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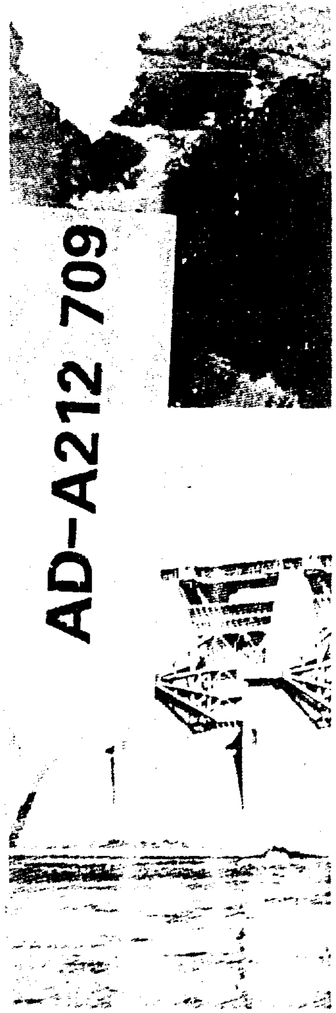
RESERVOIR BANK EROSION AND CULTURAL RESOURCES: EXPERIMENTS IN MAPPING AND PREDICTING THE EROSION OF ARCHEOLOGICAL SEDIMENTS AT RESERVOIRS ALONG THE MIDDLE MISSOURI RIVER WITH SEQUENTIAL HISTORICAL AERIAL PHOTOGRAPHS



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by

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This report reviews remote sensing capabilities for assessing archeological site erosion using sequential, historical aerial photographs. The utility of photointerpretation for measurement of bank erosion is explored to empirically document impacts to threatened reservoir-side archeological sites and to model factors affecting differential rates of erosion between and within such sites. The processes of bank and beach erosion are long term in nature, and sequential, historical aerial photographs offer one of the best time-series data sources for studying reservoir bank erosion.

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SUMMARY

In this research, remote sensing capabilities for assessing archeological site erosion rate have been evaluated using sequential, historical aerial photographs. Specifically, the utility of photointerpretation for measurement of bank erosion using sequential, historical aerial photographs was explored to empirically document bank erosion threatening reservoir-side archeological sites and to model factors affecting differential rates of erosion between and within such sites. Efforts directed toward developing a definitive and comprehensive model of bank erosion by previous researchers have been based upon on-the-ground measurements of bank recession. The variable results of this research are at least partially due to the long-term nature of the process of bank and beach erosion that cannot be monitored with sufficient time depth by contemporary measurements. In contrast, aerial photographs offer one of the best time-series data sources available for studying bank erosion.

Analysis of the phenomenon of bank and site erosion has been undertaken at several different scales: (a) the site, as more or less arbitrarily defined by the extent of cultural features like housepits or palisade ditches; (b) bank erosion and variability in that erosion with site areas defined as being 2 km along active banks centered upon the site itself; and (c) bank erosion, and its predictability, from the perspective of the overall Middle Missouri River system.

Twelve major archeological sites situated on Corps of Engineers reservoirs in North Dakota, South Dakota, and Nebraska and chosen for study are a small sample of archeological sites currently endangered by bank erosion. The situations in which these sites are found, including the specific mechanisms and determinants of bank erosion there, may not be representative of all bank erosion situations on the reservoirs studied. Therefore, these sites were believed to be representative, to some extent, of erosionally endangered cultural resources and their situations on Middle Missouri River reservoirs.

Aerial photographs obtained from a number of government repositories include those from the National Archives dating to the late 1930's that show baseline, nonreservoir erosion prior to the next series generally available from the late 1940's to mid-1950's. Contact prints spanning the year 1949 through the present with large-scale aerial photographs dating from the early

1970's to the present were provided by the US Army Engineer District, Omaha. Stereo photointerpretation focused on criteria best distinguishing an erosional bank from a beach or waterline.

At the largest and most specific spatial scale, an electronic enlargement/enhancement process was developed to examine bank erosion of the immediate site area. Site area, defined on the basis of photointerpretable indications of cultural features on the ground, was mapped and measured digitally for successive aerial photographs. Change in site area through time is linear, although the slope of this relationship differs among the three sites examined. Regression analysis yielded site-area decay curves with extinction dates predicted through the use of regression equations for three example sites. The fact that a linear regression model fits the decay curves suggests that erosion rates are relatively constant through time. While a sigmoidal model may describe bank erosion through time, the photograph dates available document only the middle, near-linear part of the model.

At a smaller, more general scale, measurement of bank erosion focuses on a 2-km segment of shoreline centered on sites considered. Using 1:10,000-scale base maps of a 2-km by 2-km quadrat centered on each site, the historical sequence of photographs of each site were inspected for site specific manifestation of beach, bank, and waterline and the positions of control points on both the photos and base map. Transects placed at 100-m intervals along the waterline, oriented perpendicular to the gradient or slope just inland from the waterline, serve as objectively determined points along which bank movement could be measured on successive photos. Using digital calipers, the amount of displacement between the baseline (earliest) location of the bank and the position of the bank interpreted from each stereo pair at each of 21 transects was measured. Calculating the distance between each successive shoreline and dividing these data by the time elapsed between each photographic overflight date allows the derivation of a rate in metres per year of recession between consecutive overflight dates. To facilitate the identification of major factors influencing bank erosion, independent variables measured included gradient of the land at the intersection of the transect with the baseline shoreline, presence or absence of beach, aspect of the bank or shore, fetch, pool level fluctuation, and soils properties.

The mean bank recession rate at individual sites, derived by averaging measurement over all 21 transects, indicates an erosion rate of about 2.5 m or

8 ft per year with most sites ranging between 1.8 and 3.08 m per year. These rates are consistent with and in some cases higher than previously reported erosion rates based on aerial photogrammetry.

Results of regression analyses show that these bank recession rates are to some extent at least predictable through reference to physically measurable, independent variables. Regression analyses designed to model rates between measurement dates using temporal pool level data did not prove to explain a very large proportion of variability in rates. It is possible that the low values derived from the use of pool management data are due to the fact that variations between measurement dates may be caused by the combined effects of unique, high energy events between dates.

Regression analyses, modeling recession rate with nontemporal data, suggest important differences between reservoirs. While combined site (12 study sites) predictions using nontemporal data had low regression values, using only aspect and fetch data did allow the explanation of between 17 and 40 percent of the spatial variability in transects in all sites within single reservoirs. Parameter estimates calculated for regression equations within specific reservoirs indicate that aspect is probably the most constant estimator--that is, it has similar effects at all reservoirs. The effects of the fetch variables differ more among reservoirs, indicating that there may be important differences in the shapes of shorelines rather than simply the directions they face that may be influencing bank erosion.

Projection of bank recession rates indicates, in some cases, that major archeological sites on Middle Missouri Reservoirs will be entirely destroyed within the next 15 to 30 years. These results indicate that archeologically relevant bank erosion can be measured using sequential aerial photographs. Although mean bank erosion rates at Middle Missouri River study sites are high enough to be of immediate concern to archeologists, it is also apparent that bank erosion rates are, at the same time, extremely variable even within sites. This variability is in large part the result of natural factors and may, therefore, be predictable and, thus, a realistic basis for prioritizing cultural resource concerns.

Finally, photointerpretation noted unrecorded features and sites, in fact continuous sites in some cases, along the bank within and beyond the 2-km segments inspected. These findings underscore the value of cumulative photointerpretation of a series of aerial photographs of different dates and types, and also suggest that in many places along the Missouri River it is not sites <u>per se</u> which may be of archeological significance but entire stretches of bank for which erosion potential must be predicted.

PREFACE

This study was conducted under Work Unit 32357 of the Environmental Impact Research Program (EIRP). The EIRP is sponsored by Headquarters, US Army Corps of Engineers (HQUSACE) and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Technical monitors were Dr. John Bushman, Mr. David P. Buelow, and Mr. Dave Mathis of HQUSACE. Dr. Roger T. Saucier, EL, WES, was the EIRP Program Manager.

The study was performed by Ebert and Associates, Albuquerque, NM, under Contract No. DACW39-86-C-0071. Dr. James I. Ebert served as principal investigator. The report was prepared by Dr. Ebert, Dr. Eileen L. Camilli, and Ms. LuAnn Wandsnider and was edited by Mrs. Gilda Miller, WES, Information Technology Laboratory, Information Products Division.

Technical reviewers of the report included the following Corps of Engineers personnel: Dr. F. Douglas Shields, Ms. Anne MacDonald, Mr. Robert J. Larson, and Dr. James J. Hester, all of WES, EL; Dr. Lawrence W. Gatto, Cold Regions Research and Engineering Laboratory; Ms. Ellen Cummings, Missouri River Division; and Messrs. Richard Berg and Edward Brodnicki, US Army Engineer District, Omaha.

The study was conducted under the direct supervision of Dr. Shields and under the technical editorial supervision of Dr. Hester, who was serving at WES under an Intergovernmental Personnel Act agreement with the University of Colorado during the time of the study. The supervisory work was performed in the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, WES. Dr. Paul R. Schroeder, acting, and Dr. John J. Ingram supervised the work as Chiefs of WREG; under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL.

Acting Commander and Director of WES during preparation of the report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.

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* Appendixes A and B are not reproduced herein but are available from the US Army Engineer Waterways Experiment Station.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiple	By	To Obtain
degree (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

RESERVOIR BANK EROSION AND CULTURAL RESOURCES: EXPERIMENTS IN MAPPING AND PREDICTING THE EROSION OF ARCHEOLOGICAL SEDIMENTS AT RESERVOIRS ALONG THE MIDDLE MISSOURI RIVER WITH SEQUENTIAL HISTORICAL AERIAL PHOTOGRAPHS

PART I: INTRODUCTION

Research: Orientation and Goals

1. This research was proposed in response to the US Army Engineer Waterways Experiment Station (WES) Broad Agency Announcement of November 1985, under topic EL-15, "Conservation of Archeological Sites," topic 7, "Remote sensing capabilities for assessing erosion rates, determining site extent, location, condition, and monitoring."

2. Specifically proposed was an analysis of the utility and appropriateness of using sequential, historical aerial photographs to identify the factors contributing to the erosion or stability of a representative sample of large, significant, and erosionally threatened archeological sites located on Corps of Engineers reservoirs along the Middle Missouri River.

3. There are two major and complimentary thrusts to this research. The first is methodological in nature, focusing on the development of efficient and practical methods for detecting and measuring progressive erosional changes in reservoir-related archeological sites. The second major thrust of this research involves the identification of different types, mechanisms, and rates of erosion and deposition at the Middle Missouri River study sites from sequential aerial photographs. While it was envisioned that a taxonomy of different processes contributing to site change would be compiled, along with a photointerpretive key to their identification, it soon became apparent that, for reasons detailed later in this report, reservoir bank erosion (and associated aggradation in some places) is virtually the only significant process affecting the integrity of the sites studied. A photointerpretive key was compiled to aid in the interpretation of bank erosion from sequential aerial photographs.

4. Deriving a definitive and comprehensive model of bank erosion processes is beyond the scope of this research. Many previous researchers from

the Corps of Engineers and other agencies have directed their efforts toward this goal. Our research, instead, is intended to supply the beginnings of a set of methods through which archeologists, confronted with reservoir and other water-body related threats to archeological sites, can utilize data derived from sequential, historical aerial photographs to detect, measure, and define the progression of bank recession.

5. The use of historical, sequential aerial photographs is central to this goal. Many recent researchers interested in the processes of coastal and reservoir bank erosion in general have based their research upon on-the-ground, contemporary measurements of bank and beach recession, with variable results. This may, in part, be because bank and beach erosion is a long-term process, and contemporary measurements do not yield the time-depth necessary to define long-term variability in the processes that cause such erosion. Others have used historical aerial photographs, again with variable results. Nonetheless, as discussed at length later in this report, we feel that aerial photographs offer one of the best data sources available for studying bank erosion.

6. In the course of this research, we have attempted to make some statements about the causes and predictability of erosion and erosion rates, and how these might be correlated with measurements taken from sequential aerial photographs. Suggestions are made in this report about the sorts of hydrologic, sedimentological, and other data, such as that concerning local climatological variation, that might be needed to explain bank erosion so detected and measured.

7. This research focuses on 12 major archeological sites along the banks of Corps of Engineers reservoirs in North Dakota, South Dakota, and Nebraska (Figure 1). These sites are, of course, a small sample of those archeological sites currently endangered by bank erosion, even along reservoirs in those states. We do not suggest that the findings determined from the study of these sites are representative of conditions at all reservoir-side sites at these or other reservoirs. The study sites were chosen, however, because they were believed to be to some extent representative of archeological sites, and their situations, on these reservoirs.

8. It should also be noted that the situations in which archeological sites are found, and therefore the mechanisms and determinants of bank erosion in those places, may not be in general terms representative of all bank

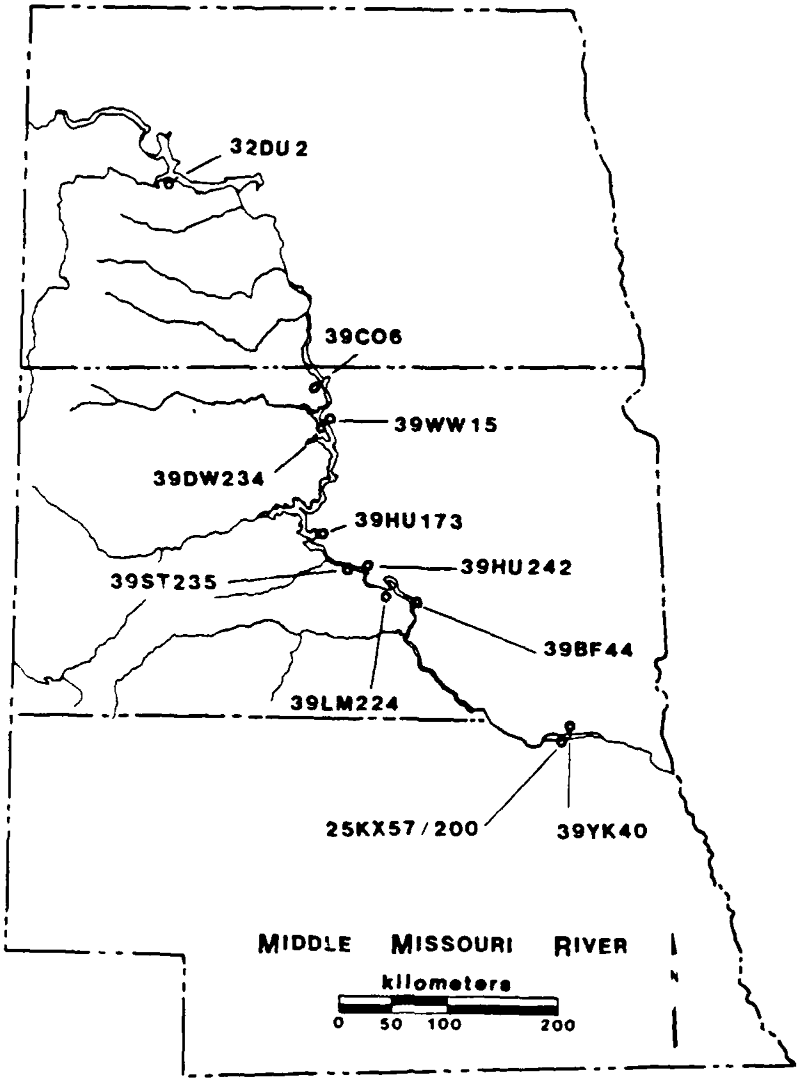

Figure 1. Locations of the 12 study sites in North Dakota, South Dakota, and Nebraska

erosion situations on the reservoirs studied, or in fact in any reservoir situation. Large archeological sites are generally thought to have been villages occupied either intensively with large populations or over considerable periods of time. It is quite likely that many careful considerations went into locating the places in which such sites were situated, and that their locations are therefore somewhat unique. In addition, the intensive cultural occupation of specific areas may affect certain sedimentological characteristics of those places, including sediment disturbance due to the digging of house and refuse pits, and the concentration of organic materials in sediments. These characteristics may affect the erodibility of sediments, and cause erosion in these places to be different than that of the reservoir shoreline in general. While we would not automatically extend our findings to bank erosion along reservoirs in general, we do feel that the methods of investigation presented here represent a good starting point for investigation of overall reservoir bank erosion.

9. Products resulting from the conduct of this research include semi-controlled base maps representing bank position through time for each site, a photointerpretive key for recognizing and interpreting bank positions, a description of methods and techniques used in this study, and tabularized data on bank position and erosion rates through time including a summary of erosion rates at each study site. These are represented through the use of several types of graphs. The factors which analyses suggest as being responsible for, or at least correlated with, regional and local bank erosion on the Middle Missouri River reservoirs are also summarized.

10. Recommendations are made concerning further research which could reinforce, amplify, and support the results of this research. In order to accomplish this goal, models which may aid in the explanation of the mechanisms and progress of bank erosion at the study sites are advanced in an attempt to explain these processes, their progression over time, and the variables that would have to be inspected over time in an attempt to verify these models.

Setting of Missouri River Terraces

11. The Missouri River Basin drains an area of 1,354,564 km^2, one-sixth of the contiguous United States, within the Rocky Mountains, Interior Plains, and Interior Highlands physiographic systems (Slizeski, Andersen, and Dorough 1982). Annual precipitation within its basin ranges from 25 to 127 cm per year, depending upon whether mountain snows or seasonal rainfall supply that water. Thus, the Missouri River was in its normal historical state subject to devastating seasonal floods and dry periods which limited the navigation capacity of the river system as a whole. In response to these problems, the Corps of Engineers and others instituted, beginning in the 1930's, a series of reservoir building projects to ameliorate these effects and to ensure a navigable width and depth of not less than 91.4 and 2.7 m, respectively (Slizeski, Andersen, and Dorough 1982). By 1965, the Missouri River basin contained 107 major reservoirs and 1,387 other, smaller reservoirs providing a total storage

capacity of over 1.38 by 10^{11} cu m of storage capacity (Slizeski, Andersen, and Dorough 1982).

12. The hydrology of the Missouri River basin is a "study in hydrological extremes" (Slizeski, Andersen, and Dorough 1982). The delay in snowmelt in the western extremes of the basin relative to that of the plains results in a characteristic "June rise" that both threatens flood damages downstream and supports agriculture in semiarid western regions. When regulated, this flow also provides a basis for year-round hydroelectric power generation as well as allowing navigation downriver.

13. Planned as early as the 1930's, the Missouri River Bank Stabilization and Navigation Project had as its primary objectives flood control, bank stabilization, land reclamation, hydroelectric power generation, and development and maintenance of a navigation channel.

14. In the ultimate furtherance of these objectives, six major dam/reservoir systems were installed along the Missouri River between 1946 and 1963. While furthering all of the engineering contingencies envisioned by the Corps of Engineers, Middle Missouri River reservoir construction has also created a situation that causes occasional unique erosional threats to archeological sites located along the terraces of the Missouri River.

15. Reservoirs are designed, and dams located, to effect optimal reservoir filling along river terraces--that is, reservoirs are filled to almost the vertical extent (but not quite) circumscribed by upstream terraces. Thus, in most places, reservoir levels lap against but somewhat below the maximum extent of containing terraces creating a geomorphological situation in which terrace margins are subjected to active and continuous bank erosion. Whereas this problem might not be one of import in regions where river terraces are comprised of highly resistant sediments, this is not the case in the Missouri River ecosystem. The sediments against which wave and wind action encroach along the Middle Missouri terrace system are largely composed of relatively incompetent shales and overlying sands and silts.

16. Although the steps or terraces characterizing the physiography of the original Missouri River valley are not everywhere present, at least five major terraces are present in some reaches of the river in the Dakotas in recent times. This is evidenced by accounts ranging from those of early historic explorers and geologists, as well as in the course of more recent studies (Coogan 1987). These terraces have been mapped along the Missouri River

between Fort Thompson and Pierre, South Dakota by Coogan (1987). They have been designated as Coogan and Irving (1959):

MT-0	The flood plain terrace of the modern river.
MT-1	A terrace about 35 ft (11 m)* above the modern river at Crow Creek, south of Fort Thompson, exposed at Lower Brule in the 1950's before the dam at Fort Thompson was closed.
MT-2	A terrace about 100 ft (35 m) above the present river level evident at Fort Thompson at 1,420 to 1,460 ft.
MT-3	Terrace about 200 ft (65 m) above the river evidenced on the north side of the Big Bend Reservoir in southern Hughes County at about el 1,510 to 1,540 ft**
MT-4	This terrace represents the lower slopes of the Coteau du Missouri (Coogan 1987), and can be seen east of Joe Creek in Hughes County, South Dakota.

17. The stratigraphy of each of these terraces consists of four major units (Coogan 1987), deposited on the Cretaceous Pierre Shale into which the Missouri Trench was originally cut. Overlying this bedrock unit are, in most places, a layer of gravel, then one predominantly of sand, and lastly one of eolian silts (loess). The latest, loess layer contains bands of humic material representing the remnants of palaeosols, which occasionally also occur in the sand layer. Stratigraphy is actually somewhat more complex than this scenario in most places, the result of numerous episodes of local cutting and filling in the Holocene.

18. Archeological remains have been found on all of these stratigraphic layers as well as on the present ground surface. Coogan (1987) has undertaken the task of unraveling the history of these terrace cuts to determine the relationship between terrace fills and Pleistocene and Holocene events to provide a framework for time-stratigraphic dating of archeological sites within the Missouri River Valley province. Working with Irving (Coogan and Irving

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* A table of factors for converting non-SI units of measurement to SI (metric) units in presented on page 9.

** All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD) of 1929.

1959) and building upon the work of Clayton, Moran, and Bickley (1976), Coogan derived a complex chronology of surfaces consisting of at least five "stable episodes" separated by less stable, cutting, and filling episodes, spanning the last 15,000 years. He concludes, among other things, that thin Holocene sediments mantling the Missouri terraces and bedrock of the Missouri River trench contain all presently known unburied and buried archeological sites in the region, that the predominant regime during the Holocene was erosional, and therefore that one cannot depend upon any sort of rule of thumb that buried sites are older than unburied ones. Most known significant Missouri River sites, from Paleoindian to historical times, lie on or within the uppermost layers of sediment on the Missouri River terraces.

19. Investigation of bank erosion on Middle Missouri River Reservoirs, thus, entails consideration of a number of important properties which include such facts as:

a. When reservoirs are filled, a preformed shore and bank situation exists due to the fact that terraces are already there, in place. Terrace surfaces are very flat, while the banks against which the reservoir waters lap have a very steep gradient, approaching vertical in some cases, broken only by intermittent minor drainages which have dissected terrace margins.

b. Bank erosion is directed, in the study area, against relatively incompetent sediments including eolian loess, silt, sand, gravels, and shales.

c. When reservoirs are filled, erosive actions are immediately directed toward a shoreline that has not, in the past, been subjected to such forces. In the literature on reservoir bank erosion, it has been suggested that this occasions an initial period of accelerated bank erosion that should soon taper off as the bank reaches equilibrium. As will be detailed later in this report, this is either not the case within our study areas, or such equilibrium has apparently not been reached in the more than 35 years since the filling of some reservoirs.

d. Due perhaps to the preferences of prehistoric peoples in the area, many large and significant archeological sites are perched immediately on the edges of terraces, and are thus in imminent danger of impact from bank erosion.

Middle Missouri River Region Archeology

20. The Middle Missouri subarea of the Northern Plains has hosted four major periods of prehistoric occupation. The 12 archeological sites examined in this study represent occupations attributed to the Paleoindian Period

(10000 to 6000 B.C.), the Plains Archaic Period (6000 B.C. to A.D. 1), the Plains Woodland Period (A.D. 1 to 900), and the Plains Village Period (A.D. 900 to 1860). While extensive discussions of human occupation of Northern Plains can be found elsewhere (Caldwell and Henning 1978; Frison 1978; Lehmer 1971; Wedel 1961), this brief summary is intended to place the sites examined here in perspective with respect to Middle Missouri prehistory.

Paleoindian Period
(ca. 10000 to 6000 B.C.)

21. Paleoindian sites have produced the earliest documented evidence for human occupation in the Plains with much of this evidence coming from sites in the Northwestern Plains. Most Paleoindian manifestations identified from the presence of finely-flaked lanceolate projectile points and extinct Pleistocene megafauna are kill and butchering sites. These sites offer ample evidence for exploitation of Pleistocene megafauna, principally mammoth and bison. The Paleoindian subsistence economy may have been much more diversified, however, and may have included a wider variety of mammals and reliance on plant resources. Faunal remains from Travis 2 (Ahler et al. 1977) in South Dakota include the remains of bison and deer or antelope occurring in equal frequencies. Elsewhere on the Plains, the variety of mammals represented includes deer, sheep, antelope, bison mammoth, camel, beaver, rabbit, elk, rodents, and canids (Frison 1974, 1976; Frison et al. 1978; Frison and Bradley 1980; Wheat 1972, 1979; Wilmsen 1974). The presence of ground-stone tools at sites such as Lindenmeier (Wilmsen 1974) also indicates reliance on plant resources.

22. Despite the enormous effort put forth by the Federal archeological salvage programs carried out during the 1950's and 1960's, recorded Paleoindian and Archaic occupations in the Middle Missouri subarea are not numerous. Lack of abundant remains attributable to this period stems chiefly from that fact that sites representing early periods are not highly visible. Sites either contain sparse accumulations of material or have been deeply buried (Wood, Nickel, and Griffin 1984). Recent erosion along reservoir shorelines has exposed previously buried archeological materials at Travis 2 (39WW15) and Walth Bay (39WW203) in South Dakota (Ahler et al. 1977; Weston, Goulding, and Ahler 1979).

Plains Archaic (ca. 6000 B.C. to A.D. 1)

23. The Plains Archaic is best known from sites in the Northwestern Plains (Frison 1978) and least known in the Central and Northern Plains subareas (Wood, Nickel, and Griffin 1984). The Archaic subsistence pattern was one based on a wide range of resources including reliance on plant resources (Frison 1978). Early Plains Archaic (ca. 5500 to 3000 B.C.) components are rare on the Plains, their paucity attributed to absence of landforms and sediments of appropriate antiquity and to destruction or burial of floodplains dating to this period (Reeves 1973). Early Plains Archaic occupations have been recognized, however, at Travis 2 (Ahler et al. 1977) and Walth Bay (Ahler et al. 1974) in South Dakota.

24. The variety of projectile point types attributed to the Middle Plains Archaic (3000 to 1500 B.C.) include McKean, Hanna and Duncan types. This period is recognized for an increased emphasis on plant foods (Frison 1978) and the appearance of roasting pits and stone circles. McKean sites have been found in South Dakota in the Black Hills area (Sanders et al. 1987). The Late Plains Archaic period (ca. 1500 B.C. to A.D. 1) is noted for the distinctive corner-notched projectile points referred to as Pelican Lake. Pelican Lake sites have been found in South Dakota around the Black Hills and in northeastern portions of the state (Haug 1976; Nowak, Hannus, and Lueck 1982). Later large, side-notched dart-type points known as Besant are attributed to a culture with highly organized bison hunting techniques revolving around use of corrals (Frison 1978; Wettlaufer 1955). Besant manifestations are included in the Late Plains Archaic by Frison (1978) and have also been attributed to later Plains Woodland occupations.

Plains Woodland Tradition (ca. A.D. 1 to 900)

25. Sites with Plains Woodland Tradition components are best known from the Central Plains and the Northwestern Plains subareas from the Missouri River eastward (Wood, Nickel, and Griffin 1984). The Plains Woodland yields the first evidence of ceramic manufacture and domesticated plants, but perhaps is more widely recognized as the period of mound construction on the plains. Kansas City Hopewell or Middle Woodland sites along the Missouri River in the eastern Central Plains include large open air habitations and campsites located in the river bottoms (Caldwell and Henning 1978; Johnson 1976).

Although early evidence of cultigens is present, most Woodland occupations represent a hunting and gathering subsistence pattern supplemented by agriculture (Johnson 1976; Wedel 1961).

26. Deposits yielding Woodland components represented by thickened cord-roughened ceramics and medium to large stemmed or corner-notched projectile points were known from early investigations of Middle Missouri sites (Wedel 1961) and have been noted as rather common in the Middle Missouri subarea of the Plains (Toom and Picha 1984). Woodland sites consist of campsites containing large quantities of bison bone, bone tools, shell, ceramic-chipped and ground-stone tools, and Besant projectile point types, although mound locations are more commonly known (Neuman 1975). Toom and Picha (1984) attribute the apparent higher frequency of mound sites to their higher visibility and to deeply buried contexts of campsites.

Plains Village Tradition (A.D. 900 to 1862)

27. The subsistence strategy during the Plains Village period was based on horticulture practiced in bottomland and riverine settings and bison hunting. Cultigens included corn, beans, squash, and, occasionally, sunflower. Plains Village sites consist of permanent settlements composed of earth-lodge structures some of which are surrounded by ditch or other type of fortification (Lehmer 1971; Wedel 1978; Wood, Nickel, and Griffin 1974). Middle Missouri subarea villages were situated on the floodplain and on level terraces overlooking the extensive bottomlands of the Missouri in the vicinity of tributary drainages. Although earth-lodge villages are a central feature of this period, dwellings and villages appear to have been seasonally occupied. Site types other than extensive earth-lodge villages are not as well known but include isolated earthlodges, campsites, burials, and artifact scatters.

28. Ceramic inventory, earth-lodge shape and construction, general artifact inventory, presence of fortifications, and geographical distribution have been used to distinguish between the two Plains Village traditions. The Middle Missouri Tradition was thought to have originated in the eastern woodlands or to have developed in place from the Plains Woodland Tradition (Lehmer 1971) and the Coalescent Tradition to have emerged from the Central Plains. Lehmer divides the Middle Missouri Tradition into the initial (A.D. 900 to 1400), extended (A.D. 1100 to 1550) and terminal (A.D. 1550 to 1675) variants. Subdivisions of the Coalescent Tradition are the initial (A.D. 1400 to 1550),

extended (A.D. 1550 to 1675), postcontact (A.D. 1675 to 1780) and disorganized (A.D. 1780 to 1862) variants. Recent studies have called for revision of the above taxonomy, some concluding that differences between variants may be more apparent than real (Steinacher 1983).

