsibility for the Section 404 program through the power to issue permits for dredge and fill activities. Additional oversight from the United States Environmental Protection Agency (EPA) was also provided, as the EPA is the primary agency charged with implementing the bulk of the CWA. Although the USACE administers the Section 404 permit program, the EPA controls the substantive water quality protection criteria that Section 404 permit applicants must meet

(Downing, Winer & Wood, 2003). The EPA has the authority to veto USACE permit decisions, although this power is seldom used. From 1972 to 1990 the USACE issued roughly 10,000 permits per year; the EPA vetoed only 11 projects during this time period (Steiner, Pieart, Cook, Rich, & Coltman, 1994).

The language of Section 404 is very limited regarding wetland protection, and only through judicial interpretations of definitions within Section 404 has this legislation risen to its current stature as a wetlands protection policy. Initially, Section 404 charged the USACE with the responsibility of issuing permits for the discharge of dredged or fill material into navigable waters. Although regulations state that fill materials are those that are excavated from the waters of the U.S. and used for the purpose of changing the elevation of a water body or replacing wet areas with dry land, Section 404 did not explicitly address the draining of wetlands (Dennison & Berry, 1993).

2.1.2. Legal Findings

The definition of "navigable waters" has been and continues to be the lynch pin for federal wetlands protection and permitting under Section 404. Following numerous congressional debates and the key 1975 *National Resources Defense Council v. Calloway* decision, "navigable waters" were expanded to what is currently referred to as "Waters of the United States" (Lewis, 2001). The USACE now defines "Waters of the United States" to mean "all waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide" (Dennison & Berry, 1993). In addition, the definition also includes "all other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce" (Downing et. al., 2003). Several other court cases throughout the late 1970s and early 1980s upheld this definition including: *U.S. v. Ashland Oil & Transporation Co.* in 1974, *United States v. Byrd* in 1979, *United States* *v. Riverside Bayview Homes Inc.* in 1985, and *Hoffman Homes v. Administrator* in 1993 (Downing et al., 2003).

The most recent defense of the broad definition of jurisdictional wetlands, *Hoffman Homes v. Administrator* in 1993, is notable for two reasons. First, it is the most recent federal court case upholding the broad definition of wetlands that allows them to fall under the jurisdiction of the federal government. The wetlands of concern in this case, as in other important rulings to follow, were small isolated intrastate wetlands. Second, the initial finding of this case was in favor of the petitioner. The court first concluded that the potential use of a wetland for migratory birds was not sufficient to invoke Congress' Commerce Clause power and that the wetlands did not contribute to maintaining the integrity of the nation's waters (Downing et al., 2003). However, on government appeal and with the testimony of wetland scientists the appeals court found in favor of the government. The court found that the interpretation of waters of the United States was reasonable and flatly rejected the premise that the wetlands served no beneficial function. The court stated, "We know now that wetlands are not nuisances but instead are vital to the well being of both humans and wildlife" (Downing et al., 2003).

The broad definition of wetlands under federal jurisdiction was not permanent. Perhaps the most recent and controversial ruling on the federal jurisdiction of wetlands was decided by the 2001 U.S. Supreme Court ruling of the *Solid Waste Management Agency of Northern Cook County v. U.S. Army Corps of Engineers*. The decision focused again on isolated, non-navigable intrastate wetlands which had been previously protected by Section 404, and the majority of the court ruled that Congress had not clearly expressed its intent to regulate such waters. The "SWANCC" decision was considered to be a major departure from prior wetland jurisdiction decisions and has provided opportunities to question many broader issues of CWA jurisdiction (Downing et al., 2003). Although the decision only affected isolated, non-navigable intrastate wetlands, numerous lawsuits since the decision have challenged the jurisdiction over other types of waters that are non-isolated.

The definitions of key terminology and judicial interpretations of federal jurisdiction are the heart of Section 404 and its application to wetlands. Without these interpretations wetlands protection and the CWA as a whole would be very limited in geographic scope. As outlined above, the interpretations of the definition of "navigable waters", "waters of the United States" and "isolated wetlands" are the critical link to federal wetland protection. When viewed as a whole, federal protection of wetlands has no doubt increased in time, but the "legal links" that grant this protection are subject to change at any time through legal and judicial reinterpretation.

2.1.3. The Wetland Permitting Process

As described above, the USACE was the agency charged with the responsibility of issuing permits for the "discharge of dredged or fill material" into "waters of the United States", with the EPA retaining oversight and veto power over permit decisions. Following the first geographically broad interpretations of its jurisdiction the USACE began its permitting process in 1975. Because its jurisdiction was so far reaching, the USACE began its permit program in three phases. July of 1975 saw the implementation of the first phase of the permitting program, with its jurisdiction applying to coastal waters, navigable inland rivers and lakes, and wetlands adjacent to these waters. The second phase began in September of 1976 and added all lakes, primary tributaries, and their adjacent wetlands. Finally, in July of 1977 the USACE added all remaining jurisdictional waters including isolated wetlands.

However, phase 2 was implemented too early for the USACE; the Corps stated that they did not have enough "regulatory resources" to cover the entire scope of CWA jurisdiction such as intrastate water bodies and smaller streams above the headwaters of rivers (Downing et al., 2003). Due to the lack of regulatory resources, the USACE implemented a system of General permits to be issued for activities thought to have very limited potential for detrimental environmental impacts. This attempt to streamline the permitting process by issuing General permits for activities deemed to be minor in nature has evolved into several categories of USACE Section 404 permits. The conditions under which various types of permits are issued vary by the type of activity, the impact of the activity, and the district or region where the activity will be located. USACE currently issues four types of Section 404 permits: Individual permits, Letters of Permission, General permits, and Nationwide permits. The following will describe and track the evolution of these permit types.

Individual Permits

Individual permits are the basic form of authorization used by USACE districts. Activities that entail more than minimal impacts require an individual permit. Processing the permits involves evaluation of individual, project-specific applications in what can be considered three steps: pre-application consultation (for major projects), formal project review, and decision-making.

Once a permit application is submitted, the USACE must inform the applicant of any deficiencies in the application within 15 days. Once the applicant has supplied all required information, USACE determines if the application is complete. Within 15 days of that determination, USACE must issue a public notice of the application for posting at governmental offices, facilities near the proposed project site, and other appropriate sites. In the public notice, USACE requires that any comments must be provided within a specified period of time, typically 30 days (33 CFR 325.5b).

When determining if the activity is necessary, the District Engineer at USACE must consider whether the activity is dependent on being located in the wetland, or if alternative sites are feasible. If the applicant can show that no practical alternatives exist, then the activities must be performed to minimize adverse impacts to the wetland. The applicant must also provide compensation for any unavoidable impacts, typically carried out through some form of mitigation. USACE evaluates public benefits and detriments of each case. Relevant factors considered by USACE include conservation, economics, general environmental concerns, aesthetics, wetlands, floodplain values, cultural values, navigation, fish and wildlife values, water supply, water quality, and any other factors judged important to the needs and welfare of the people (Connally, Johnson & Williams, 2005). In addition, individual state permitting and water quality certification requirements can provide an additional safeguard to the USACE permitting program. Section 401 of the Clean Water Act requires state certification or waiver of certification prior to issuing an Individual Section 404 permit.

Letters of Permission

The first alternate form of authorization used by the USACE for certain prescribed situations is the Letter of Permission. Letters of Permission may be used where, in the opinion of the district engineer, the proposed work would be minor, not have significant individual or cumulative impact on environmental values, and should encounter no appreciable opposition (33 CFR 325.5b2). In such situations, the permit application is coordinated with other relevant agencies as well as adjacent property owners who might be affected by the activity. Public notices and comment periods are not required. A Letter of Permission can be issued much more quickly than a standard Individual permit, since many of the Individual permit requirements are bypassed. Any project the USACE proposes to authorize under a Letter of Permission may be elevated to an Individual permit by the EPA or State Department of Environmental Management. The district USACE office will notify the applicant if a proposed activity qualifies for a Letter of Permission.

General Permits

As noted earlier, General permits arose from a lack of regulatory resources during the final phase of Section 404 implementation; they were an attempt to streamline the permit process for common activities. The USACE considers both the General permit category and the Nationwide permit category as “General” permits. But, because they can differ greatly they will be addressed as separate types. General permits are issued when, “activities are substantially similar in nature and cause only minimal individual and cumulative impacts” (USACE, 2001). A General permit covers activities in a limited geographic area, or a region of the country. General permits are reviewed every five years and an "assessment of the cumulative impacts of work authorized under the general permit is performed at that time if it is in the public interest to do so" (USACE, 2001). In developing general permits, the USACE must go through a public interest review and receive certification by the state for the General permit to be valid. Once a general permit is issued for a category or type of activity, individual projects meeting the terms and conditions of the General permit category can quickly receive authorization without additional certification review.

Nationwide Permits

Nationwide permits are a special type of general permit. They are a key means by which the Corps operates its regulatory program and simplifies its administrative activities. Activities covered under Nationwide permits can go forward without further Corps approval as long as the conditions set forth in the Nationwide permit category of work are met. By far the most common type, Nationwide permits are issued for specific activities that are deemed to have "no more than minimal adverse effects on the aquatic environment, both individually and cumulatively" (Issuance of Nationwide Permits Notice, 2002, pg. 2023). The activities that are allowed under Nationwide permits are broad and have been the source of criticism by environmental groups as well as a loophole for Section 404 permitting in the past. Unlike General permits, the work allowed by Nationwide permits applies, as the name suggests, to the entire nation. Nationwide permit categories are evaluated, updated and reauthorized every five years.

2.1.4. The Impacts and Failure of Wetland Mitigation under Section 404

The four permit types discussed above are the key means by which the USACE manages discharges into waters of the U. S. and, due to federal judicial interpretations, wetland alterations and losses. A large portion of research on Section 404 permitting focuses on the mitigation of permitted losses. The results of these studies point to certain wetland impacts, many of which would have been much more severe without compensatory mitigation. However, the success of mitigation projects and programs is often questioned. Numerous studies have found low success of wetland restoration projects required by compensatory mitigation (Josselyn Zedler & Griswold, 1989; Race, 1985).

The frequent failure of many mitigation projects occur for many reasons. Created wetlands do not often achieve the same functionality as natural wetlands, even several decades after they are created (Campbell, Cole & Brooks, 2002; Cole & Brooks 2000; Cole & Shafer 2002). This is often due to their creation in inappropriate hydrologic conditions or an inadequate program to monitor the progress of the mitigated wetland ecosystems over time (Cole & Brooks, 2000; Cole & Shafer, 2002; Erwin, 1991; Gallihugh & Rogner, 1998). Further, these constructed are typically not capable of replacing the functionality of the lost wetland. This is because mitigation does not always require restoration or creation of that same wetland type (Cole & Shafer, 2002). Finally, mitigation projects are often far from the location of the lost wetland. Consequently, wetland functions added by the constructed wetland have been moved from a place where they are needed to a place where they were superfluous.

Additional research also indicates that mitigation may not always occur, even when required as a condition of the permit. In Louisiana, 41 percent of permits issued between 1982 and 1986 required mitigation, but only 8 percent of the total area was mitigated (Sifneos, Cake & Kentula, 1992). Additional research indicates outright disregard for compensatory mitigation is not isolated. Other studies suggest that between 17 and 34 percent of restored or created wetland projects had not been constructed at all (Kusler & Kentula, 1990; Owen & Jacobs, 1992; Race & Christie, 1982). Furthermore, while attempts at mitigation may be less than successful there are many cases where permitted wetland impacts do not require mitigation. Kelly (2001) found that mitigation was required in only 3 percent of permits in North Carolina from 1984 to 1992. Further, poor record keeping by the USACE, which has been brought to light by several studies, makes accurate analyses of mitigation difficult (Holland & Ketula, 1992; Kentula, Sifneos, Good, Rylko & Kunz, 1992; Sifneos, Kentula & Price, 1992b).

Other research on Section 404 has focused on the direct impacts of the permitting program. Sifneos et al. (1992b) examined the Section 404 program in numerous areas of the country. Results for the Texas study area found a net loss of 917 acres of wetlands in the USACE Fort Worth District between 1982 and 1986 that required compensatory mitigation. Additionally, 52 percent of the number of impacted wetlands (representing 35% of the area impacted) were located in the Dallas-Fort Worth metropolitan area. The authors theorized that the real estate market during this time period was growing, and furthermore expanding into the remaining riparian woodlands in the area (Sifneos et al., 1992a). A study on Section 404 permitting and mitigation in Oregon and Washington found comparable results. Kentula et al. (1992) found that over a ten year period in Oregon (1977-1987) 183 acres of wetlands were impacted and 111 acres were created; a 43 percent net loss. In Washington from 1980–1986, 151 acrese of wetlands were impacted and 112 acress were created; a 26% net loss. Permitted activities in both states occurred near urban areas (Kentula et al., 1992). Owen and Jacobs (1992) conducted a similar study in Wisconsin, and found in the first six months of 1988, 422 acres of wetlands were allowed to be filled while 40 acres were created. The authors also conclude that while the permitting program is, in effect, a land use control it performs poorly as one.

Other work concerning Section 404 permitting is centered on pre-permit and post-permit landscape conditions and cumulative impacts. Stein and Ambrose (1995) conducted an on-site study examining riparian areas in the Santa Margarita watershed in Southern California. They concluded that while the Section 404 program had reduced overall project impacts, it had not minimized cumulative impacts. The impact of Nationwide permits was also examined. In the study area they accounted for proportionally more cumulative impacts despite the fact that they affect less total area. Using remotely sensed data in North Carolina, Kelly (2001) found that, not only were wetlands lost under the permitting program, but that habitat fragmentation had occurred in 80 percent of areas adjacent to permit sites. This suggests additional ‘nibbling’ impacts associated with permitted activities that are not taken into consideration during permit review (Kelly, 2001). The results of these studies point to a variety of impacts and losses through the Section 404 permitting program.

2.2. Effects of Wetlands on Streamflow

The effect of flood abatement is a commonly cited function of wetlands. The old adage that wetlands act like sponges (Goode, Marsan & Michaud, 1977; Bardecki, 1984) is so often declared that it is rarely questioned. As stated by Bardecki (1984, p. 166), "Virtually every publication advocating wetland protection includes this as a key value of wetland areas." Yet the scientific literature surrounding this specific wetland function is not as clear. The following review will first define and address why wetlands effect or modify streamflows. Second, research literature more specific to the research objectives will be summarized and critically evaluated.

2.2.1. Wetlands, Flooding and Water-Balance Studies

One of the primary methodologies used for wetland hydrology research is a water-balance approach. The water balance method essentially quantifies the individual hydrologic factors of a wetland in an attempt to balance its inputs and outputs. Early research employing this method often looked at the differences between drained and natural wetlands as a basis for assessment. For example, Boelter and Verry (1977) found that peat bogs in the northern U. S. reduce low-return period flood flow and reduce overall flows. The authors theorized that the storm flow reduction is due to temporary storage of storm water and relatively slow water release. A later examination by the same authors in Minnesota using the same methodology confirmed that peats do reduce peak flows (Verry & Boelter, 1978). Heikuranen (1976) had similar conclusions with the same water-balance methodology on peatlands in Finland: floods during the study period began earlier, lasted longer and had lower peak flows in undrained peatlands. Research on pocosin wetlands-wetlands that are typically found in broad, flat, upland areas far from large streams-demonstrates the same reduction effect on flooding. Comparing hydrographs derived from water balances for drained and undrained pocosins, Daniel (1981) found that the areas which had retained undrained wetlands did not have any floods whereas the drained areas had five floods during the study period. Similarly, Gilliam & Skaggs (1981) found that flood peaks were higher and earlier in areas of developed and drained pocosin wetlands in North Carolina.

Additional studies that employed the water-balance method but with different bases for comparison also come to the same conclusion. Novitski (1982) conducted experiments on four different types of wetlands based on their locations within the same watershed and compared their water-balances to areas in the same basin that do not have wetlands. This research, conducted in Wisconsin, found that all four wetland types had a negative effect on low return period floods. In other words, all of the wetlands studied reduced low probability flood peaks.

However, some research conducted with water-balance calculations on wetlands and flooding yields converse results. Again, utilizing drained and undrained peatlands for comparison Burke (1968) found that much higher flood peaks of low return period flood flows occur in the undrained peatlands. He also concluded that streamflow of lower magnitude were not affected by draining peatlands; no differences were observed in mean flows. Later, Burke (1972) found that much higher flood peaks occurred in the undrained peat areas in Ireland. He concludes that in terms of blanket peat reclamation for agriculture, not only would widespread drainage of peatlands "lead to beneficial effects on stream and river flow", but also that "floods will be reduced in frequency and magnitude" in the short term (pg. 176). Much more recent research also contradicts the previous findings that wetlands reduce flood flows as measured by the water balance method. Again in Wisconsin, Owen (1995) concluded that the wetland studied played an unimportant role in reducing flood peaks. However, there were no large flood events during the study period and the authors do note that because of the wetlands storage capacity it could have a "significant role in flood control" (pg. 185).

2.2.3. Wetlands, Flooding and Historical Streamflow Studies

A more common approach of evaluating wetlands and flooding comes in the use of historical streamflow records. This method is essentially the analysis of the characteristics of long time series of river flows, typically measured by streamflow gauges. Bay (1967) concluded that peat bogs in Minnesota store short-term runoff by comparing streamflow at two areas of the same watershed. Verry and Boelter (1975) also concluded that the two bogs they investigated in Minnesota had attenuating effects on low-return period storm peaks but no effect on the maximum peaks of high-return floods. Using data from 30 streamflow gauging stations and watersheds in Illinois, Demissie, Khan, and al-Mubarak (1991) examined the effect of the percent of wetlands in each watershed on peak flow and low-flow parameters using ratios of the flow parameters to peak and mean precipitation. The authors found that ratios of peak flow to mean precipitation generally decrease with increasing areas of wetlands. However, they also found that low-flows increase. Exceedence flows of 75, 95 and 99 percent all increase with increasing percentages of wetlands.

Comparisons of drained and undrained wetlands also continue to appear in the research literature. Brun, Richardson, Enz and Larsen (1981) investigated both mean annual and peak flows in North Dakota. The results of their regression analyses after controlling for basin area and precipitation showed that the area of drained wetlands led to an increase in both measures. Drained wetlands increased mean annual and peak annual flows by 50 and 36 percent, respectively. Results consistent with the previous research are also given by other studies, all of which find that draining wetlands increased low-return period flood peaks (Winner & Simmons, 1977; Panu, 1988).

Several authors have also used streamflow records or measurements to attempt to explain flood peaks of different recurrence intervals with various independent variables in multiple regression analyses. These studies appear to be the few that incorporate long-term historical streamflow data to account for differences in multiple watersheds with differing proportions of wetland coverage and other independent variables. The majority of this research concludes that, in terms of basin storage, wetlands have some effect in explaining the variability of flood peaks. For example, Darmer (1970) found the area of lakes and ponds to be statistically significant variables in reducing peak streamflow in recurrence intervals from 2 to 50 years in New York. Results were insignificant for 100 year flood recurrence intervals. Flippo (1977) utilized the same regression methodology for watersheds in Pennsylvania. Again, the regression coefficients for wetland storage were negative and significant in explaining peak flows in recurrence intervals from 2 to 100 years.

Both Forest and Walker (1970) and Nuckles (1970) also employed a similar regression methodology in Delaware and Virginia, respectively. Both studies yielded insignificant results and wetland storage variables were not included in subsequent equations. Conger (1971) also regressed flood flows onto variables including basin drainage area, main channel slope, and lake/wetland area as a storage term. His results indicated that the wetland storage term variables regressed on peak flows were also negative and statistically significant in 2, 5, 10, 25, 50 and 100 year recurrence intervals. Finally, Campbell and Dreher (1970) used regression analysis to explain peak flows with individual regression equations for each month of the year in an attempt to explore seasonal variation. In months that had significant results for the lake and wetland storage coefficients, six of the eight were negative (January – March and July – September). Significant positivecoefficients, although small, were found in April and May. The months of June and October through December did not yield significant results for the wetland storage variables.

Based on the previous regression studies, Novitski (1985) developed a relationship of peak flows with percent lake/wetland area. He concluded that basins with as little as five percent lake and wetland area may lead to 40 to 60 percent lower flood peaks. In addition, he also addressed the seasonal variations explored by Campbell and Dreher (1970). He concluded that as relative streamflow and percent lake and wetland area increase, the storage coefficient derived from regression analysis is positive for spring streamflow. Conversely, fall and winter streamflows relative to percent lake and wetland area result in negative coefficients for the lake and wetland storage variable.

In other words, basins with higher percentage of lakes and wetlands will have lowered flood peaks, higher runoff in spring months and lower base streamflows (Novitski, 1985). Finally, Bullock (1992) conducted a comprehensive study of flood regimes and African dambos[1]. The results of this study were derived from analysis of 77 gauged watersheds in Zimbabwe. Analyses were conducted using flood recurrence intervals of 5, 10, 50, 100, 200, 500, and 1000 years. No significant differences were found for flood frequencies and percent dambos with return periods of 50 years or less. However, recurrence intervals over 100 years do show positive relationships between percent dambo and flood frequency. Bullock concluded that dambos do not exert significant influence on the change in flood magnitude or variability or on the volume of annual flow.

2.2.4. Wetlands, Flooding and Simulated Hydrology Models

A third method of evaluating the effect of wetlands on flooding comes in the form of compuatational hydrology models. Hydrology modeling has the ability to simulate peak flows and runoff amounts using models that will accept a wide range of inputs. Research focused on modeling basin hydrology and the effects of wetlands is much more recent due to advances in model development and number of studies is limited.

In what appears to be the first computational model of wetland hydrology, Moore and Larson (1980) modeled the effects of draining wetlands on storm runoff and peak flows in two small watersheds in Minnesota. The authors utilized a four module model that accounted for snow accumulation and melt, soil characteristics, surface and subsurface drainage factors and flood routing equations. Historical records of gauged streamflow were used to test and fit the model. Results indicated that draining all wetlands in the watersheds would "increase storm runoff by significant but widely varying amounts, from about 50 to 590 percent" (pg. 357). Peak flows would also be dramatically increased, 200 to 400 percent as a result of draining of wetlands. In a later

[1] A dambo is a shallow wetland found in central, southern and eastern Africa.

study, Ammon, Wayne, and Hearney (1981) modeled the effects of wetlands on both water quantity and quality of Chandler Marsh in South Florida. The authors utilized the Storm Water Management Model (SWMM), an EPA product. Barnes and Golden (1966) used flood attenuation as an indicator of the ability of marshes to control water quantity, and defined this variable as the ratio of peak outflow discharge to peak inflow discharge. Results from the SWMM show that flood peak attenuation is higher with increasing areas of marsh. The authors conclude that Chandler Slough Marsh increases storm water detention times, shiftts runoff regimes from surface to increased subsurface regimes, and is "moderately effective as a water quantity control unit" (pg. 326).

Ogawa and Male (1986) also developed a simulation model to explicitly explore the use of wetlands as a flood mitigation strategy. The authors incorporated three rainfall intensities and three antecedent soil moisture conditions. In addition, wetland loss was input as five levels of upstream wetland encroachment (0%, 25%, 50%, 75% and 100%) and four levels of downstream wetland encroachment (0%, 25%, 50%, and 75%). The commonly used USACE models, HEC-1 and HEC-2, were run 1,629 times on three adjacent watersheds with varying sizes, elevations and areas of wetlands in eastern Massachusetts.

Results from the four degrees of downstream wetland encroachment yielded significant increases in peak flow for encroachments greater than 25 percent; complete wetland loss caused a 200 percent increase in peak flow for 38 percent of the simulations. The authors concluded that: 1) small degrees of wetland encroachment would not have significant effects on peak flows, 2) wetland encroachment on upstream tributaries only alters peak flows for a few miles downstream, and 3) the encroachment on downstream main-stem wetlands has a significant effect on peak flows. The final result is important, as it appears to be the first research to test the importance of wetland locations relative to the watershed.

The most recent research using hydrologic simulations to model wetlands was conducted by Padmanabhan and Bengston (2001). Again the HEC-1 model was used with elevation, precipitation and antecedent moisture conditions as primary inputs. The authors attempted to model the effects of restoring drained wetlands in the Maple River Watershed, of which there was about 6 percent of wetland coverage. Statistically based designed storms with 10, 25, 50 and 100 year recurrence intervals were input into the model for five separate scenarios: no restored wetlands, restored wetlands with 1 foot depth and 25 percent diversion, 2 foot depths and 25 percent diversion, 4 foot depths and 25 percent diversion, and 4 foot depths and 50 percent diversion.

Results from the model simulations (16 total) indicated that very little flood reduction would arise from wetland restoration in the watershed. The largest reduction in flooding came from the model with 4 feet of wetland storage and 50 percent diversion, yielding a 9.9 percent decrease in flood stage for a 10 year flood event. Most notably, the reductions in flood stages show minor decreases, ranging from 0.36 percent to 1.26 percent. The authors conclude that restoring drained wetlands would significantly lower flood stage elevations for low-frequency flood events. In addition, model runs for 100 year events and 40 percent wetland areas still did not have a significant flood reduction effect.

2.2.5. Summary of and Gaps in the Literature

It is clear that wetlands have some effects, both minor and major, on streamflow. The vast majority of the literature reviewed concluded that presence of wetlands reduce streamflow, at least to some extent. Likewise, the research comparing drained and undrained wetlands reached the same general conclusion; the removal of wetland functions increases streamflow. The effect of wetlands on peak streamflow and flood events is varied, but overall it appears that the presence of wetlands in a watershed will reduce or slow downstream flooding. In fact, a comprehensive review of the literature conducted by Acreman and Bullock (2003) showed that wetlands play a significant role in modifying the hydrological cycle. The authors found that for 23 of the 28 studies on wetlands and flooding, "floodplain wetlands reduce or delay floods" (p. 366).

