LOG JAM CHARACTERIZATION, DISTRIBUTION, AND STABILITY ON THE SAN ANTONIO RIVER, TEXAS

THESIS

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CHAPTER I

INTRODUCTION

LWD General

Large Woody Debris (LWD) in rivers is defined as logs with either a diameter of 0.1m or a length of 1m. LWD naturally occurs in rivers that have forested riparian areas. There are various input processes including bank erosion, windfall and flooding. Studies have documented the presence of in-stream LWD in the Pacific Northwest (Keller and Swanson 1979), the southeastern U.S. (Wallerstein and Thorne 1996), the northeastern U.S. (Bilby and Likens 1980), other parts of North America (Angradi et al. 2004), and around the world (Gurnell et al. 2000a).

Geomorphic Effects

LWD can affect the hydraulic processes and geomorphology of a channel. In large meandering streams LWD jams often divert flow towards the bank, causing an increase in local bank scour and channel widening as the channel adjusts to flow around the jam (Keller and Swanson 1979). Deposition may occur downstream of a jam where the jam causes a localized reduction in flow velocity. This deposition can initiate formation of a mid channel bar (Keller and Swanson 1979). In extreme situations a large jam can span the channel and alter the flow regime to such an extent as to cause a backwater effect that initiates a meander cutoff (Keller and Swanson 1979). In mountain streams, plunge pools often develop immediately downstream of LWD dams, scouring the sediment from the pool and initiating a series of steps and pools. LWD steps are often the location of significant sediment storage on their upstream treads because of steep valley confinement (Keller and Swanson 1979). This is an example of the morphology of a mountain river being "forced" by the presence of LWD. Some common "forced" morphologies in mountain channels include both step-pool and pool-riffle sequences (Montgomery and Buffington 1997). In a sand-bed, incising channel in northern Mississippi, LWD caused both scour and deposition. After a review of log jams, it was determined that most log jams cause a net increase in sediment storage, and may help to stabilize an unstable stream reach (Wallerstein and Thorne 2004).

Ecological Effects

LWD plays an important ecological role by creating habitat in streams of varying size and geographic region, including the southeastern U.S. coastal plain streams (Wallace and Benke 1984; Benke et al.1985; Wallace et al.1996). Benke and others (1985) measured high levels of animal and invertebrate biomass and production on submerged wood on the Satilla River in southeastern Georgia. Fish have been found to be dependent on this biomass as an energy source. Wood can also provide stable substrate for invertebrates in streams with otherwise unstable substrate (Wallace and Benke 1984). In some old-growth forest streams of northwest North America, LWD creates pools that provide important habitat for salmonid. The wood enables them to inhabit river reaches where they may not have otherwise existed (Brunfelt 1992). The pools create areas of low velocity that are necessary for rearing. Low flow areas created by LWD retain finer sediment particles important for salmonid spawning that would otherwise be transported downstream (Brunfelt 1992).

Historical LWD Management

Large amounts of LWD accumulated in the rivers of North America prior to the 19th century. Some of this wood formed massive rafts that grew large over time. In Texas there were two extremely large rafts. One was on the Red River and extended for about 75 miles (Handbook of Texas 2007), and the other was on the Colorado River (Handbook of Texas 2007). Following the removal of the Colorado raft, a major delta was formed at the river's mouth in the Gulf of Mexico (Handbook of Texas 2007).

Much of the wood in North American rivers that had accumulated prior to settlement was removed during the 19th and 20th centuries (Montgomery et al. 2003). LWD was removed for navigational purposes, flood management, and because there was a public perception that LWD was bad for rivers and aquatic habitat. Over the past twenty-five years this perception has been changing, and people are starting to see the ecological and morphological value that wood provides to rivers. There have even been some river restoration projects that have added LWD back into the river (Brunfelt 1992), although none in Texas.

Research Significance

Research of LWD jam distribution, stability, and type is important for several reasons. Because it has been shown to be an important part of the riverine ecological system, knowledge of LWD jam spatial distribution within a river basin can help in habitat assessment. LWD affects erosional/depositional processes and is important when considering the geomorphological evolution of channel reaches in different sections of a basin.

Understanding jam stability gives insight into a jam's total influence on the channel. Stable jams will not move during peak flow events, and will instead divert flow to the banks causing erosion. Unstable jams will move during high flow events and will not have as significant an influence on channel morphology. Knowledge of individual jam stability can give insight into the evolution of a channel and give river managers information on how effective jam removal might be.

LWD jams affect hydrologic processes and flood routing (Gregory, Gurnell, and Hill 1985). Knowledge of jam locations, patterns, and types common to a specific basin can help watershed managers make important decisions regarding resource dedication to the removal of jams. Removal of a jam may be necessary if backwater effects can cause flooding of adjacent human property. Major complete channel jams forming on the upstream sides of bridges are an example of unnatural jams that can increase the likelihood of upstream flooding. Given the benefits of LWD already discussed, removing jams at places other than bridges should be avoided unless absolutely necessary to protect landowner property.

Studies of LWD loading and jam distribution within main channels can contribute to LWD channel restoration projects where LWD and jams are added to a stream to restore habitat (Richmond and Fausch 1995). The ability to identify reaches where LWD and jams are more likely to form naturally will result in successful projects that simulate natural conditions. If natural distribution in relation to stream width, depth, and gradient is not taken into account, then LWD could be placed in a reach of the channel where retention and habitat formation (Richmond and Fausch 1995) will not be successful.

Research Focus

This research will be focused on the San Antonio River, TX, from the bridge crossing at Texas CR 125 to Texas FM 541 near Poth, TX (Figure 1). The total length is 56km. The main goals are: first, to determine LWD jam geographic distribution, frequency, and spacing; second, to assess jam stability and at what flows they might move; and third, to characterize and describe the range of jam types found on this reach of the San Antonio River.

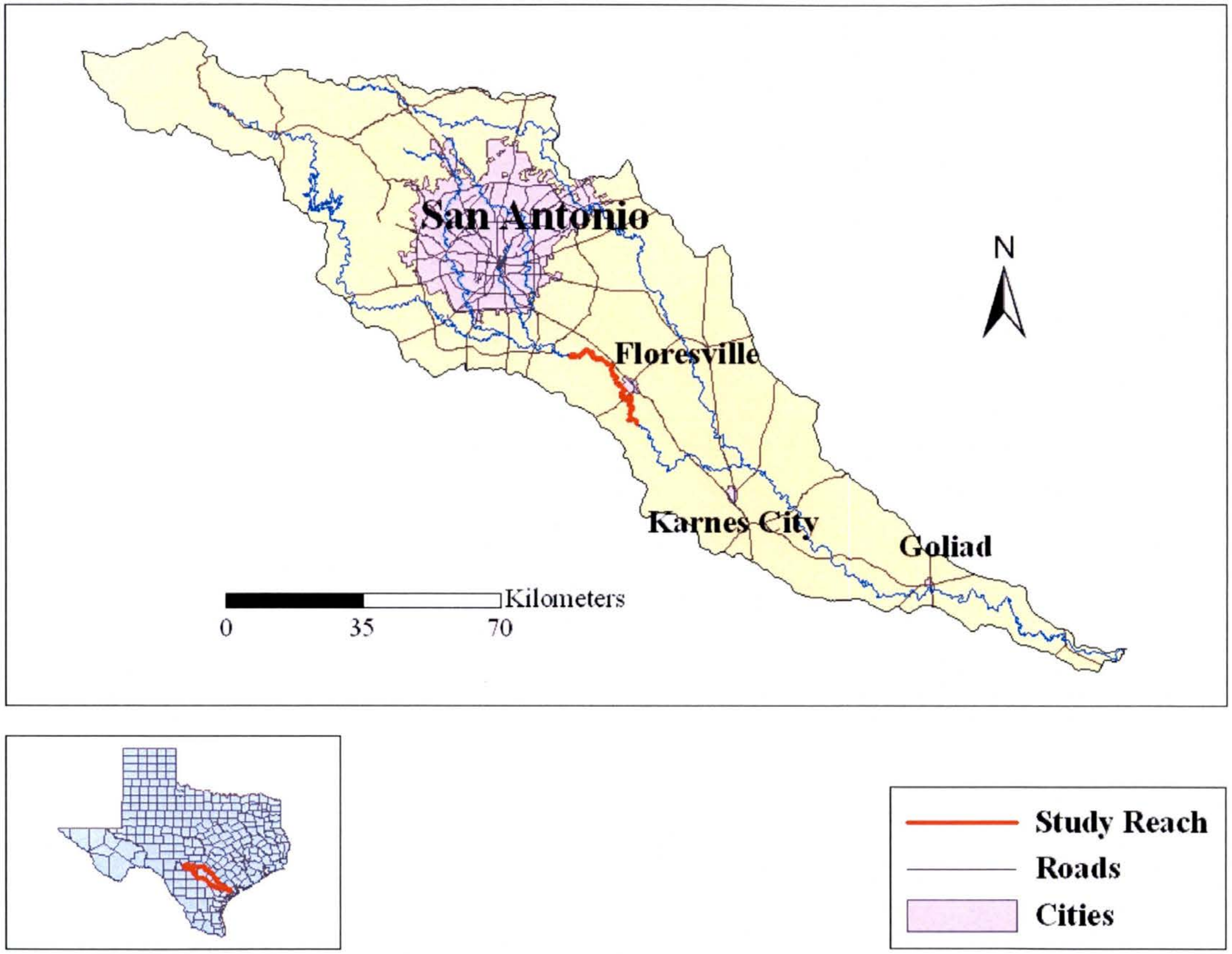

Fig. 1. Study Area. Map showing the San Antonio River watershed and the study reach (the highlighted portion of the river). Total length of the study reach is 56km.

CHAPTER II

STUDY AREA

The study area includes the main stem of the Lower San Antonio River from the bridge crossing at Texas CR 125 to Texas FM 541 near Poth, TX (Figure 1). Total length is 56km. This area drains approximately 5,300 km^2.

Climate

Climate for the study reach is Subtropical Subhumid (Larkin and Bomar 1983). Average annual precipitation is 800mm. Precipitation is bimodal, with peaks in late spring to early summer and early to mid fall (National Oceanic and Atmospheric Administration 2007).

Geology

The study reach is underlain by marine sedimentary rocks from the Cenozoic Era that become progressively younger towards the coast (Barnes 1983). Along the Balcones Escarpment north of the study reach, Cretaceous-aged Edwards limestone forms the top of the escarpment. Downstream of the escarpment the study reach begins. Here sandstones, marl, and shales dominate and the less erosive sandstone forms cuestas because of the gentle dip toward the coast. Along the San Antonio River are Pleistocene terrace deposits (Barnes 1983). The river is greatly incised and some portions of the study reach have incised into the sandstone, marl, and shale.

Physiography

The San Antonio River watershed can be coarsely divided into two physiographic provinces, the Edwards Plateau and the Gulf Coastal Plains (Figure 2) (Wermund 1996).

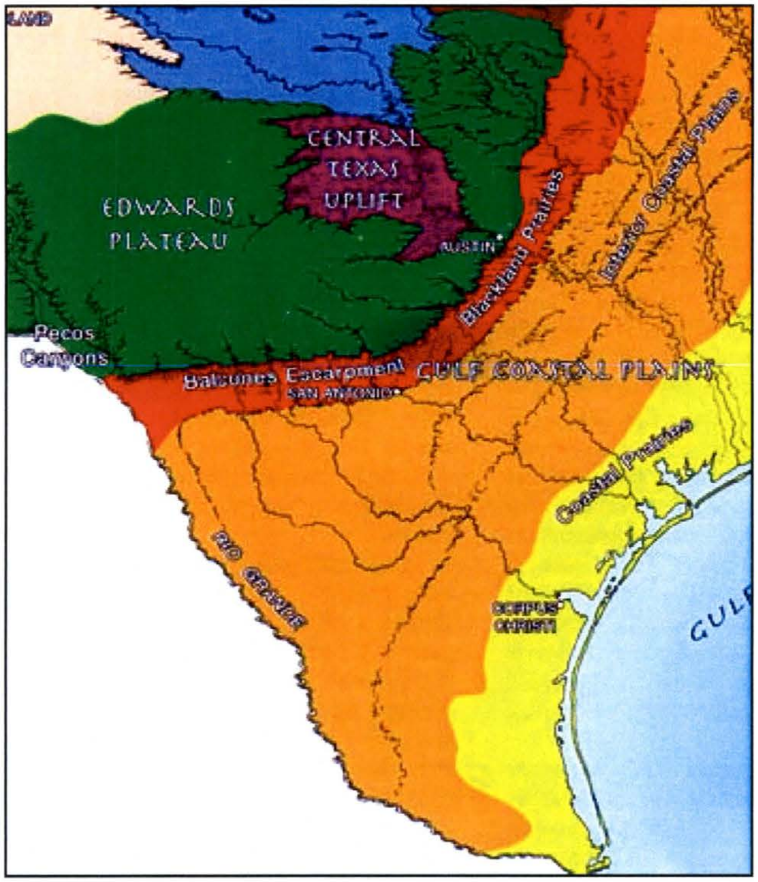

Fig. 2. Physiographic Map of Texas. The study reach lies completely within the Interior Coastal Plains (Wermund 1996).

The Balcones Escarpment separates the two provinces. Thin soils and steep topography are characteristics of the Edwards Plateau and are known to produce impressive peak discharges from flood events near the Balcones Escarpment (Baker 1977). The Gulf Coastal Plains are subdivided into three subprovinces called the Blackland Prairies, the Interior Coastal Plains, and the Coastal Prairies (Wermund 1996). The Blackland Prairies are southeast of the Edwards Plateau. The terrain is low rolling and deep clay soils dominate. Southeast the Interior Coastal Plains begin. Cuestas and valleys are characteristic of the topography and shallow sandy and clay soils dominate. The study reach is completely within this subprovince.

Vegetation

The study reach falls within the Post Oak Savannah biotic region (Figure 3) (Gould 1962). The Post Oak Savannah biome is gently rolling to hilly and mostly composed of grassy pastures interspersed with woody vegetation. The main overstory plants are post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*).

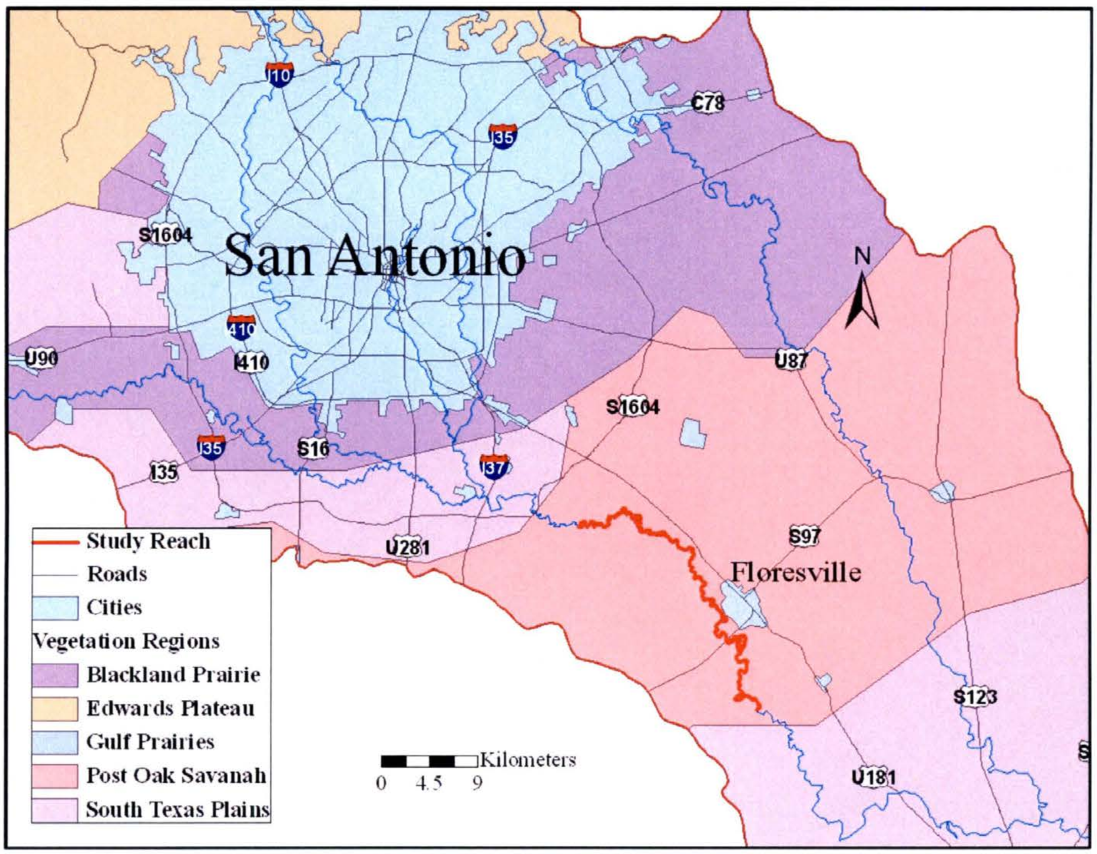

Fig. 3. The Vegetational Regions of Texas. The study reach is within the Post Oak Savannah Region (TPWD 2004).