29. The coalescence of village lifeways has been viewed as culminating with the Arikara, Mandan, and Hidatsa village tribes. Great smallpox epidemics in 1780 and 1781, 1801 and 1802, 1837 and 1838, and 1856 decimated the populations of large villages along the Middle Missouri River with 30 to 98 percent mortality rates (Lehmer 1971), while measles, chickenpox, and cholera also took their toll. The sites examined in this study were selected by the US Army Corps of Engineers because they represent significant archeological resources on the Middle Missouri presently threatened by bank erosion. These sites are representative of the range of occupation periods reviewed present in the Middle Missouri subarea. Of the Plains Village sites examined, Molstad (39W234), Whistling Elk (39HU242), Jake White Bull (39CO6), and the Cable Site (39LM224) are presently listed in the National Register of Historic Places. The majority of evidence for the village way of life of past peoples on the Plains is contained in village sites such as these. The topographic or chronologic context of other sites examined may provide unique insights into the lifeways of early nomadic peoples as well as into the mobile aspects of later occupations. As such, these less visible sites have been recommended as potentially eligible for nomination to the National Register.

PART II: RESEARCH BACKGROUND AND METHODS

Aerial Archeology along the Missouri River

30. The prominent structural remains of large, often fortified villages constructed by the prehistoric Plains Village Tradition inhabitants of the Middle Missouri region as well as by historic Mandan, Hidatsa, and Arikara have drawn the attention of aerial archeologists since the 1940's. William Duncan Strong, a pioneer of Plains archeology, unsuccessfully attempted to convince COL Charles Lindbergh to fly up the Missouri River to photograph earth-lodge villages shortly after the Lindberghs published their spectacular aerial views of southwestern Pueblos in the early 1930's (Wood, Nickel, and Griffin 1984).

31. In the late 1930's the US Department of Agriculture (USDA) began a systematic program of vertical aerial photographic coverage of the Dakotas at scales of approximately 1:20,000; these black-and-white aerial photographs were first used for the systematic location and inspection of archeological sites there by Thomas E. Huddleston, then with the US Army Engineer District, Omaha. Beginning about 1945, Huddleston (1948) relates that his:

> ...attention was drawn to the fact that a number of locations along the upper Missouri River, which are marked 'Ancient Indian Village' on the 1890 Corps of Engineers Maps, presented a very singular appearance on aerial photographs...

32. Huddleston urged archeologists to use such aerial photographs to prepare planimetric maps of the sites. He noted that the earliest available aerial photos (from 1937 and 1938) were possibly better data sources for such mapping than more recent coverage, because they had been taken during the dustbowl drought when luxuriant vegetation to be found on terrace surfaces was growing in depressions formed by earthlodges and fortification ditches, nourished by organic culturally deposited materials. He provided Waldo Wedel and Paul Cooper of the Smithsonian Institution's Missouri River Basin Surveys (MRBS) office, initiated in 1946 in Lincoln, NE, with aerial photographs and a list of 60 archeological sites located using these photographs (Wood, Nickel, and Griffin 1984). The MRBS, under the direction of these two pioneers, continued to amass aerial photographs of their study areas and used them constantly and systematically, recording possible sites on survey maps and using

them and subsequent aerial coverage to choose sites and plan for their excavation.

33. Waldo Wedel flew over the Medicine Creek Reservoir in western Nebraska in a small aircraft to obtain the first specifically archeological aerial photographs in the Plains region in the mid 1940's. Shortly thereafter, he obtained additional oblique coverage of several major village sites, including the Buffalo Pasture Site (39ST6) and the Sully Site (39SL4) in what was to become the lower Oahe Reservoir area. Subsequently, Wedel and other MRBS archeologists made hundreds of aerial overflights to photograph and document archeological sites along the Missouri (Wood, Nickel, and Griffin 1984).

34. In the summer of 1952, the Smithsonian Institution commissioned Ralph Solecki to fly over and systematically photograph sites at eight planned reservoirs in Nebraska, South Dakota, North Dakota, and Wyoming. Solecki and his cameraman, Nathaniel L. Dewell, flew more than 8,000 km, photographing 62 archeological sites in black-and-white and color emulsions from the precarious altitude of 150 to 250 m. Most of these sites are currently inundated or significantly altered by reservoir related processes. Solecki reported on his methods and results in two early publications (Solecki 1952, 1957).

35. A decade after Solecki's overflights, John M. Corbett, the Chief Archeologist of the National Park Service, sought to revive aerial archeological interests in the Middle Missouri region through the initiation of what then seemed a novel series of experiments. These experiments, conducted by the ITEK Corporation (ITEK 1965a, 1965b) for the National Park Service's Midwest Archeological Center, focused on the intensive interpretation of various scales of black-and-white and color aerial photographs flown over two study areas. One area measured 8 by 10 miles and was situated along the west bank of the river near Fort George Island in Stanley County, South Dakota, and the other area measured 6 miles in length and was located near Dores Island in Hughes County.

36. The photographs inspected in the ITEK study included USDA vertical black-and-white photos at an approximate 1:20,000 scale taken in 1938 and 1962, as well as 1:10,000-, 1:5,000-, and 1:3,000-scale black-and-white, color, and color infrared photos taken specifically for the project. Hand-held, 35-mm color photographs were also taken. These photographs were inspected using 2x and 4x monoscopic magnifiers, and a binocular stereoscope.

37. In the 8- by 10-mile study area on the Crow Creek Indian

Reservation, inspection of 47 prints yielded identifications of 22 probable sites, which were mapped on a 1:41,100-scale base map. ITEK concluded that 1:10,000-scale black-and-white and color aerial photographs yielded the best results in their experiment, although they also remarked that the 1938 USDA photos were excellent since they showed stressed vegetation and brought out village sites for this reason.

38. ITEK also advanced the opinion that their experiment resulted, in the areas studied, in a more complete and accurate survey than was previously done by the Missouri River Basin Survey. This claim, perhaps more than any other aspect of their work and conclusions, was to earn them and their methods the abject spite of MRBS reviewers. In an "Analysis Memo" commenting on the ITEK reports, addressed to Dr. Robert L. Stephenson, Director of the Smithsonian River Basin Survey from Warren W. Caldwell, Chief of the Missouri River Basin Project, it was contended that only 8 of ITEK's 22 sites could be verified on the ground, that 25 additional known sites in their study area were not seen, and that the only positives they identified were large and very obvious. Aerial photointerpretation moneys, in Caldwell's opinion, would be better spent on ground-based investigations.

39. A number of reasons for the hostility engendered by the ITEK report are enumerated by Wood, Nickel, and Griffin (1984). First, ITEK erroneously made the claim that they had "found every site which had been found by professional archeologists on the ground, (so that) field exploration which may otherwise take months to conduct can be performed in just a few hours" (Strandberg 1967), when in fact only about 30 percent of such sites were actually photointerpreted. Another is the rather bizarre claim by Strandberg in the same paper that one of these sites was "discovered by photoarcheology" (it was in fact not), and that it (39HU61, the Grannie Two Hearts Site) had been inhabited by Norsemen. In actuality, it is a two-component site of the Initial Middle Missouri Tradition (Wood, Nickel, and Griffin 1984).

40. Some more recent aerial archeological research carried out along the Middle Missouri River was conducted in the Big Bend Reservoir by the Division of Archeological Research, University of Nebraska-Lincoln, employing enlarged (1:8,100) prints of 1938-1939 USDA black-and-white aerial photographs and two additional Corps of Engineers overflights, both at 1:24,000 scale, from 1968 and 1974. Photographs were used as the basis of site identification, verification, locational control, site definition and bounding, and site

mapping; visual inspection was supplemented by 5x, 10x, and 60x magnification, and stereoscopic viewing. Project Director Terry L. Steinacher cites the discovery of a number of sites, as well as the "misidentification" of features that turned out to be old haystack rings and "topographic aberrations" (Wood, Nickel, and Griffin 1984). The most immediately useful outcome of these experiments was the use of the aerial photos for establishing, documenting, and illustrating site boundaries necessary for National Register nominations. Photos taken in early spring or late summer during dry years, it was observed, show more cultural feature detail than others.

41. Aerial photographs, then, have provided a valuable data source for archeologists in the Middle Missouri River region for more than 30 years. The archeological use of aerial photographs in this area, however, has focused almost exclusively on simply looking for evidence--largely crop marks or vegetative indicators--of major prehistoric and historic cultural features associated with large house pit villages and fortifications. Some researchers have also used aerial photographs for defining site boundaries (a subject which will be discussed elsewhere in this report), and for site mapping. This latter use, in all cases of which we are aware, constitutes sketch mapping of visible structural cultural evidence from aerial photos.

42. The goals of this project--the interpretation and measurement of bank through time--were somewhat at variance with such previous archeological uses of aerial photographs along the Middle Missouri. For this reason, in order to develop and validate appropriate methods, this study goes beyond specifically archeological applications in the immediate study area and builds upon methods developed across the country for using aerial photographs for the measurement of bank and shore erosion through time.

Sequential Aerial Photographs for the Measurement and Mapping of Bank and Shore Erosion

Historical aerial photograph coverage in the United States

43. Aerial photographs lend themselves to the measurement of change in the environment and its characteristics through time for a number of reasons. First, available aerial photographs have a considerable time-depth span in the United States. Systematic aerial photographic coverage of most of the country was initiated in the mid-1930's by the USDA for agricultural field, soils, and

irrigation mapping purposes. Shortly thereafter, the US Geological Survey (USGS) began its own systematic and repetitive mapping photography acquisition programs. After a hiatus in aerial photo acquisition (at least in the United States, if not in Europe and the Pacific) during World War II, the USGS renewed the periodic mapping coverage for the compilation of a new 7.5-min map series. The late 1950's and 1960's saw most other Federal land-management agencies, including the Bureau of Land Management, USDA Forest Service, Bureau of Reclamation, and National Park Service begin their own aerial photographic programs. Agencies involved in engineering planning, especially the Corps of Engineers, have always used relatively large-scale controlled metric aerial photographs taken with a calibrated camera for engineering mapping purposes, and retake aerial photos of their project areas periodically.

44. In the early 1970's, the National Aeronautics and Space Administration (NASA) joined in the reconnaissance experimentation, and many military and NASA high-altitude photographs were included in the USGS's national aerial photograph and remote sensor data archive at the EROS Data Center, in Sioux Falls, SD. The first Landsat (then ERTS) satellite was launched, and began to supply regular, country- (and world-) wide multispectral scanner (MSS) data with which aerial photographs could be supplemented.

45. In the late 1970's a number of government agencies initiated cooperation in the National High Altitude Photography Program designed to provide a "next generation" of high-resolution, systematic black-and-white and color infrared aerial photographs for the new metric-system mapping efforts, as well as revision of land use and land cover mapping.

46. At the same time that Federal agencies and programs have been acquiring aerial photographs of large areas of our country, many state and local government offices, as well as private engineering and aerial photography firms, have also been flying smaller areas and projects.

47. Consequently, for almost every study area chosen for any purpose in the United States, one can be assured of finding not just one or a few, but many, sets of high-quality aerial photographs through time. Beginning as early as 1934 in the eastern United States, and 1936 farther west, vertical black-and-white aerial photos at scales of between about 1:20,000 and 1:30,000 are uniformly available (except for a few states for which, unfortunately, these older aerial negatives were destroyed as a housekeeping measure by the National Archives). Additional coverage is available at least once in the

mid-to-late 1940's; by the early 1950's many overflights at a much wider range of scales (1:5,000 through about 1:60,000) become common. In the 1970's, even higher altitude overflights became practical, and scales reached 1:130,000 or so. These scales are not necessarily very useful for defining and mapping the precise locations of eroding banks, although there is much information that they can yield, especially when subjected to image analysis (enlargement and edge enhancement), as will be detailed later in this report.

Aerial coverage of the study area

48. Information concerning the availability of aerial photos was sought from the USGS EROS Data Center, the USDA Soil Conservation Service (SCS), the US Army Engineer District, Omaha, the Bureau of Reclamation, the National Archives, and the natural resources and highway departments in Nebraska, South Dakota, and North Dakota.

49. This search proved very successful, yielding at least 14 and in one case as many as 28 sets of aerial photos for each study site. Dates ranged from 1938 through 1986, and scales from 1:12,000 to 1:129,000. Black-and-white, color, and color infrared emulsions were all available for most of the sites. Characteristics of the aerial photos for each of the study sites are summarized in Table 1, and individually listed in greater detail in Appendix A.

Sequential aerial photographs in archeology

50. The use of sequential aerial photographs and their cumulative photointerpretation, or measuring changes in and impacts to sites, by archeologists in the United States has been rare. However, archeologists have used sequential, historical aerial photographs to detect changes through time in some southwestern Indian Pueblos (Stubbs 1950; Zubrow 1974) and metric terrestrial photos monitoring structural sites (Ebert 1982, 1984; Lyons and Ebert 1982). American archeologists' uses of aerial photographs and remote sensing have been, for the most part, one-time applications such as looking for visible evidence of undiscovered sites, mapping environmental characteristics in the vicinity of sites, or documenting sites for cultural management purposes.

51. While the necessity of using a series of sequential aerial photographs is quite obvious in this research, to measure sequential positions of reservoirs banks, what might be thought of as cumulative photointerpretation, can be quite beneficial. This principle is well-known in Europe and England,

Table 1

Summary of Aerial Photographic Coverage for Middle Missouri Sites

Smithsonian Number	Site Name	Dates of Coverage Earliest-latest	Number of Overflights	Range of Scales Large/Small (1:X,000)	
25KX57/200	--	1938-1984	22	20	129
32DU2	Midipadi Butte	1938-1985	17	20	80
39BF44	--	1938-1986	16	20	80
39CO6	Jake White Bull	1938-1986	14	20	80
39DW234	Molstad	1938-1986	17	20	123
39HU173	--	1939-1986	21	16	124
39HU242	Whistling Elk	1939-1984	20	20	126
39LM224	Cable	1938-1984	18	20	126
39ST235	Stoney Point	1939-1984	18	20	126
39WW15	Travis II	1938-1986	12	20	80
39YK40	Jazz and Jill	1938-1985	28	12	128

where the compilation of maps of cultural resources revealed from the air is undertaken somewhat more systematically than in this country. In England, for instance, areas in which sites are known to exist have been repeatedly flown, many times a year, in some cases since before World War I (Riley 1987). Since climatic and lighting conditions are different each time, one photograph will show certain details of a site, while another photo will show very different indications. Maps of aerially visible traces of cultural resources are compiled by overlaying interpretations made from sometimes hundreds of aerial photographs of a site or area.

52. Although the present project was directed toward measuring and predicting reservoir bank erosion, the value of cumulative photointerpretation

was apparent at a number of the study sites where the total picture of house-pit locations, fortification ditches, and the like could be seen only when features visible on a number of overflights were compiled. The cultural indications shown on the three maps compiled through electronic image analysis means, to be described in more detail in the following paragraphs, resulted from such cumulative mapping.

Aerial Photographs as a Data Source for Measurement of Bank and Shore Erosion

Oceans and major lakes

53. Although archeologists, to our knowledge, have not systematically applied sequential aerial photographs for the measurement of erosion to archeological sites, a number of scientists have experimented with and developed methods for measuring bank and shore erosion in general. The methods used in this study build upon these prior efforts. Their comments about some of the problems encountered during the course of such research, as well as their findings, are also interesting in the light of the conclusions reached in this study.

54. Researchers at the University of Virginia in Charlottesville employed vertical aerial mapping photographs to map beach erosion along 630 km of the Atlantic coast between New Jersey and North Carolina (Dolan, Hayden, and Heywood 1978; Dolan et al. 1979, 1980). These scientists note that the use of historical aerial photographs is the most cost-effective means of detecting and mapping erosion, since no other method provides the necessary time-base for processes that take place relatively slowly. Their "Orthogonal Grid Mapping System" (OGMS) (Dolan, Hayden, and Heywood 1978) involved the establishment of an offshore baseline from which measurements of shoreline position were made from aerial photographs enlarged by projection to fit a 1:5,000-scale base map. Measurements were taken at regular intervals of 100 m. Measurements from photographs from 1930, 1940, 1949, 1962, and 1970 were made of both a vegetation line demarcating the beach itself, and the visible high-water line (rather than the visible waterline itself). Differences between these measurements were shown in graphs illustrating both mean rate through time and their variance (one standard deviation to each side of the mean). The prediction of future shoreline positions was approached through the use of a linear empirical model:

$$dS = dT[(\text{rate of change}) + k(\text{standard deviation})]$$

where S is the landward limit of the shoreline for a given time interval (dT), and k is the number of standard deviations required to give a desired probability level.

55. Mean shoreline recession rates averaged 1.5 m/yr, with high rates of as much as 10 m/yr (Dolan et al. 1979, 1980). In estimating the level of possible error contained in their measurements and therefore predictions, Dolan et al. (1980) discount the significance of within-image scale variations and radial displacement errors in aerial photographs since they are taken along sedimentary coasts, which are of course quite level. Other errors are due to photographic resolution, the enlargement of photographs to fit base maps, the difficulty of precisely matching photos with the base maps, the difficulties in defining precise edges, digitizing shoreline positions, and the idiosyncrasies of interpreters and digitizer operators. These errors result, they say, in a "combined potential error in measurements from two photographs at 1:5,000 scale" of 12.5 m. Since three major sources of error are summed in this estimate (photo enlargement error, digitizing error, and interpreter error), "each with a .5 probability" (Dolan et al. 1980), the joint probability of this error is 0.125, which, when normally distributed about zero error should have a standard deviation of 6.3 m. In some cases, they contend, measurements are far closer than this figure, within 1 m of "known ground distances." In any case, Dolan et al. (1980) conclude this error amounts to ±0.32 m/yr, over a 40-year period. This conclusion puts the precision of their OGMS methods "well within the year-to-year variance of the natural beach system."

56. Another shoreline measurement experiment involving some of the same researchers (Shabica et al. 1984) used the OGMS method, but was directed toward barrier islands in the Gulf of Mexico. Interpretation instruments included a K&E Kargl reflecting projector and a Bausch & Lomb Zoom Transfer Scope. The measurement interval was 100 m, as before, and error and other parameters are cited as being the same as well. As many as 10 sets of aerial photographs spanning slightly more than 56 years were measured, and average erosion rates ranged from 3.1 to 7.4 m/yr. Shabica et al. (1984) conclude that today's shoreline erosion rates are closely representative of those of

the last 25 to 50 years and should be considered indicative of trends in the near future.

57. Also focusing on natural (i.e. nonreservoir) shore erosion, this time along the Ohio side of Lake Erie, Carter and Guy (1983) employed historic maps as well as sequential aerial photographs to map shoreline recession from 1876 to 1973. Their goal was both the prediction of future shoreline changes and the study of reasons for observed nonuniformity in erosion rates, even at places in close proximity to one another. Shores shown on US Army Corps of Engineer Lake Survey field maps at 1:10,000 scale were compared with those interpreted from 1938 and 1973 aerial photographs at scales of 1:7,900 and 1.4,800, respectively. For comparison, the smaller-scale photos and maps were projected to the 1:4,800 scale of the 1973 photos using a Map-O-Graph R projector. Control was accomplished through the matching of cultural and geographic detail; the lack of many cultural control points (building, roads, etc.) between the 1976 maps and later photographs made this difficult in some cases.

58. Rather than measuring shore recession along regularly spaced transects, Carter and Guy (1983) drew the three continuous, consecutive shorelines on base maps and then measured the alongshore length of areas of differential recession rates between obvious break points. Their recession classes were: very slow, <1 ft/yr; slow, 1 to 3 ft/yr; moderate, 3 to 5 ft/yr; rapid, 5 to 7 ft/yr; and very rapid, 7 to 9 ft/yr. Based primarily on the 1938-1973 average rate, a "2010 line" (Carter and Guy 1983) representing their prediction for the shore's location in the year 2010 was also drawn. They observe that early erosion rates were much higher prior to the building of shore protection structures in the mid-1930's and later, and that banks rather than discrete sandy beaches characterized the 1876 shoreline of Lake Erie.

59. A recent ocean shore measurement project undertaken at the University of Connecticut (Civco, Kennard, and Lefor 1986) supplements the use of historic aerial photographs with computer assisted analysis for the identification of salt-marsh vegetation types, changes in the area of which are the focus of that study. Aerial photographs from 1934, 1951, 1965, 1970, and 1981 at 1:12,000 through 1:20,000 scale were interpreted, and maps of three salt marsh areas were prepared using a Zoom Transfer Scope at 1:2,400 scale. Vegetation units as small as 1 m^2, according to the authors, could be mapped. The hand-drawn vegetation maps were then converted through the use of a drafted grid overlay into raster or picture element format; encoding maps with

an electronic digitizer was found to be more prone to errors than a totally annual approach. Comparisons between areas of vegetative zones or units from 1 year to the next were then made automatically by the computer, working upon the gridded matrix of values for each set of aerial photos.

Reservoir Bank Recession Studies

60. Perhaps the most comprehensive erosion study using aerial photographic data that is directed primarily toward reservoir bank erosion is that carried out over the last decade by Lawrence W. Gatto and William W. Doe III, at the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL). Using data from aerial photographs and other sources, Gatto and Doe have studied reservoir (and reservoir-associated river) bank erosion processes and trends at a large number of study sites around the country (Gatto and Doe 1983, 1987; Gatto 1982a, 1984a, 1984b, 1988). Citing at least 34 processes which influence the type and rate of bank erosion at reservoirs, Gatto and Doe (1983) selected 10 representative northern reservoirs (from an initial sample of 30) for historical bank recession analyses. These analyses were based partially on the availability of aerial photographs and the fact that at these reservoirs bank erosion was recognized as a problem threatening private property, recreation areas, or other site stabilization measures. Several of their study reservoirs, including Ft. Peck, Sakakawea, and Oahe, are on the Middle Missouri River.

61. Aerial photo coverage was selected on the basis of photo quality, visibility of banklines and control or reference points, the availability of stereo coverage, and time span represented. At most study sites, a 20- to 30-year span between first and last photo dates was found. Immediately upon inspection of aerial coverage, it became apparent, that, at all the study sites, bank erosion was extremely variable even within small study areas and that "recession measurements along two or three transects may not adequately characterize recession for a given bank reach" (Gatto and Doe 1983). Although personnel from Corps offices in all regions had informally observed actual bank erosion, these authors could find no reports, literature, or other evidence of systematic studies or data collection on bank recession at any of their study reservoirs.

62. Photographic control was derived by selecting stable features visible on all repetitive photos, chosen so that a line drawn between them would be, as closely as possible, parallel to the local orientation of the bank.

According to Gatto and Doe (1983), transects perpendicular to the baseline were then drawn:

> ...because of the geometric distortions in the photographs and different photographic scales, these transects did not always pass through the same ground features on all of the photographs for a site, so the positions of the transects were adjusted...

The intersections of the transects and the banklines were marked on the photographs while viewing stereoscopically with an Old Delft stereoscope at 4.5 power. The photograph distances from the baseline to bankline were then measured along the transects while viewing with a 4.0-power magnifier, and converted into equivalent ground distances using average photographic scale for the site.

63. Calculated rates of recession varied between 0 and 39 ft/yr; bank recession rates at Middle River sites are shown in Table 2. It is interesting to note that these rates, up to approximately 22 m/yr, and averaging about 7 m/yr, are of the same general magnitude (if not slightly higher) as the rates measured in the course of the present study of sites on Oahe and Sakakawea reservoirs. In a shorter and more recent description of their research, Gatto and Doe (1987) cite average erosion rates from the same study in metric units (shown within brackets in Table 2). One class of parameters Gatto and Doe address is the potential error which might result from using aerial photographs to measure bank recession. Error causing factors they list (Gatto and Doe 1983) include photo scale variations due to camera lens distortions; aircraft altitude changes; radial, relief, and tilt distortions; lack of useful reference or control points; obscured banklines; errors in calculating scale when using maps to determine ground distances; and human errors when making measurements from photographs.

64. On the basis of estimates of the errors in their aerial photographic measurements, Gatto and Doe (1983, 1987) calculate a "minimum measurable distance" (MMD) after Tanner (1978), which represents a "confidence level for photographic measurements" (Gatto and Doe 1983). Gatto and Doe (1983, 1987) also analyzed their measured recession figures in a number of ways in an attempt to assess the factors responsible for erosion at their 10 study reservoirs. A series of linear regression analyses were performed to determine whether pool levels, bank sediment textures, shoreline orientation relative to dominant wind direction, mean annual wind speed, reservoir

Table 2

Bank Recession Rates Measured from Aerial Photographs, Middle Missouri River Reservoirs (after Gatto and Doe 1983, 1987)

Reservoir	Study Sites	Transects (Total)	Years	Recession Rate
Oahe	2	11	1968-1970	≤68 ft/yr
			1970-1976	≤23 ft/yr
				[Metric: 11.9 m/yr]
Sakakawea	3	11	1958-1966	≤14 ft/yr
			1966-1976	≤19 ft/yr
				[Metric: 5.2 m/yr]
Fort Peck	1	4	1950-1958	≤3 ft/yr
			1958-1978	≤4 ft/yr
				[Metric: 0.9 m/yr]

drainage area, surface area, mean outflow, reservoir age, or the durations of the rainy season, the freeze-thaw season, or reservoir ice cover showed a linear relationship with measured recession rates.

65. Unfortunately, the "...results of most of the regressions, however, proved to be unreasonable and were not useful..." (Gatto and Doe 1983). The only moderately high correlations with recession rates were provided by duration of freeze-thaw and frozen-ground seasons and ice cover ($r^2 = 0.65$) and reservoir drainage area ($r^2 = 0.83$). At the same time, it was reasoned that other factors (wind direction, wind speed, and bank sediment characteristics) showed no correlation whatsoever and should have been very influential. A lack of correlation with reservoir age indicated that recession may be constant over the life of a reservoir, although Gatto and Doe (1987)

> ...believe...that if recession continues, its rate would likely decrease with age as an equilibrium develops between bank conditions and normal reservoir water level fluctuations. If there is a long term rise in the normal water level, then recession would probably increase...

66. Gatto and Doe attempted to utilize aerial photographs with a consideration of photographic measurement errors and stated:

> ... the data derived from aerial photographs are estimates at best... (Gatto and Doe 1987).
>
> and
>
> For measuring on-going bank recession, aerial photographs do not show the detail necessary and, if uncorrected photographs are used, contain inherent distortions which can cause large measurement errors... (Gatto 1984a)

They also, however, cite the possibility that average rates are not necessarily actual (Gatto and Doe 1987), that correlations based on small samples may be unreliable, and that the values used for independent variables may not be calculated with high enough resolution to be specific to the study sites and transects at those sites. Linear regressions, they also note, may not provide the best models for bank recession analysis. Lumping bank recession data from 10 reservoirs across the northern portion of the country might also obscure patterning specific to single or hydrologically and climatically related reservoirs.

67. To collect historical bank recession data in contrast to the contemporary measurements made on the ground, Millsop (1985) utilizes USDA vertical aerial photos taken in 1958, 1966, and 1976 at scales of 1:20,000 and 1:40,000. Millsop's (1985) annual bank recession measurements made from the aerial photographs at Lake Sakakawea between 1966 and 1976 ranged from 1.2 to 4.3 m/yr, and averaged 2.2 m/yr. He notes that these rates also correspond closely with rates measured at higher resolution by measuring between pins placed on the ground. He also notes that bank recession rates for Lake Sakakawea, measured for the same years, by Gatto and Doe (1983) were quite different, ranging from 1.8 to 13.1 m/yr, an averaging 5.8 m/yr. This discrepancy might, Millsop (1985) feels, be due to the inaccuracies of measuring from small-scale aerial photographs; he felt that his measurements from 1:40,000-scale photos might be far less accurate than those from the 1:20,000-scale photos. Both sets of rates, he also felt, might be true with intersite variation being quite large.

68. In a more recent study focusing on measuring shoreline erosion and studying erosion and slumping on prairie lakes and reservoirs, J. D. Mollard of J. D. Mollard and Associates, Ltd., Regina, Saskatchewan (Mollard 1986) inspected 32 natural lake as well as man-made reservoirs in the Canadian plains using as many as 10 sets (per site) of aerial photographs ranging in date between the 1940's and the present. Landsat MSS satellite data since 1972 was

also incorporated into this research, primarily for assessing changes in offshore sediment deposition. Airphoto and map interpretation (Mollard 1986) was combined to:

> ...determine underwater nearshore, beach, bluff, and neighboring valleyside slopes and the origin and composition of materials below them...

Specifically, shorezones are classified in terms of high, intermediate, and low deepwater wave energy; valley-side and lake shorezone topography is classified according to degree of slope both above and below the waterline; shoreline configuration is classified in plan view as long and straight, curving, or irregular with headlands and coves; and shorezone sediments are also typed. Mollard finds that bank erosion on exposed shores of natural prairie lakes varies from about 1 to 5 m/yr; it is also suggested that bank erosion on young man-made reservoirs might be as high as 12 m/yr in some settings. Reservoir erosion rates, he says, are particularly high in areas with moderate to steep underwater nearshore slopes, and projecting headlands peninsulas that face into long effective fetches aligned in the direction of the prevailing wind. At less exposed sites in young reservoirs, measured rates are on the order of 3 to 5 m/yr. These bank recession rates compare very closely with those observed during the course of this study in Middle Missouri reservoirs. Recognizing the need to predict future bank erosion, Mollard (1986) also recognizes that such prediction is extremely complex, and that "...because of the many uncertainties, judgement must be based on several lines of attack..." He goes on to recommend, among other things, obtaining aerial photographs of new reservoirs when they reach full supply level for the first time and at frequent and regular intervals thereafter.

Recognition and Classification of Bank Erosion with Remote Sensing Data

69. In the early 1970's, when earth-imaging satellite data was becoming a practical reality, an apparent need was felt to formulate general interpretative keys that would allow the integration of large-to-small scale aerial photographic data with that interpreted and measured from satellite images.

70. The two classification classics of this era were engendered by the USGS's EROS Program (Anderson, Hardy, and Roach 1972; Anderson et al. 1976). These keys recognize four classification levels, (Anderson et al. 1976)

characterized by the sorts of data from which their determination can be made (Table 3). These authors then go to advance a land use and land cover classification taxonomy at Levels I and II that, they feel, takes into account most significant land use and cover types in the United States today. Categories and subcategories within this classification applicable to the distinction between reservoirs, reservoir banks and beaches, and other types land bounding reservoirs in the present reservoir bank definition and measurement study are included in this table.

