Forensic Investigations in Soil Science
Dealing with Sedimentation

By Barrett L. Kays, Ph.D.[1]

Abstract

Floodplain sediment profiles, valley cross sections, GIS mapping, and AMS radiocarbon ^{14}C age investigations of Typic Ustifluvents covering approximately 12 square miles were used in a landmark case before the U.S. Federal Court of Claims to assist the Court in assessing the validity of monetary claims brought against the Omaha District of the U.S. Army Corps of Engineers and the United States of America. Inverse condemnation cases involving the U.S. Army Corps of Engineers frequently deal with civil waterway construction projects complete many years ago, such as the Oahe Reservoir on the Upper Missouri River. Due to the historical nature of such claims, it has been difficult to accurately assess soil, landscape, climate, river aggregation, and floodplain sediment deposition interactions and to separate natural sedimentation rates from reservoir impacts on the farms of plaintiff farmers. However, the use of soil science techniques provides an accurate means to assess historical sedimentation and to assess the causation of impacts due to the Oahe Reservoir project.

Characteristics of the Study Area

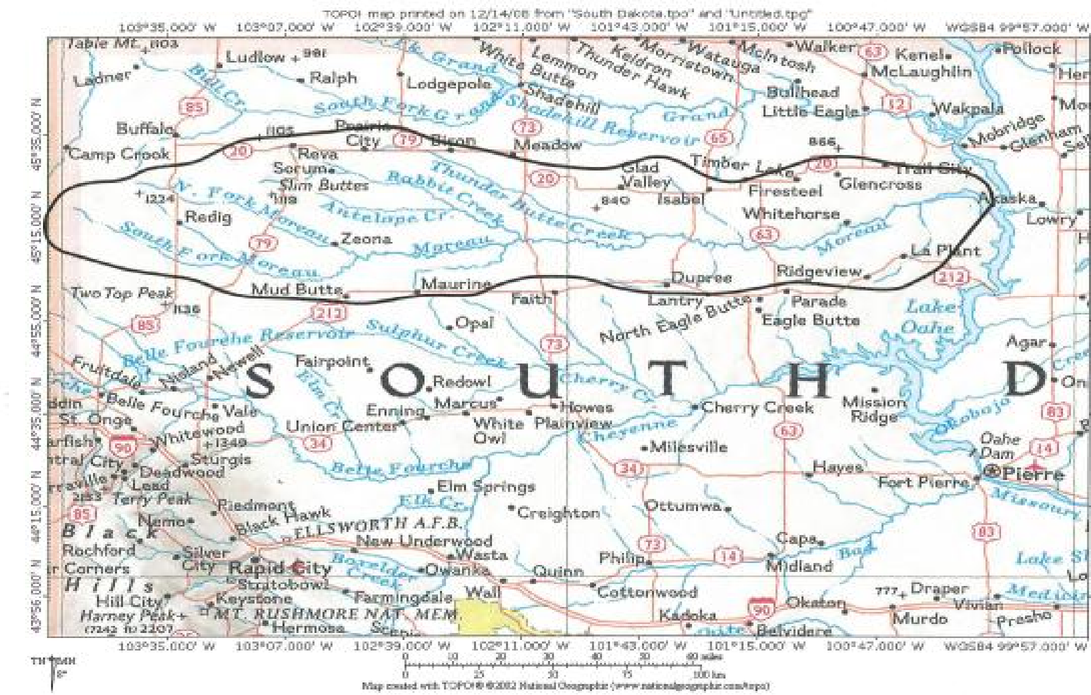
The upper reaches of the Moreau River begin in western South Dakota and drain eastward across South Dakota (Plate A-01, Appendix A). Approximately 190 miles east, the Moreau River empties into Oahe Reservoir. The Moreau River watershed drains approximately 5,200 square miles. The study area is located in the lower portion of the Moreau River watershed and within Dewey County, South Dakota (Plate A-02, Appendix A). The study area begins about 1.2 miles west of Whitehorse, South Dakota and extends eastward about 14 miles to the US Army Corps of Engineers property of Oahe Reservoir Project. The study area is located within the floodplain along this portion of the Moreau River.

Dewey County is located in northwest South Dakota and within the Northern Great Plains Region. Dewey County's landscape is characterized by its broad expansive plains interrupted by deeply entrenched streams and by its buttes that rise 100 feet or more above the plains. The climate of Dewey County is semiarid and averages 17.24 inches of rainfall per year. The annual evaporation from

[1] Barrett L. Kays, Ph.D., NC Licensed Soil Scientist, Landis, Inc., Raleigh, NC.

ponds and lakes is about 36 inches. The average size of farms in Dewey County is 4,051 acres (USDA, 1979).

The residual soils are formed by weathering of one of the three major geological formations: the Hell Creek Formation, the Fox Hills Formation, or the Pierre Shale Formation. Other soils are formed in alluvium of recent age and in loess (USDA, 1979).



Map of Moreau River Watershed in Northwest South Dakota

The major alluvial soils in the floodplain of Moreau River are: Banks Series, Trembles Series, Havrelon Series, and Lohler Series. Each of the soil series is a broadly defined by the Natural Resource Conservation Service and is used across extensive geographic areas. The Banks Series is used in 6 counties in northeast Montana, 17 counties in western North Dakota, and 4 counties in northern South Dakota. The Trembles Series is used in 5 counties in northeast Montana, 9 counties in western North Dakota, 4 counties in northern South Dakota, 1 county in southwest Wyoming, and 1 county in northwest Colorado. The Havrelon Series is used in 5 counties in northeast Montana, 3 counties in southern Montana, 10 counties in western North Dakota, and 2 counties in South Dakota. The Lohler Series is used in 5 counties in northeast Montana, 3 counties in southern Montana, 7 counties in western North Dakota, and 3 counties in northern South Dakota.

