COLOR INFRARED PHOTOGRAPHY AND THERMAL INFRARED IMAGERY OF SELECTED LOCATIONS ALONG THE MISSOURI RIVER BETWEEN OMAHA AND BLAIR, NEBRASKA

Submitted to

Department of the Army
Omaha District, Corps of Engineers
Omaha, Nebraska

By

Engineering Research Center
Colorado State University
Fort Collins, Colorado

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COLOR INFRARED PHOTOGRAPHY AND THERMAL INFRARED IMAGERY OF SELECTED LOCATIONS ALONG THE MISSOURI RIVER BETWEEN OMAHA AND BLAIR, NEBRASKA

By

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PURPOSE

The purpose of this study was to perform a preliminary investigation of the feasibility of using certain remote sensing systems from an aircraft platform for evaluating ecological changes related to the channelization and canalization of the Missouri River in the Omaha District. The Civil Engineering Department at Colorado State University collected color infrared photography and thermal infrared imagery of portions of the Missouri River between the south Omaha Bridge and the California cut-off just upstream from Blair, Nebraska. Only certain portions of this reach of the river were over-flown.

SCOPE OF REPORT

This report describes the data collection and analysis procedure and some general interpretation related to the mechanics of river flow and the environment immediately adjacent to the river. A section is devoted to the discussion of the identification of specific flow features and ecological subsystems and the corresponding effectiveness of using color infrared photography and/or thermal infrared imagery for

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evaluation of such features. Recommendations for additional study are included. This report involves, as separate exhibits, one roll of seventy-seven (77) color infrared transparencies and enlarged contact prints of the thermal infrared imagery.

PROCEDURES

A Wild RC-8 Precision Mapping Camera with a minus-blue filter was used to obtain a total of seventy-seven (77) exposures on Kodak 2443 aerographic color infrared film. Eight (8) of these exposures were at an altitude of 2500 MSL; the remaining exposures were at an altitude of 3000' MSL; the corresponding photo scale for the two flight levels were approximately 1:3000 and 1:4000, respectively. The color infrared film was processed to a positive transparency for viewing on a light table; a duplicate positive transparency was furnished to the Omaha district. Eight (8) contact prints of particularly interesting areas were made from the positive transparency; these prints were forwarded to the Omaha district for use in the field for annotating ground truth information. The Omaha district made overlays with the significant ground truth information and returned the overlays to Colorado State University in order to assist with interpretation of the color infrared photography.

A Bendix LN-2 thermal infrared line scanner with roll compensation on the magnetic tape output and a 70mm film recorder cassette were flown at a later date. The thermal infrared imagery was obtained at two levels during two separate time intervals. An early morning flight started at about 6:30am Central Daylight Time and lasted until 8:30am Central Daylight Time. This flight was flown at an altitude of 2400' MSL. A second flight which started about 11:00am Central Daylight Time and finished at approximately 12:45pm Central Daylight Time and was flown

at 4000' MSL. The 70mm film was processed to a negative transparency and prints enlarged four times were made from the negative. These enlarged prints were fabricated together to form a mosaic of the respective flight lines. The roll compensated magnetic tape record was processed by Bendix Corporation, Ann Arbor, Michigan, into a positive transparency and returned to Colorado State University for interpretation.

The color infrared photography flight was accomplished on October 13, 1971 and the thermal infrared imagery flight was accomplished on May 22, 1972. No ground truth information was collected simultaneously with the overflights of the photography; temperature measurements were made in the river prior to and during the thermal infrared imagery overflights at seven (7) stations. The ground truth information for the aerial photography work was accomplished approximately three months after the flight. A consideration for this time delay between the photography acquisition and the field sampling was noted during the interpretation process. Temperature measurements/locations and notes on the ground truth data are given in the Appendix.

Interpretation of the photography and the thermal infrared imagery was performed using relatively simple manual procedures; a Houston Fearless Corporation light table fitted with a five (5) inch diameter magnifying glass and a Bausch and Lomb Zoom 240 stereoscope were used. The enlarged prints from the 70mm film obtained directly from the line scanner were laid out in a mosaic fashion and compared with the color infrared photography and ground truth information. Due to the limited scope of this project only certain features are identified and discussed.