The inverse relationship of increased wetland area to decreased peak streamflow has also been well defined through a host of different research approaches. Flood return periods of less than 50 years appear to be reduced the most from wetland presence. Reduction of floods with return rates of greater than 50 years is not as clear, but it appears that the mitigating effects of wetlands are diminished during these events. The importance of wetlands' position in the watershed has also been demonstrated to be important, where wetlands in the upper reaches of watersheds do not diminish floods as much or for as long as those located farther down stream and especially on main-stem rivers. It is also notable that the scientific literature is almost exclusively focused on flood, peak, or other magnitudes of extreme flows. The effect of wetlands on mean and low streamflow is not as clear. However, the majority of the reviewed studies suggest that wetlands decrease streamflow that is below peak or flood magnitude as well.

One primary limitation to the reviewed literature is the failure to consider land use changes in conjunction with wetland *losses*. The literature reviewed is typically concerned with either the draining of a wetland or wetlands or their importance as basin storage. With the exception of Ogawa and Male (1986) there has been no research that considers wetland losses as a function of land use changes. Changes in land cover play a critical role in streamflow variation and flooding, especially when natural land cover is converted to impervious surfaces. Further, while research has addressed impacts of Section 404 from a wetland loss standpoint, only one study has examined these impacts on a large-scale, regional level. In a cross-sectional study, Brody, Highfield, Ryu and Spanel-Weber (2006) found that permits issued under Section 404 from 1991 to 2003 significantly increased flooding. More specifically, Individual and General permits were positive and significant, after controlling for a host of other pertinent variables, in explaining the number of exceedances over a long-term gauge average in Texas and Florida.

Finally, the importance of temporal issues has rarely been addressed. The use of historical streamflow data to produce flow volumes that correspond to recurrence intervals does inherently consider time to some extent. However, analyses using this approach do not consider other changes that occur in watersheds or other units. Longitudinal approaches are an improvement in these study designs, as they have the ability to examine the effects of wetland loss while simultaneously controlling for a host of other factors, both static and dynamic, over time.

3. RESEARCH FRAMEWORK

This Section assembles a framework that is necessary to further understand the effects of wetland loss and/or alteration through Section 404 permitting activity on streamflow. It identifies and discusses measurable variables that will be used to explain this relationship. More specifically, this Section will present a conceptual model for analyzing the prospective relationship between Section 404 permit and streamflow discharge. Based on the previous literature review, specific research hypotheses will also be presented for the independent (Section 404) variables of interest. Finally, the control variables necessary in later multivariate analyses will also be addressed in terms of their importance, inclusion in previous research, and expected directions of effect.

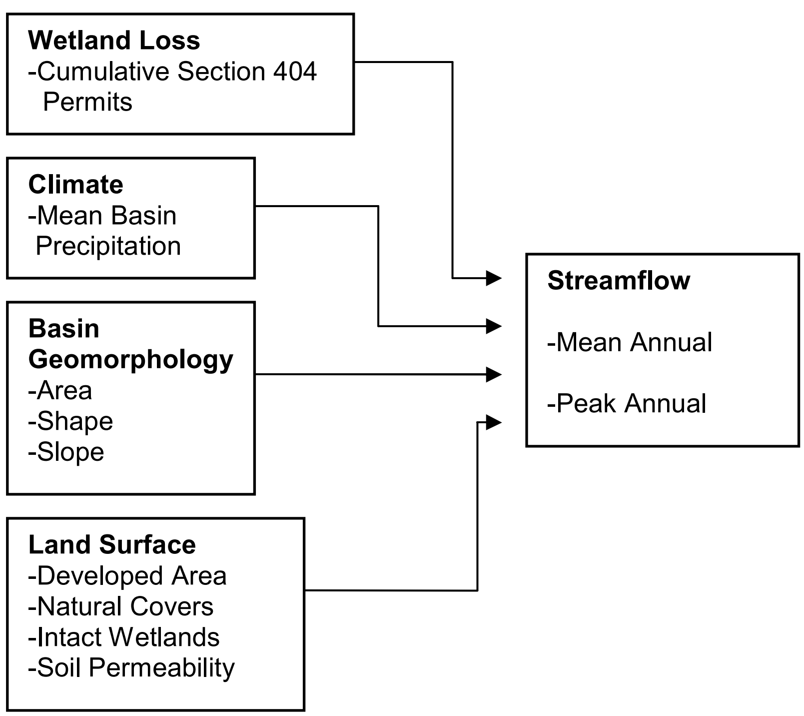

Figure 1. Conceptual Research Framework

3.1 Dependent Variables

The dependent variables in the conceptual framework are streamflow discharge measurements. These measurements are taken at several levels of temporal scale and can be aggregated over various time scales. For the purposes of this research, an annual time frame from 1996–2003 was selected. Although the streamflow data offered a much finer temporal resolution, other critical control variables cannot be accurately measured at this time resolution. Therefore, two dependent variables, mean annual flow and peak annual flow, will be investigated (see Figure 1). Mean annual flow (MAF) is the average of all measurements taken over the water year[2] (October 1 – September 30). This measure is intended characterize normal watershed discharge on a yearly basis during the study period. Peak annual flow (PAF) is the maximum recorded measurement taken in each water year. Also often referred to as the annual flood, this variable provides a measure of the high flow event for each year in the study period.

Analyzed separately, these two variables provide insight into two separate basin-level phenomena; one which measures the overall hydrologic characteristics and the other which measures one extreme. However, analyzing the two measures with the same controlling variables allows comparison between the models and, more importantly, allows the differences in independent variables across two measures of streamflow to become more apparent.

3.2 Independent Variables

As discussed in literature review contained in Section 2, the vast majority of studies conducted on the effects of wetlands on streamflow have concluded that there is an inverse relationship; wetlands, to varying extents, reduce stream discharges. While research exists concerning the presence of wetlands reducing streamflow and floods, there has been very little attention given to the effects of wetland *loss* and virtually no

[2] The water year is defined as the period between October 1st of one year and September 30th of the next. This interval is often used because hydrological systems are typically at their lowest levels near October 1.

research that has addressed the effects of *cumulative* wetland loss.

This research utilized Section 404 permits as an indicator of cumulative wetland loss. As discussed in Section 2, previously conducted research supports the primary assumptions regarding the use of Section 404 permits as *cumulative wetland loss* indicators. First, the research on the impacts of Section 404 demonstrates that wetland loss occurs under Section 404, some of which even suggests that impacts go beyond the permitted location. Second, although many permits require mitigation, the literature clearly points out that mitigation is deficient for three primary reasons: 1) mitigation projects fail to replace lost wetlands with constructed wetlands of the same function; 2) constructed wetlands fail to become functioning wetlands altogether; or 3) mitigation never takes place. These characteristics of compensatory mitigation through the Section 404 program support the use of cumulative permit counts as a measure of wetland loss.

Also as previously discussed in Section 2, Section 404 permits are issued in four different forms. Although each type of permit represents a wetland impact, the degree of impact is expected to vary based on the type of permit issued. Section 404 permits that represent large projects or significant impacts will likely have greater positive effects on watersheds' streamflow measurements. Additionally, some permit types are issued far more often than others and, while their individual impacts may be smaller, their aggregate effects may also create significant hydrologic effects. For this reason, Section 404 permits will be addressed and analyzed by type and cumulatively over time.

3.2.1 General Section 404 Permits

Also as previously stated, the USACE issues General permits. This permit type is issued for "activities are substantially similar in nature and cause only minimal individual and cumulative impacts" (USACE, 2001). It is assumed that this permit type will represent wetland impacts that are considerably smaller in nature than Individual permits. However, far more General permits are issued compared to Individual permits and, while impacts may be smaller on a case by case basis, they may also result in a nibbling effect on the portions of the landscape that have the ability to retain water.

Hypothesis 1: A unit increase in cumulative General permits will have a significantly positive effect on mean annual flow.

Hypothesis 2: A unit increase in cumulative General permits will have significantly positive effect on peak annual flow.

3.2.2. Nationwide Section 404 Permits

Nationwide permits are a special type of general permit. The most frequently issued permit type, Nationwide permits are issued for specific activities that are deemed to have "no more than minimal adverse effects on the aquatic environment, both individually and cumulatively" (Issuance of Nationwide Permits; Notice, 2002, pg. 2023). Much like General permits, the impacts represented by Nationwide permits may be small on the single permit level but they may also result in measurable hydrologic impacts on a basin scale over time.

Hypothesis 3: A unit increase in cumulative Nationwide permits will have a significantly positive effect on mean annual flow.

Hypothesis 4: A unit increase in cumulative Nationwide permits will have significantly positive effect on peak annual flow.

3.2.3. Letter of Permission Section 404 Permits

Letters of Permission are the fourth type of USACE Section 404 permit. They may be used where, in the opinion of the district engineer, the proposed work would be minor, not have significant individual or cumulative impact on environmental values, and encounter no appreciable opposition. The initial permit application is coordinated with other relevant agencies and potentially affected property owners, but the lengthy processes required by Individual permits are not required. It is difficult to gauge the level of impact associated with Letters of Permission. In some cases they may consist of small projects that do not fit into established Nationwide or General categories of work. However, as noted above small impacts may accumulate over time and result in basin scale hydrologic impacts.

Hypothesis 5: A unit increase in cumulative Letters of Permission will have a significantly positive effect on mean annual flow.

Hypothesis 6: A unit increase in cumulative Letters of Permission will have significantly positive effect on peak annual flow.

3.2.4. Individual Section 404 Permits

As previously described, the requirements for obtaining an Individual permit from the USACE can be complex, lengthy, expensive and have the potential to create public and other federal agency opposition. This is with good reason however, as Individual permits represent the largest single permitted impact to wetland resources in the State of Texas. It would stand to reason that Individual permits represent the largest (by area) loss of wetland resources and their hydrologic functions.

Hypothesis 7: A unit increase in cumulative Individual permits will have a significantly positive effect on mean annual flow.

Hypothesis 8: A unit increase in cumulative Individual permits will have significantly positive effect on peak annual flow.

The previous eight hypotheses for each permit type all follow the same general assumption: Section 404 permits represent wetland loss and thus the ability of a basin or watershed to naturally store water. As noted above, Section 404 permits that represent large projects or significant impacts will have greater positive effects on watersheds' streamflow measurements. Further, it is clear that each type of Section 404 permit should represent a different level of wetland impact and/or loss. This permit type/wetland impact relationship is reflected in the regulatory requirements necessary to obtain Section 404 permits of different types as well as the language used by the USACE in describing the four types of permits. Therefore, there should be some differences in the strength of each permit type when regressed on mean annual flow and peak annual flow.

3.3 Control Variables

For the purposes of this study a distinction has been made between the above independent variables (Section 404 permits) and variables necessary as control variables in multivariate analyses. Several additional variables are necessary to statistically control for the potential effects of Section 404 permit impacts on the two dependent variables, MAF and PAF. These control variables have been repeatedly and consistently used in hydrologic analyses and the directions of their relationships are well established. The following will outline these control variables and their expected relationship with the dependent variables. Table 1 also summarizes these variables and their expected relationship with the dependent variables.

3.3.1. Basin Area

The oldest and most consistent of these variables is drainage basin area. In addition, drainage area has been found to be the most significant factor affecting discharge (Matthai, 1990) and is the most commonly measured basin characteristic. Drainage area is a primary variable used to predict streamflow characteristics at ungauged sites (USGS, 1997). Basin area is expected to have a positive effect on MAF and PAF.

3.3.2. Basin Shape

The shape of the drainage basin can also be an integral variable affecting hydrological characteristics. In general, basin shape typically affects the characteristics of peak flow rates (Saxton & Shiau, 1986) by determining the temporal concentration of the runoff (Matthai, 1990). Streams in longer, narrower basins will peak and begin receding in the lower areas of the basin before flows from upstream areas reach the lower portions of the basin. Streams in more regularly shaped basins will typically have the same times of concentration, causing a faster rise to and recession from peak discharges (Matthai, 1990).

Basin shape measurements have been developed by many researchers over the years. Measurements include length to width ratio or shape factor (Horton, 1932), circularity ratio (Miller, 1953) and elongation ratio (Schumm, 1956). Regardless of the exact measure chosen, the metric will be dimensionless. The elongation ratio, which is the basin shape measure selected for this study, is computed by dividing the diameter of a circle with the same area as that of the basin by the length of the basin. A large elongation ratio value is an indicator of a more regularly shaped basin; whereas a small elongation ratio is indicative of a longer, narrower basin. Therefore, the effect of elongation ratio on PAF and MAF is expected to be positive.

3.3.3. Topography

Topographic measurements of drainage basins have also long been recognized as important hydrologic descriptors. The slope of a watershed affects both the temporal concentration and the amount of depressional storage. Slopes may act in concert with or against the effects of basin shape. Several forms of topographic measurements have been previously used in explaining streamflow magnitudes including mean basin slope, basin relief, relief ratio and mean stream slope. Steeper slopes increase temporal concentration and cause faster and higher peak flows (Matthai, 1990) and also make a positive contribution to mean annual flow (Stuckey, 2006). Mean basin slope was selected as the slope measure for this study. The relationship between mean slope and both mean and peak annual flows is expected to be positive.

Table 1. Description and Expected Relationships of Control Variables

Variable Name	Description	Temporal Variation	Relationship Expected with Streamflow
Basin Area	Area of the delineated drainage basin above the streamflow gauge	Invariant	+
Basin Elongation Ratio	Ratio of basin area to the circumference of a circle with the same area	Invariant	+
Mean Slope	Measure of basin topography; mean basin slope	Invariant	+
Precipitation	Annual basin precipitation;	Variant	+
Average Soil Permeability	Average soil permeability in inches/hour as measured by STATSGO	Invariant	-
Developed Area	Percent of basin classified as developed by remote sensing	Variant	+
Natural Cover Area	Percent of basin classified as under natural cover by remote sensing	Variant	-
Palustrine Scrub/Shrub Wetland Area	Percent of basin classified as Palustrine Scrub/Shrub by remote sensing	Variant	-
Palustrine Forested Wetland Area	Percent of basin classified as Palustrine Forested by remote sensing	Variant	-

3.3.4. Precipitation

Precipitation is a primary driver of the hydrologic cycle. Simply stated, four characteristics of a precipitation event contribute to its importance: intensity, depth, duration, and distribution over the drainage basin. Precipitation depth (amount) and duration can be described as the attributes of the storm exterior (Bras, 1990). Precipitation depths vary spatially and are not independent of duration; longer durations are associated with higher amounts. The factors comprising the storm interior refer to the time and spatial distribution of precipitation intensity and also vary spatially (Bras, 1990). Although these concepts are straightforward they have important repercussions on measurement and estimation.

Historic records of precipitation are typically collected at point locations, yet the amount of precipitation over an entire watershed is typically the necessary input in any study concerning hydrology. The estimation of rainfall over areal units can be derived in several ways including the arithmetic mean of stations with a unit, thiessen polygons, isohyets, and more advanced forms of spatial interpolation such as inverse-distance weighting, splines, and kriging (Running & Thornton, 1996). An inverse-distance weighting procedure was selected to interpolate precipitation amounts for this research. Interpolating precipitation in this manner addresses two of the four characteristics of precipitation events: the amount of precipitation and its distribution. Precipitation duration and intensity are related more to single events so these two characteristics of precipitation were not considered due to the temporal scale of the dependent variables. Precipitation is expected to have a positive effect on both dependent variables.

3.3.5. Soil Characteristics

Vegetation and soil characteristics of a watershed are largely intertwined and are important factors in the hydrologic cycle. Generally speaking, soils serve three primary functions: they can absorb, store and release water. The amount of water that any given soil will infiltrate and retain depends primarily upon the texture and current moisture condition of the soil (Saxton & Shiau, 1986). Numerous measures are available to quantify soil characteristics across basins. Common characteristics include soil permeability, available water holding capacity, soil thickness, and hydrologic group. Soil permeability, the ability of water to flow through a soil, was chosen as the measure for this research. The potential for higher peak and mean annual flows from basins that have low soil permeability is greater than basins with higher permeability soils, as higher permeability allows greater infiltration, more storage and less runoff (Rasmussen & Perry, 2000). Therefore, soil permeability is expected to have an inverse relationship with both MAF and PAF.

3.3.6. Land Cover

Unlike the properties of natural soils and vegetated cover, human development has created surfaces that are impermeable to both precipitation and overland water flow. Through urban development we have created streets, sidewalks, and other concrete or cement covered surfaces that stop or greatly reduce the infiltration of water. Many studies have found that significant ecosystem changes occur in watersheds with 10 – 15 percent impervious surface area (Weaver & Garmin, 1994; Wang, Lyons, Kanehl & Bannerman, 2001; Jennings & Jarnagin, 2001). Some have gone as far as to consider impervious surfaces a key environmental indicator (Arnold & Gibbon, 1996). Watershed imperviousness and storm water runoff are directly related (Schuler, 1994). Impervious surfaces create a system of nearly complete surface runoff, increasingly transforming what would have previously been a non-event from a precipitation standpoint, to the possibility of flashy peak flows with short lag times and rapid recessions (Sauer, Thomas, Stricker & Wilson, 1983; Jennings & Jarnagin, 2001).

While impervious surfaces are problematic from a runoff and flooding standpoint, the issue is exacerbated by the fact that impervious surfaces typically replace land cover types that provide infiltration. The replacement of areas that were once covered by natural permeable surfaces by less permeable or impermeable surfaces dramatically alters the hydrologic characteristics of a watershed (Schuster, Bonta, Thurston, Warnemuende & Smith, 2005). Conversely, areas that retain their natural cover represent the opposite of developed or impervious areas. They are more likely to intercept precipitation, slow runoff and have higher infiltration rates. Although different natural land covers will vary both in their ability to reduce streamflow and offset developed areas, natural cover serves as a parsimonious measure to identify areas that are minimally disturbed.

Finally, to appropriately assess the potential impact of wetland loss through Section 404 permitting it is necessary to consider the effects of intact wetlands in the study area. As discussed at length in Section 2, the research literature pertaining to wetlands and streamflow generally indicates that the presence of wetlands in a watershed will have a negative effect on streamflow. The two wetland classes that are found within the study area, Palustrine Forested and Palustrine Scrub/Shrub, were also used in analyses.

Thus, the four measures chosen to represent land cover for this research were developed area, the area under natural or vegetated cover, Palustrine Scrub/Shrub wetlands and Palustrine Forested wetlands. Developed, or built up, areas are characterized by impervious surfaces and should have positive effects on both forms of measured streamflow. In contrast, the area of natural or vegetated cover should have a negative relationship with both MAF and PAF. The two types of wetlands, Palustrine Scrub/Shrub wetlands and Palustrine Forested wetlands are expected to have negative effects on both MAF and PAF.

4. RESEARCH METHODS

This Section outlines and discusses the research methods used in subsequent analyses. It consists of four separate sub-sections. First, the study area chosen for this research is presented and described. Second, the logic used to select the sample of stream gauges for the study period and the procedure used to develop the unit of analysis, sub-basins, is explained. The final two sub-sections of this Section outline the two phases of analysis; the first being descriptive and exploratory in nature and the second explanatory in nature.

4.1. Spatial Sample Frame

The spatial sample frame for this research is the Coastal Bend of Texas. This area spans the gulf coast of Texas from the northeast to the south and also encompasses the Galveston District of the USACE, a 49 county area of approximately 52,000 square miles (see Figure 2). The study area is diverse in terms of climatic, bio-physical and anthropogenic characteristics. The average annual precipitation ranges from approximately 22 inches (southwestern) to 54 inches (northeastern). Major vegetation complexes reflect this range in precipitation and include Pine and mixed Pine/Hardwood forests in the northeastern portion of the study area, blackland and upland prairies and woods in the central portion of the study area and low, brushy vegetation in the southern portion of the study area. Overall, the study area can be viewed as a gradient beginning with dry, brushy areas in the southwest and stretching to the wetter and far more green areas to the east north east. The study area is also home to several different types of wetlands, but has also historically been an area of wetland losses. From the mid 1950s to the early 1990s the Texas coast lost an estimated 210,600 acres of wetlands to both agriculture and, increasingly, urban land uses (Moulton et al., 1997).

The area sampled for this research is both large and ecologically diverse. As stated above, its geographical extent covers a wide range of vegetation and climatic regions. This sample should allow the results of this study to be generalized to the entire Galveston District USACE, or sample population, as well as geographical areas that share similar climatic, vegetation and topographical characteristics.

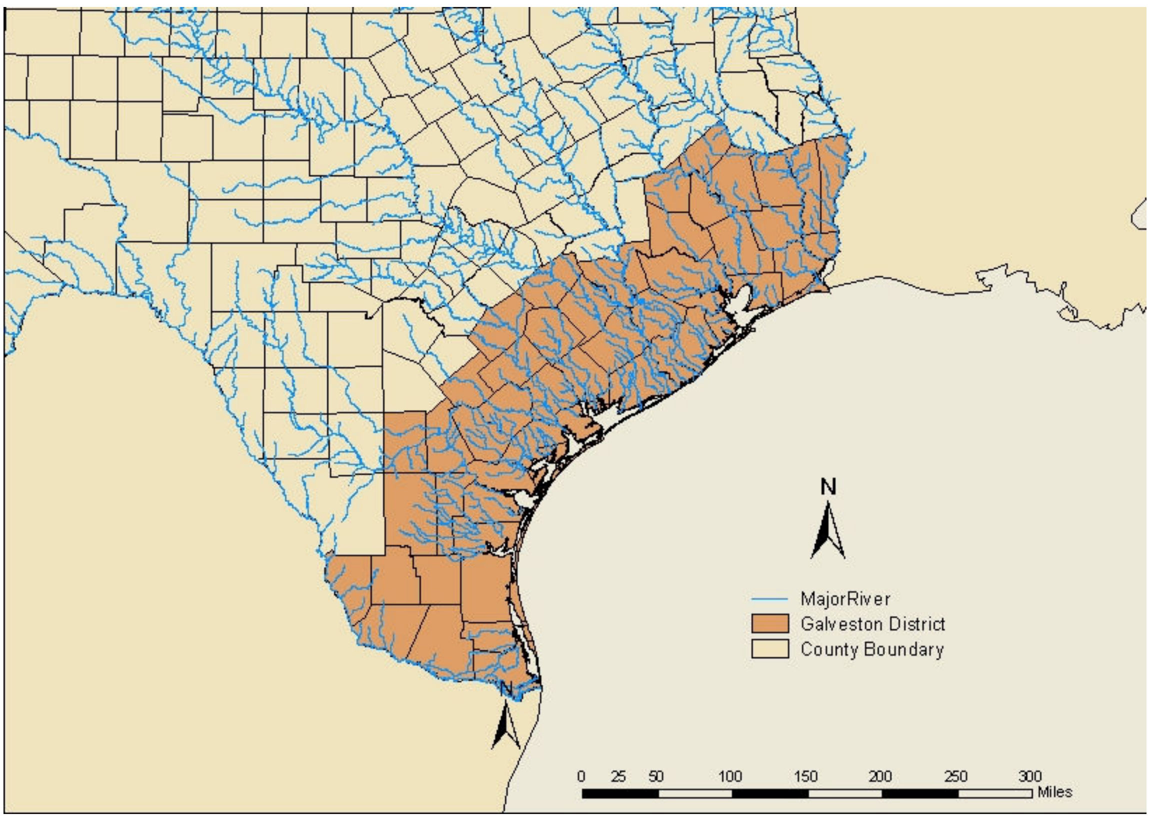

Figure 2. USACE Galveston District

4.2. Sample Selection

4.2.1 Gauge Selection

The sample and study period for this research was selected based on four primary factors. Because USGS streamflow gauge measurements provide the data for this study's dependent variables their selection was critical. First, the gauge location must have been located within the study area. Second, the gauge could not have been located at the outlet of a dam or reservoir. While it is clear that activities upstream of a streamflow gauge would certainly affect the measurements, using values that were measured at and a direct result of reservoir management would not have been appropriate. Third, the record at each gauge had to be approximately 90 percent complete in any year to be included. Finally, each gauge had to have a minimum of three years during the study period to be included. The above selection rules resulted in a set of 47 gauges having a minimum annual sample size of 33, a maximum annual sample size of 46, and an overall sample size of 322 over an 8 year period (see A2-Table 16 for specific gauge characteristics).

4.2.2 Basin Development

For each gauge that met the data requirements outlined above a distinct hydrologic unit of analysis was created. The development of sub-basins based upon an outlet, in this case the gauge location, is an established spatial data development process. The use of digital elevation models (DEMs) to conduct watershed delineations was initially created by the use of the Deterministic-8 Node (D8) algorithm (O'Callaghan & Mark, 1984). The D8 algorithm specifies that in a gridded representation of topography, flow moves from each cell to one and only one of its eight nearest orthogonal or diagonal neighbors in the direction of the steepest descent. This process was further refined to pre-process DEMs of cells that will not allow flow to resume due to surrounding neighbors of higher elevation. These spurious cell values, or sinks, can be raised or have one of their neighbors lowered in order to create a drainage enforced flow accumulation network (Jenson & Domingue, 1988; Saunders, 2000).

More recent techniques of creating drainage enforced flow accumulation surfaces have also been developed that integrate vector representations of known stream and river locations. Often referred to as stream burning, cell values in the DEM that are located at known stream and river locations are reduced. This additional step results in a DEM that will force flow direction (and thus flow accumulation) grids to follow known drainage paths (Saunders, 2000). The AGREE algorithm for pre-processing DEMs (Hellweger, 1997) with additional vector data is both computationally efficient and produces DEMs with sub-basin delineations that more accurately represent the known stream network (Saunders, 2000).

To create the sub-basins used as units of analysis, preprocessed 30 meter resolution DEMs, D8 flow direction grids, and flow accumulation grids were acquired from the National Hydrography Dataset (NHD) Plus. These datasets have already undergone the AGREE DEM pre-processing, sink filling and intermediate grid creation procedures. Gauge locations were manually checked to confirm their location was correct with respect to the stream or river name and that each point location intersected the NHD line. The batch sub-basin development routine in the ArcHydro extension of ArcGIS was used to create a unique sub-basin for each gauge of interest. In some cases, the geographic extent of the created sub-basin extended beyond the boundaries of the county-based study area. Where this occurred, the created sub-basin polygons were clipped to the geographic extent of the established USGS eight-digit hydrologic unit that they fell within. These gauge selection rules yielded 47 gauges with high data integrity (A2- Table 16) over an eight-year period. Likewise, 47 unique sub-basins were also successfully delineated using the procedures above (see Figure 3).