The United States Geological Survey has maintained three stream gauging stations on the Moreau River in Dewey County, South Dakota. USGS Station

0636000 near Eagle Butte, South Dakota drained 4,320 square miles of the watershed; its records extend from 1944 to 1958. USGS Station 06360500 near Whitehorse, South Dakota drains 4,880 square miles of the watershed; its records extend from 1953 to present (Appendix E). USGS Station 06361000 near Promise, South Dakota drained 5,223 of the watershed; its records extend from 1929 to 1958. The USGS records for Whitehorse Station were used in this study due to the nearly continuous records since 1953.

Approach to Study

The US Department of Justice contracted with Landis, Inc. to conduct a study examining the sedimentation[2] along the Moreau River. The purpose of the study was to determine the accuracy of the allegations of sediment damages and to determine the geographic extent and depth of sedimentation caused by the Oahe Reservoir Project. After examining information for the study area (USACOE, 2002 and 2003), Dr. Barrett L. Kays initially visited the project area on May 24 and 25, 2004. Based upon his preliminary review of the area, he prepared a work plan for this study. He choose to conduct an intensive study of selected locations within the floodplain through the use of sediment pits. Locations for the sediment pits were decided on the following basis: (1) fifteen sediment pits were located along the Corp Rangelines, (2) other sediment pits were located across various landforms within the floodplain, and (3) other sediment pits were located on farms used by the plaintiffs' experts.

The fifteen reference sediment pits located along the Corps Rangelines provided the best evidence of aggradation[3] adjacent to the Moreau River. The Corps Rangeline surveys provided the actual surface elevations at the dates of each survey. This allowed me to examine the number, depth, and type of sediment layers since the last survey. This also allowed me to correlate the sediment layers between survey dates to known flood events as recorded at the USGS Whitehorse gauging station. It was essential to provide accurate field surveying and to tie the surveys into Corps monuments used for the rangeline surveys. This combination of surveying, sediment examination, and gauging station data allowed me to provide an unusual degree of precision in the study of sedimentation.

Other sediment pits located away from the Corps Rangelines and across a broader portion of the floodplain allowed me to study the periods of extensive flooding across the whole of the floodplain. Since there were no accurate historical survey references in these areas, we examined the number, depth, and

---

[2] Sedimentation – is the act or process of suspension of sediment in water and thence deposition of sediment into layers and creating alluvium across a floodplain; also referred to as vertical accretion.
[3] Aggradation – is the deposition of sediment performed by a stream in order to maintain its hydraulic capacity; sediment is deposited on the inside of a meander; aggradation is a part of the overall sedimentation process; also referred to as horizontal accretion.

type of sediment layers within approximately five feet of the land surface. Samples were collected to examine the radiocarbon age of the sediments. The procedure used in sampling and radiocarbon dating of the sediments followed the procedures used by J.M. Daniels in study of sediments in Republican River watershed in Nebraska and by L.H. Gile in studies of sediments in New Mexico. This procedure allowed us to determine whether the sediment had been deposited before or after 1950 (before or after present[4]) and therefore deposited before or after the Oahe Reservoir Project. The age of the sediment also allowed us to calculate the average sedimentation rate for these areas in the floodplain.

The aggradation rates were calculated in the sediment pits along the Corps Rangelines where the deposition rates tend to be greater. The sedimentation rates were calculated in the sediment pits located across the floodplain where the deposition rates tend to be less. Both sources of deposition rates were combined to prepare proximal maps of overall sedimentation rates across each of the three parcels. The overall sedimentation rate for a parcel is based upon a weighted average rate across the land area.

Sandy sediments are generally deposited from water flowing at higher velocity, and therefore are deposited higher energy environmental settings in the floodplain. As a flood event progresses, finer textured sediments are deposited over the sandy sediments. This creates a sequence of sediment that fines upward[5]. For example, a sequence from a flood event may start with sandy sediments followed by silty sediments as the floodwaters slow and recede. In this example, the silty layer over sandy layer represents a single flood event.

Clayey sediments are generally deposited from standing water and therefore are deposited in low energy environmental settings in the floodplain, such as backwater depression and sloughs. These areas are typically the first to flood as the river comes out of its banks and are the last to drain as the flood waters recede. Initially, silty sediments may be deposited, followed by finer clayey sediments. This creates a sequence of sediment that also fines upward. In this example, the clayey layer over silty layer represents a single flood event.

Landis, Inc. employed Brosz Engineering, Inc. of Pierre, SD to assist with land surveying. Stan Schlosser Ditching of Timber Lake, SD was employed to assist with excavation of sediment pits. Dr. J. Elmo Rawlings, III of University of Wisconsin, Platteville, WI was employed to assist due to his field experience in

---

[4] Before Present (BP) – refers to dates prior to 1950 which are based upon ^{14}C radiocarbon analysis. Samples with ages of after present or after 1950 are contaminated from radioactive material from atomic explosions.

[5] Fines upward - refers to sedimentation that start with coarser sized particles and later finer sized particles being deposited during a flood event. Each flood event typically creates this fining upward cycle of deposition.

South Dakota. Mr. Perry LaRock, NCSU graduate student, served as field technician for Dr. Kays.

Review of Literature

Soil scientists and geomorphologists have studied sediments and the soils derived from those sediments (Ruhe, R.V., 1956). Dr. Kays' doctoral committee at NCSU included Dr. R.B. Daniels, and Dr. H.J. Kleiss, both were previous graduate students of Dr. Robert Ruhe at Iowa State University. Dr. Kays' doctoral committee also included Dr. S.W. Buol, one of the leading Pedologists in the United States (Buol, S.W., 2003).

Floodplains are formed by geomorphic processes and the depositional material produces characteristic landforms (Ruhe, R.V., 1975). Fluvial deposits have been studied through the use of stratigraphy (Bilzi, A.F., 1977; Brownfield, S.H., 2005; Crownover, S.H., 1994a; Crownover, S.H., 1994b; Daniels, R.B., 1985; Daniels, R.B., 1978a; Daniels, R.B., 1978b; Daniels, R.B., 1963; Kleiss, H.J., 1973; and Ruhe, R.V., 1975), using the principals of superposition whereby the overlying sediments are the younger than the underlying sediments.

