The Spatial Distribution and Abundance of Submergent Aquatic Macrophytes in the Backwaters of a Braided River Floodplain Platte River, Nebraska

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Abstract

The purpose of this study is to ascertain the effects of hydrological variation on the distribution and abundance of submerged aquatic macrophytes in backwaters of the Central Platte River, Nebraska. Pre-established wells were measured biweekly for four months revealing trends in overall water level and surface flow of specific backwaters. Indicators of Hydrologic Alteration (IHA – Richter *et al.*, 1996) were applied as a framework to test for the importance of biologically-significant parameters in controlling the macrophytes' presence and success within the backwaters. Macrophytes were sampled every metre along linear transects spaced five to fifteen metres around well sites. Species composition (grams), average biomass and total number of species were calculated for each of the sites and evaluated in relation to the IHA parameters.

Correlation analysis suggested that there was a lack of species association with the presence/absence of one species not affecting the presence of another species. This may be due to the fact that competition and coexistence between macrophyte species was limited. High external water levels on a seven-day scale may correlate strongly with both *Z.palustris* and *C.demersum* because they are shade-tolerant and can survive lower light availability at increased depths. An increase in the duration of high pulses of surface flow may dissipate the velocity of the water over time and encourage species like *C.demersum* and *Z.palusrtis,* which are more weakly rooted and less tolerant to flooding. The increase in biomass with longer durations of high surface flow may also be attributed to a reduction of this stressful velocity. The average spring surface flow is thought to correlate with an increase in the abundance of *Chara* and *P.pectinatus* because both species can tolerate disturbance and it may be beneficial in constantly supplying nutrients to these species. These nutrients may also be the cause of average biomass increases with increased average spring surface flow. *P.pectinatus* and *Chara* were also correlated with the average number of rises and falls in the surface flow at each site. These two species are very well adapted to the hydrological variation characterized by a large number of rises and falls; *P.pectinatus* survives in many areas as a generalist and *Chara* thrives in areas of constant change. *Chara* species should receive further study in these backwaters because they may be potential indicators of flood disturbance.

The damming and diversions along the Platte River has decreased the number of rises and falls, increased the duration of high water flow and shifted peak flow from spring to early summer (Richter and Powell, 1996). This may allow for macrophytes to begin growing earlier, remain undisturbed due to a reduction in velocity of peak flows and a reduction in variation of levels of surface flow. It is likely, therefore, that submerged aquatic macrophytes of the backwaters in the Platte River floodplain have increased in biomass and species composition has shifted from *Chara* and *P. pecinatus* to species such as *C.demersum* and *Z.palustris*.

Acknowledgements

If I had been told a year and a half ago that I would be addressing issues of landscape ecology with regards to the Platte River in Nebraska I would have never believed it, and I still don't; it couldn't have been possible without the following people. Foremost a thank you to Dennis Jelinski for the both the opportunity and for the encouragement I always seemed to need, and Anna van der Meulen for her amazing field companionship and commitment to the data collection. My time in Nebraska would never have been the same without the introduction and hospitality I received from Paul Currier and *all* of the staff at the Platte River Crane Maintenance Trust (Thank you !!!). Finally sincere acknowledgement must be given to Wanli Wu for inspiring me with his enthusiasm (and sharing his water data), Christie Morgan, whose patience for taxonomic keys left me in awe, Tim Cross, for his logistical support, the staff at the Herbarium of UNL at Kearney, and my parents for visiting wherever I go.

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1.0 Introduction

1.1 Geography of the Platte River

In southern Nebraska the Big Bend section of the Platte River weaves across the landscape creating a dynamic environment with the braids of its sinuous channels (Figure 1). Water that originates from spring melt in the Colorado Rockies flows through the North and South Platte Rivers to converge and flow eastward through Nebraska via the Central Platte River. The relatively flat topography, steep gradients, high flows and ample supply of coarse substrate causes the water to flow within a braided channel morphology which constantly reworks alluvial sediments between anastomosing channels (Johnson, 1994). These alluvial deposits are highly conductive, providing little resistance to water exchange between the river and the adjacent Tertiary Ogalalla aquifer that lays below much of the upland landscape. This conductivity causes the shallow water table to be very closely associated with river stage such that general fluctuations in the main channel are strongly reflected in the level of the water table (Richter and Powell, 1996).

This relationship between groundwater and river stage is important for assessing the complete impact of a long history of human alteration on the Platte River. Four large dams on the North Platte, as well as extensive diversions along the entire river, have caused substantial declines in peak and mean flows since the late eighteen hundreds. When major dams were built on the North Platte, between 1900 and 1940, the flow downstream in the Big Bend region suffered from very rapid channel narrowing, associated woodland expansion (Johnson, 1994), and channel downcutting (Richter and Powell, 1996). It has been suggested that recently, the river has regained a balance in its fluvial morphology and riparian vegetation dynamics with channel width reaching a steady state (Johnson, 1994).

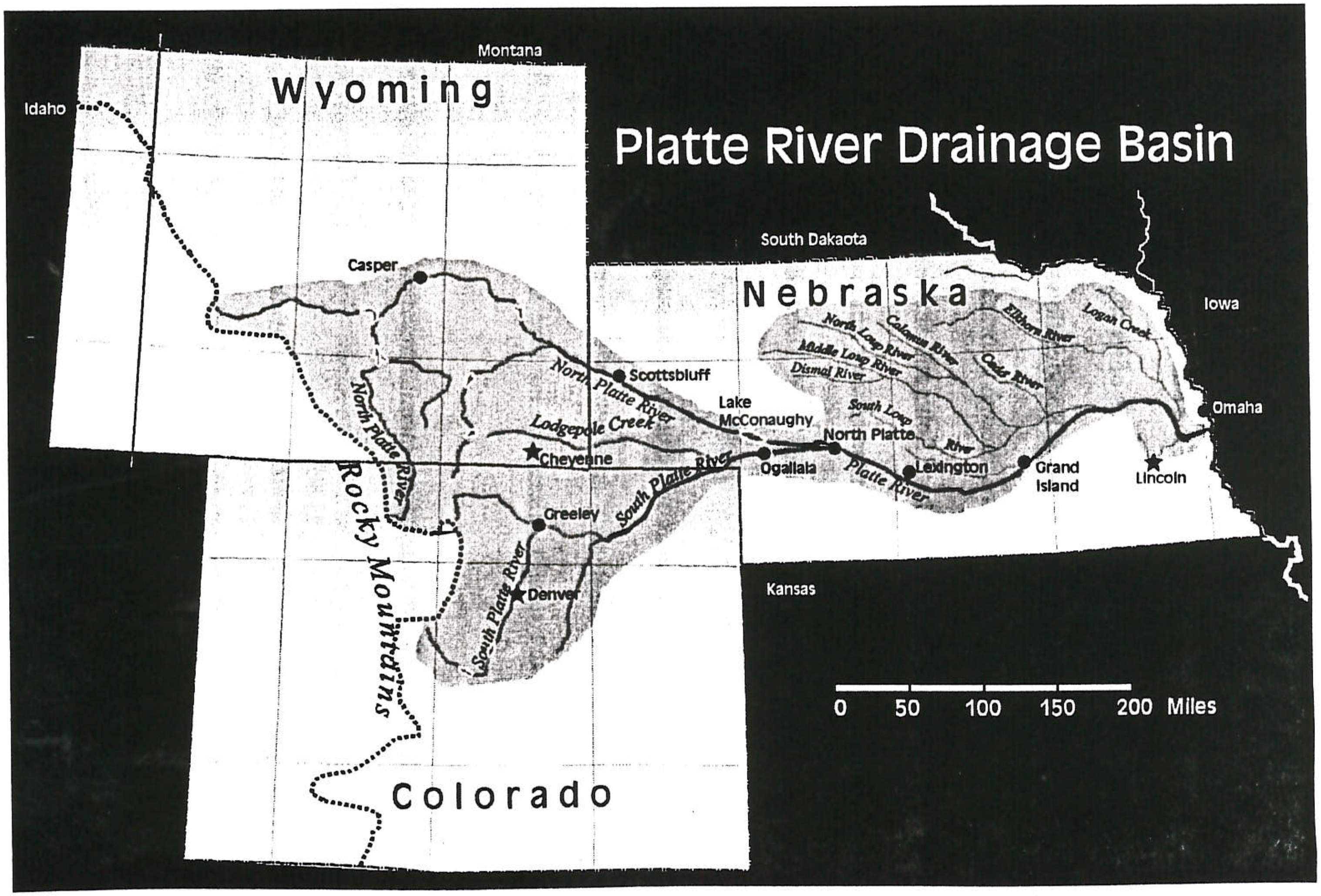


Figure 1:

Map of the Platte River watershed. Source: Platte Watershed Program.

This stability, however, has created channels that are more permanent in location in a river that was previously characterized by temporal and spatial heterogeneity (Johnson, personal communication, 13/02/98). These changes in the floodplain landscape have threatened the ecology of this Big Bend region, which is deemed an area of global ecological importance (EPA, 1996) and is protected as critical habitat for the endangered whooping crane (Currier *et al.*, 1985). Moreover, the changes in water flow and the resulting fixed, narrow and deeper channels threaten the connectivity of the floodplain. According to the flood-pulse concept (Junk *et al.*, 1989) many elements of the floodplain are functionally linked to the river ecosystem during maximum flow. It is during high flood events that key exchanges in nutrients, organic material, sediments and organisms occur between the main channel, side channels, and backwaters. Therefore, any changes which affect the natural flood regime reduce the potential for these exchanges of biota and inorganic matter (Sparks *et al.,* 1990; Bravard *et al.*, 1986).

In the past, lotic alteration studies have generally focused on the main channel while changes in the backwaters and floodplain wetlands have gone unnoticed (Sparks *et al.*, 1990). Research on the Platte River has generally avoided this bias with studies on both the main channel (Richter and Powell, 1996 and Johnson, 1994) and the wet meadows of the floodplain (Currier, 1995 and Currier *et al.,* 1985). Knowledge of the Platte River's floodplain dynamics has been limited, however, by a lack of attention to the backwaters of the Big Bend Region.

1.2 The Importance of Backwaters

A backwater is defined as a small stream that is connected downstream to the main channel, but has become disconnected at the upstream end. This causes water to periodically flow in the opposite direction of the main channel moving water towards the upstream (Bornette and Amoros, 1991). Defined more loosely backwaters can also be thought of as the peripherral wetlands and streams that are found within a river's floodplain (Bornette and Amoros, 1991).

These backwaters are ecologically important for three main reasons: (1) most of the biological activity and the physical storage of nutrients and organic matter occurs in these lateral areas where water flows with a reduced velocity allowing for increased storage capacity (Junk *et al.*, 1989); (2) these smaller water bodies may also be supplementary refugia, providing a place for amphibian and fish breeding (Willby and Eaton, 1996) and; (3) backwaters increase the diversity of the larger floodplain ecosystem because they add to habitat heterogeneity (Bornette and Amoros, 1991). Furthermore, backwaters are seldom exposed to the harsh erosional environment of the main channel and therefore offer an alternate set of conditions for aquatic organisms (Willby and Eaton, 1996). Lastly, different microhabitats within backwaters are also created because the water may have a two-directional flow and the water source often varies both within and among the floodplain water bodies (Bornette and Amoros, 1991).

