KIRWIN RESERVOIR
1996 SEDIMENTATION SURVEY

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13. ABSTRACT ***(Maximum 200 words)***

The Bureau of Reclamation (Reclamation) surveyed the underwater area of Kirwin Reservoir in May 1996 to develop a topographic map and compute a present storage-elevation relationship (area-capacity tables). The data were also used to calculate reservoir capacity lost due to sediment accumulation since dam closure on March 7, 1955. The survey used sonic depth recording equipment interfaced with a global positioning system (GPS) that gave continuous sounding positions throughout the underwater portion of the reservoir. Reservoir topography was developed by a computer program using collected and projected underwater data along with above-water topography determined from digitized contour lines from the U.S. Geological Survey quadrangle (USGS quad) maps. The USGS quads of the reservoir area were developed from aerial photography obtained in 1958 and 1971. The new topographic map of Kirwin Reservoir is a combination of digitized contours and 1996 underwater measured topography.

As of May 23, 1996, at top of active conservation elevation (feet) 1,729.25, the surface area was 5,071 acres, the total capacity was 98,154 acre-feet, and the active capacity was 89,639 acre-feet. Since initial filling in March 1955, about 1,278 acre-feet of sediment have accumulated in Kirwin Reservoir below elevation 1729.25, resulting in a 1.28 percent loss in reservoir volume. Since 1955, the estimated average annual rate of reservoir capacity lost to sediment accumulation is 31.1 acre-feet.

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KIRWIN RESERVOIR

1996 SEDIMENTATION SURVEY

by

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Sedimentation and River Hydraulics Group
Water Resources Services
Technical Service Center
Denver, Colorado

August 1997

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U.S. Department of the Interior
Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Tribes.

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INTRODUCTION

Kirwin Dam and Reservoir are principal features of the Solomon Division Kirwin Unit of the Pick-Sloan Missouri Basin Program. Additional unit features are the Kirwin main, north, and south canals, the laterals, and the drainage systems. Kirwin Dam and Reservoir, on the North Fork Solomon River, are located in Phillips County of north central Kansas less than one mile upstream of the town of Kirwin (fig. 1).

Kirwin Dam was constructed between 1952 through 1955 with first storage on March 7, 1955. The dam is a rolled earthfill structure, whose dimensions are (fig. 2):

• Hydraulic height[1]	97.3 feet
• Structural height	169.0 feet
• Top width	30 feet
• Crest length	12,646 feet
• Crest elevation	1,779 feet

Kirwin Dam's spillway, located in the right abutment about 4,000 feet southeast of the old river channel, is an ungated, overflow structure. It consists of a 1,200-foot long, unlined, shallow approach channel with approximate bottom elevation of 1720 and width of 90 feet. This approach channel provides a passageway for flood control releases when the reservoir water surface is below elevation 1750. [2] The spillway crest at elevation 1757.3 is 400 feet wide. The center portion of the spillway crest contains fifteen 5- by 5-foot gated sluiceways which provide flood control releases. Access to the spillway gallery, which contains the controls for operation of the sluiceway gates, is provided on each side of the spillway through the access house. Spillway flows through the sluiceways are confined within a chute and are discharged to a 350-foot wide, 95-foot long stilling basin whose floor elevation is 1658.0 feet. The discharge capacity is 96,000 cubic feet per second (cfs) at reservoir elevation 1,773.0, (Bureau of Reclamation, 1981).

The gated outlet works is a concrete conduit located approximately 150 feet upstream from the centerline of the dam. The outlet works serves as both a river and canal outlet facility. The releases are made from a stilling well located near the downstream side of the dam. The discharge capacity, at reservoir elevation 1,701.0, is 175 cfs to the canal and 100 cfs to the river.

Kirwin Reservoir stores water from the North Fork Solomon River and Bow Creek. The drainage area above the dam is 1,367 square miles, ranging from elevation 1,697.0, top of inactive pool, to greater than elevation 3,450 at its headwaters. The reservoir length at elevation 1,729 is around 13.8 miles, including the 8.7-mile North Fork Solomon River and the 5.1-mile Bow Creek. The average width of the reservoir is 0.6 mile.

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[1]The definition of such terms as "hydraulic height," "structural height," etc. may be found in manuals such as Reclamation's *Design of Small Dams* and *Guide for Preparation of Standing Operating Procedures for Dams and Reservoirs*,or ASCE's *Nomenclature for Hydraulics*.

[2]All elevation levels are shown in feet.

SUMMARY AND CONCLUSIONS

This Reclamation report presents the 1996 results of the first extensive survey of Kirwin Reservoir. The primary objectives of the survey were to gather data needed to:

- develop reservoir topography
- compute area-capacity relationships
- estimate storage depletion caused by sediment deposition since Kirwin Dam closure

The bathymetric survey was run using sonic depth recording equipment interfaced with a differential global positioning system (DGPS) capable of determining sounding locations within the reservoir. The system continuously recorded depth and horizontal coordinates of the survey boat as it was navigated along grid lines covering Kirwin Reservoir. The positioning system provided information to allow the boat operator to maintain course along these grid lines. Water surface elevations recorded by a Reclamation gage during the time of collection were used to convert the sonic depth measurements to true reservoir bottom elevations.

The 1996 underwater surface areas at predetermined contour intervals were generated by a computer graphics program using the underwater collected data. The above-water reservoir contours were digitized from U.S. Geological Survey 7.5 minute quadrangle (USGS quad) maps of Kirwin Reservoir. The new topographic map of Kirwin Reservoir is a combination of the digitized and underwater measured topography. The area and capacity tables were produced by a computer program that uses measured contour surface areas and a curve-fitting technique to compute area and capacity at prescribed elevation increments. The 1996 area and capacity tables were generated using the 1996 measured areas at elevation 1720.0 and less and the original measured areas for elevation 1725.0 and greater.

Table 1 contains a summary of Kirwin Reservoir's watershed characteristics for the 1996 survey. The 1996 survey determined that the reservoir has a storage capacity of 98,154 acre-feet and a surface area of 5,071 acres at reservoir elevation 1,729.25 feet. Since closure in 1955, the reservoir has accumulated a sediment volume of 1,278 acre-feet below reservoir elevation 1,729.25. This volume represents a 1.28 percent loss in capacity and an average annual loss of 31.1 acre-feet.

RESERVOIR OPERATIONS

Kirwin Reservoir is primarily an irrigation and flood protection facility (the following values are from May 1996 area-capacity tables):

- 198,467 acre-feet of surcharge storage between elevations 1,757.3 and 1,773.0.
- 215,136 acre-feet of flood control between elevations 1,729.25 and 1,757.3.
- 89,639 acre-feet of active conservation storage between elevations 1,697.0 and 1,729.25.
- 3,546 acre-feet of inactive storage between elevations 1,693.0 and 1,697.0.
- 4,969 acre-feet of dead storage below elevation 1,693.0.

The Kirwin Reservoir inflow and end-of-month stage records in table 1 show the annual (January through December) inflow and fluctuation for the operation period March 1955 through May 1996. The average annual reservoir inflow for this operation period was 34,338 acre-feet. Figure 3 show the extreme storage fluctuations of Kirwin Reservoir when in 1957 it ranged from elevation 1,694.8 to 1,729.5 to the maximum elevation on record, elevation 1,737.0, on June 2, 1995. The records also show the reservoir has operated in the inactive zones, elevation 1697.0 and below, during the years of 1978, 1980 through 1985, and 1990 through 1992, and at a low storage content, below elevation 1710, between the years 1975 through 1993. Prior to dam closure, records for 1920 through 1954 calculated a mean annual flow of 56,100 acre-feet at the dam

HYDROGRAPHIC SURVEY EQUIPMENT AND METHOD

The hydrographic survey equipment was mounted in the cabin of a 24-foot tri-hull aluminum vessel equipped with twin in-board motors. The hydrographic system contained on the survey vessel consisted of a global positioning system (GPS) receiver with a built-in radio and an omnidirectional antenna, a depth sounder, a helmsman display for navigation, a plotter, a computer, and hydrographic system software for collecting underwater data. Power to the equipment was supplied by an on-board generator.

