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1989 Walker Branch Watershed Surveying and Mapping Including a Guide to Coordinate Transformation Procedures

S. Timmins
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Environmental Sciences Division
Publication No. 3659

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1989 WALKER BRANCH WATERSHED SURVEYING AND MAPPING INCLUDING A GUIDE TO COORDINATE TRANSFORMATION PROCEDURES

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ABSTRACT

TIMMINS, S., and J. CHASON. 1991. 1989 Walker Branch Watershed surveying and mapping, including a guide to coordinate transformation procedures. ORNL/TM-11779. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 110 pp.

Walker Branch Watershed is a forested, research watershed marked throughout by a 264ft grid that was surveyed in 1967 using the Oak Ridge National Laboratory (X-10) coordinate system. The Tennessee Valley Authority (TVA) prepared a contour map of the watershed in 1987, and an ARC/INFO™ version of the TVA topographic map with the X-10 grid superimposed has since been used as the primary geographic information system (GIS) data base for the watershed. However, because of inaccuracies observed in mapped locations of some grid markers and permanent research plots, portions of the watershed were resurveyed in 1989 and an extensive investigation of the coordinates used in creating both the TVA map and ARC/INFO data base and of coordinate transformation procedures currently in use on the Oak Ridge Reservation was conducted. We determined that the positional errors resulted from the field orientation of the blazed grid rather than problems in mapmaking.

In resurveying the watershed, previously surveyed control points were located or noted as missing, and 25 new control points along the perimeter roads were surveyed. In addition, 67 of 156 grid line intersections (pegs) were physically located and their positions relative to mapped landmarks were recorded. As a result, coordinates for the Walker Branch Watershed grid lines and permanent research plots were revised, and a revised map of the watershed was produced.

In conjunction with this work, existing procedures for converting between the local grid systems, Tennessee state plane, and the 1927 and 1983 North American Datums were updated and compiled along with illustrative examples and relevant historical information. Alternative algorithms were developed for several coordinate conversions commonly used on the Oak Ridge Reservation.

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1. INTRODUCTION

The purpose of this report is twofold. Primarily, it is an informal progress report describing the work accomplished and the information compiled during the 1989 "map revision" project for the Walker Branch Watershed (WBW) at Oak Ridge National Laboratory (ORNL). WBW is a forested, research watershed occupying 97.5 ha on the Department of Energy (DOE) Oak Ridge Reservation in Anderson County, Tennessee. This project was initiated to resolve discrepancies between a physical reference grid established on the watershed in 1967 and current maps of this grid. Our goal was to locate and map this reference grid both relative to watershed landmarks and, by resurveying certain areas, to establish its absolute x,y coordinates in the local X-10 coordinate system (see Sect. 4). The revised coordinates were used in making the revised WBW map (Appendix F).

Section 3 details the 1989 surveying and mapping of WBW. We have attempted to state simply what was done and how and why it was done so that guesswork will be minimized in the event more surveying is needed. Thus, this report should provide pertinent information for any future surveying performed on WBW.

Although we strived for accuracy in every phase of the project, the problems of surveying densely forested hillsides without disturbing the watershed forced us to use an incremental approach. That is, we surveyed only the perimeter and then measured interior