The purpose of this study is to increase knowledge and understanding of local hydrological effects on species composition and biomass of aquatic macrophytes in the backwaters of the Big Bend region on the Central Platte River. By studying submersed aquatic macrophytes in relation to backwater hydrology, a correlation is expected between certain species, biomass, and diversity with parameters such as the magnitude, timing, frequency and duration of hydrological disturbance (Robach *et al.*, 1997; Spink and Rogers, 1996; Barrat-Segretain and Amoros, 1995; Bornette and Amoros, 1991). In accordance with the intermediate-disturbance theory (Fox, 1979) and its application to river systems (Ward and Stanford, 1983), it is hypothesized that those sites with very low variability or very high variability in these hydrologic parameters will have the least diversity of submergent macrophytes. In addition, the scouring effects of periodic, but infrequent flooding are expected to create new habitats and alter successional processes, the combination of which may increase macrophyte diversity (Robach *et al.*, 1997). Furthermore, it is expected that biomass, as a measure of productivity, will increase at sites that are very rarely disturbed because maximum growth can be obtained without uprooting or abrasion (Willby and Eaton, 1996; and Janauer and Kum, 1996). Finally, species composition will be affected by the hydrology of the backwaters because species will differ in their adaptations and abilities to deal with varying degrees of disturbance in the floodplain regime (Haslam, 1978 and Sculthorpe, 1967).

1.3 Macrophytes in Biohydraulic Studies

There are numerous reasons why submersed aquatic macrophytes can be used as a measure of hydrology and water chemistry and many of these aquatic plants have shown to be useful in studies of water quality, stream hydrology and flood impact (Elin *et al.*, 1997; Grasmuck *et al.*, 1995; Wilcox 1995; Dennison *et al.*, 1993; Madsen and Adams, 1989; Davis and Brinson, 1980; and Westlake, 1975). It has been found that submersed aquatic macrophytes are very sensitive to water quality variables such as chlorophyll a, dissolved phosphorous, light extinction coefficients, and nitrogen (Dennison *et al.*, 1993). The distribution of submersed aquatic plants has also been studied in terms of the turbidity of the water, the timing and duration of flooding, shading by shoreline and floating vegetation, fluctuating water levels, and surface sediments (Barrat-Segretain and Amoros, 1995; Davis and Brinson, 1980). The diversity of abiotic factors addressed in these biohydraulic studies reinforce the concept that no single environmental factor regulates macrophyte distribution. However, it is flooding and its associated disturbance, that are often cited as the key determinants of submersed aquatic macrophytes in river systems (Westlake, 1975; and Madsen and Adams, 1989).

Macrophytes are often limited by flooding because it tends to rework and alter the substrate, increase the turbidity, and cause mechanical breakage of plant shoots. It is also important to recognize the underlying effects of hydrology on habitat variables such as water temperature, water chemistry, oxygen content, and substrate particle sizes (Richter *et al.*, 1996). For example, flooding tends to dilute chemical concentrations, flowing water carries more oxygen, and lower velocities of water allow smaller particles to be deposited (Hjulstrom, 1935). By focusing on a larger scale, including the entire floodplain, it is therefore reasonable to hypothesize that in the backwaters of the Central Platte River the hydrology will both directly (through scouring and flow velocity) and indirectly (by determining water chemistry and substrate) determine the submersed aquatic macrophytes that survive in these floodplain water bodies.

1.4 Indicators of Hydrologic Alteration (IHA)

Richter *et al.* (1996) developed a suite of hydrologic parameters, known as Indicators of Hydrologic Alteration (IHA), to assess ecosystem alteration within river ecosystems. By quantifying and comparing these parameters before a substantial impact (i.e. dam building) and after the impact or 'post-disturbance' the IHA parameters improved the analysis of human altered ecosystems with a specific focus on biologically important qualities of water flow (Richter *et al.*, 1996).

The IHA method considers the full range of temporal variability and factors that are potentially important to biotic lifecycles, including: "(1) the magnitude of the water condition, (2) the timing of occurrence of a specific water condition, (3) the frequency of occurrence of a specific water condition, (4) the duration of time over which a specific water condition exists, and (5) the rate of change of the water condition over a specified time interval" (Richter *et al.*, 1996 - Table 1).

Richter and Powell (1996) applied these IHA parameters to the Platte River and considered the 'pre-impact' period to be before 1960 and 'post-impact' period after 1960. This time of impact was chosen because the majority of damming and diversions were completed between 1930 and 1950, but the river took another ten years to reach an equilibrium with these changes. By applying a method of hydrologic evaluation that has already been used in main

Table 1:

A summary of the hydrologic parameters that compromise the IHA, and their ecosystem influences. Source: Richter, Baumgartner, Powell and Braun (1996)

IHA Statistic Group	Regime Characteristic	Inter-Annual Statistic	Example of Ecosystem Influence
1. Magnitude of Monthly Mean Water Conditions	• Magnitude • Timing	1. Mean Value for each calendar month	• Habitat availability for aquatic organisms • Soil moisture availability for plants • Reliability of water supply for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, & photosynthesis in water column
2. Magnitude and Duration of Annual Extreme Water Conditions	• Magnitude • Duration	2. Annual maxima one-day means 3. Annual minima one-day means 4. Annual maxima 3-day means 5. Annual minima 3-day means 6. Annual maxima 7-day means 7. Annual minima 7-day means 8. Annual maxima 30-day means 9. Annual minima 30-day means 10. Annual maxima 90-day means 11. Annual minima 90-day means	• Balance of competitive, ruderal, and stress-tolerant organisms • Creation of sites for plant colonization • Structuring of aquatic ecosystems by aquatic vs. biotic factors • Structuring of river channel morphology and physical habitat conditions • Soil moisture stress in plants • Anaerobic stress in plants • Duration of stressful conditions such as low oxygen in aquatic environments • Distribution of plant communities in lakes, ponds and floodplains • Duration of high flows for waste disposal and aeration of spawning beds in channel sediments
3. Timing of Annual Extreme Water Conditions	• Timing	12. Julian date of each annual one day maximum	• Compatibility with life cycles of organisms • Predictability/avoidability of stress for organisms • Access to special habitats during reproduction • Evolution of life history strategies and behavioral mechanisms
4. Frequency and Duration of High/Low Pulses	• Magnitude • Frequency • Duration	13. # high pulses 14. #low pulses 15. mean duration of high pulse 16. mean duration of low pulse	• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants • Availability of floodplain habitats for aquatic organisms • Nutrient and organic matter exchanges between river and floodplain • Soil mineral availability • Access for water birds to feeding, resting and reproduction sites • Influence of bed load transport, channel sediment textures, and duration of substrate disturbance
5. Rate/Frequency of Water Condition Changes	• Frequency • Rate of Change	17. Means of positive differences b/w consecutive daily values 18. Means of negative differences b/w consecutive daily values 19. # of Rises 20. # of Falls	• Drought stress on plants • Entrapment of organisms on islands or within the floodplain as water rises • Desiccation stress on low mobility stream-edge organisms

channel analysis, this study may add to the understanding of the backwaters not as separate entities, but as an integrated part of the floodplain ecosystem. Moreover, it is hypothesized that the biological significance of the IHA parameters used in this study allows an interpretation of the water data that is likely to correlate with the response of the submersed aquatic macrophytes.

2.0 Methods

2.1 Hydrological Measurements

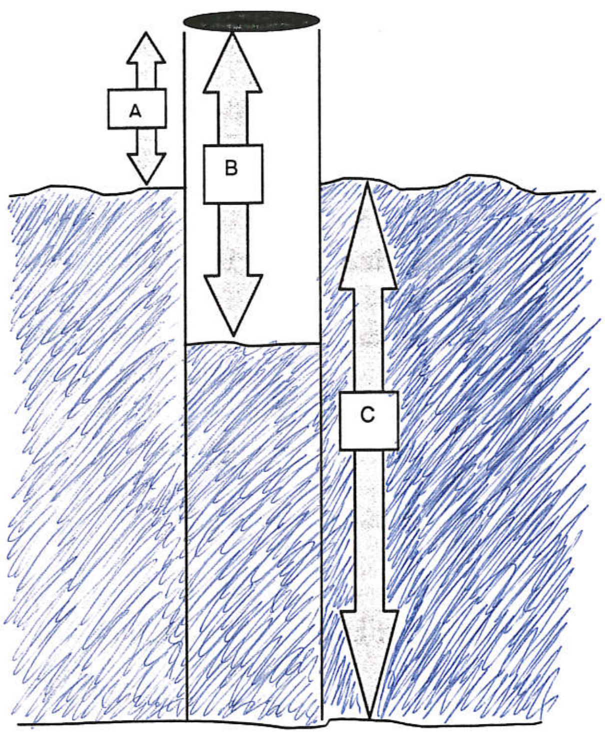
As a part of a larger study on the hydrology of the backwaters of the Platte small wells, (approximately six centimetres in diameter) made of PCV pipe, were driven down to the water table at various backwater, slough and side channel sites in the Big Bend region. These wells were measured in three to four day cycles from mid-April until mid-August. A measuring rod fitted with an incomplete electric circuit was constructed to sound upon contact with water (i.e. the water completed the circuit). This allowed measurements to be taken inside the well (from the top of the well to the surface of the water), outside the well (from the top of the well to the surface of the water), and exterior to the well (from the substrate surface to the water level). These measurements were then converted to values for overall water level and surface flow (Figure 2).

2.2 IHA Calculations

IHA parameters were calculated for the overall water level (which includes surface and ground water components), as well as separately for surface flow following methods in Richter *et al.* (1996). However, the following assumptions were made: (1) if well measurements were not possible due to submergence of the well it was assumed that the groundwater contribution remained at the value previously recorded; (2) if the groundwater was over twenty centimetres below the surface it was assumed that all of the external water was from surface flow; (3) if

Figure 2:

Diagram of the translation between field data and hydrologic data.



A represents measurement referred to as outside the well.

B represents measurement referred to as inside the well.

C represents measurement referred to as exterior to well.

Therefore,

If **A>B** (not shown):
Overall Water Level = **C**
Surface Component = zero

If **B>A** (shown in diagram):
Overall Water Level = **C**
Surface Component = **B - A**

outside and inside measurements were equal it was recorded as zero surface flow and; (4) for the calculation of duration, data was extrapolated to the date half way between measurements.

The calculated IHA variables were then evaluated for inter-correlation to determine if they were statistically independent. IHA variables which were highly correlated (i.e. >0.8) and had proven to be statistically significant with regards to the macrophyte data (Section 2.5 and 3.2) were reevaluated to determine how they should be dealt with.

2.3 Site Descriptions

Sites for vegetation sampling were based on pre-established well sites. Appendix A includes air photo locations, sketches and photographs of the study sites.

Site # 1 - sampled 17/07/97

Located in proximity to well NPPD-042 this site could be characterized as a side channel because it is almost continually connected to, and flows in the same direction as, the main channel. Interestingly, however this water body is a significant distance from the main channel (approximately 0.73 km). Sampling for macrophytes took place both upstream and downstream from a small beaver dam that is the last in a series of four dams inhibiting the flow in this location.

Site # 2 - sampled 19/07/97

Sampling took place in proximity to well NPPD#2 in a small backwater surrounded by approximately 125cm tall aquatic emergents, which shaded much of the backwater.

Site # 3 - sampled 19/07/97

Well TJ-006 was located at the confluence of two backwater streams. This backwater was the largest in area of the sites considered for this study. Shoreline vegetation was quite low and flattened and there were no species growing on the surface of the water. Beavers dammed one of the inlet backwaters.