The shore equipment included a second GPS receiver with a built-in radio and an omnidirectional antenna. The GPS receiver and antenna were mounted on a survey tripod over a known datum point. The power for the shore unit was provided by a 12-volt battery.

GPS Technology and Equipment

The positioning system used at Kirwin Reservoir was Navigation Satellite Timing and Ranging (NAVSTAR) GPS; an all-weather, radio-based, satellite navigation system that enables users to accurately determine three-dimensional position. The NAVSTAR system's primary mission is to provide passive global positioning and navigation for land, air, and sea based strategic and tactical forces and is operated and maintained by the Department of Defense (DOD). The GPS receiver measures the distances between the satellites and itself and determines the receiver's position from intersections of the multiple range vectors. Distances are determined by accurately measuring the time a signal pulse takes to travel from the satellite to the receiver.

The NAVSTAR system consists of three segments:

- The space segment is a network of 24 satellites maintained in precise orbit about 10,900 nautical miles above the earth, each completing an orbit every 12 hours.

- The ground control segment tracks the satellites, determining their precise orbits. Periodically, the ground control segment transmits correction and other system data to all the satellites, and the data are then retransmitted to the user segment.

- The user segment includes the GPS receivers which measure the broadcasts from the satellites and calculate the position of the receivers.

The GPS receivers use the satellites as reference points for triangulating their position on earth. The position is calculated from distance measurements to the satellites that are determined by how long a radio signal takes to reach the receiver from the satellite. To calculate the receiver's position on earth, the satellite distance and the satellite's position in space are needed. The satellites transmit signals to the GPS receivers for distance measurements along with the data messages about their exact orbital location and operational status. The satellites transmit two "L" band frequencies (called L1 and L2) for the distance measurement signal. At least four satellite observations are required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time; the time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers (for hydrographic surveying the altitude, Kirwin's water surface elevation parameter was known, which realistically meant only three satellite observations were needed to track the survey vessel; during the Kirwin Reservoir survey, the best 6 available satellites were used for position calculations).

The GPS receiver's absolute position is not as accurate as it appears in theory because of the function of range measurement precision and the geometric position of the satellites. Precision is affected by several factors----time, because of the clock differences, and atmospheric delays caused by the effect on the radio signal of the ionosphere. Geometric dilution of precision (GDOP) describes the geometrical uncertainty and is a function of the relative geometry of the satellites and the user. Generally, the closer together in angle two satellites are from the receiver, the greater the GDOP. GDOP is broken into components: position dilution of precision (x,y,z) (PDOP) and horizontal dilution of precision (x,y) (HDOP). The components are based only on the geometry of the satellites. The PDOP and HDOP were monitored during the Kirwin Reservoir Survey, and for the majority of the time they were less than 3, which is within the acceptable limits of horizontal accuracy for Class 1 and 2 level surveys (Corps of Engineers, 1991).

An additional and larger error source in GPS collection is caused by false signal projection, called selective availability (S/A). The DOD implements S/A to discourage the use of the satellite system as a guidance tool by hostile forces. Positions determined by a single receiver when S/A is active can have errors of up to 100 meters.

A method of collection to resolve or cancel the inherent errors of GPS (satellite position or S/A, clock differences, atmospheric delay, etc.) is called differential GPS (DGPS). DGPS was used during the Kirwin Reservoir survey to determine positions of the moving survey vessel in real time. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties. Differential positioning is not concerned with the absolute position of each unit but with the relative difference between the positions of two units, which are simultaneously observing the same satellites. The inherent errors are mostly canceled because the satellite transmission is essentially the same at both receivers.

At a known geographical benchmark, one GPS receiver is programmed with the known coordinates and stationed over the geographical benchmark. This receiver, known as the master or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the necessary corrections or differences are transmitted to the mobile GPS receiver on the survey vessel. For the Kirwin Reservoir, position corrections were determined by the master receiver and transmitted via an ultra-high frequency (UHF) radio link every 3 seconds to the survey vessel mobile receiver. The survey vessel's GPS receiver used the corrections along with the satellite information it received to determine the vessel's differential location. Using DGPS resulted in positional accuracies of 1 to 2 meters for the moving vessel compared to positional accuracies of 100 meters with a single receiver.

The Technical Service Center (TSC) mobile and reference GPS units are identical in construction and consist of a 6-channel L1 coarse acquisition (C/A) code continuous parallel tracking receiver, an internal modem, and a UHF radio transceiver. The differential corrections from the reference station to the mobile station are transmitted using the industry standard Radio Technical Commission for Maritime Services (RCTM) message protocol via the UHF radio link. The programming to the mobile or reference GPS unit is accomplished by entering necessary information via a notebook computer. The TSC's GPS system has the capability of establishing or confirming the land base control points by using notebook computers for logging data and post-processing software. The GPS collection system has the capability of collecting the data in 1927 or 1983 NAD (North American Datums) in the surveyed area's state plane coordinate system's zone. For Kirwin Reservoir, the data were collected in the Kansas's 1927 NAD north state plane zone.

Survey Method and Equipment

The Kirwin Reservoir hydrographic survey was conducted on May 20 through May 23, 1996 at reservoir water surface elevation 1,731.2. The bathymetric survey was run using sonic depth recording equipment interfaced with a DGPS capable of determining sounding locations within the reservoir. The survey system software continuously recorded reservoir depths and horizontal coordinates as the survey boat moved across close-spaced grid lines covering the reservoir area. Most of the transects (grid lines) were run primarily in a north-south direction. Data were also collected along the shore as the boat traversed to the next transect and as it maneuvered in the open areas between the trees. Thick tree growth within the reservoir prevented the boat from surveying some areas, such as those near the shoreline, shallow water areas in the main body, and coves or inlets along the banks. In some areas the growth was so thick the survey vessel ended the collection in 18 to 20 feet of water or at approximately bottom elevation 1712. This included large areas of the reservoir around Bow Creek and the large cove areas of the reservoir that exist at reservoir elevation 1720 and above. Figure 4 illustrates the reservoir area covered by the 1996 underwater survey versus the contours digitized from the USGS quad maps (the light outside dashed line represents the elevation 1729 contour and the heavy inside dashed line represents the elevation 1720 contour). The survey vessel's guidance system gave directions to the boat operator to assist in maintaining course along these predetermined lines. During each run, the depth and position data were recorded on the notebook computer hard drive for subsequent processing by TSC personnel. The underwater data set includes 24,328 data points. A graph plotter was used in the field to track the boat and ensure adequate coverage during the collection process. The water surface elevation recorded by a Reclamation gage during the time of collection was used to convert the sonic depth measurements to true lake bottom elevations.

For stationing the master GPS unit, there were no known benchmarks or datums that overlooked the reservoir. For the underwater collection the hydrographic survey crew established a datum using the hydrographic GPS units and software. In establishing the control for the reference datum the second order National Geodetic Survey benchmark (Kirwin), located just north of the reservoir, was used. The control was brought in from the Kirwin benchmark to a pipe on the dam marked 75+99.5, 17.5US. This method calculated 1927 NAD state plane coordinates of North 488,248.337 and East 1,681,399.747 at this location. The shore-based master GPS unit, which transmits the correction information to the mobile GPS unit on the survey vessel, was stationed at this new datum site throughout the survey. This location was chosen because it was accessible and overlooked the reservoir. The location allowed for good radio transmission of the differential corrections to the mobile survey vessel throughout the reservoir survey. During post processing of the collected data, the few collected points without differential correction were removed.