Alluvium deposited along meandering rivers produce distinctively different characteristics than alluvial fans or deltas. Meandering rivers deposit fining-upward alluvial cycles of sediment from each flood event (Pettijohn, F.J., 1975). The sedimentary deposits in the floodplain produce excellent records of past hydrologic conditions because they preserve the record of the past geomorphic processes (Daniels, J.M., 2003).

The sediment accumulation in floodplain is subject to pedogenesis during periods between intervals of deposition. The dominant control on pedogenesis or soil formation is the rate of sedimentation. The threshold rate of pedogenic assimilation appears to be about 0.0016 feet/year (Daniels, J.M., 2003) for semi-arid floodplains. Slower depositional rates allow for pedogenic processes to develop, while faster rates bury the surface with sediment before pedogenic processes can be expressed.

During extended periods of slower depositional rates, soil horizons are developed distinguishing the soil from the sediment. The dominant controlling factor on soil formation is the vertical and horizontal accretion and can produce the three soil/sediment relationships: (1) cumulic soil profiles developed in alluvium, (2) multiple buried soils separated by pedogenically unaltered sediment, and (3) pedogenically unaltered sediment. During periods of faster rates of deposition, the developed soil horizons are buried (Buol, S.W., 1965). The buried soils or palesols are thought to be due to drier climates of the past (Gile, L.H., 1968; Holliday, V.T., 1985; Rawlings, J.E., 2001; and Rawlings, J.E., 1999) and palesols were formed during periods of slower sedimentation.

Soil scientists and geomorphologists have used landscape relationships, landscape stability, and other means to provide relative ages of sediments and soils (Daniels, R.B., 1985; Fenton, T.E., 1974; Goldin, A., 1983; Hogan, J.D., 1963; Kleiss, H.J., 1994; and Ruhe, R.V., 1956). Landscape relationships have been developed for the study of semi-arid landscapes (Gile, L.H., 1970; Gile, L.H., 1968; Goldin, A., 1983; Haas, A., 1986; Holliday, V.T., 1985; Kohut, C., 1995; Martel, Y.A., 1974; and Paul, E.A., 1997).

The geomorphic surfaces across the semi-arid floodplains are formed by deposition and erosion by both wind and water. The relationship of the remaining sediments can best be understood using reference sites of known depositional history. When this has not been possible, soil scientists and geomorphologists have used radiocarbon dating to determine the age of fluvial sediments in the floodplain (Bilzi, A.F., 1977; Birkeland, P.W., 1999; Crownover, S.H., 1994a; Crownover, S.H., 1999b; Daniels, J.M., 2003; Gile, L.H., 1981; Gile, L.H., 1970; Gile, L.H., 1968; Harksen, J.C., 1974; Hogan, J.D., 1963; Holliday, V.T., 1985; and Martel, Y.A., 1974).

The relationship between the radiocarbon age and depth of upland soils in the Great Plains have been extensively developed (Paul, E.A., 1997). The relationship between the radiocarbon age and depth of fluvial deposits in the Great Plains has also been developed (Daniels, J.M., 2003; and Holliday, V.T., 1985).

One of the key problems in dating the fluvial deposits is that frequently older sediments have been found to overlay younger sediments (Daniels, J.M., 2003; Gile, L.H., 1968; Haas, H., 1986; Harksen, J.C., 1974; Holliday, V.T., 1985; Huang, Y., 1999; Kohut, C., 1995; McDowell, L.L., 1969; Paul, E.A., 1997). This apparent conflict with super-position has primarily occurred when an old surface has been truncated or when humic acids in the organic fraction leach downward (Huang, Y., 1999; Martel, Y.A., 1974; Matthews, J.A., 1981; and Runge, E.C.A., 1973).

The radiocarbon ages of the surficial fluvial deposits are influenced by age of the organic matter (Hsich, Y., 1996; and Huang, Y., 1999); and organic matter is influenced by vegetation growing on the floodplain (Boutton, T.A., 1996). The organics have a mean residency time in the soil in the range of 100 to 200 years (Martel, Y.A., 1974; and Matthews, J.A., 1981). Recent alluvial sediments and soils are contaminated by additions of ^{14}C materials that have been deposited from aerial deposition of radionuclide from atomic bombs (Anderson, D.W., 1984; Hsich, Y., 1996; and Martel, Y.A., 1974).

Use of Corps Rangeline Surveys to Date Sediment Layers

Targets were mounted in the sediment pits representing elevations from the Corps surveys at various dates. For example, photograph P-08a (Appendix B) shows targets representing the surface elevations at time of the 2003, 1989, 1976, and 1968 rangeline surveys. The corresponding Plate B-08 shows the top of the pre-2003, pre-1989, pre-1976, and pre-1968 sediments. Therefore, Plate B-08 shows that the sediment deposits between 1989 survey (1,623.80 foot elevation) and 2003 survey (1,622.49 foot elevation) by difference is 1.31 feet in depth. Ten sediment layers were identified within this 1.31 feet and it was determined that the sequence of sediments represents five flood events. According to the USGS Whitehorse gauging station data, the five largest peak flow events within this period occurred in 1993, 1994, 1995, 1996, and 1997 (Appendix E). Therefore, the corresponding layers are identified with the year of each peak event. Using this procedure, 0.27 feet of sediment represent the flood of 1997 at Sediment Profile #8. Plate R-03 summarizes the compilation of sediment pits and thickness of layers corresponding to each of the flood events.

Relationship of Aggradation Rates to Watershed

The aggradation rates summarized in Plate R-03 shows variable sediment thickness since 1962. The average aggradation rate was greatest in years 1997 and 1987. The highest aggradation rate was for 1997 when the Moreau River experienced the highest discharge rate of record for the USGS Whitehorse Station (Appendix E). Aggradation rates are known to vary considerably depending upon various hydrology factors. In order to better understand the relationships, several correlations were conducted.