A survey of the riparian woody species at two locations adjacent to the San Antonio River was conducted by Bush and Van Auken (1984). The two study sites were located between 3.8 and 5.0km south of Floresville, which is at the lower end of the study reach. Figure 4 depicts the three physical regions of the riparian area where transects were taken. They found that tree diversity increased with increasing distance from the

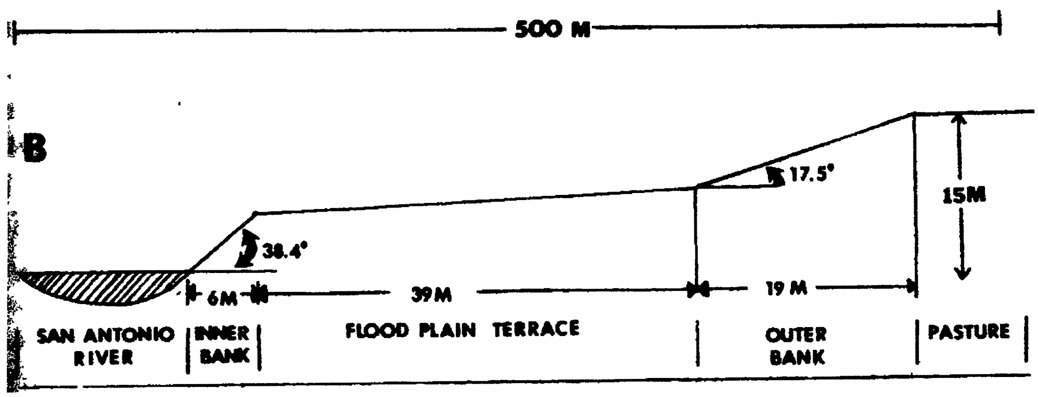

Fig. 4. Riparian Vegetation Survey Site Diagram. The inner bank is very steep. The floodplain terrace is wide and confined by an outer bank (Bush and Van Auken 1984).

inner bank and that total basal area decreased with increasing distance from the bank. Tree density was highest at both the inner and outer banks and lower on the flood plain. They suggested that density was greater at the river's edge as a result of more frequent tree falls during floods which could allow for more light gaps, thus preventing one large tree species from dominating (Bush and Van Auken 1984). Texas sugarberry (*Celtis laevigata*) is the dominant species with an importance value of 36%, followed by boxelder (*Acer negundo*), cedar elm (*Ulmus crassifolia*), and cottonwood (*Populus deltoides*). Most cottonwoods (*Populus deltoides*) and black willows (*Salix nigra*) are isolated to the inner bank of the river as opposed to the floodplain terrace and outer bank. Box elder (*Acer negundo*) has the highest importance value along the inner bank. Texas sugarberry (*Celtis laevigata*), cedar elm (*Ulmus crassifolia*), and American elm (*Ulmus Americana*) are more evenly distributed from the inner bank to the outer bank (Bush and Van Auken 1984). Most of the species were fast-growing because the high intensity floods that can occur on the incised, narrow flood plains of southwest Texas (Kochel and Baker 1982), disturb the riparian forest frequently.

Most cottonwoods (*Populus deltoides*) have diameters and heights of 0.91-1.52m and 18-30m respectively, and have large, protruding branches and open crowns (Preston 1976, 124). Black willows (*Salix nigra*) are small to large trees and can reach heights and diameters of 37 and 1.2m (Preston 1976, 133). Boxelder (*Acer negundo*) is a small tree that does not often reach heights of 23m and diameters of 1.2m (Preston 1976, 307).Texas sugarberry (*Celtis laevigata*) is a medium tree that is normally 0.91-1.52m in diameter and 18-24m high. American elm (*Ulmus Americana*) is a large tree that is normally 0.91-1.8m in diameter and 23-30m tall (Preston 1976, p, 225).

Land Use

Land use and land cover are important factors when analyzing the hydrologic regime and processes operating in a watershed. Land use influences rates of both erosion and runoff processes. Urbanization can cause a significant increase in runoff because of the addition of impermeable surfaces in a watershed as well as stormwater and sewer connections that flow into a river.

The 1992 land use for the watershed is shown in Figure 5 (United States Geological Survey 2000). Land use percentages for the watershed are determined from the 1992 land use data layer by the author (Table 1). First, the land use value for each pixel was dissolved into the major group it was within (Developed, Herbaceous

Planted/Cultivated, etc…). Then each group's percent coverage in the watershed was calculated. Ashe juniper (*Juniperus ashei*) forest land covers the majority of the uppermost part of the watershed, which coincides with the Edwards Plateau. The city of San Antonio is located directly downstream of the Edwards Plateau. The middle of the basin is largely agricultural. The study reach is surrounded mostly by farms and pastures (Figure 6). Patches of rangeland and forested areas are interspersed. The city of Floresville, a town of 5,868 people (Handbook of Texas 2007), occurs about midway through the reach.

Population and development have exploded in the watershed in the last one hundred years. In 1900 the population of San Antonio was 53,321, in 1950 it was 408,442 and in 2000, it was 1.14 million (Handbook of Texas 2007). This growth and urbanization in the upper part of the basin is likely to have a profound effect on the system.

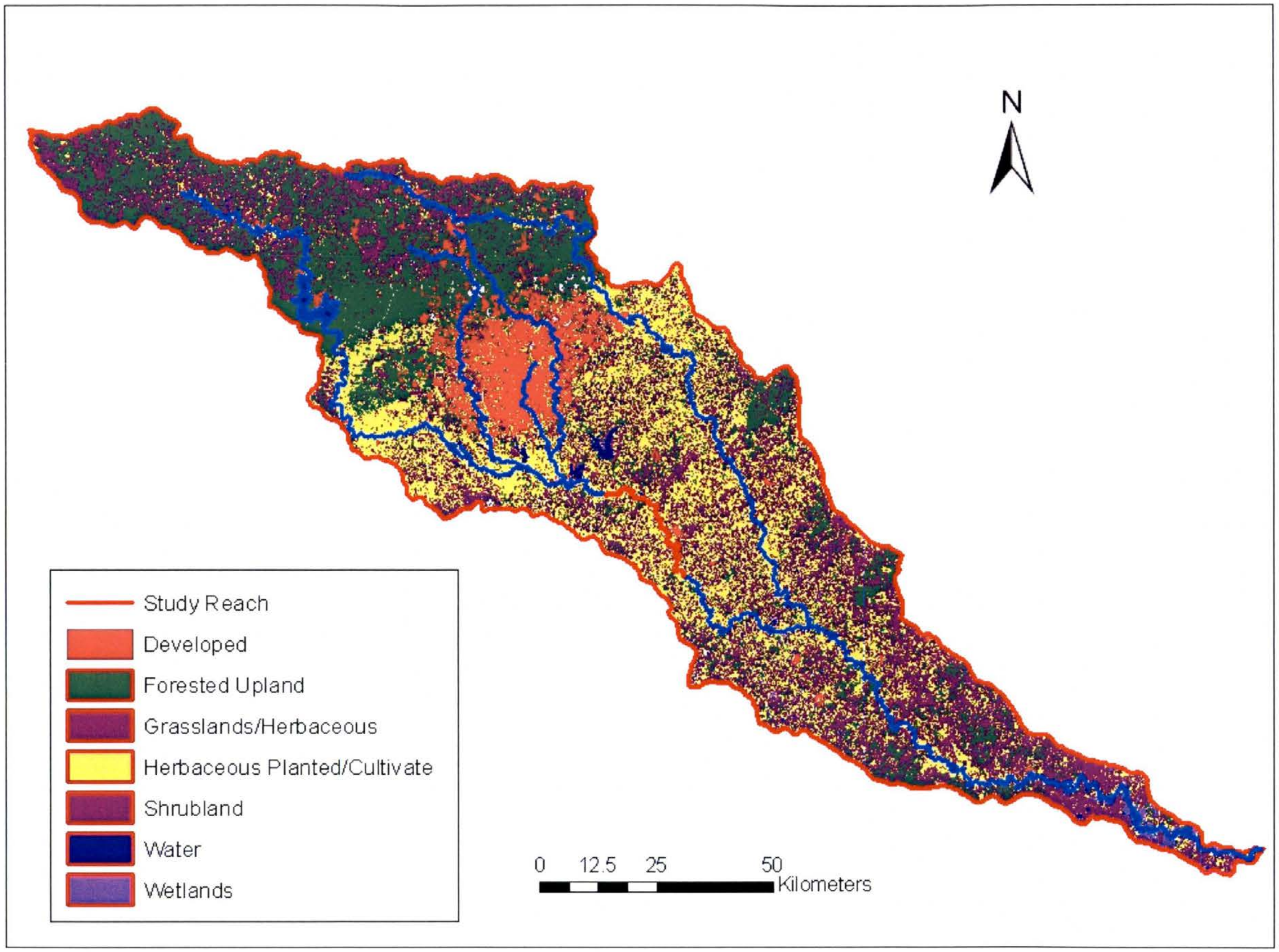

Fig. 5. 1992 Land Use. (USGS 2000)

Table 1. 1992 Land Use Percentages. Determined from the original land use data by the author (USGS 2000).

Land Use (1992)	Percent Coverage (%)
Water	1
Developed	7
Barren	1
Forested Upland	31
Shrubland	18
Grasslands/Herbaceous	14
Herbaceous Planted/Cultivated	27
Wetlands	1

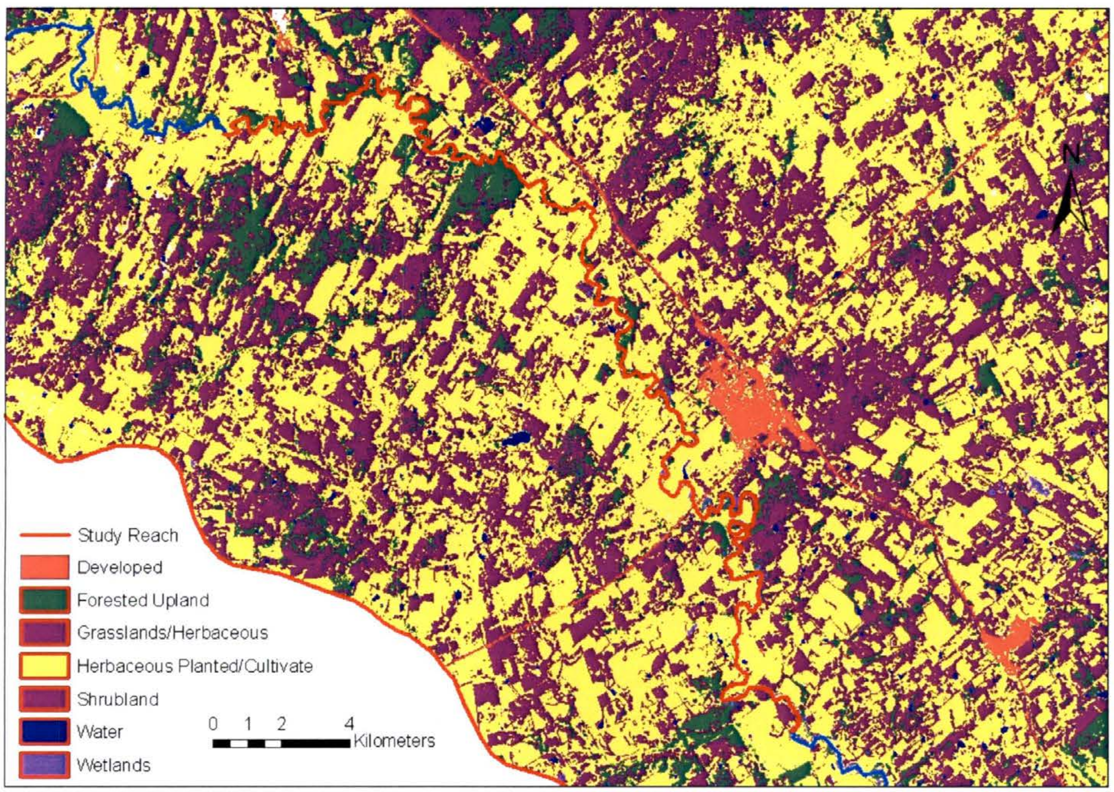

Fig. 6. Study Reach 1992 Land Use. (USGS 2000)

Flow Regime

The flow regime in the study reach is analyzed using data from three USGS gage stations: Elmendorf (08181800), Falls City (08183200), and Goliad (08188500) (Figure 7). The Elmendorf gage is the closest to the study reach. These gages have a period of record extending from 1924 to present. The total contributing drainage area to each station is 4514, 5473, and 10,155km^2 respectively.

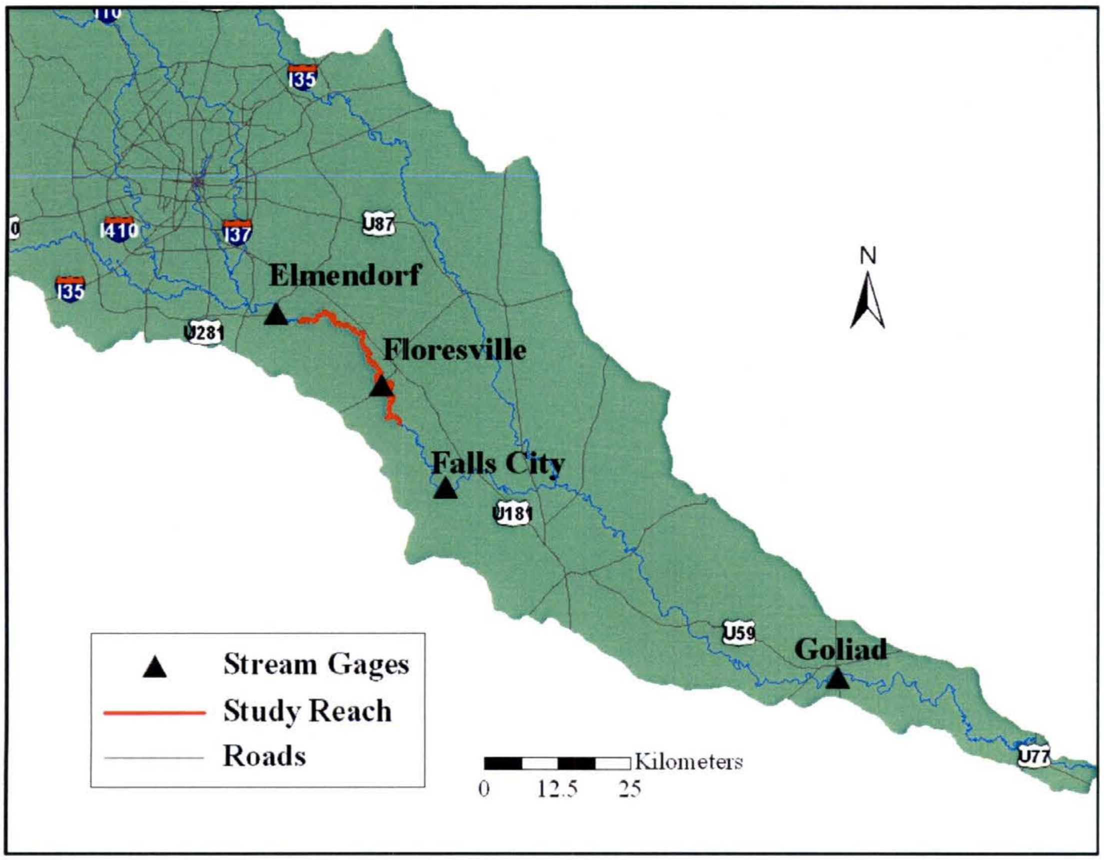

Fig. 7. USGS Stream Gages.

Annual flow in the basin is variable from year to year (Figure 8), yet a trend of increasing flow is apparent from 1955 to present, probably due to increased urbanization. Inter-year variability can be explained by the year to year variable rainfall patterns of central Texas (Earl and Kimmel 1995, 37). Discharge also varies on a monthly time frame (Figure 9). The high flow season is from May through July, and the lowest flows occur in August. River discharge also fluctuates on a daily basis due to inflow from a water treatment plant below San Antonio. For example on November 27, 2006, the discharge varied from around 6.2 to 4.5cms in a 24 hour cycle (USGS 2007).

A flow duration curve is shown for the Elmendorf gage in Figure 10. The 50th percentile flow is 9cms. Figure 11 shows a storm hydrograph for the Elmendorf, Falls City, and Goliad gages. The flood peaks are highest at the beginning of the study reach. As you move downstream along the study reach, the flow regime becomes less flashy. Table 2 shows the flood return periods for the Elmendorf gage.