The potential for additional interpretation from both the color infrared photography and the thermal infrared imagery must certainly be recognized. For example, very accurate spatial information may be derived from the color infrared transparencies using either analog or analytical photogrammetry procedures. The magnetic tape record from the thermal infrared line scanner may be subjected to both analog and digital processing procedures which can be used to enhance radiometric differences in the scene. None of these procedures were exercised in this particular analysis.

GENERAL INTERPRETATION

One of the most striking features of this section of the Missouri River, which is obvious either on the color infrared photography or the thermal infrared imagery, is the degree of man-made control of the river and the apparent stability of the fluvial processes. For example, a uniform width channel of approximately 650' exists throughout the entire study reach. Little evidence of erosion or sediment deposition processes exist; banks and floodplains are well established by vegetation; and little evidence exists that would indicate overbank flows due to flooding. Point bars and chutes are non-existent, rather this section of river resembles a man-made canal; certainly the characteristics of a natural river are absent except for small amounts of erosion and deposition around spur dikes and training walls.

The general impression from the ecological standpoint obtained from the color infrared photography is that the natural sedimentation processes and subsequent vegetation development will gradually continue to fill in the remaining back water areas and produce in the near future an almost perfect canal shape throughout this reach. The shallow bodies of quiet

water subject to sedimentation processes and extensive water vegetation growth and decay will be in a continuing state of recession. This natural process may be quite desirable for developing suitable alignment of the river for navigation and flood control, but certainly limits the utilization of off-river available water spaces for recreation and wildlife habitat.

Associated with this gradual stabilization of the river banks is the natural vegetation of these areas by cottonwoods and willows. These dense vegetation types undoubtedly provide considerable cover and habitat for wildlife. On the other hand, the clearing and the reforestation of some of the more accessible sites with grasses and more varieties of trees could provide outstanding recreational facilities for the local urban population. Tremendous potential exists for developing public parks and beautifully landscaped industrial parks on the contiguous flood-plain. In conjunction with such development, small-sized, man-made lakes could add to the use factor for such areas. These lakes and other man-made developments could provide an outstanding fishery and wildlife habitat.

The pollution aspect of the river appears to be a rather serious problem. Cases of poor quality sewage effluent, return of sediment pollution, and thermal pollution were in evidence. On the color infrared photography "blobs" of some material resembling a petroleum product exists throughout the whole study reach. Unless measures are taken to improve the water quality, this waterway will tend to become a very undesirable environment which will have impact upon future recreational uses, domestic and industrial water supplies, and the general ecology of the river system. The thermal infrared imagery of the thermally enriched returns from the O.P.P.D. power plant identifies the path of this flow in the river. The

persistence of the temperature gradient between the effluent and receiving water and the lack of lateral mixing are of paramount importance in evaluating the nature of the overall effect of such flows upon the biological processes in a river.

Apparently a tremendous task has been accomplished in providing flood control and navigation for barge traffic through this reach of the Missouri River. It is obvious both from the photography and imagery that this control is in effect and that now a considerable potential exists for coordinated development of the banks and near floodplain for additional high use areas by the local population. Unless such efforts are made, the environment in the river and adjacent to the river can rapidly deteriorate into a relatively limited use area. An accelerated program of water pollution control, reforestation, and a limited amount of construction work could develop this stretch of the Missouri River into an ecologically sound, high-use area.

SPECIFIC INTERPRETATION EXAMPLES

Based on the ground truth information collected by the Omaha district and annotated on eight (8) selected color infrared prints, a limited discussion will be presented dealing with certain features. The interpretation of the thermal infrared imagery with the associated water temperature measurements will also be included.

Photograph #5165 shows the effluent from the South Omaha Sewage Treatment Plant. This effluent is a dark colored substance and appears to mix fairly well with the receiving stream. The flow pattern at the surface indicates that there is quite a little turbulence through this particular region which promotes the mixing process. This effluent was not apparent on the thermal infrared imagery so the authors concluded that the

temperature of the effluent was about the same as the river or the plant was not in operation at the time of the thermal infrared overflight. High quality aerial photography and thermal infrared imagery allows the interpreter to monitor the performance and operation of sewage treatment plants. The chemical analysis of a water sample taken just below the outfall of the South Omaha Sewage Treatment Plant, is included in the appendix of this report.