The underwater data were collected by a depth sounder which was calibrated by lowering a deflector plate below the boat by cables with known depths marked by beads. The depth sounder was calibrated by adjusting the speed of sound, which can vary with density, salinity, temperature, turbidity, and other conditions. The collected data were digitally transmitted to the computer collection system via a RS-232 port. The depth sounder also produces an analog hard copy chart of the measured depths. These graphed analog charts were printed for all survey lines as the data were collected and recorded by the computer. The charts were analyzed during post-processing, and when the analog charted depths indicated a difference from the recorded computer bottom depths, the computer data files were modified.

RESERVOIR AREA AND CAPACITY

Topography Development

The topography of Kirwin Reservoir was developed from the 1996 collected underwater data and from the USGS quad maps. The upper contours of Kirwin Reservoir were developed by digitizing the contour lines of elevation 1,720.0, 1729.0, 1730.0, 1740.0, and 1757.0, from the USGS quad maps that covered the Kirwin Reservoir area. The USGS quad maps were developed from aerial photography dated 1958 and 1971. ARC/INFO V7.0.2 geographic information system software was used to digitize the USGS quad contours. The digitized contours were transformed to Kansas' NAD 1927 north state plane coordinates using the ARC/INFO PROJECT command.

Following are the ARC/INFO resulting digitized areas from the USGS quads versus the original reported areas reported in March of 1955:

(1) USGS digitized 1720 contour area was 3,637 acres, or 99.8% of the original 3,757-acre area
(2) USGS digitized 1729 contour area was 4,973 acres, or 98.9% of the original 5,030-acre area
(3) USGS digitized 1730 contour area was 5,289 acres, or 101.9% of the original 5,190-acre area
(4) USGS digitized 1740 contour area was 6,964 acres, or 100% of the original 6,965-acre area
(5) USGS digitized 1757 contour area was 10,257 acres, or 97% of the original 10,550-acre area.

It is assumed that the area differences are due to the quad scale (one inch equals two thousand feet) and the different methods of digitizing the contour areas. The underwater topography on the USGS quad maps, elevation 1720 and below, was noted to be from a Reclamation map dated 1952.

The elevation 1,729.0 contour digitized from USGS quad maps was used to perform a clip of the Kirwin Reservoir triangular irregular network (TIN) such that interpolation was not allowed to occur outside the 1,729.0 contour. This complete contour was selected since it was the elevation that most nearly enclosed the 1996 underwater data collected at reservoir elevation 1731.2. This clip was performed using the hardclip option of the ARC/INFO CREATETIN command. Using ARCEDIT, the underwater collected data and the digitized 1720 and 1729 contours from the USGS quad maps were plotted (figure 4). The plot found that the majority of the underwater data occurred completely within the elevation 1729 clip and required only minor adjustments to enclose all collected data.

For developing the 1996 Kirwin Reservoir contour map and calculating the surface areas, data information was needed for the underwater reservoir areas not surveyed. Using ARCEDIT, the digitized elevation 1720 USGS quad contour and the 1996 underwater collected data layers were overlaid or plotted on-screen. Using ARCEDIT, elevation points were added to develop reservoir contours and to calculate surface areas for elevation 1720 and below. Location of these points was determined by using the 1720 contour as the pattern and the elevation information of the individual 1996 collected data points. The majority of the additional points used the 1720 contour pattern to determine where they were to be placed assuming no change, but when the 1996 collected data indicated that a change had occurred, the placement of the data points reflected the underwater reservoir conditions. In the cove areas of the reservoir additional points were also placed to develop the contours below elevation 1720. Figure 5 has the resulting contours for elevation 1710 and 1720 along with the digitized 1720 and 1729 contours, 1996 collected underwater data, and additional data points.

Contours for elevations 1720.0 and below were computed from the developed underwater data using the TIN surface modeling package within ARC/INFO. The underwater survey data were collected in the Kansas north zone state plane coordinates in NAD 1927 (a TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x,y coordinates and z values). TIN was designed to deal with continuous data such as elevations. The TIN software uses a method known as Delaunay's criteria for triangulation. Triangles are formed between all data points including all boundary points. This method preserves all collected survey points. The method requires that a circle drawn through the three nodes of a triangle will contain no other point, meaning that sample points are connected to their nearest neighbors to form triangles using all collected data. Elevation contours are then interpolated along the triangle elements. The TIN method is discussed in great detail in the ARC/INFO V7.0.2 *Users Documentation.*

In creating the TIN, points that fell within a set distance of each other were weeded out to eliminate flat triangular elements (flat triangles occur where all three points making up a triangle have the same elevation). Elimination of redundant points helped to improve the performance of the contouring process and helped create more continuous contours in the lower elevations of the reservoir.

The linear interpolation option of the ARC/INFO TINCONTOUR command was used to interpolate contours from the Kirwin Reservoir TIN. In addition, the contours were generalized by weeding out vertices along the contours. This generalization process improved the presentability of the resulting contours by removing very small variations in the contour lines. This generalization had little bearing on the computation of surface areas and volumes for Kirwin Reservoir. The contour topography at 2-foot intervals is presented on figure 6, drawing number 371-D-364.

Development of 1996 Contour Areas

The 1996 contour surface areas for Kirwin Reservoir were computed at 2-foot increments, from elevation 1,680.4 to 1,720.0, using the Kirwin Reservoir TIN discussed above. The 1996 survey measured the minimum reservoir elevation at 1,680.4 feet. These calculations were performed using the ARC/INFO VOLUME command. This command computes areas at user specified elevations directly from the TIN and takes into consideration all regions of equal elevation. As discussed in the survey method and equipment section, large areas of the underwater portion of the reservoir were not surveyed due to the thick tree growth. This accounts for the fact that the 1996 areas were only computed for elevation 1,720.0 and below. Due to the lack of 1996 survey data the final 1996 area computations assumed no change in surface area from elevation 1725 and above.

1996 Storage Capacity

The storage-elevation relationships based on the measured surface areas were developed using the area-capacity computer program ACAP85 (Bureau of Reclamation, 1985). Surface areas at 2-foot contour intervals from minimum reservoir elevation 1,680.4 to elevation 1,720.0 and the original surface areas at 5-foot contour intervals from elevation 1,725.0 to 1,770.0 and 1,773.0 were used as the control parameters for computing the Kirwin Reservoir capacity. The program can compute an area and capacity at elevation increments 0.01- to 1.0-foot by linear interpolation between the given contour surface areas. The program begins by testing the initial capacity equation over successive intervals to ensure that the equation fits within an allowable error limit, which was set at 0.000001 for Kirwin Reservoir. This capacity equation is then used over the full range of intervals fitting within this allowable error limit. For the first interval at which the initial allowable error limit is exceeded, a new capacity equation (integrated from basic area curve over that interval) tests the fit until it also exceeds the error limit. Thus, the capacity curve is defined by a series of curves, each fitting a certain region of data. Final area equations are derived by differentiating the capacity equations, which are of second order polynomial form:

$$y = a_1 + a_2x + a_3x^2$$

where:

y = capacity
x = elevation above a reference base
a_1 = intercept
a_2 and a_3 = coefficients

Results of the 1996 Kirwin Reservoir area and capacity computations are listed in table 1 and columns (4) and (5) of table 2. Listed in columns (2) and (3) of table 2 are the original surface areas and recomputed capacity values. A separate set of 1996 area and capacity tables has been published for the 0.01-, 0.1-, and 1-foot elevation increments (Bureau of Reclamation 1996). A description of the computations and coefficients output from the ACAP85 program is included with these tables. Both the original and 1996 area-capacity curves are plotted on figure 7. As of May 1996, at elevation 1,729.25, the surface area was 5,071 acres with a total capacity of 98,154 acre-feet and an active capacity of 89,639 acre-feet.