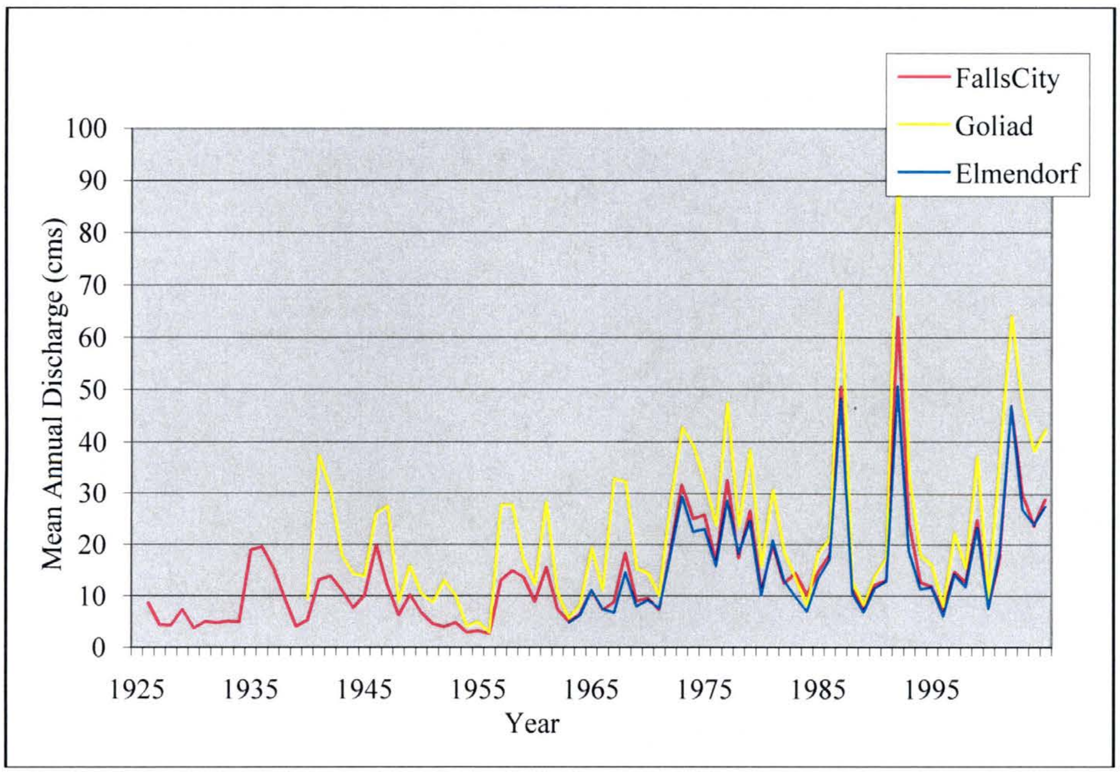

Fig. 8. Annual Discharge (1924 – 2005). Notice the upward trend around the 1970s (USGS 2007).

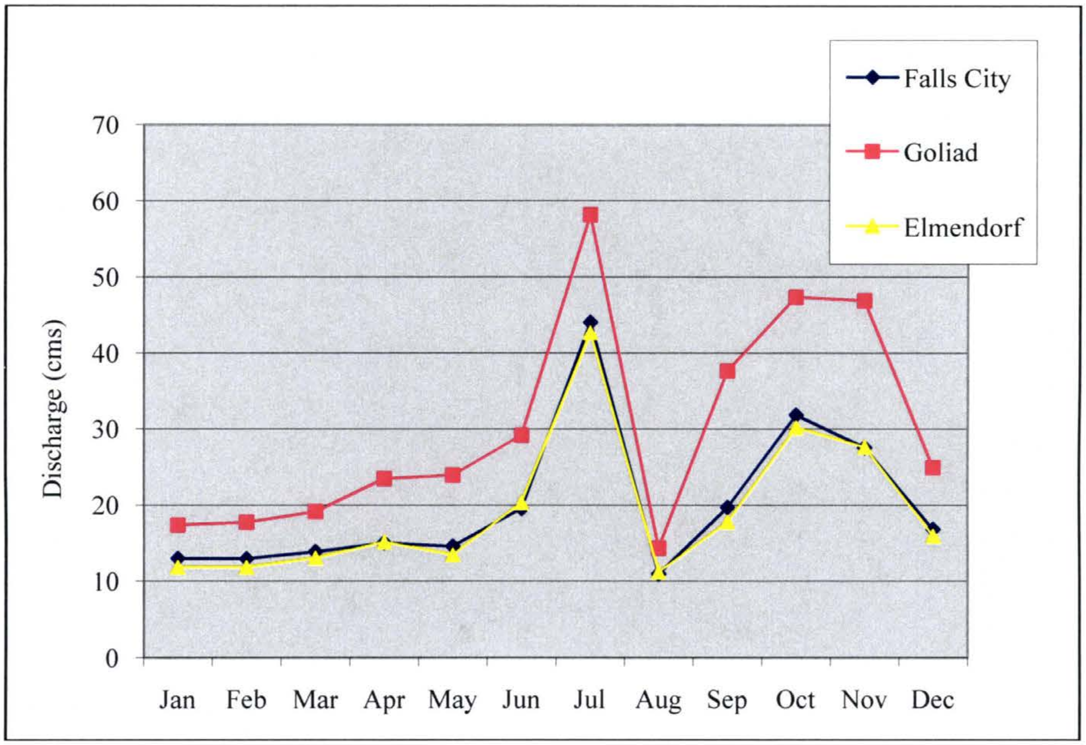

Fig. 9. Mean Monthly Discharge (1965 – 2005). (USGS 2007)

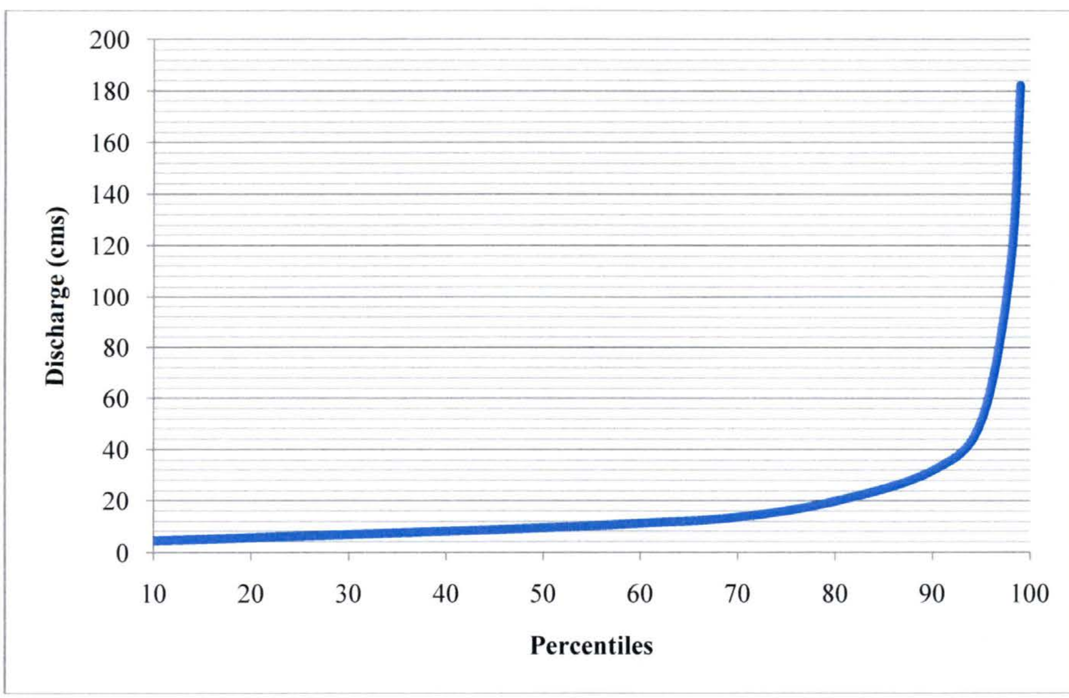

Fig. 10. Flow Duration Curve (Elmendorf). Created from mean daily flow records obtained from the USGS website. Data are from 1995-2004 (USGS 2007).

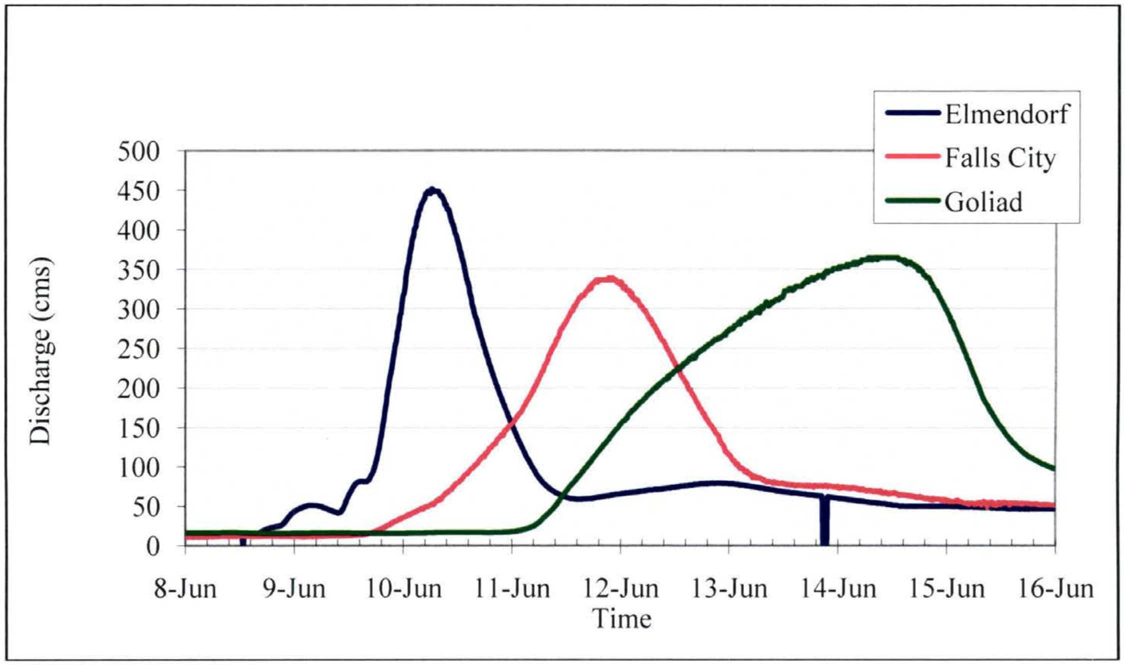

Fig. 11. Storm Hydrograph 6-8-04 to 6-16-04. The flow is flashier in the upper basin than in the lower basin (USGS 2007).

Table 2. Elmendorf Flood Frequency.

Year	Date	Flow (cms)	Rank	Return Period
2004	11/23/04	589	6	7.3
2003	6/10/04	456	12	3.7
2002	10/25/02	430	14	3.1
2001	7/6/02	1920	2	22.0
2000	11/4/00	309	23	1.9
1999	6/11/00	212	29	1.5
1998	10/18/98	2127	1	44.0
1997	8/23/98	204	30	1.5
1996	6/24/97	391	17	2.6
1995	9/15/96	65	42	1.0
1994	6/29/95	251	25	1.8
1993	5/2/94	159	33	1.3
1992	5/6/93	436	13	3.4
1991	5/27/92	586	8	5.5
1990	4/6/91	242	26	1.7
1989	7/16/90	586	7	6.3
1988	6/11/89	120	39	1.1
1987	7/21/88	157	34	1.3
1986	6/1/87	578	9	4.9
1985	6/5/86	1017	4	11.0
1984	10/11/84	297	24	1.8
1983	11/5/83	53	43	1.0
1982	9/19/83	134	38	1.2
1981	10/7/81	219	27	1.6
1980	6/14/81	510	11	4.0
1979	8/11/80	165	32	1.4
1978	6/2/79	365	19	2.3
1977	11/2/77	351	20	2.2
1976	4/20/77	510	10	4.4
1975	5/7/76	320	22	2.0
1974	6/8/75	217	28	1.6
1973	8/8/74	379	18	2.4
1972	9/27/73	1133	3	14.7
1971	5/8/72	346	21	2.1
1970	8/4/71	177	31	1.4
1969	5/27/70	148	36	1.2
1968	8/28/69	91	40	1.1
1967	1/18/68	844	5	8.8
1966	9/22/67	425	16	2.8
1965	10/3/65	142	37	1.2
1964	5/18/65	428	15	2.9
1963	10/24/63	151	35	1.3
1962	2/18/63	83	41	1.1

CHAPTER III

LITERATURE REVIEW

Literature

LWD studies have focused on a range of channel characteristics tied to the presence of LWD. Studies have investigated the influence of LWD on river channel morphology (Robison and Beschta 1990a; Nakamura and Swanson 1993; Montgomery et al. 1995; Abbe and Montgomery 1996; Wallerstein and Thorne 2004). The ecological value of LWD has been studied by Bilby and Likens 1980; Wallace and Benke 1984; Benke et al. 1985; Smock et al.1989; and Malanson and Butler 1990. Others have focused on the dynamics of LWD as simulated in flumes (Young 1991; Braudrick et al. 1997; Braudrick and Grant 2000; Braudrick and Grant 2001).

Many studies have looked at LWD distribution along streams and those factors influencing its distribution and loading in a channel or basin (Keller and Swanson 1979; Marston 1982; Wallace and Benke 1984; Robison and Beschta 1990a; Robison and Beschta 1990b; Gregory, Davis, and Tooth 1993; Nakamura and Swanson 1993; Piegay 1993; Richmond and Fausch 1995; Gippel, Finlayson, and O'Neill 1996; Piegay and Gurnell 1997; Gurnell and Sweet 1998; Piegay, Thévenet, and Citterio 1999; Gurnell et al. 2000a; Gunell et al. 2000b; Hering et al. 2000; Diez, Elosegi, and Pozo 2001;

Martin 2001; Wing and Skaugset 2002; Abbe and Montgomery 2003; Kraft and Warren 2003; Webb and Erskine 2003; Angradi et al. 2004; Koehn, Nicol, and Fairbrother 2004; Wallerstein and Thorne 2004; Pettit et al. 2005; Wyzga and Zawiejska 2005; Comiti et al. 2006). Some studies have assessed LWD stability (Gregory, Gurnell, and Hill 1985; Wallerstein and Thorne 1996; Marcus et al. 2002; Haschenburger and Rice 2004). Beaver dam stability has also been assessed (Butler 1989; Butler and Malanson 2005).

Many of these studies have taken place in North America and Europe. In North America the majority of the research has been conducted in the Pacific Northwest. A few study sites have been located in the New England area, north central U.S., midwest, and the southeast. No log jam frequency, distribution, or stability studies have been undertaken in Texas.

Most studies have looked at LWD distribution within different stream orders or within selected stream reaches within a drainage basin. This has limited the analysis to relatively short river reaches. The study reach with the longest longitudinal distance was conducted on a stream reach of 163km (Marston 1981). A few other particularly long longitudinal distance studies have been conducted by Angradi et al. (2004) 146km, Pettit et al. (2005) 106km, Gregory, Davis, and Tooth (1993) 66km, and Piegay, Thévenet, and Citterio (1999) 60km.

LWD Dynamics

Input

LWD is input into streams due to natural processes. In stable streams, not actively incising or meandering, LWD input can be due to tree mortality, windthrow, or floods (Downs and Simon 2001). In low order, high-gradient mountain streams LWD input can occur during a snow-avalanche event (Malanson and Butler 1990) or massive landslides (Keller and Swanson 1979). In active, lowland streams input is mainly due to bank failures along incising stream reaches and erosion along the outside of meander bends (Wallerstein and Thorne 2004). Input can be from naturally occurring geomorphic processes such as bank erosion or it can be episodic, such as input from a flood or landslide (Bisson et al. 1987). Beavers also contribute to LWD input with their construction of dams and have been shown to influence stream morphology (Butler and Malanson 2005).

Channel evolution models have been developed to describe the development of river systems in the absence of LWD. Schumm and Watson (1984) developed a model that contains five stages of channel evolution (Figure 12). These stages occur along a channel profile downstream from a knickpoint (Watson et al. 1993). In stage one there is a dynamic equilibrium where sediment supply equals sediment transport. Immediately downstream of the knickpoint a stage two reach develops, and the channel incises because of a transport capacity greater than the sediment supply (Watson et al. 1993).

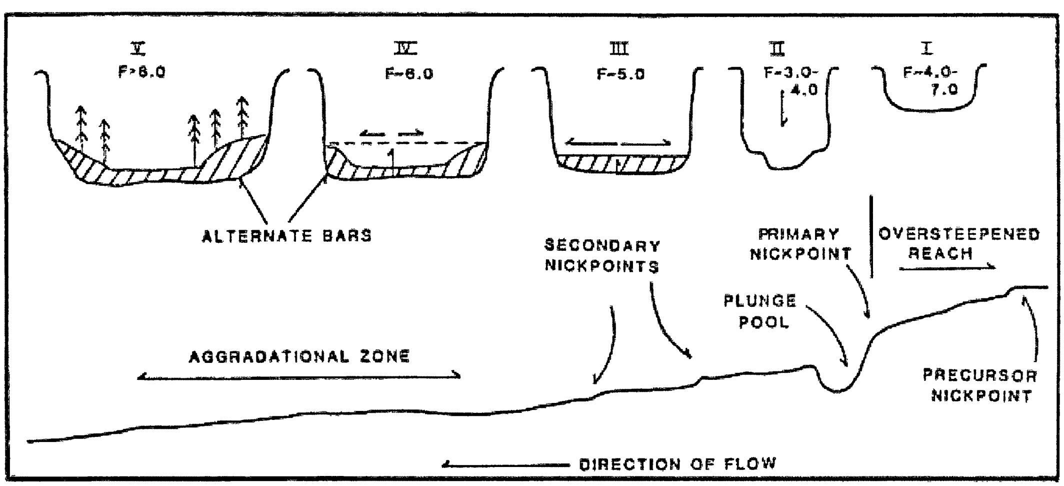

Fig. 12. Channel Evolution Model. (Schumm and Watson 1984)

A stage three reach develops further downstream where the channel starts to widen due to massive bank failures. In stage four the reach begins to aggrade and narrow, as the sediment supply is now greater than the transport capacity. The final downstream reach is in equilibrium and starts to develop riparian vegetation on berms as a consequence of its stability (Watson et al. 1993). Input of LWD would be greatest during Stages 2 and 3 of the (Schumm and Watson 1984) CEM stage model where channel widening and bank instability are active (Wallerstein and Thorne 2004). In stages 4 and 5, LWD input may decrease due to increased bank stability (Wallerstein and Thorne 2004).