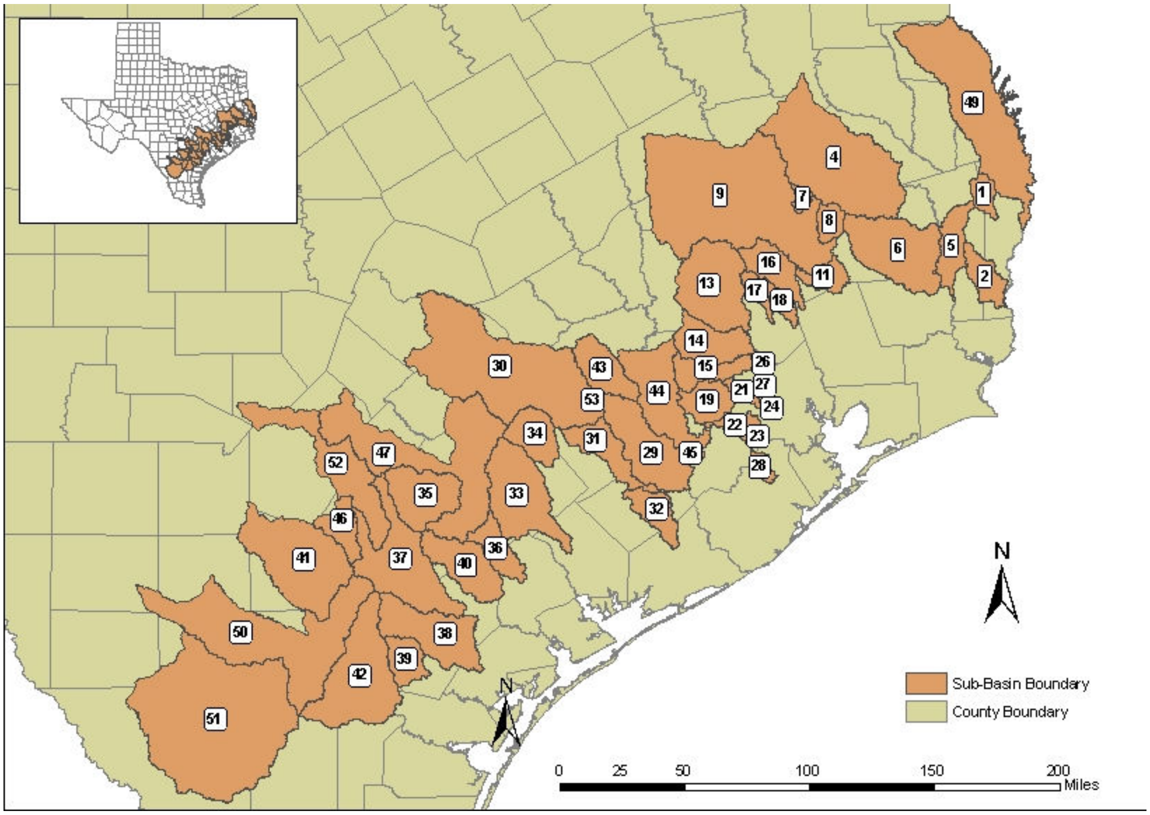

Figure 3. Delineated Sub-Basins and Identification Codes

4.3. Concept Measurement

4.3.1. Dependent Variables

Mean daily streamflow from 1996–2003 for gauges within the 49 county study area was acquired from the Austin, TX office of the USGS. Because not all of the data was approved for publication by the USGS, daily values were checked and cleaned for missing values. Variables were created to count the number of days per year with streamflow values and the number of years meeting the selection requirements. Once gauges that met these requirements were identified, two separate variables were created: mean annual flow (MAF) and peak annual flow (PAF). Both variables were created by collapsing daily values on USGS site numbers and a year identifier in and subsequently log-transformed to better approximate a normal distribution[3]. The two dependent variables are summarized below in Table 2; their distributions are presented graphically in Figure 4 and Figure 5. Descriptive statistics are presented by gauge in A2-Table 16.

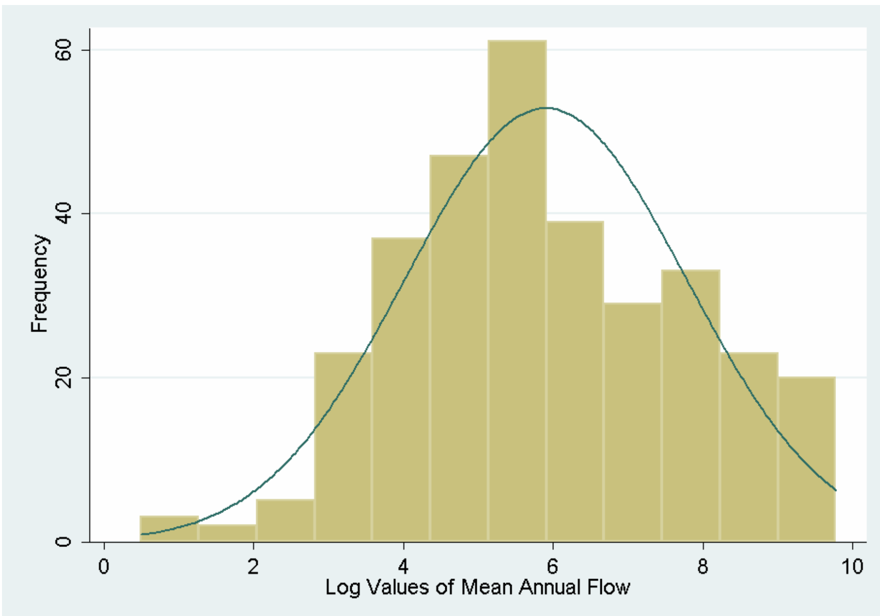

Figure 4. Histogram of Log-Transformed Values of Mean Annual Flow

[3] Peak Annual Flow was normally distributed following log transformation based on a test of skewness-kurtosis. Mean Annual Flow was not normally distributed based on the skewness-kurtosis test. However, a ladder of power transformations identified log transformation as the most appropriate transformation to achieve a near normal distribution.

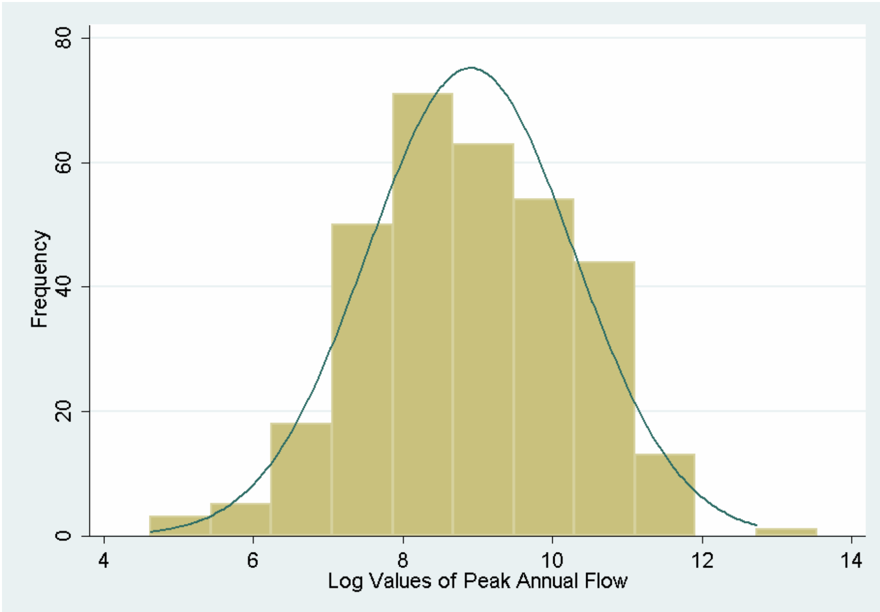

Figure 5. Histogram of Log-Transformed Values of Peak Annual Flow

Table 2. Concept Measurement

Variable	Description	Source	Mean	Std. Dev.	Min	Max
Mean Annual Flow (log-transformed)	Mean annual flow at each USGS gauge location	USGS	1703.08 (5.90)	3169.22 (1.88)	1.65 (0.50)	17766.25 (9.77)
Peak Annual Flow (log-transformed)	Maximum daily flow at each USGS gauge location, by year	USGS	17148.72 (8.91)	27053.36 (1.38)	102 (4.62)	338000 (12.73)
Individual Permits (Cumulative)	Count of Section 404 Individual permits in each sub-basin	USACE	0.28 (2.68)	1.05 (8.54)	0 (0)	11 (64)
Letter of Permission (Cumulative)	Count of Section 404 Letters of Permission permits in each sub-basin	USACE	0.66 (4.66)	4.34 (30.58)	0 (0)	45 (277)
General Permits (Cumulative)	Count of Section 404 General permits in each sub-basin	USACE	4.28 (29.83)	29.54 (182.65)	0 (0)	309 (1749)
Nationwide Permits (Cumulative)	Count of Section 404 Nationwide permits in each sub-basin	USACE	3.25 (17.04)	17.47 (44.89)	0 (0)	228 (586)
Precipitation	Mean annual precipitation for each sub-basin; units in inches	NOAA, GIS	36.36	9.44	15.31	59.62
Contributing Drainage Area	Drainage area of sub-basin; units in square miles	GIS	918.50	956.87	17.24	3097.35
Elongation Ratio	Ratio of the diameter of a circle with the same area as the basin by the basin length	GIS	0.70	0.13	0.48	0.99
Mean Slope	Mean slope of sub-basin, measured in percent	GIS	1.96	1.20	0.18	4.89
Soil Permeability	Average basin soil permeability, in inches/hour	NRCS, GIS	0.90	2.26	0.31	10.46
Natural Cover	Proportion of sub-basin that has natural land cover	NOAA, GIS	0.51	0.19	0.05	0.88
Palustrine Scrub/Shrub	Proportion of sub-basin classified as Palustrine Scrub/Shrub wetland	NOAA, GIS	0.007	0.008	0.0	0.05
Palustrine Forested	Proportion of sub-basin classified as Palustrine Forested wetland	NOAA GIS	0.067	0.067	0.0	0.23
Developed	Proportion of sub-basin classified as developed	USGS	0.066	0.001	0.003	0.52
						n = 322 for all variables

4.3.2. Independent Variables

Data on Section 404 permits were obtained from the Galveston District of the USACE. The raw form of the data was unfit for analysis so several steps were taken to prepare the dataset. First, the permit dataset was cleaned to remove any duplicate records based on year, applicant name, permit number and permit type. Records that were duplicated based upon these four fields were deleted. Second, some cases had identical longitude-latitude coordinates across years and permit types. Working under the assumption that permit expiration dates had been extended or the permit amended and reissued, the permit with the latest date was retained and all others deleted. Third, some cases had identical latitude-longitude coordinates (within and across years) but the permit type was different. Working under the assumption that the category of work had been expanded, the highest impact category of work was retained and other records deleted. For example, if a Nationwide permit was issued at the same location as an Individual permit the Nationwide permit was deleted and the Individual permit was retained. This assumed the permits were ranked Individual, Letter of Permission, General, Nationwide from highest to lowest.

This procedure resulted in a total of 8,278 permits issued in the Galveston District USACE during the time period 1996 – 2003. Only 3,191 of these permits fell within the study area during the study period (see Table 2). Section 404 permits were then added into a GIS based on their given latitude-longitude coordinates and spatially joined to their corresponding sub-basins (see Figure 6). Once permit locations were attributed to the sub-basin in which they were located they were summed, resulting in counts of permits by year and permit type by sub-basin. Cumulative counts of Section 404 permits by type across years were also generated (see Table 2).

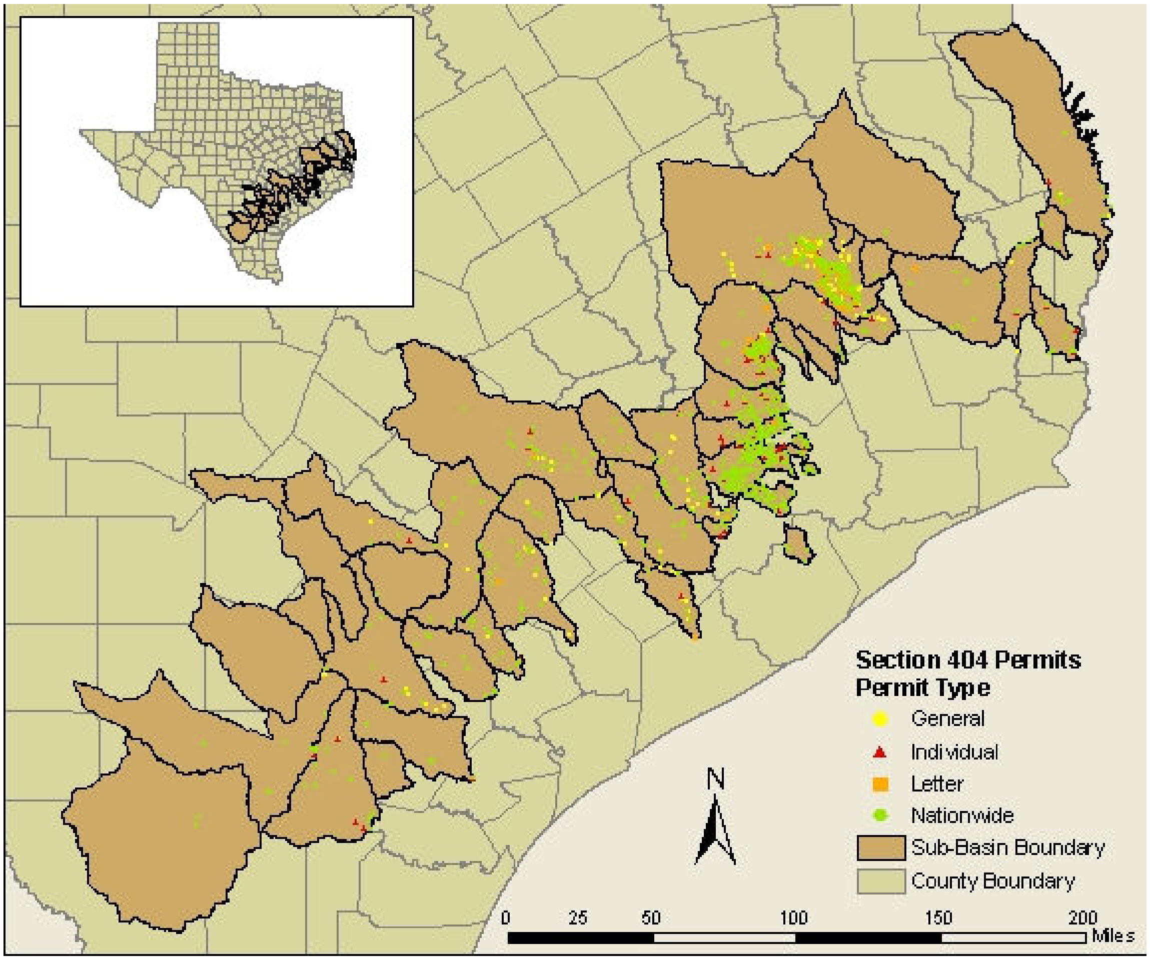

Figure 6. Section 404 Permits by Permit Type, 1996 - 2003

4.3.3. Control Variables

Geomorphic Variables

Contributing drainage area was calculated in GIS. The area of each delineated sub-basin was derived using simple field calculations. Following this calculation, the stream network and streamflow gauges were laid over the sub-basins to visually inspect for sub-basins that were nested, or drained directly into downstream sub-basins. When this occurred (three instances) the area of the upstream basin(s) were added to the area of the downstream basin to arrive at a contributing drainage area. Mean slope was also derived in GIS. Using the native DEM, a slope raster was created. This raster was summarized using the delineated sub-basin boundaries resulting in a mean slope measure for each sub-basin. Elongation ratio was partially calculated in GIS. First, basin length was calculated by creating lines that spanned the distance from the gauge location to the farthest point upstream that intersected the drainage divide. Second, the lengths of these lines were calculated in GIS. Finally, the elongation ratio was calculated using the formula:

$$ER = \frac{\sqrt{4 \times A / \pi}}{L}$$

where A is the basin area and L is the basin length. All geomorphic variables are summarized in Table 2.

Soils

Soil permeability was calculated using the State Soil Geographic Database (STATSGO) generated by the Natural Resources Conservation Service. This database contains two attribute fields that denote soil permeability, one for the highest permeability (PERMH) and one for the lowest permeability (PERML). These two values were averaged for each soil component in all mapping units. The spatial boundaries of each soil component were then intersected with the sub-basin boundaries, and areas were recalculated. Proportional areas were then calculated based on the area of the soil component by the area of the basin. Finally, the proportional areas were totaled, resulting in an area weighted, mean soil permeability measure by sub-basin (see Table 2).

Precipitation

Total monthly precipitation data was collected from the National Climatic Data Center (NCDC) for the period 1995 – 2004. Annual total precipitation was summed over the water year (October 1 – September 30) to match the time period for the dependent variables. NCDC data is gathered at point locations, so locations both within and surrounding the study area were gathered. The total number of precipitation stations varied by year, with a minimum of 279 and a maximum of 305. An inverse-distance weighted interpolation procedure was used to generate a continuous surface (raster) of precipitation for each water year. The resulting precipitation rasters were subsequently summarized by the delineated sub-basin boundaries to yield mean basin precipitation by water year for each year in the study period and for each sub-basin (see Table 2).

Land Cover Variables

Land cover variables were created using the National Oceanic and Atmospheric Agency's (NOAA) Coastal Change Analysis Program (CCAP) land cover datasets for Texas. The CCAP data is a nationally standardized spatial database of land cover and land cover change created from Landsat images in 1996 and 2001. The spatial resolution of this dataset is 30 meters, approximately 0.25 acres per pixel. Each land cover class represented in the CCAP datasets in 1996 and 2001 was summarized by the sub-basin boundaries, resulting in the proportion of each land cover class in each sub-basin.

Three land cover classes were combined to represent proportion developed: High Intensity Developed, characterized by highly developed areas where impervious surfaces account for 80 to 100 percent of the total cover; Medium Intensity Developed, characterized by areas with a mixture of constructed materials and vegetation where impervious surfaces account for 50 to 79 percent of the total cover; and Low Intensity

Developed, characterized by areas with a mixture of constructed materials and vegetation where impervious surfaces account for 21 to 49 percent of total cover (NOAA, 1995).

Six land cover classes were combined to represent the proportion with natural cover: Pasture/Hay, characterized by areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops; Grassland/Herbaceous**,** characterized by areas dominated by grasses or herbaceous vegetation, generally greater than 80 percent of total vegetation; Deciduous Forest, characterized by areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover where more than 75 percent of the tree species shed foliage simultaneously in response to seasonal change; Evergreen Forest, characterized by areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover, where more than 75 percent of the tree species maintain their leaves all year; Mixed Forest characterized by areas dominated by trees generally greater than 5 meters tall, and deciduous nor evergreen species are greater than 75 percent of total tree cover; and Scrub/Shrub, characterized by areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation, including tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions (NOAA, 1995).

Finally, the percentages of the two wetland classifications that make up over 96 percent of the wetlands found in the study area, Palustrine Forested and Palustrine Scrub/Shrub, were calculated. Palustrine Forested wetland area is described as all tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent and where the total vegetation coverage is greater than 20 percent. Palustrine Scrub/Shrub wetlands are described as all tidal and non tidal wetlands dominated by woody vegetation less than 5 meters in height, all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent and where the total vegetation coverage is greater than 20 percent (NOAA, 1995). The species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions (Cowardin, Carter, Golet & LaRoe, 1979).

Finally, land cover does not remain static over time; land cover classes are in a constant state of change. Unfortunately, land cover classification datasets do not exist at a finer temporal resolution even though the CCAP database is the finest temporal dataset available for this scale of analysis. To address this shortcoming of the data, the change in land cover percentages between 1996 and 2001 was calculated and rate of change factor was determined. This factor was applied to the years 1997–2000 and 2002-2003 to create imputed land cover variables for those years. This imputation procedure is not perfect as it assumes a constant rate of change which typically is not accurate for urban areas. Ultimately, this procedure produced no differences in the signs of the regression coefficients or changes in their statistical significance.

4.4. Data Analysis

Data analysis for this research took place in two phases. The first phase of analysis is exploratory in nature, examining several aspects of the Section 404 data gathered for this research. This first analysis aims to better understand the pattern of Section 404 activity within the sub-basins during the study period through the use of basic descriptive statistics, cartography, and spatio-temporal statistical techniques. Phase I also serves as an important preliminary step to explanatory analyses. Spatial clusters or outliers identified by exploratory space-time data analysis may provide important indicators of permitting activity and areas that are unique in terms of wetland loss. Phase 2 of data analysis is explanatory in nature. It seeks test the hypotheses outlined in the Section 3 through the use of multivariate statistical techniques.

4.4.1. Phase I: Exploring the Spatial and Temporal Patterns of Section 404 Permits

There were several approaches to taken to Phase I data analysis. First, basic descriptive statistics were calculated for Section 404 permits. Second, two forms of spatial statistics were utilized to better understand the spatial and temporal characteristics of Section 404 permits. The identification of spatial patterns through exploratory spatial data analysis (ESDA) is increasingly considered fundamental to understanding the processes of various phenomena. ESDA is commonly described as a set of analytical methods used to describe and visualize spatial distributions, identify spatial clusters, hotspots or spatial outliers, and suggest spatial regimes or other forms of spatial heterogeneity (Anselin 1988, 1999; Dall'erba, 2005). The addition of temporal variables into ESDA, or Dynamic ESDA, is also considered important to understanding spatial data over time (Rey & Janikas, 2006).

Two primary spatial statistic analysis methods were computed on Section 404 permits: the Mantel Index and Moran's *I*. The Mantel Index is a method used to assess space-time interactions using discrete spatial data points. Essentially, it is a correlation between distance and time interval for pairs of incidents (Mantel, 1967). More specifically, it is a test for correlation between two dissimilarity matrices that summarizes comparisons between pairs of points, one for spatial distance and one for temporal distance (Mantel & Bailar, 1970). The Mantel Index takes the form:

$$r = \frac{1}{(n^2 - n - 1)} \sum_{i}^{n} \sum_{j}^{n} \left[\frac{X_{ij} - \overline{X}}{s_x} \right] \left[\frac{Y_{ij} - \overline{Y}}{s_y} \right]$$

where X_{ij} is the distance between events *i* and *j* in time and Y_{ij} is the distance between events *i* and *j* in space; s_X and s_Y are the standard deviations of the space and time distances, respectively, and *n* is the number of events.

Similar in nature to a Pearson's Product-Moment correlation, the values of the Mantel Index also range from -1 to 1. The null hypothesis tested is that the time and space distances are independent. However, these two dimensions are likely to be interdependent, so traditional significance testing is inappropriate. Consequently, Monte Carlo simulation is necessary to gain meaningful significance values for the Mantel Index (Levine, 2004). The Mantel Index was also computed separately for each permit type and all permits in the study area. Following the initial computation of the Mantel Index, 999 simulations were run to assess its statistical significance.

Moran's *I* (Moran, 1950) is a weighted correlation coefficient used to detect spatial autocorrelation. Departures from randomness often indicate spatial patterns such as clusters. The Moran's *I* statistic takes the form:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} \left(X_i - \overline{X}\right)\left(X_j - \overline{X}\right)}{\sum i \left(X_i - \overline{X}\right)^2}$$

where N is the number of spatial units at locations i and j; X is the variable of interest; $\overline{X}$ is the mean of X; and w_{ij} is a matrix of spatial weights.

This statistic also takes on values from -1 to 1. Large positive values of Moran's *I* indicate positive spatial autocorrelation, meaning that nearby areas have similar values. When neighboring values are dissimilar, Moran's *I* will be negative.
There are many forms of spatial weights matrices that can be introduced into the equation for w_{ij} and the selection of the appropriate weights matrix is often subjective.

Weights matrices can be contiguity based (dichotomous), distance based (such as inverse distance, more weight given to closer observations) or k-nearest neighbor based (defined number of neighbors). For this study a contiguity based weights matrix was selected in which basins where classified as neighbors if they shared any portion of a border with each other. Distance weights would have been inappropriate due the units of analysis being areal in nature. K-nearest neighbor weights would have been inherently subjective, as there is no justification for determining the number of neighbors. The value of X was raw counts of Section 404 permits within each sub-basin. Significance values were assessed following 999 permutations, in which a reference distribution is calculated for spatially random layouts with the same data (Anselin, 1994).

4.4.2. Phase 2: Explaining the Effect of Section 404 Permitting on Mean and Peak Streamflow

The longitudinal nature of this research provides an advantageous study design that is often referred to as panel data, cross-section time-series (CSTS) data or pooled data, CSTS models take the generic form of:

$$y_{i,t} = \beta_0 + \beta x_{i,t} + \varepsilon_{i,t}\,;\;\; i = 1,\ldots.\mathrm{N};\; t = 1,\ldots.\mathrm{T}$$

where observations are indexed by both unit (*i*) and time (*t*). CSTS data designs are well suited to assess the dynamics of change over time because they can detect effects that cannot be identified with cross-sectional designs. In addition, they provide more degrees of freedom and more efficiency than cross-sectional designs (Batalgi, 1995).

However, the characteristics of CSTS data analysis can also lead to violated assumptions that are different from, as well as more frequent than, those encountered in cross-sectional study analyses. There are several forms of multivariate CSTS regression models; the selection of the most appropriate modeling approach was given careful consideration. The following will focus on detecting violated assumptions in the dataset, methods of overcoming potential violations, and the overall logic used to guide the CSTS analysis.