SEDIMENT ANALYSES

Sediments have accumulated in Kirwin Reservoir to a total volume of 1,278 acre-feet since dam closure in March 1955. This volume was calculated at top of reservoir water supply elevation 1,729.25. It must be noted that the 1996 underwater survey was conducted at water surface elevation 1731.2, but that the final product relied on the original measured surface areas at elevation 1725.0 and greater for computing the 1996 reservoir area and capacity tables. Column 6 of table 2 gives the measured sediment volume by elevation, and the area curve on figure 7 illustrates the resulting measured surface areas and calculated capacities. This table and figure illustrate that the majority of the sediment deposit is in the lower elevations of the reservoir. The average annual rate of sediment deposition between closure and May 1996 (41.1 years) was 31.1 acre-feet per year. The storage loss in terms of percent of original storage capacity was 1.28 percent. Tables 1 and 2 contain the Kirwin Reservoir sediment accumulation and water storage data based on the 1996 resurvey.

The original 50-year sediment deposition estimate was 10,750 acre-feet, which was projected to settle below elevation 1729.25. The 1996 study found very little sediment accumulation, (1,278 acre-feet) within Kirwin Reservoir considering the size of the drainage basin and the large projected estimate. Prior to reservoir impoundment, a sediment range line network was established for monitoring sediment inflow. A review of the range lines that were resurveyed found little change except in the original river channels. The collected information indicated that there was some sediment inflow, but that there was not enough information for conclusive results. The computed sediment accumulation was very similar to that found in Webster Reservoir, which is located southwest of Kirwin Reservoir on the South Fork of the Solomon River.

Table 1 gives some clues as to why the sediment accumulation is lower than original projections. The mean annual runoff of the 1,367-square-mile-basin, for the 41.1 year period of record, was 34,338 acre-feet, or only 0.47 inches. Prior to dam closure, the records for 1920 through 1954 calculated a mean annual flow of 56,100 acre-feet at the dam. Lovewell Reservoir, located on White Rock Creek approximately 85 miles northeast of Kirwin Reservoir, had a calculated mean annual runoff of 3.4 inches. Kirwin Reservoir drainage basin has a much lower runoff, reflecting the lower sediment contribution. Another factor is illustrated in item 45 of table 1 and on figure 3, which depicts the range in reservoir operation. The reservoir has operated at full conditions in a few years--above elevation 1729.25--but in many more years the reservoir has operated at low reservoir content, below elevation 1710, and there have even been years when it operated in the inactive zone, below elevation 1697. These low reservoir operating conditions probably have caused some of the upper-reservoir accumulated sediments to move towards the dam, and some of this accumulated material is assumed to eventually be flushed downstream through the outlet works.

The measured surface areas, column 2 and 4, and the calculated sediment volume, column 6 of table 2, along with the area curves of figure 7 show some interesting results. The table shows the 1996 surface areas at less than the original areas below elevation 1705 due to sediment accumulation and then show 1996 surface areas larger than the original areas at elevations 1710 and 1715. The resulting reservoir capacity loss due to sediment distribution is a maximum of 1,741 acre-feet at elevation 1710 and a minimum of 1,025 acre-feet at elevation 1720. These results are explained by comparing the new reservoir topography at elevation 1710 with the original topography on the USGS quad map and by examining past reservoir operations. Since dam closure, the reservoir has operated at elevation 1710 or below around 40 percent of the time. Comparing the original and the 1996 topography, it appears that a second inflow channel has developed just above the confluence of Bow Creek and the Solomon River. This second channel explains why the 1996 surface areas--approximately elevation 1710--are larger than the original areas. It is assumed this original reservoir bottom material was eroded downstream by river inflows during low reservoir elevations, and deposited downstream near the dam. For determining the sediment contribution from the drainage area over the 41.1 years of reservoir operation, the value at reservoir elevation 1729.25--1,278 acre-feet--was used.

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RESERVOIR SEDIMENT DATA SUMMARY

Kirwin Reservoir
NAME OF RESERVOIR

1
DATA SHEET NO.

DAM	1. OWNER Bureau of Reclamation	2. STREAM North Fork Solomon River	3. STATE Kansas
	4. SEC. 33 TWP. 4S RANGE 16W	5. NEAREST P.O. Kirwin	6. COUNTY Phillips
	7. LAT 39° 39' 49" LONG 99° 07' 29"	8. TOP OF DAM ELEVATION 1,779.0	9. SPILLWAY CREST EL. 1757.3

RESERVOIR	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, AC	13. ORIGINAL CAPACITY, AF	14. GROSS STORAGE ACRE- FEET	15. DATE STORAGE BEGAN
	a. SURCHARGE	1,773.0	14,660	198,470	513,020	
	b. FLOOD CONTROL	1,757.3	10,640	215,115	314,550	3/07/55
	c. POWER					
	d. WATER SUPPLY	1,729.25	5,071	89,650	99,435	16. DATE NORMAL OPERATION BEGAN
	e. IRRIGATION					
	f. INACTIVE	1,697.0	1,010	3,400	9,785	
	g. DEAD	1,693.0	720	6,385	6,385	3/55
	17. LENGTH OF RESERVOIR 13.8[1] MILES			AVG. WIDTH OF RESERVOIR 0.6 MILES		

BASIN	18. TOTAL DRAINAGE AREA 1,367 SQUARE MILES	22. MEAN ANNUAL PRECIPITATION 23.7[2] INCHES
	19. NET SEDIMENT CONTRIBUTING AREA 1,367 SQUARE MILES	23. MEAN ANNUAL RUNOFF 0.47[3] INCHES
	20. LENGTH MILES AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF 34,338[4] ACRE-FEET
	21. MAX. ELEVATION 3,450 MIN. ELEVATION 1,697	25. ANNUAL TEMP. MEAN 54°F RANGE -22°F to 112°F[5]

SURVEY DATA

26. DATE OF SURVEY	27. PER.	28. ACCL.	29. TYPE OF SURVEY	30. NO. OF RANGES OR	31. SURFACE AREA, AC.	32. CAPACITY ACRE-FEET	33. C/I RATIO AF/AF
3/07/55			Contour (D)	5-ft	5,071[6]	99,432[6]	2.90
5/23/96	41.1	41.1	Contour (D)	2-ft	5,071[7]	98,154[7]	2.86

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIP.	35. PERIOD WATER INFLOW, ACRE FEET			WATER INFLOW TO DATE, AF	
		a. MEAN ANN.	b. MAX. ANN.	c. TOTAL	a. MEAN ANN.	b. TOTAL
5/23/96	23.7[2]	34,338[4]	129,300	1,411,300	34,338	1,411,300

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SEDIMENT DEPOSITS TO DATE, AF		
	a. TOTAL	b. AV. ANN.	c. /MI.²-YR.	a. TOTAL	b. AV. ANNUAL	c. /MI.²-YR.
5/23/96	1,278[8]	31.1	.02	1,278	31.1	.02

26. DATE OF SURVEY	39. AV. DRY WT. (#/FT³)	40. SED. DEP. TONS/MI.²-YR.		41. STORAGE LOSS, PCT.		42. SEDIMENT	
		a. PERIOD	b. TOTAL TO	a. AV.	b. TOTAL TO	a.	b.
5/23/96				.031[8]	1.28[8]		

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW ELEVATION .											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-105	105-110	110-115	115-120	120-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

Table 1. - Reservoir sediment data summary (page 1 of 2).