Transport

Once wood has been input into the stream, it will either remain in place or be transported downstream. The transport of wood is dependent on its physical properties, the quantity of supplied wood, and stream characteristics (flow regime and morphology) (Gurnell et al. 2002). LWD physical characteristics that influence its transport include wood length, density, orientation relative to main flow direction, diameter, and presence/absence of a rootwad. The two most important parameters are the presence of rootwads and the orientation of the wood relative to flow (Braudrick and Grant 2000). The dominant channel characteristics influencing the ability of the river to transport the wood are water velocity, water depth, and channel slope (Braudrick and Grant 2000). Channels that are deeper, such as incised channels, will have a greater capacity to transport LWD.

The length of the tree bole (trunk) on its own does not play a significant role in determining transport. Rather, the ratio of channel bankfull width to length of the tree bole has a great influence over transport (Montgomery et al. 2003). The larger this ratio, the more likely the LWD is to move through the channel. Wood density also affects the likelihood of transport. Dry wood floats because it has a specific gravity less than water, but saturated wood is more stable because it has an effective density greater than water (Montgomery et al. 2003).

In large rivers, slope and channel type have an influence over LWD dynamics (Gurnell et al. 2002). In large European rivers meandering reaches retain more LWD than braided reaches (Piégay and Gurnell 1997). Low sinuosity and the absence of secondary channels can result in greater transport of LWD through a river because of a lower trapping efficiency (Piégay and Gurnell 1997).

Formation of Log Jams

Log jams form when pieces of LWD accumulate and become racked together (Figure 13). They are usually formed when logs in transport encounter an obstruction and deposit. These obstructions can be trees growing on the bank or in-channel island, sediment bars in the channel, or larger logs in the channel that the channel has trouble moving (Nakamura and Swanson 1993). These larger logs are called ‘key members’ (Abbe and Montgomery 2003). A key member initiates a jam. ‘Racked members’ are smaller logs which become lodged against a key member or another obstruction, and ‘loose members’ fill the interstitial space of a jam (Abbe and Montgomery 2003).

Fig. 13. Log Jam Example. A LWD jam near Elmendorf on the San Antonio River. Jam spans the channel and two 'key members' can be seen.

There are a number of different jam classification schemes. A particularly good classification for jam types was developed by Abbe and Montgomery (2003). Jams where the wood had not moved since it had been deposited in the channel are referred to as autochthonous or in situ jams. Jams where the wood had been transported due to fluvial processes are called allochthonous jams, and jams that contain both in-situ and transported wood are combination jams.

Another classification system developed by Gregory, Davis, and Tooth (1985) separates the jams into classes based on percent channel coverage and geomorphic influence. Active dams form a complete blockage of the channel and cause a local step in the stream profile. Passive dams span and block the channel but do not form a step. Partial dams only partially block the channel.

Wallerstein, Thorne, and Doyle (1997) developed a classification system based on the relationship of the jam to the channel in an incising, sand-bed stream in northern Mississippi. Dam jams create a log step and block sediment movement, deflector jams form pools and bars because of flow deflection, parallel/bar head jams form on the outside of meander bends or at the head of a bar, and underflow jams are where logs suspended above the channel bed cause local scour.

LWD Dynamics Throughout the Drainage Basin

LWD dynamics change across a drainage basin as the main channel increases in wetted area from a narrow headwater channel to a wide coastal plain stream. The distribution of in-channel LWD varies within a drainage basin because of differences along the drainage network in the channel's capacity to redistribute the LWD (Keller and Swanson 1979).

In headwater streams the bankfull width to mean tree height ratio is low. Thus, many of the fallen trees span the entire channel and are stable. This can produce a random distribution of LWD in headwater streams, because the channel size and peak flows are not large enough to transport and redistribute the large fallen trees into jams (Keller and Swanson 1979). As the number of tributaries contributing to the main stem increases downstream, the channel width increases such that this ratio becomes greater than one. Trees are able to be transported and distinct jams are formed that sometimes span the entire channel width (Keller and Swanson 1979). As width increases even farther downstream, so does the channel's transport capacity. Log jams rarely span the channel but build on obstructions and bars in the channel and on the outside of meander bends (Keller and Swanson 1979). Log jam frequency decreases downstream, but log jam size increases (Swanson et al. 1982).

Total LWD concentrations (kg/m^2) have been observed in the Pacific Northwest to decrease downstream (Keller and Swanson 1979). Total concentrations are calculated by dividing the total biomass in a reach by the total channel surface area. LWD concentration is greatest in headwater streams where the channel does not have the capacity to transport the wood, and the LWD often remains in place for many years (Keller and Swanson 1979). LWD concentration decreases downstream because of an increase in the transport of LWD downstream and onto the floodplain as the stream area per unit length increases (Keller and Swanson 1979).

LWD Residence Times

LWD residence time varies with channel size and geographic region. The longer a log remains in one place, the more logs it can collect and the more time it has to influence the channel's flow and morphology (Wallerstein and Thorne 1996). The return period of a flood that is capable of moving a large amount of debris is one of the most important controls on LWD residence time (Wallerstein and Thorne 1996).

Debris jams have been found to remain in one place for greater than 200 years in British Columbia (Keller and Tally 1979). In a small U.K. stream ($11.4 km^2$ basin) Gregory, Gurnell, and Hill (1985) observed a change in the position or character in 16 of 270 dam jams in less than 12 months. The highest recorded discharge during this period was near bankfull ($4.71 m^3 s^{-1}$). Over a one year period in an incised, sand-bed stream drainage system with channel widths ranging from about 11-33m in northern Mississippi, the majority of jams remained stationary (Wallerstein and Thorne 1996).

CHAPTER IV

RESEARCH DESIGN AND METHODS

Focus

The study reach for this project extends along the San Antonio River, from the bridge crossing at Texas CR 125 to the crossing at Texas FM 541 (refer to Figure 1). This reach was chosen because it is highly incised and vertically confined. Confined rivers can have powerful flood flows and a limited ability to transfer LWD onto the floodplain. The reach is in a region that has a high flash-flood potential and is one of the flood-dominated rivers described in the Instream Flows report by the National Research Council (National Research Council 2005, p, 16-18). This means that floods are more significant in forming the channel morphology than baseflow or bankfull flows. Project goals are: first to determine the in-channel log jam distribution, frequency, and spacing along the study reach; second, to assess jam stability and the flows that might move them; third, to characterize and describe the specific jam types found on the San Antonio River.

Variables and Definitions

Log Jams

Log jams are the focus of this research. Thus, only log jams were measured and not individual pieces of LWD. Log jams are defined as a jam that is composed of at least one stable key member or other obstruction holding racked LWD. Some exceptions were taken into account in the field considering the context of a jam. Small jams with an accumulation of small woody debris were not mapped. The main point of this definition was to avoid mapping unstable or relatively small jams, as these are unlikely to exert a significant influence on the channel morphology, but to focus on jams that are likely to affect channel morphology. The jam must be within the active channel area. Log jams on top of banks were not recorded.

Gathering and Analysis of Data

Field Mapping

Fieldwork was conducted between November 2006 and February 2007. Log jams were recorded along the length of the study reach. A GPS was used to record locations along with important attributes (category of jam, estimated percent channel lateral coverage, location in channel cross-section, picture ID number, and any other pertinent comments). Photographs were taken of all recorded log jams. Jam size was recorded in the field. Each jam was assigned to one of four categories: small, medium, large, or huge (Figure 14). This was a subjective assessment and was utilized to give an idea of how jam size might change downstream. A jam's percent lateral coverage and channel cross-sectional location were recorded (Table 3). A jam's percent lateral coverage was assessed as the area of the jam visible from the surface and did not include any submerged logs. Jam type was also recorded in the field (Table 4).

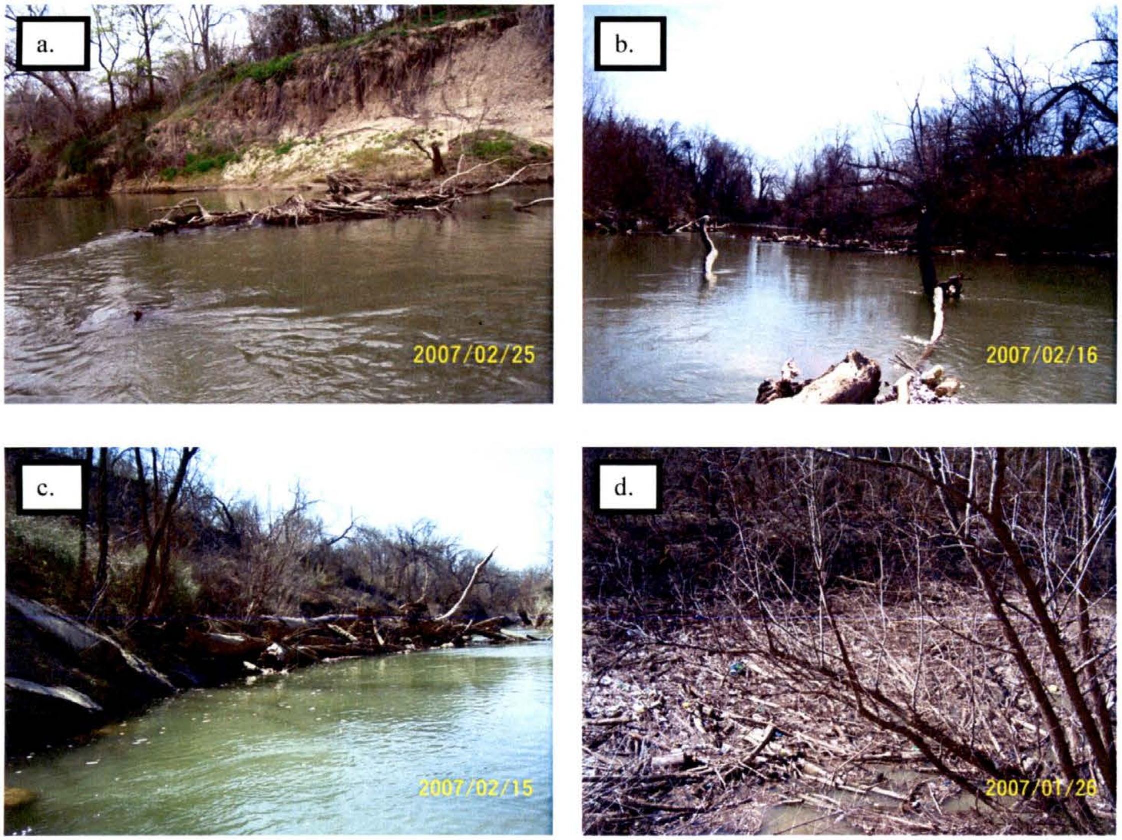

Fig. 14. Jam Size Category Examples. Pictures a-d represent small to huge jams.

Table 3. Lateral Coverage and Channel Location Categories.

Item	Categories
Percent Lateral Coverage	0-5% 5-20% 21-40% 41-60% 61-90% 91-100%
Channel Location	River Left Mid Channel River Right

Table 4. Jam Classification System. Most categories and descriptions used to create classification system are gathered from Gregory, Gurnell, and Hill 1985; Wallerstein, Thorne, and Doyle 1997; and Abbe and Montgomery 2003.

LWD Jam Type	Description
Complete Jam	Key member or members completely span the channel with many racked members
Tree-Fall Jam	A fallen key member with racked members. Fallen key member is on the side of the channel and has not moved since falling into the channel
In-Channel Obstruction Jam	Bar or standing tree within the wetted area is causing the jam
Outside of Meander Bend Jam	Jam located on the outside of meander bend
Other	Other jam type besides the ones described

Jam Distribution

Using the field data, ArcGIS 9.2 was used to calculate jam frequency per kilometer. Average jam spacing was also calculated in ArcGIS by measuring the linear distance between each jam. Simple linear regression relationships were developed between jam frequency and distance downstream, drainage area, and sinuosity. This allowed for visualization and determination of patterns of log jam distribution.

Stability Assessment

Air Photos

Jams present on December 7, 2003 were mapped using 30cm resolution, low-level aerials taken for the San Antonio River Authority (SARA 2004). Jam locations were all visited in the field during fieldwork conducted from November 2006 – February 2007. Jam locations mapped in 2003 were compared to locations mapped in the field. Mean daily flow from the Elmendorf USGS gage was used to assess flows in between December 7, 2003 and November 2006 – February 2007. If any log jams had moved it was assumed to have moved at the highest flow that occurred between 2003 and 2007.

An attempt was made to map log jams using United States Department of Agriculture one meter resolution satellite photos taken in 2004. However, most of the photos were taken during a high flow event, obscuring the majority of the jams. Only one photo was able to be used. This NAIP photo taken June 2, 2004 was used for comparison with a full channel jam observed on an air photo taken December 7, 2003. Flows between the two dates were examined to assess jam stability.

Field Site

A jam site was also monitored in the field at the FM 775 road crossing. A picture was taken of the jam site on March 29, 2007 and the site was revisited on April 13, 2007. The jam moved between the two dates. Flows were assessed between the two dates to determine at what flow the jam moved.

CHAPTER V

RESULTS

LWD Distribution

Figure 15 shows the total jams per kilometer for the study reach. An increase in frequency is apparent at about 34km. Also at 34km is the highest number of jams measured per km. Possible reasons for this cluster of log jams are discussed in the next chapter. Figure 16 shows spacing between jams versus distance downstream. Jam spacing decreases at about 34km downstream. Overall average jam spacing is 412m. Upstream of 33km the average spacing is 635m, and downstream it reduces to 276m. Figure 17 is a map of the study reach displaying the distribution of jams mapped in the field from November 2006 – February 2007. Figures 18 and 19 show jam frequency versus sinuosity and drainage area. There does not appear to be a significant relationship for either one. Figure 20 divides the study reach into two halves and compares the jam size between the two halves. Overall jam size increases with distance downstream. Figure 21 shows the percent lateral coverage of jams and how it changes downstream. Even though the frequency and number of jams increase downstream, many of them cover only 0-20% of the channel. Figure 22 shows the distribution of jam types along the study reach. Bar Jams and Old Bank and Bar Jams were combined to form the In-Channel Obstruction category. This was done because it was often difficult to distinguish between these jam types in the field. A significant increase in In-Channel Obstruction Jams is observed with distance downstream.

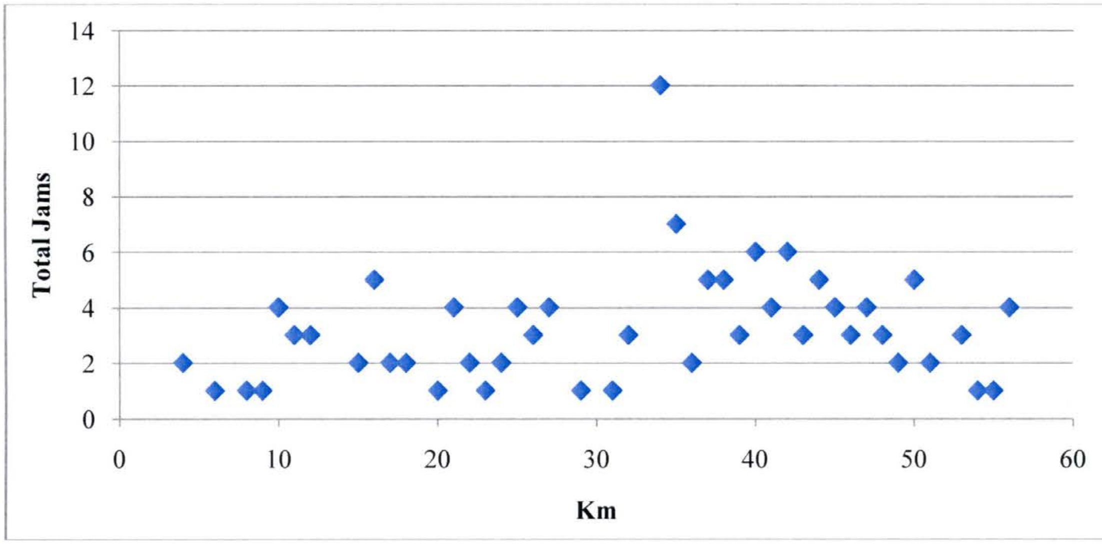

Fig. 15. Jams Per Kilometer. Zero km is the beginning of the study reach, and 56km is the end.