71. What this indicates, according to Anderson et al. (1976), then, is that even Landsat MSS data (in digital form or at available visual product scales of 1:250,000 through 1:1,000,000) should to some extent be useful in discriminating the banks or shores of reservoirs in contrast to surrounding

Table 3

Land Erosion Classification Levels and Taxonomies

Classification Levels

Classification Level	Typical Data Characteristics
I	Landsat Multispectral Scanner Data
II	High-altitude aerial photographs at less than 1:80,000 scale
III	Medium-altitude data taken between 1:20,000 and 1:80,000 scales
IV	Low-altitude data taken at more that 1:20,000 scale

Land Use and Land Classification Taxonomies

Level I	Level II
1 Urban or built-up land	11 Residential
	13 Industrial
	14 Transportation, utilities
	16 Mixed urban or built-up land
2 Agricultural land	21 Cropland and pasture
5 Water	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
7 Barren land	72 Beaches
	74 Bare exposed rock
	76 Transitional areas

agricultural, urban, or other lands. The nominal pixel size, and thus resolution, for Landsat MSS is 80 m by 80 m, however, a somewhat gross resolution for actually measuring bank recession in most places (perhaps not all) over the 15 years since such data have been available. In the case of the highest average annual bank recession rates in this study, for instance (7.32 m/yr at the Molstad Site, 39DW234), erosion should just be discernible in a comparison between 1972 Landsat MSS and recent MSS data. If used to measure, for instance, fluctuations in shore-bounded area around an entire reservoir, Landsat MSS data might prove quite sensitive.

72. The problem, of course, would be discriminating with any degree of certainty the bank itself, as contrasted with a water body, beaches, or eroded sediments, and the uneroded land above the bank. Anderson et al. (1976), in their two-level classification, imply that such distinctions can be made using Level II aerial photographs even at scales smaller than 1:80,000. Even at this scale using stereo photointerpretation methods, it is difficult to discern actual bank lines. During the course of this project, all photointerpreters defining reservoir banks on overlays felt distinctly uncomfortable with any but the most exceptional quality aerial photos of scales smaller than about 1:40,000. Hence, the following interpretative classification and key devised for the recognition of reservoir banks and/or shores should probably be considered to be a Level III classification.

73. When photointerpreting transitional features such as erosional banks, not only the feature itself but those features of land types bounding it must be the subject of an interpretive key. Following usages and illustrations provided by Brown et al. (1979) and Loelkes et al. (1983) is the following discriminatory photointerpretation. Discrimination of the actual bank, as can be seen from inspection of this key, depends just as much upon recognizing those land cover types that bound it. Within-type photo indicator differences as well as differences between types, are expressed in Table 4 in terms of tone, texture, shape, relationship to other features, and vertical relief (after Ray 1960).

74. The erosional bank itself, in fact, in almost all cases can be discriminated only through stereo photointerpretation. This is logical, since in the areas focused on in this study, banks are often quite high, but just as often nearly vertical or even slightly undercut in places. While some banks might thus be discernible in the course of monoscopic photointerpretation due

Table 4

Photointerpretive Key Developed for Discrimination of Erosional Reservoir Banks along the Middle Missouri River

Photo Indicators	Identified Feature
	Water Surface
Tone	Water surface is distinguishable primarily by photographic tone and texture. Calm water surface is dark toned in both black and white (where it is black) and color (black) to blue) aerial photos, while its tone in color infrared photographs is determined by the amount of suspended sediments and varies from black to light blue.
Texture	The photographic texture of the water surface is determined by the regularity and definition of waves and their orientation to incident sunlight. A very fine, regular wave texture is usually seen on all but the calmest surfaces. If incident sunlight is such that it reflects directly into the camera lens from the water surface, that surface or portions of it may appear to be the brightest object in a photographic scene, rather than very dark. Such a water surface reflection is easily recognizable since it will not occur in previous or subsequent frames along a flight line.
Shape	The shape of the boundary of the water surface can vary from extremely smooth, in the case of shallowly sloping beach or other shore contacts, to almost randomly irregular in small-scale photographs when it laps directly against convoluted shorelines.
Relationship to other features	In relation to other features, the water surface can be bounded by a beach, or alternatively it can impinge directly upon a bank or upon a shore that does not display a distinct vertical bank.
Vertical relief	Stereoscopically viewed, the water surface is extremely flat, to such an extent in fact that no vertical relief at all can be determined.

(Continued)

(Sheet 1 of 4)

Table 4 (Continued)

Photo Indicators	Identified Feature
	Beach
Tone	Since, in the study area, beaches are uniformly composed of light colored, fine sediments, they are very light gray to white in tone on all photographic emulsions. Areas of beaches recently wetted by waves can be slightly darker in tone than higher portions of the beach.
Texture	Beaches themselves are extremely uniform, fine-to-indiscernible photographic texture. Due to the presence of cobble- and boulder-size material on some of the beaches along the main stem reservoirs, both photo tone (above) and texture will vary in these areas from those of the beach itself.
Shape	Beach shape is usually smooth and straight or smoothly curving on the lakeward edge, while its shape on the shoreward side is determined by bank shape.
Relationship to other features	The relationship of a beach to other features is variable in that a beach is only visible if it is uncovered or only slightly covered by the water surface. In cases of high water, beaches are not visible.
Vertical relief	Topographically, beaches are very low gradient, low enough in most cases to be indiscernible under stereoscopic interpretation.
	Slumped Sediment
Tone	Slumped sediment detached from a bank can fill a short distance between beach and bank, or if a beach is not present between the water surface and the bank. Slumped sediment is generally of medium tone due to irregularities which create slight shadow effects. Organic materials in slumped sediment may also contribute to a slightly dark tone.
Texture	The photographic texture of such sediment is visibly coarser than that of the beach or water surface.
Shape	Slumped sediment indicators are less regular in shape and outline, particularly lakeward, than either water surface or beach indicators.
Relationship to other features	Slumped sediment typically occurs in short segments along bank and occupies a relatively thin strip between water and bank, or beach and bank.

(Continued)

(Sheet 2 of 4)

Table 4 (Continued)

Photo Indicators	Identified Feature
	Slumped Sediment (Continued)
Vertical relief	The vertical relief of slumped sediment is discernibly greater than the water surface or beach, but its height is less than that of the bank itself.
	Erosional Bank
Tone	The erosional bank, a feature of primary interest in this study, it also perhaps the most difficult to discern. Its photographic tone--or more properly the tone of bounding shadow indicators--can in some places be sharply dark, but in other cases there may be virtually no tonal indication. If the bank is not strictly vertical, or if radial displacement allows the definition of the toe of the vertical bank, then the exposed face can be light in tone. If it is composed of darker sediments, or rack (such as Pierre Shale at 39DW234), it may however be medium to dark gray in tone.
Texture	Such an exposed erosional bank face is also often of fine and uniform texture, although if of extremely convoluted shape, it can appear rougher in texture.
Shape Relationship to other features	In terms of shape, banks can range from long and uniformly straight, to highly convoluted. In most cases viewed in this study, straight banks also exhibited uniform vertical relief, while their convolutions--inundated relict drainages dissecting terrace edges--are less uniformly vertical in relief, with shallower gradients.
Vertical relief	It is in terms of their three-dimensional relief that erosional banks are best defined. Since the base-to-height ratio of stereo photographs with 60-percent overlap exaggerates vertical heights up to about seven times normal, and since in the case of most erosional banks these heights are considerable or at least abrupt in comparison with surrounding surface, they are sharply visible and unambiguously determinable in most cases under a stereoscope. It is difficult to understand how erosional banks in many cases can be mapped using only monoscopic interpretation, however.

(Continued)

(Sheet 3 of 4)

Table 4 (Concluded)

Photo Indicators	Identified Feature
	Shoreward Surface
Tone	The shoreward surface is the surface found on the top side of the erosional bank, away from the slump, beach, and water surfaces that may be seen lakeward from it. In virtually all cases in our study areas, at least portions of the shoreward surface are covered by grassland and brush throughout the years included in the aerial photographs. In some cases, trees occur near the bank edge and obscure the bank for short distances. In nearly all cases, the photographic tone of the shoreward surface is darker than beach or slumped sediments, but considerably lighter than either shadows under the bank, or the water surface. For this reason, when no beach or slumped sediment is present, even if the bank cannot be confidently discerned, the abrupt boundary between shoreward surface and water surface can be defined.
Texture	The shoreward surface's texture depends upon its vegetative cover, as well as its topographic variations which catch shadow depending upon their orientation and the sun angle on the photo date. In the case of uniform grass or shrub cover on flat terrace surfaces, texture is fairly uniform. Brush or trees, that in fact often grow differentially in cultural features (housepit depressions and fortification features) coarsen the shoreward surface's texture.
Shape	The shape of the shoreward surface is determined by its interface with the shape of the erosional bank or with the waterline.
Vertical relief	Topographically, the shoreward surface is in some cases remarkably level, while in other cases it varies considerably due to prereservoir topographic contours. In the case of the Midipadi Butte study area in North Dakota (32DU2), for instance, the shoreward surface rises abruptly, beyond the actual erosional bank, at least 50 m. In some other cases, for instance at the Cable Site (39LM224) or Whistling Elk (39HU242), the shoreward surface is in most places almost totally level for some distance inland.

(Sheet 4 of 4)

to shadow marks, most aerial mapping photographs are taken in midday. When stereo pairs of aerial photographs, taken along a flight line with about a 60-percent overlap (as, in fact almost all mapping photos), are viewed on a stereoscope, the vertical relief of the erosional bank is easily seen in aerial photos of scales of about 1:40,000 or larger (in some cases, smaller-scale photographs of high quality are useful as well).

Methods for Measurement of Bank Erosion

75. The methods we have incorporated in this research build upon those developed for the National Park Service's Interagency Archeological Services and outlined in a report entitled "Using Aerial Photographs to Measure the Erosion of Archeological Sites" (Ebert and Lyons 1986). This publication was initiated to provide National Park Service Personnel with a series of methods to be used to measure erosional impacts to park archeological sites. It outlines ways that sequential, historical aerial photographs can be used for measuring erosion of archeological sites in a simple manner.

Selection of study sites

76. The sites forming the basis of this study were selected from 25 sites designated at a meeting of Corps of Engineers archeologists in 1986 as being representative of erosionally endangered cultural resources along Middle Missouri River reservoirs. The 12 study sites examined were chosen because they are representative of the erosional threats identified by Corps of Engineers archeologists. These sites and their locations are shown in Table 5. Details of the archeological significance of these sites, and the perceived erosional threats to them, are given in the draft final report.

77. Laboratory methods. Building upon methods developed previously (Ebert and Lyons 1986), the following methods were adapted for the measurement of bank erosion at the 12 study sites:

a. Acquisition of aerial photographs. The first step in this project was the search for all available aerial photographs of the study sites. Inquiries were made of all applicable Federal and state sources for the areas in which the study sites were located; four major agencies were found to hold the aerial photos covering the sites. These agencies, the aerial photographic coverage located and used, and its scale, emulsion, and other characteristics are listed in Appendix A.

Table 5

Locations of the Study Sites

	Site	Legal Description	Latitude	Longitude
		Nebraska		
1)	25KX200	T33N R2W SEC 17	42° 50'00"	97° 34'00"
2)	25KX57	T33N R2W SEC 18	42° 50'00"	97° 34'00"
		North Dakota		
3)	32DU2	T147N R19W SEC 1	47° 35'44"	102° 13'00"
		South Dakota		
4)	39C06	T22N R30E SEC 22	45° 51'00"	100° 23'30"
5)	39LM224	T107N R74W SEC 2	44° 06'00"	99° 40'50"
6)	39HU242	T109N R76W SEC 3	44° 16'20"	99° 57'45"
7)	39HU173	T112N R80W SEC 4&9	44° 32'00"	100° 25'00"
8)	39BF44	T106N R71W SEC 15	43° 59'20"	99° 20'00"
9)	39ST235	T4N R33E SEC 13	44° 18'30"	100° 06'00"
10)	39DW234	T17N R31E SEC 7	45° 27'30"	100° 21'00"
11)	39WW15	T124N R79W SEC 32	45° 31'00"	100° 25'00"
12)	39YK40	T93N R57W SEC 16	42° 52'00"	97° 35'45"

b. *Compilation of base maps.* Base maps at a scale of 1:10,000, a graphically manageable scale, were made by photomechanically enlarging US Geological Survey, 1:24,000-scale, 7-1/2-min topographic quad sheets. Those sheets listed in Table 6 were used for this purpose.

(1) Portions of these topographic sheets, containing the area around the site, a 2-km by 2-km square, and sufficient additional area within which mapped details useful for photographic control could be found, were enlarged onto frosted mylar photographic film, each measuring 55 cm by 55 cm. Map detail was screened at 60 percent of full black level in order to provide contrast between the map details and later drafted shorelines.

(2) Also, it should be noted that the shorelines shown on the published US Geological Survey maps bear little or no relationships to actual water levels, shores, or banks. In the early stages of this research, the US Geological Survey mapping office in Denver was contacted and asked

Table 6

USGS 7.5-min Topographic Quad Sheets Used for Compiling Study Site Base Maps

Site	USGS Quad Sheet
25KX57/200	Tabor SE, Nebraska-South Dakota 1968
32DU2	Twin Buttes, North Dakota 1967
39CO6	Kenel, South Dakota 1967
39WW15	Mobridge, South Dakota 1967
39YK40	Tabor SE, Nebraska-South Dakota 1968
39BF44	Bedashosha Lake, South Dakota 1974
39HU173	Okobojo SW, South Dakota 1973
39LM224	Lower Brule, South Dakota 1966
39DW234	Moreau, South Dakota 1968
39ST235	Rosseau, South Dakota 1973
39HU242	DeGray, South Dakota 1973

about the meaning of what appeared to be water levels or shorelines on several of the maps. In some cases, the nominal average pool level was used as the waterline; in other cases, the water level on the day on which the aerial photographs from which the map was compiled was drawn.

(3) Paper copies of the base maps, with drafted shorelines determined from aerial photographs, were provided in the draft copy of this report.

c. Control location. Next, the enlarged mylar base maps and each set of aerial photographs were inspected to determine appropriate photo control points. Requirements for such control points are that they are visible on both the aerial photographs and the base maps. These points were to be used to match and, during overlay projection, for dimensions. In most cases, at least three identifiable control points--such features as the intersections of roads, small stock tanks, or buildings--could be found on maps and aerial photographs. At some of the study sites including 39CO6 and 32DU2, however, finding matching control points on maps and each photograph proved difficult due to the lack of map detail. In these cases, a method that might be described as using serial control was used in which identifiable trees, shrubs, and other photovisible features were used as control to match consecutive photointerpretive overlays to one another. Although such features rarely persist throughout the entire photo time sequence, sufficient points to allow matching from one photo date to another can be found.

d. Formulation of a photointerpretive key. Photointerpretation, while it may be thought of to some extent as an art, must be guided by replicable interpretive rules or keys to be consistent. To formulate such a photointerpretive key, the aerial photographs of the study sites were first preliminarily inspected using a mirror stereoscope. A key specifying tonal, textural, and contextual factors allowing the discrimination of water surface, beach, slumped sediment, erosional banks, and shoreward surface was compiled. This key is included in Table 4 following a discussion of aerial photointerpretive mapping of shores and banks.

e. Photointerpretation and overlay mapping. Using the photointerpretative key, each date of aerial photographs was interpreted using a Topcon mirror stereoscope with 1.8-, 3.0-, and 6.0-power magnification (Figure 2). During photointerpretation, a transparent mylar overlay was superimposed atop one of the photographs of the stereo pair, and secured to that photo with drafting tape. The locations of control points were then marked with a 4x0 rapidograph and acetate ink. Next, the photointerpreter carefully traced a 2-km segment of bank line, centered on the study site and visible in stereo on the aerial photographs. In cases where more than two aerial photos were necessary to view the 2-km bank line segment, the overlay was fixed to the central photographs in the necessary series so that it would not be moved or repositioned. Stereo photointerpretation is invaluable in identifying banks from aerial

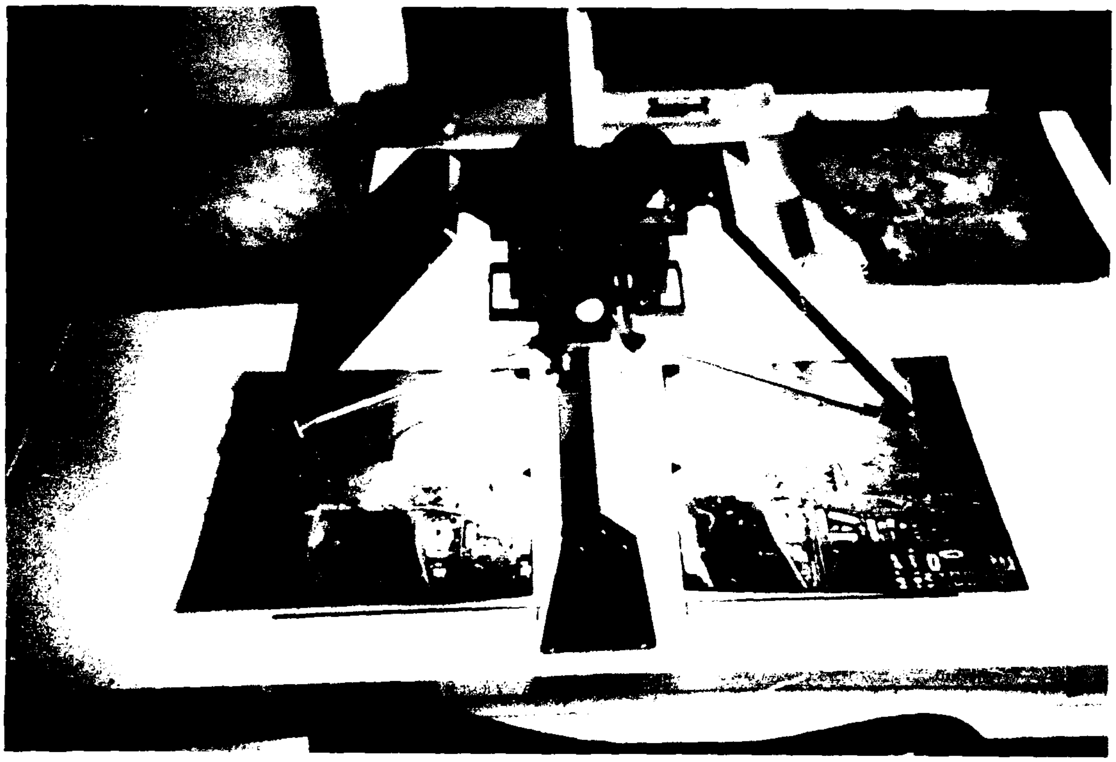

Figure 2. Mirror stereoscope with an x-y tracking attachment

photographs because of the relief cues the operator can see. One of our concerns early in this stage was that the width of the rapidograph line would constitute a source of error.

(1) A 6x0 rapidograph was experimented with, but it clogged after only a few minutes of use.

(2) A 4x0 rapidograph seemed to be the best compromise between practicality and line width; the 0.18-mm-wide ink line made by the tip of this pen would, it was calculated, have a scaled width of 3.60 m on a 1:20,000-scale photograph.

After a bit of consideration, however, a means was devised to make this a nonproblem: it was decided to use the edge of the line to define the bank, rather than its center. Using this drafting method, any size pen would be perfectly acceptable.

f. Projection of bank lines to base map scale. Each photointerpretive overlay was next projected to 1:10,000 scale using a Map-O-Graph opaque projector with a special flat field lens. This was accomplished by matching chosen photo control points against their corresponding locations on the 1:10,000-scale base map and redrafting the bank line at the base map scale (Figure 3).

g. Definition of transects and measurement. A series of transects along which measurements were to be made was constructed on the base map sheet. These transects were oriented perpendicular to the slope of the landscape at the point they intersected the earliest interpreted reservoir bank and were spaced a scaled distance of 100 m apart (1 cm apart on the 1:10,000-scale base map) at that point. The transects were oriented in this manner primarily to help answer the question of whether the apparent bank recession being measured was due simply to variations in reservoir pool levels rather than actual erosion. Upon analysis and further consideration, this possible problem seems relatively insignificant in our measurements, as discussed later at greater length. Twenty-one transects were defined for each site, with one intersect (No. 11) centered on the archeological site itself, and ten intersects spaced 100 m apart on each side of the archeological site. The earliest interpreted bank line was used as a baseline from which to make measurements to consecutive bank lines. After each interpretive overlay was matched and drafted onto the base map, the distance between it and the baseline bank was measured, along each of the 21 transects, using digital calipers (Figure 4). Measurements were made to the nearest 0.01 mm; the Fowler Max-Cal calipers used have a nominal accuracy of 0.03 mm, which scales to 0.03 m at the 1:10,000-scale map.

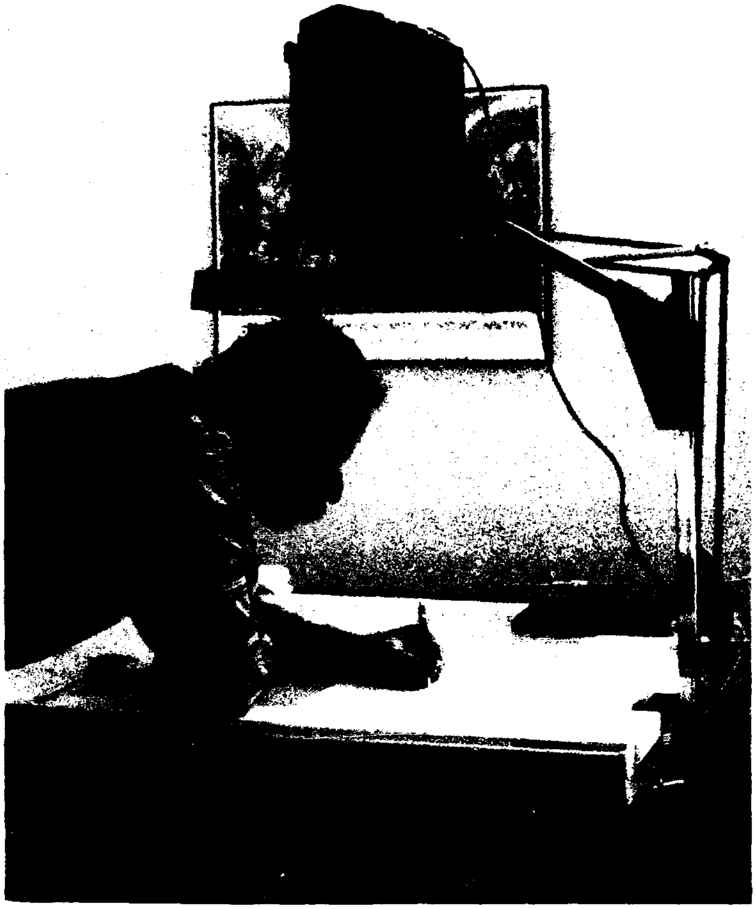

Figure 3. Projecting interpreted bank lines to scale and rectification with a Map-O-Graph opaque projector

Sources and Magnitude of Errors in Measurements from Aerial Photographs

78. An assessment of the possible sources and amounts of error in the photointerpretation and mapping methods used to study bank recession along the 2 km reaches of shoreline is facilitated by a breakdown of error into two basic types. The first of these is the inherent error. Such errors are not occasioned by the specific measurements made here but are already contained within the data sources and devices used in making those measurements. Inherent errors which must be considered in this project include errors contained in the aerial photographs, in maps used for control, and in the projection and measurement devices used to actually make the measurements. Inherent errors can be empirically estimated at some level, based on geometric, statistical, and engineering parameters.

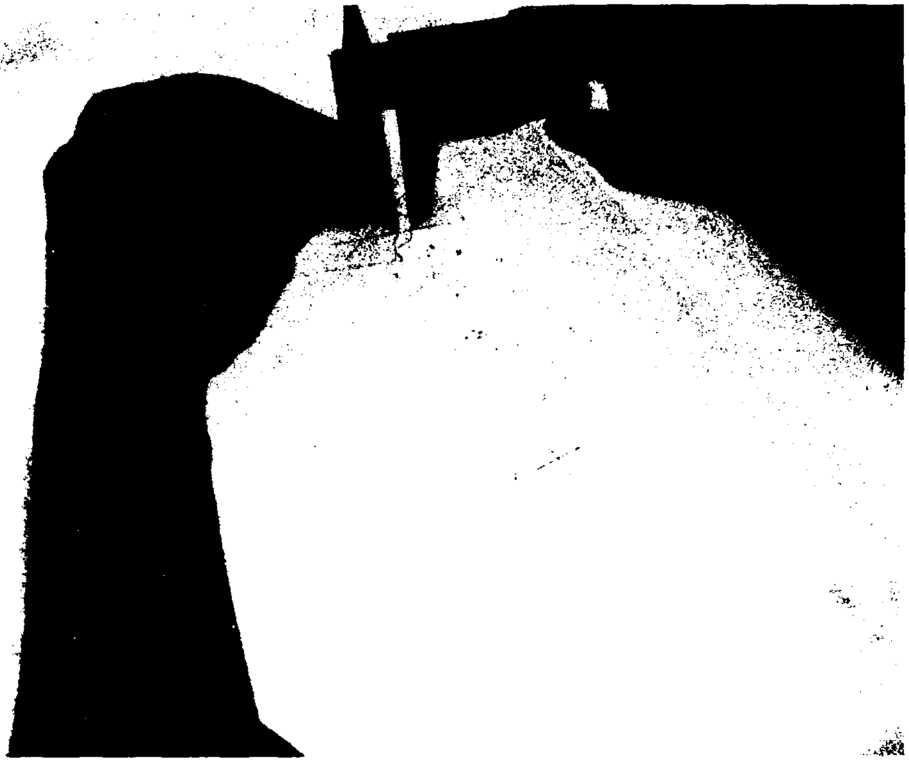

Figure 4. The measurement of distances between bank lines along transects with digital calipers

79. Another type of error affecting any measurement is the operational error. Operational errors are those arising from the actual process of making the specific measurements at hand. Operational errors depend upon the individuals making measurements. In this research, such errors would include the variation introduced in interpreting the positions of bank lines, errors in rectification and control matching during projection, variations in measurement technique using calipers, etc., and some errors due to human decisions such as at what level of precision one will carry out computer or other analyses. Operational errors depend, then, on situationally and personally unique factors of measurement and cannot really be estimated fully.

80. For this reason, most assessments of errors entailed in interpreting, mapping, and measuring spatial data from aerial photographs focus solely on inherent errors. Gatto and Doe (1983), in considering errors that might affect their measurements of bank recession at northern Corps of Engineers reservoirs, cite inherent errors in aerial photographs as most important, including "...scale variations due to camera lens distortions and aircraft altitude changes..." and "...radial, relief and tilt distortions...." Gatto and

Doe also found, as we did when trying to map specific archeological sites, that measurements within small test areas are increasingly difficult as the scale of the aerial photographs used becomes smaller. Errors (both inherent and human) of the same basic magnitude in measurement from smaller-scale photographs represent a greater proportion of the total measurement than in larger-scale photos. Gatto and Doe (1983) adopted a rule-of-thumb for accepting or rejecting measurements based on Tanner's (1978) concept of the MMD. The MMD represents a confidence measure as a distance below which one cannot, it is assumed, reliably measure from aerial photograph. If a measurement they compared between two aerial photographs of different dates was less than the combined MMD of both photographs or if it indicated that the bank moved outward toward the reservoir, that measurement was not represented as an absolute value but rather a range of values.

81. Millsop (1985) also explicitly used Tanner's MMD method to define the level of precision to which he measured from historical aerial photographs in his bank recession research along the shores of Lake Sakakawea. Millsop's (1985) distance measurements were made from aerial photographs with a divider and an engineers' scale to:

> ...the nearest 0.21 mm. This corresponds approximately to the strict limit of measurement which the human eye can accurately measure, as defined by Tanner (1978)...

82. In measuring patterns of Atlantic and Gulf of Mexico coastal shoreline and island erosion and change using sequential historical aerial photographs, Dolan et al. (1980), Shabica et al. (1984), and Dolan and Hayden (1983) have calculated and estimated the extent of measurement errors, using a number of methods. Correcting their error figures for the 1:5,000 scale at which their photographs were interpreted onto base maps during projection, they calculate such factors as inherent photo resolution limit of 0.02 m, photo blur translating to 0.01 to 0.15 m, and the precision of the digitizer used to trace high waterlines translating to 1.25 m (Dolan et al. 1980). A much larger error in these measurements is occasioned by the difficulty of matching control features on photographs with the base maps, estimated by Dolan and Hayden (1983) to be approximately a 10-m ground distance. "The combined error of all measurement steps was calculated with a maximum value of 12.85-m ground distance, although it is commonly on the order of 5 m" (Shabica et al. 1984). Another source of inherent error that must be taken into

account in any procedure requiring the matching of photographs to maps for control and rectification purposes is that error inherent in the maps themselves. National Map Accuracy Standards published by the Office of Management and Budget as a guide to acceptable government maps are in reality somewhat difficult to interpret. As reproduced for photogrammetrists in the American Society of Photogrammetry's Manual of Photogrammetry (Slama 1980), they require the following:

a. Horizontal accuracy. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 in.; for maps on publication scales of 1:20,000 or smaller, not more than 10 percent of the points tested shall be in error by more than 1/50 in. The limits of horizontal accuracy shall apply in all cases to positions of well defined points only. Well defined points are those that are easily visible or recoverable on the ground, such as bench marks; property boundary monuments; intersections of roads, etc.; and corners of large buildings or structures.

b. Vertical accuracy. As applied to contour maps on all publication scales, not more than 10 percent of the elevations tested shall be in error by more than one-half of the contour interval. This means that at a map scale of 1:24,000, the scale from which our base maps (and the maps used by Dolan et al. (1980) and the other references cited) were compiled, at least 90 percent of well defined points must be accurate to within a distance of 40 ft, or 12.9 m. Ten percent of such points can be in error greater than this distance; this is level of accuracy to which the USGS and their mapping contractors strive. Map magnification, luckily, will not increase this error. Less fortunately, this means that if only well defined points are used for control matching, the inherent map error in accuracy of control matching that can be expected may be as great as the sum of the other inherent and operational errors estimated by the authors of this report. An error of nearly 25 m in controlled mapping, the sum of these errors, would be fatal in most bank recession measurements from aerial photographs of which these authors are aware.