Serial Autocorrelation

First, CSTS data sets are often plagued with observations that are not independent over time (Worrall & Pratt, 2004a). Observations that are not independent over time (i.e. serially correlated) violate regression model assumptions, bias the standard errors, and cause the estimations to be less efficient (Gujarati, 2005; Wooldridge, 2002). Further, due to the nature of CSTS data, traditional tests for serial autocorrelation such as Durbin-Watson are inappropriate (Wooldridge, 2002). Wooldridge (2002) developed a test for serial autocorrelation for CSTS data that uses regression residuals from a first-differenced regression (Drukker, 2003). Tests for serial autocorrelation were conducted using the Wooldridge test for serial autocorrelation in panel data (Wooldridge, 2002; Drukker, 2003). All tests for serial autocorrelation were positive and significant for both dependent variables (see Table 3).

Table 3. Tests for Serial Autocorrelation and Contemporaneous Correlation

	Wooldridge's Test	Pesaran's Test
Mean Annual Flow		
General	40.570	31.758
Nationwide	40.977	32.123
Letter	40.468	32.071
Individual	40.803	31.758
Peak Annual Flow		
General	11.896	24.149
Nationwide	11.591	23.460
Letter	11.896	24.178
Individual	11.878	23.611

All values are significant at the $p<0.001$ level

Spatial Autocorrelation

Second, because CSTS data consists of multiple observations within each cross-section, spatial autocorrelation may also pose a problem. Similar to serial autocorrelation, spatial autocorrelation violates the assumption of independent observations and can also deflate standard errors (Anselin, 1988). However, unlike serial autocorrelation (where errors are dependent over time) spatial autocorrelation arises when errors are dependent over space. This violation of independence is especially prevalent when the units of analysis are contiguous, as is the case with the sub-basin unit of analysis for this research, unlike units that are randomly sampled in space.

Spatial autocorrelation also presents problems in a CSTS study design as there are no CSTS techniques that can directly account for spatial autocorrelation. Nonetheless, identification of potential biases arising from spatial autocorrelation is important. Several statistics are available to test for the presence of spatial autocorrelation. The Moran's *I* test, probably the most common and arguably the best statistical test for spatial autocorrelation, was selected to identify the presence of spatial autocorrelation in the dependent variables. Due to the longitudinal arrangement of the data, the mean of the dependent variable over the study period was tested using a binary, contiguity based weights matrix. MAF had a Moran's *I* value of 0.1252 (p = 0.130) and PAF had a Moran's *I* value of -0.0037 (p =0.572). Both values were insignificant and indicated that multivariate statistical models will not suffer from spatial autocorrelation.

Contemporaneous Correlation

CSTS data can often have issues of contemporaneous correlation, also referred to as cross-sectional dependence. Contemporaneous correlation arises when observations from specific units are correlated with observations in other units across the same time period (Worrall & Pratt, 2004b). Analysis results that do not account for this correlation may lead to incorrect inferences through downward biased standard errors (Baltagi, 2005).

Many previous empirical studies have relied on the Lagrange Multiplier (LM) test developed by Breusch and Pagan (1980), which is based on the average of the squared pair-wise correlation of the residuals. However, in situations where N is large (cross-section sample size) and T is small (number of time periods) the LM test has been shown to be inappropriate (Pesaran, 2004). Further, several other tests have been developed to address the inadequacy of the LM test in the N>T situation (Frees, 2004; Pesaran, 2004). Pesaran's test for cross-sectional dependence was selected to detect issues of contemporaneous correlation in the data. These tests are based on the average of pair-wise correlation coefficients of the regression residuals from each individual regression in the panel, and have the ability to work with unbalanced panels (Pesaran, 2004). Using this test, contemporaneous correlation was detected in all four models for both MAF and PAF (see Table 3).

Heteroskedasticity

While heteroskedasticity, or non-constant variance in the error term, is a potential problem even for purely cross-sectional data, a different form of heteroskedasticity can arise in CSTS data. Because there are several cross-sectional units measured over time, the assumption of constant error variance across time *and* cross-sections is typically restrictive in CSTS data (Batalgi, 2005). However, similar to heteroskedasticity in cross-sectional data, CSTS heteroskedasticity can also leads to biased standard errors (Batalgi, 2005). Several tests have been proposed to detect heteroskedasticity in CSTS models, including the use of auxiliary regressions (Glejser, 1969) and the Breusch-Pagan test (Breusch and Pagan, 1980). I chose to adopt the use of auxiliary regressions. Although this approach was initially developed for cross-sectional data, it has been advocated for and applied to CSTS data (Franzese, 2002; Worrell & Pratt, 2004b).

These tests were conducted by first estimating an ordinary least-squares (OLS) regression model, regressing on to the independent variables thought to be contributing to the heteroskedasticity the absolute value of the OLS residuals and examining the F statistic. The F test is essentially a test of CSTS heteroskedasticity against the null hypothesis of homoskedasticity (Worrell & Pratt, 2004b). These tests, using mean basin precipitation as the sole independent variable resulted in statistically significant F statistics of 21.88 ($p = 0.000$) and 9.32 ($p = 0.002$) for MAF and PAF, respectively. The use of auxiliary regressions is meant to identify the variable or variables that are responsible for non-constant variance. However, because the test statistics were significant using only a necessary and basic and time-variant independent variable, I concluded that heteroskedasticity was present in both models.

Model Selection

It is important to note that all of the above tests detect violations of independent and identically distributed (iid) errors, all of which can lead to (typically downward) biased standard errors and thus inappropriate inferences based significance values. Because the primary reason to statistically model MAF and PAF was to assess the significance of wetland loss through Section 404 permits (as opposed to making point estimates), estimating models with appropriately calculated standard errors was of critical importance.

Each of the above violations of regression assumptions narrows the range of potential statistical analysis methods. First, pooled OLS is certainly not an option given the serial autocorrelation and contemporaneous correlation. Second, fixed-effects panel regression is also not appropriate given the importance of time-invariant control variables. Third, random-effects panel regression is also a problematic approach given both serial autocorrelation and contemporaneous correlation.

Two methods are considered appropriate when dealing with, and correcting for, the four violations outlined above: Feasible Generalized Least Squares (FGLS) and Prais-Winsten with Panel Corrected Standard Errors (PCSE). Past research regarding FGLS in this analysis setting where N>T has shown that FGLS produces both inconsistent and inefficient estimates unless T >= N (Beck & Katz, 1995). Consequently, PCSE was the modeling procedure chosen for analysis. As its full title suggests, this modeling approach first estimates a regression model using Prais-Winsten regression, a linear regression that is corrected for first-order serially correlated residuals[4]. Following the Prais-Winsten estimation, adjustments are made to the standard errors based on the CSTS error structure under the assumptions of heteroskedastic and contemporaneously correlated errors. This approach yields the most conservative standard errors and thus cautious significance values.

[4] Some authors (Beck & Katz, 1995; Worrell & Pratt, 2004a) advocate the use of a serially-lagged dependent variable in the place of Prais-Winsten estimation. This approach was not taken because the lagged dependent variable is not important from an interpretation standpoint and artificially inflates R^2 values.

4.5 Validity Threats

No study design is perfect and this research is no exception. Although all attempts have been made to arrive at accurate and appropriate results, examining and recognizing potential threats to validity that result from the design of the research is necessary. Although validity threats are discussed in a variety of methodological texts, the following uses the terminology and approach of Cook and Campbell (1979).

4.5.1. Statistical Conclusion Validity

Although Phase I of the research is exploratory in nature, sample size still plays an important role in assessing the significance of the spatial statistics. In terms of potential sample size limitations, the Mantel Index is of little concern. The study area contains 3,191 total Section 404 permits, each of which is considered an observation in the calculation of this statistic. Calculations of Moran's *I* are however performed annually and utilizes sub-basins as the unit of analysis. This leads to an annual sample size of 47, far smaller than using the discrete permit locations used by the Mantel Index. Statistical conclusions should be made with caution as influential data points could potentially skew results.

The second, explanatory phase of the research provided annual sample sizes that ranged from $35 < n < 46$. Longitudinal analysis of the data did provide an increased level of statistical power with an overall sample size of $n = 322$. This is certainly not an extremely large sample, but should be large enough to avoid issues related to inadequate sample size.

4.5.2. Internal Validity

Internal validity threats may be an issue when trying to control for all of the factors that may contribute to flooding. Any natural environment is a complex system and modeling these systems and their alterations is an equally complex undertaking. To the extent that was possible, all necessary control variables were included to reduce the likelihood of spurious relationships. The use of longitudinal analysis was a great aid in reducing any possible history threats. Further, synchronizing the amount of wetlands measured by remote sensing in 1996 with permits that began to be issued in 1996 reduces history threats that could arise from previous wetland loss.

Stream gauge attrition is a unique methodological issue that may affect the internal validity of this study. In some cases, stream gauges did not make measurements during some portion of all of a year. As discussed previously, the requirements for including a stream gauge in the analyses were strict. For a stream gauge to be included, it was required to have at least 90 percent of its daily measurements per year and at least three consecutive years of record.

4.5.3. Construct Validity

Construct validity is perhaps the biggest validity threat of this research. One of the primary purposes of this study is to assess the effects of Section 404 permits on streamflow. Section 404 permits are assumed to be an indicator of wetland loss, and the research literature supports this assumption. Research on Section 404 has shown definite wetland losses as measured by USACE records as well as observation driven field research. Permit counts are, however, limited in measurement accuracy because they provide no estimate of the impacted area. Therefore, permit counts are an indicator of wetland loss, but not a substitute for estimated area of wetland loss.

The use of four separate categories of Section 404 permit types does however combat this threat and, to some extent, may provide insight into how well Section 404 permits perform as indicators of wetland loss. Each permit type represents a different level of allowable impact to wetland environments. If the results point to increased effects from permit types that allow larger losses, they will support the validity of Section 404 permits as an indicator of wetland loss.

4.5.4. External Validity

External validity is also a potential validity threat posed by this research design for two reasons. First, the ability to generalize the results of this study to other areas may be limited by the characteristics of the study area. For example, areas where the hydrology is affected more by physical characteristics such as large changes in elevation or climatic characteristics such as snow melt may react differently to Section 404 permitting activity. This research is probably best generalized to geographic areas that have shallow topography, contain basins that are relatively rural as measured by land cover, have primarily Palustrine wetlands, and have climates that are not exceptionally arid.

Second, the impact on wetlands created by General permits may impose limitations on the ability to generalize the results of this study, that are based on this permit type, to areas that fall under the jurisdiction of different USACE Districts. The impacts that this type of permit represents vary by USACE District. General permits are issued for specific activities on a regional scale; activities that are eligible for a General permit in the Galveston District USACE may be much different than eligible activities in other districts such as the Fort Worth District or the Jacksonville District.

5. EXPLORING THE SPATIAL AND TEMPORAL PATTERNS OF SECTION 404 PERMITS

This Section consists of two main sections that examined the implementation of Section 404 permits in the delineated study area within the Galveston District USACE. Permits were characterized spatially and temporally through the use of basic descriptive statistics and graphics. In addition, the two spatial-statistical methods described in Section 4, the Mantel Index and Moran's *I* were employed to gain better insight into potential patterns across space and time.

5.1. Descriptive Spatial and Temporal Analysis of Section 404 Permits

Over the eight year study period 3,191 Section 404 permits were issued within the delineated sub-basins (see Table 4). Over half of the permits issued during the study period were General permits (1,706) and nearly 36 percent were Nationwide permits (1,134). Individual permits (3.17 percent; 101 permits) and Letters of Permission (7.83 percent; 250 permits) combined accounted for only 11 percent of permits issued during the study period.

Table 4. Annual and Total Section 404 Permits

	Individual		Letter		General		Nationwide		Total	
Year	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent
1996	14	2.82%	42	8.47%	347	69.96%	93	18.75%	496	15.54%
1997	12	3.25%	27	7.32%	274	74.25%	56	15.18%	369	11.56%
1998	15	7.28%	37	17.96%	53	25.73%	101	49.03%	206	6.46%
1999	21	6.60%	35	11.01%	178	55.97%	84	26.42%	318	9.97%
2000	10	2.78%	45	12.50%	229	63.61%	76	21.11%	360	11.28%
2001	7	1.58%	25	5.64%	320	72.23%	91	20.54%	443	13.88%
2002	12	2.45%	19	3.88%	132	26.94%	327	66.73%	490	15.36%
2003	10	1.96%	20	3.93%	173	33.99%	306	60.12%	509	15.95%
Total	101	3.17%	250	7.83%	1706	53.46%	1134	35.54%	3191	100.00%

Over the study period, General and Nationwide permits always accounted for at least 74 percent of the issued permits in each year. General permits ranged from a low of 26.94 percent (132 permits) in 2002 to a high of 74.25 percent (274 permits) in 1997. The smallest number of General permits was 53 in 1998; the highest was 347 in 1996. Nationwide permits range from a low of 15.18 percent (56 permits) in 1997 to a high of 66.73 percent (327 permits) in 2002. Notably, when one of these two categories has low counts in one year it is made up by higher counts in the other permit category (see Figure 7). This relationship is apparent in 2002 and 2003, where the count General permits drop of sharply compared to Nationwide permits, which during these two years are triple their counts in any other years.

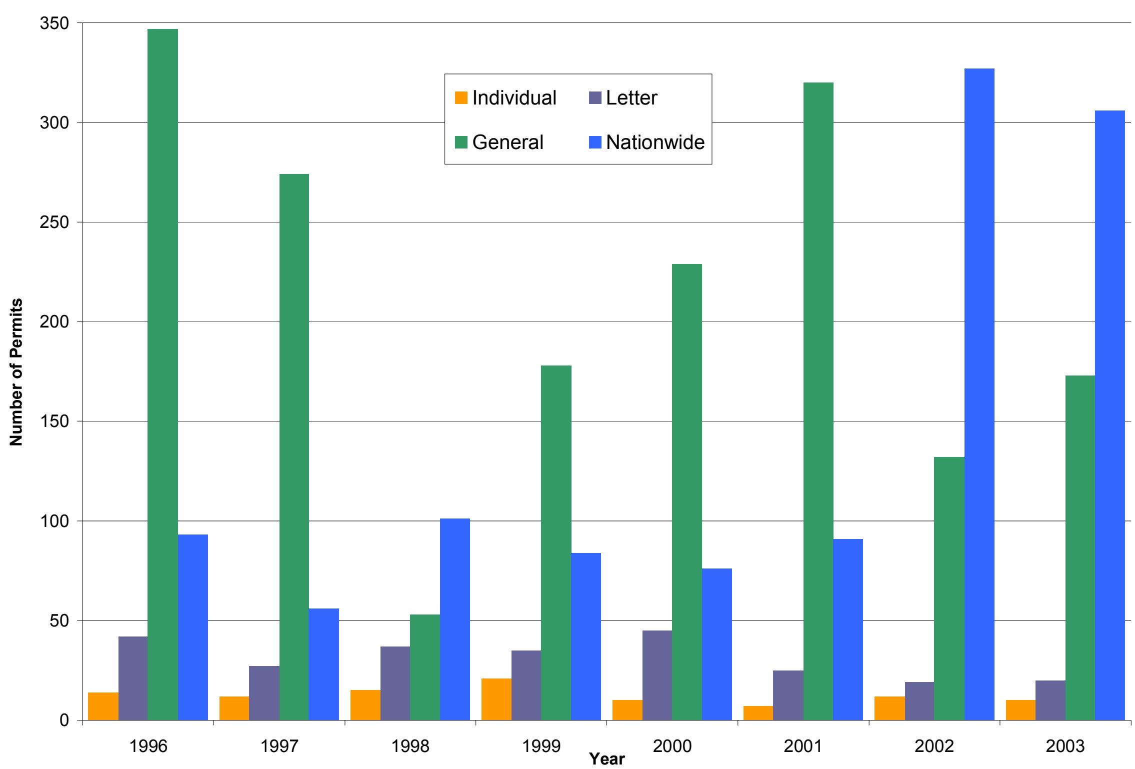

Figure 7. Issued Section 404 Permits by Year and Type

Individual and Letter of Permission permits are consistently the least frequently issued types of permits. Individual permits range from a high of 7.28 percent (15 permits) in 1998 to a low of 1.58 percent (7 permits). The highest number of annual Individual permits was 21 in 1999, the lowest number was 7, occurring in 2001. Letter of Permission permits were issued at a slightly higher rate, ranging from a high of 17.96 percent (37 permits) in 1998 to a low of 3.88 percent (19 permits) in 2002. The numbers for Letter of Permission permits in 2002 and 2003 differ only by one permit; 19 and 20 permits respectively. In terms of raw counts, 2002 was also the lowest year for Letter of Permission permits; the maximum number of Letter of Permission permits was 45, issued in 2000.

When viewing all types of Section 404 permits over time a trend appears. The years 1996 – 1998 show decreasing levels of Section 404 activity, from 496 permits in 1996 to 209 permits in 1998. In 1999 however, this trend reverses itself and the number of issued Section 404 permits starts increasing (see Figure 8). This upward trend does appear to start leveling out around 2003, but without a longer time-series it is difficult to tell if this is a slower year or a true decrease in the upward trend. As noted above, this upward trend is driven primarily by General permits in 1999–2001 and Nationwide permits in 2002–2003.

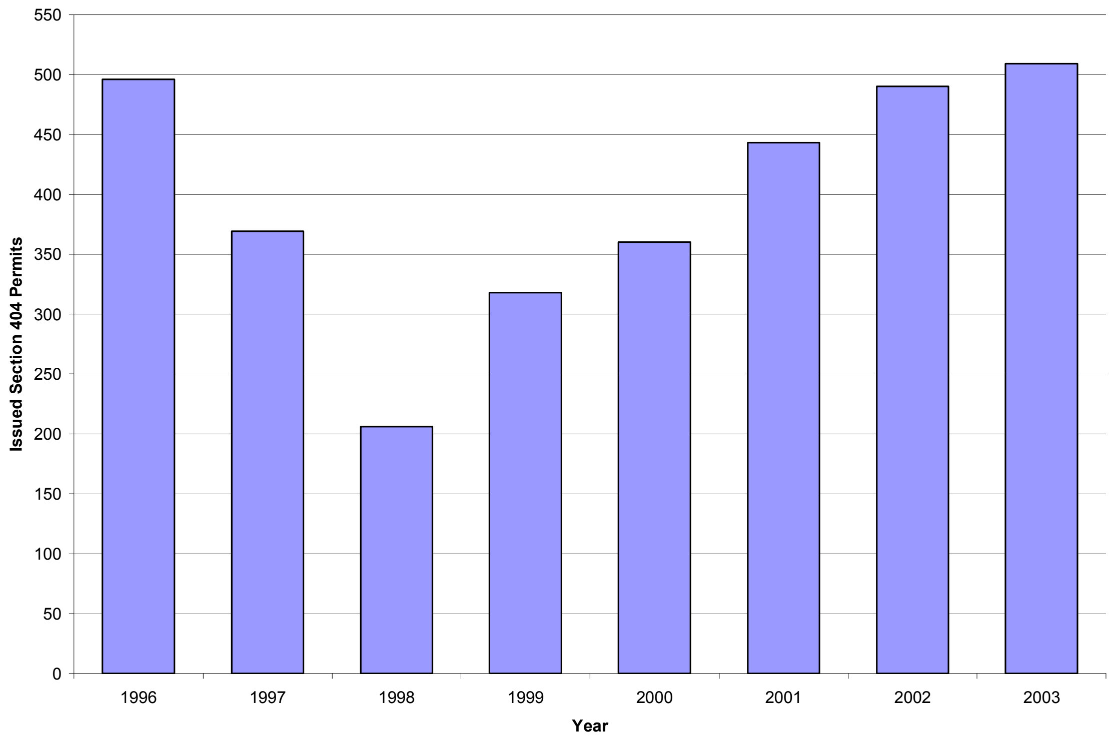

Figure 8. Total Section 404 Permits by Year

Summarizing permit counts by sub-basin creates a more detailed view of Section 404 permitting. Eight of the sub-basins do not contain any Section 404 permits of any type during the study period. Four of these sub-basins are located in the southernmost portion of the study area (41, 42, 46 and 52); while the other four are smaller sub-basins (53, 18, 8 and 1) located in the eastern portion of the study area (see Figure 3 and Figure 9). The highest concentration of permitting activity occurs in a single sub-basin in the eastern portion of the study area (see Figure 9). This sub-basin (9), located north of the city of Houston and intersecting six counties (Leon, Houston, Polk, Trinity, Madison and Walker) has a total permit count of 2,353 permits during the study period, consisting primarily of General (1,572) and Nationwide (504) permits. This is also the second largest sub-basin and is located in an area with a higher concentration of wetlands.

Between these two extremes there is still a fair amount of variation, but the sub-basin with higher counts of Section 404 permits tend to be near Sub-basin 9.

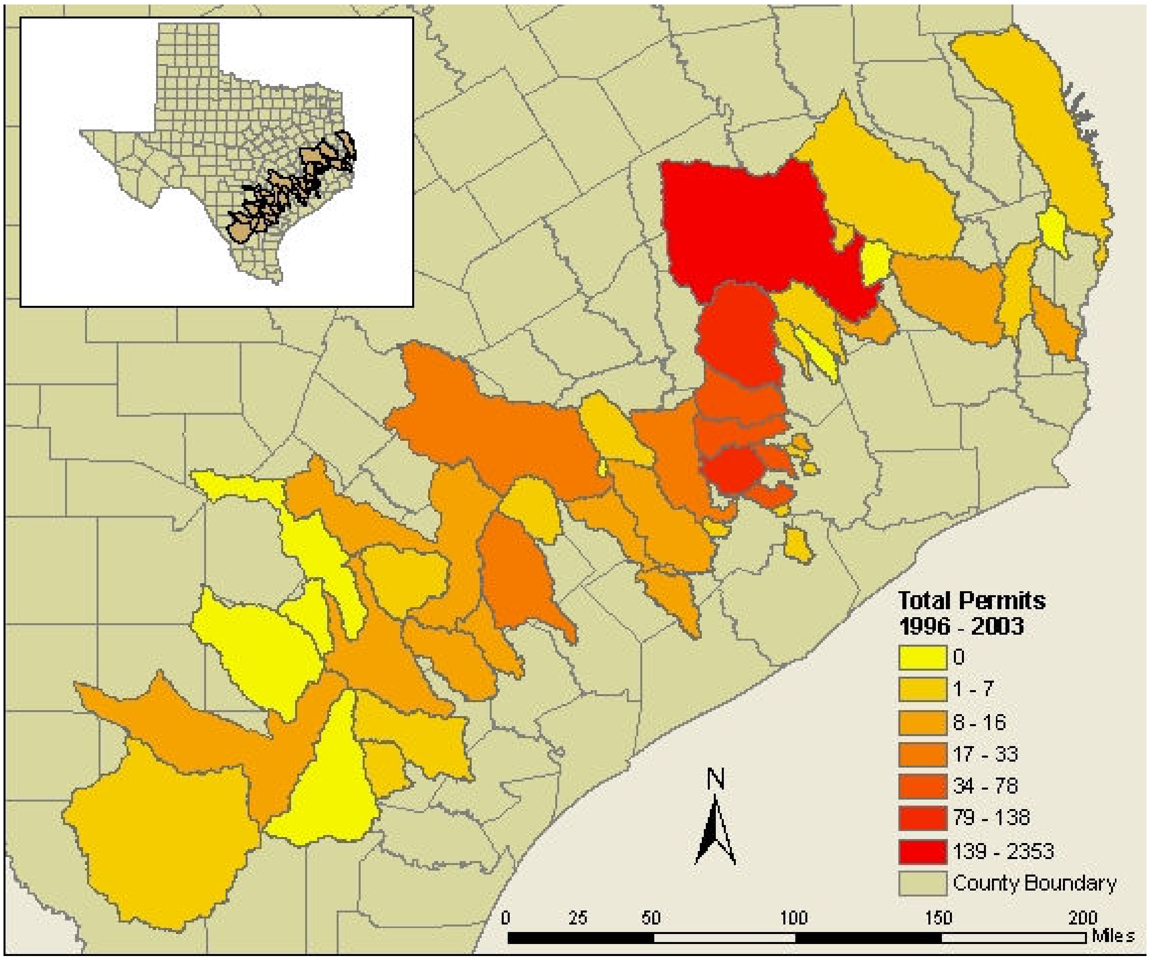

Figure 9. Section 404 Permits by Sub-Basin, 1996-2003

The counts of General and Nationwide permits by sub-basin closely follow the counts of total permits. Consistent with the results noted above, Sub-basin 9 continues to contain more of both permit categories than any other unit. However, on the whole, the count of Nationwide permits by sub-basin are much higher than General permits. For example, seven sub-basins have 39 or more issued Nationwide permits during the study area, compared with only two sub-basins exceeding this threshold for General permits (see Figure 10). This is an interesting phenomena considering that more General permits were issued across the study area (1378) than Nationwide (1047). Nationwide permits are also more evenly distributed across sub-basins than General permits (see Figure 11). Only eight sub-basins had no Nationwide permits issued during the study period, compared with 23 sub-basins that had no General permits issued during the study period. Again, Sub-basin 9 is the obvious driver of General permits during the study period with 1,572. The next highest count is Sub-basin 13, which contains 44 General permits.