It is interesting to note the band of black willow growing immediately adjacent to the left bank and the difference in coloration in this stand of black willow apparently due to age. This interpretive key can be very valuable for documenting the historic sedimentation process along the banks. The cottonwood trees farther inland represents an older floodplain development and the contact line between the willows and the cottonwoods represent a distinct change due to the channelization through this section.

Photograph #5196 illustrates one of the most valuable uses of color infrared photography in connection with fluvial processes. That is, a slight change in suspended material concentration in water produces a significant tone change on color infrared film. Characteristically, water with suspended material appears to have a range of blue tones ranging from very dark blue to a very light blue. Waters with very little suspended material appear dark blue; whereas, water containing higher concentrations of suspended material takes on a light blue tone. If turbidity is used as a measure for the suspended material concentration one can use the four large ponds to visualize the effect of this suspended material concentration on tone. Particularly between ponds 3 and 2, and ponds 2 and 7, a very slight change in the turbidity produces a considerable tone change on the photograph. The data on the Metropolitan Utilities District Water Treatment ponds are given in the appendix.

It is interesting to also note on this photograph that some sediments are being flushed back to the river and the tone of that water represents a very high concentration of suspended material. This tone change, enhanced on color infrared positive transparencies, representing a variation in suspended material concentration can be used to great advantage. The authors feel that this tone can be quantified with sufficient ground truth over any given river section to effectively monitor the change in suspended material concentration. In addition, the variation in tone provides a good indication of mixing processes, sources and sinks of sediment transport, and general flow conditions in the river.

Again the vegetative cover on the left bank indicates the boundary between the more recent deposits as compared to the older floodplain development. On the right bank and back up into the urbanized area of the photograph are a variety of trees representing maples, hackberry, elms, ash, and conifers. At this time of year there is a considerable variation in the tone of the tree types depending on a variety of conditions, but even under common growing conditions of the mid-summer the authors have found that tree species and vegetation types may be differentiated by the characteristic tone of the red color.

Photograph #5204 shows an area including cottonwood trees and grassed areas. By limiting the extent of the area covered by cottonwood trees and encouraging the growth of grass, an area such as this can be used very effectively for high-use, recreational sites. Color infrared photography can be used very effectively for managing such areas from the standpoint of forestation and grass cultivation as well as from the standpoint of public use monitoring. For example, plant life experiencing some stress

of either a man-made or natural origin, may oftentimes be detected on color infrared photography and a remedy employed to preserve such plant life.

The water body in this particular photograph has a relatively dark green color which indicates low suspended sediment concentration, but probably with some algal growths in the water.

Photograph #5208 in the California cut-off area appears to be an excellent wildlife habitat area. The tone of the water indicates that the suspended material concentration is relatively low, but again there is quite a lot of bio-mass in the water body in certain areas. The extensive growths of cattail immediately adjacent to the water edge will undoubtedly provide a continually expanding encroachment upon this small water body and depending on the depth of water may eventually block the entire waterway. In order to preserve this water body for future use, some steps should be taken to control the encroachment of this type of plant life. A considerable growth is beginning to occur out in the lake. With an adequate water weed control program this water body could undoubtedly be developed into a warm water fishery unit. Additional water supply to this system, perhaps by pumps tapping the underlying groundwater reservoir, might materially enhance the water quality and fisheries potential for this area.

The cottonwood areas would appear to afford good habitat for deer and other small game. Again selective forestation on these islands might provide a more suitable habitat for wildlife and use potential for the general public.

Photograph #5212 also in the California cut-off area was particularly interesting since a channel-like feature was represented on the photo-

graph. Ground truth identified this particular lineament as a break in slope between higher, flatter ground and the lower level, more recent, floodplain. The lighter color bank represents the bank of this slope facing to the southwest and consequently having a drier surface material. The photograph is very useful for illustrating the tone differences due to soil type and variation in moisture content. On highly vegetated ground the difference in soil type/soil moisture content may not be immediately evident, but may have to be inferred by the type and tone of the vegetative cover. But, in general, color infrared photography can be quite useful for identifying soil/soil moisture differences, and the proximity of the water table.

Photograph #5221 in the De Soto Bend cut-off area illustrates quite well the land building process behind the dikes. The more recent deposits near the downstream end of the training dike are in evidence. Vegetation will begin to grow naturally on these more recent deposits to further increase the rate of accretion and stability of such deposits.