83. A few points can be made in an argument for still being able to accept the results of this and other bank recession measurements made from historical and sequential aerial photographs. This argument requires partitioning the error or faithfulness of measurements into two categories somewhat differently than the inherent versus operational dichotomy detailed above. Measurements can also be thought of as having properties of both accuracy and precision.

a. Accuracy is the faithfulness of a measurement to the real world; this is the property of measurements dealt with in the

National Map Accuracy Standards (Slama 1980). They can be tested against the real world, and are in this sense comparable for the most part with inherent errors.

b. Precision refers to the repeatability of measurements, with respect to one another. The precision of measurements depends largely upon the abilities of the individual making those measurements, and the inherent error of the actual measuring device--dividers and scales, or digitizers, or digital calipers in the case of this research. Practically, the inherent errors of measurement devices are very small compared to the errors in precision that people make.

84. In the case of the measurements upon which the research reported here are based, lack of accuracy when compared to maps is in some cases quite noticeable. This is especially true where aerial photographs exhibit considerable relief and thus inherent radial displacement and scale errors. This is demonstrated by the lack of close correspondence between the mapped contours of base maps and bank line measurements at 39DU2, our site with the greatest relief differences (see the maps for 39DU2 in the appendices).

85. It is the relative distance between controlled representations of bank lines that are being measured between, however, rather than their correspondences with the base maps. The base maps are used actually to provide only consistent control points, rather than (necessarily) accurate control points. Unfortunately, precision errors (comprised mostly of operation errors) are not possible to estimate, since they depend not only upon the individual, but the conditions under which the measurements are made as well. An individual's precision of measurement can vary with factors as mundane as amount of sleep and feelings at the time the measurements are made. Control of these conditions over time would be impossible.

86. Such measurements will be consistent, however, if they are made at the same time, and under the same conditions for the measurement instrument operator. Although three such operators made the measurements in the case of this research, all of the measurements for sequential shorelines for each site were made within a short period of time (during one measurement session). In experiments with the repeated measurement of small distances using digital calipers, one of the authors, Ebert, usually averaged within 1 to 5 percent in terms of precision or repeatability. What is more, most inherent error can be estimated only in terms of a plus-or-minus error. This means that, for instance, the measurement precision and accuracy of a digital caliper device such as that used in this research, for example, be 0.03 mm less or greater

than the actual distance. It would vary around the true distance in both directions during measurements, and during a large number of measurements this two-way error between measurements would tend to compensate for itself. It can be considered, in many instances, to be a form of self-correcting noise rather than a real problem.

PART III: DATA ANALYSIS AND CONCLUSIONS

Bank Erosion: Causes, Processes, and Variables

87. Bank erosion, its causes, and its effects on our environment and landform are not just topics of recent interest. A classical treatment of the forms which lakeshore landforms take and the processes which give rise to such features by the geomorphological pioneer G. K. Gilbert (1884) is still one of the most complete descriptive treatments of such phenomena. Building on the premise that "In shore sculpture the agent of erosion is the wave..." Gilbert (1884) explains that the significant type of wave in this process is the wind wave proper, existing during the continuance of the wind; the swell, which continues after the wind has ceased, is far less important in bank and shore erosion. While the wave is the chief agent, it is in turn influenced in its energy and ability to erode sediments, and the effects upon sediments, by many factors. These include the depth and shape of near offshore slope, the height of wave crest, the nature of undertow which removes eroded sediments, the type of sediment being eroded. Gilbert's primary illustration of the variability of wave-cut landforms based on different combinations of these causes focuses on cliffs, wave-cut terraces, beaches, barriers, and other littoral features apparent around ancient, abandoned lakes such as those on the margins of the Plains of San Augustin in New Mexico.

88. Reservoir bank and shore erosion, of which Gilbert probably had few illustrations in 1884, is similar in many ways to that on oceans and natural lakes, but there are important differences as well. Reservoirs create a unique erosional situation in that their impoundments create erosional shores on slopes previously unaffected by lacustrine processes, causing immediate and accelerated erosion and sedimentation (Lawson 1985). Upon reservoir filling, flooding or almost instantaneous shoreline erosion causes the loss of vegetation which may have protected sediments for millennia. Hydrologic conditions are altered through the modification of the water table and of the previous drainage system, by overbank flooding, and by fluctuation of reservoir water levels within a variable zone. Rapid injection of sediment into the water column adjacent to the shoreline causes offshore features to form quickly, modifying the erosional regime. While water level variations of different time scales may be equivalent in their effects per unit time, they are quite likely

of widely different predictability; seiche-induced water level differences, for instance, could only be predicted or measured given a large, dense network of recording stations.

Time scales

89. The factors which influence reservoir-related erosion can be attributed to several time scales. Water levels in many reservoirs are manipulated on a short-term basis, often on the order of a few days, according to the purposes for which the reservoir system was built. Other short-term differences in erosion can be caused by weather, and wind and barometric pressure differences, for instance, can cause water levels to differ from place to place on a single reservoir (seiche). Long-term fluctuations in water level at reservoirs result from changes in climatic parameters, droughts for instance, for several years or more. Bridging the periods between these are seasonal fluctuations, which cause periodic water level fluctuations (Lawson 1985). Water level fluctuations are of course important in determining the nature of bank and shore erosion on reservoirs, because they determine which areas or sediments wave erosion reaches and affects.

Morphology

90. Shore morphology is another area in which reservoirs differ from most natural shores. Reservoirs usually have an elongated shape, with greater shoreline development (ratio of shoreline length to circumference of a circle with the same area as the pool) (Lawson 1985); i.e., reservoir shores are often convoluted, irregular, and complex. Factors affecting erosion in reservoirs can therefore be expected to vary significantly from place to place, even over short distances. Reservoirs are deepest near dams, whereas natural lakes are deepest in their centers, also enhancing spatial variability in erosion along reservoir shores. The geotechnical properties of sediments along reservoirs therefore will vary along their length, as well.

Equilibrium of shorelines

91. Newly created reservoir shores are immediately in disequilibrium with their new lacustrine environment, and are thus highly unstable. The length of time required to reach equilibrium will vary, because of the factors just described, from reach to reach in many larger reservoirs. Although it is tempting to think that shorelines in some places may reach equilibrium quickly, some of the results of the present study show that apparently this has not happened at our study sites in more than 30 years. The complexity

of the different components of shorezones, and therefore the difficulty of assessing the factors that affect its shape and evolution (Dean and Maurer 1984; Bruun and Schwartz 1985; Dietz 1963) are compounded in reservoirs by often great short- and medium-term changes in pool level, which constantly change the identity of the shore zone profile (Lawson 1985). Specifically, profiles of eroding reservoir margins often differ from typical natural coastal profiles in having prominent, abrupt bluffs adjacent to a foreshortened beach profile. In many cases, a backshore zone is entirely absent, with the waterline lying at or above the bluff toe. Natural lakeshore processes and predictions may not, therefore, be completely appropriate analogs for characterizing reservoir shores, and since large reservoirs are a relatively recent phenomenon, the behavior of their shores is poorly understood. Reservoir shore processes may in fact include many factors in common with riverbank erosion, such as meander geometry, in an unknown combination with lakeshore processes (Warren 1987).

92. Numerous processes, as well as factors which account for their intensity and occurrence, interact to cause reservoir bluff or beach erosion and subsequent shoreline recession. According to Lawson (1985), "No single process or parameter uniquely accounts for erosion or recession of a bank or bluff."

93. A recent summary prepared at CRREL of processes and phenomena affecting bank erosion at northern-latitude reservoirs (Gatto and Doe 1983) illustrates the complexity of these factors (Table 7, Figure 5).

94. The variables that any study incorporates in an attempt to explain and predict a phenomena of interest, of course, vary with the objectives of that study. A discussion of variables significant in explaining and predicting reservoir bank erosion germane to this study is presented by Millsop (1985), who conducted studies above Garrison Dam at Lake Sakakawea in North Dakota to assess the reasons that bank erosion there showed little sign of reaching equilibrium since the filling of that reservoir.

95. Millsop (1985), in agreement with Gilbert (1884), observes that the primary cause of reservoir bank erosion is waves. The effects that waves have on banks, and hence the types and amounts of erosion and bank recession they cause, are in turn dependent upon many measurable factors or variables. In large northern reservoirs such as Lake Sakakawea, as well as the other lakes considered in this study, important variables include: reservoir pool levels;

Table 7

Processes of Reservoir Bank Erosion and Contributing Factors (Gatto and Doe 1983)

```
                Frozen
Perennially                 Seasonally                 Unfrozen

Frost wedging
Frost heaving
Ice wedging
Thermoerosional niching and falling
Ground-ice slumping
-----Ice lenses------------------------
-----Ice scour-------------------------
-----Ice push--------------------------
-----Ice pile-up-----------------------
-----Ice shelving----------------------
-----Ice cover let down----------------
-----Ice rafting-----------------------
-----Snow erosion----------------------
-----Thawed soil slides----------------
-------------------Positive pore-water pressure----------------
-------------------------Groundwater piping--------------------
-------------------Chemical weathering-------------------------
---------------------------Waves-------------------------------
--------------------------Currents-----------------------------
-------------------Water level fluctuations--------------------
---------------------------Wind--------------------------------
---------------------------Falling Trees-----------------------
---------------------------Man-induced erosion-----------------
---------------------------Debris Sliding----------------------
---------------------------Sloughing---------------------------
--------------------------Bank sediment characteristics--------
--------------------------Biological Factors-------------------
-----------------------------------------------------Sheet Flow
---------------------------------------------------Rill erosion
--------------------------------------------------Gully erosion
------------------------------------------------Raindrop impact
-----------------------------------------------------Landslides
-----------------------------------------------------Earth fall
---------------------------------------------------------Slumps
```

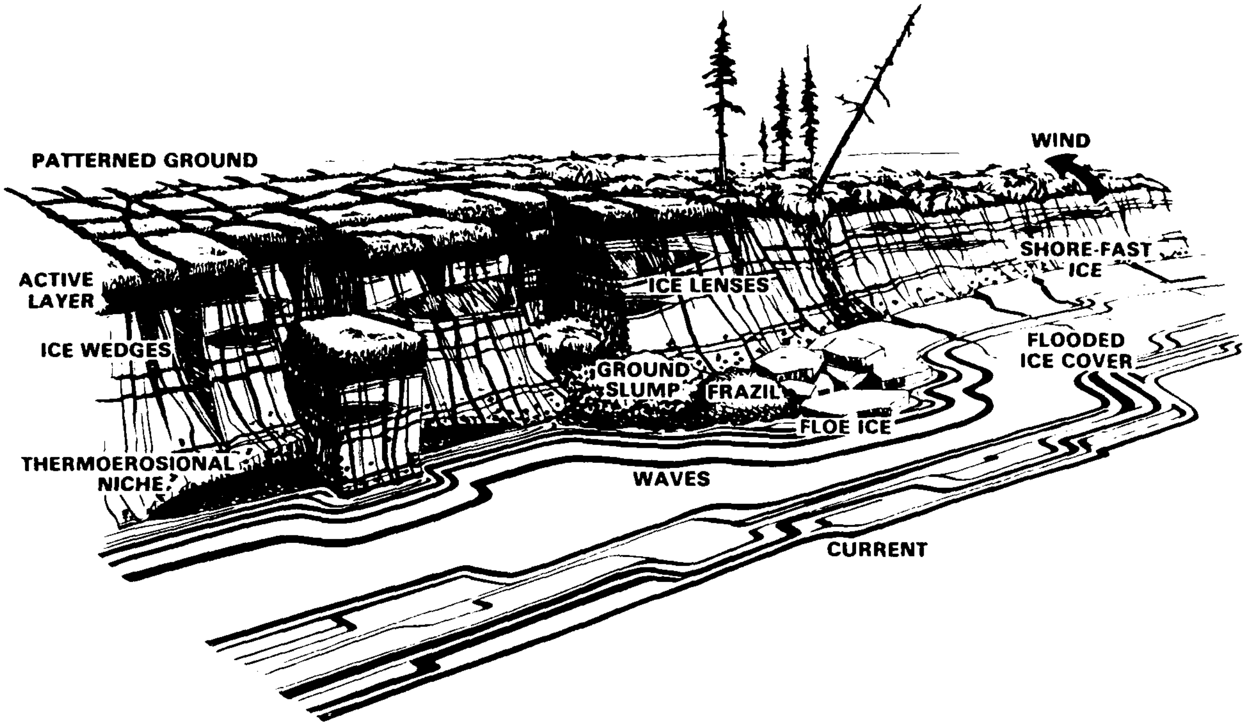

Figure 5. Bank erosion processes and bank characteristics contributing to erosion at northern reservoirs (from Gatto and Doe 1983)

wind velocity, direction, and duration; bank orientation; bank geology; bank form; vegetation cover; the existence of natural riprap, beaches, or other sheltering structure; and offshore bathymetry. "Activating factors" (Millsop 1985) include the actions of ice on shores (Gatto 1982b, 1984c), slumping or bank failure of various types, and rainfall and overland water flows. These variables or factors and their own dependent variables are as Millsop (1985) summarized in Table 8.

96. To assess the various contributions and interactions of these variables, Millsop (1985) made measurements of bank recession--his "independent variable"--over a 4-year period using measurements at pins on the ground, and over longer historical periods using aerial photographs. He compared bank erosion rates and trends in those rates with bank profiles measured on the ground, wind, pool level data, evidence of overland water flows, precipitation, ground water (measured with piezometers), the frost-thaw cycle (measured through direct observation as well as frost tubes and thermographs), and the nature of bank sediments (using field and laboratory measures).

Table 8

"Activating Factors" and Associated Dependent Variables Recognized and Measured at Lake Sakakawea, ND (after Millsop 1985)

Activating Factor	Dependent Variables
Wave Erosion	Bank orientation, geology and geometry; natural rip-rap and vegetative cover; offshore profile; offshore islands; pool levels; wind direction, strength, and duration.
Overland Erosion (Rainsplash and Runoff)	Preexisting moisture condition; bank orientation, geology and geometry; vegetative cover; precipitation intensity, duration, and direction.
Ground Water	Bank geology and geometry; topography; precipitation and snowmelt amounts; pool level fluctuations.
Frost-Thaw	Preexisting moisture condition; bank orientation, geology and geometry; vegetative cover; frost rate, depth, and duration; volume and concentration of ice; freeze-thaw cycles; rate of thaw; snowmelt amounts.
Lake Ice-shove	Bank orientation, geology and geometry; pool level; degree of ice cracking and refreezing; wind strength, duration, and
direction.	
Vibration (man-made, wave-induced or storm-induced)	Location, intensity, and duration.

97. Most bank erosion, Millsop (1985) concludes, occurs through the process of bank failure or shear. Types of bank shear movements include falls of overhanging masses (cantilever failure), topples or forward tilts, slides (transitional or rotational), lateral spreads, and flows. Most shear events are combinations of these types.

Wave action

98. Millsop's (1985) analyses illustrated that wave action is the dominant erosional process at Lake Sakakawea, as it is on natural lakes in

that area (Reid 1985). Wind-driven waves undercut banks during high water, bank shear occurs causing sediment collapse when water levels lower and sediments dry, and sediment is then removed at moderate to high-water levels. Natural rip-rap or sheltering factors, rainfall, and overland erosion are of very minor importance there due to the dry climate, which is the case at all of the reservoirs studied here as well. Ground water, too, is relatively unimportant except that related to reservoir levels. Frost-thaw cycles can also be significant causes of bank failure but affect primarily jointed bedrock. These cycles are less important in homogeneous fine-grained sediments similar to those found at the archeological sites upon which this study focuses. Bank disturbance by human and animal activity are also acknowledged as important in some places. Human activity is also noted in this study as being an important, if difficult to control for (in both scientific and legal terms), variable. This human activity occurs at the archeological sites in this study in two forms: the effects caused by past human activity (i.e. differences between archeological and culturally unaffected sediments), and by present-day archeological looting. Not considered here are waves induced by reservoir navigation; even in heavily navigated reservoirs, vessel induced waves probably account for only about 5 percent of bank erosion (Gatto 1984c).

Bank erosion processes

99. Erosional processes observed and measured during this research are also attributable, on an ultimate level, to the action of waves, affected primarily by their energy and their effects on different portions of the beach/ bank profile due to fluctuations in reservoir pool levels. During periods of higher water level, bank profiles are cut to the vertical in fine-grained, homogeneous sediments, or less often undercut. When levels lower, shears of these vertical banks result in topples or forward tilts (Figure 6), as well as less consolidated flows (Figure 7). Sheared or slumped material is then removed by further wave and current action.

100. An observed factor which may aggravate wave action in some cases, or ameliorate it in others, is the existence along many reservoir shores of tremendous amounts of often massive driftwood logs derived from the Missouri River Valley forests which are now submerged (Figure 8). These now-dead trees apparently float to the surface continuously, and batter against shores during storms; it may be however, that they also offer an element of shoreline protection under certain conditions. Though the interaction of driftwood with

Figure 6. Large blocks of sediment shearing from the bank at the Jones Village Site, 39CA3

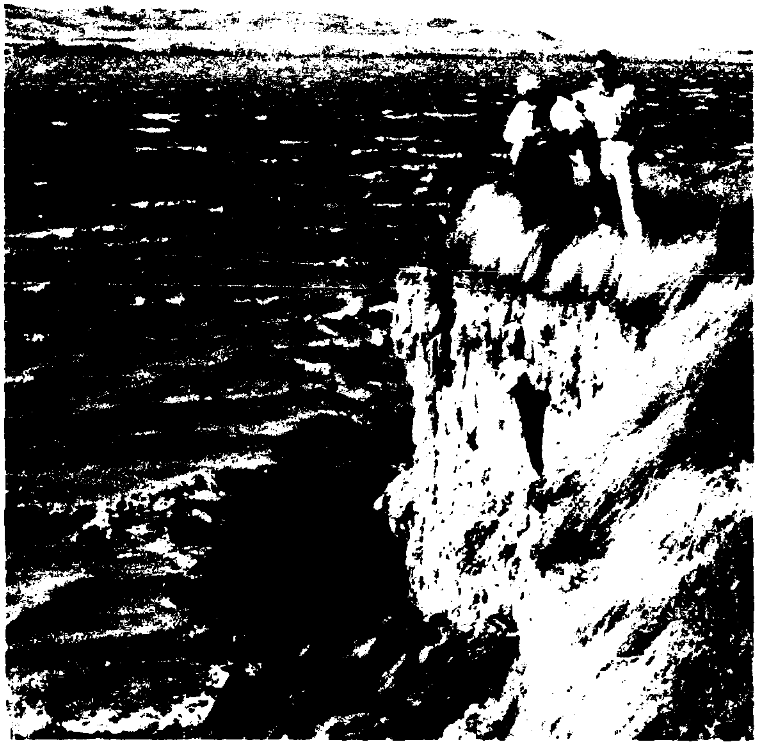

Figure 7. Sediments recently collapsed probably due to topple or cantilever failure of jointed silty sediments at the Jones Village Site, 39CA1

Figure 8. Large numbers of huge driftwood logs pound against shores during storms, exacerbating bank erosion

winter ice is not known, the two will probably continue to be participants in the shore system of Missouri River reservoirs for many decades.

101. Subsurface soil liquidity and resultant shear failures caused by thawing and freezing are a common feature not only along reservoir shores in the area (Figure 9), but also on slopes not immediately adjacent to reservoirs or their banks, as illustrated by crazily tilting fenceposts, especially in the Big Bend area of South Dakota (Figure 10).

102. In some areas, biological and cultural agents form what may be an important subset of mechanical factors disturbing the integrity and thus increasing the susceptibility of bank sediments to shear failure. While plant cover and roots may increase the competence of sediments, our study sites are covered almost entirely by grass cover with shallow root systems; this makes overland water flows and rill erosion almost nonexistent, but has little effect on resistance to bank sediment slump and removal. Birds and animals burrow into banks, and may help cause bank failures (Figure 11). Another sort of "biological burrowing" that may be quite significant, particularly because it occurs only at archeological sites, is caused by illegal artifact looting

Figure 9. Successive shear failures, probably caused by freezing and thawing processes

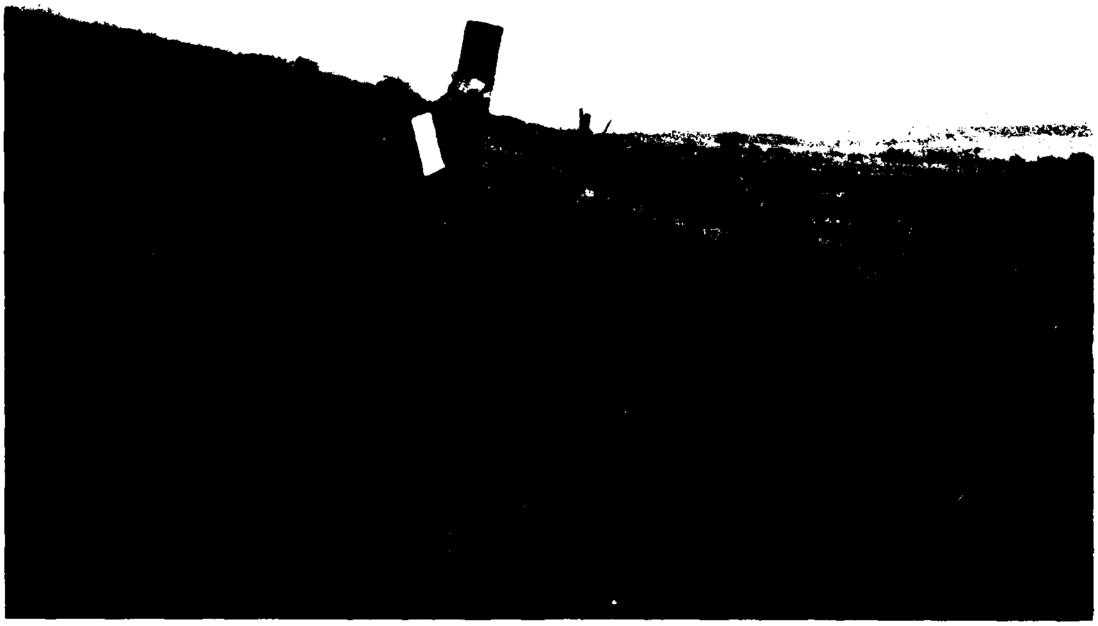

Figure 10. Slippage of surface soil layers during thawing causes fenceposts in the Big Bend area to tilt in a downslope direction

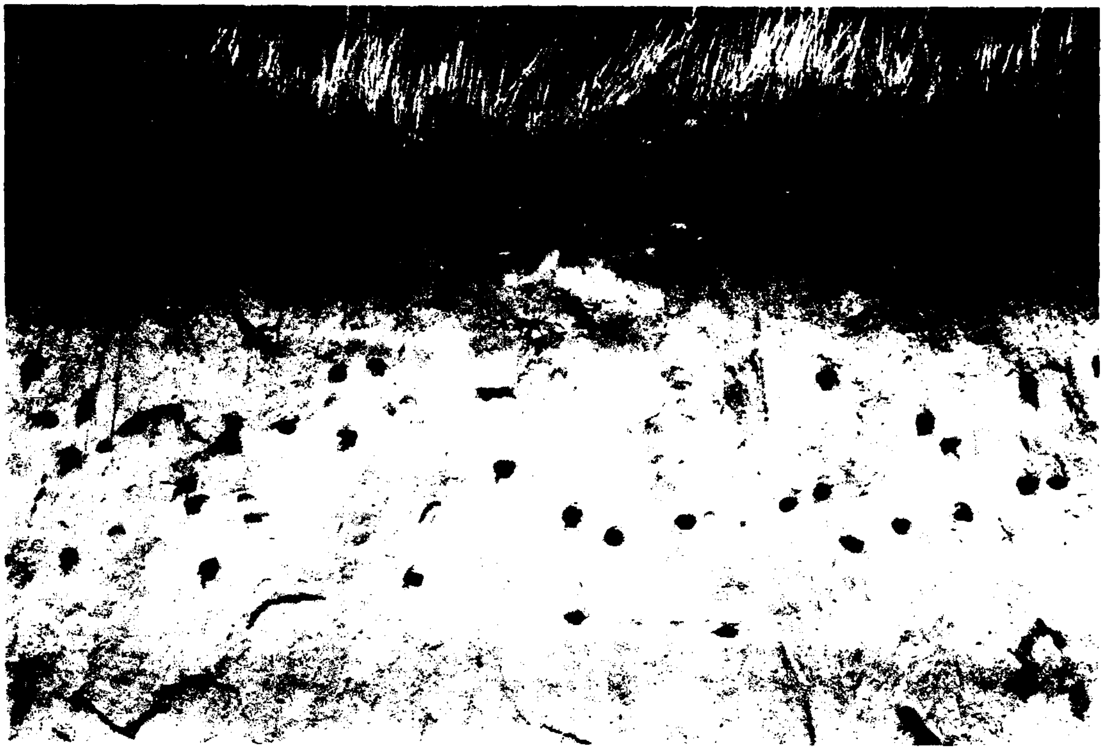

Figure 11. Birds and burrowing mammals can weaken banks, facilitating collapse, while plant roots strengthen near-surface sediments

(Figure 12). Looters remove astonishingly large amounts of sediment and undermine banks very effectively at some sites, and this activity occurs year after year. Illegal artifact collecting, then, poses a double threat to cultural resources. This is one cause of bank erosion that would be relatively easy to combat and control (Site 39CO6).

Variables and measures

103. The variables recorded in this study were designed to meet analytical goals outlined earlier in this report, specifically: (a) to allow the measurement and description of bank recession amounts and rates through time at the study sites, (b) to facilitate the identification of major processes and factors influencing bank erosion at each study site, and in general in the study area, and (c) to illustrate approaches that might be productive in modeling bank erosion and predicting its future course at the study sites as well as along the shores of Missouri River reservoirs in general. At the same time, another somewhat more operational goal or consideration in this research was to avoid overcomplicating our analyses at this developmental stage. The scope of work for this research was written to include, for the most part,

Figure 12. Systematic and widespread undermining of banks during illegal looting activities may be a major factor facilitating bank collapse and erosion at some sites

variables with values that could be measured using the same aerial photographs from which bank erosion itself was measured. Variable classes, including measures of pool levels and their fluctuations, measures of relevant soils characteristics, gradient, and fetch, used in the analyses which follow were derived independently. A short description of each of the variables measured, and their presumed significance, appears in the following paragraphs.

104. Bank recession. Bank recession is, of course, our independent variable. That is, it is the property of environmental change that we attempt to explain and predict, using measurements of other environmental characteristics that presumably cause or at least vary in a patterned manner with bank recession.

105. Bank recession was measured, as described beginning in

paragraph 75, at 21 transects, spaced 100 m apart, at each of the study sites. Transect 11 was arranged to pass through the center of the archeological site focused upon, and the other transects covered 1 km along the shore on each side of the archeological site. Photointerpretation and map transfer methods were also described in Part II. The scaled amount of bank recession in metres between a baseline shoreline (the earliest postreservoir filling shoreline) was recorded for each photographic overflight date interpreted.

106. Calculating the distance between each successive shoreline and dividing these data by the time elapsed between each photographic overflight date allow the derivation of a rate in metres per year of recession between consecutive overflight dates.

107. Gradient. Transects were arranged perpendicular to the gradient of the land at the intersection of the transect with the baseline shoreline, as interpreted from the 1:10,000-scale base map (derived from USGS 1:24,000, 7-1/2-min topo sheets). The gradient, in terms of topographic rise overrun, of the immediate shore was calculated from map contour lines.

108. This was done to provide information necessary to determine whether the bank recession being interpreted from the aerial photographs might actually be due simply to an apparent waterline change as the pool level increased or decreased, in the same way that the waterline moves back and forth on a shallow-gradient boat ramp, for instance, as pool levels change.

109. In the following analyses, this variable is not used since it was later determined that in the study sites (a) the gradient at the shore or bank is actually impossible to determine from map contours since it is markedly steeper than the shoreward surface gradient, and (b) banks at almost all places are of such a steep gradient that this problem really isn't a problem. In illustration of this, a series of analyses were done at those sites with enough subsequent banklines to allow correlation between raw recession values and pool levels on the day the aerial photographs were taken; this analysis is described later in this report.

110. Presence or absence of beach. This is simply a determination of whether a discernible beach, in the sense of an exposed, relatively level, highly reflective sand shelf between the waterline and the bank itself, is present at each transect at each study site.

111. Aspect of the bank or shore. For each transect at each site, the aspect of the bank or shore was measured. The aspect is the direction that

the shore faces, expressed in terms of the angle in degrees clockwise from north of a line normal to (that is, perpendicular to a tangent at) each transect. Aspect was measured because it is an indicator of the wind direction that should create waves most directly affecting bank or shore erosion at each transect.

112. Fetch. Fetch is a measure of the distance over which wind-driven waves originate, and is therefore indicative of the energy of wind-driven waves. Waves driven farther by the wind are larger and stronger. Another way of thinking of fetch is that a small fetch means that a bank or shore is more sheltered.

113. Fetch was measured in kilometers to a resolution of 0.1 km in three directions from the intercept of each transect at each site with the shore after Phillipps (1986). The first fetch direction measured was shore-normal, i.e. perpendicular to a tangent to the shore at each transect. Fetch distances at angles of 45 deg both right and left of the shore-normal fetch were also measured. This was done because winds are not always, of course, shore-normal and are variable about a dominant direction over even short periods. It also allows an assessment of the shelteredness of the shore at each transect, which might not be apparent if, for instance, it was located at the end of a narrow cove.

114. Pool levels and their fluctuation. In the foregoing discussion of bank erosion factors and processes, one variable identified by previous researchers was the extent of pool levels and their fluctuation. Although pool level on the aerial photo date could perhaps be measured from aerial photographs (although there would be problems with scale and resolution), pool level and its dynamics between the photo dates, in the periods when bank erosion was actually taking place, obviously cannot.