Site # 4 - sampled 20/07/97

Sampling occurred in a backwater near well TNC#2-1, which is located within the water body only during very high flow. The fluctuating shoreline kept shoreline vegetation from one to two metres away from the water's edge, but the vegetation was on average 200 cm tall.

Site # 5 - sampled 21/07/97

Three small backwaters were sampled as one site because they are connected for a large part of the year. This site is very close (20 m) to the main channel.

Site # 6 - sampled 26/07/97

Well TNC#1-2 is very close to the main channel, but separated by an area of high elevation. Shoreline vegetation is restricted from the shoreline by fluctuating water levels, but is up to 250cm tall. *Lemna* was very abundant on the surface of the water often covering up to one hundred percent of this backwater.

Site # 7 - sampled 23/07/97

This backwater, with well TNC#4-1, has a beaver dam upstream and a partial dam within the sampling area.

Site # 8 - sampled 24/07/97

This site is located near SM-Gauge North, in a fairly regulated backwater to the north of Wild Rose Ranch. This site is shaded by tree growth.

Site # 9 - sampled 24/07/97

Well SM-053 is located further downstream in the same backwater as Site # 8. This site is also surrounded by cottonwood trees, has shoreline vegetation approximately 150 cm in height.

Site # 10 - sampled 26/07/97

Well SM-002 is located in a narrow slough with natural prairie grasses and no trees. This sampling site is found to the east behind Wild Rose Ranch. The shoreline vegetation is approximately 200 cm tall.

Site # 11 - sampled 26/07/97

This site is found in the same slough as Site # 10, but in an area where the backwater has increased in width at SM-Gauge-Central. The shoreline vegetation is the approximately 200 cm tall, but is probably less influential than at Site 10, because the increase in width reduces its capacity to shade submergent macrophytes.

2.4 Vegetation Sampling

At each site transects were set across the width of the backwater at regular shore intervals from five to fifteen metres, the exact distance depending on the length of the backwater. A 0.25m x 0.25m plot (as suggested in Best, 1982; Forsberg, 1959) was randomly placed at each metre along the transect and the above substrate biomass (therefore, excluding roots and tubers) of the submersed aquatic macrophytes was harvested within the quadrant. The number of transects varied to allow the collection of vegetation from 10 (at Site 2 -a very small backwater slough) to 30 quadrants, with an average of 20 quadrant samples per site.

All the vegetative sampling occurred once per site, between July 17th, 1997 and July 26th, 1997. The length of time taken to complete sampling at all sites was deliberately kept to a minimum to avoid variability in the growing period between sites. This time period was also chosen based on seasons of greatest biomass for most submersed aquatic macrophytes being in late July and early August (Barrat-Segretain and Amoros, 1995; Chambers and Prepas, 1990; Duarte and Kalff, 1990; and Sculthorpe, 1967). Quadrant harvesting is recommended as the most accurate method of estimating standing biomass (Downing and Anderson, 1985).

Samples were rinsed and sorted by species (following Prescott, 1969 and Larson, 1993) and verified with comparisons to collections in the herbarium at the University of Lincoln at Kearney. All samples were then dried at 105°C for twenty-four hours to constant dry weight and measured to the nearest hundredth of a gram. Species weight, as well as average biomass per quadrant, and total species number were calculated for each site.

2.5 Statistical Analysis

Simple linear regressions were performed with the IHA parameter being set as the independent variable and the macrophyte data designated as the dependent variable. IHA parameters were screened for zero values such that IHA parameters with a zero value at ten or more of the study sites were omitted. The species of macrophytes that were only found at one site were also omitted but their presence was incorporated into both average biomass and number of species. Statistically significant R-values were then determined and recorded.

To address issues of competition and coexistence between species, macrophyte association was analyzed using a table of dummy variables with 0 indicating 'not present' and 1 indicating the 'presence' of each species at the study sites. Based on this, between species correlations were then evaluated to determine if the presence of one species affected the presence of any others.

3.0 Results

3.1 Macrophyte Data

After macrophytes were harvested and identified, a tabulation was made for each site (Table 2). Nine species were identified, including eight vascular plants and *Chara* (a plant-like algae). Five of these species were located at only one out of eleven sites. The remaining four species of *Potomogeton pectinatus, Zannichellia palustris* and *Ceratophyllum demersum* and *Chara*, were fairly wide spread, growing at eight, nine, five and seven sites respectively. Both the average biomass per quadrant (Figure 3), and the number of species (Figure 4) at each site varied substantially. For example, Site 5 had no macrophytes while Site 6 and Site 7 had an

Table 2:

The dry weight, in grams, of all species harvested at each of eleven sample sites in backwaters of the Platte River, Nebraska.

Site #	Species *Chara* species	*Elodea canadensis*	*Potomogeton pectinatus*	*Zannichellia palustris*	*Ceratophyllum demersum*	*Sagittaria latifolia*	*Vallisneria americana*	*Veronica anugallis-aquatica*	*Eleocharis robbinsii*	*Veronica* immature	Unidentifiable	Total
1		11.17	1.78	0.04		0.04						**13.03**
2	3.80		0.10	0.28								**4.18**
3	0.67		9.72	0.70			0.03	0.78				**11.91**
4	22.71		5.60	1.88	6.54						0.01	**36.74**
5												**0.00**
6	46.02		45.89	1.68	33.74							**127.33**
7			1.03	8.10	121.40							**130.54**
8			1.52	0.04	15.12							**21.35**
9	4.67		1.14		5.01				0.01	0.03	0.02	**7.41**
10				0.01								**0.01**
11	1.30			2.26								**3.56**

Figure 3:

Average grams of biomass per quadrant (0.25m X 0.25m) at each study location. Error bars represent standard error of the mean.

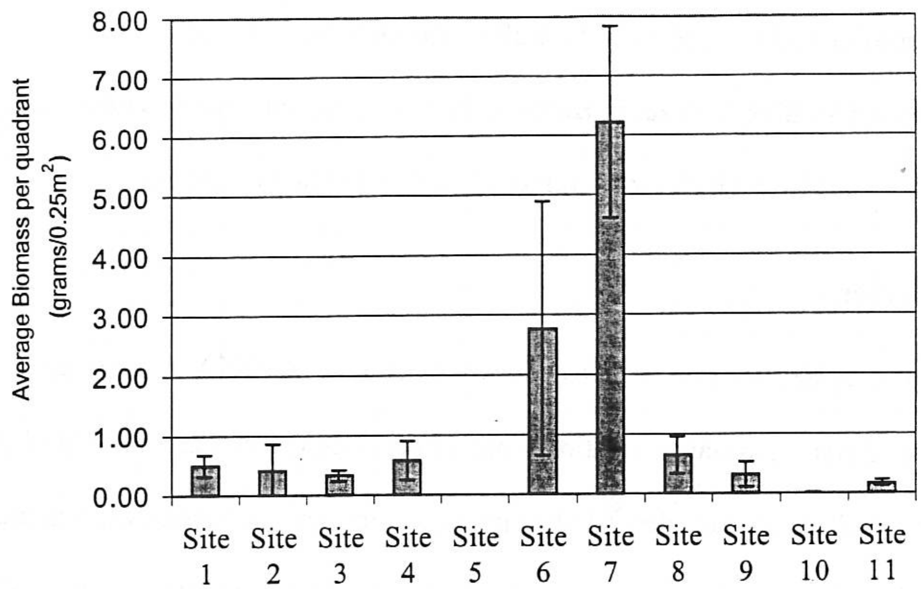
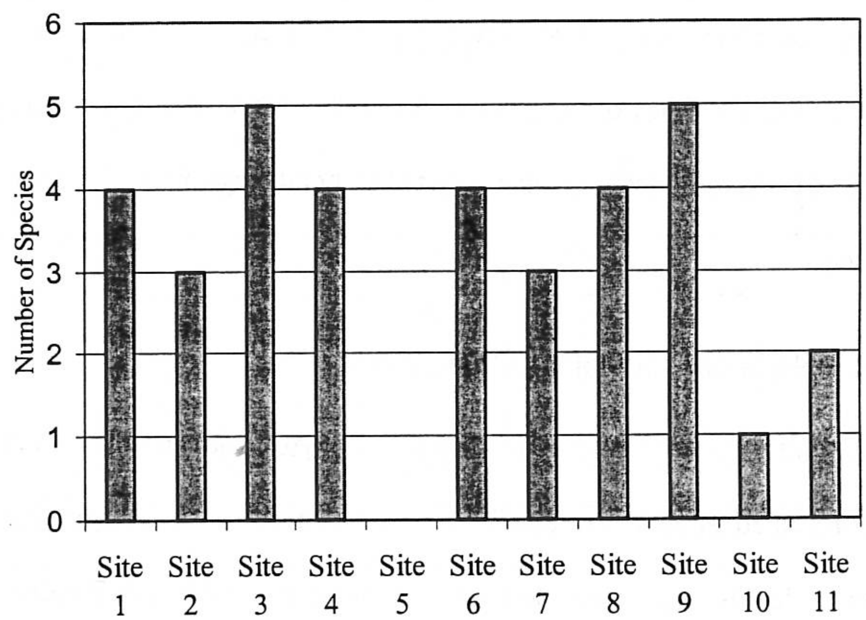


Figure 4:

Total number of species harvested at each site.



average of 6.70 and 5.68 g/quadrant respectively. In general, macrophyte diversity was fairly low, but evenly distributed across sites. Site 2 and Site 3 had the highest number of species with 5 each, and Site 5 had no macrophytes growing in its waters.

A correlation table to assess macrophytes species association (Table 3a and 3b) revealed a low inter-correlation (<0.7 and >-0.7) for all species except *Vallisneria americana* with *Veronica anugallis-aquatica*, *Elocharis robbinsii* with the *Veronica* (immature), and *Elodea canadensis* with *Sagittaria latifolia* which were all significantly correlated (1.000).

3.2 IHA Values

Following Richter *et al.* (1996) a 'score card' of all the IHA parameters can be found in Appendix B. After an initial correlation table was created to determine which of these IHA parameters could not be considered independently, some modifications were made. These changes included the combination of the April and May average surface flow, with their mean being redefined as "surface flow-spring mean". This seasonal parameter may, in fact, be more meaningful because it represents a natural cycle instead of limiting the hydrological phenomena to arbitrary calendar dates. The number of rises and falls in surface flow were also combined and the average taken because the two were highly correlated at 0.99 and both can be considered indicators of the frequency of variation in the surface flow. A second correlation table (Appendix C) was completed to ensure that statistically significant IHA values were independent.

3.3 Macrophyte and Hydrology Regressions

Simple linear regressions between macrophyte variables and IHA parameters at each site (Table 4) revealed statistically significant R-values for four hydrological parameters. High overall water levels on a seven day time scale correlated with both *Z.palustris* ($R=0.61$, $P<0.05$) and *C.demersum* ($R=0.63$, $P<0.05$). The spring mean levels of surface flow were correlated with

Table 3:

A test for association of submergent aquatic macrophyte species based on a correlation table.

a) A table of 'dummy' variable for macrophyte species versus study site. A '1' indicates the species was present and a '0' indicates it was not.

Site #	Species *Chara*	*Elodea canadensis*	*Potomogeton pectinatus*	*Zannichellia palustris*	*Ceratophyllum demersum*	*Sagittaria latifolia*	*Vallisneria americana*	*Veronica anugallis-aquatica*	*Eleocharis robbinsii*	*Veronica immature*
1	0	1	1	1	0	1	0	0	0	0
2	1	0	1	1	0	0	0	0	0	0
3	1	0	1	1	0	0	1	1	0	0
4	1	0	1	1	1	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	1	0	1	1	1	0	0	0	0	0
7	1	0	1	1	1	0	0	0	0	0
8	1	0	1	1	1	0	0	0	0	0
9	1	0	1	0	1	0	0	0	1	1
10	0	0	0	1	0	0	0	0	0	0
11	1	0	0	1	0	0	0	0	0	0

b) A correlation table of macrophyte species versus macrophyte species based on the presence of each species at each site listed above.