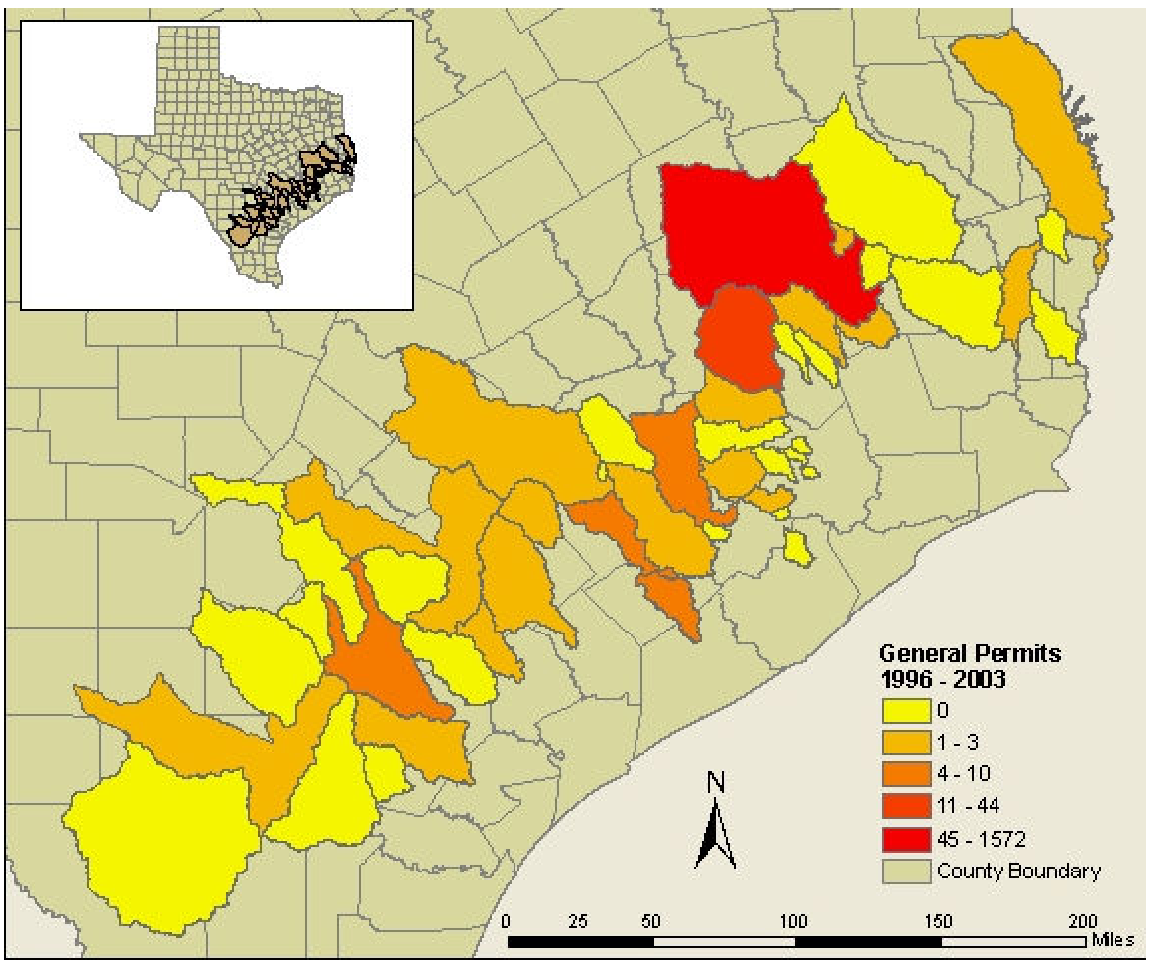

Figure 10. General Permits by Sub-Basin, 1996 - 2003

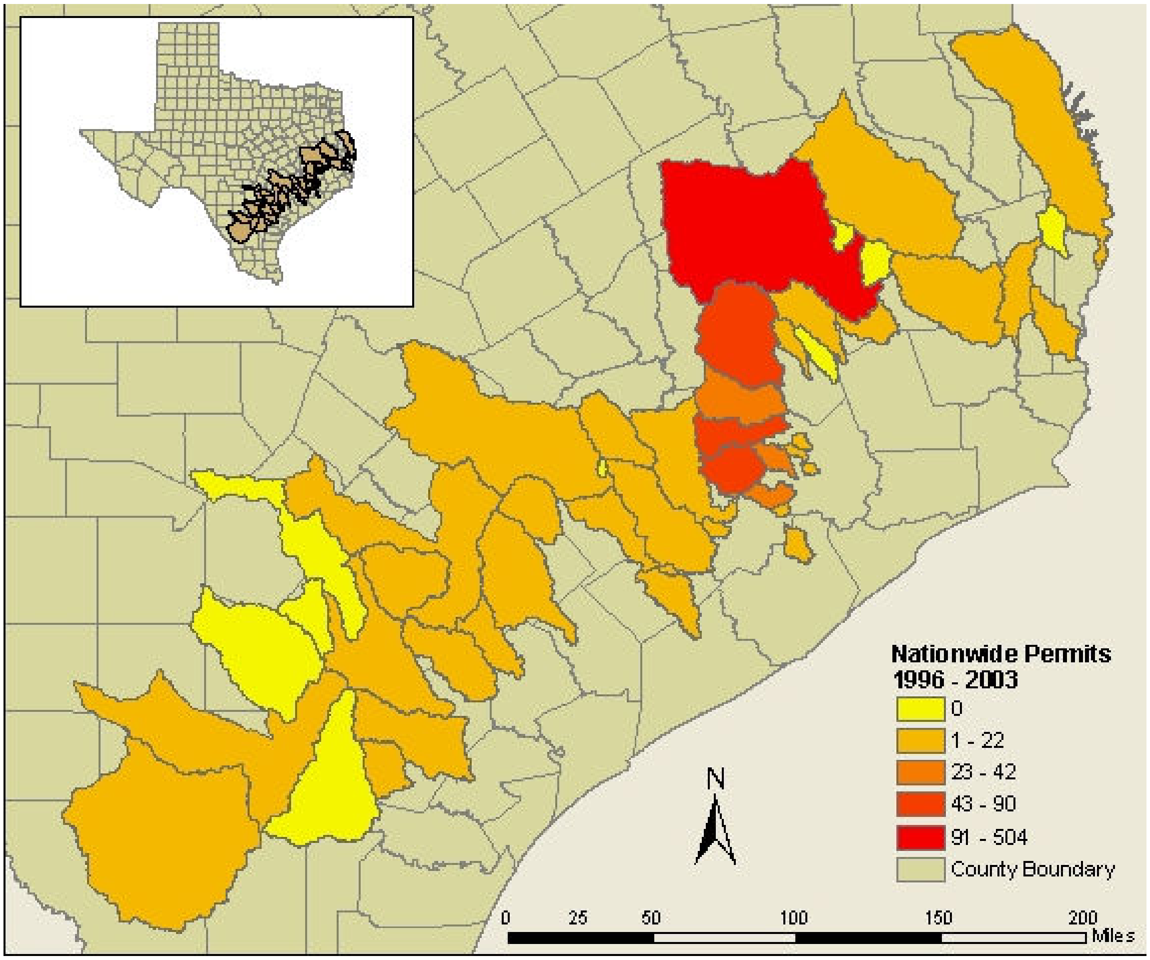

Figure 11. Nationwide Permits by Sub-Basin, 1996 - 2003

Letter of Permission permits show the least spatial variation across sub-basins during the study period. Only seven (15%) sub-basins during the study period contain issued Letters of Permission (see Figure 12). The maximum number of Letters of Permission in any sub-basin is 233, which is again Sub-basin 9. This figure accounts for 93 percent of all Letter of Permission permits. Most other sub-basins that were issued any Letters of Permission only have a single permit issued during the study period. The exception is Sub-basin 13, which has 11 permits and is adjacent to Sub-basin 9.

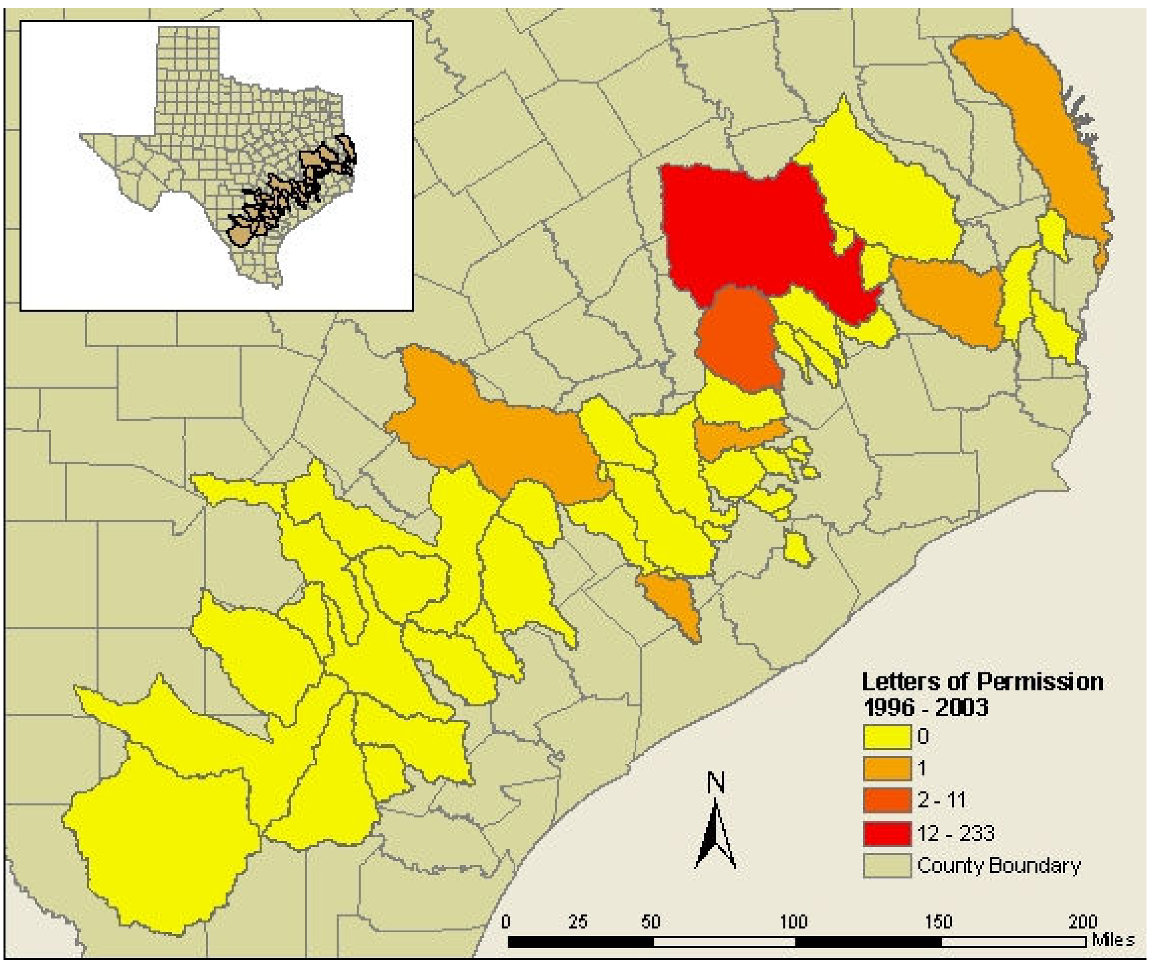

Figure 12. Letters of Permission by Sub-Basin, 1996 – 2003

Finally, Individual permits within sub-basins during the study period show slightly more variation across space than Letters of Permission, but not nearly to the extent of General or Nationwide permits. A little over half (53 percent) of sub-basins were issued Individual permits during the study period. Permit activity within a single sub-basin again accounts for a large percentage of this permit category. Sub-basin 9 contains 44 Individual permits during the study period; which represents nearly 44 percent of all issued permits of this type. Sub-basin 13 is once more a distant second with 14 permits. However, this is closely followed by Sub-basins 19, 15 and 14 with 9, 8 and 4 Individual permits, respectively. These four sub-basins are also all adjacent along a north-south path (see Figure 13).

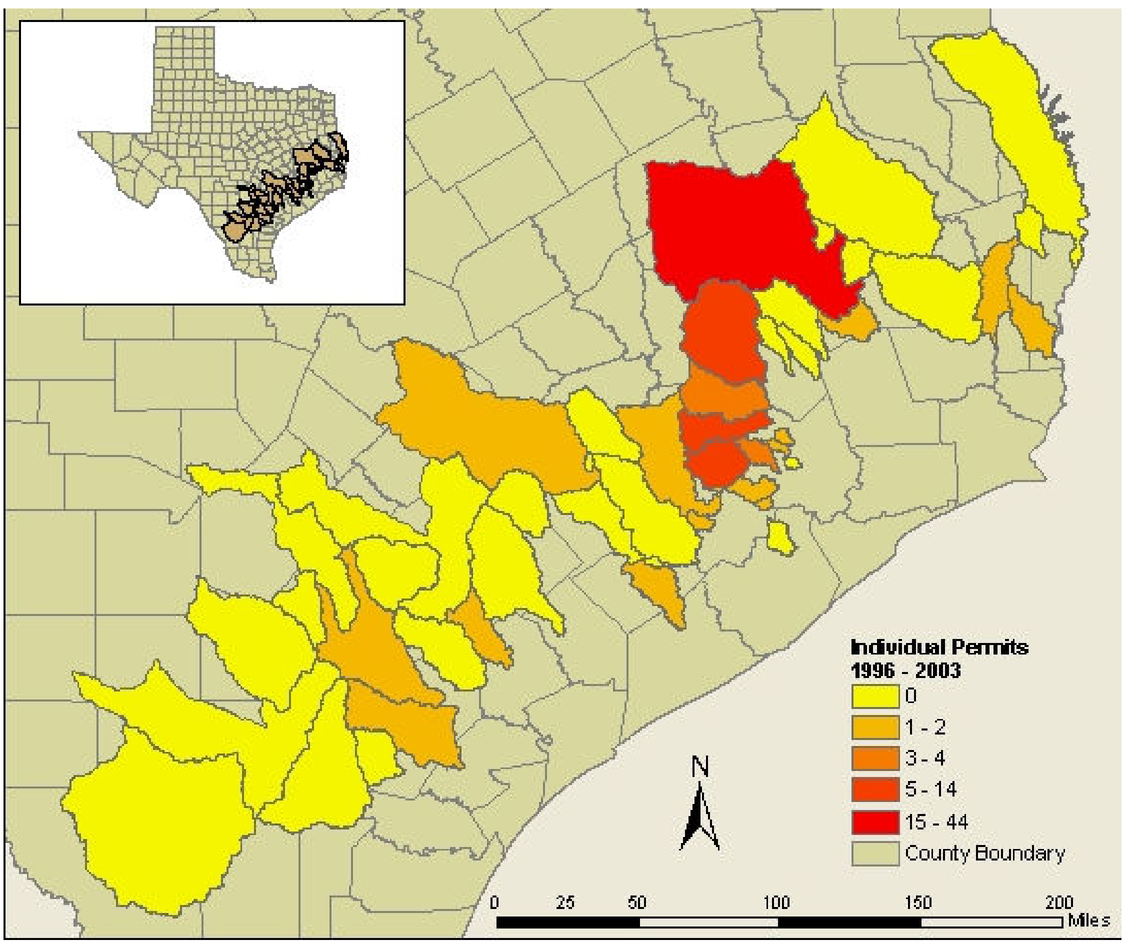

Figure 13. Individual Permits by Sub-Basin, 1996 - 2003

5.2. Exploratory Space-Time Analysis of Section 404 Permits

Another way to characterize the spatial-temporal patterns of Section 404 permits can by accomplished by statistical techniques. Two spatial-statistical methods described in Section 4, the Mantel Index and Moran's *I*, were calculated on Section 404 permits during the study period to elucidate any potential patterns across space and time.

The exploratory space-time data analysis began with calculating the Mantel Index using two matrices: one measuring geographic distance between Section 404 point locations, the other measuring temporal distance between annual Section 404 issue dates. The Mantel Index was computed individually for all permit types as well as the total number of permits during the study period across the study area. Three of the permit categories, General, Individual, and Letter of Permission did not show any spatio-temporal patterns (see Table 5). The Mantel Index for General permits is -0.0003 and is statistically insignificant. The direction of the relationshipfor Individual permits is in the opposite direction at 0.0170 but is also statistically insignificant. Letters of Permission also have a positive Mantel Index value of 0.0241 but are also insignificant.

Table 5. Mantel Space-Time Index on Section 404 Permits

Permit Type	N	Mantel (*r*)
General Permits	1706	-0.0003
Individual	101	0.0170
Letter of Permission	250	0.0241
Nationwide	1134	0.0700***
All Permits	3191	-0.016***

p<*0.05 p<**0.01 p<***0.005

The Mantel Index for Nationwide permits is, however, positive and statistically significant (0.07, $p < 0.005$) indicating a positive association between geographic distance and temporal proximity (i.e. spatio-temporal correlation). Conversely, when calculating the Mantel Index for all Section 404 permits, regardless of permit type, the statistic yields a statistically significant value of -0.016 ($p < 0.005$). This result suggests an inverse relationship between geographic distance and temporal distance. Both significant Mantel Index values, positive for Nationwide permits and negative for all permits in the study area suggest spatio-temporal correlations in opposite directions, yet these relationships are thus far difficult to expand upon given the global nature of the Mantel Index.

As previously described, a Moran's I test for spatial autocorrelation was also calculated annually for each permit type as well as all permits as a whole. Permit counts were used as the value of X and a contiguity-based weights matrix was utilized. The results from the annual Moran's I tests closely mirror those of the Mantel Index (see Table 6). Moran's *I* values for General permits are all negative across all years of the study period and three of these years (1999, 2001 and 2003) are significantly negative ($p < 0.05$). In other words, dissimilar values are located nearer to each other in space. In this case, contiguous sub-basins are likely to have dissimilar counts of General permits across the study period.

Individual permits demonstrate a fluctuating pattern of positive and negative spatial autocorrelation. Beginning in 1996, Individual permits have positive Moran's *I* values but alternate annually from negative to until the year 2003, when they maintain a positive value. Only two years have statistically significant values ($p<0.05$), 1999 and 2001, both of which are negative. This again suggests that, in these two years, contiguous sub-basins are likely to have dissimilar counts of Individual permits across the study period.

Table 6. Annual Moran's *I* Values for Permits by Types and Year

	Permit Type				
Year	General	Individual	Letter	Nationwide	All Permits
1996	-0.0373	0.1285	-0.0071	-0.0094	-0.0322
1997	-0.0355	-0.0205	-0.0421	0.1344	-0.0343
1998	-0.0373	0.1228	-0.0126	0.1228	0.0066
1999	-0.0582*	-0.0981*	-0.0589*	0.2491*	-0.0657*
2000	-0.0552	0.0622	-0.0565*	0.2253	-0.0521
2001	-0.0597*	-0.1119*	-0.0581	0.1052	-0.0582
2002	-0.0538	0.0892	-0.0608*	-0.0595	-0.0566
2003	-0.0569*	0.0024	-0.0367	-0.0719*	-0.0640*

p<*0.05; p<**0.01; p<***0.005

The annual Moran's *I* values for Letter of Permission permits do not differ notably from the earlier General permit patterns. All eight years have negative values of spatial autocorrelation. Only three of these years are significant at the $p < 0.05$ level- 1999, 2000 and 2002. Yet again, this demonstrates that contiguous sub-basins are likely to have dissimilar counts of Letter of Permission permits across the study period.

Contrary to the spatial pattern of General and Letter of Permission permits, Nationwide permits vary between positive and negative spatial autocorrelation. Beginning in 1996, the Moran's *I* value for Nationwide permits is negative, but all subsequent years until take on positive values until 2002 when they revert back to negative. However, only two years have statistically significant (p <0.05) results. Significantly negative spatial autocorrelation is evident in 2003; significantly positive spatial autocorrelation arises in 1999. This is the first and only year that results in positive, significant spatial autocorrelation, revealing a cluster of sub-basins whose counts of Nationwide permits in 1999 are similar.

Finally, when examining the spatial autocorrelation of all permits regardless of permit type the negative values again arise. In all but one year (1998) Moran's *I* values are negative. In only two years, 1999 and 2003, do Moran's *I* values have statistically significant (p <0.05) results. This result closely parallels the previous Mantel Index for all permits, which resulted in a significantly negative value.

5.3. Summary of Spatial-Temporal Section 404 Permit Analysis

The descriptive results of the spatial and temporal analysis of Section 404 permitting activity highlight several important characteristics. First, the percentages of permits by type are distributed as expected. Far more General and Nationwide permits were issued than Letters of Permission and Individual permits. Further, more Letters of Permission were issued than Individual permits. This break-down of permits by type is to be expected and signals that the study area does not greatly deviate from nationwide USACE permit numbers. For example, across the United States in 2001, the USACE issued approximately 83,243 Section 404 permits (USACE, 2001). Of those permits, 75,847 or 91 percent were Nationwide or General permits. As described above, in the study area for this research General and Nationwide permits account for 89 percent of issued permits, a mere 2 percent differ from the national average.

The observed difference in Individual and Letter of Permission permits is also to be expected. Although there are no public annual statistics on the differences between the issuance of these two permit types provided by USACE, the higher numbers of Letters of Permission relative to Individual permits make sense. This relationship occurs much in the same way that General and Nationwide permits always outpace Letters of Permission and Individual permits. The regulatory process is by far the most stringent when attempting to obtain an Individual permit, and less so for Letters of Permission. This same relationship is apparent when comparing Nationwide and General permits to Letters of Permission and Individual permits; the regulatory process is purposefully abbreviated for the two former permit types. Therefore, when activities that involve Section 404 permitting can be classified as Nationwide or General this advantage is utilized. On the whole, the proportion of permits in each permit type appears to follow the expected pattern.

Second, Sub-basin 9 is an obvious driver of Section 404 permitting activity in the study area during the study period. This single sub-basin contains 2,438 total Section 404 permits or approximately 76 percent of all permits issued within the delineated sub-basins during the study period. Several other factors also make this sub-basin unique and potentially explain its divergence in terms of permit counts. First, Sub-basin 9 has more wetlands area than any other sub-basin; approximately 409 square miles of this sub-basin's land cover is classified as wetland based on the NOAA-CCAP data in 2001. Only two other sub-basins have this much wetland area, Sub-basin 4 and Sub-basin 42 with approximately 397 and 405 square miles, respectively. After these three sub-basins, the area of wetland drops off substantially to 229 square miles (Sub-basin 6). Second, although Sub-basin 9 has two neighbors with similar wetland areas, it also contains more rivers and streams (as measured by overall length) than any other sub-basin. There are 2,950 miles of rivers and streams within Sub-basin 9, approximately 518 miles more than any other sub-basin. The sub-basin with the next highest river and stream length is the southern-most sub-basin, Number 51, with 2,382 miles of rivers and streams. Sub-basin 51 is also the largest sub-basin in the study area. Although Sub-basin 9 may have far more Section 404 permits than any other sub-basin, these are supported by the characteristics of basin area, specifically the area of wetlands and length of rivers and streams. Thus, the descriptive statistics have highlighted an observation that deserves further examination.

The Mantel Index for space-time interaction was statistically insignificant for three permit types: General, Individual and Letter of Permission. Two of these permit types, Individual and Letter of Permission permits also have small sample sizes relative to the other two permit types, a possible explanation for their insignificance. However, General permits have the largest sample size of all permit types and did not reveal any spatio-temporal pattern, which is most likely due to the fact that the vast majority of this permit type is found within a single sub-basin. The positive and statistically significant Mantel Index value for Nationwide permits can be interpreted as a correlation between space and time. Although the Mantel Index is a global spatial statistic, this result most likely reflects the high number of Nationwide permits issued in 2002 and 2003 relatively near to each other in both temporal and spatial dimensions (see Figure 7 and Figure 14).

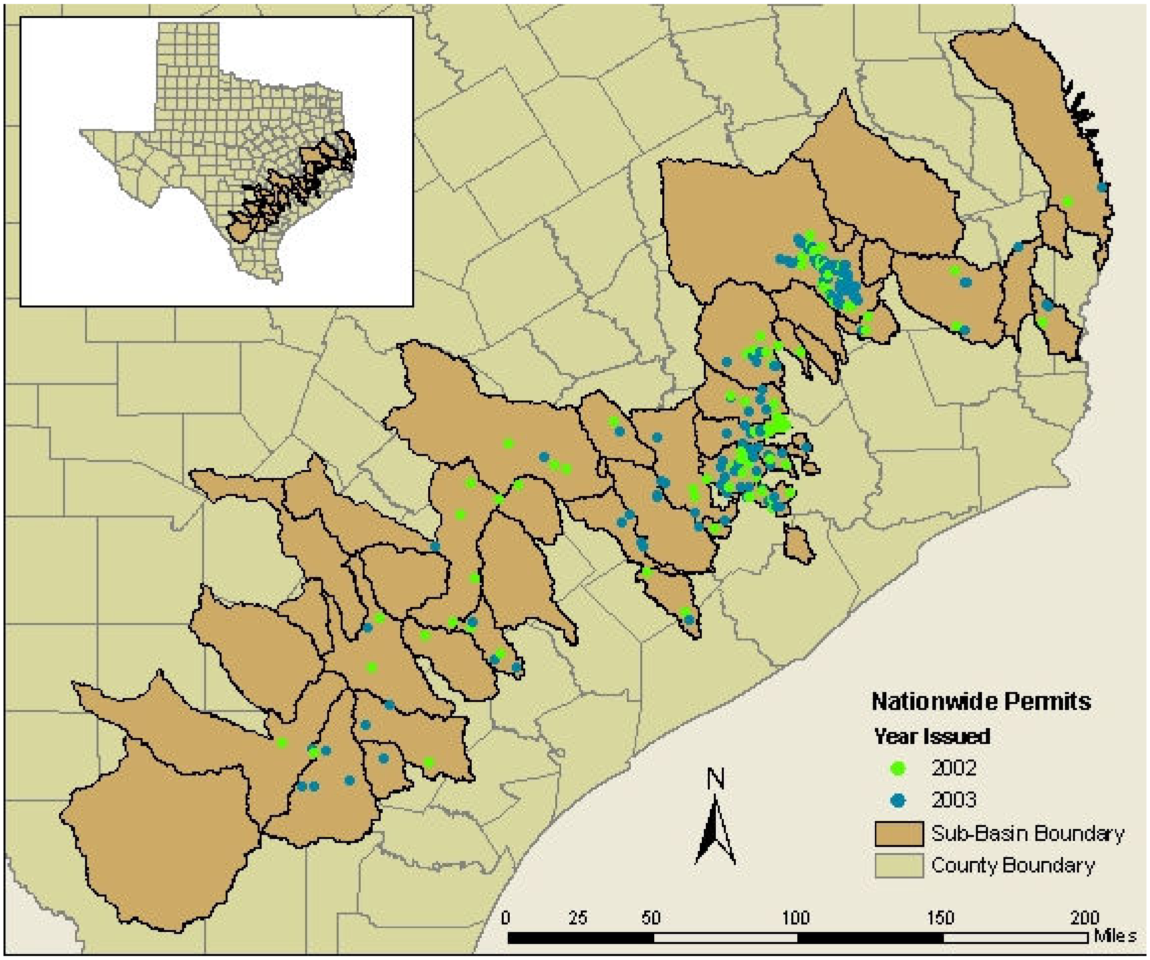

Figure 14. Nationwide Permit Locations in 2002 - 2003

The negative Mantel Index for all permits can be interpreted as an inverse relationship between space and time. Again, the global nature of the statistic does not point directly to an exact reason for this relationship. The temporal (see Figure 8) and spatial (see Figure 6) distribution of all permits likely reflects an increasing temporal trend in all permits following 1998 and a near spatial randomness of discrete permit locations, hence the negative relationship. This interpretation is strengthened by the Moran's *I* values for all permits by sub-basin, all of which are negative. This is another sign of a lack of spatial clustering, albeit one that is measured by areal units as opposed to discrete permit locations.