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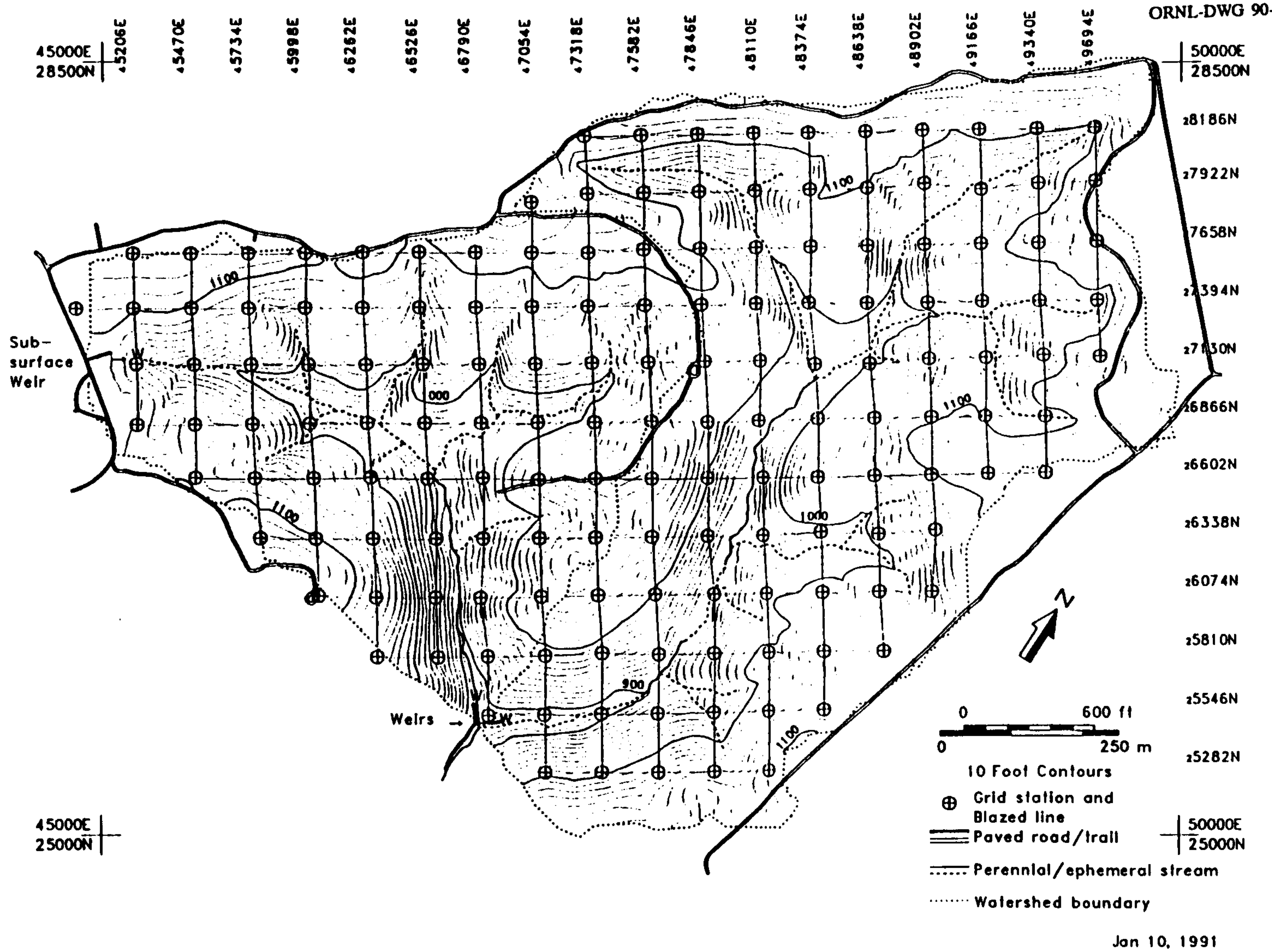

Fig. 1. The Walker Branch Watershed 264-ft reference grid, as surveyed in the late 1960's using compass and chain.

grid intersections relative to landmarks. This approach, while less than optimal, was accurate enough to resolve major inaccuracies in previous maps of the WBW reference grid. We are confident that future surveys can refine the 1989 map but that the refinements necessary will be on the order of feet rather than tens of feet.

Section 4 is an outgrowth of the mappping work and provides a guide to using and transforming geographic data for the Oak Ridge Reservation. An understanding of, and confidence in, local control point coordinates and the transformations applied to them was essential to the resolution of the problems involved in mapping the WBW grid. In an effort to obtain satisfactory answers to questions this project raised, we have compiled substantial information regarding the use of ORNL coordinate systems as well as the state of existing geographic control data for Walker Branch. A number of new conversion algorithms, including an interactive VAX program, were developed. Section 4.1 describes transformations from NAD-27 data into NAD-83, and Sect. 4.2 deals strictly with conversions from NAD-83 geodetic (latitude, longitude) data to NAD-83 state plane (X, Y) coordinates. Section 4.3 focuses on local coordinate systems, and Section 4.4 is a summary of the conversion pathways discussed.