Average aggradation rates calculated for sediment pits along the Corps rangelines have been analyzed in relationship to (1) peak discharge rates for Moreau River, (2) Oahe Lake levels, and (3) number of consecutive days Oahe Reservoir is above normal pool elevation.

The average aggradation rates are best correlated with the peak discharge of Moreau River (Plate A-15, Appendix A). It is logical for there to be a reasonably positive relationship between high flows and rates of aggradation.

The relationship between average aggradation rates and Oahe Lake levels is poorly correlated (Plate A-16, Appendix A). The Oahe Lake was at a higher level for the flood of 1979, 1984, 1986, 1991, 1995, and 1996, than it was for the flood of 1997.

The relationship between average aggradation rates and number of consecutive days Oahe Reservoir is above normal pool elevation is also poorly correlated (Plate A-17, Appendix A). At the time of flooding, the Oahe Lake was above normal pool for a longer period in 1986, 1995, and 1996, than it was for the flood of 1997, by 236%, 229%, and 557%, respectively.

Use of Radiocarbon Ages to Date Sediment Layers

AMS radiocarbon dating of soils has been conducted for numerous upland soils across the Great Plains Region. A recent study of the Great Plains Region shows the range of soil ages correlated with the depth below the surface (Paul, E.A., 1997). Paul's research demonstrated that prairie topsoils range in age up to about 2,500 years before present, and that prairie subsoils range from about 2,500 years to about 7,000 years before present (Plate A-11, Appendix A).

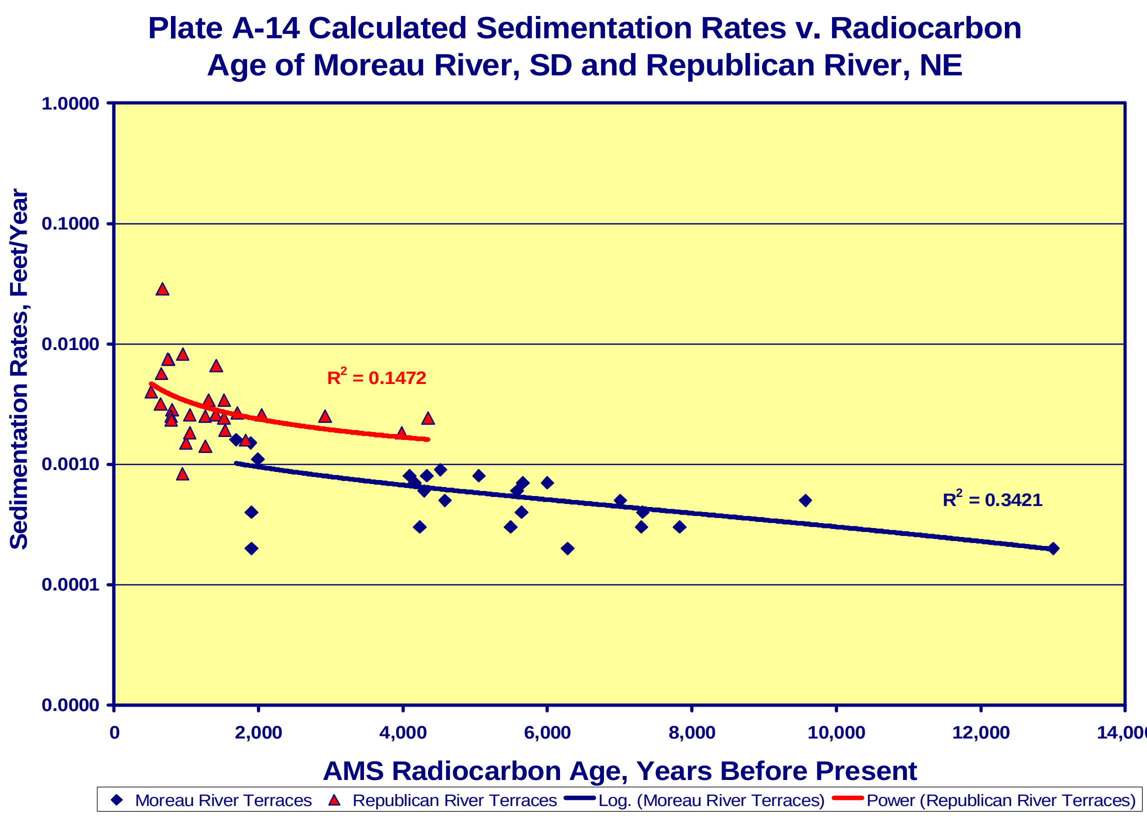
AMS radiocarbon dating of soils and sediments in the floodplain of Republican River watershed in southwest Nebraska shows ages ranging from about 500 years to about 4,000 years before present (Daniels, J.M., 2003)(Plate A-12, Appendix A). The age of the soils increases with depth below the surface of the fluvial sediments. AMS radiocarbon dating of sediment layers has been used to calculate average sedimentation rates for alluvial soils in the Republican River watershed.

The results of the AMS radiocarbon dating of sediments in the Moreau River floodplain are shown in Appendix C and correspond to soil profiles in Appendix B. The age of the sediments increases with depth below the surface of the fluvial sediments (Plate A-13, Appendix A). The relationship between depth and age of sediments is similar between the Republican River floodplain and the Moreau River floodplain. The Moreau River sediments range somewhat older that those in Republican River.