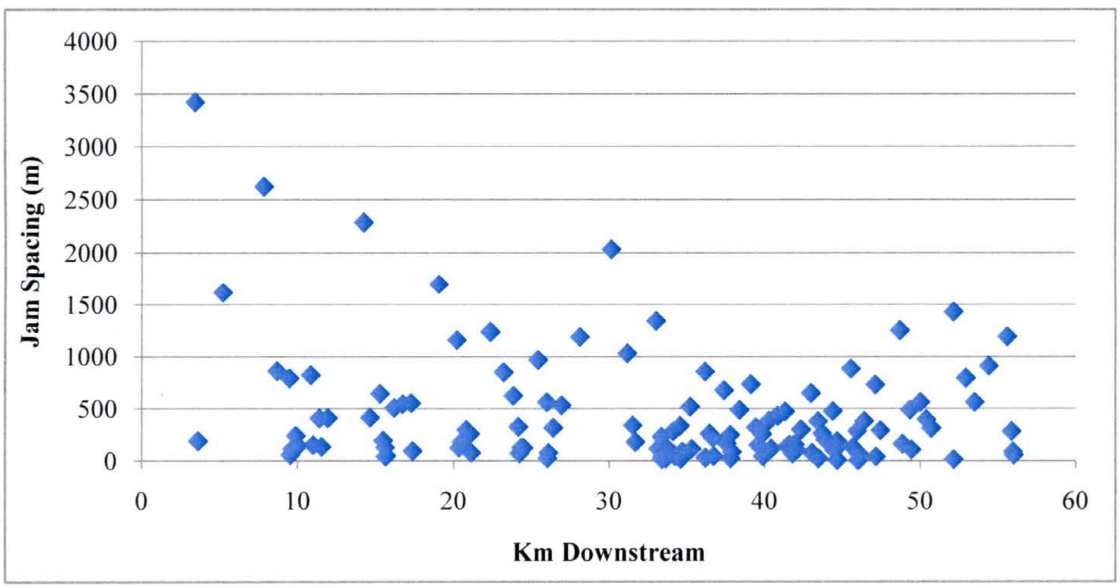

Fig. 16. Jam Spacing. Jam spacing plotted against kilometers downstream. Jam spacing decreases further downstream.

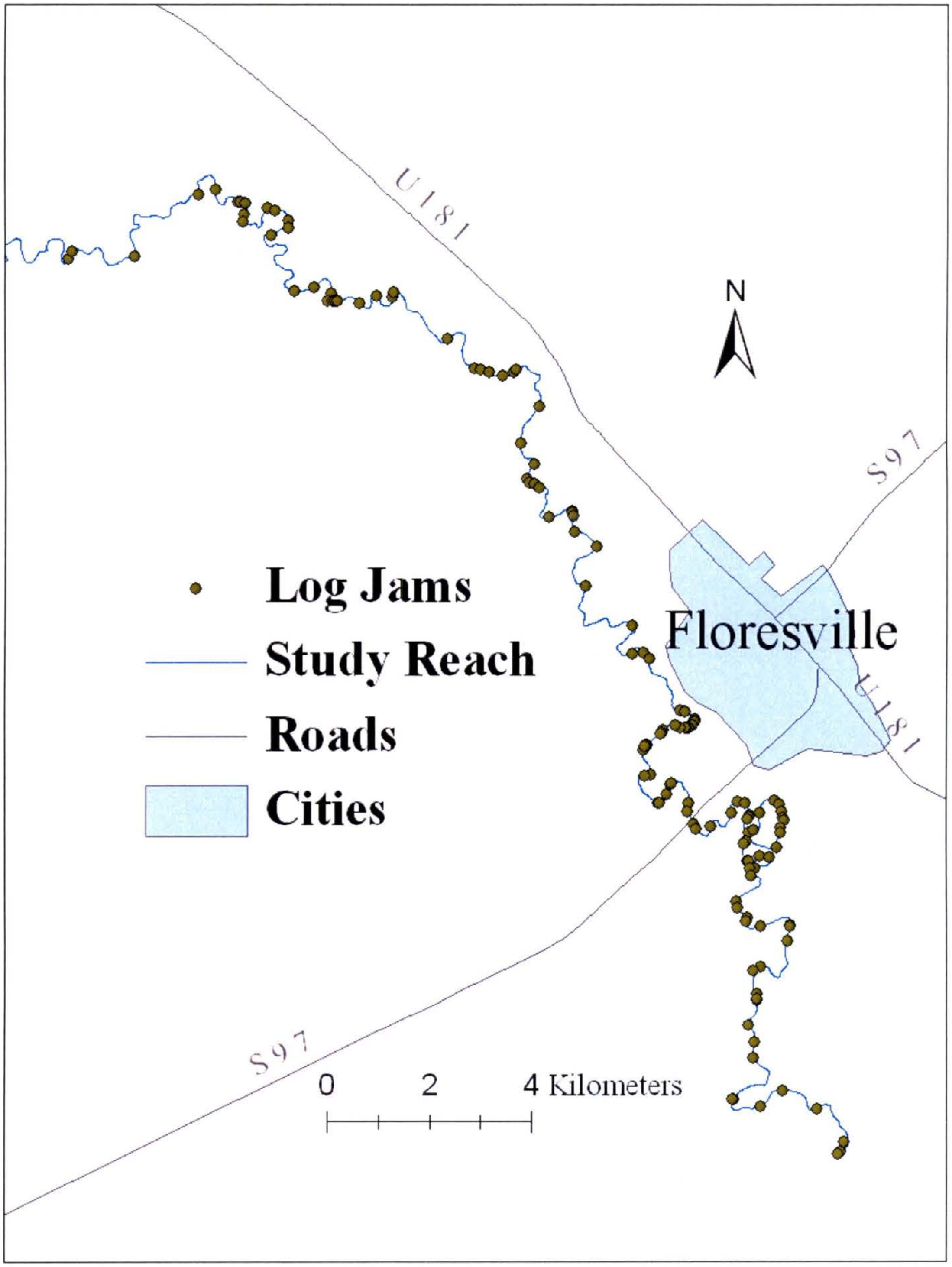

Fig. 17. Field Mapped Log Jams. Log jams mapped in the field from November 2006 – February 2007.

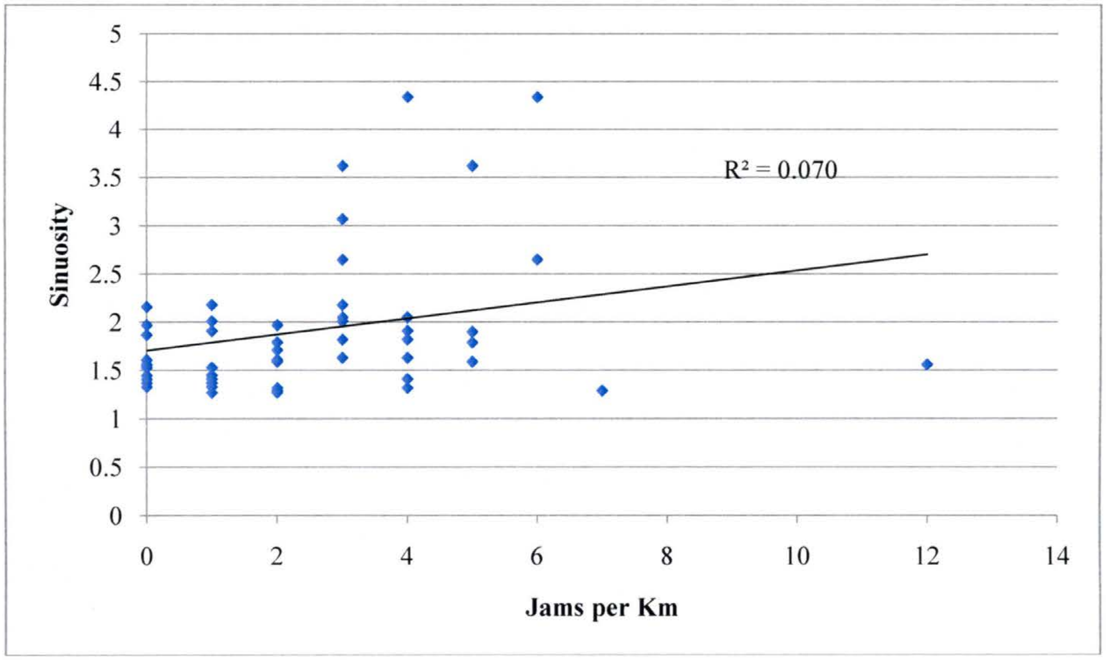

Fig. 18. Jam Frequency Versus Sinuosity.

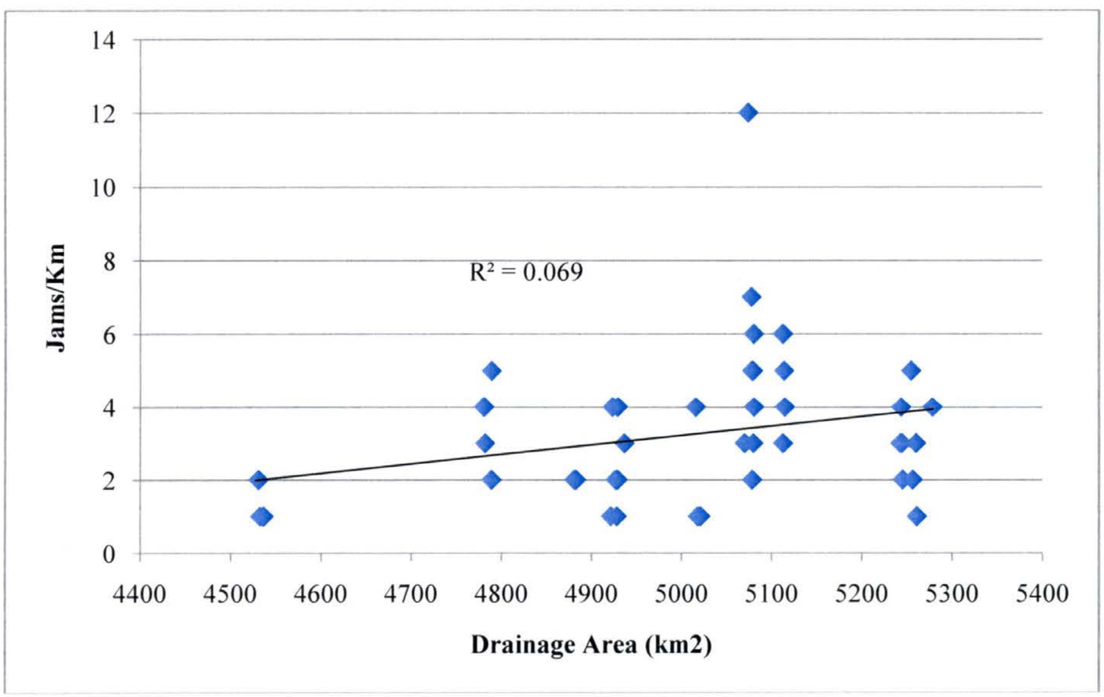

Figure 19. Jam Frequency Versus Drainage Area.

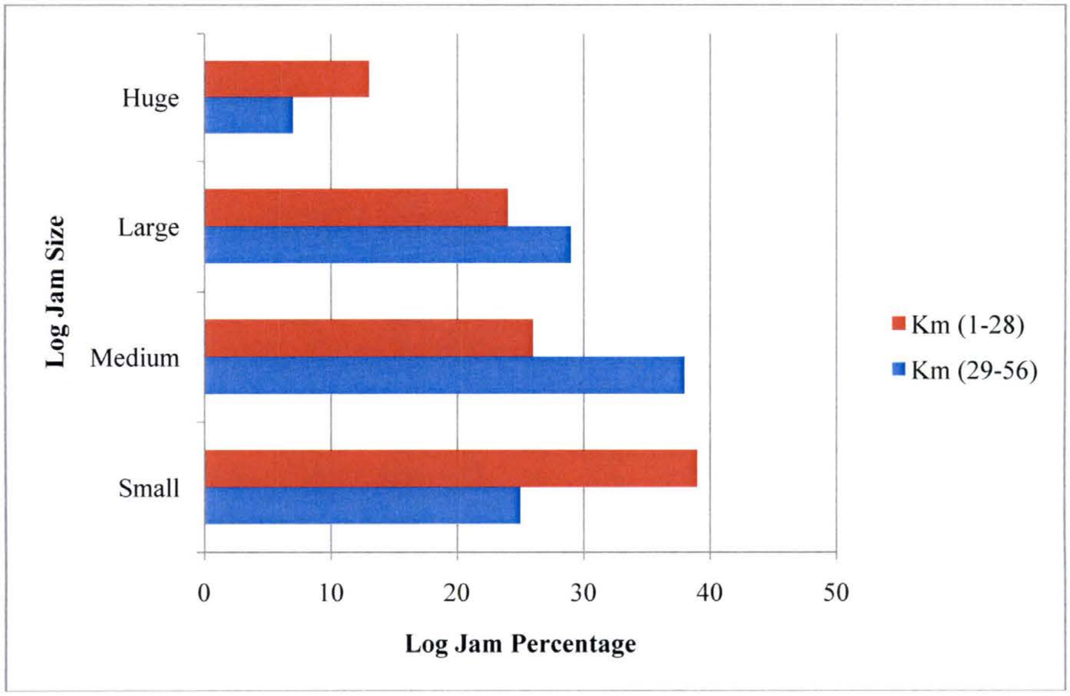

Fig. 20. Jam Size Upstream and Downstream. The study reach was divided halfway into an upstream and a downstream reach. There is an overall increase in jam size downstream.

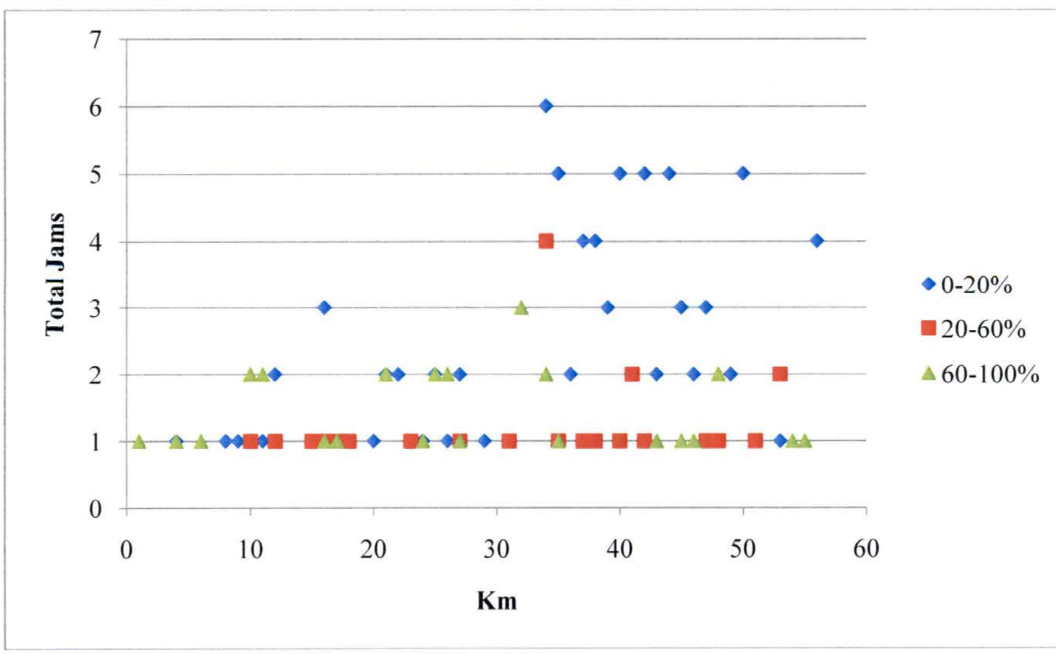

Fig. 21. Percent Lateral Channel Coverage Frequency. Many of the jams downstream cover only 0-20% of the channel.