45. RANGE IN RESERVOIR OPERATION[9]

YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF	YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AF
1955	1,693.2	1,675.6	21,300	1956	1,698.1	1,692.5	7,600
1957	1,729.5	1,694.8	123,100	1958	1,728.2	1,725.9	28,200
1959	1,727.9	1,724.0	23,300	1960	1,731.6	1,725.1	60,900
1961	1,732.1	1,725.4	60,900	1962	1,730.5	1,726.4	52,800
1963	1,728.8	1,724.9	33,500	1964	1,726.8	1,719.8	16,300
1965	1,730.4	1,719.7	82,000	1966	1,729.2	1,723.8	30,300
1967	1,726.2	1,723.6	29,900	1968	1,727.5	1,722.2	51,800
1969	1,732.0	1,727.4	69,300	1970	1,729.8	1,723.9	25,500
1971	1,725.8	1,718.6	19,800	1972	1,719.6	1,713.4	16,000
1973	1,718.0	1,710.8	30,900	1974	1,718.4	1,709.9	23,700
1975	1,722.4	1,710.5	57,200	1976	1,719.8	1,707.8	12,500
1977	1,711.6	1,700.7	20,000	1978	1,706.8	1,696.2	15,700
1979	1,708.3	1,699.7	23,800	1980	1,707.0	1,695.6	9,900
1981	1,697.5	1,695.4	3,900	1982	1,702.1	1,696.0	9,000
1983	1,705.5	1,696.8	9,700	1984	1,706.1	1,696.8	15,500
1985	1,706.3	1,697.0	17,200	1986	1,711.5	1,702.1	20,400
1987	1,715.3	1,704.7	36,300	1988	1,714.2	1,703.6	11,100
1989	1,707.4	1,700.1	12,200	1990	1,707.0	1,695.8	12,400
1991	1,697.8	1,695.5	3,800	1992	1,704.9	1,695.7	15,600
1993	1,735.1	1,704.9	129,300	1994	1,734.7	1,728.1	58,700
1995	1,737.1	1,729.0	91,100	1996	1,731.2	1,730.2	18,900

46. ELEVATION - AREA - CAPACITY DATA FOR **1996 CAPACITY**[10]

ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY
1680.4	0	0	1681	1.4	0	1682	31.8	17
1684	262.6	311	1686	384.1	958	1688	491.9	1,834
1690	601.6	2,928	1692	704.8	4,234	1693	(765)	4,969
1694	825.0	5,764	1696	948.7	7,538	1697	(1,006)	8,515
1698	1,063.3	9,550	1700	1,207.3	11,820	1702	1,320.0	14,347
1704	1,471.6	17,139	1706	1,612.2	20,223	1708	1,865.4	23,700
1710	2,186.4	27,752	1712	2,541.8	32,480	1714	2,913.9	37,936
1716	3,222.2	44,072	1718	3,479.1	50,774	1720	3,655.4	57,908
1725	4,396	78,037	1729.25	5,071	98,154	1730	5,190	102,002
1735	6,140	130,327	1740	6,965	163,089	1745	7,860	200,152
1750	8,980	242,252	1755	9,960	289,602	1760	11,435	343,089
1765	12,510	402,952	1770	13,885	468,939	1773	14,660	511,757

47. REMARKS AND REFERENCES

[1] Length at reservoir elevation 1729 from USGS quad maps of reservoir. North Fork Solomon River = 8.7 miles and Bow Creek = 5.1 miles.

[2] Average precipitation at Kirwin Dam, 1955-1996.

[3] Calculated using mean annual runoff value of 34,338 AF, item 24.

[4] Computed annual inflows from North Fork Solomon River and Bow Creek, 3/55 through 5/96 (by calendar year).

[5] Bureau of Reclamation Project Data Book, 1981.

[6] Original surface area and capacity at elevation 1,729.25, top of water supply. Original capacity recomputed by Reclamation's ACAP program using original surface areas.

[7] Surface area and capacity at elevation 1729.25 computed by ACAP program using 1996 and original surface areas. 1996 surveyed only underwater portion of reservoir below elevation 1731.2. Due to heavy vegetation adequate data collected at elevation 1720 and below. During the 1996 underwater survey reservoir was at elevation 1731.2. Elevation 1725.0 and above from original measured areas.

[8] Total capacity loss calculated by comparing original recomputed capacity and 1996 capacity at reservoir elevation 1729.25, top of water supply elevation.

[9] Maximum and minimum elevations and inflow values in acre-feet by calendar year, from 1955 through 5/96.

[10] Capacities computed by ACAP computer program. Areas at elevation 1725 and above from original survey.

48. AGENCY MAKING SURVEY Bureau of Reclamation

49. AGENCY SUPPLYING DATA Bureau of Reclamation | DATE August 1997

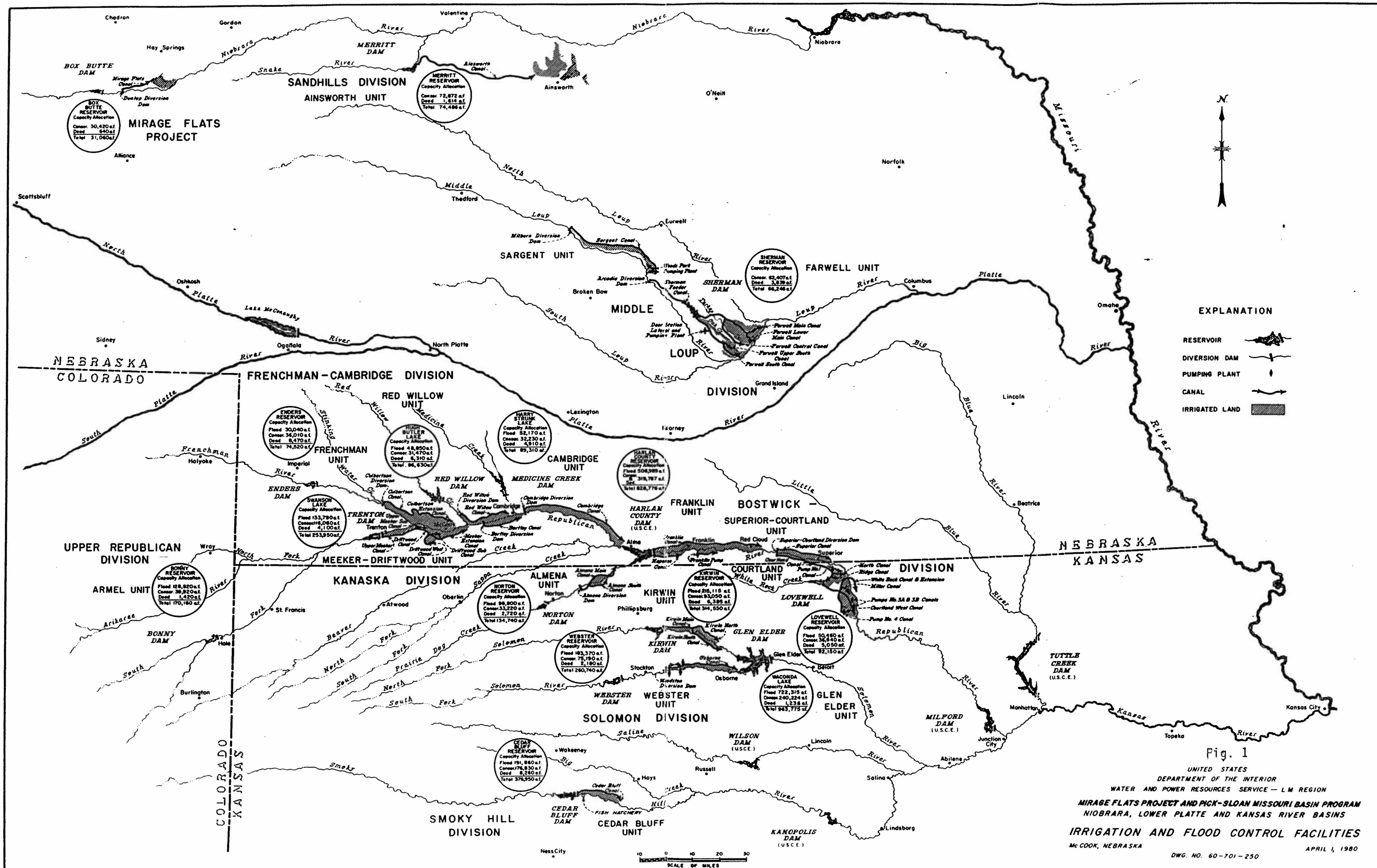
Table 1. - Reservoir sediment data summary (page 2 of 2).