The annual Moran's *I* tests for spatial autocorrelation do not reveal any hot-spots or clustering of Section 404 permitting activity, with the single exception of Nationwide permits in 1999. Not surprisingly, the positive and significant Moran's *I* for Nationwide Permits in 1999 appears to be primarily driven by Sub-basin 9, which has 13 Nationwide permits and its southerly neighbors which all have counts above 5 (see Figure 15). In fact, there are far more years of significantly negative spatial autocorrelation, indicating that sub-basins with higher permits counts are likely to have neighbors with lower permit counts. With only one sub-basin displaying clustering of permits in a single year and other spatial results indicating the opposite, there does not appear to be a consistent spatial or spatio-temporal trend in the Section 404 permit data. Therefore, the need for additional control variables to represent areas of permit clustering is unnecessary.

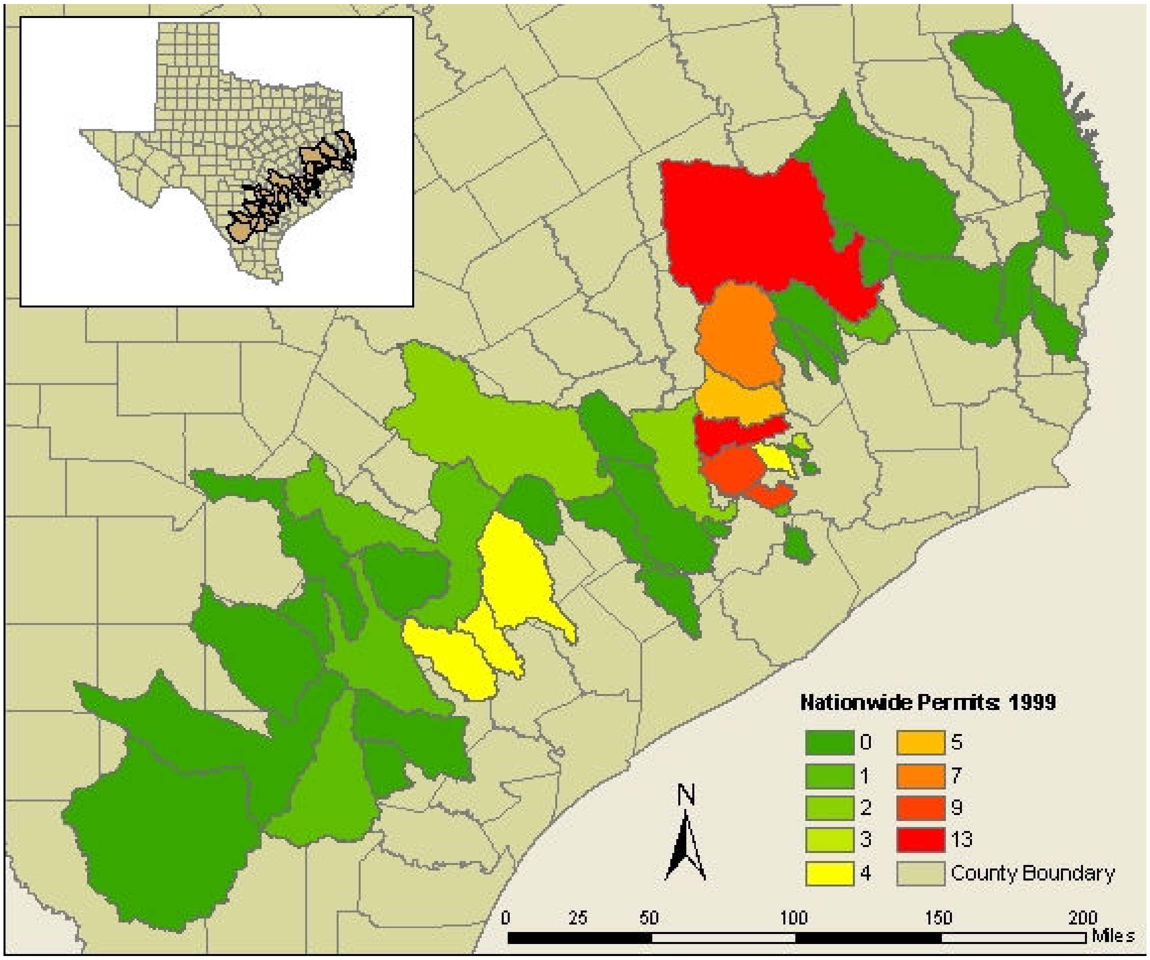

Figure 15. Nationwide Permits by Sub-Basin in 1999

6. EXPLAINING THE EFFECT OF SECTION 404 PERMITTING ON MEAN AND PEAK STREAMFLOW

This phase of analysis seeks to explain the effects of Section 404 permitting on two measures of streamflow: mean annual flow and peak annual flow. These two dependent variables were analyzed using the cross-sectional time-series statistical approach that was arrived to in Section 4. Each permit type was analyzed separately. This approach was used for two reasons. First, theoretically, each permit type represents a different level of impact; by analyzing them separately but in models with the same variables their relative impacts can be compared. Second, the numbers of some of the permit types are highly correlated and introducing them into the same regression models created multicollinearity. Correlations among Section 404 permit types, along with the other control variables, are presented in A1-Table 15. No other modeled variables displayed high correlations or other potential issues with multicollinearity.

The ability for Sub-basin 9 to skew results as an outlier was also considered prior to conducting the explanatory analyses. As described previously, this sub-basin contained a much higher level of Section 404 permitting activity than other sub-basins. However, the removal of this sub-basin had no appreciable effect on the overall findings, statistical relationships or interpretations. Consequently, results presented below include the observations for Sub-basin 9.

The following presents the results of each dependent variable separately, mean annual flow first followed by peak annual flow. A brief summary of results and their impact on the hypotheses posited in Section 3 is included after each dependent variable. Finally, a discussion focusing on the results of modeling the two dependent variables is presented that compares the dependent variables and their interpretations.

6.1. Modeled Results of Mean Annual Flow

6.1.1. General Permits and Mean Annual Flow

The General permits model was significant, with a Wald χ^2 value of 1298.03, and it explained nearly 67 percent of the variance in MAF, with and R^2 of 0.656. Precipitation was positive and significant at the $p<0.001$ level[5] (see Table 7). General permits were also positive and significant, which supports *Hypothesis 1*. The three geomorphic were positive with respect to MAF and had the expected signs, with the exception of mean slope. Basin area and basin shape (elongation ratio) were both statistically significant at the $p<0.001$ level. Natural land cover had a sign that was opposite the expectation, but was insignificant. Average soil permeability showed an inverse relationship with MAF, but was also statistically insignificant. The two wetland land cover variables, Palustrine Forested and Palustrine Scrub/Shrub, had conflicts with positive signs, also differing with their expected signs. Palustrine Forested land cover was statistically insignificant. However, Palustrine Scrub/Shrub was significant at the $p<0.05$ level, a surprising result. Finally, the sign for Developed land cover was positive as expected but statistically insignificant. *Hypothesis 1,* which is that General permits will have a significantly positive effect on mean annual flow, is supported by the results of the General permits model.

[5] The *p*-values presented in Tables 7–14 are two-tailed tests of significance. In the results text, *p*-values presented for Section 404 permit types are one-tailed based on the direction of the hypothesized relationships. In the interest of analytic caution, the *p*-values contained in the text for control variables are two-tailed.

Table 7. Regression Models on Mean Annual Flow and General Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0554 (0.0123)	0.2782	4.51	0.000	0.0313	0.0795
General Permits	0.0007 (0.0002)	0.0032	3.22	0.001	0.0003	0.0011
Basin Area	0.0010 (0.0001)	0.5091	6.71	0.000	0.0007	0.0013
Elongation Ratio	0.2502 (0.0352)	0.2516	7.11	0.000	0.1812	0.3191
Mean Slope	-0.0919 (0.0664)	-0.0586	-1.38	0.166	-0.2221	0.0382
Natural Cover	0.0041 (0.0066)	0.0421	0.62	0.534	-0.0088	0.0170
Average Permeability	-0.0035 (0.0330)	-0.0042	-0.10	0.916	-0.0681	0.0612
Palustrine Forested	0.0221 (0.0177)	0.0788	1.25	0.212	-0.0126	0.0569
Palustrine Scrub/Shrub	0.1428 (0.0719)	0.0639	1.99	0.047	0.0019	0.2837
Developed	0.2002 (0.2288)	0.0305	0.87	0.382	-0.2483	0.6487
Constant	2.0768 (0.5703)		3.64	0.000	0.9590	3.1946
Wald χ^2	1298.03					
p-value	0.000					
R^2	0.656					n = 322

6.1.2. Nationwide Permits and Mean Annual Flow

The Nationwide permit model was significant, with a Wald χ^2 value of 1172.84, and it explained nearly 67 percent of the variance in MAF, with an R^2 of 0.656. Precipitation was positive and significant at the $p<0.001$ level (see Table 8). The relationship between Nationwide permits and MAF was also positive and statistically significant at $p<0.05$. Basin area and basin shape (elongation ratio) were both positive and statistically significant at the $p<0.001$ level. Mean basin slope was negative, which was opposite the expected sign, but insignificant. Natural land cover also had a sign that was opposite the expected direction, but was insignificant. Average soil permeability again showed a statistically insignificant but expected inverse relationship with MAF.

The two wetland land cover classes again showed positive relationships with MAF, also differing with their expected directions. Both the Palustrine Forested and Palustrine Scrub/Shrub land cover classes were statistically insignificant at $p<0.05$, however the Palustrine Scrub/Shrub class was within a $p<0.10$ range of significance. The developed land cover class was positive as expected but statistically insignificant. The final model supported *Hypothesis 3*, which stated that a unit increase in Nationwide permits will have a significantly positive effect on MAF.

Table 8. Regression Models on Mean Annual Flow and Nationwide Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0555 (0.0126)	0.2787	4.42	0.000	0.0309	0.0801
Nationwide Permits	0.0028 (0.0017)	0.0127	1.66	0.097	-0.0005	0.0060
Basin Area	0.0010 (0.0001)	0.5091	6.76	0.000	0.0007	0.0013
Elongation Ratio	0.2499 (0.0383)	0.2513	6.53	0.000	0.1749	0.3249
Mean Slope	-0.0851 (0.0660)	-0.0542	-1.29	0.197	-0.2145	0.0442
Natural Cover	0.0039 (0.0065)	0.0401	0.60	0.550	-0.0088	0.0166
Average Permeability	-0.0083 (0.0336)	-0.0100	-0.25	0.805	-0.0742	0.0576
Palustrine Forested	0.0234 (0.0178)	0.0832	1.31	0.190	-0.0116	0.0583
Palustrine Scrub/Shrub	12.5991 (7.6397)	0.0564	1.65	0.099	-0.0237	0.2757
Developed	0.2650 (0.2299)	0.0404	1.15	0.249	-0.1857	0.7156
Constant	2.0160 (0.5813)		3.47	0.001	0.8767	3.1552
Wald χ^2	1172.84					
p-value	0.000					
R^2	0.656					n = 322

6.1.3. Letters of Permission and Mean Annual Flow

The Letters of Permission permit model was significant overall, with a Wald χ^2 value of 1221.06, and it explained nearly 67 percent of the variance in MAF, with an R^2 of 0.656. Precipitation was positive and significant at the $p<0.001$ level. The relationship between Letters of Permission and MAF was also positive and statistically insignificant at $p<0.01$, which supported *Hypothesis 5* (see Table 9). Basin area and basin shape were both had positive signs and were statistically significant at the $p<0.001$ level. Mean basin slope was had a negative sign, but was statistically insignificant. The signs and statistical significances of the land cover variables paralleled the two previous models: natural land cover was positive and insignificant, average soil permeability was negative insignificant, Palustrine Forested and Palustrine Scrub/Shrub both showed a positive relationship with MAF, and the developed land cover was again positive but insignificant. Similar to the General permit model, Palustrine Scrub/Shrub was positive and significant at the $p<0.05$ level, against the expected relationship. *Hypothesis 5*, a unit increase in Letters of Permission will have a significantly positive effect on MAF, was supported by the regression model.

Table 9. Regression Models on Mean Annual Flow and Letters of Permission

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0555 (0.0123)	0.2787	4.52	0.000	0.0315	0.0796
Letters of Permission	0.0041 (0.0013)	0.0186	3.13	0.002	0.0015	0.0066
Basin Area	0.0010 (0.0001)	0.5091	6.79	0.000	0.0007	0.0013
Elongation Ratio	0.2489 (0.0350)	0.2503	7.12	0.000	0.1804	0.3175
Mean Slope	-0.0912 (0.0661)	-0.0581	-1.38	0.168	-0.2208	0.0385
Natural Cover	0.0042 (0.0066)	0.0430	0.63	0.526	-0.0087	0.0170
Average Permeability	-0.0026 (0.0329)	-0.0031	-0.08	0.937	-0.0671	0.0618
Palustrine Forested	0.0221 (0.0177)	0.0786	1.25	0.212	-0.0126	0.0567
Palustrine Scrub/Shrub	0.1429 (0.0716)	0.0640	2.00	0.046	0.0025	0.2833
Developed	0.1890 (0. 2260)	0.0288	0.84	0.403	-0.2540	0.6320
Constant	2.0713 (0.5708)		3.63	0.000	0.9525	3.1901
Wald χ^2	1221.06					
p-value	0.000					
R^2	0.656					n = 322

6.1.4. Individual Permits and Mean Annual Flow

Finally, the Individual permit model was significant overall, with a Wald χ^2 value of 1274.74, and it explained nearly 66 percent of the variance in MAF, with an R^2 of 0.658. Precipitation was positive and significant at the $p<0.001$ level (see Table 10). Individual permits were also positive and significant at $p<0.001$, which supported *Hypothesis 7*. Again, basin area and basin shape both had positive signs and were statistically significant at the $p<0.001$ level. Mean basin slope was again negative but statistically insignificant. The land cover variables reacted in a fashion similar to the other three models: natural land cover was positive and insignificant, average soil permeability was negative and again insignificant, Palustrine Forested and Palustrine

Scrub/Shrub both showed a positive relationship with MAF, and the developed land cover was again positive but insignificant. Similar to the previous permit models, Palustrine Scrub/Shrub was again insignificant at the $p<0.05$ level, but within the $p<0.10$ range and opposite the expected relationship. Finally, *Hypothesis 7,* which was that Individual permit will have a significantly positive effect on MAF, was supported by the regression model.

Table 10. Regression Models on Mean Annual Flow and Individual Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0553 (0.0123)	0.2777	4.49	0.000	0.0312	0.0795
Individual Permits	0.0212 (0.0071)	0.0963	2.98	0.003	0.0072	0.0351
Basin Area	0.001 (0.0002)	0.5091	6.40	0.000	0.0007	0.0013
Elongation Ratio	0.2591 (0.0374)	0.2605	6.93	0.000	0.1858	0.3324
Mean Slope	-0.0906 (0.0669)	-0.0577	-1.36	0.175	-0.2217	0.0404
Natural Cover	0.0034 (0.0063)	0.0352	0.54	0.592	-0.0090	0.0159
Average Permeability	-0.0162 (0.0347)	-0.0195	-0.47	0.641	-0.0841	0.0518
Palustrine Forested	0.0221 (0.01782)	0.0786	1.24	0.215	-0.0128	0.0570
Palustrine Scrub/Shrub	12.8302 (7.4632)	0.0574	1.72	0.086	-0.0180	0.2746
Developed	0.3410 (0.2638)	0.0520	1.29	0.196	-0.1762	0.8582
Constant	2.0475 (0.5755)		3.56	0.000	0.9196	3.1754
Wald χ^2	1274.74					
p-value	0.000					
R^2	0.658					n = 322

6.2. Summary of Results on Mean Annual Flow

With few exceptions, the key results of the four permit type models including coefficients and their directions, significance values and coefficients of determination vary only slightly. First, mean basin precipitation and basin area followed common logic with respect to MAF. Both were positive and highly significant across all four permit types regardless of the addition of control variables; a relationship that was certainly expected. The measure of basin shape, elongation ratio, was also positive and significant across all four permit type models in all of the blocks in which it appears.

Second, the land cover control variables added very little in explanation of MAF. Both the percent of the basin in natural cover and developed were insignificant in all four permit models. Further, natural cover went in the opposite direction of what was expected. Average soil permeability was also insignificant in all four permit type models, but did react in the expected direction. The results from these three land cover variables suggested that other variables played a more important role in explaining MAF.

Third, both variables that measured the percent of wetlands in each sub-basin, Palustrine Forested and Palustrine Scrub/Shrub went in unexpected directions. The two variables were both positive with respect to their relationship with MAF. Palustrine forested remained statistically insignificant in all four permit type models. Palustrine Scrub/Shrub was, however significant in the models for Letters of Permission and General permits. In models for Nationwide and Individual permits, it was significant at $p<0.10$. This is an interesting result, as it goes against the expected outcome.

Finally, following a statistical significance threshold of $p<0.05$, all four hypothesized relationships of Section 404 permits and MAF were supported by the regression models. General permits, Nationwide permits, Letters of Permission, and Individual permits remained positive and statistically significant despite the effects of adding additional control variables. These results supported four of the hypotheses concerning Section 404 permits. *Hypothesis 1*, *Hypothesis 3, Hypothesis 5,* and *Hypothesis 7* were all supported by the regression results; all four of these permit types, after controlling for other pertinent factors, significantly increase MAF over the study area and period.

6.3. Modeled Results of Peak Annual Flow

6.3.1. General Permits

The General permits model was significant overall, with a Wald χ^2 value of 476.96, and it explained nearly 55 percent of the variance in PAF, with an R^2 of 0.548. Precipitation was positive and significant at the $p<0.001$ level (see Table 11). General permits were also positive and significant at $p<0.05$, in support of *Hypothesis 2*. Basin area and elongation ratio both had positive signs and were statistically significant at the $p<0.001$ level. Mean basin slope had an unexpected negative sign, but was insignificant.

Natural land cover went opposite the expected direction but was statistically insignificant. Average soil permeability had an inverse relationship with PAF and was statistically significant at the $p<0.05$ level. The two wetland land cover variables, Palustrine Forested and Palustrine Scrub/Shrub, had different relationships with PAF. Palustrine Forested land cover had a positive relationship, but was statistically insignificant. Palustrine Scrub/Shrub did, however, have a negative effect on PAF and was significant at the $p<0.05$ level. Finally, Developed land cover was positive as expected and statistically significant at $p<0.05$ level. *Hypothesis 2*, a unit increase in General permits will have a significantly positive effect on PAF, was supported by the regression model.

Table 11. Regression Models on Peak Annual Flow and General Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0392 (0.0154)	0.2673	2.55	0.011	0.0091	0.0693
General Permits	0.0005 (0.0002)	0.0031	2.30	0.022	0.0001	0.0009
Basin Area	0.0006 (0.0001)	0.4148	6.42	0.000	0.0004	0.0008
Elongation Ratio	0.1458 (0.0293)	0.1991	4.97	0.000	0.0883	0.2032
Mean Slope	-0.0583 (0.0900)	-0.0504	-0.65	0.517	-0.2347	0.1182
Natural Cover	0.0068 (0.0041)	0.0949	1.66	0.097	-0.0012	0.0148
Average Permeability	-0.0579 (0.0273)	-0.0947	-2.12	0.034	-0.1115	-0.0043
Palustrine Forested	0.0221 (0.0194)	0.1070	1.14	0.255	-0.0160	0.0602
Palustrine Scrub/Shrub	-0.1693 (0.0790)	-0.1029	-2.14	0.032	-0.3241	-0.0146
Developed	0.5093 (0.2830)	0.1055	1.80	0.072	-0.0454	1.0640
Constant	6.1998 (0.6553)		9.46	0.000	4.9156	7.4841
Wald χ^2	476.96					
p-value	0.000					
R^2	0.548					n = 322

6.3.2. Nationwide Permits

The Nationwide permits model was significant overall, with a Wald χ^2 value of 346.56, and it explained approximately 55 percent of the variance in PAF, with an R^2 of 0.553. The regression model also generated the expected relationship for precipitation and Nationwide permits. Precipitation was again positive and significant at the $p<0.001$ level (see Table 12). Nationwide permits were positive and significant at $p<0.05$, supporting *Hypothesis 4*. As with previous models, basin area and elongation ratio were both positive and statistically significant at the $p<0.001$ level, and mean basin slope was negative but insignificant. Natural land cover was again positive but insignificant.

Average soil permeability continued to have an inverse and statistically significant relationship with PAF. Similar to the General permits model, Palustrine Forested and Palustrine Scrub/Shrub had opposite relationships with PAF. Palustrine Forested land cover had a positive but statistically insignificant coefficient. Palustrine Scrub/Shrub did again have a negative and statistically significant (p<0.05) coefficient. Finally, Developed land cover was positive as expected and statistically significant at p<0.05. *Hypothesis 4*, Nationwide permits will have a significantly positive effect on PAF, was supported by the regression model.

Table 12. Regression Models on Peak Annual Flow and Nationwide Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0390 (0.0156)	0.2660	2.50	0.013	0.0084	0.0696
Nationwide Permits	0.0026 (0.0013)	0.0160	1.97	0.049	0.0000	0.0051
Basin Area	0.0006 (0.0001)	0.4148	6.42	0.000	0.0004	0.0008
Elongation Ratio	0.1512 (0.0323)	0.2065	4.68	0.000	0.0878	0.2146
Mean Slope	-0.0508 (0.0898)	-0.0440	-0.57	0.572	-0.2269	0.1253
Natural Cover	0.0063 (0.0040)	0.0883	1.58	0.114	-0.0015	0.0141
Average Permeability	-0.0634 (0.0275)	-0.1037	-2.31	0.021	-0.1173	-0.0095
Palustrine Forested	0.0230 (0.1995)	0.1115	1.15	0.248	-0.0161	0.0622
Palustrine Scrub/Shrub	-0.1865 (0.0834)	-0.1133	-2.24	0.025	-0.3499	-0.0231
Developed	0.5920 (0.2812)	0.1227	2.10	0.035	0.0406	1.1433
Constant	6.1552 (0.6645)		9.26	0.000	4.8529	7.4576
Wald χ^2	346.56					
p-value	0.000					
R^2	0.553					n = 322

6.3.3. Letters of Permission

The Letters of Permission model was significant overall, with a Wald χ^2 value of 488.09, and it explained nearly 55 percent of the variance in PAF, with an R^2 of 0.546. The regression model also produced the expected and hypothesized relationships for precipitation and Letters of Permission. Precipitation had its typical positive and significant relationship with PAF at the $p<0.001$ level (see Table 13). Letters of Permission were also positive and significant at $p<0.05$, supporting *Hypothesis 6*. Both basin area and elongation ratio had positive coefficients and were statistically significant at $p<0.001$. The coefficient for mean basin slope was negative but again insignificant. Natural land cover continued to have a positive but statistically insignificant relationship with PAF. Average soil permeability also had an inverse and statistically significant relationship ($p<0.05$) with PAF. As with the two previous models, Palustrine Forested land cover had a positive but statistically insignificant coefficient, while Palustrine Scrub/Shrub had a negative and statistically significant ($p<0.05$) relationship with PAF. Finally, Developed land cover was again positive but only significant at the $p<0.10$ level. *Hypothesis 6*, a unit increase in Letters of Permission will have a significantly positive effect on PAF, was supported by the regression model.

Table 13. Regression Models on Peak Annual Flow and Letters of Permission

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0393 (0.0153)	0.2680	2.56	0.011	0.0092	0.0693
Letters of Permission	0.0026 (0.0012)	0.0160	2.23	0.026	0.0003	0.0049
Basin Area	0.0006 (0.0001)	0.4148	6.51	0.000	0.0005	0.0008
Elongation Ratio	0.1448 (0.0292)	0.1977	4.95	0.000	0.0875	0.2021
Mean Slope	-0.0578 (0.0896)	-0.0500	-0.64	0.519	-0.2335	0.1179
Natural Cover	0.0068 (0.0041)	0.0959	1.67	0.094	-0.0012	0.0148
Average Permeability	-0.0573 (0.0273)	-0.0937	-2.10	0.036	-0.1109	-0.0038
Palustrine Forested	0.0221 (0.0194)	0.1070	1.14	0.254	-0.0159	0.0601
Palustrine Scrub/Shrub	-0.1694 (0.0787)	-0.1030	-2.15	0.031	-0.3237	-0.0151
Developed	0.5008 (0.2815)	0.1038	1.78	0.075	-0.0508	1.0525
Constant	6.1964 (0.6549)		9.46	0.000	4.9128	7.4800
Wald χ^2	488.09					
p-value	0.000					
R^2	0.546					n = 322

6.3.4. Individual Permits

Lastly, the Individual permits model was significant overall, with a Wald χ^2 value of 620.54, and it explained approximately 55 percent of the variance in PAF, with an R^2 of 0.553. Precipitation was had its usual positive and significant ($p < 0.01$) relationship with PAF (see Table 14). Individual permits were also positive and significant at $p<0.001$, supporting *Hypothesis 8*. Basin area and elongation ratio both had positive and statistically significant coefficients at $p<0.001$. Mean basin slope was negative but again insignificant.