In the bare field area, moisture content differences are evident. One can gain some appreciation for the resolution of the film by noting the individual goose decoys in this particular area. As an example of another very useful ecological index, it is interesting to note that wildlife counts, for example, goose and duck popultaions, can be facilitated through the use of high quality aerial photography. Certainly the aspect of wildlife population and habitat trends associated with river control works must be considered.

On photograph #5229, the white markings at the surface of the water on the downstream side of the photograph were interpreted to indicate that

some sub-surface roughness of a considerable size was lying on the bottom of the channel in this area. Also a short distance upstream there appears to be some point disturbances which may be caused by a buoy or some other object affixed in the water. Specular reflection can be used in some instances to enhance surface wave action and turbulence induced by boundary conditions.

This photograph illustrates a wide variety of colorations in the trees due to species and/or variation in the Fall change process. The photograph also illustrates the application of high resolution photography for monitoring harvesting operations and estimating associated agricultural yields. A good deal of this productive land has been reclaimed from the old, uncontrolled river.

Photograph #5236 included a rather interesting coloration in the grass cover along the far right bank of the photograph. Ground truth information confirmed that the yellow areas were wild creeping alfalfa and that the large blotchy red area was sweet clover; a very distinct tone difference is represented by two variations of plant life. An inventory of interpretive keys could be developed for a variety of plant species.

The back water areas are relatively stagnant and undoubtedly contain quite a lot of dead vegetative matter and will gradually fill in with time. Quite a lot of debris has collected among the spur dikes along the right bank; the rip-rap along the left bank seems to be in very good condition. High resolution color infrared photography can be used to effectively monitor the condition of rip-rap.

RECOMMENDATIONS FOR ADDITIONAL STUDY

This demonstration project has verified the usefulness of color infrared photography taken with a precision mapping camera for use in general evaluation of rivers. The thermal infrared imagery obtained with a line scanner operating in the 8μm to 14μm band has proven to be effective for identifying and delineating thermal pollutants. In many cases, relatively simple interpretation processes are satisfactory; when deemed necessary, however, more refined data reduction procedures are available for processing both high quality aerial photography and thermal infrared imagery.

Color infrared photography obtained with a precision mapping camera and simultaneous thermal infrared imagery can provide a very useful combination of data collection for supplementing river sampling data, for monitoring ecological changes in the river and on the floodplains, and for generally identifying the performance of a total river system. Optimum use of remotely sensed data is accomplished in conjunction with a well planned ground truth collection program.

A remote sensing mission over the total length of the Missouri River in the Omaha district involving thermal infrared imagery and color infrared photography on at least an annual basis is highly recommended. The integration of such remotely sensed data immediately into the ongoing program of the Omaha district could provide a very effective media for co-ordinating routine sampling of the river system, construction and maintenance programs, and for managing water quality improvement programs.

APPENDIX

Temperature Measurements/Location

Station No.	Location	Date	Time	Temp (F)
1	Sta. 82+20 of R656.9 R/B	19 May 72	0615	63 1/2°
		22 May 72	0730	68°
2	Between two revertments, landward of Sta. 10+00 of R663.81 L/B	19 May 72	0615	63 1/2°
		22 May 72	0730	67°
3 a	Sta. 9+37 of D669.5 L/B	19 May 72	0615	63°
		22 May 72	0730	67°
b	1/4 distance across stream	19 May 72	0628	62°
c	1/2 distance across stream	19 May 72	0624	62°
d	3/4 distance across stream	19 May 72	0620	63°
e	Sta. 0+87.55 of D669.48 R/B	19 May 72	0615	66°
		22 May 72	0730	72°
4	50' behind Sta. 0+00 of R671.3 R/B	19 May 72	0615	63 1/2°
		22 May 72	0730	68°
5	Sta. 7+00 of D677.56 L/B	19 May 72	0615	62 1/2°
		22 May 72	0730	68°
	(Sand bar behind dike)	22 May 72	0730	62 1/2°
6 a	In lake, 150' d/s of outlet, 100' east of levee, behind Sta. 140+00 of R691.41A L/B	19 May 72	0615	63 1/2°
		22 May 72	0730	69 1/2°
b	5' from shore, off Sta. 140+00	19 May 72	0620	63 1/2°
7 a	50' u/s of Fish Creek, L/B Behind Sta. 17+50 of R694.6 R/B	19 May 72	0615	68°
		22 May 72	0730	73°
b	100' u/s of Creek mouth	22 May 72	0730	66°

Notes/Ground Truth

Photo No. 5165 - Gibson Bend, vic Mile 611.4 - A water sample was taken ten feet downstream from the outfall of the South Omaha Sewage Treatment Plant.