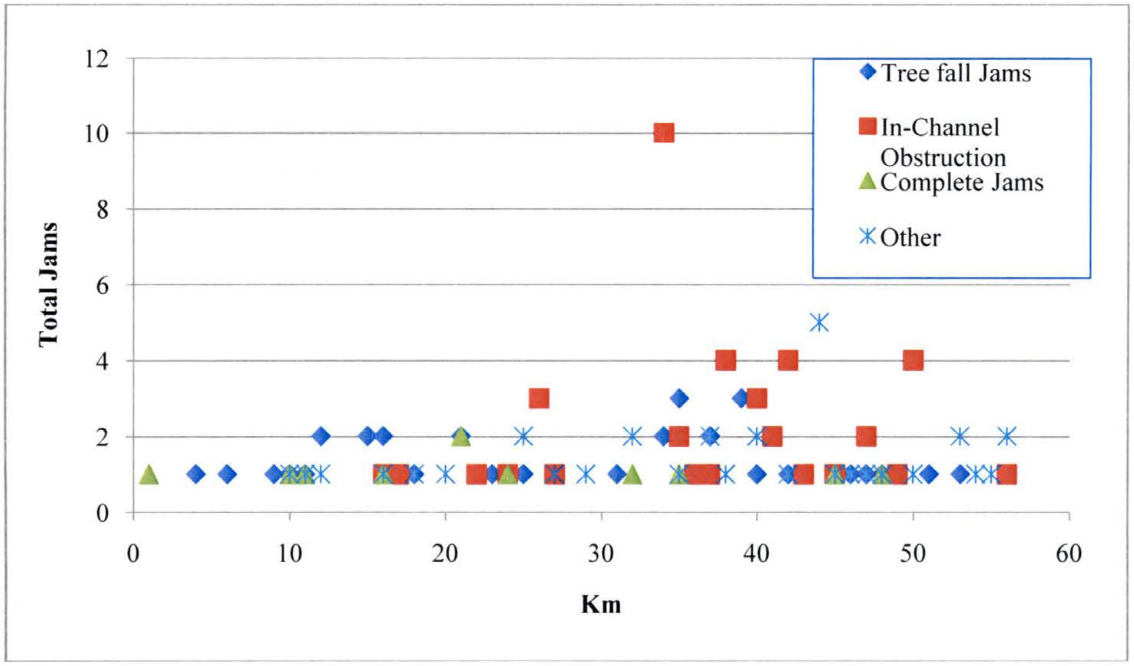

Fig. 22. Jam Type Distribution. In-Channel Obstruction jams form on bars or trees in the water. These jams increase with distance downstream along the study reach.

Jam Stability

Overall Jam Stability

Figure 23 shows the total number of jams that moved compared to those that remained stable between December 7, 2003 and November 2006 – February 2007. Five jams appeared stable but this could not be determined to 100% certainty. This was due to poor jam visibility on the air photos and small jam size. Excluding the five jams where movement could not be determined, 90% of the jams moved and 10% of the jams remained stable.

On December 7, 2003 seven jams completely spanned the channel. All of them moved before fieldwork in November 2006 – February 2007 (Figure 24). Figure 25 is an example of a full channel jam on December 7, 2003 that had moved by January 27, 2007. Peak flow records from this time period were analyzed and it has to be assumed that the jams moved at the highest peak flow event during this period on November 23, 2004 (Figure 26). Figure 27 shows the hydrograph for this flood, which peaked at 589cms.

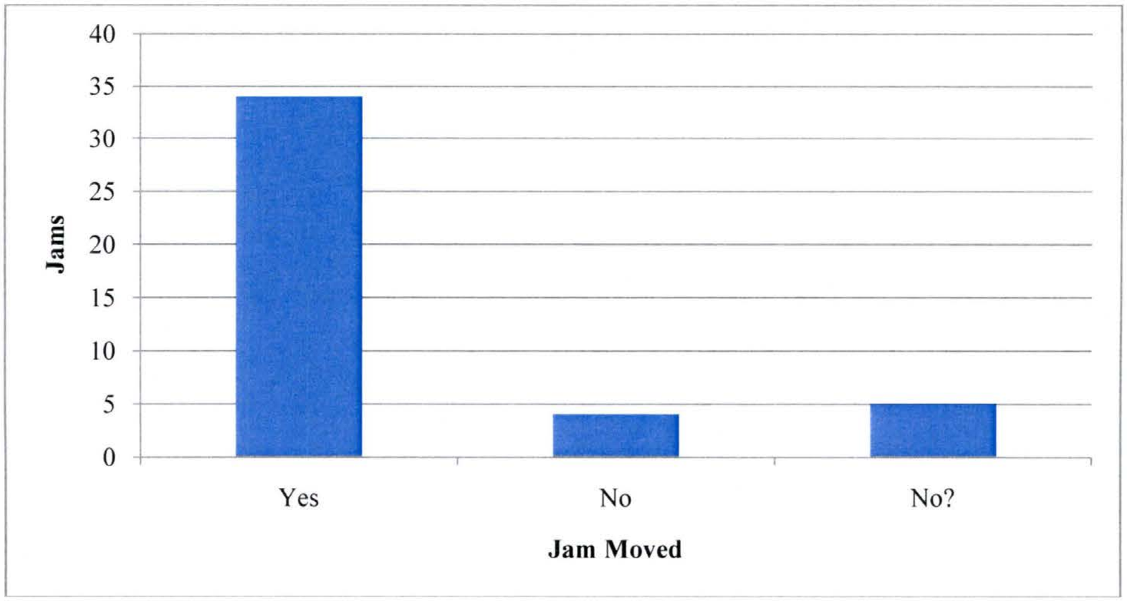

Fig. 23. Jam Stability. (Between December 7, 2003 and February 2007) "Yes" means the jam moved. "No" means the jam did not move. "No?" means that it could not be determined if the jam moved or not.

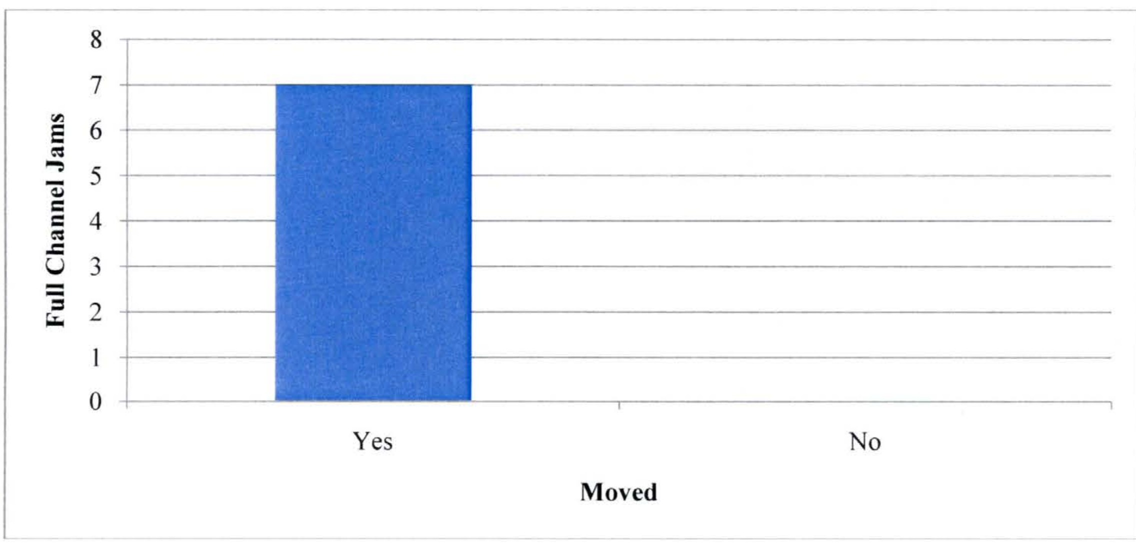

Fig. 24. Full Channel Jam Stability. (Between December 7, 2003 and February 2007) All seven of the full channel jams mapped moved.

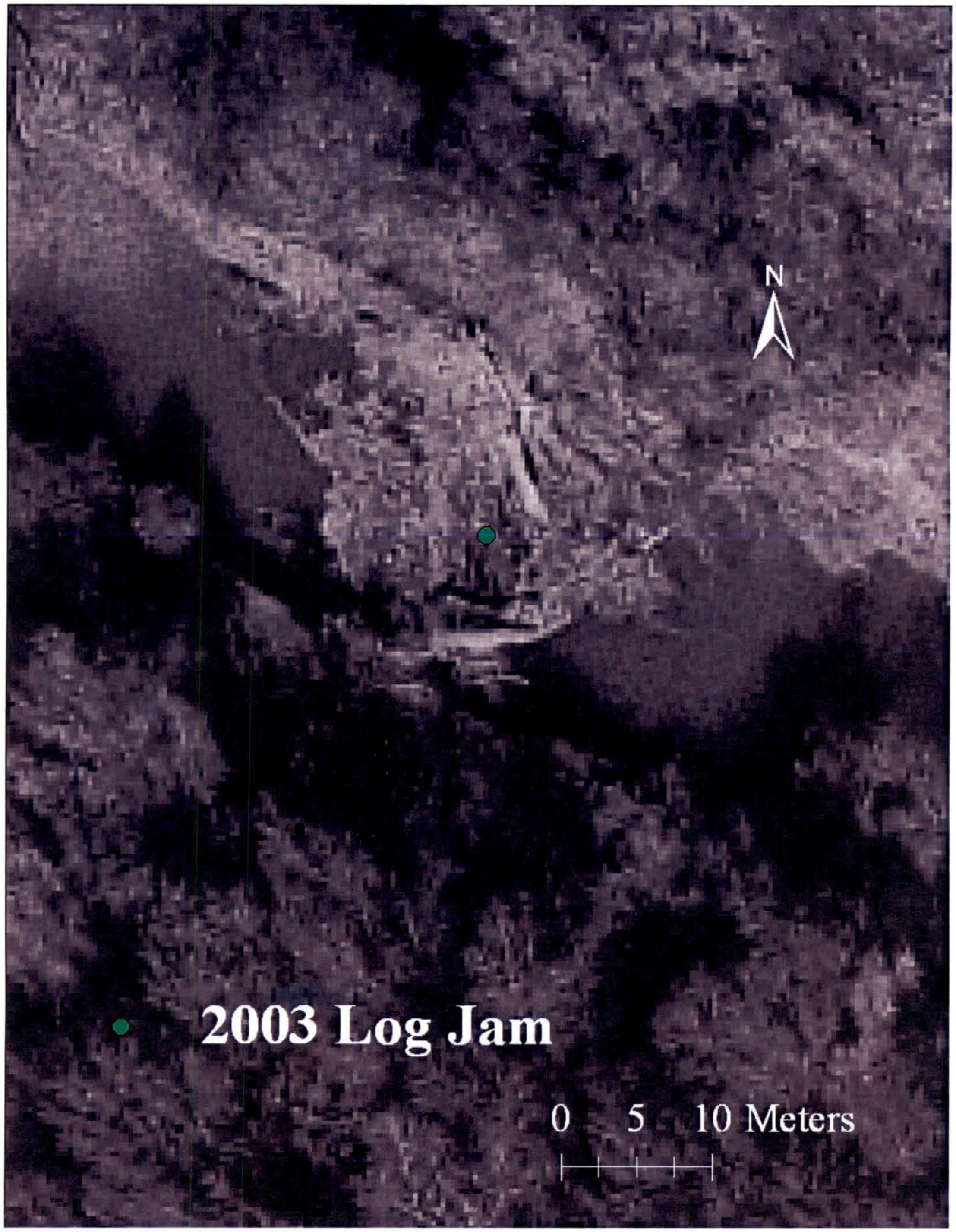

Fig. 25. Jam Stability Assessment Site. (Between December 7, 2003 and January 27, 2007) Full channel log jam mapped on air photo December 7, 2003. The site was visited in the field on January 27, 2007 and the jam was gone.

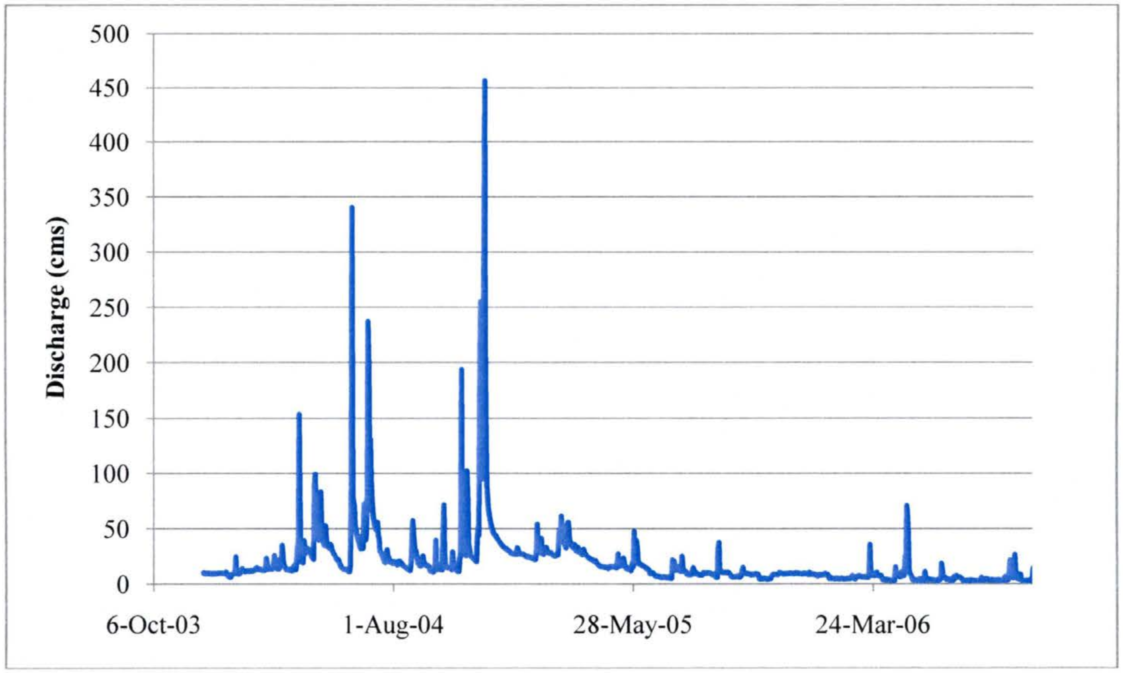

Fig. 26. Mean Daily Stream Flow. (December 7, 2003 – February 26, 2007) Data from the Elmendorf gage are shown. It is necessary to assume the log jams moved at the 456cms mean discharge event on November 23, 2004. (USGS 2007)

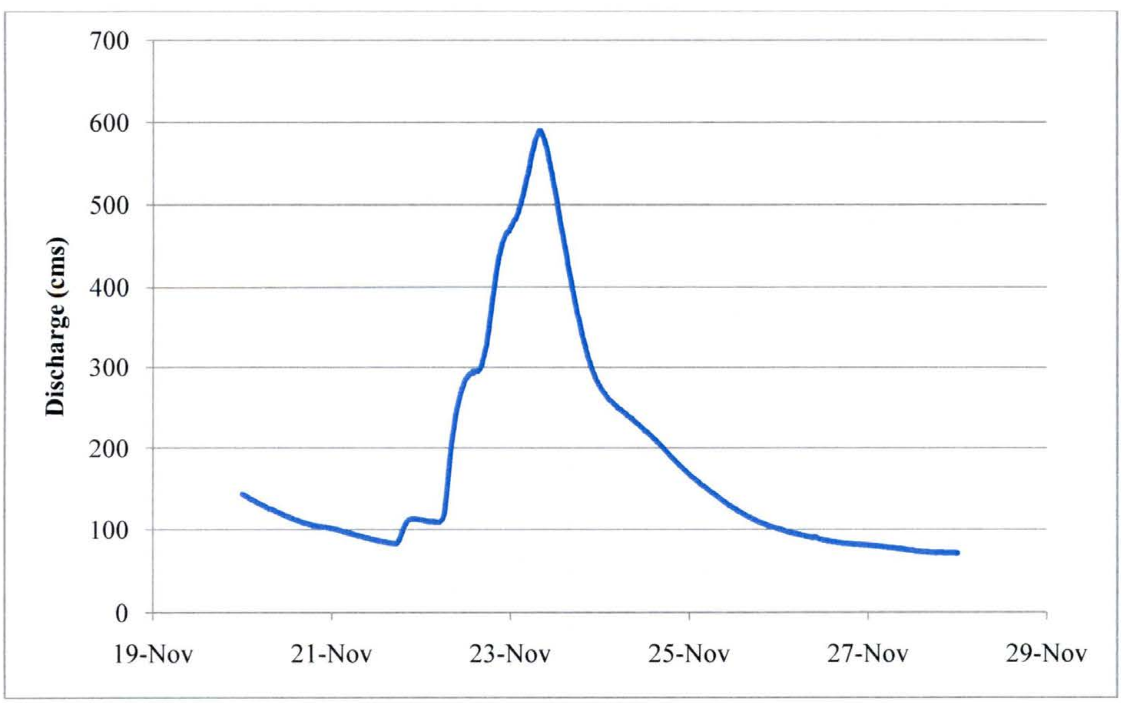

Fig. 27. November 23, 2004 Flood. It is assumed that most of the log jams moved during this flood. The peak was 589cms. (USGS 2007)

Site Specific Jam Stability

Figure 28 shows the log jam field site at the FM 775 road crossing. A full channel jam was observed at this site on March 29, 2007 (Figure 29). The study site was revisited about two weeks later on April 13, 2007 and the jam was gone (Figure 30). The flow record between the two dates was analyzed (Figure 31). A flood of 180cms occurred on April 1, 2007, and the jam probably moved during this flood. The yearly peak flow record for the Elmendorf gage was analyzed (Figure 32), and this flow has a return period of 1.4 years (Refer to Table 2).