	Chara	*Elodea canadensis*	*Potomogeton pectinatus*	*Zannichellia palustris*	*Ceratophyllum demersum*	*Sagittaria latifolia*	*Vallisneria americana*	*Veronica anugallis-aquatica*	*Eleocharis robbinsii*	*Veronica immature*
Chara	1.000									
Elodea canadensis	-0.516	1.000								
Potomogeton pectinatus	0.542	0.194	1.000							
Zannichellia palustris	0.241	0.149	0.241	1.000						
Ceratophyllum demersum	0.559	-0.289	0.559	-0.043	1.000					
Sagittaria latifolia	-0.516	1.000	0.194	0.149	-0.289	1.000				
Vallisneria americana	0.194	-0.100	0.194	0.149	-0.289	-0.100	1.000			
Veronica anugallis-aquatica	0.194	-0.100	0.194	0.149	-0.289	-0.100	1.000	1.000		
Eleocharis robbinsii	0.194	-0.100	0.194	-0.671	0.346	-0.100	-0.100	-0.100	1.000	
Veronica immature	0.194	-0.100	0.194	-0.671	0.346	-0.100	-0.100	-0.100	1.000	1.000

Table 4:

R-values for singular multiple regression between independent indicators of hydrologic assessment and submergent aquatic macrophyte data. For surface flow degrees of freedom is equal to 8 and $\alpha = 0.05$, therefore for statistical significance R>0.632. For water level degrees of freedom is equal to 10 and $\alpha = 0.05$, therefore R>0.576 means the result is statistically significant.

	Dependent Variables (Macrophyte Data)					
Independent Variables (IHA Parameters)	Biomass (g/quad)	Number of Species	Chara (g)	P.pectinatus (g)	Z.palustris (g)	C. demersum (g)
Water Level – Month with High Mean	0.145	0.266	0.040	0.017	0.026	0.031
Water Level – Month with Low Mean	0.027	0.097	0.033	0.138	0.218	0.026
Water Level - April Average	0.239	0.337	0.096	0.209	0.245	0.283
Water Level - May Average	0.283	0.209	0.151	0.115	0.350	0.400
Water Level - June Average	0.401	0.301	0.033	0.233	0.465	0.489
Water Level - July Average	0.037	0.358	0.363	0.127	0.011	0.046
Water Level – August Average	0.328	0.135	0.179	0.049	0.223	0.359
Water Level – Julian Day with High	0.336	0.305	0.160	0.132	0.014	0.198
Water Level – Julian Day with Low	0.066	0.007	0.068	0.155	0.169	0.175
Water Level - High on Three Day Scale	0.378	0.372	0.004	0.242	0.508	0.501
Water Level - Low on Three Day Scale	0.052	0.037	0.344	0.330	0.071	0.211
Water Level - High on Seven Day Scale**	0.537	0.320	0.080	0.241	0.611*	0.634*
Water Level - Low on Seven Day Scale	0.040	0.039	0.356	0.338	0.076	0.204
Water Level – Number of High Pulses	0.003	0.273	0.213	0.224	0.140	0.014
Water Level – Number of Low Pulses	0.066	0.409	0.177	0.119	0.212	0.055
Water Level – Duration of High Pulses	0.258	0.272	0.026	0.091	0.126	0.210
Water Level – Duration of Low Pulses	0.308	0.039	0.018	0.280	0.436	0.410
Water Level – Number of Rises	0.203	0.077	0.278	0.135	0.245	0.367
Water Level – Number of Falls	0.138	0.351	0.192	0.175	0.171	0.200
Surface Flow – Month with High Mean	0.241	0.280	0.100	0.084	0.195	0.171
Surface Flow - Spring Mean**	0.671*	0.178	0.881*	0.993*	0.018	0.109
Surface Flow - June Average	0.187	0.267	0.190	0.053	0.492	0.437
Surface Flow - July Average	0.102	0.425	0.031	0.248	0.090	0.163
Surface Flow – August Average	0.062	0.559	0.238	0.302	0.188	0.107
Surface Flow – Julian Day with High	0.246	0.239	0.065	0.071	0.234	0.211
Surface Flow – Julian Day with Low	0.594	0.369	0.558	0.525	0.282	0.273
Surface Flow - High on Three Day Scale	0.158	0.372	0.202	0.042	0.467	0.412
Surface Flow - High on Seven Day Scale	0.140	0.274	0.182	0.064	0.424	0.366
Surface Flow - Number of High Pulses	0.022	0.312	0.158	0.281	0.158	0.205
Surface Flow - Duration of High Pulses**	0.810*	0.233	0.408	0.444	0.767*	0.772*
Surface Flow - No. of Rises and Falls**	0.427	0.337	0.648*	0.813*	0.023	0.010

* - indicates statistically significant R-values   ** - indicates hydrological parameters with statistically significant R-values

three macrophyte variables including: the average biomass per quadrant ($R=0.67$, $P<0.05$), grams of *P.pectinatus* ($R=0.99$, $P<0.05$), and *Chara* ($R=0.88$, $P<0.05$). *P.pectinatus* ($R=0.81$, $P<0.05$) and *Chara* ($R=0.65$, $P<0.05$) were also correlated with the average number of rises and falls in the surface flow at each site. Finally the duration of high pulses (>75%) in surface flow had significant R-values when regressed with average biomass per quadrant ($R=0.81$, P<0..05) grams of *Z.palusrtis* ($R=0.77$, $P<0.05$) and *C.demersum* in grams ($R=0.77$, $P<0.05$).

Three results become evident from the regression data above. First, there are four out of thirty-one hydrological variables that show strong regressions with the macrophyte data and secondly all the correlations are positive when the slopes of the regression equations are considered (Table 5). Last, species number was the only dependant variable that did not have any statistically significant linear regressions with the entire list of hydrological variables.

4.0 Discussion

4.1 Lack of Correlation with Species Diversity

Contrary to the hypothesis that species diversity would increase at an intermediate level of disturbance (Fox, 1979) the total number of species at each site did not show any statistically significant correlations with the IHA parameters. This is may be due to the fact that so few species were found. Although, it is not uncommon to have less than ten submersed macrophytes in the backwaters of a river (Robach *et al.*, 1997), this small number makes statistical analysis more difficult.

4.2 Sources of Error in IHA Parameters

In calculating the components of overall water and surface flow from the well data (Figure 2) it was assumed that there was a negligible delay in water transfer through the highly porous sand between the groundwater and surface water of the backwaters. Although the porous

Table 5:

Summary of statistically significant linear regressions with R-values and regression equations.

R-Value	Regression Equation
0.661	*Z. pallusrtis* (g) = -1.80 +(0.0666 x water level high on a seven-day scale)
0.634	*C. demersum* (g) = -33.2 + (1.05 x water level high on a seven-day scale)
0.671	Average Biomass per Quadrant = 1.27 +(1.07 x surface spring average)
0.993	*P. pectinatus* (g) = 1.16 +(9.29 x surface spring average)
0.881	*Chara* (g) = 2.46 +(8.85 x surface spring average)
0.810	Average Biomass per Quadrant = -0.575 +(0.433 x duration of high surface pulse)
0.767	*Z. palustris* (g) = -1.09 +(0.426 x duration of high surface pulse)
0.772	*C. demersum* (g) = -20.0 +(6.57 x duration of high surface pulse)
0.813	*P. pectinatus* (g) = -3.24 + (2.13 x surface average # rises and falls)
0.648	*Chara* (g) = -0.869 + (1.83 x surface average number of rises and falls)

sediments would have limited the subsurface flow into the backwater only slightly this may have caused a small error in the surface flow calculations.

The transferal of the IHA framework from main channel gauge records to backwater well measurements also created some complications. For example, some variables could not be calculated because, unlike the gauging of main channels, the hydrological data of the backwaters could not be sampled as frequently or throughout the entire year. As a result of this, IHA values based on a one-day scale were not calculated because the water data was not collected on a daily basis and the three-day scale was sufficient in quantifying the resolution of the data. Variables on a 90-day scale were also left out because hydrological data was only collected for an 18-week field season. Finally, the rise and fall rates of the backwaters could not be calculated with enough accuracy because measurements were not taken frequently enough. If rise and fall rates were calculated on these inconsistent measurements, they would likely be underestimated.

4.3 Lack of Macrophyte Species Association

In general, there were few statistically significant correlations between the presence and absence of species at the eleven study sites. These low inter-correlations indicate that the presence of one species of macrophyte does not increase or decrease the possibility of a different species from growing at the site. This lack of competition in naturally coexisting species is often the case with submerged aquatic macrophytes (Chambers and Prepas, 1990).

The few species that were highly correlated were single samples found only at one site with *Elodea canadensis* and *Sagittaria latifolia* only found at Site 1, *Vallisneria americana* and *Veronica anugallis-aquatica* found only at Site 3, and *Eleocharis robbinsii* and *Veronica* immature only at Site 9. These single occurrences limit any conclusions regarding whether the species exclusively coexist. The high correlation of these few species may, instead, be caused by the site's ability to support a higher diversity including both species rather than the effect one species is having on another. Below, each of the four IHA parameters found to be affecting macrophyte abundance and distribution are discussed.

4.4 Importance of Spring Surface Flow

Average biomass for *Chara* spp. and *P.pectinatus* was strongly correlated with the average spring surface flow. This increase in biomass may be explained if spring surface flow acts primarily as a supply of nutrients despite increased disturbance. For example, it has been found that flowing waters of low nutrient concentrations may actually be a better source of nutrients than higher concentrations in quiescent waters (Davis and Brinson, 1980). This means that up to a certain threshold velocity the advantages of nutrient transport may outweigh the physical disturbance created by increased spring surface flow. Moreover, early pulses of growth, caused by an increase in nutrient availability, may also create a positive feedback system common to many areas of macrophyte growth. This positive feedback mechanism begins when a few macrophytes become established. These individuals slow down the velocity of flow in the backwater that allows for further recruitment of macrophytes which in turn reduces the flow even more (Westlake, 1975; Bornette and Amoros, 1991). The high nutrient availability in the higher spring flows could begin this positive feed back mechanism by allowing for the initial success in recruitment.

The positive correlation between *P.pectinatus* and high average spring surface flows may be due to its life history strategy, which includes wintering as tubers beneath the substrate (Spink and Rogers, 1996). This gives *P.pectinatus* the ability to recolonize disturbed areas very quickly without the problems of initial rooting in faster flowing waters.

The fact that *Chara* weight is correlated to this average spring surface flow may be related to its status as an early successional colonist. *Chara* species are often the initial colonizers of open surfaces and thrive in environments where the substrate is newly deposited and constantly reworked (Bornette and Amoros, 1991). These aquatic algae have actually been known to decrease in abundance as summer progresses and succession continues (Chambers and Prepas, 1990). This means that larger average flows in the spring could delay the recruitment of species less disturbance-tolerant than the *Chara*.