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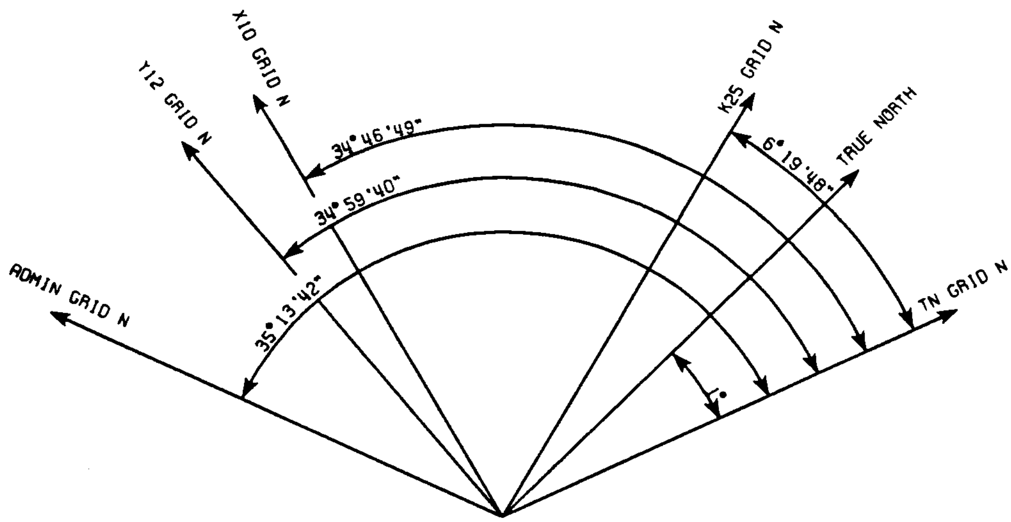

Fig. 2. Relationship of four Oak Ridge grid norths and TN Lambert north to true north.

2. BACKGROUND AND SUMMARY

In 1967, the Walker Branch watershed was surveyed using compass and chain. Grid lines were blazed through the forest using yellow paint on trees, and grid line intersections were marked by aluminum pegs tagged with the last four digits of their easting and northing. In this way, a 264-ft (4 chain) reference grid with coordinates in the ORNL (X-10) system was established (Fig. 1). This grid provides a system for locating sites and mapping the watershed with potential accuracy, after the 1989 revision, of better than plus or minus 5 ft.

Surveying and mapping on the watershed or elsewhere within the Oak Ridge Reservation is complicated by the existence of four local grid systems. Each of the DOE plants and the Oak Ridge Townsite has its own system:

Plant	Grid System Name
Oak Ridge National Laboratory	X-10
Oak Ridge Gaseous Diffusion Plant	K-25
Y-12 Plant	Y-12
Oak Ridge Townsite	Administrative

These local grid systems are distinct from the Tennessee state plane system, which is the legal coordinate system for the state of Tennessee. The Tennessee state plane system is a Lambert projection of the earth's shape, so it is also known as TN Lambert.