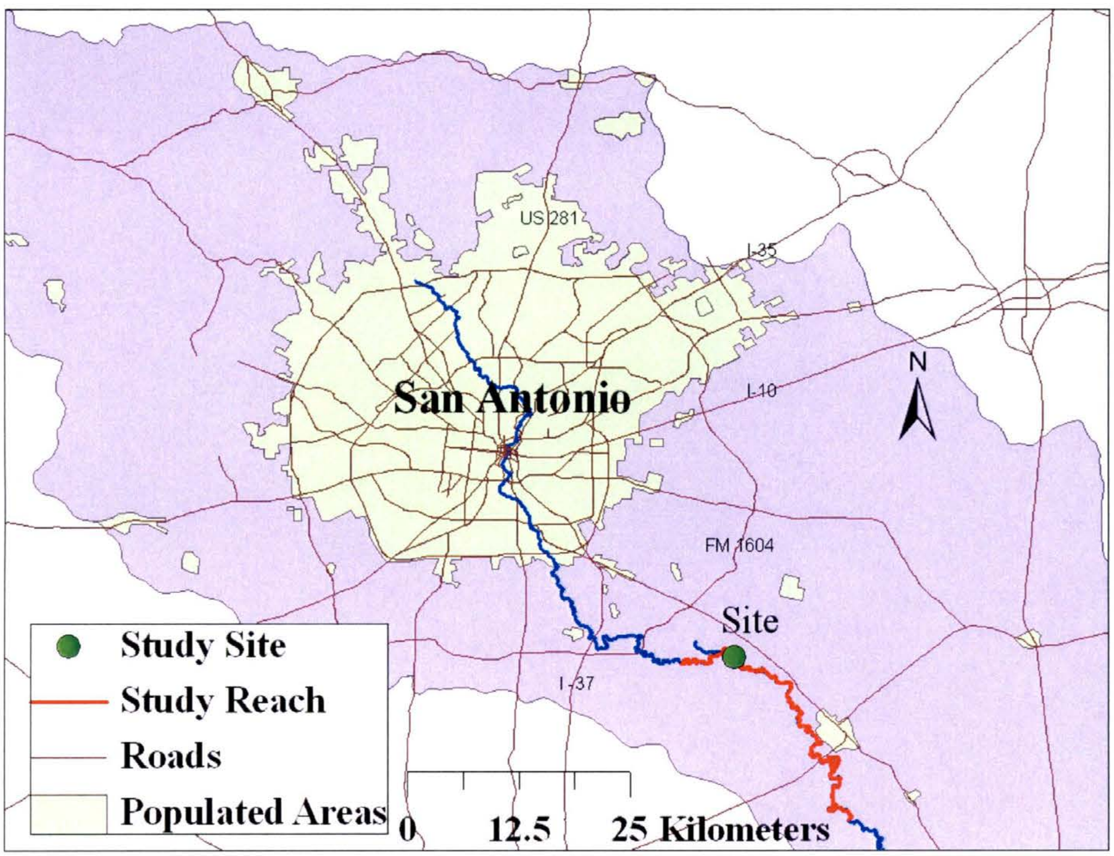

Fig. 28. Log Jam Field Study Site. Site located at FM 775 bridge crossing below San Antonio.

Fig. 29. Field Site March 29, 2007. A full channel jam can be observed.

Fig. 30. Field Site April 13, 2007. The jam was gone.

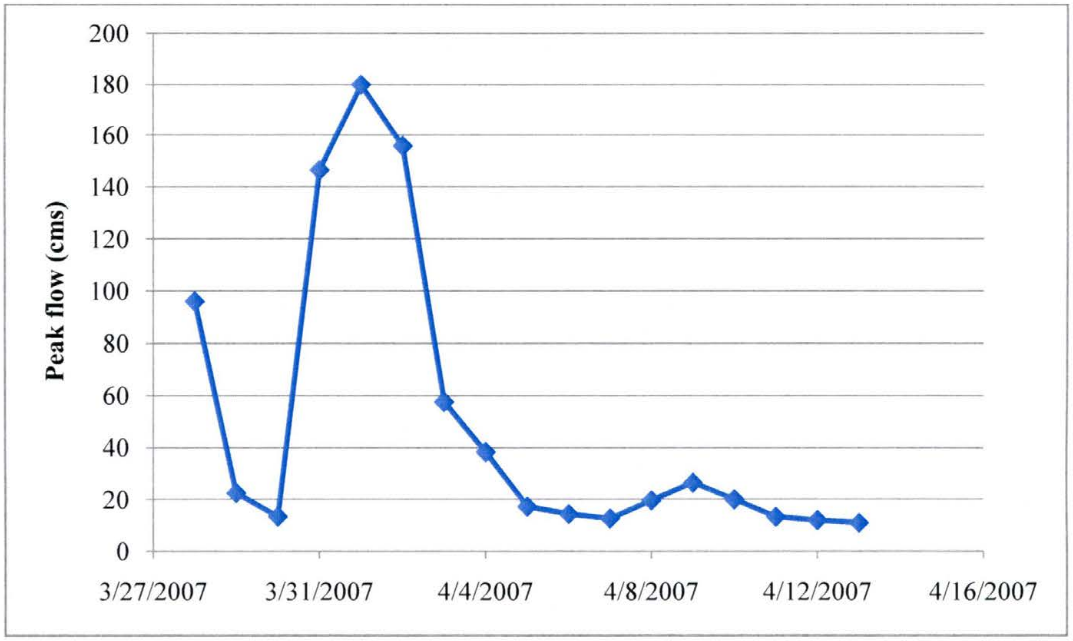

Fig. 31. Site 1 Peak Flows. The flow record between March 29, 2007 and April 13, 2007 at the USGS Floresville gage near the study site (USGS 2007). It has to be assumed that the jam moved at the 180cms event on April 1, 2007.

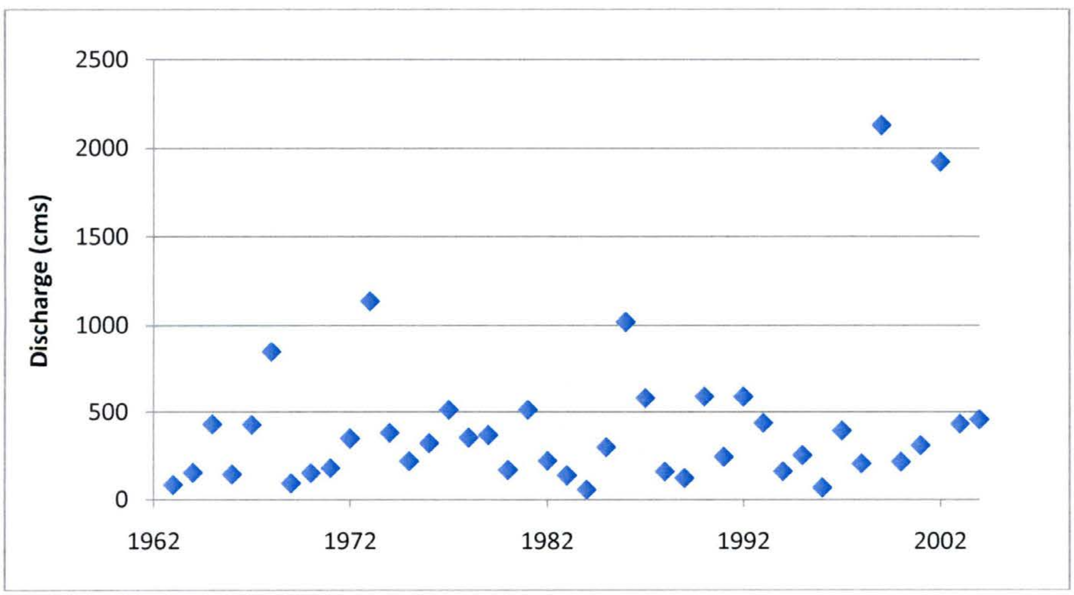

Fig. 32. Elmendorf Peak Flows. 70% of the yearly peak flows between 1962 and 2006 are above 180cms. Since 1997, every year experienced a flow in excess of 180cms with the exception of 2006. The highest possible residence time of a jam could be four years in a drought, but is probably a maximum of 1-2 years.

Site Two Jam Stability Assessment

A full channel jam was mapped on an air photo on December 7, 2003 but was gone on an NAIP air photo taken on June 2, 2004 (Figure 33). The mean stream flow between the two dates is shown in figure 34. The flood hydrograph for the largest flood between the two dates is shown in figure 35. The jam likely moved at 173cms, a peak flow that has a return period of 1.4 years (Refer to Table 2).

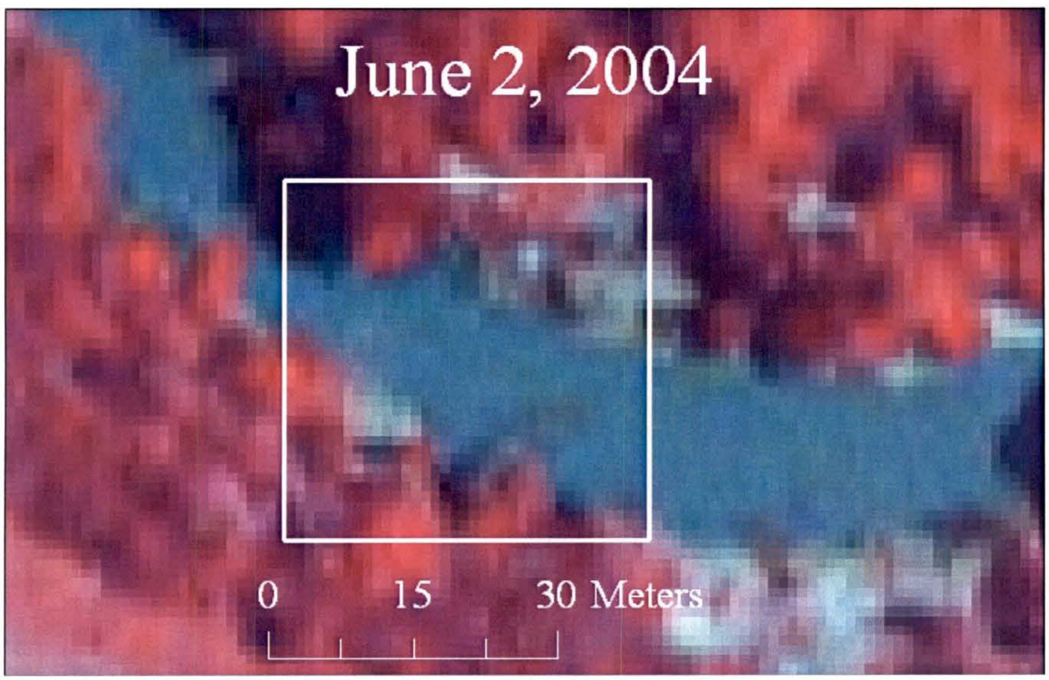

Fig. 33. Log Jam Study Site 2. (December 7, 2003 and June 2, 2004) Log jam mapped on air photo December 7, 2003. The log jam was not visible on a photo June 2, 2004. The average flow for the two dates was 12.7cms and 9.6cms respectively (USGS 2007).

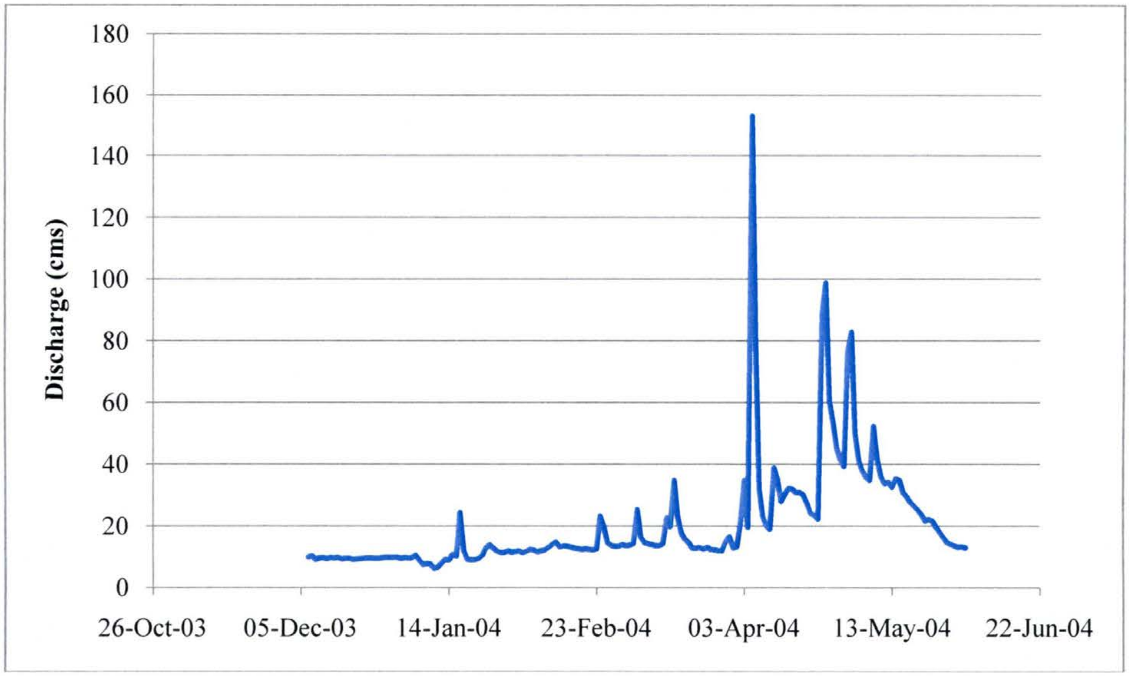

Fig. 34. Elmendorf Mean Stream Flow. (December 7, 2003 – June 2, 2004) It has to be assumed that the jam moved during the largest flow on April 5, 2004. (USGS 2007)

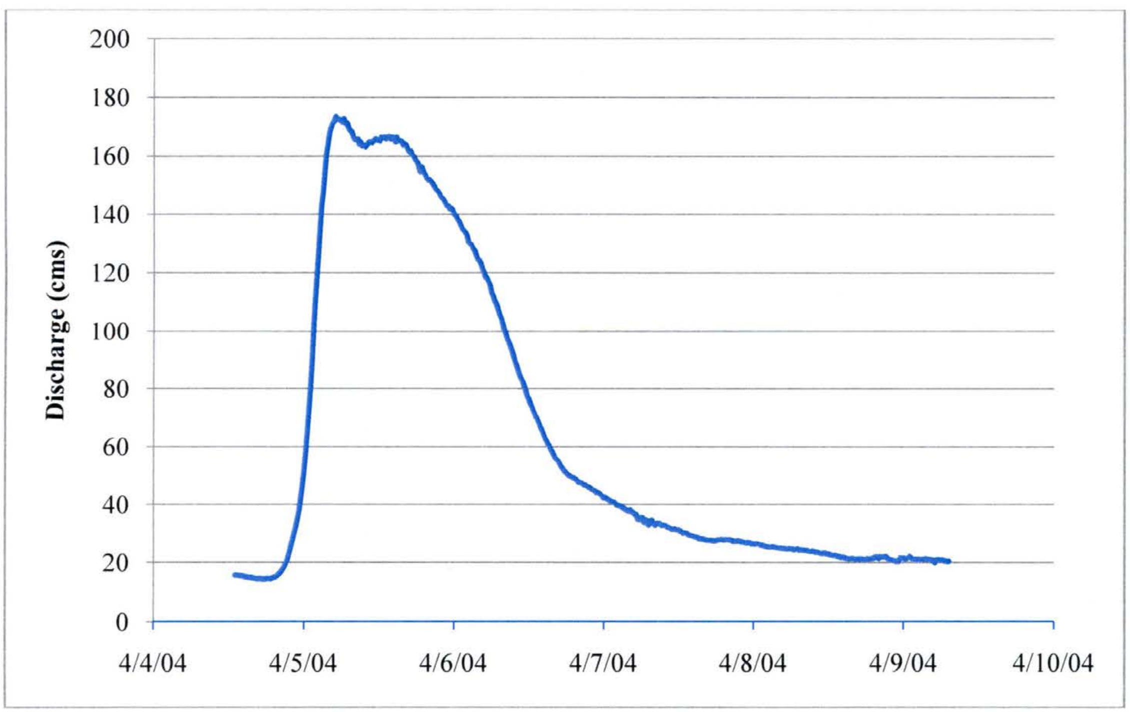

Fig. 35. April 5, 2004 Flood Hydrograph. The flood peak was 173cms. It is assumed that the log jam moved during this flood.(USGS 2007)

Jam Classification

The San Antonio River has a number of different jam types. Table 5 shows the total number of each jam type observed along the study reach. Following the table are descriptions of each of the jam types observed during field mapping.

Table 5. Number of Jam Types Observed.

Jam Type	**Total**	**Percent**
Complete Jam	9	6.3
Tree-Fall Jam	41	28.9
In-Channel Obstruction Jam	45	31.7
Outside of Meander Bend Jam	8	5.6
Other	39	27.5
Total	**142**	**100**

Complete Jams

These jams completely span the channel and are caused by various reasons. Large trees that fall in the river can block the channel, causing other LWD to accumulate on their upstream sides (Figure 35). Logs longer than the channel width can become lodged in between the banks (Figure 36). For 5 out of 9 complete jams, the initiating reason for formation could not be determined (Figure 37). All of the complete jams induce deposition on their upstream sides by blocking the channel and preventing continued flow and transport of LWD downstream.