4.5 Average Number of Rises and Falls - measuring variability in Surface Flow

P.pectinatus and *Chara* are the two macrophyte species that displayed significant correlation with the average number of rises and falls in surface flow. The number of rises and falls is indicative of variability in the backwater as the constant resurgence of surface flow may carry dissolved nutrients, create frequent disturbances and rework sediments. As mentioned above *Chara* species may be positively correlated with an increase in the number of rises and falls because it does well in areas where sediment is constantly being deposited and shifted around.

These results lead to the suggestion that *Chara* may be a potential indicator for hydrologic disturbance which 'resets' the succession of aquatic macrophytes in the Platte River floodplain. However, this relationship would have to be studied more carefully as *Chara* species are also characterized as being more successful in ground supplied waters (Bornette and Amoros, 1991).

The significant correlation with *P.pectinatus* and the number of rises and falls is less clear. *P. pectinatus* is, however, often cited as being highly tolerant of various conditions (Sculthorpe,1967; and Davis and Brinson,1980), and this r-type growth strategy may allow for its success in variable environments. Davis and Brinson (1980) found that *P.pectinatus* is highly resistant to both short and long-term ecosystem changes, allowing it to be rated as the most widespread and abundant of all North American submersed species.

4.6 Importance of High Water Levels Based on a Seven Day Scale

Perhaps the most perplexing of the statistical results is the positive correlation between high water levels on a seven-day scale with both *Z.palustris* and *C.demersum*. It may be that this result reflects a tolerance of both of these species to shade. If the depth of the water is high on a seven-day scale, a reduction in availabile light for macrophytes may last for a potentially stressful duration. However, *Z.palustris* and *C.demersum* are fairly shade tolerant (Davis and Brinson, 1980), and may be able to deal with this stress successfully and continue adding biomass.

4.7 An Indicator for Disturbance - The Duration of High Pulses in Surface Flow

The positive correlation between the duration of high pulses in surface flow with *Z.palustris*, *C.demersum* and average biomass per quadrant could be easily misinterpreted. Initially it would seem that this long duration of disturbance would limit the growth of species like *C.demersum* which are weakly rooted and *Z.palustris* which displays a limited resistance to flooding (Davis and Brinson, 1980). However, what may actually be occurring is a reduction in flow velocity as the floodwaters take longer to move through the backwaters and hence the duration of peak flows would be lengthened by an increase in residence time. This reduction of velocity due to a temporal spread of floodwaters may also explain the positive correlation with biomass because the slower flow reduces the force that could physically damage the plants vegetative growth or substantially disturb the substrate.

4.8 Site Specific Comments

The presence of *Elodea canadensis* only at Site 1 and its domination within the site is fairly interesting. It seems likely that the silty substrate caused by the reduction in flow both upstream and downstream of the beaver dam favors *Elodea canadensis*, but this type of substrate is also suitable for *C. demersum* which does not grow at all in this site. In accordance with Sculthorpe (1967), a second factor that may limit *C.demersum*, but not the *Elodea canadensis* is the presence of suspended organic material. The frequent disturbance caused by cows, which cross just upstream in this backwater and also have a tendency to rub against the wells (Currier, 1995), may contribute to this suspended load and should also be considered as a disturbance factor at Site 2.

The lack of macrophytes at Site 5 is also noteworthy because it is likely a result of the coarse sandy substrate found exclusively at this site. The poor nutrient conditions and the inability of many macrophytes to root in this type of substrate are well-documented (Westlake, 1975; Madsen and Adams, 1989; and Chambres and Prepas, 1990). However, the small distance between this backwater and the main channel must not be overlooked as the overriding landscape feature. The high velocity flows which Site 5 receives, due to its proximity to the main channel, creates a sedimentary environment in which only these coarse large particles are deposited and it is therefore the hydrology which ultimately inhibits the use of this site for macrophyte growth.

The exceptionally high average biomass per quadrant at Site 6 and Site 7 is also interesting and may be linked to the success of *C.demersum* at both of these sites. *C.demersum* is often found with calcareous deposits on its foliage. This remains on the specimens even after drying and may therefore increase the dry weight. However, other sites with *C.demersum* do not have exceptionally high biomass (Site 4, 8 and 9), and it may just be that the productivity of those two sites is very high.

4.9 The Importance of Surface Flow

As predicted, the most significant hydrologic variables that affected the submergent aquatic macrophytes in the backwaters of the Platte River were related to the surface flow. Apart from the success of *Z.palustrus* and *C.demersum* in deeper water bodies on a seven-day scale, most macrophyte growth could be potentially explained by factors determined by the flooding regime of the site. Surface water flows are often related to mechanical breakage of macrophyte species, uprooting, sedimentation, and substrate reworking. These surface water flows have undoubtedly been altered with the channelization of the Platte River, and the decrease in connectivity within the floodplain due to historical damming and diversions.

A previous study using IHA parameters on the Central Platte River determined that the hydrology of the main channel has undergone changes including monthly mean flows that have increased in late summer and spring at both Odessa and Grand Island, with July-October flows increasing by 91-458% and April-June flows by 54-75%. A loss of variation has also occurred because the average rate for both the rise and fall of water levels has been reduced. Furthermore, dam regulation which gradually releases spring snow melt has shifted flood peaks by 29-38 days into the summer. Damming regulation may also be contributing to the extended duration of high flow periods since 1960 (Richter and Powell, 1996). It is likely, therefore, that the damming of the Platte River in the middle of the century may have created backwaters characterized by higher average biomass per unit area for two main reasons: (1) the shift of peak flows by approximately one month has meant that spring flow averages that may have naturally had a high enough discharge and velocity to disrupt the growth of macrophytes will now have the opposite effect and may even increase macrophyte success due to the continuous supply of nutrients in relatively slow flowing spring water. (2) the extended duration of high flows due to the gradual release of melt waters through dams may increase the biomass because the retaining of water reduces the intensity of disturbance, which may have naturally limited macrophyte growth to a greater extent than observed at the present.

Based on the significant correlation between IHA parameters and particular species, it is also quite likely that the species composition may have been affected after the damming. If the dampening of the number of rises and falls in the main channel is also characteristic of backwater flow regimes, this reduction in variation would have caused a decrease in the abundance of *P.pectinatus* and *Chara* spp. Conversely, species that thrive in lower velocity waters such as *Z.palusris* and *C.demersum* may have increased, since these hydrological alterations due to the aforementioned increases in duration of high pulses.

4.10 Recommendations for Future Study

If further studies are to be made on the macrophytes of the backwaters in the Big Bend Region of Nebraska one setback of this study should be avoided. Although much of the literature recommended that sampling occur during periods of highest biomass (late July to early August), it would be advantageous to harvest macrophytes earlier on in the field season for several reasons. Due to severe reductions in flow near the end of the summer many potential sampling sites dry up. This not only limits the possibilities for sampling; it biases the sites to those with larger subsurface inputs that maintain above ground water levels. The time of sampling should also be reconsidered based on the seed production of *Potomogeton pectinatus* and *Zannichellia palustris*. In the absence of seeds, it is very challenging to differentiate between these two species. The relative abundance of *Chara* spp. may also increase if sampling occurred before the 'successional' processes mentioned above (Section 4.2), replace this initial colonizer.

Even with the problems associated with the chosen sampling period, this study reveals the importance which flooding regimes and their associated surface flows can have in the backwaters of areas like the Big Bend Region of the Platte River. The responses of macrophyte growth and species composition to these hydrologic parameters should receive further consideration because of the ability of macrophytes to further alter the floodplain hydrology by slowing flow velocity and increasing sedimentation. Macrophytes in the backwaters of the Platte River may initially capitalize on the altered flow regimes each spring. With delays in peak flow macrophytes may establish themselves in areas which were previously unsuitable (due to disturbance) and then create a positive feedback mechanism in which they slow velocity and increase finer grained sedimentation which increases colonization which still further decreases velocity. Further study including more study sites and a more opportune sampling period would enhance the preliminary relations observed between the Indicators of Hydrological Assessment and submergent aquatic macrophytes within these complex, diverse and critical components of the Central Platte River floodplain.

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Appendix A

Airphotos, Sketches, and Photos
Of Study Sites

Symbol	
———	Vegetation sampling transects
	Water
•	Well
	Beaver Dam
□	Area included in photo

From West to East Along the Central Platte River

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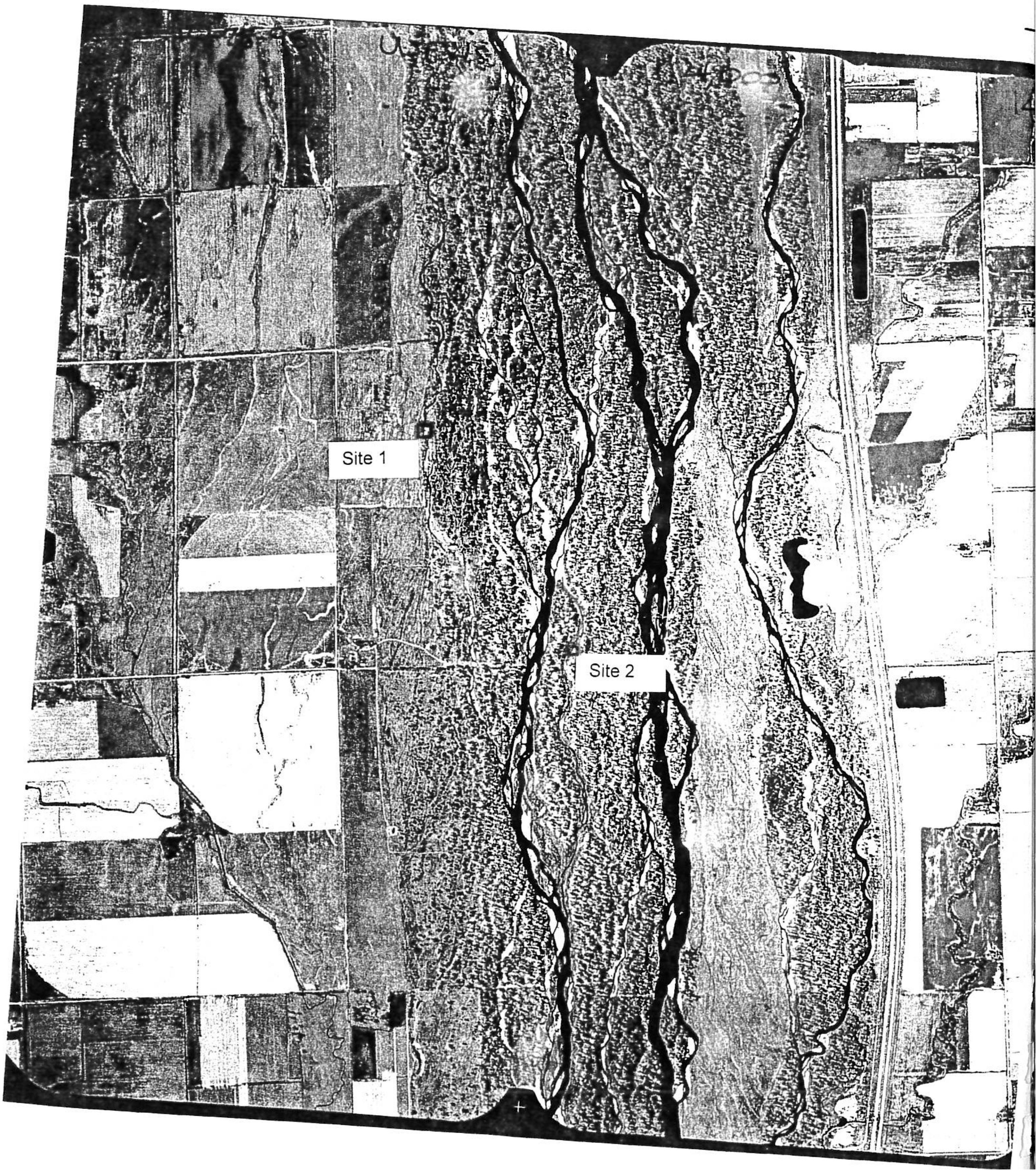