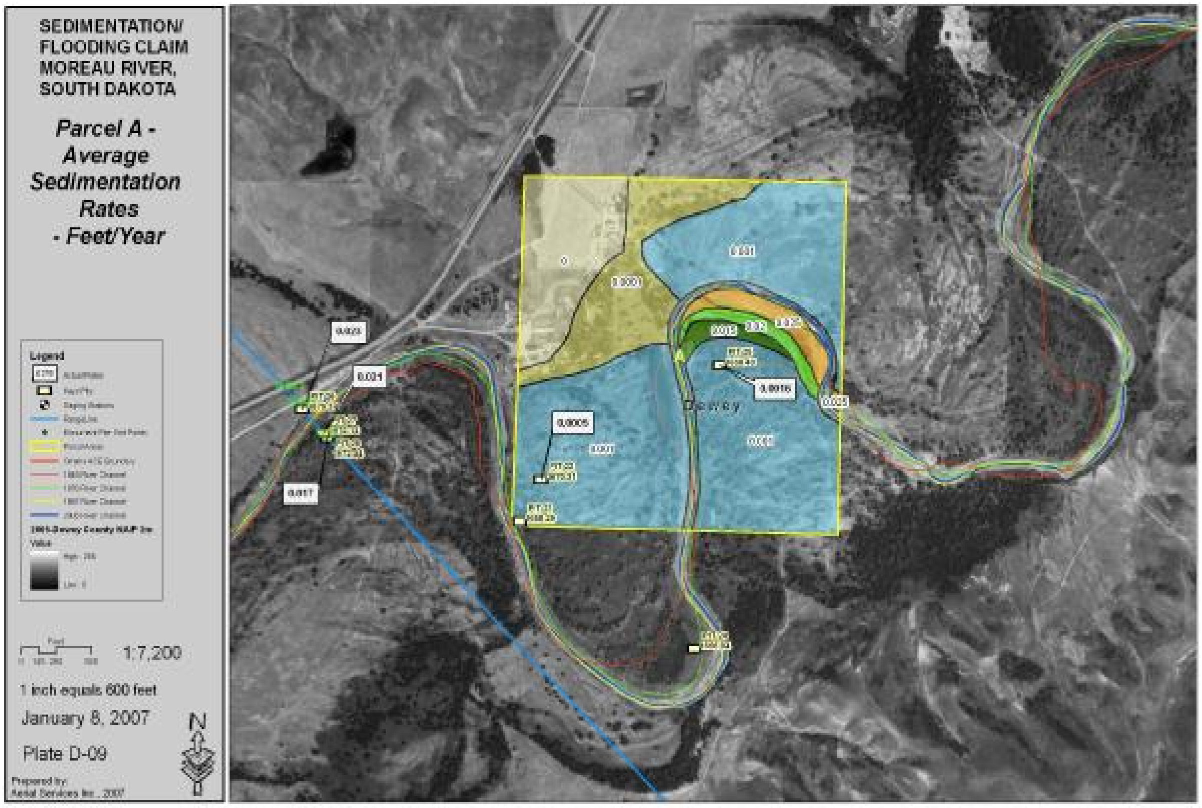
AMS radiocarbon dating of sediment layers has been used to calculate average sedimentation rates for alluvial soils in Moreau River floodplain. The correlation between the sedimentation rates and the age of the sediments in Moreau River floodplain is similar to the Republican River floodplain (Plate A-14, Appendix A). Because of the similarity between the two studies, it is highly probable that average sedimentation rates for the Moreau River floodplain represent natural processes unaffected by the Oahe Reservoir Project.

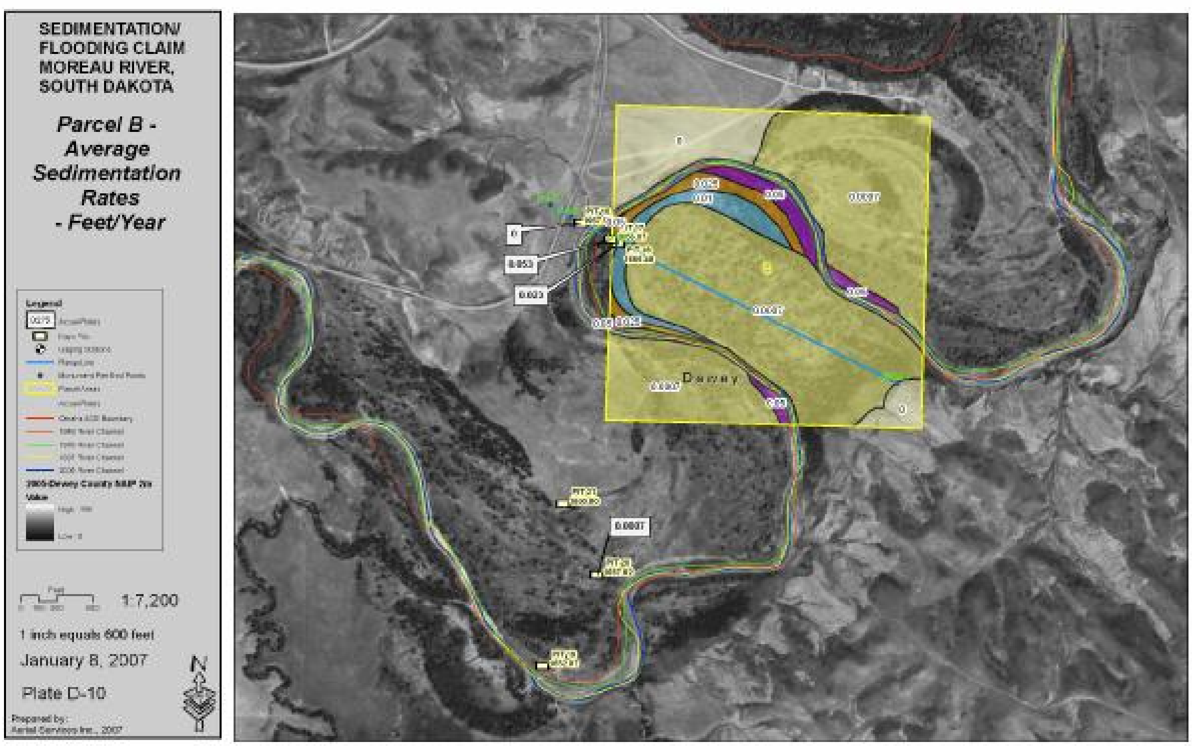
This analysis is based upon twenty-seven radiocarbon samples collected from the sediment pits and summarized in Plate C-01 (Appendix C). The radiocarbon test results are shown in Plate C-02 through Plate C-34 in Appendix C. The location of the samples within each sediment profile is shown in Appendix B. Twenty-four of the radiocarbon samples show that the age of the sediment layer is prior to 1950 (Before Present) and thus occurred prior to the Oahe Reservoir Project. Three of the samples indicate some degree of contamination from material deposited after 1950.