115. Pool level data are of course carefully collected at high (as often as hourly) resolution. They present a serious data reduction problem. What is more, our study sites were located at different places on the reservoirs, while pool levels are recorded at the dams themselves.

116. In order to comply with our goal of keeping the present analyses relatively simple, but to still have general measures of the pool dynamics of reservoirs between the aerial photo dates, three gross measurements were made from graphs appearing in Plate No. 3 in the Corps of Engineers' "1986-1987 Missouri River Main Stem Reservoirs Annual Operating Plan and Summary of

Actual 1985-1986 Operations," prepared by the Missouri River Reservoir Control Center in Omaha. These graphs include pool elevations in feet above mean sea level for the years 1955 through 1986. These graphs are presented here as Figures 13 and 14. These data served at the basis for measurement of the temporal, pool-level variables used in regression analysis.

117. From these graphs, the maximum and minimum pool levels that

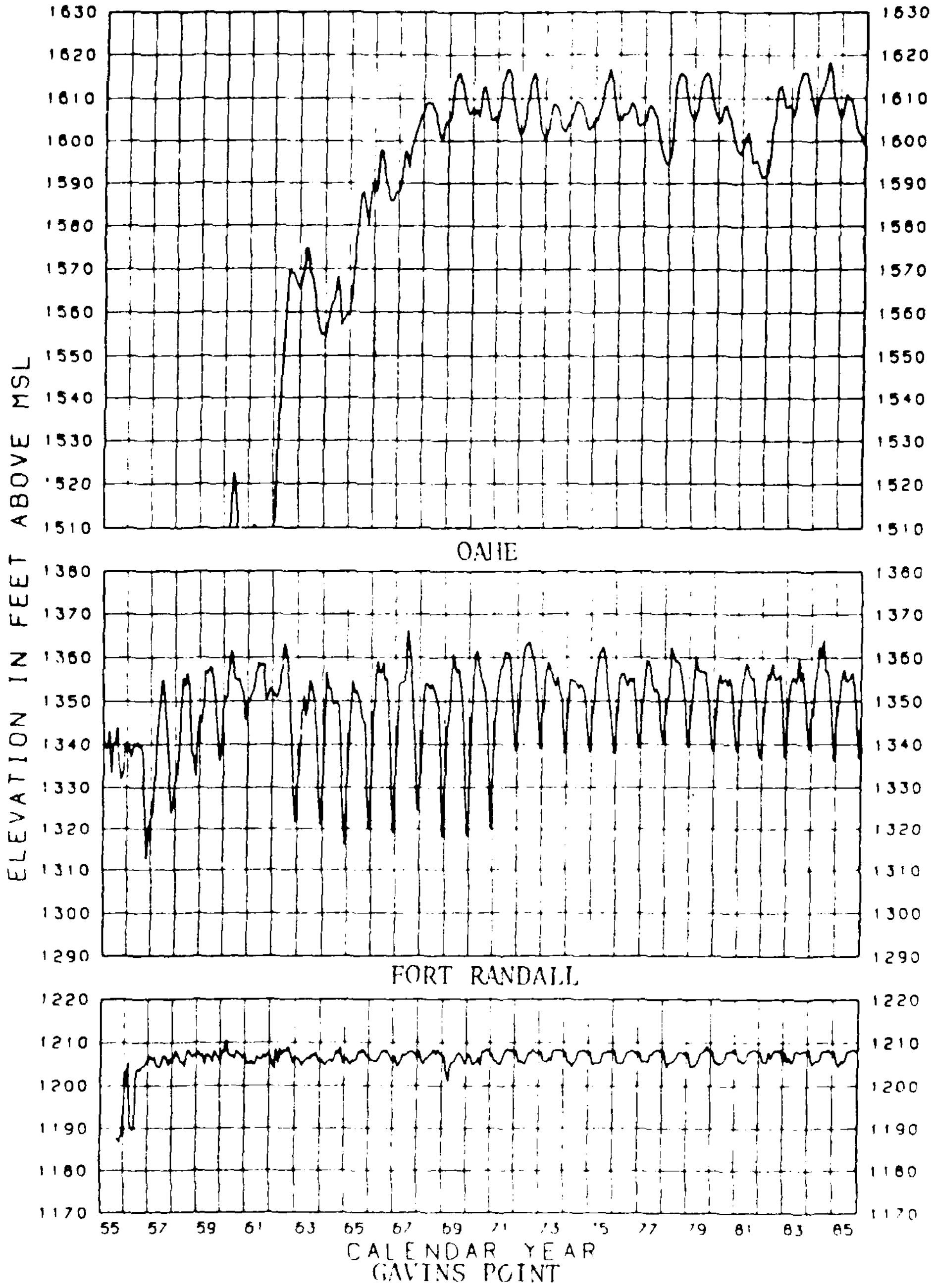

Figure 13. Simplified pool levels for Oahe, Fort Randall, and Gavins Point reservoirs

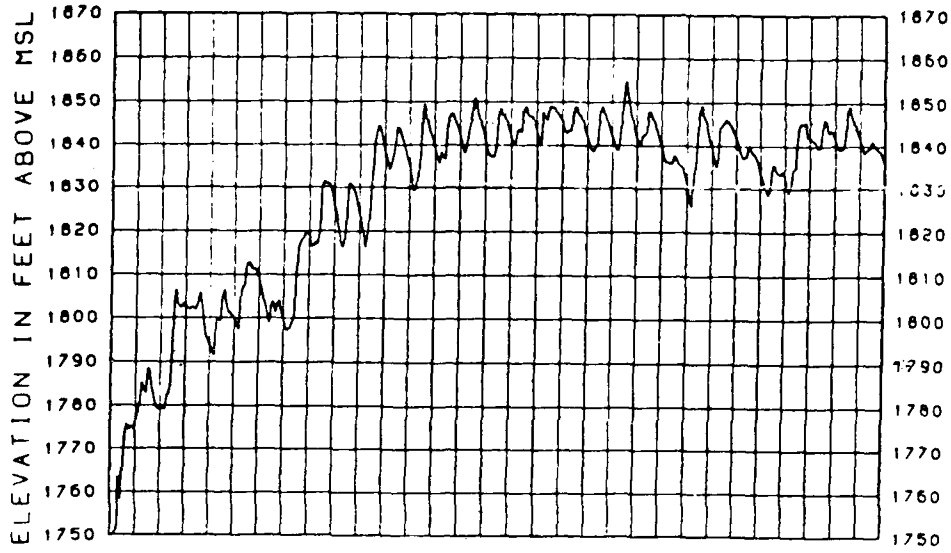

Figure 14. Lake Sakakawea pool level through time

occurred between each aerial photograph date for which bank recession was measured at each site were estimated to a resolution of 1 m. The difference between maximum and minimum pool level for each period between photo dates was calculated as well. Finally, a pool fluctuation index was determined by counting pool level peaks, separated by valleys of pool level minima, between each photo date.

118. Soils properties. A final class of independent data with assumed relevance to bank erosion that we attempted to measure was soils properties. Soils classifications developed by the USDA's SCS are available for most counties in the study area but are derived primarily for agricultural purposes; these classifications are thus also almost always difficult to relate to most nonagricultural investigations. The SCS soils classifications are based on the description of a suite of properties for each of a number of soils associations and series, so that even continuous variables are broken down by nominal soils unit categories, and the data generally available for such variables are given as ranges typical of each soils unit. For many purposes, then, such variables may be simplified to such an extent as to be practically worthless for explanatory purposes at high spatial resolution.

119. What is more, the agriculturally oriented classifications mapped by the SCS pertain in almost all cases to surface properties of soils and the areas they cover, extending in most cases to depths of 60 in. or less. Obviously, this takes into account only a portion of the variability in sediments that comprise banks at most of the study sites.

120. Nonetheless, inspection of the variability in bank recession rates and the SCS soils descriptions between and within the study sites does indicate that differences in soils are perhaps of some explanatory importance. Rather than attempt to use nominal classes, three classes of continuous variables incorporated in these soils descriptions which seemed to vary the most with measured bank recession rates were extracted from published and unpublished SCS data for the counties containing our study sites for which it was available. These variables are:

a. Erosion factor (K). This is one of six factors used in the Universal Soil Loss Equation to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. K is based primarily on percentage of silt, sand, and organic matter (up to 4 percent) and on soil structure and permeability. Values of K range from 0.05 to 0.69 and indicate the susceptibility of a soil to sheet and rill erosion; the higher the value, the more susceptible is a soil to such erosion by water.

b. Liquid limit and plasticity index. These measures are derived from the Atterberg limits, and indicate the plasticity characteristics of a soil. They are based by the SCS on test data from the survey area or from nearby areas and on field examination.

121. These index measures are given as ranges for each soils class in SCS country soils descriptions. Some soils units contain estimates of all three indexes, and some contain only one or two indexes.

122. To determine these variable values, the soil unit intersected by each measurement transect at each site was first identified. The range of values contained within each soils description was then averaged, to derive a single, central value, and these were then coded for each transect in each site.

Measurements, Variables, and Data Structure

123. At the end of the last section, a summary of the types of data interpreted and measured in the course of this research was given. The term variable is used in most scientific research in at least two different ways. The actual measurements taken during research are often called variables, but the term can be used in another sense as well--the analytical variables included in attempts to model or explain phenomena. The phenomena to be explained are dependent variables, while those that the scientist believes to

be causal, or to affect, or at least vary with the dependent variables are independent variables.

Problem orientation and dependent variables

124. The focus of this research, and the analyses set forth are rates of reservoir bank recession as they vary in space and in time. For the independent variable, RATE, there are at least three basic scales or magnitudes of variation in space and time that are important to consider. These are:

a. The mean rate of bank recession at the site over the period of record.

   This rate is a site-specific average bank recession rate measured from the first or baseline bank date through the latest bank date, averaged for all measurement transects or, alternatively, for any single measurement transect. It is affected by both spatial and temporal variation within the site as a whole. In the case of this research, this rate is found by averaging the recession rates for each of the 21 transects measured at each site, over the time of record. This rate is expected to differ to some extent from one site to another due to a combination of site-specific variables, within-site spatial variation between transects, and variations within each transect through time.

b. The variation in bank recession rates over space at each site.

   This is the difference in bank recession rates throughout the time of record (between the first and last bank measured) among 100-m spaced transects at each site. Variation between average rates among transects at a site will be due to differences in independent variables that do not vary through time, specifically bank orientation, fetch (a measure of shelteredness of each point on the bank), and the characteristics of soils or sediments as they vary between transects with each 2-km stretch of bank line.

c. Variation in bank recession rates over time at each transect.

   Measurement of bank recession using multiple sets of sequential aerial photographs allows the breakdown of rates into time periods. These rates vary due to independent variables that change through time, or have different values within the time periods between successive aerial photograph (and therefore bank measurement) dates. Such independent variables include properties of the pool level at each reservoir; these probably, however, interact in various ways with the nontemporal independent variables at each site. Other nonmanageable independent temporal variables, such as the occurrence of storms and local high winds that are difficult or impossible to measure for each site, probably also have important effects in terms of variability in bank recession over high-resolution time.

125. Dependent variables designed to represent each of these types and scales of resolution are used in the analyses presented in this section. These variables are:

- a. A gross site-specific bank recession measure consists of the average of bank recession at all transects within each study site over the total time period measured for that site. This rate is designated SRATE in the data structure.
- b. A mean bank recession rate at each transect within the site consists of the total bank recession distance measured at each transect within each site. This distance is divided by the total time period represented between the first (baseline) and last bank position measured. This rate is designated as TRATE in the data structure.
- c. Bank recession rates for each transect in each site are measured by dividing the difference between bank positions at successive measurement (aerial photo) dates by the elapsed time between each successive measurement date. This dependent variable is designated RATE in the data structure.

Variables

126. The derivation, and assumed importance, of the independent variables measured from the aerial photographs, or by independent means, used in the analyses presented here are described in the preceding paragraphs.

127. Measurement variables used to calculate dependent variables, along with the dependent variables and the independent variables used in the analyses presented here, are listed and summarized in Table 9.

Bank Recession Rates at Study Sites

SRATE, TRATE AND RATE for individual sites

128. A first level of analysis is approached here through the presentation of simple tables and graphs for each site depicting SRATE, TRATE, and RATE. Table 10 presents site-averaged or SRATE values, along with their standard deviations (SD), and a summary of number of photo measurement dates used and the first and last photo dates, for each of the 12 study sites. Sites are arranged in order of bank recession rates, from highest to lowest. A review of this table indicates that sites are being lost at a rate of about 2.5 m or 8 ft/yr. Although it may seem unrealistic to report rates to two decimal places, it must be remembered that summary statistics presented in Table 10 represent rates averaged from a series of measurements; and, that in any case,

Table 9

Measurement, Dependent, and Independent Variables Used in Analyses

ASPECT	The direction, in compass degrees, that the bank at the intersection of each measurement transect faces. This is a direction perpendicular to the tangent of the bank at each transect, or normal to the bank
DATE	The date at which each bankline was interpreted and between which distances between banks were measured
DISTDIF1	The distance between the baseline bank and the bank measured at each date
DISTDIF2	The distance between a bank and the bank interpreted prior to the time at which each bank was defined
FETL	The fetch distance (that is, the unimpeded water distance) in kilometres between the intersection of each transect with the bank at an angle of 45 deg to the left of the normal fetch
FETR	The fetch distance in kilometres at the intersection of each transect with the bank at an angle of 45 deg to the right of the normal fetch
FLUCT	The number of peaks in pool level fluctuation counted between successive bank measurement dates
K	Soil erodibility factor as described in the section above
LEVDIFF1	The difference in pool level between the baseline (earliest) bank time measured, and the latest bank
LEVDIFF2	The difference in pool level between successive bank measurement dates through time
LEVEL	The pool level above mean sea level on the date that the aerial photographs from which each bank measurement were taken
LIQ	Liquid retention index for soils, as described in paragraph 120b
NORFET	Fetch distance in kilometres along a line normal to the bank at the intersection of each transect

(Continued)

Table 9 (Concluded)

PDIFF	Absolute difference in metres between the maximum and minimum pool elevations occurring between successive photo/measurement dates
PLAST	Plasticity index for soils at each transect
PMAX	Maximum pool level achieved at any time between successive photo/measurement dates
PMIN	Minimum pool level achieved at any time between successive photo/measurement dates
POINT	Numerical designator for each transect
RATE	The rate of bank recession (expressed in metres per year) between two successive measurement dates for each transect. This is the distance between the two dates divided by the time between these dates
SRATE	The mean bank recession rate at each individual site, derived by averaging TRATE over all of the 21 transects at each site
TRATE	Mean bank recession rate (metres per year) at each transect for the entire period of measurement. This is derived by dividing the distance between the first and the last dated banklines for each transect by the elapsed time between those two transects

Table 10

Overall Erosion Rates (SRATE) for Middle Missouri River Sites

Site	Number of Photos	Photo Date First	Photo Date Last	Erosion Rate Mean m/yr	Erosion Rate SD m/yr
39DW234	8	9-27-62	5-30-86	7.32	4.51
39CO6	3	6-13-68	7-31-82	3.08	2.22
39LM224	4	6-21-65	8-12-77	2.95	1.59
39BF44	7	8-5-55	5-31-86	2.59	0.90
32DU2	3	5-25-66	10-18-85	2.44	1.28
25KX57/200	6	6-18-57	9-8-78	2.37	2.45
39HU242	5	6-17-68	6-3-83	2.33	1.09
39ST235	6	6-17-68	6-3-83	2.23	0.49
39WW15	5	7-25-70	5-30-86	1.82	0.85
39HU173	4	6-18-68	5-31-86	0.60	0.72
39YK40	8	6-28-56	5-23-83	0.41	0.60

inherent and operational errors affecting measurements have been acknowledged. The decimal places by which measurements are reported are, of course, the consequence of the physical process of measurement, and statistical operations should not be taken simply as a reflection of accuracy or precision.

129. A few general observations should be made concerning SRATE's. First, these rates are all well within the magnitude of bank erosion or recession rates made by other researchers measuring bank and shore erosion at manmade reservoirs, as well as natural lakes and oceans cited previously in this report. The sites with the highest SRATE's also exhibit the highest standard deviations in rates over space, generally speaking. This means that the variation between rates at transects within these sites is highest.

130. There is also a striking variation in SRATE's between sites; the mean (average) SRATE among all of the study sites is 2.56 m/yr, with a standard deviation of 1.80 m/yr. Clearly, simply citing an average rate of bank recession for archeological sites and their surrounding banks along Middle Missouri reservoirs is not necessarily a completely workable strategy for predicting actual rates of erosion at any of them.

131. Tables and graphic representations of TRATE and RATE at individual

sites, as well as the distances and times used to calculate these variables, are presented in Appendix B under the sections for each site. Specifically, tables and graphs included for each site are:

a. A table of the scaled distances (in metres) between the site baseline and each measured bank line through time (DISTDIF1), by DATE.

b. A table of the scaled distances (in metres) between successive measured bank lines through time (DISTDIF2), by DATE.

c. A table showing elapsed time between DATE's, expressed in decimal years.

d. A table representing between-date bank recession rates in metres per year.

e. A table showing bank recession rates averaged over the period of record, or TRATE (i.e. between the baseline or first and the last measured bank line) by transect at each site.

f. A graph showing the means and range (standard deviation) of TRATE's for each transect.

g. A graph showing the mean of all RATE's (i.e. bank recession rates at each transect for each time period measured, lumped for all transects through time.

132. While the various rates depicted for each site, and some of their site-specific implications, will be discussed below, there is an important general observation that must be made here. Some of the TRATE's in some of the sites, as well as some of the site-averaged RATE's for successive dates, exhibit means and ranges that appear to indicate that the banks have moved outward into the reservoir, rather than uniformly receding in a shoreward direction.

133. Strictly speaking, of course, true banks--that is, sediments consolidated prior to reservoir filling--cannot move in a poolward direction. In the reservoir bank recession studies cited in the preceding paragraphs of this report, for instance, Gatto and Doe (1983, 1987) and Millsop (1985), conventions were adopted to drop or disregard such negative recession measurements.

134. In the analyses presented here, we will not adopt such a convention for a number of reasons. First, we feel that arbitrarily dropping such values erodes the usefulness of calculating standard deviations for measurements. Expressions of the variation of measurements, such as the standard deviation, are intended to express the effects of measurement error among other things. If there are inherent and/or operational errors in our measurements, as described in paragraphs 78-86 of this report, then doctoring

measurements obscure these errors in accuracy and precision.

135. Perhaps more importantly, however, we would point out that, especially when multiple measurements of banks (such as at our 2-km stretches of bank/shore surrounding each study site) are made, in contrast to simple point measurements, the definition of banks and their characteristics may vary within a study site. A characteristic of the overall banks surrounding study sites on the reservoirs examined in this study is that these may vary from high, steep banks of prominent headlands, to low banks (or essentially no banks at all) in inlets formed by the flooding of prior drainages cutting through terrace surfaces into the river valley itself. In other words, all banks are not equal, particularly in terms of gradient.

136. Another possibility is that sediment buildup of some sort may actually be taking place, causing the bank to appear to move toward the reservoir pool rather than away from it. This might be due to the creation of beaches by alongshore currents, or the slumping of large blocks of sediment from banks into the pool or onto the beach at different photo dates.

Study sites summary

137. Summary discussions of photointerpreted bank recession at each of the 12 study sites presented refer to tables of scaled distances measured between baselines and bank lines and between successive bank lines and bank recession rates included in Appendix B. Periods of rapid bank recession and the locations which have experienced the most rapid recession are discussed. Site maps illustrating transect location and topography are available in the draft final report.

a. Site 39BF44 is located on an eroding terrace immediately north of Wolf Creek and is the only site examined on Lake Francis Case. The site contains three prehistoric occupational components including Plains Woodland, Initial Middle Missouri, and Coalescent components. Photographs from which shoreline measurements were made include seven sets of stereo pairs taken over a period spanning 30.9 years (Appendix B). Transects 1 through 5 are situated along the west and southwest-facing shore of a peninsulalike area formed by the terrace between Wolf and Crow Creeks. This point of land has experienced the most rapid rates of erosion. Transect 12, intersecting a low lying west-southwest-facing terrace immediately north of the mouth of Wolf Creek, also has a high erosion rate. Considering the entire overall recession distances for the 30-year period of investigation, the average recession rate for all transects was calculated at 2.58 m/yr. Average erosion rates using individual periods of observation range between less than 1 m/yr to over 7 m/yr. As can be seen, transects 1 through 5 and transect 12 have the highest overall measures of average rate and standard deviation. The area of site shoreline is represented by transects 11, 12, and 13, each of which exhibits moderately high recession rates. Periods of the most rapid recession for these transects fall between 1969 and 1973, 1981 and 1983, and 1983 and 1986 (Appendix B).

b. Site 39ST235 (Stony Point) is located on a level expanse of terrace at the base of a series of steep bluffs bordering Lake Sharpe and includes the remains of a Post-Contact Coalescent earth-lodge village and earlier Initial Middle Missouri remains. Field investigations reported the terrace conforms to the MT-2 landform described by Coogan and Irving (1959). The site is situated in the middle of the expanse of shoreline examined between transects 9 and 11 on a bulging section of terrace. Five sets of aerial photographs spanning a 15-year period between the baseline date and 3 June 1983 were used to measure the recession rate (Appendix B). Translating distances measured between photo dates into erosion rates, the rates for the period preceding Sep 1968 are very high for transects 1 through 9. Rates for succeeding periods are moderate to low for these transects. Between 1972 and 1982, rates appear to be stabilized for most transects but rise again for the period between 1982 and 1983, especially for transects 11 through 21. Apart from aspect, transects 1 through 9 differ from the others in that they are situated on Sully-Sansarc complex soils. This soil complex is distinguished by 9- to 25-percent slopes compared with 3- to 9-percent slopes for soils along the remainder of the shoreline investigated. Differences in slope are not perceptible at the scale of the USGS topographic quadrangle, but may account in part for differences in erosion rate between transect locations.

c. Site 32DU2 (Midipadi Butte Site) is located on a flat-topped butte which rises 50-m above the western shore of Lake Sakakawea and includes house depression constructed in the period between A.D. 1781 and 1815 as well as Woodland Tradition ceramic and lithic artifacts. The bank line defining the edge of the actual site at 32DU2 and its intersection with the water line has a variable morphology. The slope of the bank near the edge of the mesatop is at an approximate 45-deg angle, while it becomes progressively steep as it nears the waterline.

(1) Photointerpretation illustrates that this steep butte face was present at the site prior to reservoir filling and the effect of reservoir filling can be assessed by inspection of the aerial photographs taken on 5 Sep 1966 (just after the filling of the reservoir) and 10 Oct 1985. These illustrate a trend of the foreshortening of the horned peninsula upon which the mesa containing the site is located, as well as the less pronounced but still obvious collapse and retreat of the bank edge atop the

butte. If anything, the slope of the bank defining the outside edge of the site itself has become more shallow, while still losing sediment. That 32DU2 is undergoing significant bank recession is obvious; the relationship of this bank recession to independent variables affected by wave dynamics may be more complex than in most of the study sites, however.

(2) Three sets of aerial photography spanning a period of 19.5 years were examined to obtain edge recession data (Appendix B). Transects 6 and 11 intersect the northwestern and southeastern corners of the butte and have the highest erosion rates, 5.8 and 2.3 m, respectively. Highest rates for the intervening transects are less than 2.7 m/yr. Mean rates for periods of observation range from less than 1 to more than 5 m/yr. The negative rates for transect 7 may be attributable to slumping of the butte edge during the period between 1982 and 1985. A trend through time in overall cannot be accessed with only two periods of observation.

d. Site 39LM224 (Cable Site) is located on a broad terrace which extends north into Lake Sharpe. Cultural remains include an earth-lodge village attributed to the Extended Coalescent. The site is listed in the National Register of Historic Places. The terrace surface is slightly indented along a line paralleling and about 25 m from the shoreline. Bank recession distances are relatively great along this section of shoreline, averaging 2.94 m/yr between 1965 and 1977. Using a baseline date of 21 June 1965, total distance eroded exceeds 100 m at several transects (Appendix B). Seven sets of aerial photographs for the period been 1965 and 1984 were examined to obtain these measures of bank retreat, but average bank recession listed in Table 10 (2.92 m/yr) could be calculated only for the period prior to 1977. Transects 10, 11, and 12 intersect the site area and have overall measures of bank retreat of from 65 to 120 m for the period between 1965 and 1984. Compared with transects 11 and 12, transect 10 intersects the western edge of the terrace and has relatively high rates of erosion. Erosion rates through time begin with moderate rates of about 4 m/yr for the period prior to 1969 and rise to over 10 m/yr for the period prior to 1981. Rates then decline after 1981, but negative rates indicated for the periods prior to 1982 and 1984 do not represent aggradation at the shoreline. The small scale of the 1984 photographs, 1:80,000, is probably responsible for difficulty in interpreting the bank line on this date resulting in less precise measurement. Photograph scale does not explain the negative measurements obtained with the 1982 photos. These are, however, within a more acceptable margin of interpretation error. It should also be pointed out that if negative recession rates are dropped from tables presented in Appendix B, the overall mean erosion rates for transects at this site are increased markedly. Transects 10, 11, and 12, for example, would have erosion rates of 9.75, 5.24, and 5.27, respectively, if averaged for the periods between 1965 and 1981, rather than rates of 5.61, 0.69, and 1.10, respectively.

e. Site 39WW15 (Travis 2 Site) is located to the west of a point of land on the west side of a former tributary drainage to the Missouri River which now forms a small embayment. The site includes surface and subsurface artifact distributions along the east bank of Lake Oahe that contain projectile points typologically assigned to Paleoindian and Plain Archaic occupations. Shallow slopes (generally less than a 15-ft rise over a distance of 1,000 ft) characterize the entire shoreline within the study area. Differences in bank recession distances among transects dates point to landform and gradient as major influences in recession rate at this site. Five sets of aerial photographs taken between 1970 and 1986 were used to measure bank erosion at the site (Appendix B). On the first photo date, 25 July 1970, the point of land west of the small embayment intersected by transect 14 is partially inundated. Pool level on this date measured 1,608.5 ft. A higher pool elevation on 30 May 1986 of 1,617.4 ft is responsible for the total submergence of the point on succeeding photographs. The total recession distances as measured from the large-scale, high-quality 1986 photographs do indicate the largest recession distances for transects 14 and 15 that border the embayment on the west and east, respectively. These areas also have the lowest gradients of any areas along the shoreline. The remainder of the shoreline investigated slopes to a greater degree, although no steep banks are present on the portion of the shoreline examined. Transects 8 through 13 intersect the site and have total recession distances of from 20 to almost 27 m. Averaging recession rate for periods between photo dates, these distances translate into a little over 1 m of bank erosion per year for transects 8 through 10. Transects 12 and 13 have slightly lower rates.

f. Site 39HU242 (Whistling Elk) is located on the east bank of Lake Sharpe. During a survey of this site by the University of Nebraska (Steinacher 1983), it was noted that extensive erosion had taken place at this site, listed in the National Register of Historic Places, since the time of its original recording in 1968. This shoreline erosion revealed evidence of a buried Plains Village site consisting of an earth-lodge village surrounded by a fortification ditch. Bank recession rates measured over the period between 1968 and 1983 (Appendix B). Transects 8 through 11 intersect the site shoreline and have low to moderate rates for this section of shoreline. Rates are initially quite high for transects 1 through 7 to the west of the site, while transects 12 through 21 evidence high rates for the period between 1981 and 1983. Average recession rates for transects 8 through 11 are close to those observed by Toom for the period between 1979 and 1983. Toom and Picha (1984) observed between 1/2 and 2 m of bank erosion per year, while mean rates measured from aerial photographs are between about 1/2 to 1 m/yr. Rates also appear to increase through time averaging about 2 m/yr prior to 1981, increasing to almost 5 m/yr for the period between 1981 and 1983.

g. Site 39YK40 (Jazz and Jill Site) is located in a high bank of the Lesterville stream approximately 400 m upstream from the entrance of this drainage into Lewis and Clark Lake. It consists of five fire areas situated 15 m below the present ground surface and from 5 to 15 m above the stream bottom (Blakeslee and O'Shea 1983). Since the site is located in the exposed bank of a tributary drainage to the Missouri River, it is not susceptible to reservoir shoreline erosion. This area is not visible on aerial photographs due to heavy forest cover, and degree of recession was, therefore, not investigated at this location. The reservoir shoreline was investigated, however, to determine if the Lesterville stream was susceptible to flooding during periods of high reservoir pool elevation. Accordingly, the study area was centered at the mouth of the drainage on which the site is located, and bank recession distances were measured for the reservoir shoreline for the period between 1956 and 1983 (Appendix B). Transects 8 through 11 are positioned around the entrance of the stream into the reservoir. Transects 8 and 9, intersecting the shallow gradient of a terrace on the downstream side of the entrance, evidence the greatest initial recession distances between photo dates. Transects 10 and 11, intersecting a high bluff on the opposite side of the stream, show comparatively little erosion. Average erosion rates for these transects are quite low and have little variability. Rates for periods between photograph dates appear to be generally low and relatively uniform. At no time does the Lesterville drainage itself become flooded. Thus, if reservoir pool elevation does not exceed 1,208.3 ft, the maximum elevation for the period studied, the site should not be affected by reservoir shoreline erosion.

h. Sites 25KX57 and 25KX200 (Weigand) consists of a dense deposit of ceramics and lithics extending for a distance of 50 m along the east bank of Weigand Creek and 30 to 35 m along the west bank of the creek and shore of Lewis and Clark Lake. The site was described as centered around the original bank of Weigand Creek (Blakeslee and O'Shea 1983) and now extends into Lewis and Clark Lake. Bank erosion measurements were made for the period between 1957 and 1978 (Appendix B). Transects 14 and 15 intersect either side of the mouth of Weigand Creek and transect 13 intersects the shore of Lewis and Clark Lake to the west of the creek where 25KX57 is located. Transects 9, 10, 11, and 12 intersect the shore of Lewis and Clark Lake to the west of 25KX57 where 25KX200 is located. 25KX200 is situated on an elevated portion of terrace. After reservoir construction, this area formed a point of land extending into the lake as do smaller and more culturally disturbed areas on either side of Weigand Creek. Transects 10, 11, 14, and 15, intersecting points of land formed by these terrace extensions, evidence the greatest overall and between-photo date amounts of bank recession. Highest measures of bank recession through time are indicated for transect 11. Transects 9, 12, and 13 display an opposite pattern, one in which the shoreline is aggrading in shallow embayments on either side of the point intersected by transect 11. These patterns of shoreline erosion can be identified in the averaged recession rates for periods between photo dates. Average rates of bank recession in the site area are highest for transects 10, 11, 14, and 15 and are lowest and actually negative for transects 12 and 13. When compared between photo dates, bank erosion appears to have increased through time until 1978. The progress of shoreline recession and aggradation continues so that by 1985 the former points of land have become reduced and embayments are ringed with wide beaches.

i. Site 39CO6 (Jake White Bull) is an Extended Middle Missouri fortified earth-lodge village located on the east-facing slope of the second terrace above the Missouri River. The site is listed in the National Register of Historic Places. Bank recession was measured from a baseline bank on 13 June 1968 using two sets of subsequent photographs (Appendix B). Portions of the shoreline with the largest bank recession distances are located at points of land bordering tributary drainages to Lake Oahe which are intersected by transects 15 and 20. Recession rates are highest for the 8-year period prior to 1976. Three transects, transects 5, 7, and 8, evidence negative distances or shoreward movement of the bank for the period between 1976 and 1982. Inspection of aerial photography of these locations indicated that bank slumpage on east/southeast-facing slopes may be primarily responsible for these measurements. Recession rates averaged for the two periods investigated range between about 2 and 4 m/yr with the exception of transects 15, 20, and 5. Transects 15 and 20 average about 7 and 9 m/yr, respectively. Transects 10 through 14 intersect the site shoreline and have erosion rates of between 1.8 and 4.3 m/yr. These measures are quite comparable to the average of about 3 m/yr observed by Larson-Tibesar personnel for the period between 1975 and 1986 (Sanders et al. 1987).

j. Site 39DW234 (Molstad Site) is an Extended Coalescent earth-lodge village, a National Register property located on the west bank of Lake Oahe on the second terrace above the former Missouri River floodplain. The terrace forms a prominence bordered on the north, east, and south by Lake Oahe and underlain by Cretaceous Pierre shales which are exposed in the bank directly below and to the north of the site. Shoreline recession was measured using eight sets of aerial photographs and appears to have been quite rapid, initially. One reason for the high initial erosion rate is that the terrace below the one on which the site is located became completely inundated between 1962, the earliest photo date, and 1968. After this period, recession rates are appreciably lower. The overall mean recession rate calculated for all transects is 7.31 m/yr, the highest mean rate of any site studied. Areas with very high erosion rates are situated to the north and south of the site where study transects intersect tributary drainages. These sections of shoreline have erosion rates from 5 to about 40 m/yr (Appendix B). Transect 11 intersects the shoreline in the vicinity of the site. Recession rate averaged for all periods of observation is 9 m/yr for this transect.

k. Site 39HU173 is situated on an extension of a broad upper terrace above the former floodplain of Spring Creek about 2.5 km east of the former confluence of the creek with the Missouri River. This elongated section of terrace terminates on each end in a point formed by the former courses of tributary drainages with Spring Creek. University of Nebraska investigations recorded 21 stone features, including 11 stone circles, 7 rock clusters, 2 rock lines, and 1 rock cairn tentatively attributed to both Woodland and Plains Village groups based on two projectile point fragments recovered from surface contexts. Bank recession measurements were made using a baseline date of 18 June 1968 and three sets of aerial photographs spanning a period of about 18 years (Appendix B). Study transects 6 through 17 intersect the site shoreline. Although bank erosion has taken place at the southeastern portion of the peninsula where transects 14 through 17 intersect the shoreline, the majority of the site shoreline has experienced little erosion. The erosion that has taken place at the southeastern portion of the site is not uniform between observation periods. Averaged photograph rates are well under 1 m/yr. Average recession rates for periods between photograph dates is highest prior to 1973, an average of 1 m/yr, and falls to 0.11 and 0.64 m/yr for the periods prior to 1981 and 1986, respectively.