Table 2 - Summary of 1996 survey results.

(1) Elevation (feet)	(2) Original Area (acres)	(3) Original Capacity (acre-feet)	(4) 1996 Area (acres)	(5) 1996 Capacity (acre-feet)	(6) Measured Sediment Volume (acre-feet)	(7) Percent Measured Sediment	(8) Percent Reservoir Depth
1773.0	14,660	513,035	14,660	511,757	-	-	100.0
1770.0	13,885	470,218	13,885	468,939	-	-	97.3
1765.0	12,510	404,230	12,510	402,952	-	-	92.9
1760.0	11,435	344,368	11,435	343,089	-	-	88.5
1757.3	10,639	314,568	10,639	313,290	-	-	86.1
1755.0	9,960	290,880	9,960	289,602	-	-	84.1
1750.0	8,980	243,530	8,980	242,252	-	-	79.6
1745.0	7,860	201,430	7,860	200,152	-	-	75.2
1740.0	6,965	164,368	6,965	163,089	-	-	70.8
1735.0	6,140	131,605	6,140	130,327	-	-	66.4
1730.0	5,190	103,280	5,190	102,002	-	-	61.9
1729.25	5,071	99,432	5,071	98,154	1,278	100.0	61.3
1725.0	4,396	79,315	4,396	78,037	1,278	100.0	61.3
1720.0	3,757	58,933	3,655	57,908	1,025	80.2	53.1
1715.0	2,974	42,105	3,068	40,927	1,178	92.2	48.7
1710.0	2,071	29,493	2,186	27,752	1,741	136.2	44.2
1705.0	1,585	20,353	1,542	18,646	1,707	133.6	39.8
1700.0	1,273	13,208	1,207	11,820	1,388	108.6	35.4
1695.0	834	7,940	887	6,620	1,320	103.3	31.0
1693.0	720	6,386	765	4,969	1,417	110.9	29.2
1690.0	549	4,483	602	2,928	1,555	121.7	26.5
1685.0	371	2,183	323	604	1,579	123.6	22.1
1680.0	200	755	0	0	755	59.1	17.7
1675.0	39	158	0	0	158	12.4	13.3
1670.0	7	43	0	0	43	3.4	8.8
1665.0	5	13	0	0	13	1.0	4.4
1660.0	0	0	0	0	0	0.0	0.0

(1) Elevation of reservoir water surface.
(2) Original reservoir surface area.
(3) Original calculated reservoir capacity computed using ACAP from original measured surface areas.
(4) Reservoir surface area from 1996 survey for elevations 1720 and below. Areas for elevation 1725 and greater are original measured areas.
(5) 1996 calculated reservoir capacity computed using ACAP, from 1996 surface areas.
(6) Measured sediment volume = column (3) - column (5).
(7) Measured sediment expressed in percentage of total sediment 1,278 acre-feet at elevation 1729.25.
(8) Depth of reservoir expressed in percentage of total depth (113 feet).

Note: The 1996 survey developed updated underwater reservoir topography from elevation 1720.0 and below. Surface areas at elevation 1725 and above are original measured areas. Reservoir elevation was at 1731.2 during 1996 underwater survey.


EXPLANATION
RESERVOIR
DIVERSION DAM
PUMPING PLANT
CANAL
IRRIGATED LAND
MIRAGE FLATS PROJECT
BOX BUTTE DAM
BOX BUTTE RESERVOIR Capacity Allocation Conser. 30,420 a.f. Dead 640 a.f. Total 31,060 a.f.
SANDHILLS DIVISION
AINSWORTH UNIT
MERRITT DAM
MERRITT RESERVOIR Capacity Allocation Conser. 72,872 a.f. Dead 1,614 a.f. Total 74,486 a.f.
SARGENT UNIT
FARWELL UNIT
SHERMAN DAM
SHERMAN RESERVOIR Capacity Allocation Conser. 62,407 a.f. Dead 3,839 a.f. Total 66,246 a.f.
MIDDLE LOUP DIVISION
FRENCHMAN-CAMBRIDGE DIVISION
RED WILLOW UNIT
FRENCHMAN UNIT
CAMBRIDGE UNIT
MEDICINE CREEK DAM
RED WILLOW DAM
ENDERS DAM
TRENTON DAM
MEEKER-DRIFTWOOD UNIT
UPPER REPUBLICAN DIVISION
ARMEL UNIT
BONNY DAM
KANASKA DIVISION
ALMENA UNIT
NORTON DAM
HARLAN COUNTY DAM (U.S.C.E.)
FRANKLIN UNIT
BOSTWICK - SUPERIOR-COURTLAND UNIT
COURTLAND UNIT
DIVISION
KIRWIN UNIT
KIRWIN DAM
LOVEWELL DAM
GLEN ELDER DAM
GLEN ELDER UNIT
WEBSTER DAM
WEBSTER UNIT
SOLOMON DIVISION
WILSON DAM (U.S.C.E.)
MILFORD DAM (U.S.C.E.)
TUTTLE CREEK DAM (U.S.C.E.)
SMOKY HILL DIVISION
CEDAR BLUFF DAM
CEDAR BLUFF UNIT
KANOPOLIS DAM (U.S.C.E.)
NEBRASKA
COLORADO
KANSAS
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
WATER AND POWER RESOURCES SERVICE — L M REGION
MIRAGE FLATS PROJECT AND PICK-SLOAN MISSOURI BASIN PROGRAM
NIOBRARA, LOWER PLATTE AND KANSAS RIVER BASINS
IRRIGATION AND FLOOD CONTROL FACILITIES
Mc COOK, NEBRASKA
APRIL 1, 1980
DWG. NO. 60-701-250
GPO 855-627
Fig. 1