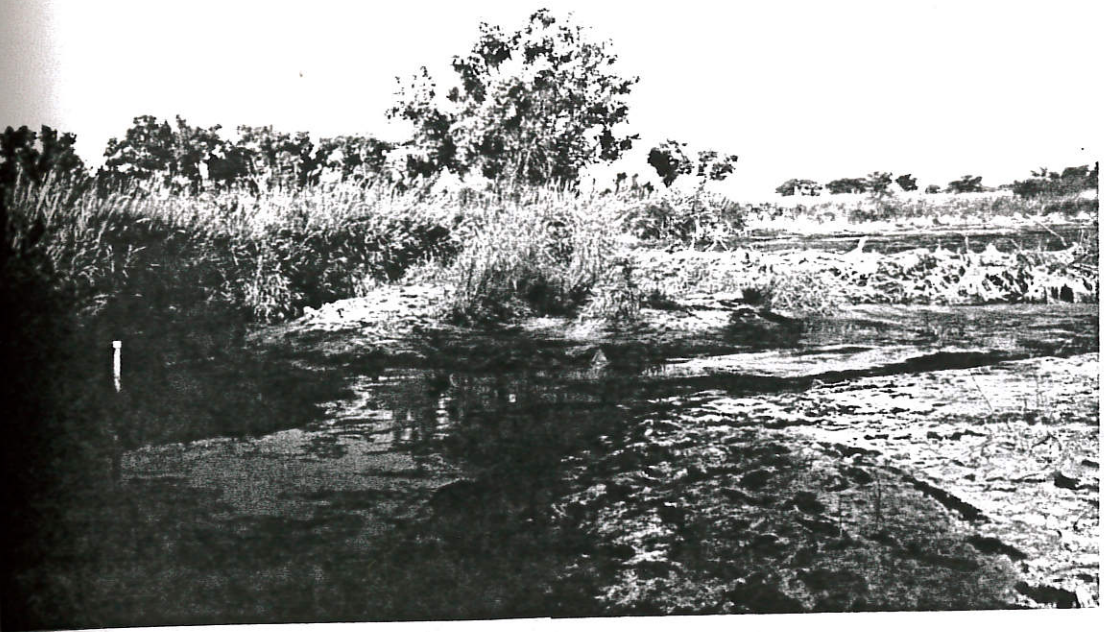

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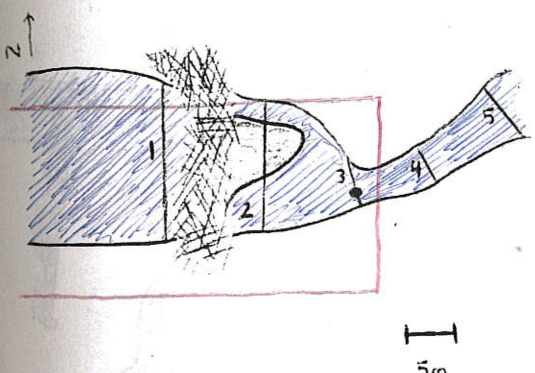

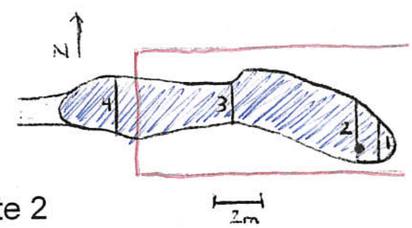

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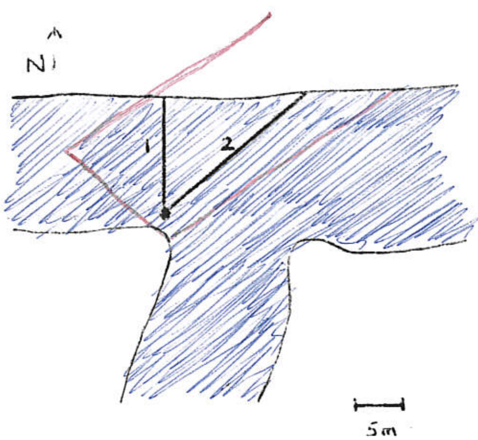

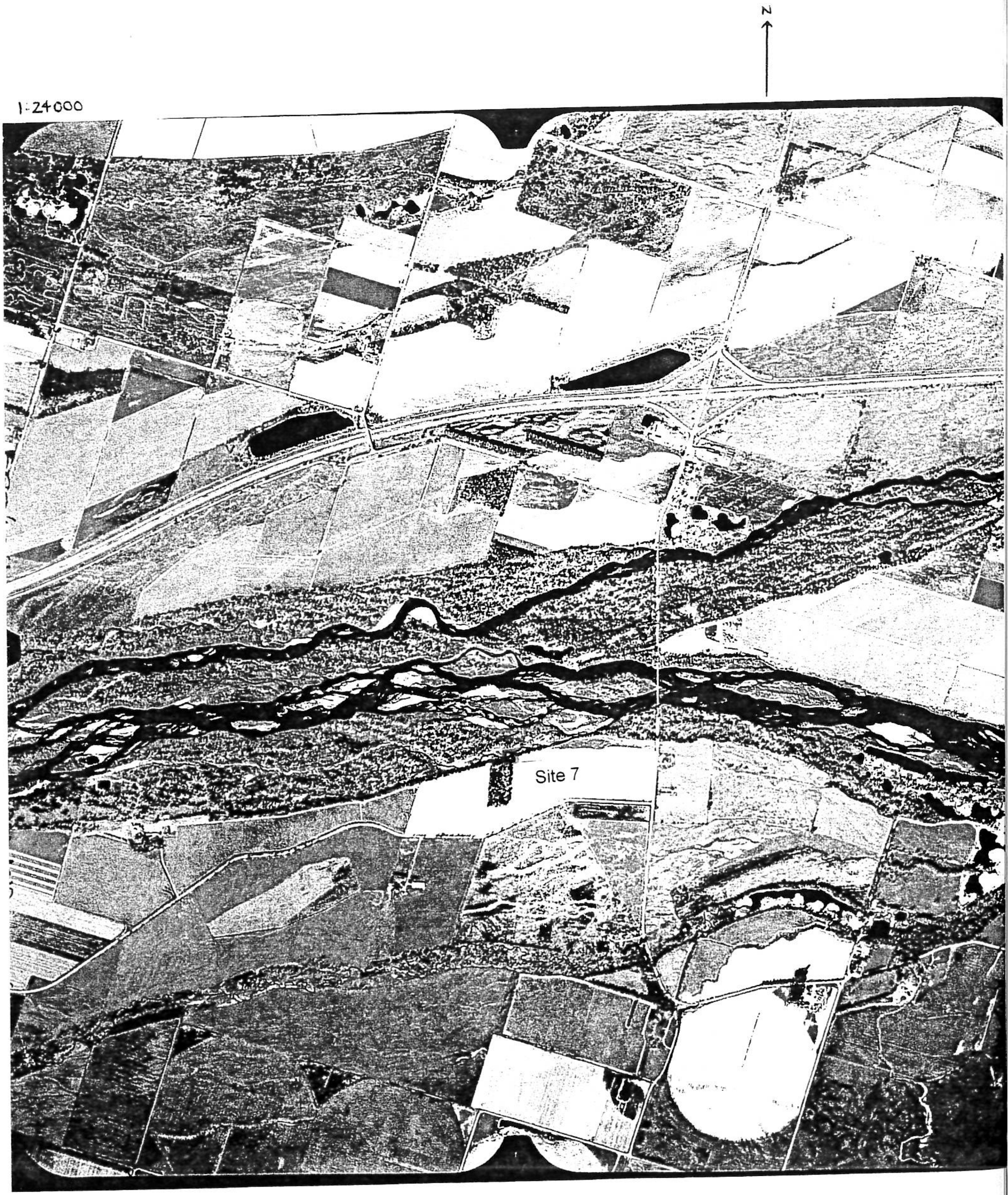
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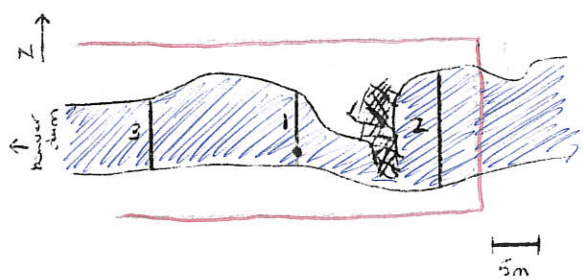
Site 7



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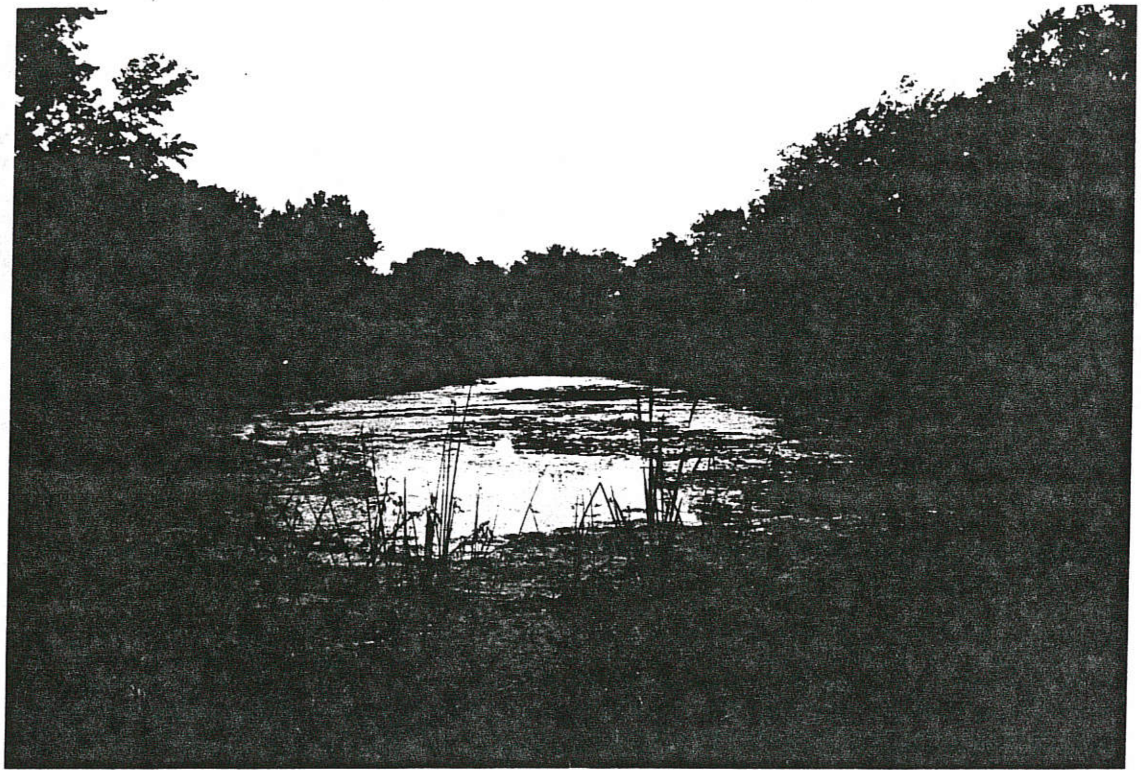