Natural land cover had a positive but insignificant relationship with PAF. Average soil permeability was again negative and statistically significant at $p<0.05$. As with the three previous models, Palustrine Forested land cover had a positive but statistically insignificant coefficient. Palustrine Scrub/Shrub wetlands had a negative and statistically significant ($p<0.05$) relationship with PAF. Finally, Developed land cover was positive and statistically significant at the $p<0.05$ level. *Hypothesis 8*, a unit increase in Individual permits will have a significantly positive effect on PAF, was supported by regression model.

Table 14. Regression Models on Peak Annual Flow and Individual Permits

	Coefficient (Std. Error)	Beta Coefficient	Z	p-value	95% Confidence Interval	
Precipitation	0.0389 (0.0153)	0.2653	2.53	0.011	0.0088	0.0689
Individual Permits	0.0165 (0.0063)	0.1018	2.63	0.009	0.0042	0.0288
Basin Area	0.0006 (0.0001)	0.4148	6.00	0.000	0.0004	0.0008
Elongation Ratio	0.1557 (0.0298)	0.2126	5.23	0.000	0.0973	0.2140
Mean Slope	-0.0566 (0.0909)	-0.0490	-0.62	0.534	-0.2347	0.1215
Natural Cover	0.0061 (0.0039)	0.0849	1.56	0.118	-0.0015	0.0137
Average Permeability	-0.0679 (0.0273)	-0.1110	-2.49	0.013	-0.1215	-0.0144
Palustrine Forested	0.0219 (0.0195)	0.1062	1.12	0.261	-0.0163	0.0602
Palustrine Scrub/Shrub	-0.1819 (0.0817)	-0.1105	-2.23	0.026	-0.3420	-0.0218
Developed	0.6285 (0.3011)	0.1302	2.09	0.037	0.0383	1.2186
Constant	6.1908 (0.6553)		9.45	0.000	4.9064	7.4751
Wald χ^2	620.54					
p-value	0.000					
R^2	0.553					n = 322

6.4. Summary of Results on Peak Annual Flow

With respect to the coefficients and their signs, significance values and coefficients of determination, the results of the four permit type models only have modest differences. First, R^2 values were nearly identical across all four models. First, mean basin precipitation, basin area and elongation ratio followed the expected outcomes with respect to PAF. All three coefficients were positive and highly significant across all four permit types regardless of the addition of control variables. These relationships were certainly expected.

Second, three of the land cover control variables proved to be important predictors of PAF. In all four regression models average soil permeability had a statistically significant inverse relationship with PAF. Palustrine scrub/shrub wetlands also demonstrated significant negative effects on PAF; all four regression models supported this result. The percent developed area in each basin was also statistically significant across all four regression models; this positive relationship between peak flows and impervious surface was also expected. However, the percent of the basin in natural cover was an insignificant land cover control variable in all four permit models. Overall, three of the five land cover controls made significant contributions to explaining PAF.

Finally, all four hypothesized relationships of Section 404 permits and PAF were supported by the regression models. General permits, Nationwide Permits, Letters of Permission, and Individual permits all remained statistically significant predictors despite the control variables. These results supported the four hypotheses concerning Section 404 permits. *Hypothesis 2*, *Hypothesis 4, Hypothesis 6* and *Hypothesis 8* were all supported by the regression results. All four types of Section 404 permits, after controlling for other pertinent factors, significantly increase PAF over the study area and period.

6.5. Overall Summary of Explanatory Results

When examined as a whole, the modeled results of MAF and PAF by permit type showed some similarities, but also demonstrated some distinct differences. To better understand the results of these two models across the Section 404 permit types, they are first discussed in terms of the characteristics that remain stable across the two dependent variables. Conversely, and potentially more interesting, MAF and PAF models are then contrasted based on several characteristics that change between the two dependent variables and amongst permit types.

6.5.1. Common Characteristics of Mean Annual and Peak Annual Flow Models

A key similarity found in all of the regression models is the importance, and relative importance, of basin area, precipitation and basin shape. In all eight full regression models, standardized regression coefficients identified these three variables as the most important contributors to explaining MAF and PAF. In all models basin area, precipitation, and elongation ratio had the first, second and third highest relative impacts, respectively, in explaining the variation in both MAF and PAF. These results are not surprising; they are well substantiated by many other empirical studies. Nonetheless, I believe they do demonstrate the stability of these measures and the robustness of the models as a whole over the study period.

One strange similarity found in the models for the two dependent variables was the effect of the mean basin slope variable. Not only was mean slope insignificant across all models and permit types, its coefficient displayed a directional change against the expected direction when the land cover variables were loaded. Changes in the direction of a coefficient’s sign can often be an indicator of multicollinearity. However, upon examining the standard errors and confidence intervals for mean slope between the geomorphic and land cover models this potential issue was greatly diminished if not dismissed. Across all four permit types and both dependent variables, the positive coefficient for mean slope in the geomorphic models fell within the mean slope confidence interval for the land cover model. In other words, mean slope added nothing to the explanatory power of the regression models and was extremely insignificant.

6.5.2. Divergent Characteristics of Mean Annual and Peak Annual Flow Models

Important differences were also apparent between results for the two dependent variables. Two control variables were important predictors of PAF but were insignificant with respect to MAF. Percent developed area showed positive and significant effects on PAF, but had no significant relationship with MAF. Average soil permeability was also a significant predictor of PAF; it had a statistically significant inverse relationship with PAF but no relationship with MAF. These results were indicative of two separate but related issues. Both variables show significant relationships with PAF, the dependent variable measuring the single extreme event in each year. The percent of developed area in each basin likely contributes to increased runoff and overland flow in high precipitation events. Likewise, the inverse relationship of average soil permeability with peak streamflow likely demonstrated the ability of a sub-basin to store more runoff. This also demonstrates the potential importance of a sub-basin's capacity to deal with precipitation events that preceded a single, extreme peak-flow event. Conversely, these two variables showed no measurable effect on MAF. This was most likely due to explaining the average of daily streamflow in the sub-basins, where the effects of extreme values are diluted by the large number of low-flow events.

The differences in explaining the long-term measure versus the single event measure are also apparent in the models' coefficients of determination. As noted above, the R^2 values were remarkably similar within the two dependent variables; different Section 404 permit types did not add to the explanatory power of any of the models. It was, however, apparent that the predictor variables did a better job explaining MAF over PAF. The average R^2 value for the MAF models was 0.656; the average for the PAF models was 0.550, an 11 percentage point decrease.

The Effect of Palustrine Wetlands

Further, the wetland types addressed in the study area had different effects on PAF and MAF. The four MAF regression models showed a positive relationship with Palustrine Scrub/Shrub wetlands, models for General permits and Letters of Permission were significant at $p<0.05$; models for Nationwide permits and Individual permits were significant at $p<0.10$. On the whole, this suggested that increasing percentages of Palustrine Scrub/Shrub wetlands lead to increases in mean annual flow. This relationship runs counter to both the expected relationship as well as the research literature that pertains to wetlands and long-term averages.

In fact, the coefficients for this variable have an interesting interpretation. The two significant coefficients are both approximately 0.142, and because the coefficients are semi-elastic, the interpretation of this value amounts to a 1 unit (in this case 1 percent of basin area) increase in Palustrine Scrub/Shrub wetlands results in a 14.2 percent *increase* in MAF. For the average sub-basin in the study area, which was 660 square miles and had a mean flow of 1,703 cubic feet per second (cfs), this amounts to "adding" 6.6 square miles to Palustrine Scrub/Shrub wetland and results in an approximate average increase of 242 cfs or approximately 1,945 cfs. However, in terms of standardized coefficient (β) magnitude, Section 404 permits always are lower in magnitude than basin area, precipitation and elongation ratio.

This result is especially interesting considering the effect of Palustrine Scrub/Shrub wetlands on PAF. In all four of the regression models explaining PAF, Palustrine Scrub/Shrub wetlands had a statistically significant ($p<0.05$) negative effect on PAF. Coefficients for Palustrine Scrub/Shrub wetlands ranged from -0.1693 to -0.1865, with an average coefficient of -0.1768. The interpretation in this case is a 1 percent increase in Palustrine Scrub/Shrub wetlands results in a 17.68 percent *decrease* in PAF. For the average sub-basin in the study area, which was 660 square miles and had a peak flow of 17,149 cfs, adding 6.6 square miles of Palustrine Scrub/Shrub wetland would result in an approximate average decrease of 3,032 cfs or an approximate peak flow of 14,117 cfs. However, in terms of standardized coefficients (β), Palustrine

Scrub/Shrub wetlands were always smaller in magnitude than basin area, precipitation, and elongation ratio. But, as discussed above, the percent developed was also a significant predictor of PAF and more important than Palustrine Scrub/Shrub. While Palustrine Scrub/Shrub led to an average decrease of 17.68 percent of PAF, a 1 percent increase in developed area led to an average increase of between 50 and 63 percent of PAF. Overall, the percent of a sub-basin in developed or impervious cover greatly increases and offsets any peak-flow reductions that were made by Palustrine Scrub/Shrub wetlands.

The Effect of Section 404 Permits

Finally, the most critical results of the regression models explaining MAF and PAF are the importance of the Section 404 permit types. In all eight full regression models, the cumulative counts of Section 404 permits were statistically significant in explaining the variation of both MAF and PAF. The differences in the effects of Section 404 permits across the dependent variables and permit types were, however, the most notable results of these models.

First, with respect to the models explaining MAF, all four permit types ranked last in relative importance based on their standardized (β) regression coefficients. The differences in their unstandardized coefficients were also telling. As the wetland impact was increased, based upon the permit type and their regulatory requirements, the coefficient increased as well. The model for General permits saw a one permit increase leading to a 0.07 percent increase in MAF. One Nationwide permit resulted in a 0.28 percent increase in MAF. Adding a Letter of Permission resulted in a 0.41 percent increase in MAF, and an Individual permit increased MAF by 2.1 percent. At best, all of the coefficients indicated minimal increases in MAF from Section 404 permitting. For comparison, using the average study period average MAF, a 2.1 percent increase raised MAF up from 1703 cfs to 1738 cfs; a one inch increase in *mean annual* precipitation increased MAF 5.5 percent or up to 1797 cfs. Neither of these figures leads to a significant increase in MAF, a long-term measure that is somewhat difficult to change.

They do, however, begin to demonstrate that the different permit types measure increasing levels of wetland loss.

Second, all four permit types were significant in all four Section 404 permit models explaining PAF. Here too, Section 404 permits ranked last in terms of the relative importance of statistically significant variables (at least $p<0.05$). As was the case with permit types on MAF, as the regulatory requirements and thus the potential wetland impact increased the coefficients also increased. For example, one General permit increased PAF by 0.05 percent, a small upward movement nearly equivalent to its effect on MAF. A single Nationwide permit led to a 0.26 percent increase in PAF; again small and very near the increase in MAF. Adding a Letter of Permission resulted in the same increase in PAF: 0.26 percent, less than this permit types effect on MAF and equivalent to the effect of a Nationwide permit on PAF. Finally, a single Individual permit increased PAF by 1.65 percent, again less than the increase of this permit type on MAF. Similar to the effects of Section 404 permits on MAF, their role in increasing PAF is minor and less than the effect of Section 404 permits on MAF. Using the Individual permit model as an example, a 1.65 percent increase in the study period and area average PAF of 17,149 only adds 283 cfs, an increase that is not likely to have an effect on an extreme event. Although the increase in PAF resulting from Section 404 permitting is small, permit types again display some order. Increases in the impact of permit types increase the effect on PAF, especially Individual permits.

Overall, while Section 404 permits demonstrated statistically significant results on MAF and PAF, the effects were small. Increases in Section 404 permits produced only small increases in MAF and PAF. From a statistical standpoint, more important determinants of MAF were basin area, precipitation, basin shape and, in some cases, Palustrine Scrub/Shrub wetlands. More important determinants of PAF also included basin area, precipitation, basin shape, and developed area. However, both average soil permeability and Palustrine Scrub/Shrub wetlands were negative factors with respect to PAF. It is, however, important to note that these increases represent the effects of *a single permit*. When these effects are considered cumulatively over time, Section 404 permits are likely to have much larger effects on MAF and PAF. Long-term effects of Section 404 permits by type are demonstrated in A3-Table 17.

7. DISCUSSION

Several results from both the phases of analyses lead to topics that are worthy of further discussion. This Section will examine and expand on the results of the exploratory analysis and discuss the findings of the explanatory analysis. The policy implications of the research findings will also be discussed at the three levels of government where beneficial policy changes could be implemented.

7.1. Discussion of Exploratory Analysis

The results of the exploratory analysis on Section 404 permits reveal several interesting findings. First, the number of issued permits contained within the boundary of Sub-basin 9 is a point worthy of discussion. This hydrologic unit had by far more Section 404 permits of every type than any other sub-basin. Sub-basin 9 does not, however, contain any large population centers. In fact, despite its size and proximity to Houston, it ranks 9^{th} in total population and 27^{th} in population density compared to the other 47 sub-basins. It does, however, contain Lake Livingston in the upper portion of the watershed. The presence of the lake, coupled with its proximity to a major population center suggests that the increase in permitting activity is due to recreational and exurban development activities. Previous research on Section 404 permitting in the Galveston District has found the evidence that supports this explanation. Of 11,135 Section 404 permits issued in the Galveston District between 1991 and 2003, 78 percent of permits were issued outside of urban areas (Brody et. al., 2008). Although wetland loss resulting from urban land use conversion is a widely supported finding, far fewer studies have determined that wetland loss is driven by exurban or sprawl development (see Hansen, Knight, Marzluff, Powell, Brown, Gude & Jones, 2005; Hasse & Lathrop, 2003). The pattern of Section 404 permitting activity in Sub-basin 9 suggests that wetland loss is exacerbated by exurban development.

The results of tests for spatio-temporal interaction and annual spatial autocorrelation are also worth consideration. Analyzing the space-time patterns of Section 404 permits by type only revealed a positive association between geographic distance and temporal differences for Nationwide permits. This result most likely reflects the abrupt increase in Nationwide permits issued in 2002 and 2003 relatively near to each other in both temporal and spatial dimensions. As was the case with the descriptive analysis, Sub-basin 9 is the likely cause of this result. Additionally, the sub-basins that neighbor Sub-basin 9 in a southerly direction (see Figure 14) also contained a higher number of Nationwide permits compared to other sub-basins. It is also notable that these sub-basins follow and intersect the north-western boundary of Harris County, and thus areas close proximity to Houston and outlying suburban areas. This pattern is again indicative of development, but more likely in this case to be driven less by exurban, or rural development, and more by suburban or comparatively higher density development.

Aggregate level tests for spatial autocorrelation showed no consistent pattern of clustered permit activity by sub-basin. Only one year, 1999, demonstrated positive spatial autocorrelation for Nationwide permits. In fact, sub-basins were far more likely to have a negative value of spatial association. There are two potential explanations for these results. First, Sub-basin 9 had such high counts of permits that neighboring sub-basins did not compare statistically; effectively serving as an influential unit of analysis. However, this does not explain the results in other areas, as Sub-basin 9 can only influence the sub-basins it borders, of which there are only six. The result of the annual Moran's *I* tests in other years and for other permits suggest that Section 404 permits are more or less evenly distributed over time and space. Similar to the lack of spatio-temporal interactions shown by the Mantel Index, this may also indicate rural development that involves far less intensive permitting activities.

7.2. Discussion of Explanatory Analysis

The results of modeling MAF and PAF not only supported the eight hypotheses laid out in Section 3, but also had several characteristics that are worth further consideration. First, all types of Section 404 permits had significant, positive effects on both MAF and PAF. More importantly, the effects of permit types on the dependent variables increased as their assumed impact by type increased. This “type of permit effect” is demonstrated in A4-Figure 16 and Figure 17. Graphs of the permit coefficients and their 95 percent confidence intervals aid in the confirmation of this effect.

Larger per-permit increases were seen for Individual permits than any other permit for both flow variables. The lower end of the coefficient’s confidence interval do not overlap with any other permit type in MAF models, and only slightly overlap with the upper limit of the confidence interval for Letters of Permission in PAF models. Letters of Permission and Nationwide permits had similar per-permit increases for both MAF and PAF, but still nearly five-times less than the increases seen by Individual permits. Their effects on MAF and PAF are demonstrated by similar ranges of confidence intervals, differing only by a narrower range for Letters of Permission (see A4-Figure 16 and Figure 17).

General permits had the least effect of any issued permit type in the study area; they increase both dependent variables less than a tenth of a percentage point and had a narrow range of effect (see A4-Figure 16 and Figure 17). This effect on increases in flow based on the “type of permit effect” is perhaps one of the more important findings of this research. Despite being the by far the least frequently issued permit type, Individual permits have the largest impact on mean and peak streamflow. The “type of permit effect” demonstrates that Section 404 impacts are indicators of wetland loss.

Previous research has also supported the use of Section 404 permits as indicators of wetland loss. Brody, Zahran, Highfield, Grover & Vedlitz (2007) demonstrated the effects of Section 404 permitting on flood damage in Texas. After controlling for a host of pertinent factors, cumulative Section 404 permits were significantly positive when predictors of flood damages. Two studies in Florida found similar results. Brody, Zahran, Maghelal, Grover & Highfield (2008) analyzed 383 damage producing flood events from 1997 – 2001. Again, cumulative Section 404 permits were positive and significant when predicting on flood damage. Highfield & Brody (2006) found that Individual permits issued within Special Flood Hazard Areas in Florida were positive and significant in explaining aggregate flood damage from 1997–2002.

Although this study relied on streamflow measurements instead of property damage, it does support a pattern of research that corroborates the use of Section 404 permits as wetland loss indicators. Further, this is the third study that has found that Individual permits have the largest effect on streamflow and measures that are a direct result of extreme streamflow. The pattern of previous research and the findings in this study greatly support the internal validity of Section 404 permits as indicators of wetland loss and highlights the potential importance of this measure serving as a vital indicator in future research.

It is somewhat surprising that Nationwide permits and Letters of Permission had similar effects on MAF and the same effect on PAF. This may be due to either less than expected impacts from Letters of Permission, or greater than expected impacts from Nationwide permitting. Previous research has found that Nationwide permits accounted for proportionally more cumulative and substantial impacts compared to other permit types (Stein & Ambrose, 1998). Alternatively, although Letters of Permission are an abbreviated form of a Section 404 permit, they do require input from relevant state and federal agencies. In the case of the study area, these agencies would include state agencies such as Texas Parks and Wildlife, Texas Commission on Environmental Quality and the Texas General Land Office as well as federal agencies including the U.S. Fish and Wildlife Service and U.S. Environmental Protection Agency. It seems probable that input from any one of these agencies could elevate the permit type to Individual. Thus the typical impact of Letters of Permission could be less than what was assumed. While there are clear demarcations of permit type effects resulting from this research, future studies would benefit from a better understanding of the difference in wetland loss and impact within permit types.

Second, as discussed in Section 6, the per-permit increase of MAF and PAF was minimal. It is, however, important to realize these increases represent a single permit. For example, the smallest increase in both MAF and PAF is caused by General permits; one General permit increases MAF by a mere 0.07 percent and PAF by a similar 0.05 percent. Yet General permits were, on average, the most issued type of permit with approximately 213 issued per year. Sub-basin 9 had an average MAF of 8,975 cfs and an average PAF of 57,000 cfs over the study period. One General permit increases MAF up to 9,981 cfs and PAF up to 57,029 cfs. However, one year of average permit activity (184 permits) increases MAF up to 10,131 cfs and PAF up to 62,244 cfs; these are increases of 12.8 and 9.2 percent, respectively. A less extreme example is Sub-basin 13, which had an average MAF of 584 cfs, an average PAF of 17,115 and an average of 6 General permits per year. Five years of average General permit activity adds 12 cfs to the MAF, and increase of 2 percent. The same five years of General permitting activity adds nearly 257 cfs to the study period PAF, an increase of 1.5 percent.

Nationwide permits and Letters of Permission produced a greater increase in the two flow variables but were similar by type. Sub-basin 22 had a study period average MAF of 309 cfs, PAF of 6,566 cfs and an annual average of only 5 Nationwide permits. Even though a single Nationwide permit increased MAF by 0.28 percent and PAF by 0.26 percent, 10 years of average Nationwide permitting activity adds 43 cfs to MAF (a 14 percent increase) and adds 854 cfs to PAF (a 13 percent increase). A second example is Sub-basin 13, which contained a study period average of 2 Letters of Permission per year. After 10 years of average permitting activity, the average MAF of 584 cfs increases 48 cfs, an 8.2 percent increase. Under the same scenario, the study period average PAF of 17,116 cfs increases 2,225 cfs after 10 years of average permitting activity, a 13 percent increase.

Finally, Individual permits result in the largest per-permit increase: 2.1 percent for MAF and 1.6 percent for PAF. Although they are the least issued permit type, their numbers could also add up quickly. For example, sub-basin 30 had only 2 Individual permits issued during the 8 year study period, an average of 0.25 permits per year. If Individual permits were issued at the same rate, 8 years would see only two additional Individual permits but would result in a 120 cfs or a 4.24 percent increase in MAF and a 1,096 increase in PAF or 3.3 percent increase. These increases would occur only as the result of two additional Individual permits.

It is important to note that each of these per-permit increases occur while after controlling for all other variables in the models. Although these interpretations demonstrate the cumulative effects of Section 404 permitting, there are two variables in the model that are likely to have been affected by permitting activity. The two wetland land cover types, Palustrine forested and Palustrine Scrub/Shrub account for over 96 percent of wetlands in the study area and would be expected to be decreased by permitting activity. These changes could be addressed by estimating the wetlands lost due to permitting activity. However, making assumptions about how much wetland is lost due to Section 404 permit types is problematic, as the area lost due to each permit varies within permit type, probably differs over time and, most importantly, is unknown. Nonetheless, given the results, the role that wetlands play in modifying MAF and PAF are certainly worthy of further research.

In explaining streamflow, Palustrine Scrub/Shrub wetlands increased MAF and decreased PAF. With respect to PAF, a one percent increase in the Palustrine Scrub/Shrub wetland reduced peak flows from 16.93 to 18.65 percent. This reduction far outweighs the increases imposed by all four types of Section 404 permits. Decreases in PAF as a result of the presence of wetlands is well supported in the research literature covered in Section 2.

In terms of MAF, two models showed statistically significant positive effects of Palustrine Scrub/Shrub wetlands at $p<0.05$, increasing MAF approximately 14 percent; the other two were both positive but insignificant ($p<0.10$). Although this variable did not have the expected direction of effect, there is some support for this result. In the small amount of research pertaining to MAF and wetlands, increases in MAF were seen as a result of wetland loss or drainage (Bardecki, 1987; Brun et. al., 1981). However, increases in less extreme streamflow values were found by Demissie et al. (1991); wetlands increased low flows, up to 75 percent exceedence values. Two other authors found no difference in annual flows (Bullock, 1992; Burke, 1968). It does, then, stand to reason that Palustrine Scrub/Shrub wetlands maintain streamflow during periods of lower flow and relatively normal flow.

As Section 2 revealed, seasonal differences in the effect of wetlands on streamflow have also been investigated. Research conducted by Novitizki (1985) highlighted the importance of wetlands in reducing peak flows, but also found that wetlands can produce higher spring flows. Campbell and Dreher (1970) also found positive coefficients for wetlands and peak streamflow in April and May. This is likely a similar effect for the models on MAF and PAF. During the study period peak flows occurred, on average, in late June. Flow in the spring months, however, contributed most to the MAF. Therefore, it appears that the Palustrine Scrub/Shrub wetlands contribute to streamflow in the spring months, maintaining streamflow and boosting MAF, but decreasing peak flows through their ability to store runoff. These alterations of varying streamflow magnitudes were well summarized by O'Brien (1988), who, through admittedly broad generalizations, determined that wetlands can create "flashy" overall streamflow, but still function to reduce floods.

It's also notable that while the Palustrine Forested areas are statistically insignificant in all eight models they accounted for the vast majority of wetlands by percent and area; they had an average coverage of 4.3 percent or 14.65 square miles. Although Palustrine Scrub/Shrub wetlands showed significant effects with respect to MAF and PAF, they accounted for far less of wetland areas in the study area. The average sub-basin had only 0.3 percent or 1.22 square miles Palustrine Scrub/Shrub wetlands. However, the fact that Palustrine Forested wetlands are not significant should not diminish their potential importance on streamflow. Based on the bivariate correlations in Table 15, this wetland type appears to be associated with a control variable that suggests Palustrine Forested wetlands may be an indicator of other factors that influence streamflow. Mean slope had a positive association with Palustrine Forested wetlands; this association was negative with respect to Palustrine Scrub/Shrub. At this geographic scale of analysis, basins with higher percentages of the Palustrine Forested wetlands may also contain more areas that slope down to rivers and streams. In other words, this wetland type may be more indicative of slope at this scale than its streamflow modification functions. Additionally, considering that the study area has little topographical relief, Palustrine Forested wetlands are likely to flank rivers and streams giving more support to this explanation.

Finally, results from the models explaining MAF and PAF with respect to Section 404 permits may not appear as expected. In all eight models, Section 404 permit types had positive, albeit small, effects on both mean and peak annual flow. Conversely, Palustrine Scrub/Shrub had positive effects on MAF and negative effects on PAF. It would seem to follow then, that if Section 404 permits were an indicator of wetland loss they would have a negative effect on MAF, but this was not the case. The most parsimonious and logical explanation for this result does not revolve around wetland loss, but by what type of land cover the wetland was replaced. I speculate that Section 404 permits are often replaced with less pervious surfaces. While these wetland replacement surfaces may be impervious or developed, they may also be compacted soil resulting from construction projects or even failed attempts to return the wetland to its pre-project state. Further, while MAF did not have a significant relationship with the proportion of developed area, replacing a wetland with a less permeable surface will lead to increased flow. In other words, the effect of existing development on MAF does not have the same strength as the effect of replacing a wetland with development or other less pervious land cover. This conclusion is at least partially supported by the increase in the size and effect of both the unstandardized and standardized regression coefficients by permit type, the same type of permit effect is seen on MAF.