Fieldwork

138. It is always desirable to check results or conclusions measured or interpreted from one sort of data with an independent data source. In remote sensing, this activity is often referred to as ground truth checking, implying that information gleaned from aerial photos must be proven by seeing it on the ground. Of course, actually being on the ground is not always necessary; interpretations made from one date or type of aerial photographs can also be supported by similar observations made from another set of aerial photographs. In one sense, this is a property built into any project involving the use of sequential, historical aerial photographs.

139. In many ways, in fact, the truth of at least some kinds of measurements of change from sequential photographs are difficult or impossible to

check in any specific way. The reservoir bank changes upon which this research focused are of this nature, for the bank lines imaged on the historical aerial photos are of course no longer there, and one cannot go back, find them, and measure them on the ground. Neither can contemporary ground measurements made on existing banks, nor short-term measurements of bank recession, really serve to confirm measurements of historical change.

140. It was reasoned, however, that it should be possible to make measurements of portions of bank lines at a sample of the sites studied here on the ground, and compare them with our historical data to at least support the consistency of these measures over time. A field check of a sample of the study sites would also allow ground photographs characterizing bank conditions to be taken, and allow supportive observations to be made. With these goals in mind, a three-week field reconnaissance was undertaken between 28 Sep and 18 Oct 1987. Sites visited are listed in Table 11.

Table 11

Missouri River Sites Fieldwork

28 Sep to 18 Oct 1987

Oct 02	32DU2
Oct 03-08	39DW234, 39WW15, 39CO6
Oct 09-10	39LM224
Oct 13	39YK40
Oct 14-15	25KK57/200

141. The chief activity at each site visited, with the exception of 39YK40 and 25KX57/200, was mapping a portion of the bank using a Wilde T-16 theodolite equipped with a Lietz RED-2 Electronic Distance Meter (EDM). After a suitable instrument location was established, from which a portion of the bank line centered on the actual site could be covered, angles and distances to a range-pole mounted prism were shot in. Shots were taken at points which would allow the resolution of what were judged to be significant changes in the linearity of the bank. Control points that could be used to match mapped bank lines to the 1:10,000 base maps used to control the photointerpreted overlays, described in paragraph 77, were also shot in.

142. Vertical angles and slope distances were transformed to horizontal distances and elevation differences, and these data were used to plot the portions of bank line measured at each site to 1:10,000 scale using Generic CADD

Version 3.0 (Logitech, Inc.). These bank lines were then transferred to the 1:10,000 scale base maps, and distances between those 100-m transects covered by the EDM-mapped banks and the last aerial photo-mapped bank line were measured. The EDM-mapped bank line segments are shown on the 1:10,000-scale map copies attached to draft copies of this report. Bank erosion rates were determined by averaging scaled, measured distances so determined by time elapsed between the last photo measurement and the EDM measurements. Bank recession rates determined in this manner are compared with overall, aerial photo-measured rates in Table 12. In all cases, the EDM-mapped bank line sediments fell either behind or on the last photographically interpreted bank line.

Table 12

Comparisons of EDM-Measured and Aerial Photo-Measured Bank Recession Rates

Site	Number of Transects	Elapsed Years	EDM-Measured Rate	Overall Photo-Measured Rate	Recent Photo-Measured Rate
39C06	5	5.191	1.95 m/yr	3.08 m/yr SD = 2.22	1.63 m/yr (1976-1982) SD = 3.42
39WW15	12	1.348	3.19 m/yr	1.82 m/yr SD = 0.85	2.32 m/yr (1981-1986) SD = 2.07
39LM224	3	2.946	2.57 m/yr	2.95 m/yr SD = 1.59	8.44 m/yr (1981-1977) SD = 5.52
39DW234	5	1.356	1.95 m/yr	7.32 m/yr SD = 4.51	1.34 m/yr (1982-1986) SD = 3.69
39HU242	3	4.360	1.16 m/yr	2.33 m/yr SD = 1.09	4.74 m/yr (1981-1983) SD = 3.26

143. At site 32DU2, an EDM map of the edge of the mesatop containing the site was made, but due to the nature of the topography, this cannot be compared in any direct way with the bank line there at 1:10,000 scale. A further discussion of the reasons for this problem, and comparisons of the EDM map with two previous site-boundary maps at 32DU2, appears in the draft report in the section for this site.

144. Site 39YK40 does not lie along the shore of Lewis and Clark Lake, but is located between 500 m and 1 km from its shore in a small, steep-sided valley unaffected by the reservoir pool. Since the aerial photo measurements were made along the reservoir shore, no comparisons could be made. The

erosional situation at 39YK40 is discussed in its section in the appendix of the draft report.

145. Site 25KX57/200 was not EDM-mapped because the entirety of its unstabilized shoreline was inaccessible and, in fact, could not be defined when this site was visited. The waterline, at that time at least and probably for most of its existence (to judge from the historical aerial photographs), consisted of water underlying a thick mat of reeds and other vegetation. Measurements of the bank line and its recession at this site made in any manner may, for this reason, be difficult to interpret.

146. For those sites where comparisons can be made, however, three of the EDM-measured rates are within or almost within one standard deviation of the aerial photo-measured rates. For 39LM224, the two rates are within a few percent of one another. The EDM-measured rate at 39WW15 seems quite high compared with the aerial photo-measured rates, although it is still almost within one standard deviation. Verbal reports from local archeologists indicate, however, that high water in the summer and fall of 1986 may have caused above average erosional effects. This seeming inconsistency, then, might serve as a reminder that some of the most significant bank recession may be caused by short-term events, and that averages can be misleading. The elapsed time between the last photo-measured date and the EDM measurements is short, only about 15 months. Using a shorter measurement period, the rate calculated for the period between 1981 and 1986 is quite comparable to the EDM-measured rate.

147. The EDM-measured recession rate at 39DW234, where the highest erosion rates were photographically measured, is low. Elapsed time between EDM measurement and the latest photointerpreted bank line at this site is also only about 15 months, however. The very rapid initial recession rate between 1962 and 1968 during which the terrace below the one on which the site is located was inundated contributes is a significant fashion to the high overall photointerpreted rate at this site. The erosion rate calculated for the period between 1982 and 1986, 1.34 m/yr, is quite comparable to the EDM-measured rate.

Analysis of Pool Levels and Apparent Bank Recession

148. In an attempt to analyze variation in the characteristics of banks that might lead to "negative" measurements of apparent bank erosion, we first

tried to measure the gradient at the intersection of each transect with the bank. Our measurement transects were oriented perpendicular to the gradient, as shown on the 1:5,000-scale base map enlargements. These enlargements were made from 1:24,000-scale, 7.5-min USGS topographic quads, with contour lines at intervals of 10 to 20 ft.

149. Unfortunately, this contour resolution does not, in our opinion, allow the accurate calculation of gradient at the critical point between the reservoir pool and the surfaces containing archeological remains on Middle Missouri reservoirs, given the topography of the terrace-reservoir system.

150. The following questions still remain, however. Is there, in the case of some transects within some or all of the study sites, a relationship between pool levels and apparent bank recession or the lack thereof? If the gradient (however unmeasurable) of the shore zone at a transect is shallow, and a true bank (i.e., a tall, vertical, or near-vertical sediment cross section) is not present, might not an increase in pool level cause an apparent shoreward shift in the bank and a decrease cause an apparent poolward shift, without any real erosion or aggradation taking place?

151. It is important to examine the possible effects of pool level on bank line recession. To examine this question further, pool elevation data for each measurement (aerial photo) date for each of the study sites were obtained from the US Army Engineer District, Omaha (the variable LEVEL in Table 8). A series of correlation analyses were performed at those sites with more than two photo measurement dates; variables used in these analyses were DISTDIF2 (the distance that banks were measured to have changed between successive photo dates), and LEVDIF2 (the difference in pool level between successive photo dates). It was reasoned that if, indeed, pool level were influencing the apparent distance between bank lines, these two variables would show positive and significant correlations.

152. Of the 12 study sites, 9 had enough photo dates to accomplish such correlation analyses. The results are shown in Table 13. In this table, the R (regression coefficient) values and their significance levels are shown. For the nine sites analyzed in this way, there were 180 transects with sufficient (no missing) data to be used in correlation analyses. For 105 of the transects used in this analysis, R values were negative. Among the 180 with sufficient data for these correlation analyses to be performed, there are 14 transects for which the correlation coefficients are significant at the 0.1

Table 13

Correlations of Between-Date Measurements (RATE) and Pool Levels for Aerial Photo Dates, by Transect

Site 25KX57/200			Site 39WW15			Site 39HU173		
Transect	R*	p(R)**	Transect	R*	p(R)**	Transect	R*	p(R)**
1	-0.278	0.650	1	-0.295	0.704	1		
2	0.766	0.131	2			2		
3	-0.171	0.783	3			3		
4	0.539	0.348	4	-0.273	0.726	4		
5	-0.014	0.982	5	-0.762	0.247	5		
6	-0.153	0.806	6	-0.085	0.914	6		
7	0.167	0.787	7	0.224	0.775	7	-0.277	0.820
8	-0.730	0.161	8	-0.121	0.879	8		
9	-0.438	0.460	9	-0.550	0.449	9	-0.996	0.054
10	-0.376	0.532	10	0.219	0.780	10	0.424	0.721
11	0.660	0.224	11	-0.276	0.723	11		
12	0.256	0.677	12	-0.782	0.216	12	0.905	0.278
13	0.050	0.936	13	-0.727	0.272	13	-0.996	0.054
14	0.543	0.344	14	-0.214	0.78	14	-0.917	0.260
15	0.596	0.287	15			15	-0.299	0.806
16	0.295	0.629	16	0.553	0.466	16	0.759	0.450
17	-0.380	0.527	17	0.221	0.778	17		
18	-0.049	0.936	18	-0.067	0.932	18	0.999	0.007
19	-0.056	0.927	19			19	0.350	0.771
20	-0.264	0.667	20	-0.336	0.664	20	-0.419	0.724
21	-0.094	0.879	21	-0.350	0.649	21		

Site 39LM224			Site 39HU242			Site 39YK40		
Transect	R*	p(R)**	Transect	R*	p(R)**	Transect	R*	p(R)**
1			1	0.069	0.930	1	-0.599	0.15
2	-0.487	0.512	2	0.202	0.797	2	-0.089	0.84
3	0.817	0.046	3	-0.146	0.853	3	-0.284	0.53
4	-0.274	0.598	4	0.610	0.389	4	-0.198	0.66
5	0.011	0.982	5	0.008	0.991	5	0.282	0.53
6	-0.182	0.722	6	0.204	0.795	6	-0.010	0.98
7	0.485	0.504	7	-0.232	0.767	7	0.064	0.89
8	-0.421	0.405	8	-0.067	0.932	8	0.607	0.14
9			9	0.478	0.521	9	0.402	0.37
10	0.077	0.884	10	-0.246	0.753	10	-0.051	0.91
11	-0.220	0.647	11	-0.442	0.557	11	0.238	0.60
12	-0.318	0.538	12	0.958	0.041	12	-0.462	0.29
13	0.069	0.895	13	0.144	0.855	13	-0.425	0.34
14	-0.325	0.528	14	-0.693	0.306	14	-0.813	0.02
15	-0.121	0.819	15	-0.175	0.825	15	-0.494	0.25

(Continued)

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* R = Pearson's product moment coefficient.

** p(R) = probability.

Table 13 (Concluded)

Site 39LM224			Site 39HU242			Site 39YK40		
Transect	R*	p(R)**	Transect	R*	p(R)**	Transect	R*	p(R)**
16	0.621	0.187	16	-0.040	0.954	16	0.535	0.21
17	-0.009	0.985	17	-0.400	0.599	17	-0.457	0.30
18	-0.054	0.918	18	-0.182	0.817	18	-0.127	0.78
19	-0.648	0.351	19	-0.315	0.584	19	-0.696	0.08
20	-0.310	0.549	20	-0.581	0.418	20	0.236	0.60
21	0.310	0.549	21	-0.175	0.825	21	-0.228	0.62

Site 39DW234			Site 39BF44			Site 39ST235		
Transect	R*	p(R)**	Transect	R*	p(R)**	Transect	R*	p(R)**
1	0.604	0.203	1	-0.934	0.0065	1	-0.418	0.486
2	0.598	0.209	2	-0.913	0.0108	2	-0.350	0.563
3	-0.101	0.984	3	-0.806	0.0526	3	-0.265	0.666
4	0.085	0.872	4	-0.637	0.1739	4	-0.137	0.824
5	-0.799	0.056	5	-0.703	0.1199	5	-0.633	0.251
6	0.114	0.828	6	-0.739	0.0923	6	-0.518	0.371
7	0.363	0.478	7	0.128	0.8080	7	-0.407	0.495
8	0.140	0.789	8	0.207	0.6937	8	-0.816	0.091
9	0.140	0.791	9	-0.178	0.7351	9	0.594	0.290
10	0.170	0.746	10	-0.176	0.7382	10	-0.377	0.531
11	0.431	0.392	11	0.167	0.7506	11	-0.393	0.512
12	0.360	0.482	12	-0.327	0.5266	12	-0.467	0.427
13	0.406	0.423	13	0.149	0.7771	13	-0.148	0.811
14	0.163	0.757	14	-0.035	0.9466	14	-0.868	0.056
15	0.548	0.259	15	0.148	0.7798	15	-0.395	0.510
16	0.437	0.386	16	-0.188	0.7215	16	-0.615	0.269
17	0.525	0.284	17	-0.496	0.3162	17	-0.695	0.192
18	0.392	0.454	18	-0.449	0.3716	18	-0.673	0.212
19	0.482	0.332	19	0.112	0.8312	19	-0.509	0.381
20	0.695	0.124	20	0.055	0.9168	20	-0.485	0.406
21	0.357	0.486	21	0.109	0.8361	21	-0.570	0.315

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* R = Pearson's product moment coefficient.

** p(R) = probability.

level. Of the correlation coefficients for these 14 transects, 11 are negative. A negative correlation coefficient in this analysis signifies that as the pool level increased, the apparent bank line moved poolward rather than shoreward, or as the pool level decreased, the bank line moved shoreward.

153. This is essentially the opposite of what would be expected if pool level were influencing apparent bank recession measurements. It may be that bank slumping at some transects is causing the interpretation of poolward movements; however, bank collapse following pool level decreases may also be produced. Given the extremely small number of transects for which correlations (negative or positive) are significant even at the 0.1 level (a very liberal level of significance), it is likely that the appearance of poolward measurements of bank erosion are due to random combinations of inherent and operational errors.

Aspect and Bank Recession

154. All treatments of the causes of bank erosion and recession cited previously in this report focused on the action of waves and wind as a primary causal factor. People often speak of prevailing winds, but in practice the relationships between wind speed, direction, and duration from place to place are difficult to measure and characterize. Wind-rose graphs for a number of weather recording stations in North Dakota, South Dakota, and Nebraska were obtained from the US Department of Transportation for possible use in this study, but reducing and interpreting these data proved too complex to be incorporated here.

155. Instead, it was reasoned that if prevailing wind directions, velocity, and durations were constant over time (an assumption that is possibly valid given the 20+ year record at some of the study sites), and if, in fact, wind direction, especially winds of high energy, are important in bank recession rates, then the aspect and fetch of reservoir shorelines should vary in a patterned way with bank recession rates.

156. As a preliminary assessment of whether such patterning does in fact exist, the general aspects of the study sites were examined in relation to bank recession rates. The general aspect of each site was measured by the perpendicular, facing poolward, of a line drawn from the shore intersect of transect 1 to the shore intersect of transect 21 for each site. The

patterning of these general aspects of the study sites (that is, the direction they generally face) is distinctive, to say the least. Because of the northwest-to-southeast trend of almost all portions of the Missouri River within North Dakota, South Dakota, and Nebraska, the study sites can be divided into two very distinct groups: those facing between north and east (aspect northeast) and those facing between south and west (aspect southwest). A compass rose showing the general aspects of the study sites is presented in Figure 15.

157. Tables 14 and 15 list the mean values of RATE's (bank recession rates between consecutive bank measurements) and their standard deviations for sites with northeast and southwest general aspects, respectively. An

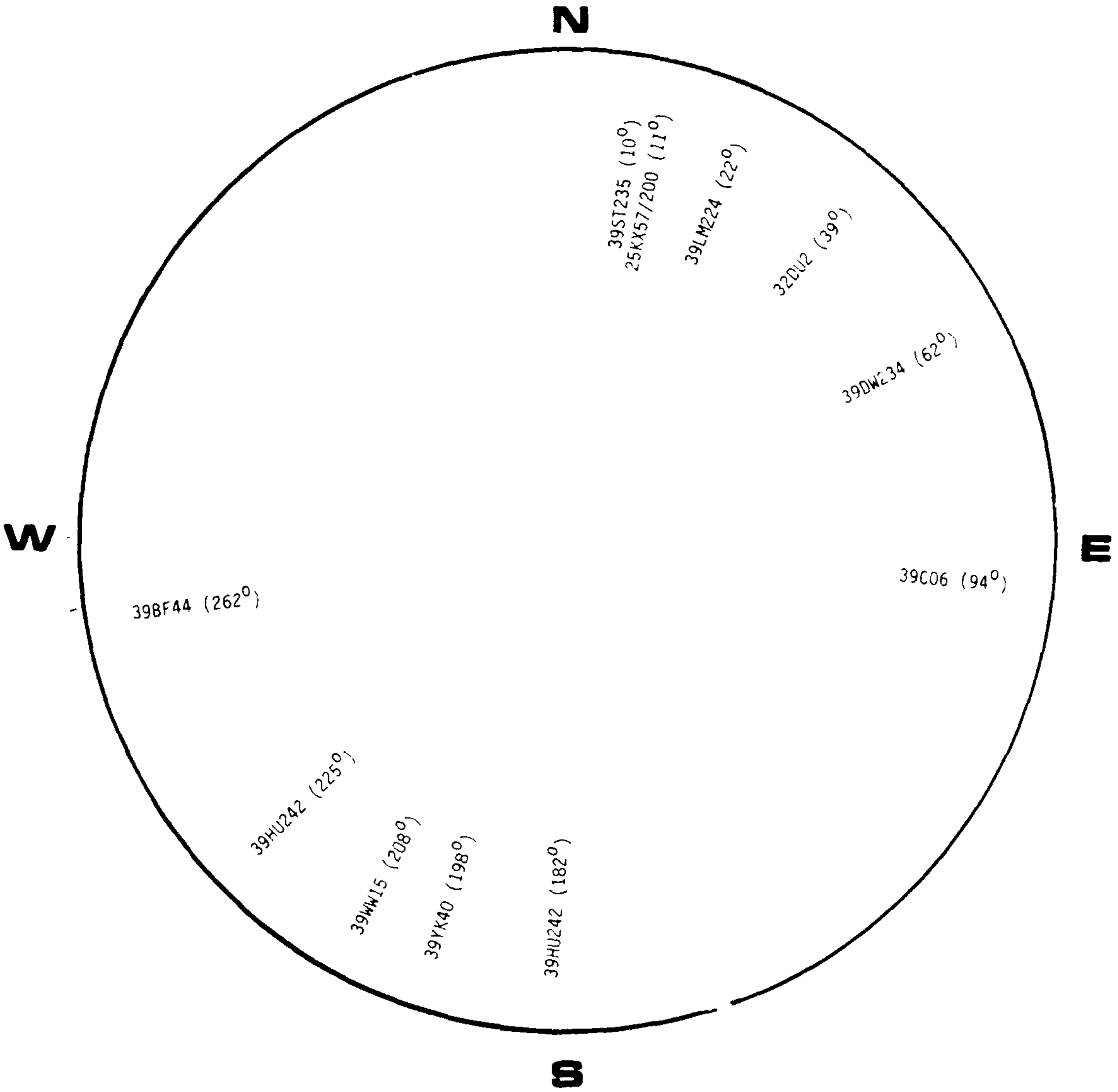

Figure 15. Compass rose showing the general aspects of the study sites

Table 14

Between-Date Rates (RATE) for Those Sites with General Northeast (NE) Aspects

Date	Reservoir	Site	Mean Rate*	SD	Low Rate**	High Rate†
18JUN1957	Lewis & Clark	25KX57/200	0.0000	0.0000	0.0000	0.000
05AUG1964	Lewis & Clark	25KX57/200	1.7179	3.6658	-1.9479	5.384
28APR1966	Lewis & Clark	25KX57/200	1.0721	5.8323	-4.7602	6.904
04JUN1967	Oahe	39DW234	14.0972	15.2712	-1.1740	29.368
13JUN1968	Oahe	39C06	0.0000	0.0000	0.0000	0.000
28JUN1968	Oahe	39DW234	50.4035	62.1659	-11.7624	112.569
01SEP1968	Sharpe	39LM224	4.2932	4.3866	-0.0934	8.680
01SEP1968	Sharpe	39ST235	24.8083	40.0762	-15.2679	64.884
23JUL1969	Sharpe	39LM224	4.2278	10.4286	-6.2008	14.656
04SEP1970	Lewis & Clark	25KX57/200	2.8472	6.0707	-3.2235	8.918
15SEP1972	Lewis & Clark	25KX57/200	5.7646	10.1160	-4.3514	15.881
04NOV1972	Sharpe	39ST235	2.1349	1.7052	0.4297	3.840
18AUG1974	Oahe	39DW234	4.2234	4.4524	-0.2290	8.676
09MAY1976	Oahe	39DW234	13.5265	15.1610	-1.6345	28.688
10MAY1976	Sharpe	39ST235	0.6449	1.2888	-0.6439	1.934
19JUN1976	Oahe	39C06	4.1953	2.9810	1.2144	7.176
12AUG1977	Sharpe	39LM224	2.2781	2.5868	-0.3087	4.865
08SEP1978	Lewis & Clark	25KX57/200	2.0173	3.1975	-1.1802	5.215
01SEP1981	Sharpe	39LM224	10.9761	5.1824	5.7937	16.159
02OCT1981	Oahe	39DW234	-0.6166	5.5802	-6.1967	4.964
30JUL1982	Sakakawea	32DU2	1.3186	0.5619	0.7568	1.881
31JUL1982	Oahe	39C06	1.6281	3.4154	-1.7873	5.043
03SEP1982	Sharpe	39LM224	1.5567	7.9305	-6.3739	9.487
03SEP1982	Sharpe	39ST235	0.2436	1.4381	-1.1945	1.682
08SEP1982	Oahe	39DW234	2.6094	18.0490	-15.4396	20.658
03JUN1983	Sharpe	39ST235	20.7444	12.0400	8.7044	32.784
30OCT1984	Sharpe	39LM224	-3.2473	7.3645	-10.6118	4.117
18OCT1985	Sakakawea	32DU2	8.0590	6.9775	1.0815	15.037
30MAY1986	Oahe	39DW234	1.3430	3.6925	-2.3495	5.035

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* Mean rate is the mean value of RATE's (bank recession rates between consecutive bank measurements) and their standard deviations.

** Low rate is mean rate minus one standard deviation.

† High rate is mean rate plus one standard deviation.

Table 15

Between-Date Rates (RATE) for Those Sites with General Southwest (SW) Aspects

Date	Reservoir	Site	Mean Rate*	SD	Low Rate**	High Rate†
23MAY1963	Francis Case	39BF44	1.7102	0.8786	0.8316	2.589
24JUN1964	Lewis & Clark	39YK40	0.6527	1.7410	-1.0883	2.394
25APR1966	Lewis & Clark	39YK40	2.3196	3.8495	-1.5299	6.169
15AUG1969	Francis Case	39BF44	1.2285	1.2228	0.0057	2.451
10SEP1970	Lewis & Clark	39YK40	-0.8808	1.3107	-2.1916	0.430
15SEP1972	Lewis & Clark	39YK40	0.8531	3.6306	-2.7774	4.484
04NOV1972	Sharpe	39HU242	2.0000	2.4323	-0.4323	4.432
29MAY1973	Oahe	39HU173	1.0094	1.2910	-0.2816	2.300
05OCT1973	Francis Case	39BF44	6.8796	3.9777	2.9019	10.857
01AUG1975	Lewis & Clark	39YK40	1.0358	2.8386	-1.8028	3.874
10MAY1976	Sharpe	39HU242	2.2658	1.4001	0.8657	3.666
13SEP1977	Oahe	39WW15	1.1325	3.1386	-2.0061	4.271
16AUG1978	Oahe	39WW15	-2.8883	8.0415	-10.9298	5.153
08SEP1978	Lewis & Clark	39YK40	-0.2248	3.3221	-3.5470	3.097
01SEP1981	Francis Case	39BF44	1.3087	1.5366	-0.2279	2.845
01SEP1981	Sharpe	39HU242	1.8508	1.9455	-0.0948	3.796
01OCT1981	Oahe	39HU173	0.1109	0.9577	-0.8468	1.069
02OCT1981	Oahe	39WW15	3.6577	7.7433	-4.0856	11.401
23MAY1983	Lewis & Clark	39YK40	0.2898	1.9064	-1.6166	2.196
03JUN1983	Sharpe	39HU242	4.7401	3.2643	1.4759	8.004
27OCT1983	Francis Case	39BF44	6.8432	11.1604	-4.3172	18.004
30MAY1986	Oahe	39WW15	2.3183	2.0732	0.2451	4.392
31MAY1986	Francis Case	39BF44	1.9983	4.6571	-2.6588	6.655
31MAY1986	Oahe	39HU173	0.6447	2.4334	-1.7887	3.078

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* Mean rate is the mean value of RATE's (bank recession rates between consecutive bank measurements) and their standard deviations.

** Low rate is mean rate minus one standard deviation.

† High rate is mean rate plus one standard deviation.

inspection of these tables shows that the highest mean rates for sites with general aspects within the northeast quadrant are an order of magnitude greater than the high rates for those sites generally facing southwest. Wind direction, then, is an important factor in predicting episodes during which high bank recession rates occur and sites and transects where high rates occur as well.

Multiple Regression Analysis

158. Multiple regression analysis is a procedure which is useful both for identifying the relative contributions of suspected independent variables on a dependent variable, and for predicting different future values of a dependent variable on the basis of a number of independent variables. It is incorporated in the analyses here with both of those goals in mind.