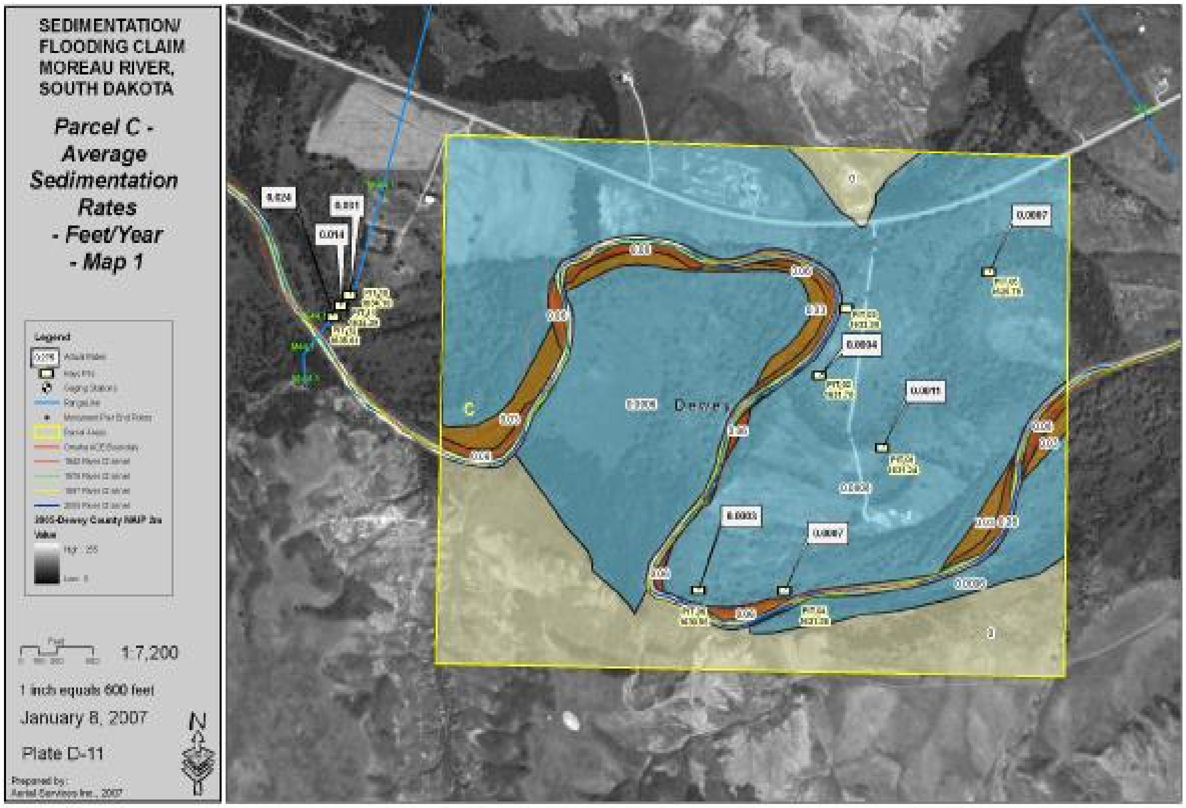
Four radiocarbon samples were taken near the ground surface. Three of these samples indicate radiocarbon ages prior to 1950. The three samples Beta 196018, Beta 197926, and Beta 197929 were collected at depths of 1.01 to 1.04 feet, 1.05 to 1.40 feet, and 0.62 to 0.87 feet, respectively. One of the samples indicated contamination with post 1950 aged material at depths of 0.45 to 0.69 feet. These samples show that most of the sediment material from 0.5 to 1.5 feet depth was deposited prior to 1950.



Most importantly, the radiocarbon data of the Moreau River floodplain clearly demonstrates that the age of sediments below about 0.7 foot depth dates to well before the Oahe Reservoir Project. Additionally, some of the sediment at depths less than 0.7 feet dates to well before the Oahe Reservoir Project. The radiocarbon data clearly shows that the average sedimentation rates are natural and have not changed from the rates before the Oahe Reservoir Project.


SEDIMENTATION/
FLOODING CLAIM
MOREAU RIVER,
SOUTH DAKOTA
Parcel A -
Average
Sedimentation
Rates
- Feet/Year
Legend
1:7,200
1 inch equals 600 feet
January 8, 2007
Plate D-09
N
0.023
0.021
0.017
0.0005
0.0016
0.025
Dewey


SEDIMENTATION/
FLOODING CLAIM
MOREAU RIVER,
SOUTH DAKOTA
Parcel B -
Average
Sedimentation
Rates
- Feet/Year
Legend
1:7,200
1 inch equals 600 feet
January 8, 2007
Plate D-10
N
0
0.053
0.023
0.0007
Dewey



Conclusions

This study evaluates the various allegations regarding the sedimentation along the Moreau River upstream of the Oahe Reservoir Project. The conclusions stated in this report accurately reflect the facts in this case, according to my professional scientific judgment.

1. The Moreau River floodplain has experienced natural rates of sedimentation, both before and since the alleged date of taking (on or about April 1, 1997). The weighted average rates of sedimentation have been accurately measured for Parcels A, B, and C. The weighted average rates of sedimentation are consistent with natural rates of sedimentation for other floodplains in semi-arid regions of the Great Plains.

    a. The weighted average rates of sedimentation for the three parcels were:
        i. Parcel A was 0.0022 feet/year,
        ii. Parcel B was 0.0039 feet/year, and
        iii. Parcel C was 0.0016 feet/year.

b. The above sedimentation rates were calculated using a combination of both ^{14}C radiocarbon ages and aggradation rates measured along the Corps rangelines.

c. These rates of sedimentation are comparable with studies of natural rates Daniels, R.B., 2003) for the Republican River floodplain in Nebraska and as the comparison shows on Plate A-14 of this report.