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Kirwin Reservoir

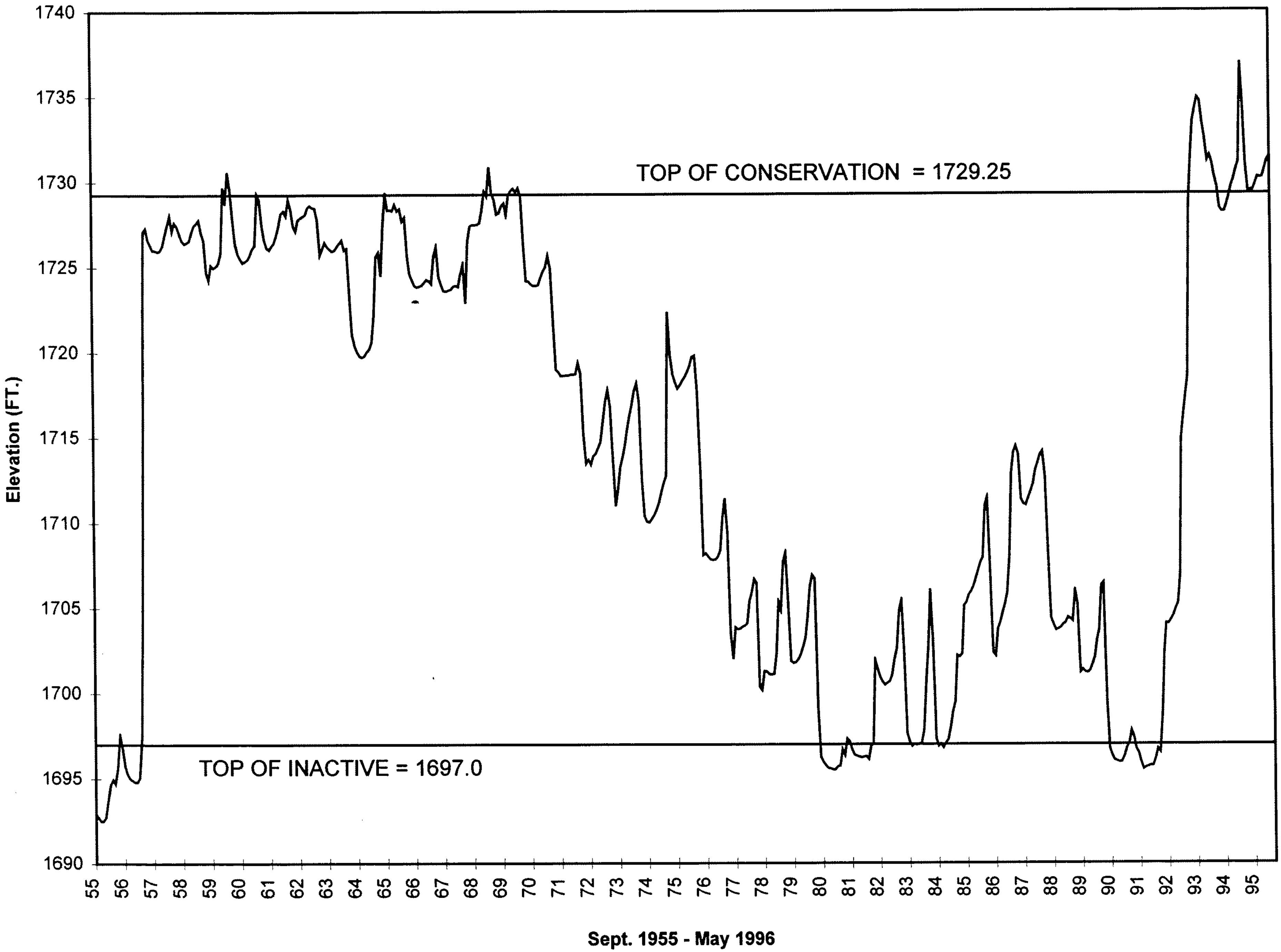


Fig. 3


N
W
E
S
Feet
0 1000 2000 3000
UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
SOLOMON DIVISION
KIRWIN - KANSAS
KIRWIN RESERVOIR
1996 UNDERWATER COLLECTED DATA
DRAWN BY ______ TECHNICAL APPROVAL ______
CHECKED BY ______ APPROVED ______
Group Manager
Denver, Colorado APR 10, 1997