159. Two very different kinds of independent variables are incorporated into the analyses described here. Some of the independent variables (see Table 9 for a list and summary explanation--only the analytical variables are considered here, not the measurement variables from which some analytical variables were derived), as measured, are constant through time but vary in space from place to place. These are:

ASPECT, FETL, FETR, K, LIQ, NORFET, PLAST

Other independent variables vary through time. These variables are:

FLUCT, PDIFF, PMAX, PMIN

160. Two dependent, analytical variables were designed for purposes of the regression and other analyses presented here which could be examined in the light of each of these groups of independent variables.

161. RATE is the rate of bank recession, in metres per year, derived between two successive bank measurement dates. Each transect at each site has more than one RATE; some transects have as many as seven RATE's. The time periods associated with RATE measures each have their own values of FLUCT, DIFF, PMAX, AND PMIN. To each of these RATE time segments can also be assigned values for the nontemporal independent variables, although these are

constant within sites, and within reservoirs, so their inclusion into regressions using RATE as a dependent variable would probably overpower and obscure the correlation with temporal variables. Regression analysis of the variable RATE with FLUCT, PDIFF, PMAX, and PMIN were designed to attempt to explain the variation of bank recession rate over time.

162. TRATE is the bank recession rate, expressed in metres per year, between the earliest and latest measured bank lines at each transect. One transect has only one TRATE. For this reason, it is not meaningful to assign values of the temporal independent variables to TRATE's; that is, there is no variation through time for TRATE's, thus no potential correlation with temporal variables. Regression analyses of the variable TRATE with ASPECT, FETL, FETR, K, LIQ, NORFET, and PLAST were designed to examine the relationship between differences in bank recession rate from place to place, rather than changes in rate through time.

Regression methods

163. All of the statistical analyses described here were performed using the statistical analysis system (SAS) for personal computers (SAS Institute 1985). The first step in each regression analysis, then, was determining which variables, given the values of each to be incorporated into each regression analysis, were normally distributed. Following Millsop (1985), we regarded the distribution of values for a variable to be normal if its skewness was between +1 and -1, and/or the Shapiro-Wilk Statistic, W, was 0.05 or greater. Variables with values outside these ranges were regarded as nonnormal, and were not incorporated into the regression analyses. The distribution of values of a variable at one site, of course, might be nonnormal, while the distributions of its values at another site, or within a larger grouping, might be normal. This caused variables to be used in different combinations when regression analysis was performed on a site-by-site basis.

164. It is also necessary to avoid using variables that exhibit colinearity--that is, correlate closely with one another--in multiple regression analyses. If the correlation (Pearson's Product Moment Coefficient, r) between any two variables was greater than 0.8, only one of those variables was incorporated into the regression analysis; the other was discarded.

165. The regression analyses were performed using a maximum R-square improvement method. This method finds the best one-variable model, the best two-variable model, etc. either by adding variables with successively smaller

partial contributions to the resulting regression equation, or by replacing variables to increase the total variability explained (r^2) value.

Analyses and results

166. The first group of multiple regression analyses took RATE as the dependent variable, and regressed it against each of the temporal variables PMIN, PMAX, PDIFF, and FLUCT that had normally distributed values for the group of RATE's examined. The purpose of these analyses was to examine the contribution of the temporal pool level variables only on changing bank recession rates through time. Results of these analyses are summarized in Table 16.

Table 16

Results of Multiple Regression of RATE with Fluctuation Variables

Site	Variables*	R^2	Probability
All sites	PMIN FLUCT PDIFF	0.051	0.0001
39WW15	FLUCT PDIFF	0.146	0.0176
39YK40	FLUCT PDIFF	0.023	0.1881
39BF44	FLUCT PMAX PMIN	0.184	0.0001
39DW234	FLUCT PMAX PMIN	0.267	0.0001

* Variables are listed in order of contribution to regression results; all normally distributed variables used in regressions; no regression results for sites where pool level variables not normally distributed; and sites with no pool data excluded.

167. The r^2 values listed represent the proportion of the variability in the dependent variable represented by a regression equation incorporating the independent variables listed. The independent variables are listed in the order to the magnitude of their contribution to this total r^2 value; the first variable explains more variability than the second, and so forth; together, their contributions totaled r^2. The probability value is the probability of reaching this level of explanation by chance, given the values of the variables used in the regression analysis. Although it is conventional in much research to accept only those results with a probability greater than, say, 0.001, we will not automatically make probability the criterion for acceptance here. The results summarized in Table 16 indicate that when single sites are

considered, the variable FLUCT, a simple count of the number of fluctuations of pool level occurring between each measurement date, is the best single predictor of RATE. Only when all sites are combined is FLUCT replaced by PMIN as best predictor. Overall, the r^2 values are quite low, with a maximum of about 27 percent of the total variability in RATE explained by any three temporal pool level variables. This indicates, simply, that pool level variables, at least measured the way they were in this study, are not good predictors of rates or changes in rates within sites or, indeed, within the RATE's as grouped at all sites. In fact, the r^2 value for all sites together is the worst for this series of analyses.

168. In an attempt to explain more of the variability in RATE's, the temporal variables were coupled with the fetch and aspect variables NORFET, FETR, FETL, and ASPECT in a series of regression analyses summarized in Table 17.

169. The number of variables included in Table 17 changes from site to site; this is because those regression models chosen only include variables offered until there is no further improvement in r^2 greater than 0.01. This

Table 17

Results of Regression Analyses of RATE by Individual Sites, Against Variables

Site	Variables*	r^2	Probability
32DU2	FLUCT NORFET FETR	0.411	0.0001
39C06	PMIN FETL ASPECT	0.332	0.0014
39WW15	NORFET FETR FLUCT PMIN FETL	0.358	0.0006
39YK40	PMIN ASPECT PDIFF FLUCT	0.091	0.0083
39BF44	FLUCT NORFET FETR	0.272	0.0001
25KX57/200	FETL FLUCT PDIFF PMIN ASPECT FETR	0.114	0.0592
39LM224	FLUCT ASPECT NORFET PMAX	0.170	0.0005
39DW234	FETL PMAX PMIN FLUCT	0.360	0.0001

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* Variables listed in table are those incorporated into regression results until no improvement in r^2 greater than 0.01 could be realized; variables listed in order of their contribution to r^2. Sites with no pool data excluded.

cutoff point was arbitrarily taken as that point beyond which the inclusion of more variables in the model would be inefficient. In fact, it is probably a very liberal estimate for such a cutoff point in most regression analyses.

170. Probability levels are all greater than 0.001 except at 25KX57/200, where the r^2 value is relatively low in any case. Both temporal (pool level) variables and nontemporal variables figure in each regression model accepted. It is interesting that the variable PMIN appears more often than PMAX in the regression models. It is also interesting that, at a majority of the sites, pool level variables take precedence over the nontemporal (topographic) variables in explaining RATE. This is probably an indication that, for use as data in developing predictive models to describe RATE, the individual site may be too small a spatial unit for analysis. It may also be an indication that in such regression analyses of a temporally variable measure such as RATE, the influence of temporal independent variables obscures the importance of nontemporal variables.

171. To assess whether this in fact is the case, another series of regression analyses was performed, this time modeling TRATE--the mean rate through all measurement within each transect--as a function of nontemporal variables. Values of the temporal variables cannot, of course, be assigned to TRATE's, since temporal values will vary but TRATE will not. Normally, distributed soils data (K, PLAS, and LIQ) were also included in the independent data sets, where present. These analyses are summarized in Table 18.

Table 18

Results of Multiple Regression Analyses of TRATE with Normally Distributed, Nontemporal Variables

Site	Variables**	r^2	Probability
32DU2	NORFET FETR ASPECT	0.234	0.1985
39HU173	FETL PLAST ASPECT NORFET	0.281	0.4160
39LM224	FETL ASPECT	0.567	0.0008
39DW234	NORFET ASPECT	0.336	0.0253
39ST235	LIQ ASPECT	0.011	0.9090
39HU242	FETL ASPECT NORFET	0.632	0.0006

* Sites not shown for which no normal variables occur or no regression solutions could be reached.

** Variables listed in respect to their contribution to r^2.

172. When considered on a site-by-site basis like this, the nontemporal variables explain roughly the same sort of proportion of total TRATE variability as the combined temporal and nontemporal variables did for RATE's. The significance of the r^2's, however, is quite low in at least three of the six analytical cases summarized in Table 18. This is probably because there are far fewer TRATE values (only 21) per site than there are RATE values (up to 147 per site). TRATE samples on a site-by-site basis, then, are quite small.

173. It might, it was reasoned, be advantageous to lump sets of TRATE's from sites to be able to perform analyses on larger samples. It was decided to do this in a manner that would allow control for temporal variables to some extent. The regression analyses summarized in Table 19 were done for all sites combined and for all sites on each of the reservoirs. Only one study site fell on Lake Sakakawea, so its r^2 and significance value alone comprise the Lake Sakakawea sample. For one site and reservoir, 39BF44 on Lake Francis Case, no variable values were normally distributed and a regression analysis proved meaningless. The analyses are summarized in Table 18. Soils variables were not included in this last series of regression analyses because of the fact that they are not available for all of the study sites,

Table 19

Results of Multiple Regression Analyses of TRATE with Normally Distributed, Nontemporal Data

Site Locations	Variables*	R^2	Probability
All sites combined	ASPECT FETR NORFET	0.102	0.0001
Lewis and Clark (39YK40, 25KX57/200)	NORFET FETL FETR ASPECT	0.314	0.0064
Oahe (39HU173, 39WW15, 39CO6, 39DW234)	ASPECT NORFET FETR FETL	0.395	0.0001
Sharpe (39HU242, 39LM224, 39ST235)	ASPECT FETL NORFET FETR	0.240	0.0081
Sakakawea (32DU2)**	NORFET FETR ASPECT	0.234	0.1985

* Variables listed with respect to contribution to r^2; regression analysis ended when no improvement in r^2 greater than 0.01 could be realized.

** Results for Lake Francis Case (containing site 32DU2) could not be analyzed due to lack of any normally distributed independent variables.

and variables with missing values render the regression procedures used here ineffective. The analyses summarized in Table 19 did not result in any improvement over those described in Table 18, although their r^2 values are quite similar if the site-specific analyses of 39HU242 and 39LM224 are disregarded. One interesting result of the Table 19 regression analyses is that either ASPECT or NORFET are the most significant independent variables in each variable set. These are in fact the simple independent variables that one might expect would be most important in explaining differences in bank recession rates from place to place; aspect should be an important variable since it serves as an indicator of that direction of wind that should strike the shore head on, while normal fetch measures the potential energy of waves striking at this aspect. It was surprising to these investigators that these variables figured so little in the results of the previous regression analyses.

Regression equations for reservoirs

174. The regression analysis summarized in Table 19 also produced matrices listing the constant values calculated to arrive at a regression equation for predicting new (future) values for the dependent variable. These values are examined in Table 20 to illustrate differences in predictions of bank recession between various reservoirs studied here. The values listed as parameter estimates serve as constants in a regression equation of the form listed earlier in this section.

Discussion of regression analysis results

175. The above analyses indicate that bank recession rates are variable through time and within as well as between sites. This variation has been shown through a simple calculation of mean rate of bank recession (SRATE) as an aggregate of between date rates over the 21 measurement transects within each study site, as well as the inspection of site-specific tables and graphs of within-site spatial variation, and within-transect temporal variation.

176. Regression analyses were directed toward explaining both changes in rates over time in transects, and differences in rates in space (between transects) to better describe these dimensions of variability. Regressions designed to model rates between measurement dates (RATE's) using temporal (pool level) variable data did not prove to explain a very large proportion of variability in rates. This is perhaps because our pool level variables are

Table 20

Parameter Estimates for Variables in Regression Equations Derived by Regression of TRATE with Nontemporal Variables

		r^2	Probability
All sites combined	Intercept	4.0205	0.0001
	ASPECT	-0.0060	0.0002
	FETR	0.3713	0.0216
	NORFET	-0.3935	0.0025
Lewis and Clark Lake	Intercept	18.8353	0.0007
	ASPECT	0.0034	0.1956
	NORFET	-6.5995	0.0017
	FETL	0.7071	0.0901
	FETR	-0.5052	0.1259
Lake Oahe	Intercept	4.4808	0.0001
	ASPECT	-0.0163	0.0001
	NORFET	1.6234	0.0001
	FETR	-0.9469	0.0028
	FETL	0.2605	0.4452
Lake Sharpe	Intercept	3.9346	0.0063
	ASPECT	-0.0076	0.0048
	FETL	0.5158	0.1719
	NORFET	-1.2941	0.1516
	FETR	0.6844	0.3367
Lake Sakakawea	Intercept	2.0486	0.1455
	NORFET	0.2504	0.0475
	FETR	-0.1077	0.3727
	ASPECT	-0.0095	0.6499

not well developed, being made from low-resolution graphic data rather than reduced from the much more detailed pool level data available. It is also possible, however, that the low r^2 values derived from the use of pool management data are due to the fact that variations between measurement dates may be caused by the combined effects of many unique, high energy events (storms, particularly) between dates.

177. To improve explanatory success in modeling RATE variations, nontemporal measured variables were added to an additional series of analyses. This effort proved partially successful, resulting in a maximum of about 60 percent of the variability in RATE being explainable at some sites. The average r^2 values, however, are still between 10 and 30 percent.

178. It is probable that the addition of more independent variables,

measured with higher resolution, would result in additional improvement in r^2 values. One good candidate for a new variable or variables would be more specific measures that reflect variability in the erosion susceptibility of sediments. Data on sediment properties, to be useful in bank recession studies, would have to be designed to measure these properties at the same sort of resolution, over relatively large shoreline stretches, at which one would want to make predictions. It is likely that such measures, which might incorporate grain size/proportion analyses, would probably be labor intensive, and their interpretation complex.

179. Additional variables that might be of value in increasing the success of regression analyses would be those measuring climatic or weather properties. High temporal resolution data on weather events exist, but it is possible that they might not be of high enough spatial resolution to aid equally in predictions of all places along remote reservoir banks. The relatively low temporal resolution provided by sequential historical aerial photograph dates was discussed in paragraph 176. In addition to higher resolution temporal data, however, it might be useful to have higher resolution spatial data to construct effective models of bank recession rates as they vary, in a more or less continuous manner, with topographic variables. This might be accomplished by digitally recording bank lines after or even during stereo photointerpretation, essentially recording such information as aspect, fetch, etc. continuously, or making them continuously definable.

180. Regression analyses modeling TRATE with nontemporal data suggest important differences between reservoirs. While all reservoir predictions using nontemporal data were of little success (i.e., had a low r^2 value), using aspect and fetch data only allow the explanation of between 17 and almost 40 percent of spatial variability in transects in all sites within single reservoirs.

181. Parameter estimates or multiplicative constants calculated for regression equations within specific reservoirs indicate that ASPECT is probably the most constant estimator--that is, it has similar effects at all reservoirs. The effects of the fetch variables differ more from reservoir to reservoir, indicating that there may be important differences in the shapes of shorelines rather than simply the directions they face that may be influencing bank erosion.

182. In conclusion, the results of our regression analyses show that

bank recession rates are to some extent at least predictable through reference to physically measurable, independent variables. The independent variables we have used in this exploratory study are, however, not completely sufficient or refined to allow more than about one-half of the variability in bank erosion to be explained through regression analysis.

183. Probably the best way to actually predict the position of an eroding reservoir bank at some time in the future, then, is to assume that these same bank recession rates will continue with the same amount of variation in the foreseeable future. The new position of the bank at some time in the future, then, can be expressed (after Dolan, Hayden, and Heywood 1978) by an increments to the present shore position determined by

$$dS = dT\ [(\text{rate of change}) + k(\text{standard deviation})]$$

where S is the landward limit of the shore for a given time interval dT, and k is the number of standard deviations required to give a desired probability level. Then one would use additional information gained through these exploratory analyses to qualify or adjust predictions empirically arrived at.

Site Specific Measurements Using Electronic Image Analysis

184. The measurement technique focusing on transects spaced 100 m apart along 2 km segments of the reservoir shore centered on the study site was designed to allow the characterization of bank erosion trends through time at a relatively wide range of spatial scales. The "philosophy" behind this method is that bank recession at an archeological site is a process inherent in a larger and more inclusive system, some of the components of which are sediments, the reservoir pool with its wave and current dynamics, and the bank and beach that form the interface between these components. This system operates not simply at a specific spot along the shore, but is influenced by variability in processes along a segment of shoreline. There is some question in the literature on shoreline erosion (Phillips 1986) about just how great a reach of shore must be considered to understand the operation of this system; depending on the specific erosion related phenomena being studied, Phillips recommends distances between 100 m and 60 km.

185. To more closely depict the effects of bank erosion on the actual sites themselves, however, experiments were also undertaken using an alternative, and far more site specific, method. This method involves using enlarged and electronically enhanced portions of aerial photographs, rather than stereoscopic viewing. Even very large archeological sites are quite small in most aerial photographs; a site measuring 500 m, for instance, appears only 2.5 cm across at a 1:20,000 scale. Interpretive overlay mapping of extremely small areas leads to error which can constitute a large proportion of the total measurements. Photographic enlargement, however, can lead to a degradation of resolution and contrast due to the creation of two new generations--a negative and a positive--in the enlargement itself. If original photo scale is sufficiently large, then photo enlargements are acceptable (Figure 16). However, smaller-scale photographs such as that shown in Figure 17, at about the same degree of enlargement as Figure 16, are more difficult to photoenlarge acceptably.

186. Electronic image enlargement and edge enhancement performed on an International Imaging Systems analog image analysis system (Figure 18) were employed in an attempt to remedy these problems. This system focuses a highly

Figure 16. Site 39LM224, 26 Oct 1938

Figure 17. Site 39LM224, 10 Oct 1984

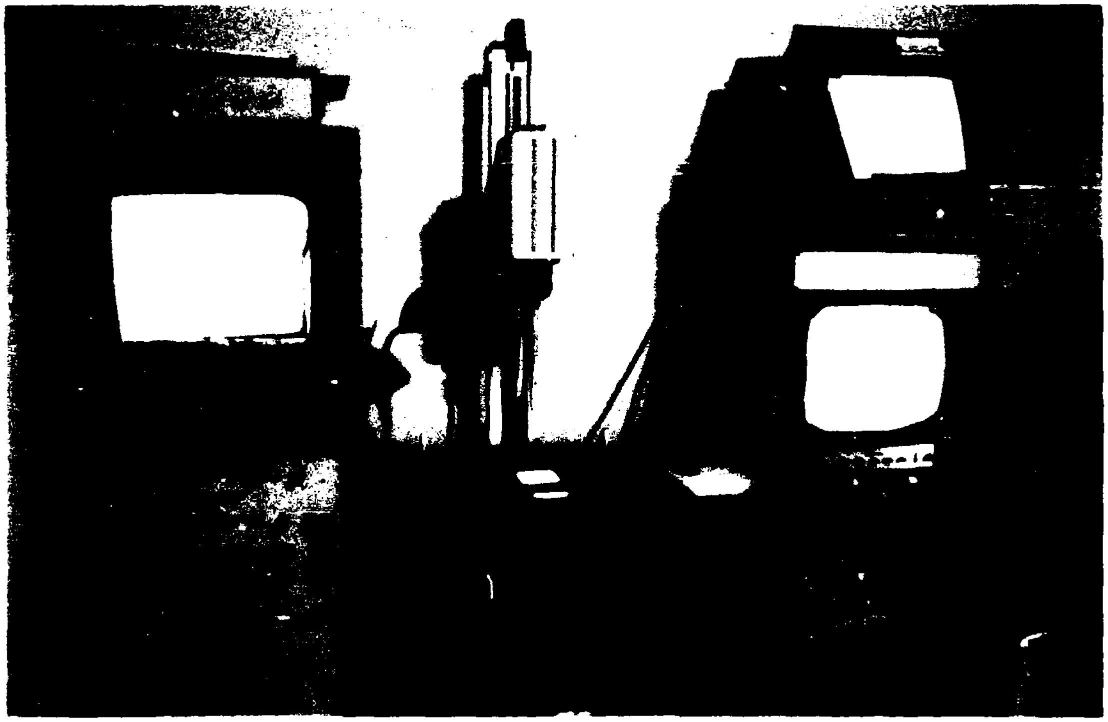

Figure 18. Electronic image analysis system used to edge and contrast enhance magnified portions of aerial photographs for site-specific mapping purposes

stable video camera equipped with a macro lens (and, if necessary, extension rings and bellows) on a small portion of a photo placed on a light table. The resulting video signal, without the multigenerational characteristics of successive photo negatives and prints, is then processed. Contrast is increased through a histogram stretch and edge enhancement. This procedure involves superimposing otherwise identical negative and positive video signals and then slightly delaying one signal to increase the definition of edges where photo densities change. Edge enhancement is particularly effective on subtle linear features--such as bank lines.

187. Successive aerial photographs showing three of the study sites, 39CO6, 39LM224, and 39DW234, through time were analyzed using the analog image analysis system, and slides were taken from the edge enhancer screen. A time-series of these images depicting the Cable Site, 39LM224, in Lyman County, South Dakota, is shown in Figures 19 through 26.

188. Next, the slides of the video images were projected, to scales of about 1:1,000, and control points in and around the sites were used to ensure rectification relative to one another. While details from the USGS quad