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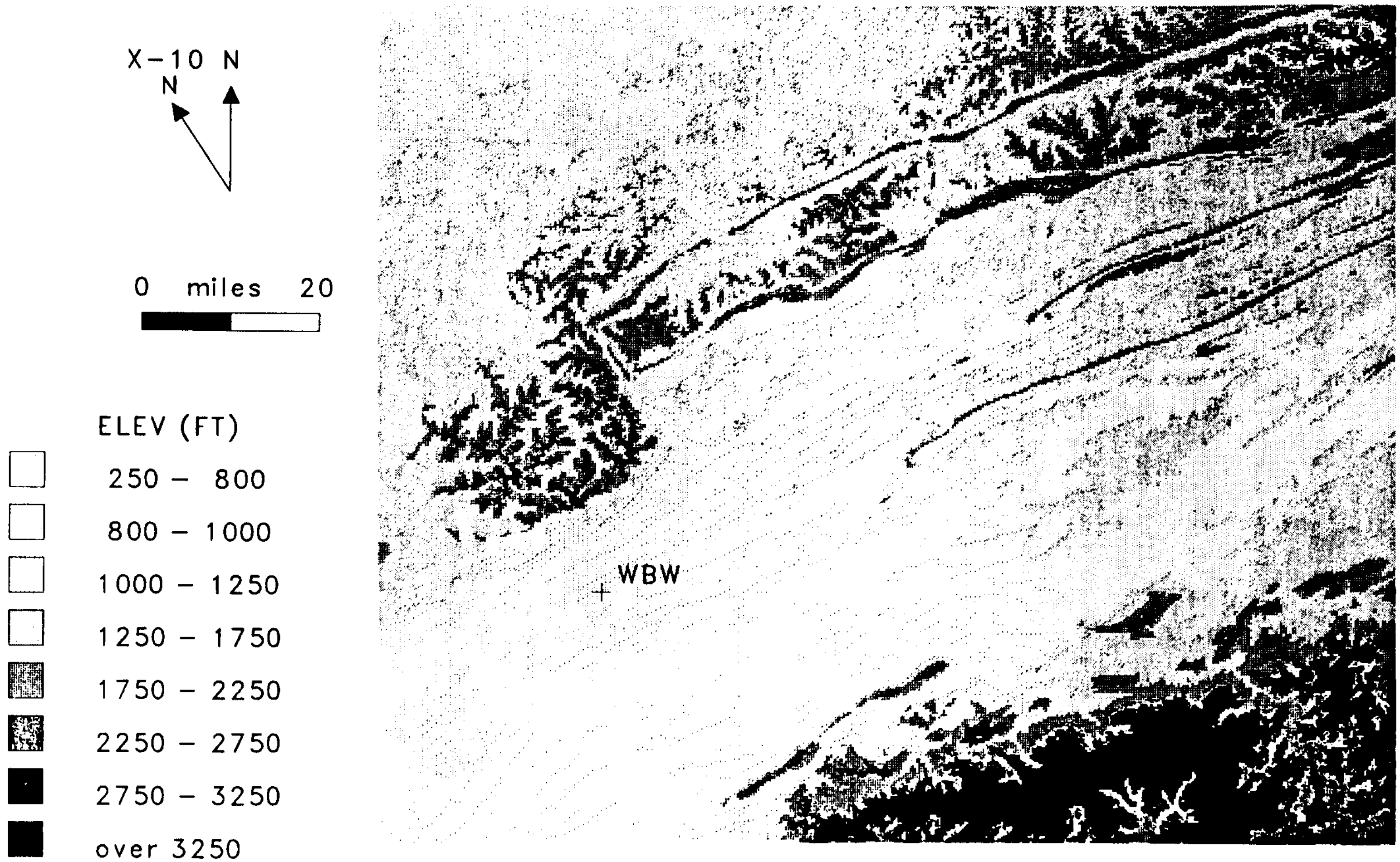

Fig. 3. Knoxville area digital elevation map showing location of Walker Branch Watershed and the prevailing NE-SW ridges.

The local grid systems are all topographically controlled but differ in their orientation (Fig. 2). As Figure 3 shows, the east-west lines of the X-10 system run approximately parallel to the prevailing SW-NE ridges; consequently, the X-10 grid does not run north-south, east-west but is rotated about 34° to the northwest.

Maps of the reservation may be produced in any of these four systems. However, since Administrative (ADMIN) is the standard grid system for WBW data storage in the Environmental Sciences Division's GIS (using ARC/INFO), accurate methods for converting to and from ADMIN are needed.

In 1987 TVA, under contract with Martin Marietta Energy Systems, Inc., produced a high-quality contour map of WBW (in ADMIN and TN state plane coordinates) at a horizontal scale of 1 in. = 100 ft. and with a 2-ft contour interval. This map was produced from aerial photographs with ground surveying of the registration points known as photo-identifiable points (Table 1). Surveying was performed in TN state plane, and for absolute positioning, the map has TN state plane reference crosses, ADMIN crosses, and seven photoregistration points. The map has neither X-10 coordinate reference crosses nor the reference grid. Still, it is quite detailed, including roads, weirs, monitoring facilities, and buildings and, when overlayed with the WBW reference grid, is considered to be the base map for the watershed.

However, recent research involving spatial studies of WBW has revealed various discrepancies between field observations of the 264-ft reference grid and its overlayed position on the TVA contour map. For

Table 1. Walker Branch Watershed photoidentifiable control points, Tennessee Lambert, 1927 Datum.

Control point	X (ft)	Y (ft)	Elevation (ft)	Description
48.1 [a]	2510623.4	575825.3	1081.3	Pole
48.2	2512300.2	574982.0	857.4	SE corner tower
49.1 [a]	2510487.7	575242.1	1093.9	South pole
49.2	2511287.3	574413.6	913.4	Centerline rd at tower
50.1	2509001.0	572938.9	960.9	Auto tires
50.2	2509780.3	573300.5	833.2	Pole
59.1	2505674.3	576549.2	922.1	Pole
59.2 [a]	2506391.3	575522.2	1111.7	Fence corner
59.3 [a]	2507012.5	574814.5	1099.8	T-road
60.1	2506755.1	577400.2	932.3	Pole
61.1	2508333.5	578642.5	950.7	Pole
61.2 [a]	2509090.1	576512.9	1060.4	Light spot
61.3	2509887.6	576666.7	1074.9	Pole
61.4	2509127.3	575523.3	1058.6	Hill top
62.1	2509354.3	579528.4	993.4	Pole
62.2 [a]	2509898.5	578882.6	1178.9	Lone tree
62.3 [a]	2510971.0	577330.5	1133.72	Pole