7.3. Policy Recommendations

As a result of examining the effects of Section 404 permitting on mean and peak streamflow, this research provides important insights into better informed wetland policies. The results of this study point to some detrimental effects of Section 404 permitting on streamflow, and more importantly on peak streamflow. As wetland losses accumulate over time, the potential for higher peak streamflow and, thus damaging floods increases in likelihood. The Section 404 program is implemented at the federal level, but has important implications for both state and local levels of government. All three of these levels of government-federal, state and local, would benefit from policies that better protect the wetlands critical to healthy streamflow.

7.3.1. Federal Policy Recommendations

This research has demonstrated that Section 404 permits do have a cumulative effect on mean and peak streamflow, an effect that is likely to increase peak streamflow and prove to be detrimental over time. Perhaps the most critical issues for federal policy should be addressed by the program's controlling entity, the USACE. The USACE routinely issues Findings of No Significant Impact (FONSI) that apply to the Nationwide and General permitting programs. These findings are required for the program under the National Environmental Protection Act (NEPA) but have never been elevated to require an Environmental Impact Statement (EIS). These FONSI's for the Nationwide and General permitting programs state that an EIS is not required because, "…the NWP program authorizes only those activities that have minimal adverse environmental effects, individually or cumulatively" (USACE, 1998). In response to pending litigation, USACE agreed to voluntarily assess the Nationwide and General permitting programs through an EIS in 1998. This EIS was, however, never completed because it was deemed unnecessary by the USACE. Further, the USACE has refused to provide a definition for "minimal adverse environmental effects" or to conduct a cumulative impact analysis (Copeland, 2008). In light of the results presented in this research, an

EIS with data-driven definitions of minimal adverse effects, and based on cumulative impacts of Nationwide and General permits is warranted.

7.3.2. State Policy Recommendations

The State of Texas has essentially no power over Nationwide and General permits, and very little over Individual permits or Letters of Permission. The State of Texas, like 21 other states in the U.S., can only regulate wetland loss through Section 401 Water Quality Certifications (WQC). These certifications must be made following the issuance of an Individual permit or Letter of Permission. The State of Texas has exempted all Nationwide and General permits from WQC with the exception of those that return water from a disposal site (TCEQ, 2008). The power to veto Section 404 permits through State Section 401 WQC has often been referred to as the "sleeping giant" of wetlands protection, although in practice this power is rarely used (Steiner et. al., 1994). Section 404 of the CWA does not restrict states from assuming power over the permitting program, but currently only two states, Michigan and New Jersey, have assumed power over the Section 404 program (Environmental Law Institute, 2008). Taking over the Section 404 program would no doubt be a financial and regulatory burden; this is the primary reason that so few states have assumed control over this program (Glubiak, Nowka & Mitsch, 1986). In addition, state control over wetland areas in Texas would likely be politically impractical considering the strength of property rights advocates.

The State of Texas does have a "Texas Wetlands Conservation Plan" on file with the Texas Parks and Wildlife Department. This conservation plan can be distilled into two approaches to achieve wetlands conservation. In its own words, the plan provides "incentives (financial, technical and educational) to landowners to encourage their stewardship," concluding that the most effective way of state regulation is to "work through the existing structure by improving landowner access to information regarding the regulatory process" (TPWD, 1997, pg. 26). The plan does not, however, contain any state financial incentive program aside from listing federal and non-profit agencies that are willing to assume conservation easements or receive donated land.

An obvious first step to strengthening, or establishing, a state program aimed at successful wetland preservation would be the development of a Wetlands Preservation Plan with concrete goals and methods of implementation. Texas does maintain a wetlands monitoring program and also has rudimentary designations of critical wetlands (ELI, 2008). Expanding on these two monitoring characteristics with implementation mechanisms could come in several forms. For one, the "sleeping giant" in the form of Section 301 could be awakened; the State, through the TCEQ could use its veto power for wetland projects that threaten critical wetland areas. This is the approach taken by the State of Arkansas, which has not partially or wholly assumed any regulatory authority from Section 404, but reviews Section 401 permits through a state Multi-Agency Wetlands Planning Team (Arkansas Multi-Agency Wetlands Planning Team, 2001). It also operates and incentive-based program aimed at private wetland preservation, creation and restoration. The Arkansas Wetland and Riparian Zone Tax Credit Program, makes up to $50,000 available for private wetland preservation and restoration (Arkansas Multi-Agency Wetlands Planning Team, 2001).

A second and more comprehensive step to reducing the impacts of Section 404 permitting and promoting wetland preservation would be the development of a state wetland permitting program. This would obviously be a more financially and politically difficult solution, but one that would be inherently stronger than relying on Section 401 and incentives alone. Although only eight states have assumed authority to regulate coastal and freshwater wetlands, fifteen others have developed a wetland permitting program that complements the USACE Section 404 program (ELI, 2008).

For example, the State of Florida, through its water management districts, regulates and issues permits for wetland impacts through its Environmental Resource Permits (ERPs). This program serves as an additional layer of wetland regulation that supplements the Federal Section 404 program. The ERP program requires mitigation and state Individual permits for activities that exceed one acre of wetland impact and a

General permit category that is analogous to the USACE Nationwide permit. Florida's ERP program does more than add another layer of permitting requirements. There are many cases where an ERP permit is required when a Section 404 permit is not, creating a stricter and more comprehensive method of regulatory oversight. The ERP program, and all other state programs, must at a minimum meet and typically exceed Section 404 requirements.

Further, the ERP program is administered by Florida's Water Management Districts, units that are created based upon natural watersheds. This creates a regulatory unit that is more appropriate than a USACE District, which typically covers many counties within states or encompasses entire states. Permitting oversight, monitoring and jurisdictional determinations are likely to be more appropriate and accurate when they are conducted by staff that is familiar with the unique characteristics of the watershed. A similar regulatory permitting structure, based perhaps on Texas' existing groundwater management districts, would be a significant step toward preserving critical freshwater wetlands, such as Palustrine Scrub/Shrub wetlands, and reducing the adverse impacts of relying solely on Section 404.

7.3.3. Local Policy Recommendations

Many localities nationwide have taken an interest in the importance of their wetland resources. An estimated 5,000 to 6,000 counties, cities and towns have adopted specific wetlands protection regulations and many states offer model wetland protection ordinances to assist local governments (Kusler, 2007). The State of Texas, through the General Land Office, provides a handbook outlining regulatory mechanisms that may offer opportunities for wetland protection. However, no models of wetlands protection ordinances are found in the handbook. Moreover, no local ordinances that are aimed directly at wetland regulation or preservation in Texas municipalities could be located.

Nonetheless, are several actions that could be taken by local communities to strengthen their wetland preservation efforts. These actions range from simple, easily achieved actions to more complex efforts. First, even local governments and counties that do not have the power to, or choose not to, regulate land use could support wetland preservation efforts by submitting comments on federal Section 404 permits and state Section 401 WQC and also by reporting violations. Comments submitted on behalf of local and county governments may give increased weight to state decisions over Section 401 WQC. Second, local governments that participate in land use controls have possibly the highest capacity to protect wetlands. Land use regulations are perhaps the strongest way to protect critical wetlands at the local level. Inventorying, prioritizing and placing wetland areas into plans to protect open space is an effective form of land use regulation that would protect wetlands and the local level. Open space regulation, and in this case wetland protection, is commonly implemented through zoning designations, zoning overlay districts, and subdivision ordinances (Bengston, Fletcher & Nelson, 2004). These three land use mechanisms are well within reach of home rule cities.

A third form of community level wetland preservation can include various forms of land or development rights acquisition. Acquiring wetland areas can occur in many forms including outright (fee simple) purchase, conservation easements or transfer of development rights. All three of these approaches are effective and permanent forms of land acquisition for wetland preservation. In the case of outright purchase the initial costs may be high, especially compared to land use controls. Conservation easements are typically donated, so the initial financial costs are small but the approach relies on willing landowners (Wright, 1993). Transfers of development rights have proven to be effective forms of protecting large areas of land and the initial financial costs to a local government are typically much less than outright land purchases (Pizor, 1986).

The methods outlined above cover the most common forms of local-level mechanisms for wetland protection. There are certainly other, more creative forms of wetland preservation that can be used at the local level. This is not intended to be an exhaustive list. Rather, the overriding goal is to demonstrate that there are local-level mechanisms for wetland preservation in communities. All three of these approaches could be implemented in communities within the study area of this research, as well as any other communities interested in wetland protection and preservation.

7.3.4. Summary of Policy Recommendations

Successful policy changes to preserve wetlands and reduce the cumulative impacts of Section 404 permitting will not result from a single policy change at one level of government. Federal level actions are typically broad and not well defined, as demonstrated above. Policy changes at this level are important but may not be strong or specific enough to result in sweeping change. Nonetheless, environmental assessments cumulative wetland loss under Section 404 is a step in the right direction.

State level efforts are perhaps the most important among the three levels of government. Using tools that are already in place, such as Section 401 WQC, a state could reduce the immediate impacts of Section 404 permits. In addition, developing regulations that exceed USACE requirements would add an increased level of protection and could have the most beneficial effects in the long-term. Local level efforts should also not be ignored. Although communities cannot veto Section 404 permits, they do have the ability to comment on applications that affect their jurisdictions. Further, municipalities have the power to introduce land use controls and land acquisition programs to preserve wetlands, removing the possibility of wetland loss through Section 404 altogether. Overall, an increase in regulatory involvement at the state level coupled with multiple methods of land use control at local levels is the most practical way to reduce wetland loss and impacts through federal Section 404 permitting.

8. CONCLUSIONS

8.1. Research Summary

First, this research has confirmed that Section 404 permits are an indicator of natural hydrologic degradation in the form of wetland loss. This confirmation comes after statistically controlling for climatic, geomorphic and land cover factors. Results also demonstrated that permit types have effects that react according to the level of impact that is assumed under the Section 404 regulatory framework. These results were based on eight years of streamflow records and Section 404 permitting activity.

Second, this study has also demonstrated that the effects of the Section 404 permits increase mean and peak streamflow within the USACE Galveston District study area during the study period 1996–2003. Support for *Hypotheses 1-8,* which stated that a unit increase in Individual permits, Letters of Permission, Nationwide permits, or General permits would increase mean and peak streamflow was provided by the explanatory analyses. The regression coefficients indicated the increases in mean and peak streamflow on a per-permit basis were small relative to other control variables. However, viewing the results as per-permit increases does not consider the effect of accumulations of Section 404 permits over time. These cumulative effects have the ability to modify mean and peak streamflow to an extent that may become hazardous over time.

Research literature on the effects of wetlands on streamflow generally finds that wetlands reduce peak streamflow, reduce low magnitude floods and may have negative effects on high magnitude floods. Research pertaining to wetlands' effects on less extreme streamflow is less clear, but suggests that wetland decrease streamflow that is below peak or flood magnitude as well. This study found that Palustrine Scrub/Shrub wetlands had different effects on mean and peak streamflow. This wetland type had positive effects on mean annual streamflow, but decreased peak annual streamflow.

Third, exploratory space-time data analysis of Section 404 permits suggested that permit activity may be driven by suburban and, possibly to a grater extent, exurban land development patterns. This implication was driven by two results. First, Sub-basin 9 had much higher levels of permitting activity despite the fact that it does not contain a significant population or major population centers. Second, the overall lack of spatial and spatio-temporal statistical patterns shows that with few exceptions, Section 404 permits were not issued intensively within sub-basins over time. Both results suggested a pattern of wetland development through Section 404 permits that does not display the characteristics expected of urban development.

Finally, the policy recommendations to reduce the impacts of Section 404 permitting and preserve wetlands were threefold. First, an assessment of the Nationwide and General permitting program, which the USACE claims has minimal impacts on an individual and cumulative basis, should be conducted. Second, the State of Texas should expand on its current wetlands plan and use Section 401 WQC as a tool to reduce Section 404 permitting activity. Statewide wetlands regulation in the form of environmental permitting similar to the model Florida uses would be the strongest approach to reducing Section 404 impacts and preserving wetlands and should be investigated as a long-term solution. Lastly, the role of local governments should not be overlooked, as they have land use control and land purchasing mechanisms that would couple well with increased state regulation.

8.2. Limitations and Future Research

While this study provides a greater understanding and contributes to the base of knowledge concerning the impacts of Section 404 permitting on mean and peak streamflow, it is only a first step. Further research is necessary to provide more specific insights into both the pattern and streamflow effects of Section 404 permitting.

First, the study area only consisted of 47 sub-basins over an eight year period. The restrictions placed on the sample of stream gauges were focused on data integrity over time; this constraint limited the sample size. Future research may benefit by focusing less on gauge data integrity and more on capturing a geographically larger and temporally longer sample. This could potentially be addressed through weighting observations by record length.

Second, because of temporal limitations on control variables, this research was conducted on an annual scale. This temporal scale ignores seasonal fluctuations in streamflow, precipitation, and other natural characteristics that vary by season. Additional research would benefit from exploring seasonal components of streamflow measures and their reactions to Section 404 permitting.

Third, although the effects of Section 404 permits differed by type, very little is known about variations within type. Examining the types of projects and activities that are allowed within permit types and generating estimates of the area of impacted or lost wetlands would be a significant contribution. Research in this area could also identify the factors that drive Section 404 activity, allowing the creation of proactive policies to preserve wetlands that are most threatened.

Finally, this research measured Section 404 permits, wetland coverage and other land cover controls as the proportion of area that they covered in each sub-basin. This approach ignores important aspects of the setting and location of wetlands and wetlands impacted as a result of Section 404 permits. Additionally, each control variable is limited to a single value in each year for each unit of analysis. These two characteristics of this research ignore the spatial variability that is inherent within each sub-basin. Statistical models that incorporate the characteristics of existing wetland settings as well as the individual effect of wetlands lost through Section 404 would be a great contribution. Knowledge of the area of wetland losses estimated from the permit record would also offer the ability to simulate the effects of Section 404 permitting and incorporate spatio-temporal variability within sub-basins.

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APPENDIX 1.

Table 15. Pearson's Product-Moment Correlation Matrix

	MAF	PAF	General	Nationwide	Letter	Individual	Precipitation
MAF	1.000						
PAF	0.901	1.000					
General	0.240	0.210	1.000				
Nationwide	0.189	0.131	0.819	1.000			
Letter	0.235	0.205	0.997	0.797	1.000		
Individual	0.239	0.195	0.884	0.823	0.870	1.000	
Precipitation	0.272	0.195	0.075	0.115	0.068	0.116	1.000
Basin Area	0.605	0.560	0.274	0.127	0.272	0.211	-0.196
Elongation Ratio	0.567	0.490	0.002	-0.057	-0.001	-0.017	0.049
Mean Slope	0.121	0.172	0.125	-0.040	0.120	0.084	0.023
Natural Cover	0.143	0.198	0.140	0.057	0.135	0.145	0.121
Soil Permeability	0.052	0.023	0.043	0.057	0.032	0.144	0.155
Palustrine Forested	0.422	0.355	0.143	0.076	0.140	0.156	0.494
Palustrine Scrub/Shrub	0.233	0.063	0.047	0.135	0.050	0.102	0.293
Developed	0.170	0.239	-0.020	-0.213	-0.017	-0.130	-0.076

	Basin Area	Elongation Ratio	Mean Slope	Natural Cover	Soil Permeability	Palustrine Forested	Palustrine Scrub/Shrub
Basin Area	1.000						
Elongation Ratio	0.592	1.000					
Mean Slope	0.194	-0.081	1.000				
Natural Cover	0.069	0.025	0.591	1.000			
Soil Permeability	-0.096	0.019	0.423	0.519	1.000		
Palustrine Forested	0.181	0.315	0.440	0.445	0.286	1.000	
Palustrine Scrub/Shrub	0.021	0.123	-0.056	-0.015	-0.102	0.481	1.000
Developed	0.250	0.086	0.637	0.549	0.262	0.277	-0.053

APPENDIX 2.

Table 16. USGS Stream Gauge Descriptions and Map Reference Identification

USGS Gauge Id	Map Id	Area_Km	Flow		Years (t)	Mean Annual Observations
			Mean Annual	Peak Annual		
08029500	1	333.13	157.06	3228.00	5	358.40
08030500	2	607.27	7678.44	47875.00	8	352.50
08033500	4	4350.51	2129.36	18071.43	7	362.00
08041000	5	784.13	7530.98	26771.43	7	360.71
08041500	6	2228.46	783.16	14488.57	7	350.43
08066170	7	149.19	31.68	3075.57	7	354.14
08066200	8	365.52	96.02	4761.43	7	359.14
08066250	9	7078.18	8202.66	57000.00	7	358.00
08066500	11	429.22	7570.81	58550.00	8	358.13
08068000	13	2133.24	440.63	17115.71	7	354.29
08068500	14	1034.24	295.58	9268.75	8	356.38
08069000	15	726.41	236.80	6565.71	7	356.86
08070000	16	840.04	186.06	7400.00	6	359.67
08070500	17	272.64	69.43	4912.17	6	361.17
08071000	18	305.78	89.19	2890.00	3	361.00
08073500	19	717.69	301.48	2007.50	8	354.63
08074500	21	246.20	151.47	5235.71	7	355.29
08075000	22	290.50	301.36	6566.25	8	351.50
08075400	23	50.43	43.12	1980.29	7	359.14
08075770	24	47.62	28.74	1119.00	8	362.75
08076000	26	71.05	122.62	5541.25	8	350.13
08076500	27	74.65	45.93	1505.00	3	361.67
08078000	28	221.60	94.55	2574.29	7	360.86
08117500	29	1869.04	582.32	11270.00	7	358.43
08161000	30	5609.51	2489.37	33225.00	8	361.50
08162000	31	939.17	2117.35	27471.43	7	354.86
08162500	32	672.87	2711.65	37085.71	7	349.43
08164000	33	2124.00	266.63	10055.00	6	362.83
08164300	34	862.37	102.83	7575.71	7	357.29
08175000	35	1422.77	112.54	9333.75	8	357.63
08176500	36	692.46	2200.41	28285.71	7	357.71
08188500	37	2519.17	806.89	21135.71	7	347.14
08189500	38	1808.29	134.50	10059.88	8	355.38
08189700	39	631.27	28.80	1944.38	8	352.50
08177500	40	1294.50	139.32	14124.00	5	339.40
08208000	41	2959.85	102.80	7535.00	6	352.50
08211000	42	2776.06	465.42	11798.75	8	357.25
08111700	43	970.79	152.46	10886.67	3	364.00
08114000	44	1813.65	6448.39	59416.67	6	352.67

Table 16 Continued

USGS Gauge Id	Map Id	Area_Km	Flow		Years (t)	Mean Annual Observations
			Mean Annual	Peak Annual		
08115000	45	116.67	31.86	1481.80	5	362.80
08183500	46	650.39	580.05	13060.00	8	356.63
08175800	47	4152.17	2167.39	65795.00	8	354.25
08028500	49	4245.42	7821.47	47885.71	7	354.43
08210000	50	4817.03	524.66	12667.50	8	361.13
08194500	51	7600.22	265.14	9373.75	8	360.88
08186000	52	2122.00	140.33	11210.13	8	354.25
08160800	53	44.64	4.49	390.33	6	358.67

APPENDIX 3.

Table 17. Cumulative Impact of Section 404 Permit Types

	Mean Annual Flow				Peak Annual Flow			
Years	General	Nationwide	Letter	Individual	General	Nationwide	Letter	Individual
1	254.2153	675.9207	218.1969	455.808	1828.512	6320.264	1393.356	3572.351
	14.93%	39.69%	12.81%	26.77%	10.66%	36.86%	8.13%	20.83%
2	508.4307	1351.841	436.3938	911.6159	3657.024	12640.53	2786.713	7144.702
	29.86%	79.38%	25.63%	53.53%	21.33%	73.71%	16.25%	41.66%
3	762.646	2027.762	654.5906	1367.424	5485.536	18960.79	4180.069	10717.05
	44.78%	119.07%	38.44%	80.30%	31.99%	110.57%	24.38%	62.49%
4	1016.861	2703.683	872.7875	1823.232	7314.049	25281.06	5573.425	14289.4
	59.71%	158.76%	51.25%	107.06%	42.65%	147.42%	32.50%	83.33%
5	1271.077	3379.604	1090.984	2279.04	9142.561	31601.32	6966.781	17861.76
	74.64%	198.45%	64.06%	133.83%	53.31%	184.28%	40.63%	104.16%
10	2542.153	6759.207	2181.969	4558.08	18285.12	63202.64	13933.56	35723.51
	149.28%	396.90%	128.13%	267.65%	106.63%	368.55%	81.25%	208.31%
15	3813.23	10138.81	3272.953	6837.119	27427.68	94803.96	20900.34	53585.27
	223.91%	595.35%	192.19%	401.48%	159.94%	552.83%	121.88%	312.47%
20	5084.307	13518.41	4363.938	9116.159	36570.24	126405.3	27867.13	71447.02
	298.55%	793.80%	256.25%	535.30%	213.25%	737.10%	162.50%	416.63%
25	6355.383	16898.02	5454.922	11395.2	45712.8	158006.6	34833.91	89308.78
	373.19%	992.25%	320.31%	669.13%	266.56%	921.38%	203.13%	520.78%

Note: Increases based on the average annual number of issued permits (Table 4) and average annual mean and peak annual flow (Table 2). Values represent flow increase and percent increase by number of years.

APPENDIX 4.

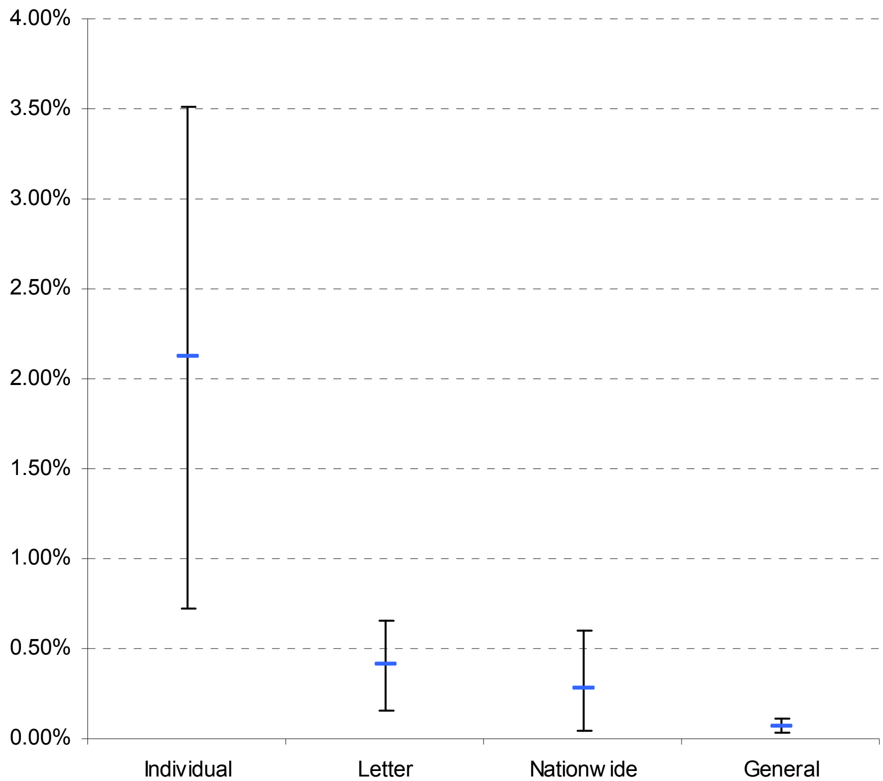

Figure 16. Comparison of Type of Permit Effect for Mean Annual Flow

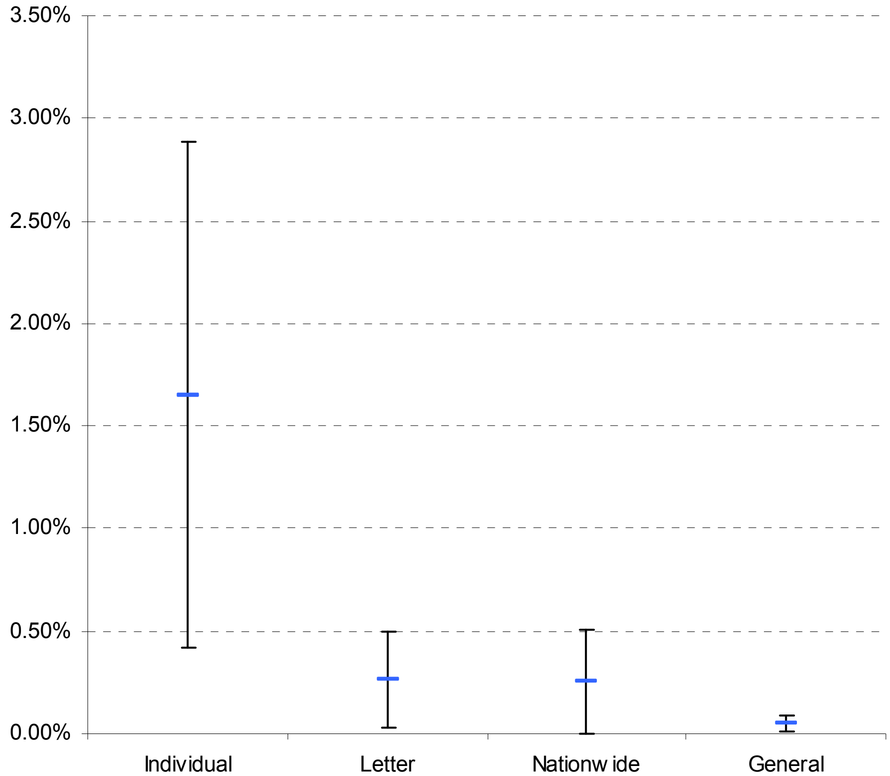

Figure 17. Comparison of Type of Permit Effect for Peak Annual Flow

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