Fig. 36. Complete Jam 1. A large tree (Notice large rootwad near left bank) fell into the river and has been collecting LWD to form a complete channel jam.

Fig. 37. Complete Jam 2. The key log of the jam is about as wide as the channel and is forcing this jam formation.

Fig. 38. Complete Jam 3. Logs have accumulated and formed a raft. The key member that initiated jam formation could not be identified.

Tree-Fall Jams

Bank erosion is the main mechanism of LWD input along the study reach. Trees fall into the stream and create a depositional location for LWD being transported downstream (Figure 39). LWD accumulates at these jams until a flood capable of transporting or breaching the jam occurs.

Fig. 39. Tree-Fall Jam.

Bank Jams

Bank jams were not mapped in the field because they occur outside the bankfull area. They are formed during floods when in channel LWD is transported out of the channel and encounters trees along the bank. Logs in transport deposit and accumulate at these trees over time and build to form a jam (Figure 40). This jam is active only during high flows.

Fig. 40. Bank Jam.

In-Channel Obstruction Jams

There are two sub-categories within this category: Old Bank and Bar Jams and Bar Jams.

Old Bank and Bar Jams

The flow of the San Antonio River has significantly increased over the years (Figure 41) with the 30th and 50th percentile flows almost doubling since the 50s and 60s (Figure 42). During fieldwork trees were observed whose lower trunks were submerged and surrounded by water during normal river flows (Figure 43). These trees probably grew along the edge of a channel bank that has since been drowned as mean flows in the river increased over the past 50 years. These trees can block the transport of entrained LWD and initiate jam formation (Figure 44). These types of jams were observed to be more numerous in the downstream portion of the study reach.

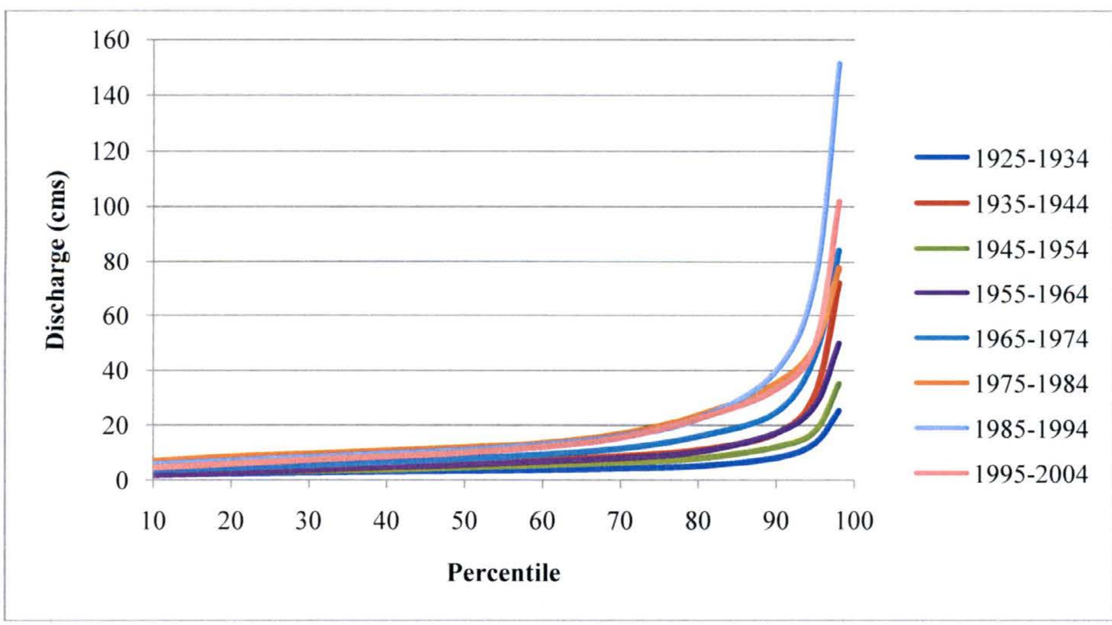

Fig. 41. Flow Duration Curve by Decade. The flow of the San Antonio River has significantly increased since the 1960s. The Falls City gage was used for analysis (USGS 2007).

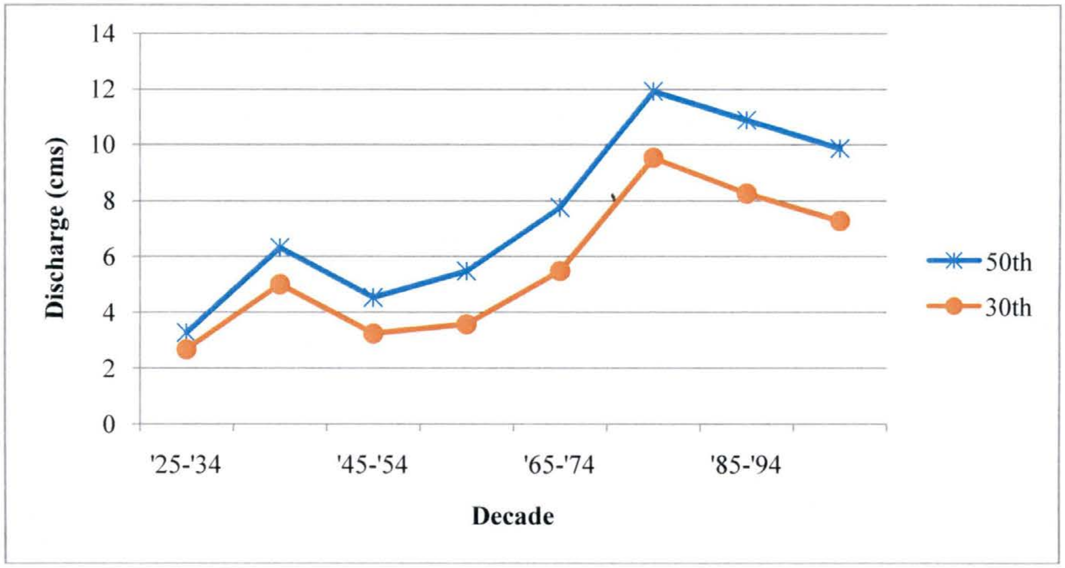

Fig. 42. 50th and 30th Percentile Flows. The 50th percentile has nearly doubled since the 50s and 60s (USGS 2007).

Fig. 43. Submerged Tree Base. The flow was approximately 7cms for this day. This is about a 30th percentile flow. The tree grew during a time when the river's normal flow was significantly less.

Fig. 44. Old Bank Jam. Notice old trees that probably used to be the edge of the bank.

Bar Jams

Log jams were observed on both mid-channel and side-channel bars (Figures 45, 46, and 47). Bars provide an in-channel obstruction that can collect LWD over time during high flows. This is especially the case when the bar is vegetated. Bars, particularly vegetated bars or islands, provide stable sites where jams can reoccur over time.

Fig. 45. Bar Jam 1. Vegetation on a mid-channel bar initiates jam formation.

Fig. 46. Bar Jam 2. Mid-channel bar causing a jam.

Fig. 47. Bar Jam 3. Side-channel bar causing jam.

Bridge Jams

Only one major bridge jam occurs in the river reach (Figure 48). The FM 117 Bridge is low and does not have the clearance necessary for wood to transport downstream. This jam is stable in its location at the bridge and thus probably has a significant impact on the channel. It is periodically removed, but each time a new jam forms at the same location.

Fig. 48. Bridge Jam. A large jam at the FM 117 Bridge. The bridge blocks the channel and the transport of LWD downstream. The jam is removed and reforms every few years.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

Log Jam Distribution

The frequency and distribution of log jams in the study reach were analyzed for any relationship to channel morphology parameters. Log jam frequency versus sinuosity has a low R^2 value of 0.07. It must be concluded because of the weak relationship that sinuosity does not have a significant impact on log jam distribution when examining the entire channel reach. However, there appears to be a localized sinuosity influence because there are seven one kilometer segments (The study reach was divided into 1 km segments. There are a total of 56 segments within the study reach.) that have calculated sinuosity values greater than 2.5 and each has no less than 3 jams. Log jams were periodically observed at the outside of meander bends due to LWD deposition where the channel margin was encountered. Of all the 1 km segments, 53% had fewer than 3 jams within them.

Log jam frequency did not show a significant relationship with drainage area. The drainage area increase was slight (4527-5278km^2) along the study reach. Two large tributaries increased the drainage area by 244 and 128km^2 at 10 and 46 kilometers downstream respectively. The significant increase in jam frequency that was observed at river km 32 occurs following the confluence of the Seguin Branch tributary with the main river. The drainage area increases by about 49km^2 with this confluence. A portion of the city of Floresville is within the Seguin Branches drainage area. It is hypothesized that increasing flows due to urbanization in Floresville increase total LWD input. Log jam frequency increased downstream while spacing decreased. However, log jam size increased. This agrees with hypotheses that jam size increases with increasing drainage area and channel transport capacity (Swanson et al. 1982). Larger flows can transport larger and more wood, thus inducing greater jam size. However, it is not in agreement with the idea that log jam spacing increases downstream (Swanson et al. 1982). An increase in spacing would be the result of greater LWD transport distances, and this was not observed on the San Antonio River.

Log jam types were shown to be variable. Full Channel jams were observed to be fairly evenly distributed along the study reach. In-Channel Obstruction jams increased after about the 35km mark. This was also noted in both the field and on the aerial photos. Many of these In-Channel Obstruction Jams are the result of LWD accumulations at standing trees now within the channel wetted area. There are two important things to note when assessing jam distribution. First, the jam spacing decreased from an average of 621m/jam to 286m/jam after about 33 kilometers downstream. One possible factor causing this increase is that the tributary Lodi Branch inputs into the San Antonio River directly upstream of this location. Lodi Branch is channelized and flows through parts of Floresville (Figure 49). It is reasonable to assume that larger and faster peak flows due to urbanization have possibly increased LWD supply from the surrounding area. Second, the FM 117 bridge crossing (Figure 49) is low and effectively blocks most wood from transporting downstream (Figure 49). There is a recurring jam at this bridge that is cleaned out every few years by the San Antonio River Authority. This jam dramatically decreases the supply of wood to the reach of river downstream of the bridge. The first significant increase in jams occurs directly downstream of the confluence of the Seguin Branch and Lodi Branch tributaries with the San Antonio River.

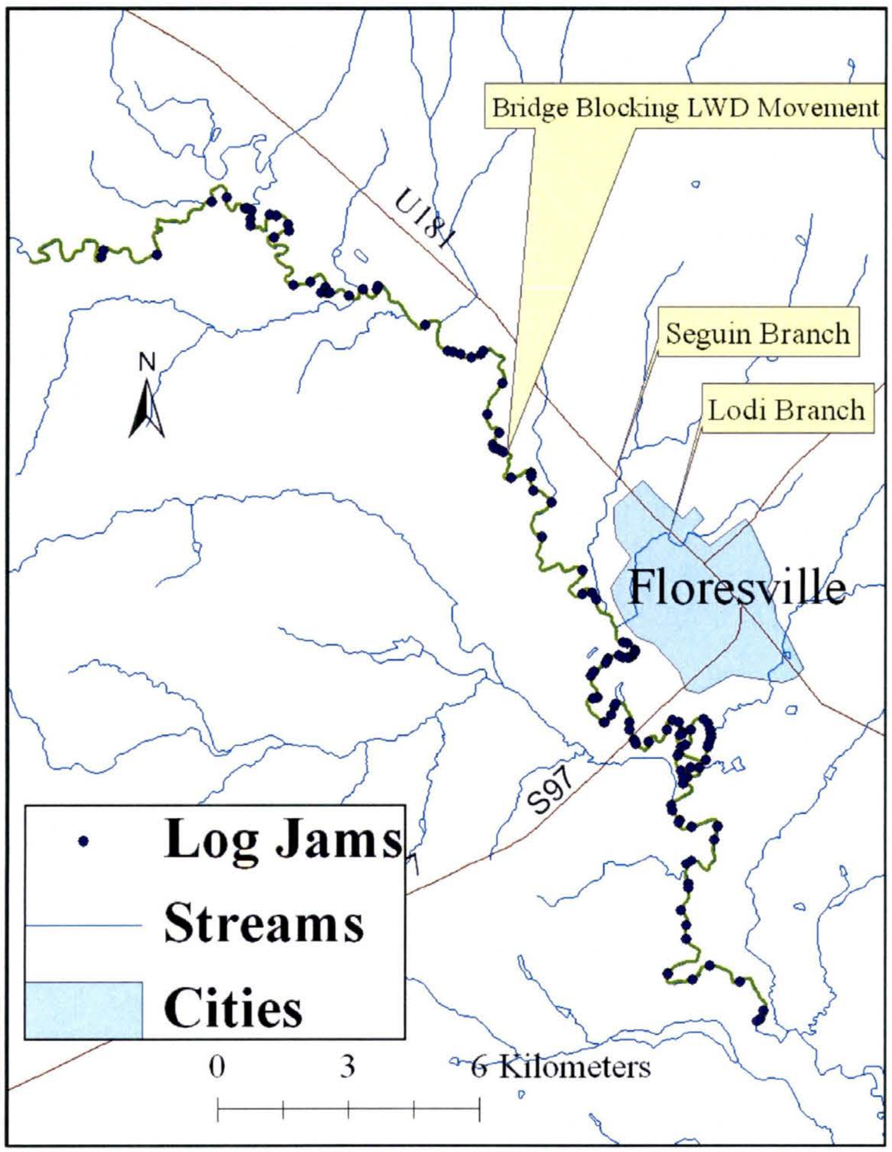

Fig. 49. Factors Affecting Jam Distribution. Notice the greater frequency of jams directly after Lodi Branch joins the San Antonio River. The 117 bridge provides an effective barrier to LWD movement downstream.

Jam Stability

Jam stability appears to be very low. Most of the jams mapped from 2003 aerial photos had moved prior to fieldwork, and the highest discharge between December 7, 2003 and February 2007 was 589cms. This peak flow has a return period of 7.3 years (Refer to Table 2). The full channel log jam at the field site studied (at river km 11) moved within approximately two weeks of first observance. The highest discharge during this period was 180cms. This peak flow has a return period of 1.4 years (Refer to Table 2). From analysis of aerial photo pairs, a second full channel jam is shown to have moved at 173cms between December 7, 2003 and June 2, 2004.

High jam mobility is related to the incised nature of the San Antonio River which promotes frequent deep, confined flows with the potential to transport wood. Confined channels typically have high stream power. Discharge increases lead to velocity increases and deeper flows. Wood stability has been directly correlated with a stream's connectivity with the floodplain and in-channel islands (Gurnell et al. 2002). Absence of a connection, such as in an incised channel, causes LWD stability to be decreased as the retention of individual pieces of LWD is reduced.

Log jam influence on channel morphology along the study reach is considered minimal because of the high degree of LWD mobility. However, there are anomalies where bridges block large amounts of LWD and create permanent deposition sites. Also, large individual logs probably cause small localized deposition and scour. A few other jams were shown to be stable over time.

Comparison to Other Studies

The average overall spacing of 412m per jam is large compared to other studies. However, many of these studies have been conducted on streams with smaller widths and drainage areas than the San Antonio River. Trees in the old growth forests of the Pacific Northwest (where many studies have taken place) are much larger than trees along the San Antonio River. This decreases the ability of Pacific Northwest streams to transport LWD jams. The large spacing in the San Antonio River could be attributed to channel incision and flows with high stream power capable of transporting LWD long distances.

Most of the large jams in the San Antonio River were shown to be highly mobile. This high mobility is in contrast to other log jam studies, especially in the Pacific Northwest. In the Pacific Northwest jams have been shown to be stable for years (Abbe and Montgomery 2003). However, once again many of these studies have been conducted on smaller streams and in old growth forests.

Jam Types

There are specific, recurring jam types that develop along the study reach. These types are Old Bank and Bar, Bar, Tree-Fall, Complete, and Bank Jams. Not every jam could be put into a category because of the variation inherent in nature. The majority of the jams are similar to other general jam types documented in previous LWD research. One jam type that was not described by the literature, but was present on the San Antonio River was the Old Bank and Bar Jams. Field evidence on the San Antonio River suggests that when a river experiences a continued increase of mean daily flow, the wetted width of the channel associated with mean flow will increase. Trees that formerly lined the channel banks will remain but with their lower trunks submerged. The trees remain standing and have the ability to initiate jam formation. The frequency of In-Channel Obstruction Jams increased with distance downstream. This is because both the number of trees within the channel wetted perimeter and the number of in-channel sediment bars increased. Tree-Fall and Complete Jams were fairly uniformly distributed throughout the study reach.

Management Implications

LWD jams are shown to be highly mobile within the study reach. Because of the high mobility and unpredictability of jam locations, removal can be troublesome. Stable jams observed to cause flooding and channel widening should be removed, along with jams forming at bridges. Jam locations which are the most predictable, reoccur the most, and probably the most stable are where in-channel trees and bars occur. They provide a stable obstruction through time. If removed, these jams are likely to re-form. Given the benefits of LWD jams to riverine ecosystems and the high mobility of wood in the San Antonio River, consideration should be given to allow in-channel LWD and jams to remain in place unless proven to be stable over time.

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