Fig. 4

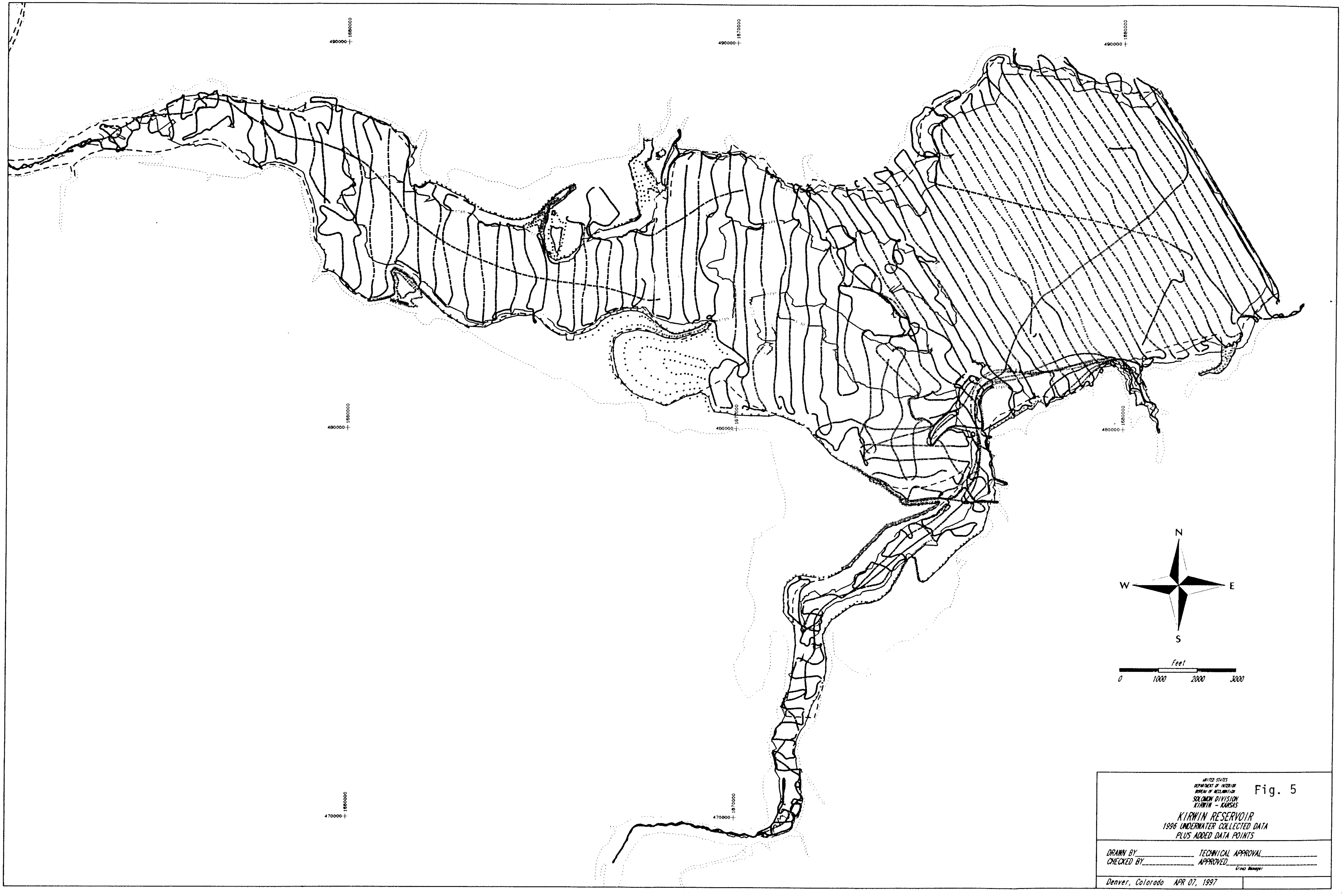
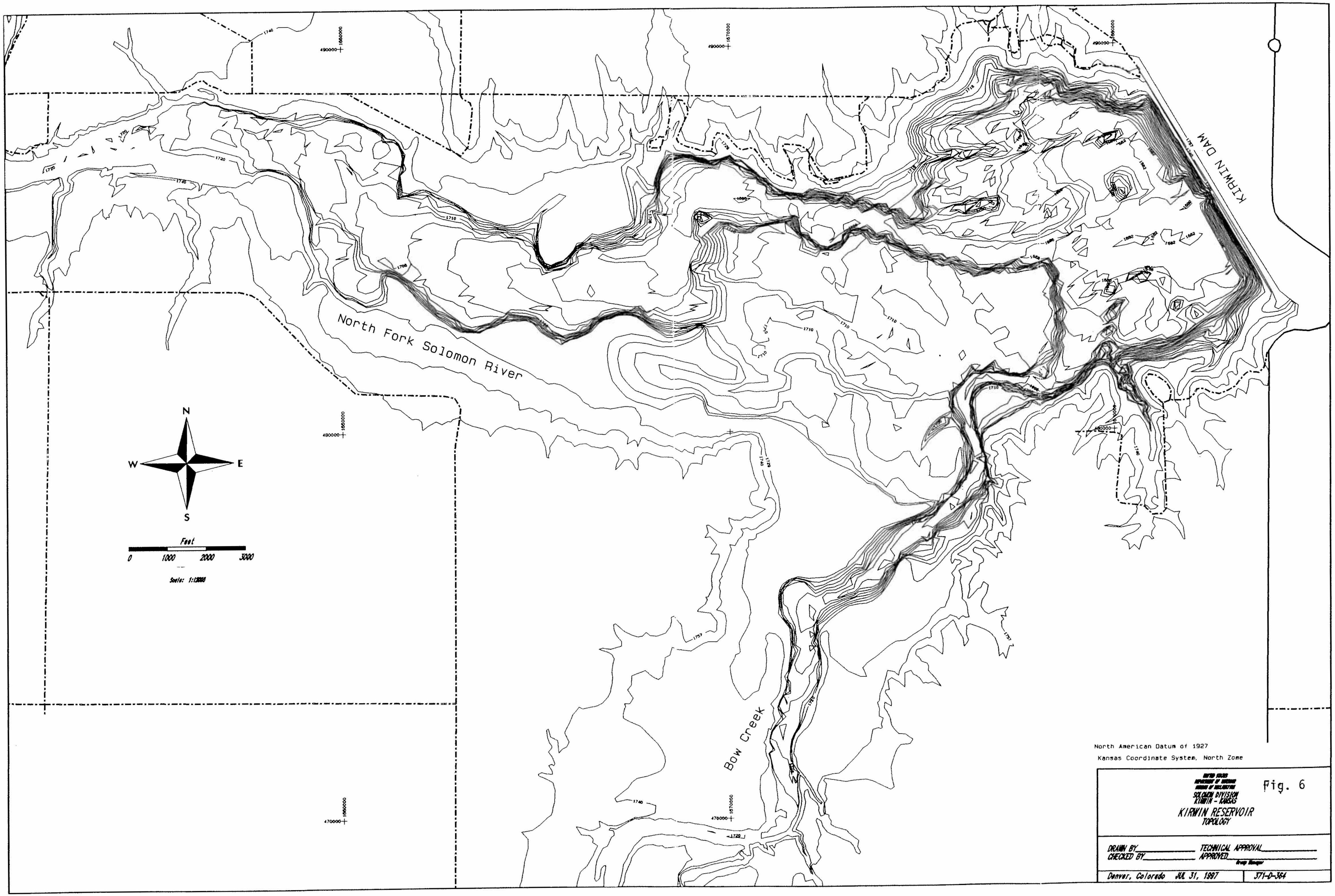
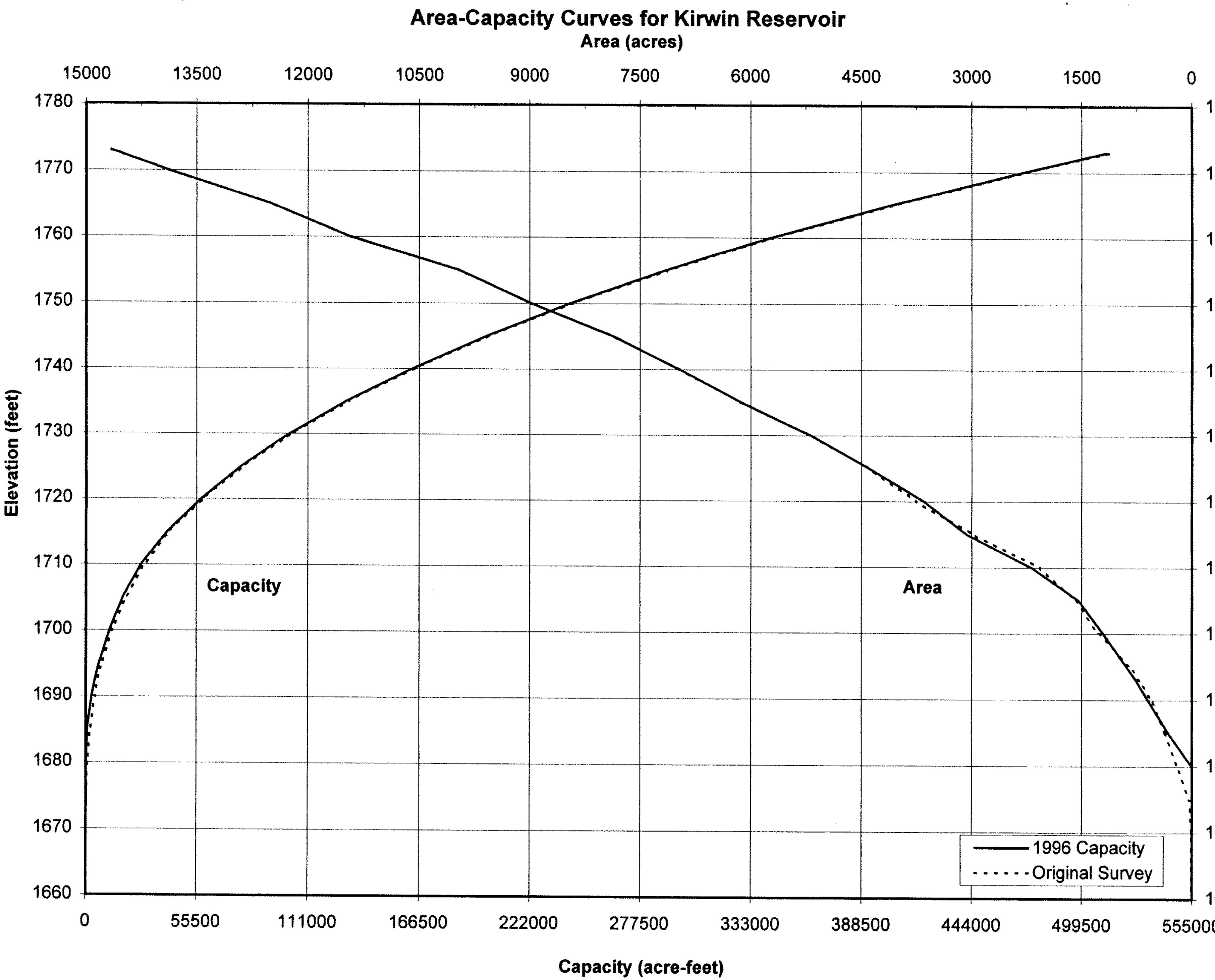

N
W
E
S
Feet
0
1000
2000
3000
UNITED STATES
DEPARTMENT OF INTERIOR
BUREAU OF RECLAMATION
SOLOMON DIVISION
KIRWIN - KANSAS
KIRWIN RESERVOIR
1996 UNDERWATER COLLECTED DATA
PLUS ADDED DATA POINTS
DRAWN BY______________ TECHNICAL APPROVAL______________
CHECKED BY______________ APPROVED______________
Group Manager
Denver, Colorado APR 07, 1997

Fig. 5


KIRWIN DAM
North Fork Solomon River
Bow Creek
N
S
E
W
Feet
0 1000 2000 3000
North American Datum of 1927
Kansas Coordinate System, North Zome
SOLOMON DIVISION
KIRWIN - KANSAS
KIRWIN RESERVOIR
TOPOLOGY
DRAWN BY
CHECKED BY
TECHNICAL APPROVAL
APPROVED
Denver, Colorado JUL 31, 1997
371-D-364
Fig. 6



Area-Capacity Curves for Kirwin Reservoir
Area (acres)
15000
13500
12000
10500
9000
7500
6000
4500
3000
1500
0
1780
1770
1760
1750
1740
1730
1720
1710
1700
1690
1680
1670
1660
Elevation (feet)
Capacity
Area
1996 Capacity
Original Survey
0
55500
111000
166500
222000
277500
333000
388500
444000
499500
555000
Capacity (acre-feet)

Fig. 7

RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.