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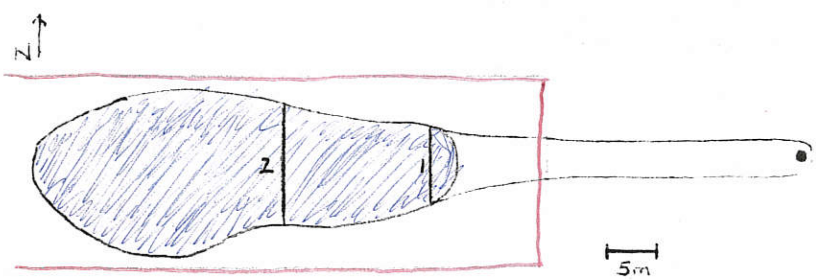

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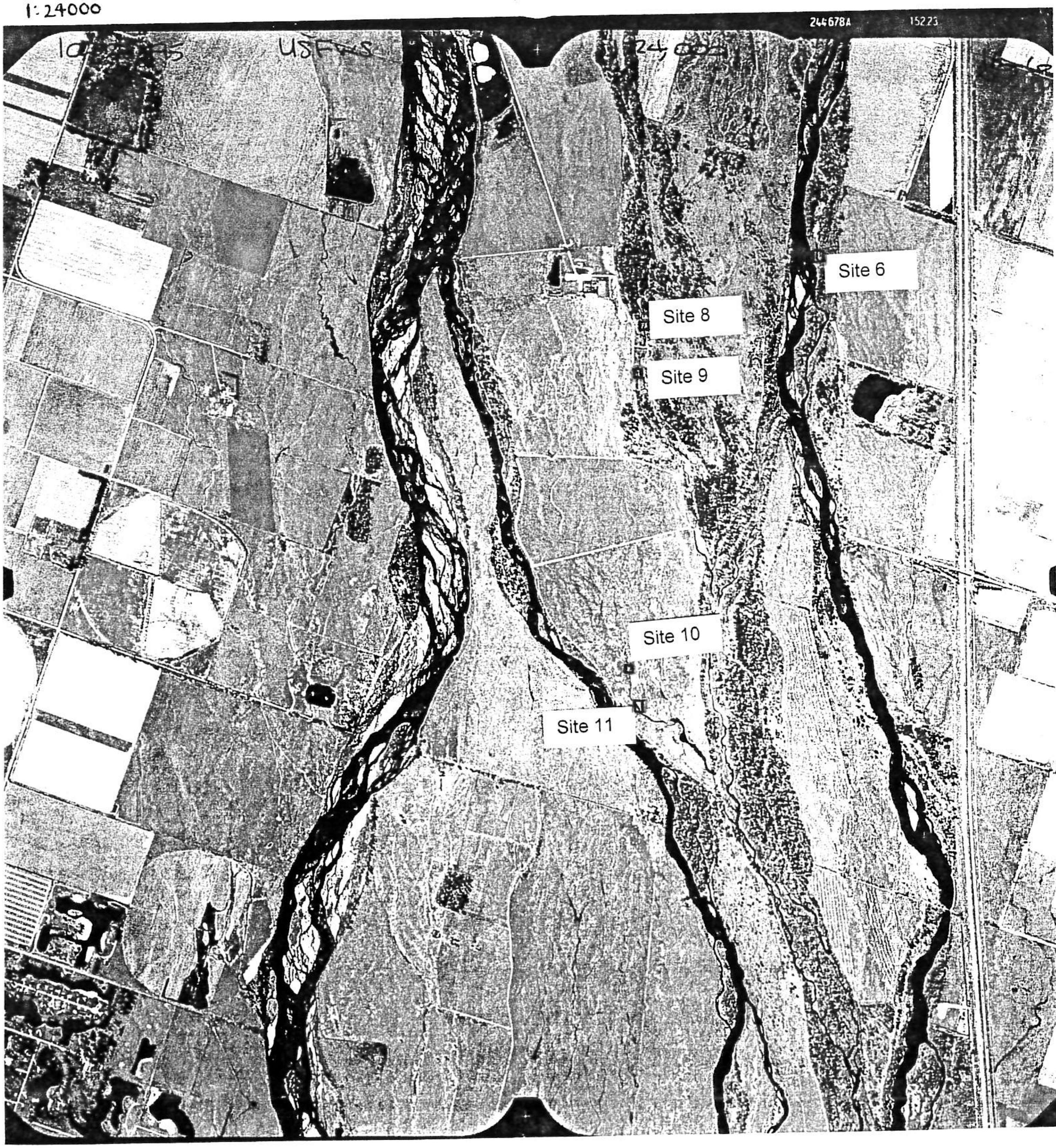

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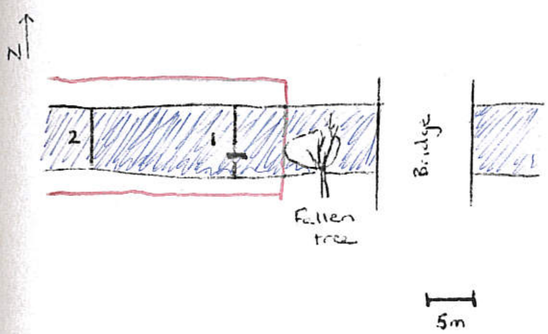
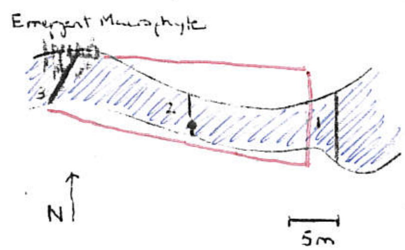
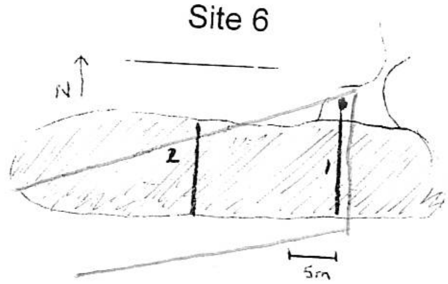


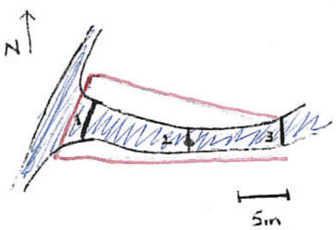


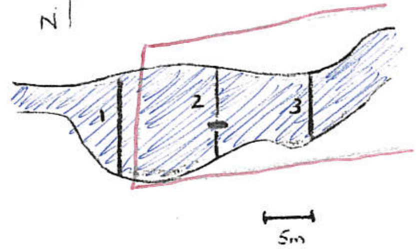
Site 9

Site 6



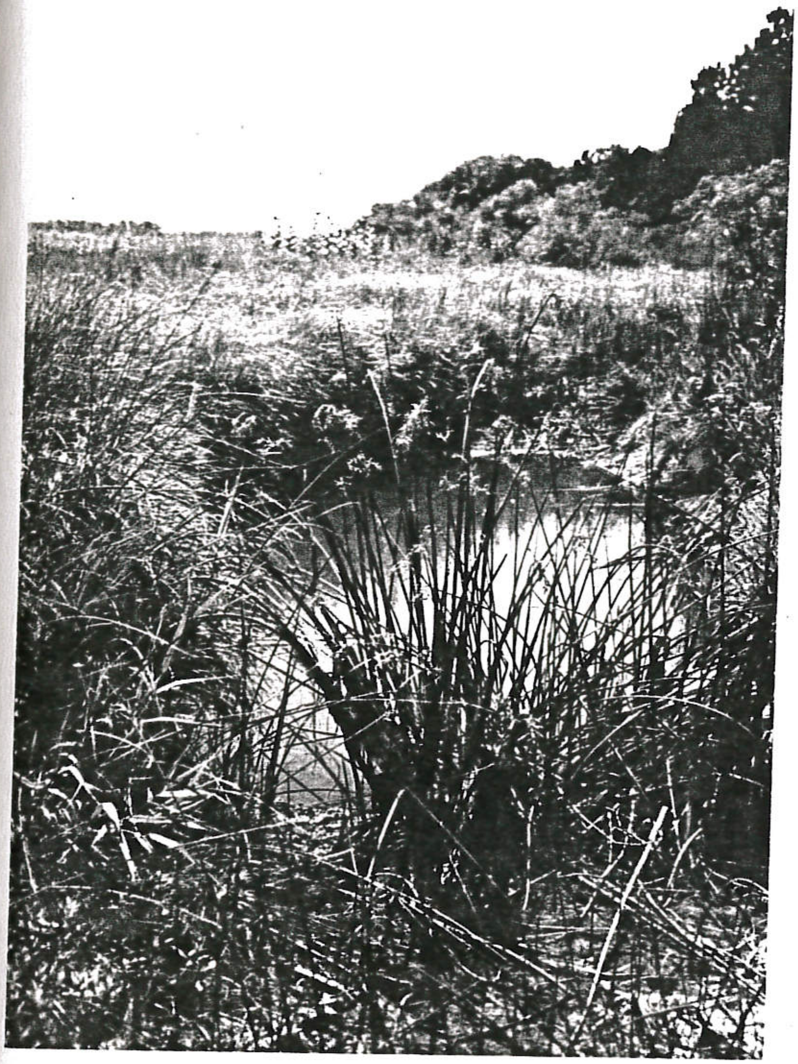
Site 10

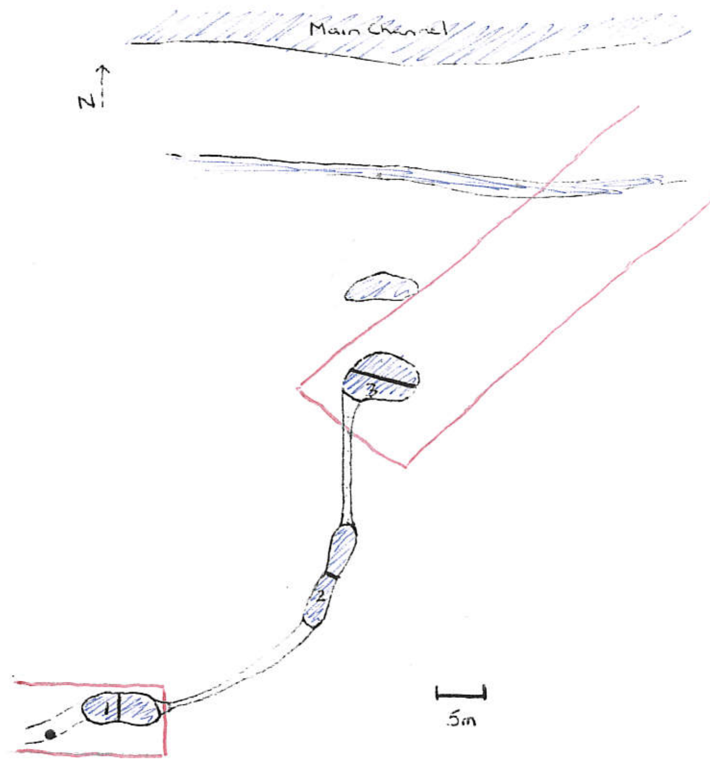




Site 11

1:24000





Site 5

Appendix B:

IHA "Score Card" as recommended by Richter et. al (1996).