Figure 19. Site 39LM224, 26 Oct 1938

Figure 20. Site 39LM224, 1 Sep 1955

Figure 21. Site 39LM224, 21 Jun 1965

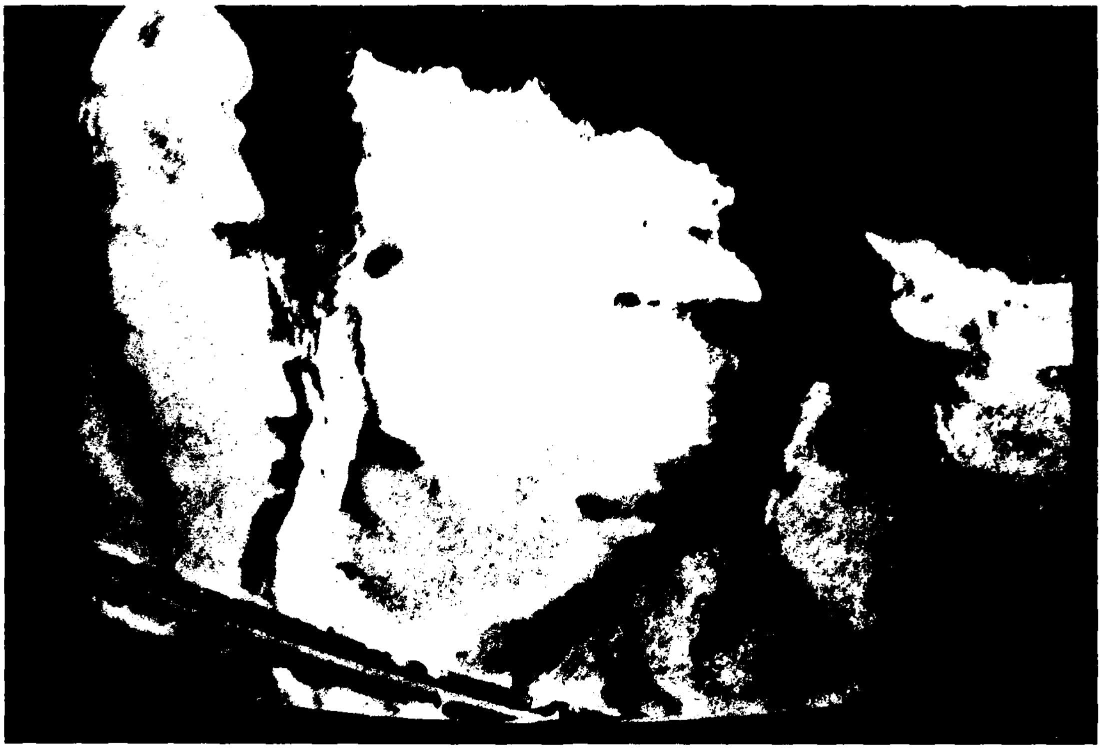

Figure 22. Site 39LM224, 23 Jul 1969

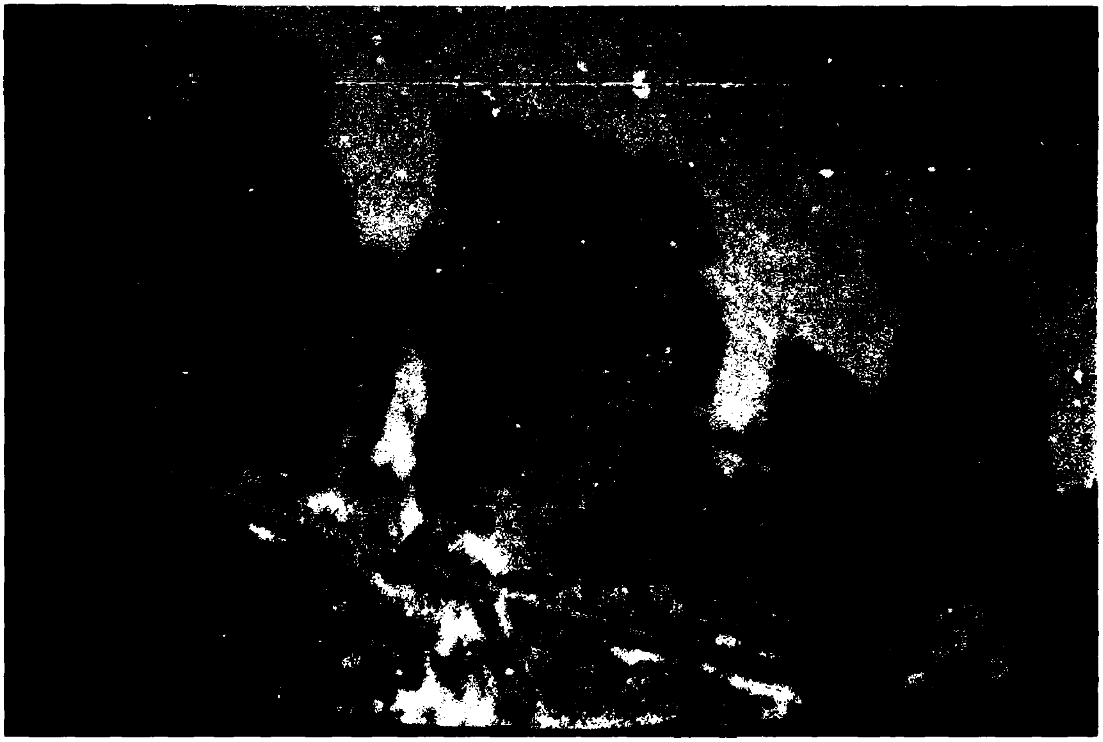

Figure 23. Site 39LM224, 15 May 1975

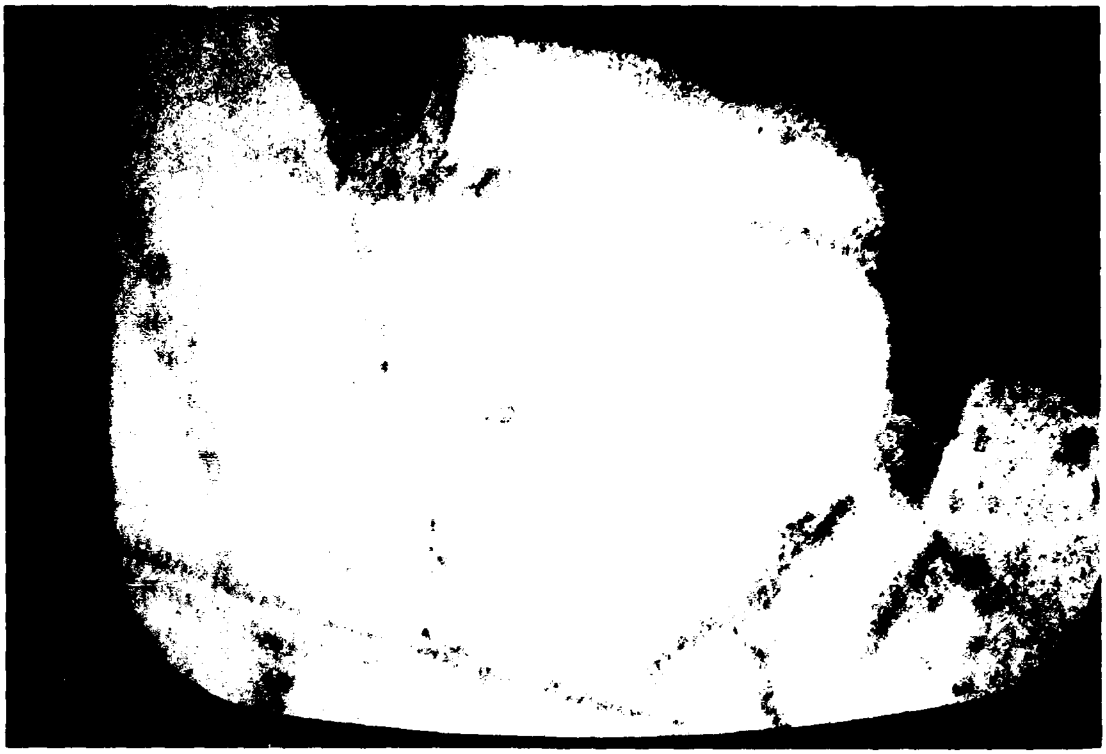

Figure 24. Site 39LM224, 9 Apr 1977

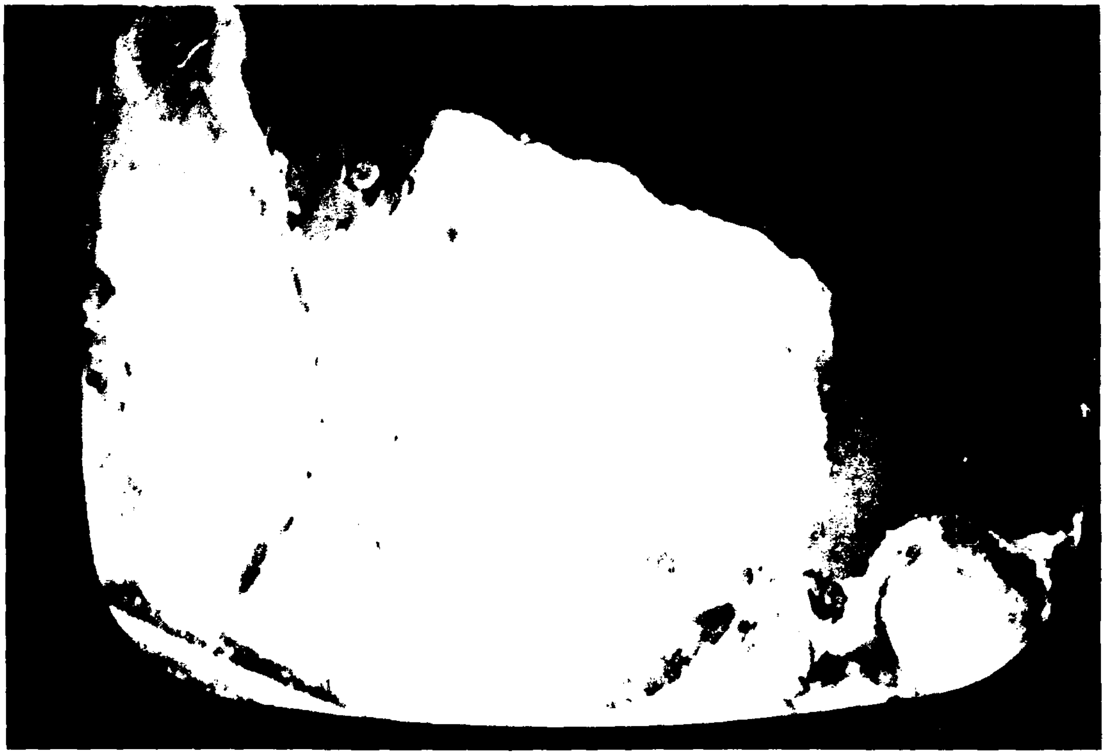

Figure 25. Site 39LM224, 30 Oct 1981

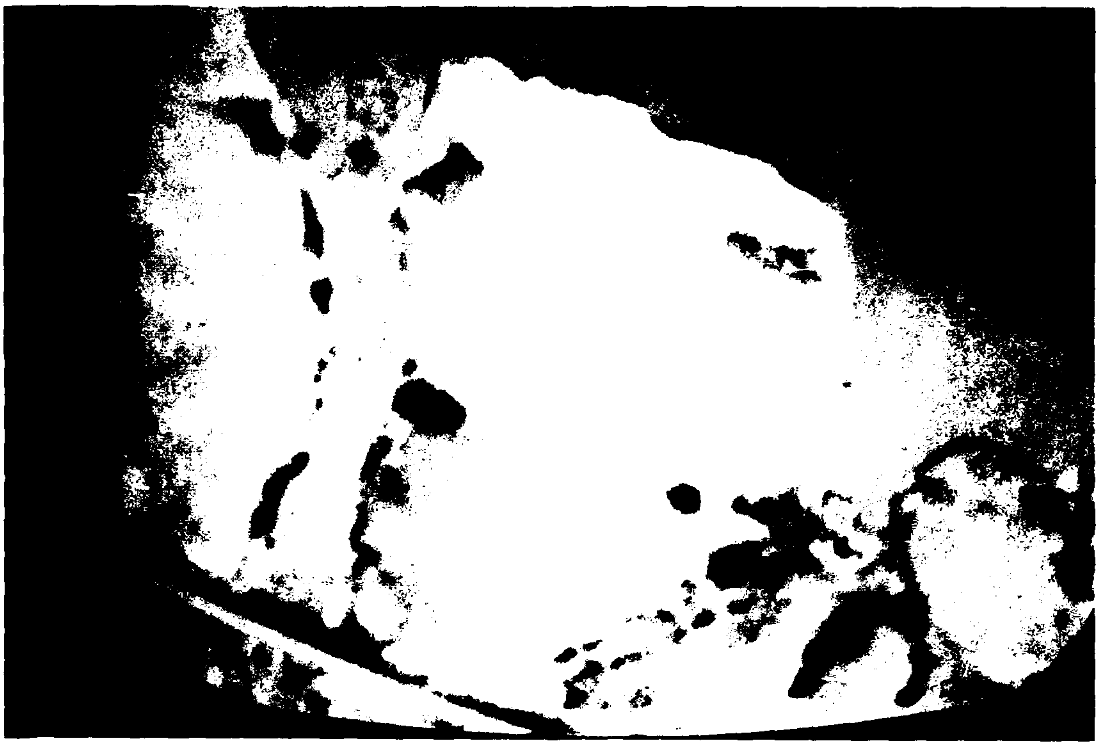

Figure 26. Site 39LM224, 30 Oct 1984

sheets allowed the initial two-dimensional rectification of baseline site area details, there was in some occasions insufficient map detail in the specific site areas to allow the control of successive projections. For this reason ephemeral control points, such as bushes or cultural features--visible from one date to another, but not necessarily throughout the entire series--were also used.

189. Maps for sites 39LM224, 39CO6, and 39DW234 made in this manner, including selected shoreline positions through time, are shown in Figures 27 through 29.

190. A digital planimeter was used to measure the areas of the sites as they were prior to reservoir filling, and the successive amounts of site area lost due to bank recession at later dates (Figure 30). It should be mentioned here that defining the boundaries of a site is, in almost all cases, a rather arbitrary exercise, whether it is done using evidence visible on aerial photographs or through survey or excavation on the ground. In the three experimental cases illustrated here, site boundaries were defined on the basis of cultural features that could be cumulatively photointerpreted from the aerial photographs--the maximum extent of fortification ditches and housepits, for

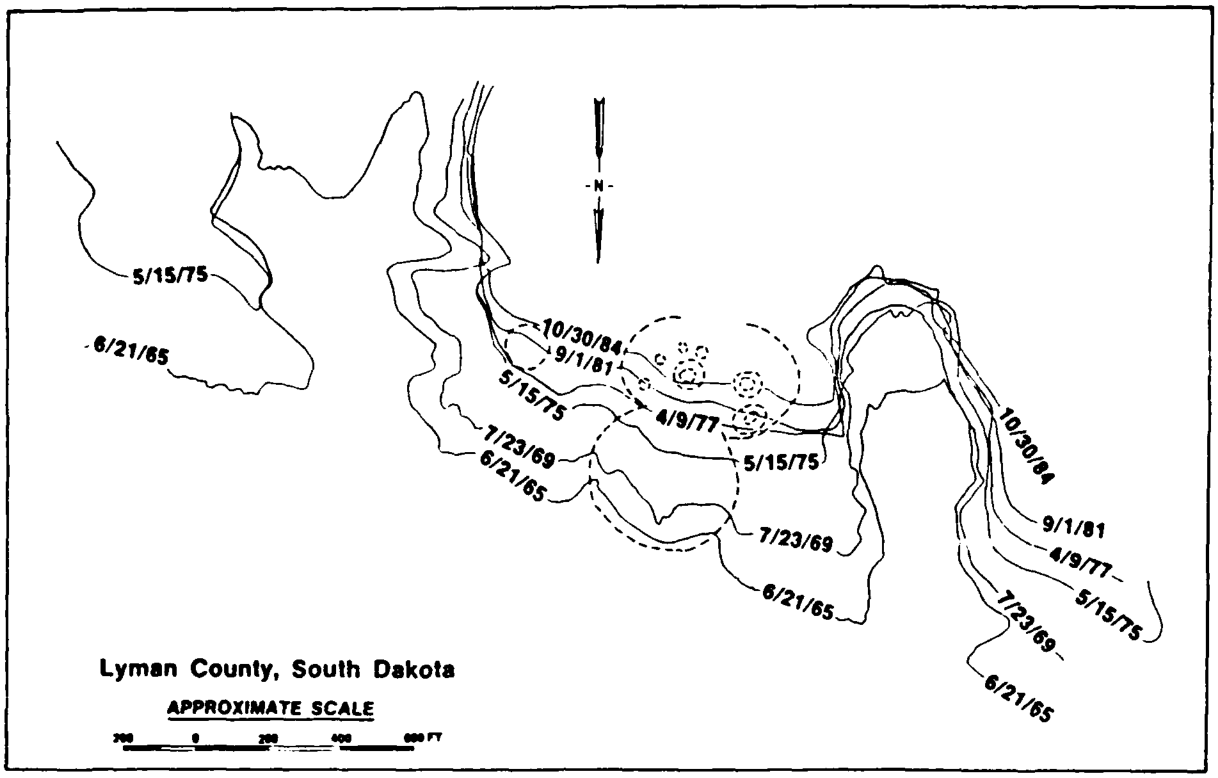

Figure 27. Image analysis--derived site area map of the Cable Site, 39LM224

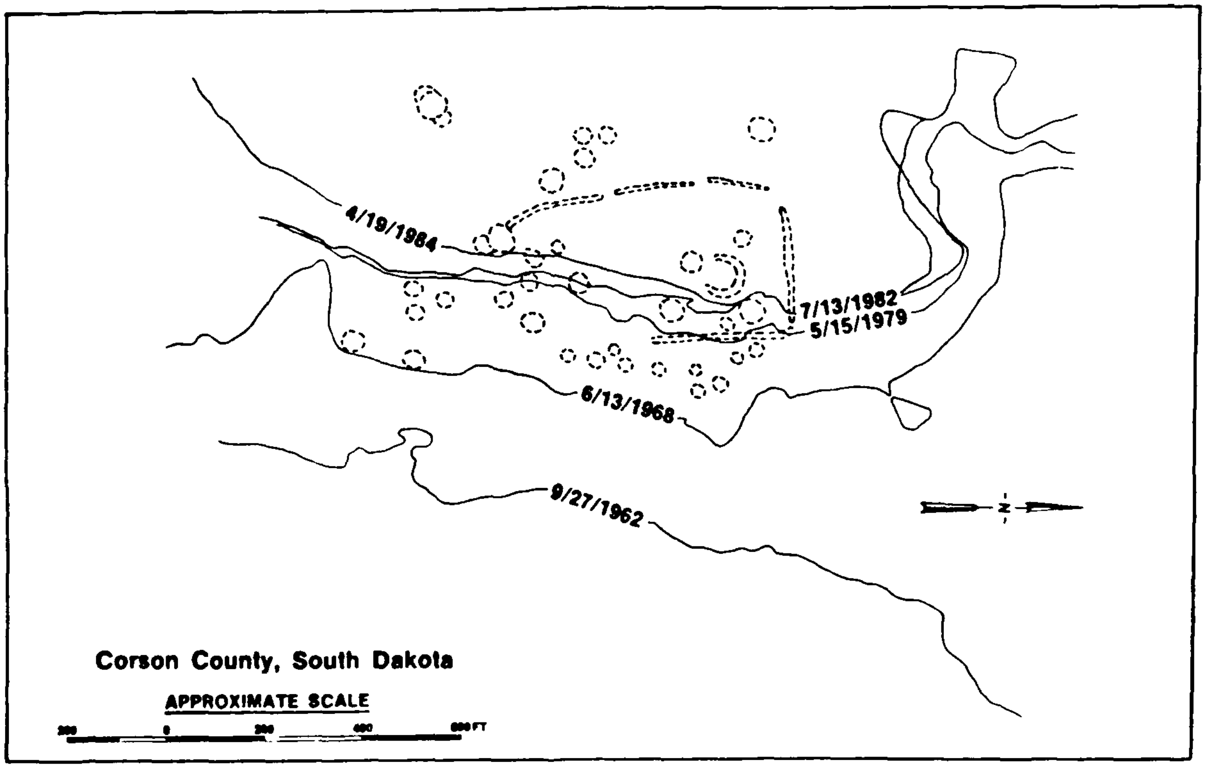

Figure 28. Image analysis--derived site area map of the Jake White Bull Site, 39CO6

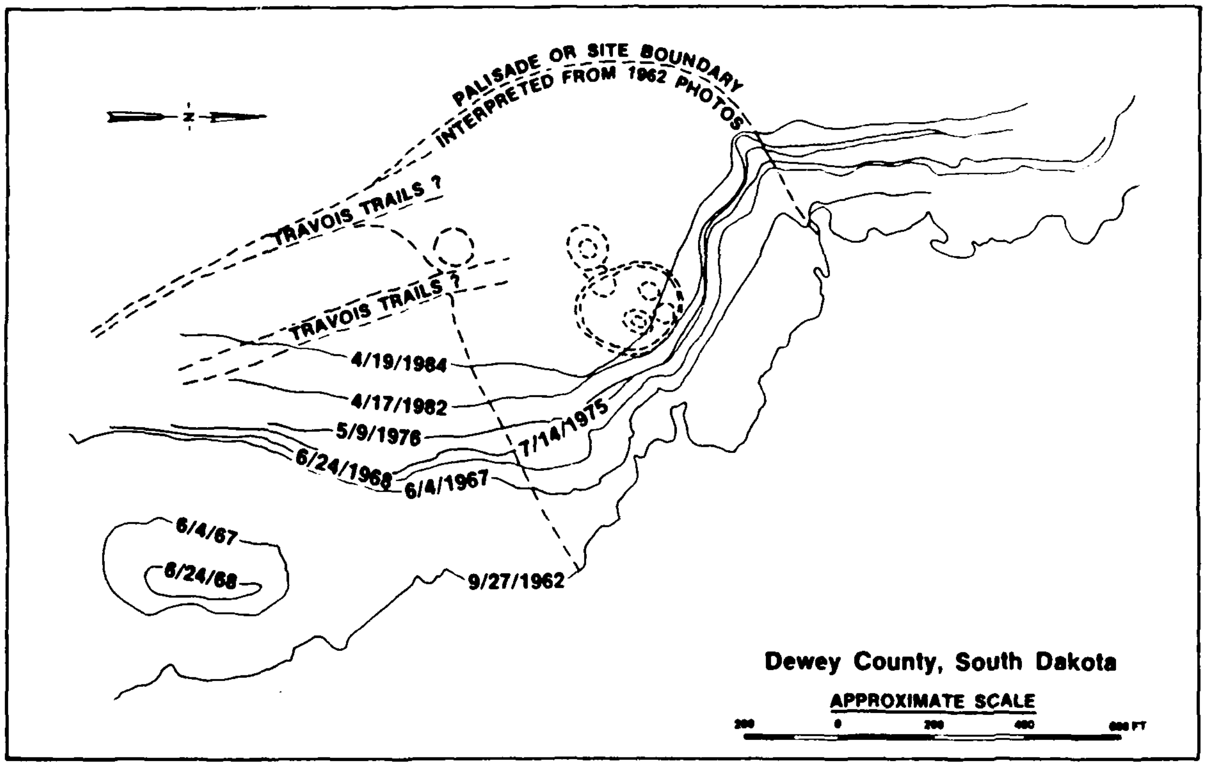

Figure 29. Image analysis--derived site area map of the Molstad Site, 39DW234

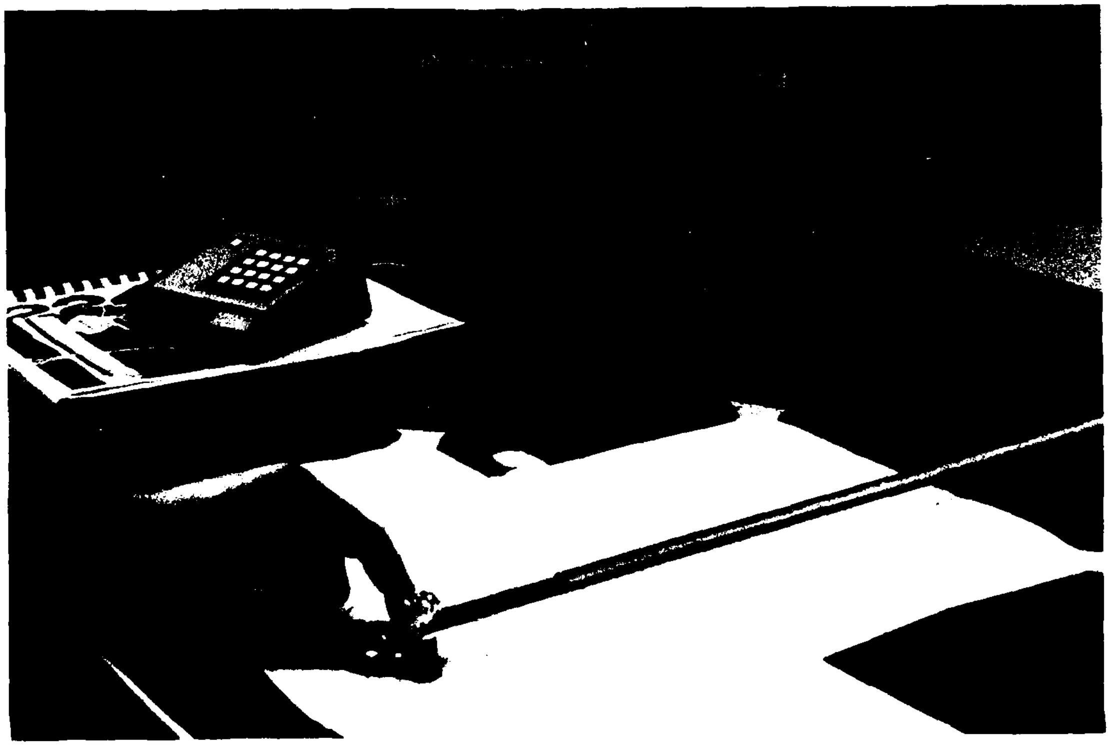

Figure 30. Measurement of areas of sites lost using a Numonics digital planimeter

the most part. While these boundaries are not necessarily true in any sense, they are consistent for within-site measurements.

191. Site area was plotted against aerial photograph dates for each site (Figure 31), and regression equations derived for the resulting point swarms. It is interesting to note that the regression lines shown in this figure are linear, and they fit their respective point swarms well. In discussions with field personnel at reservoirs, and in a majority of the more theoretical literature, a recurrent theme is that while reservoir bank erosion may be very rapid shortly after pool filling, a leveling off of erosion rates should be noted soon due to the shoreline reaching an equilibrium state. In support of this idea, it has been noted (Mollard 1986) that bank recession proceeds much more slowly at natural lakes than at reservoirs of comparable size in the same areas.

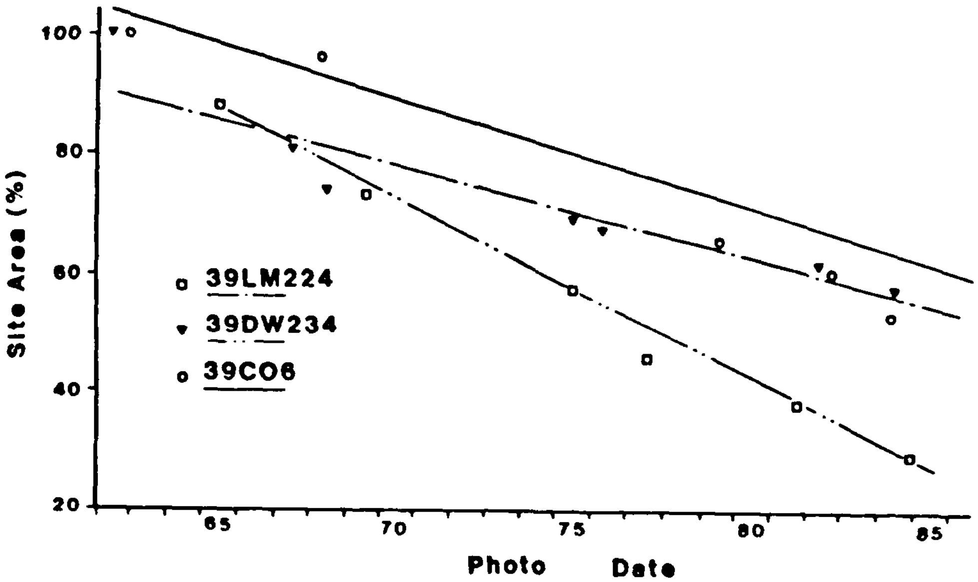

Figure 31. Graph of extinction curves for Sites 39DW234, 39CO6, and 39LM224

192. Unfortunately, no sign of the approach of such an equilibrium state is given by the linear form of the regression lines in Figure 31. At the only site to show a definite trend, as a matter of fact (39CO6), the rate of area loss may actually be increasing. Similar findings were announced by Millsop (1985) as one result of high-resolution, on-the-ground measurements of bank recession at Lake Sakakawea. There is no way to tell whether the absence of diminishing bank erosion rates indicates that these rates will always remain high or whether the banks being studied here have simply not begun to

reach equilibrium in the 25 to 36 years that have elapsed since the closing of the reservoirs.

193. As a final step in this exercise, the regression lines for each site were projected to their intercept with the x axis, at which time--given a linear area loss model--each site would theoretically be gone, or extinct. It must be remembered, of course, that the boundaries used to measure initial site areas were defined solely on the basis of photointerpretations of cultural features. Given the large variations in erosion rates calculated much more consistently and precisely along the 2 km shore reaches, there is no reason to believe that these "predictions" would necessarily be highly accurate, certainly not to the extent implied by listing the day of extinction. We do intend to be at those sites on their extinction days, however, to test these predictions.

194. There are unavoidable geometric variations in images reproduced from video screens, as well, which may affect the accuracy of maps compiled from such images, although these probably constitute only a small error in proportion to the enlarged size of the archeological sites in these renditions. We do feel, however, that the enlarged and enhanced views of immediate site areas shown in the examples above, the site area maps, and the site extinction dates given in Table 21 serve to dramatize in a graphic way the impact of reservoir bank recession at these sites.

Table 21

Extinction Dates Predicted by Regression Equations

Site	Extinction Date
39LM224	1 Mar 1994
39DW234	24 May 2019
39CO6	8 Apr 2009

Conclusions and Recommendations

195. The research described here focuses on the detection, measurement, and exploration of trends in, and causes of, bank erosion at archeological sites along the Middle Missouri River. The discussion of a few more specific

question areas addressed during the course of this research serves as a conclusion to this report. The discussion of these questions also suggests areas in which additional, immediate, and longer-term activities and research might be planned.

a. Is bank erosion causing impacts to archeological sites along the Middle Missouri River?

(1) In a specific sense, the results of this study illustrate conclusively that bank erosion is taking place at the 12 sites studied. This erosion falls within the range of general reservoir bank erosion rates measured by physical scientists in a number of similar studies. The amount of erosion also agrees with estimates given by archeologists for sites along Middle Missouri and other reservoirs.

(2) Although bank erosion is demonstrably taking place at all of the study sites, its rates are variable from site to site. Determining the amount of management concern that should result from different rates of bank erosion at each site will undoubtedly involve a complex equation in which many variables, including archeological significance and tradeoffs between economic and other resource values, must figure. Exploration of such decision making is beyond the scope of this study.

(3) Nonetheless, the results of this study emphasize that there is a pressing need to make such decisions. Some of the archeological sites studied will be gone within a few decades, as will probably hundreds more not studied. It should also be borne in mind that while archeological sites occupy only a small portion of the shores of Corps of Engineers reservoirs, bank erosion is taking place along entire shorelines where it threatens other resources such as vegetation, habitat, and the boundaries between public versus private property. Bank erosion is far more than simply an archeological problem.

(4) Data such as those collected here, from historical and sequential aerial photographs, can serve as one of the major bases for locating areas with differential rates of bank erosion and for planning and prioritizing to meet the problems posed by bank recession.

b. Can these effects be detected and measured using sequential, historical aerial photographs?

(1) The results of this study demonstrate that they can be detected and measures via aerial photography. They also suggest that it is important to use as complete an aerial photographic database as possible--that is, to discover and use as many sets of aerial photographs as can be found--to ensure the maximum possible temporal resolution and separate it from high resolution spatial variation.

(2) One of the major differences between this study and previous bank erosion studies is the use of all available, appropriately scaled aerial photographs, rather than only a few, to measure changes in bank position at each study site.

(3) Even when all of the historical aerial photographs available for an area through time are used, the temporal representation of changes in bank position is not ideal but is variable through time. Using as large a selection of aerial overflight dates as possible can help mitigate this problem. Future bank erosion measurement efforts should, for this reason, not attempt to use any sort of sample of available, historical aerial photographs.

c. Can bank recession measurements from sequential, historical aerial photographs serve as a data source for the estimation or prediction of future bank recession-related impacts to archeological sites along the Middle Missouri River reservoirs?

(1) This question requires the consideration and separation of two types or dimensions of variation that can be studied and predicted: temporal and spatial.

(2) Existing aerial photographs (not taken to measure bank lines, but at the same time are all we have with which to measure), were taken at fortuitously variable times. They record the position of reservoir banks, of course, at the instants they were taken. As suggested by the body of literature reviewed in this report, however, the dynamics of reservoir bank recession are caused by natural or other factors of short duration, many of which might even be thought of as catastrophic. The incongruence of natural and photographic events, as well as the temporal scale of their occurrences, make it likely that we will never be able to correlate time-specific independent variables with bank recession in a reliable way.

(3) If the purpose of doing so is to predict future bank recession, one also would have to be able to predict the specifics of future independent variables (storms and their intensity and location, for instance). Until this is possible, predictions of concomitant bank recession will only be possible after the fact, in a high resolution, temporal sense.

(4) A far more likely--and, upon contemplation, useful--prospect is the prediction of spatial variation in bank erosion at lower temporal scale. In the course of this study, it was observed that bank recession rates are variable over a range of spatial scales. While rates were demonstrated to be variable between the study sites, they were in some cases much more variable within the sites.

(5) Variability at different spatial scales may be an extremely important property of bank erosional dynamics for a number of reasons. First, the resources threatened by bank erosion are not constant over space but also have characteristic frequencies in different places. For example, archeological sites have been argued to be spaced not randomly but regularly in any number of arguments supported theoretically as well as with recourse to data. Spatial variation in the susceptibility of reservoir banks to erosion, conditioned by nonrandom topographic, pedological, and other properties at a range of scales, must certainly be important in designing and engineering of physical bank protection measures, as well.

(6) If predictions could be made about bank recession specifying that while 95 percent of the bank in an area of concern had to be protected (or its archeological record studied) and another 5 percent of the bank did not, millions of dollars could be saved in only a few miles of shoreline.

(7) The results of this study suggest that it may be possible to make such statements, at spatial frequencies between 100 m and 1 km. It is likely that much higher and lower spatial frequencies may also be important, however, in both research and more practical terms. For this reason, future bank recession research should be designed to allow the collection of data with which the widest possible range of spatial frequencies--from a few metres through entire reservoir bank lines--can be analyzed.

(8) The best way to collect such data would be to digitize interpretations of bank position at high resolution over entire reservoir bank lines. Such a data base would allow the application of power spectrum, Fourier, or other spatial analyses to investigate variability over time at a wide range of spatial scales.

(9) Such analyses would also ideally incorporate data on independent variables such as archeological sites and materials, topographic variation, and other relevant natural or cultural properties affecting bank erosion susceptibility, also at a wide range of scales.

d. How consistent are bank recession rates at specific reservoirs, and how well can they be extended to other reservoir bank recession rates?

(1) It is important to distinguish between spatial versus temporal variation in answering this question, as well. At a very general spatial scale, bank erosion at different places along reservoir shores is quite consistent, other things being equal. These other things can vary at a large scale, too, however. For instance, shore orientation, as compared to prevailing winds, causes bank

recession at even a gross spatial scale to be different on opposite sides of a reservoir.

(2) At higher spatial scales, however, site-specific as well as within-site characteristics are important. For this reason, prospects for transferring some sort of general predictive model developed at specific places on one reservoir to specific places on another reservoir are not encouraging. Such a lack of high spatial resolution congruence, both within and between reservoirs, was probably responsible for Gatto and Doe's (1983) lack of success in correlating bank recession at a large number of northern reservoirs (measured from aerial photographs) with all other assumed independent variables.

(3) One general observation about bank erosion and retreat that can, however, be made on the basis of this study--and that crosses reservoir boundaries--is that bank erosion may be a more significant threat to archeological sites and materials (as well as to other bank properties, including encroachment into private land) than has been imagined previously. The scientific literature on bank erosion, as well as experiential observations made by many reservoir personnel, suggests the common sense principle that while reservoir banks would be expected to erode rapidly after reservoir filling, rates should slow or level off quickly. The results of this study illustrate that this is not the case, at least at the sites studied here over a period of as much as 30 years. Bank erosion and recession may continue to be a relatively constant threat to the integrity of reservoir shorelines and the resources they contain over long periods of time.

e. How can methods be improved in future studies of reservoir bank recession relevant to cultural resource studies, as well as other bank recession measurements?

(1) Embodied in the previous conclusions are a number of suggestions. These suggestions concern data collection, how analyses can be performed, and studies otherwise structured, to enhance the value of future reservoir bank erosion studies and the usefulness of their results in practical applications.

(2) First, more rather than fewer sets of aerial photographs should be used to ensure the highest possible temporal data resolution, thus possibly improving prospects of predicting erosion trends through time. Going hand-in-hand with the need for high temporal resolution bank retreat measurements is the necessity for collecting all relevant independent data with a temporal dimension at scales which allow comparisons to be made with bank retreat data itself. Methods need to be devised, for instance, to reduce such information as the characteristics of the weather, or of pool level fluctuations, to

measures that can be correlated with changes in bank position through the variable time periods measurable from aerial photographs taken at fortuitous times in the past.

(3) The widest possible range of spatial scales of bank retreat must also be available for future studies. This will probably best be accomplished through the high-resolution digitization of the banklines across entire reservoir shores.

(4) A further argument for the measurement of the position of banks for entire reservoirs, and perhaps for all reservoirs, is that reservoir shores and banks are logically a major focus of Corps of Engineers interests and responsibilities. Reservoir shores and banks, in effect, are in and of themselves an important resource within the context of the Corps' responsibilities. Not knowing exactly where actively changing banklines of reservoirs are is comparable to an agency such as the Park Service not knowing where their park boundaries are, or the Bureau of Land Management not mapping the changing distribution of range resources.

(5) Measurements from aerial photographs, as illustrated by this study, offer the best way to map both the positions of past banklines, the locations of banklines in the present, and those of the future.

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APPENDIX A

AERIAL PHOTOGRAPHS COVERING MIDDLE MISSOURI RIVER STUDY SITES

(Data on file at US Army Engineer Waterways
Experiment Station (WES) CEWES-EE-R)

APPENDIX B

BANK RECESSION MEASURES SITE TABLES AND GRAPHS

(Data on file at US Army Engineer Waterways Experiment Station (WES) CEWES-EE-R)