2. The vertically accreted sediments occurring below 0.7-foot depth across the floodplain were deposited prior to 1950. No sediment below 0.7 foot depth was found to be contaminated with post 1950 aged ^{14}C material. Some of the vertically accreted sediments occurring at less than 0.7-foot were deposited prior to 1950. The sedimentation rates based upon the radiocarbon data shows that the average rate is 0.0006 feet/year or 0.0072 inches/year.

   a. The 14C radiocarbon ages of sediment near the land surface proves that sediment was deposited before 1950 and prior to the Oahe Reservoir Project.

   b. The sedimentation rates calculated from the radiocarbon ages proves that the average rate of deposition has been very slow and amounts to a thin veneer across the floodplain.

3. Scouring and aggradation occurs during high flows along the Moreau River channel. These areas of aggradation are small in area, but have faster rates of sediment accumulation that the remainder of the floodplain. The average measured depth of aggradation for the flood of 1997 was determined to be 0.45 feet. The annual rate of aggradation along the Moreau River between 1962 and 1997 was most highly correlated with the annual peak flows of water coming down the river.
   a. The aggradation rates are based upon measured values field surveys from 1962 through 2003 and confirmed by examination of sediment pits.
   b. The sediments are deposited in many layers of sediment allowing reasonably accurate measurement of sediment thickness for various flood events.

4. The annual rate of aggradation outside of the stream channel is not caused by the Oahe Reservoir Project. The annual rate of aggradation along the Moreau River is poorly correlated with the water level in Lake Oahe, and is poorly correlated with the length of time above normal pool for Lake Oahe.

5. Dr. Schaefer states on page 2 of his report that “The ranchers who suffered losses from these floods and sedimentation assumed the floods were the result of the construction and operation of Oahe Reservoir. Their assumption is reasonable give the lack of flooding and sedimentation in prior years.” Dr.

Schaefer never submits in his report any valid basis to support these assumptions of causation.

6. Dr. Schaefer states on page 11 of his report that "The depth of sediment was determined by collecting soil and sediment samples with a one inch diameter probe and logging the depth of sediment above the natural (pedogenic) soil profile." Dr. Schaefer never attempts to date the age of the pedogenic soil material and thus has no idea when it was deposited or formed; therefore his depth of "recent sediment" that he measured could have been deposited prior to the Oahe Reservoir Project. Dr. Schaefer measurements are invalid and based upon unproven assumptions.

7. Dr. Schaefer states on page 34 of this report that "Sedimentation effects from the March 1997 event occur from the Corps take line upstream to above the confluence of the Little Moreau River with the Moreau River." However, Dr. Schaefer merely assumes that the sedimentation effects occurred in 1997 and fails to submit any evidence to prove when it occurred.

8. Mr. Nielsen states on page 4 of his report that "The depth of recent sediment within the Moreau River floodplain study area can be estimated or interpolated spatially from the depth to the soils' Ab horizon." However, Mr. Nielsen never attempts to prove the age of the Ab horizons (buried A horizons) therefore the depth of recent sediment could have been deposited before the Oahe Reservoir Project.

9. Mr. Nielsen states on page 7 of his report that "From observation made at the study sites the average depth to a buried soil layer was about 24 inches and the average depth to a thin layer of buried organic debris was about 28 inches. Given these observations an assumption can be made that approximately 2 foot of alluvial sediments can be attributed to the 1997 flooding event." Many of Mr. Nielsen's depth measurements are in pits located along the Corps rangelines. However, Mr. Nielsen fails to recognize that his measurements are in significant conflict with the elevations field surveyed along the Corps rangelines from 1962 to 2003. The Corps rangeline surveys and the author's measurements of actual aggradation along the rangelines demonstrate that Mr. Nielsen measurements are invalid and based upon unproven assumptions.

Literature Cited

Anderson, D. W. and E. A. Paul. 1984. Organo-mineral complexes and their study by radiocarbon dating. SSSAJ 48:298-301.

Bilzi, A. F. and E. J. Ciolkosz. 1977. Time as a factor in the genesis of four soils developed in recent alluvium in Pennsylvania. SSSAJ 41:122-127.

Birkeland, Peter W. 1999. Soils and Geomorphology. Third Edition, Oxford University Press, Inc., New York.

Boutton, Thomas W. 1996. Stable carbon isotope ratios of soil organic matter and their use as indicators of vegetation and climate change. In: Boutten, T.W. and S. Yamasaki (Eds.), Mass Spectrometry of Soils, pg. 47-82, Mercel Dekker, Inc., New York.

Brownfield, S. H., W. D. Nettleton, C. J. Weisel, N. Peterson, and C. McGrath. 2005. Tephra influence on Spokane-flood terraces, Bonner County, Idaho. SSSAJ 69:1422-1431.

Buol, S. W., R. J. Southard, R. C. Graham, and P. A. McDaniel. 2003. Soil Genesis and Classification. Iowa State University Press, Ames, Iowa.

Buol, S. W. 1965. Present soil-forming factors and processes in arid and semiarid regions. Soil Sci. 99:45-49.

Crownover, S. H., M. E. Collins, and D. A. Lietzke. 1994a. Soil-stratigraphic correlation of a doline in the Valley and Ridge Province. SSSAJ 58:1730-1738.

Crownover, S. H., M. E. Collins, and D. A. Lietzke. 1994b. Parent materials and stratigraphy of a doline in the Valley and Ridge Province. SSSAJ 58:1738-1746.

Daniels, J. Michael. 2003. Floodplain aggradation and pedogenesis in a semiarid environment. Geomorphology 56:225-242.

Daniels, R.B., E.E. Gamble, D.K. Cassel, and L.A. Nelson. 1985. Soil erosion class and landscape position in the North Carolina piedmont. SSSAJ 49(4):991-995.