For External Water Data

	Month with High Mean	Month with Low Mean	April Average	May Average	June Average	July Average	August Average	Julian Day with High	Julian Day with Low
Site # 1	6	8	59.30	50.30	61.00	16.40	11.50	97	216
Site # 2	4	7	26.00	20.67	20.30	3.75	4.67	112	207
Site # 3	6	8	47.00	31.12	50.63	33.44	7.83	175	222
Site # 4	6	4 and 8	0.00	0.50	19.22	4.75	0.00	177	143
Site # 5	6	4	0.00	0.33	16.00	2.50	3.50	168	136
Site # 6	6	7	40.00	31.77	45.78	10.44	16.11	177	210
Site # 7	6	7	45.25	44.62	60.78	20.56	26.57	176	211
Site # 8	6	4	21.00	20.33	20.00	16.85	19.25	227	210
Site # 9	8	5	--	26.00	37.78	38.00	39.44	227	141
Site # 10	6	8	26.20	27.14	33.27	24.12	21.17	163	223
Site # 11	6	8	33.83	30.71	34.80	18.62	16.93	117	216

	High on Three Day Scale	Low on Three Day Scale	High on Seven Day Scale	Low on Seven Day Scale	Number of High Pulses	Number of Low Pulses	Duration of High Pulses	Duration of Low Pulses	Number of Rises	Number of Falls
Site # 1	81.0	0.0	81.0	0.0	6	1	8	32	13	16
Site # 2	30.0	0.0	30.0	0.0	7	1	6	18	8	12
Site # 3	107.0	0.0	56.0	0.5	2	1	23	28	8	24
Site # 4	43.0	0.0	39.3	0.0	2	0	13	0	5	5
Site # 5	36.0	0.0	25.3	0.0	3	0	12	0	6	7
Site # 6	66.0	0.0	61.0	0.0	3	1	13	32	11	15
Site # 7	101.0	12.0	89.0	12.5	4	1	9	37	16	17
Site # 8	23.0	15.0	22.8	16.0	6	3	9	6	14	11
Site # 9	48.0	20.0	45.0	20.7	6	6	5	6	15	16
Site # 10	36.0	18.0	36.0	18.5	1	1	28	30	17	13
Site # 11	38.0	5.0	37.0	6.5	3	1	14	28	13	14

For Surface Water Data

	Month with High Mean	April Average	May Average	June Average	July Average	August Average	Julian Day with High	Julian Day with Low	High on One Day Scale	Low on One Day Scale
Site # 1	4	0.10	0.00	0.00	0.00	0.00	97	0	0.3	0.0
Site # 2	0	0.00	0.00	0.00	0.00	0.00	0	0	0.0	0.0
Site # 3	6	0.37	0.98	26.95	6.02	0.13	175	133	86.3	0.0
Site # 4	7	0.00	0.31	0.50	0.70	0.00	183	176	2.9	0.0
Site # 5	8	0.00	0.33	0.99	0.00	3.50	227	136	11.0	0.0
Site # 6	5	3.02	6.67	3.03	1.16	1.82	134	208	10.0	0.0
Site # 7	6	0.00	0.00	18.22	0.00	0.00	176	132	56.5	0.0
Site # 8	--	--	--	--	--	--	--	--	--	--
Site # 9	8	--	0.00	0.00	0.06	0.20	216	173	0.9	0.0
Site # 10	0	0.00	0.00	0.00	0.00	0.00	0	0	0.0	0.0
Site # 11	--	--	--	--	--	--	--	--	--	--

	High on Seven Day Scale	Low on Seven Day Scale	Number of High Pulses	Number of Low Pulses	Duration of High Pulses	Duration of Low Pulses	Number of Rises	Number of Falls
Site # 1	0.3	0.0	1	0	7	0	0	1
Site # 2	0.0	0.0	0	0	0	0	0	0
Site # 3	76.3	0.0	6	4	5	9	14	12
Site # 4	2.8	0.0	3	0	7	0	5	5
Site # 5	5.5	0.0	4	0	5	0	5	6
Site # 6	8.9	0.0	3	0	11	0	16	15
Site # 7	44.5	0.0	1	0	14	0	2	2
Site # 8	--	--	--	--	--	--	--	--
Site # 9	0.8	0.0	3	0	3	0	3	4
Site # 10	0.0	0.0	0	0	0	0	0	0
Site # 11	--	--	--	--	--	--	--	--

Appendix C:

A correlation table for IHA variables.

	Overall Water Level																	
	Month with High Mean	Month with Low Mean	Spring Mean	June Mean	July Mean	August Mean	Julian Day with High	Julian Day with Low	High on Three Day Scale	Low on Three Day Scale	High on Seven Day Scale	Low on Seven Day Scale	No. of High Pulses	No. of Low Pulses	Duration of High Pulses	Duration of Low Pulses	No. of Rises	No. Fall
Overall Water Level																		
Month with High Mean	1.000																	
Month with Low Mean	-0.286	1.000																
Spring Average	0.035	0.723	1.000															
June Average	0.236	0.610	0.910	1.000														
July Average	0.658	0.191	0.478	0.503	1.000													
August Average	0.677	-0.142	0.381	0.370	0.721	1.000												
Julian Day with High	0.607	-0.655	-0.335	-0.201	0.381	0.475	1.000											
Julian Day with Low	-0.421	0.735	0.731	0.496	0.201	0.057	-0.382	1.000										
High on Three Day Scale	0.138	0.479	0.677	0.872	0.407	0.084	-0.085	0.323	1.000									
Low on Three Day Scale	0.545	-0.275	0.055	0.011	0.609	0.849	0.581	0.004	-0.218	1.000								
High on Seven Day Scale	0.153	0.496	0.780	0.938	0.268	0.245	-0.212	0.328	0.866	-0.101	1.000							
Low on Seven Day Scale	0.546	-0.266	0.062	0.011	0.619	0.851	0.574	0.021	-0.221	0.999	-0.110	1.000						
Number of High Pulses	-0.111	-0.353	0.216	-0.004	-0.040	0.232	-0.061	-0.018	-0.168	0.105	0.029	0.100	1.000					
Number of Low Pulses	0.660	-0.418	0.114	0.043	0.660	0.803	0.583	-0.209	-0.142	0.706	-0.085	0.706	0.509	1.000				
Duration of High Pulses	-0.023	0.452	-0.014	0.035	0.246	-0.157	-0.005	0.357	0.114	0.062	-0.127	0.067	-0.845	-0.370	1.000			
Duration of Low Pulses	-0.189	0.894	0.866	0.805	0.279	0.206	-0.459	0.823	0.617	-0.043	0.697	-0.035	-0.157	-0.238	0.300	1.000		
Number of Rises	0.379	0.170	0.571	0.462	0.585	0.846	0.164	0.452	0.078	0.800	0.316	0.805	0.149	0.496	0.062	0.494	1.000	
Number of Falls	0.175	0.591	0.809	0.779	0.743	0.382	-0.034	0.584	0.750	0.092	0.566	0.103	0.026	0.252	0.204	0.684	0.374	1.00
Surface Flow																		
Month with High Mean	0.654	-0.631	-0.251	0.048	0.146	0.119	0.619	-0.677	0.274	-0.059	0.138	-0.054	-0.101	0.234	-0.296	-0.467	-0.274	-0.05
Spring Average	0.000	0.094	0.163	0.175	-0.157	-0.007	0.149	0.217	0.134	-0.300	0.158	-0.302	-0.197	-0.100	0.069	0.297	-0.065	0.13
June Average	0.000	0.333	0.401	0.526	0.446	0.025	0.192	0.411	0.839	-0.084	0.454	-0.066	-0.285	-0.126	0.301	0.438	0.006	0.71
July Average	0.008	0.352	0.194	0.252	0.406	-0.235	0.161	0.304	0.586	-0.317	0.085	-0.300	-0.383	-0.107	0.478	0.192	-0.312	0.63
August Average	0.041	-0.697	-0.446	-0.367	-0.445	-0.253	0.144	-0.423	-0.258	-0.325	-0.340	-0.329	-0.190	-0.247	-0.055	-0.357	-0.389	-0.36
Julian Day with High	0.631	-0.629	-0.247	0.054	0.162	0.124	0.637	-0.650	0.303	-0.047	0.135	-0.041	-0.127	0.217	-0.265	-0.442	-0.268	-0.01
Julian Day with Low	0.518	-0.482	-0.288	-0.028	0.080	0.150	0.776	-0.505	0.191	-0.048	0.053	-0.044	-0.286	0.194	-0.132	-0.322	-0.262	-0.04
High on Three Day Scale	0.007	0.274	0.352	0.486	0.420	-0.008	0.204	0.363	0.820	-0.111	0.415	-0.093	-0.304	-0.146	0.303	0.389	-0.040	0.68
High on Seven Day Scale	0.007	0.315	0.365	0.490	0.444	-0.016	0.199	0.384	0.821	-0.121	0.405	-0.103	-0.308	-0.131	0.327	0.396	-0.049	0.71
Number of High Pulses	0.375	-0.294	-0.218	-0.023	0.230	-0.194	0.494	-0.334	0.343	-0.325	-0.102	-0.313	-0.366	0.035	0.179	-0.322	-0.517	0.23
Number of Low Pulses	0.000	0.339	0.225	0.265	0.471	-0.197	0.112	0.319	0.591	-0.243	0.077	-0.225	-0.316	-0.069	0.470	0.195	-0.252	0.67
Duration of High Pulses	0.159	0.050	0.327	0.562	-0.097	0.091	0.160	0.080	0.641	-0.202	0.749	-0.200	-0.121	-0.219	-0.237	0.349	0.069	0.14
Duration of Low Pulses	0.000	0.339	0.225	0.265	0.471	-0.197	0.112	0.319	0.591	-0.243	0.077	-0.225	-0.316	-0.069	0.470	0.195	-0.252	0.67
No. of Rises and Falls	0.155	0.000	0.023	0.142	0.079	-0.150	0.381	0.050	0.376	-0.401	0.072	-0.393	-0.409	-0.098	0.243	0.084	-0.353	0.31

Surface Flow													
Month with High Mean	*Spring Mean*	*June Mean*	*July Mean*	*August Mean*	*Julian Day with High*	*Julian Day with Low*	*High on Three Day Scale*	*High on Seven Day Scale*	*No. of High Pulses*	*No. of Low Pulses*	*Duration of High Pulses*	*Duration of Low Pulses*	*No. of Rises and Falls*
1.000													
0.054	1.000												
0.224	0.003	1.000											
0.176	0.182	0.778	1.000										
0.395	0.372	-0.190	-0.107	1.000									
0.995	0.044	0.290	0.211	0.412	1.000								
0.807	0.491	0.233	0.251	0.372	0.809	1.000							
0.266	-0.003	0.997	0.785	-0.121	0.334	0.255	1.000						
0.244	0.013	0.996	0.824	-0.158	0.309	0.248	0.997	1.000					
0.722	0.237	0.493	0.741	0.390	0.739	0.681	0.539	0.553	1.000				
0.136	0.003	0.806	0.978	-0.151	0.179	0.119	0.816	0.850	0.688	1.000			
0.491	0.437	0.390	0.042	0.135	0.496	0.558	0.383	0.352	0.183	-0.053	1.000		
0.136	0.003	0.806	0.978	-0.151	0.179	0.119	0.816	0.850	0.688	1.000	-0.053	1.000	
0.408	0.782	0.429	0.675	0.389	0.422	0.704	0.447	0.469	0.768	0.530	0.399	0.530	1.000