[a] indicates control points within the watershed boundary.

instance, a grid peg mapped 10 ft east of a stream might actually be 10 ft west of the stream. Although these differences are not necessarily significant for all WBW projects, they are an obstacle for some projects and do pose annoying questions. For example: Where is the grid physically located relative to landmarks? What is its absolute position in X-10 coordinates? Are there problems with the transformation procedures? Has the 264-ft reference grid (which is not visible on the aerial photographs) been placed on the base map accurately?

To resolve these questions, we chose to resurvey portions of the watershed as cost- and time-efficiently as possible. The goal was to locate existing control points on the watershed, establish new control points, and survey (verify) as many grid lines and intersections as possible. Because the watershed is heavily forested, however, electronic surveying equipment was used only along the perimeter roads. (We did not wish to disturb the watershed in any way.) Thus, new control points were surveyed along the perimeter, but it was practical to survey only a small portion of the grid itself.

Once in place, these control points along perimeter roads were used to register a blue-line overlay (transparent engineering grid with eight squares per inch) on the TVA base map. Thus, the blue-line grid represented the absolute position of the X-10 grid. WBW interior grid intersections were then located on the overlay using field measurements between the pegs and mapped landmarks such as streams, roads, or valley bottoms. This resulted in a revised WBW reference grid and map based on a combination of surveying and manual placement of measured pegs.

In conjunction with this work, several questions arose that demanded significant attention. The first centers on the introduction in 1983 of a new North American Datum for surveying (NAD-83). (See Sect. 4.1 for explanation of the NAD.) In 1987, because of this adjustment, a Global Positioning System (GPS) was used to resurvey the benchmarks for the local grid systems (Adams et al. 1988). One benchmark for each system (the pivot point) was chosen and its local grid system coordinates held fixed. Then, all other points were given new coordinates in this system relative to their NAD-83 coordinates. Thus, the local grids were changed from 2-D systems to 3-D, NAD-83 based systems.

In resurveying WBW, we found that TVA's TN state plane coordinates for the seven photoidentifiable points on their WBW map were not based on NAD-83 as we had assumed. Instead, TVA had retained the older NAD-27 coordinates (Table 1). This coordinate choice was unfortunate because the map was made in 1987, but NAD-83 values for benchmarks might not have been available. In short, because NAD-83-based coordinate conversion programs are not directly applicable to NAD-27 coordinates, they are not appropriate for transforming the WBW base map into local coordinate systems. Thus, procedures for converting NAD-27 values to NAD-83 had to be documented and incorporated into the WBW map revision.

Moreover, it was necessary to compare these procedures with transformation equations TVA presumably used in making the map itself. We found these TVA equations, based on local grid system control values (see Appendix D), to be inaccurate as did the Adams Craft, Herz and Walker survey company (personal communication 12-89, K. Craft of

Table 2. Conversion from NAD-27 to NAD-83 of ten points spanning the Oak Ridge Reservation

Station	Input Coordinates(a) X	Input Coordinates(a) Y	Latitude	Output coordinates(b) Longitude	Northing(N)	Easting(E)	Zone	Convergence	Scale Factor
a	2460000	560000	35 55 13.73748	084 26 46.83094	177205.720	740211.070	TN	0 54 34.46	0.99994953
b	2490000	600000	36 1 44.41774	084 20 33.89476	189398.246	749355.183	TN	0 58 12.80	0.99995417
c	2520000	610000	36 3 18.12469	084 14 26.51092	192446.433	758499.375	TN	1 1 47.88	0.99995581
d	2550000	580000	35 58 16.00181	084 08 28.13398	183302.295	767643.773	TN	1 5 17.68	0.99995125
e	2510000	540000	35 51 47.69714	084 16 43.26507	171109.731	755451.618	TN	1 0 27.81	0.99994853
f	2490000	530000	35 50 12.21725	084 20 48.28022	168061.532	749355.459	TN	0 58 4.37	0.99994840
231a	2517807.68	596543.16	36 1 5.44998	084 14 56.13555	188344.660	757831.240	TN	1 1 30.53	0.99995355
600	2518534.67	597529.31	36 1 15.07259	084 14 47.07218	188645.250	758052.824	TN	1 1 35.84	0.99995370
300	2525730.77	603870.90	36 2 16.49587	084 13 18.08103	190578.248	760246.199	TN	1 2 27.94	0.99995471
T-21	2500930.91	573492.13	35 57 20.44807	084 18 26.40472	181318.425	752687.150	TN	0 59 27.43	0.99995065
BP-19	2501725.8	565507.7	35 56 1.35818	084 18 18.41777	178884.694	752929.471	TN	0 59 32.11	0.99994991