Vegetation -

1. Around the plant the grass is mowed with a row of silver maple on the plant-side of the street.

2. There is unmown grass in the upper left corner.

3. Across the street is an area of cottonwood with an understory of willow.

4. In the lower left corner is a stand of young cottonwood with some willow mixed in.

5. Across the river from the plant is a stand of willow showing age gradation.

A stand of cottonwood further inland is shown in various shades of color caused by the fall coloration stage of the trees and their aspect to the camera.

Photo No. 5196 - Florence Bend, vic Mile 626.0 - There are many varieties of trees planted in the urban part of this photo. Time would not permit each tree to be labeled, however they consist mainly of Maples, Hackberry, Elms, Ash and Conifers. On the riverside of the street are two distinct types with an open area overgrown by sumac.

Data on Metropolitan Utilities District Water Treatment Ponds.

Numbers are as indicated on the overlay.

	Turbidity Jackson Units	pH	Alkalinity	Temp.	Hardness
River	75	8.40	155	58° F.	239
#6	60	8.30			
#3	3.4	9.70			
#2	2.25				
#7	.15		70		156
#1	Empty for repairs				
Clarifiers (round ponds)					
#1	5.9	11.15	62		
#2	Paritally filled, a raft was being floated for painting				
#3	1.6	11.5	62		
#4	Covered with styrofoam for winter protection				

Notes: The blues in ponds 2 and 3 may be caused by a decrease in turbidity and the change in pH. Alum and chlorides are introduced in these ponds which may have a large effect on the imagery color.

Across the river is a band of willow, then an open stand of cottonwood. Beyond the cottonwood is unmown grass.

Photo #5204 - Upper Calhoun Bend vic Mile 641.5 - The trees in this photo are mainly cottonwood with an understory of Canary Grass.

The area in the center of the photo is mowed grass.

Variations in the color of the trees due to the stage of the trees in fall coloration.

Photo #5208 - California Cutoff vic Mile 649.8 - Cottonwood appears pinkish while the willows are red. The cattails vary from tan to brown depending on how they are bent over and their maturity stage.

The lower half of the photo is mainly pasture. In the lower right corner is an area of unmowed ungrazed canary grass. There are Angus and Charolais cattle in the right pasture.

Photo #5212 - California Cutoff vic Mile 650.5 - Soil samples of the channel-like area were taken. Sample 1 was on a southwest facing slope (approx. 25%) 3 feet higher than sample 2 which was from a level area.

Photo #5221 - DeSoto Cutoff vic Mile 644.5 - In the lower right corner is a field of harvested corn surrounding a lake with goose decoys for hunting. Above this are fields of sudan grass, one which is very thin and shows mainly the soil background.

Photo #5229 - DeSoto Cutoff vic Mile 642.6 - The white markings on the river are probably wind waves which may be intensified by specular reflection.

In the middle right side of the photo is an open area of grass with many wheel tracks. The small white objects in this area are beehives. This area was formerly a farmstead and has many planted varieties of trees (Apple, Kentucky Coffeetree, White Oak and Honey Locust).

Photo #5236 - Middle Calhoun Bend vic Mile 639.1 - The yellow areas in the pasture in the lower right corner are Wild Creeping Alfalfa (Medicago setiba) which is probably dead. The large "blotchy red" area is Sweet Clover. The objects which appear as a cut up log are cattle feed bunks.

To the right of the pasture is a cornfield which has been harvested for silage. The image is mainly of the soil.

A water sample was taken at the point indicated on the photo.

DEPARTMENT OF THE ARMY
MISSOURI RIVER DIVISION, CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA 68102

MRD Lab. No. 72/10 & 72/11

24 February 1972

Subject: Chemical Analyses of Water

Project: Missouri River
Intended Use: -
Source of Material: Omaha Sewage Outlet and River Mile 639.2

Submitted by: Chief, Engineering Division, Omaha District
Date Sampled: 19 January 1972, Date Received: 19 January 1972
Method of Test or Specification: APHA Standard Methods

References: Omaha District Request No. M-851 (Civil) dated 21 January 1972.