Daniels, R.B. and E.E. Gamble. 1978a. Relations between stratigraphy, geomorphology and soils in coastal plain areas of southeastern United States. Geoderma 21(1):41-65.

Daniels, R. B., E. E. Gamble, and W. H. Wheeler. 1978b. Age of soil landscape in the Coastal Plain of North Carolina. SSSAJ 42:98-105.

Daniels, R. B., M. Rubin, and G. H. Simonson. 1963. Alluvial chronology of the Thompson Creek watershed, Harrison County, Iowa. Am. J. Sci. 261:473-487.

Fenton, T. E., W. P. Dietz, and F. F. Reicken. 1974. Chemical properties of upland summit and associated cumulic soils in loess areas of Tama County, Iowa. Agron. Abstr., pg. 158.

Gile, L. H., J. W. Hawley, and R. B. Grossman. 1981. Soils and geomorphology in the Basin and Range area of southern New Mexico – Guidebook to the desert project. New Mexico Bur. Mines Mineral Resources Memo. 39.

Gile, L. H. 1970. Soils of the Rio Grande Valley border in southern New Mexico. SSSJ 34:465-472.

Gile, L. H. and J. W. Hawley. 1968. Age and comparative development of desert soils at the Gardner Spring Radiocarbon Site, New Mexico. SSSAJ 32:709-716.

Goldin, Alan and R. B. Parsons. 1983. Geomorphic surfaces and soils in the Camas Prairie Area, Washington. SSSAJ 47:275-280.

Haas, Herbert, Vance Holliday, and Robert Stuckenrath. 1986. Dating of Holocene stratigraphy with soluble and insoluble organic fractions at the Lubbock Lake Archaeological Site, Texas: An ideal case study. Radiocarbon 28:473-485.

Harksen, J. C. 1974. Radiocarbon dating of terraces along Bear Creek, Pennington County, South Dakota. South Dakota Geological Survey, Report of Investigations No. 108.

Hogan, J. D. and M. T. Beatty. 1963. Age and properties of Peorian loess and buried palesols in Southwestern Wisconsin. SSSAJ 27:345-350.

Holliday, Vance T. and J. Elmo Rawling III. 2006. Soil-geomorphic relations of lamellae in eolian sand on the High Plains of Texas and New Mexico. Geoderma 131(1-2):154-180.

Holliday, Vance T. 1985. Morphology of Late Holocene soils at the Lubbock Lake Archeological Site, Texas. SSSJ 49:938-946.

Hsich, Yuch-Ping. 1996. Soil organic carbon pools of two tropical soils inferred by carbon signatures. SSSAJ 60:1117-1121.

Huang, Yongsong, Baocai Li, Charlotte Bryant, Roland Bol, and Geoffrey Eglinton. 1999. Radiocarbon dating of aliphatic hydrocarbons: A new approach for dating passive-fraction carbon in soil horizons. SSSAJ 63:1181-1187.

Kleiss, H.J. 1994. Relationship between geomorphic surfaces and low activity clay on the North Carolina Coastal Plain. Soil Sci. 157(6):373-378.

Kleiss, H.J. 1973. Loess distribution along the Illinois soil-development sequence. Soil Sci. 115(3):194-198.

Kohut, Connie, D. Muehlenbachs, and M. J. Dudas. 1995. Authigenic dolomite in a saline soil in Alberta, Canada. SSSAJ 59:1499-1504.

Martel, Y. A. and E. A. Paul. 1974. The use of radiocarbon dating of organic matter in the study of soil genesis. SSSAJ 38:501-506.

Matthews, John A. 1981. Natural ^{14}C age/depth gradient in a buried soil. Naturwissenschaften 68:472-474.

Matthews, John A. 1980. Some problems and implications of ^{14}C Dates from a podzol buried beneath an end moraine at Haugabreen, southern Norway. Geografiska Annaler 62A:185-208.

McDowell, L. L., J. C. Stephens, and E. H. Stewart. 1969. Radiocarbon chronology of the Florida Everglades peat. SSSAJ 33:743-745.

Noller, Jay Stratton, Janet M. Sowers, and William R. Lettis (Eds.). 2000. Quaternary Geochronology: Methods and Applications. American Geophysical Union, Reference Shelf 14, Washington, DC.

Pettijohn, F.J. 1975. Sedimentary Rocks. The John Hopkins University, Baltimore, MD.

Rawling III, J.E., G.G. Fredlund, and S.A. Mahan. 2001. "Numerical age estimates of Quaternary Stratigraphy exposed on table edges in Badlands National Park", Geological Society of America Annual Meeting, Boston, MA.

Rawling III, J.E. and G.G. Fredlund. 1999. "Episodic mid-late Holocene eolian activity evidences by buried soils in cliff dunes at Sheep Mountain Table, Badlands National Park, South Dakota", Geological Society of America Annual Meeting, Denver, CO.

Ruhe, Robert V. 1975. Geomorphology: Geomorphic Processes and Surficial Geology. Houghton Mifflin Co., Boston, MA.

Ruhe, R. V. and W. H. Scholtes. 1956. Ages and development of soil landscapes in relation to climatic and vegetational changes in Iowa. SSSAJ 20:264-273.

Runge, E. C. A., K. M. Goh, and T. A. Rafter. 1973. Radiocarbon chronology and problems in its interpretation for Quaternary loess deposits – South Canterbury, New Zealand. SSSAJ 37:742-746.

Skipp, Gary L. and Isabelle Brownfield. 1993. Improved Density Gradient Separation Techniques using Sodium Polytungstate and a Comparison to the Use of Other Heavy Liquids. US Geological Survey, Open-File Report 92-386.

USACOE. 2002. Moreau River – Oahe Project – South Dakota Sedimentation Study. Hydraulics Section, Omaha District, Omaha, NE.

USACOE. 2003. Aggradation Study – Moreau River, South Dakota. Hydraulics Section, Omaha District, Omaha, NE.

USDA. 1979. Soil Survey of Dewey County, South Dakota. Soil Conservation Service, Washington, DC.