TEST RESULTS

Tests Made	Test Sample	
MRD Lab. No.	72/10	72/11
Source	South Omaha Sewage Outlet	Missouri River Mile 639.2
Time samples	1400	1030
Air Temperature, F	28	28
Water Temperature, F	32	32
Total Alkalinity as $CaCO_3$, ppm	380	212
Total Hardness as $CaCO_3$, ppm	245	330
Turbidity, Jackson Candle, units	700	700
Chloride (Cl), ppm	156	18
pH value	7.0	7.5
Calcium (Ca), ppm	72	93
Magnesium (Mg), ppm	16	24
Sodium (Na), ppm	210	85
Total Dissolved Solids, ppm	868	696
Sodium Absorption Ratio	5.85	2.03
Potassium (K), ppm	17	8.6
Sulfate (SO_4), ppm	148	283
Nitrate as N, ppm	0.00	0.75
Ammonia (NH_3), ppm	10.2	0.52
Total Phosphorous as PO_4, ppm	14	0.05
Chemical Oxygen Demand (C.O.D.)	338	57
Fecal Coliform, Colonies per 100 ml	750000	5500
Conductivity, Micro-mho per ccm	1605	1005

Submitted by:

E. J. DEKLOTZ
Director, MRD Laboratory

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DEPARTMENT OF THE ARMY
MISSOURI RIVER DIVISION, CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA 68102

MRD Lab. No. 72/12

15 February 1972

Subject: Classification Tests on Soil

Project: Missouri River
Intended Use: California Cutoff
Source of Material: -

Submitted by: Chief, Engineering Division, Omaha District
Date Sampled: 10 January 1972, Date Received: 21 January 1972
Method of Test or Specification: -

References: (A) Omaha District Request No. S-1275 (CIVIL) dated 21 Jan 72.
(B) Unified Soil Classification System, Tech. Memorandum No. 3-357, May 1967.
(C) ER 1110-2-1906.

Visual classification, mechanical analysis, Atterberg limits, and moisture tests have been completed in accordance with Reference (A) on 2 soil samples. The results of the tests are reported on 2 tables attached. Classifications are in accordance with Reference (B).

Submitted by:

E. J. DEKLOTZ
Director, MRD Laboratory

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SOIL CLASSIFICATION RECORD SHEET

PROJECT:	BORING NO:	NRD LAB. NO:
Missouri River, California Cutoff	--	72/12
STATION: --	**RANGE:** --	**SURF. ELEV:** --
DEPTH TO WATER TABLE: --	**BOTTOM OF HOLE:** --	

SAMPLE NO.	DEPTH TO BOTTOM OF SAMPLE	MOIST-URE (%)	PLASTICITY (ATT. LIMITS)		GRADING (Cumulative percents finer)								GRADATION CURVE ANALYSIS					CLASSIFICATION		REMARKS	
					HYD. ANALYSIS		U. S. STANDARD SIEVE SIZES														
					FINES			SAND			GRAVEL										
			L.L.	P.I.	.005mm	.02 mm	200	40	10	4	3/4 in.	3 in.	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	C_u	C_c	Tech. Memo 3-357, May 67			PL
1	0.0	11.0	25	3			67	100										Sandy silt	ML	Note (a)	22
2	0.0	26.2	68	44														Fat clay	CH	Note (b)	24

DEPARTMENT OF THE ARMY
Missouri River Division, Corps of Engineers
Division Laboratory
P. O. Box 103, Downtown Station
Omaha, Nebraska

15 February 1972

Table No. 2--Summary of Classification Tests

Project: Missouri River, California Cutoff MRD Lab. No. 72/12

Note: By visual examination and classification, samples not tested were compared and grouped with typical test samples as described below:

(a) Sandy silt, ML. Gray-brown. Fine sand.] Soft at plastic limit. Similar to Sample 1 (67% fines, 33% sand; LL-25, PI-3).

(b) Fat clay, CH. Gray. Tough at plastic limit. Similar to Sample 2 (LL-68, PI-44).