(a) NAD-27 TN Lambert.
(b) Geodetic positions and NAD-83 TN Lambert calculated by the NGS using program GPPC83, v.1, 1983 Datum.

Adams Craft, Herz and Walker, Oak Ridge, Tenn. to S. Timmins, ORNL/ESD, Oak Ridge, Tenn.).

Coordinates for the seven photoidentifiable points have now been updated to NAD-83 and are available in Sects. 3.5 and 4.1.3. We also obtained NAD-83 coordinates from the National Geodetic Survey (NGS) for six arbitrary NAD-27 points and five benchmarks with NAD-27 coordinates spanning the entire Oak Ridge Reservation (Table 2).

Other questions involved the accuracy of conversions between the four local grid systems and between these and TN state plane. Because WBW researchers need to establish the absolute X-10 positions of the WBW reference grid, and since the GIS data for the base map is stored in ADMIN coordinates, an accurate conversion between ADMIN and X-10 coordinates is required. The transformation procedures from the 1987 Global Positioning System survey are encapsulated in a program named GRIDCHG (Adams et al. 1988), described in Sect. 4.3.1, which performs all transformations between local grid systems via state plane (NAD-83) coordinates. Also, because state plane coordinates changed with the definition of the 1983 Datum, algorithms for updating coordinates based on the earlier NAD-27 are required.

Because of the frequent need to convert spatial data from one reference system to another, a major portion of this report, Sect.4, is devoted to the derivation and application of such transformation procedures. Generally, transformations between any of the four local coordinate systems are best performed via TN state plane, using either special equations or interactive computer software. Wherever possible, we advocate use of either GRIDCHG, equations based on GRIDCHG definitions (Appendix C), or TRANSFORM (see Appendix D). Where necessary, we developed precise but nevertheless approximate regression equations (i.e., based on coordinates rather than grid system definitions) to perform these transformations or projections.

In summary, the following main accomplishments were made during the course of this map revision project. We hope that this report will serve as a useful reference not only for future field work and mapping, but for manipulation of geographic data as well.

* Several existing control monuments on WBW were located and 25 new stations placed in the field with better than 2-ft accuracy. These new stations were located relative to Adams, Craft, Herz and Walker (AC) survey markers KC-4, KC-5, 101, 904 and 905 and TVA photoidentifiable point 59-2 (see Table 1 and Sect. 3.2).
* Grid intersections for the WBW reference grid (blazed lines) were measured over much of the watershed. Locations of 67 of 156 pegs were recorded with better than 5-ft accuracy (see Sect. 3.3). Relative to its nominal postition, the grid appears to be rotated to the west or northwest about the weirs approximately 2°. The average shift (actual X-10 position vs nominal position) is 45 ft west and 11 ft north.
* Three checks of TVA stations vs AC stations revealed agreement to within 2 ft. (Since a photoidentifiable

point is usually a crooked power pole, this is reasonable.) These checks were made between AC 904 and TVA 59-2 and between AC KC-4, KC-5 and various poles marked on the TVA map along the right-of-way.

* An unresolved difference was found between ADMIN values calculated by the TVA equations from NAD-27 values (Appendix D) and newer methods based on NAD-83. Because these equations were used to make the TVA base map, this difference is important. To arrive at ADMIN values comparable to those obtained through GRIDCHG (Sect. 4.3.1), it is necessary to add -0.4 ft in the easting and 3 ft in the northing (Sect. 3.5.1). The source of this difference was traced to the NAD-27 values TVA quoted for various reservation benchmarks (Sect. 3.5.1 and Appendix E). Although the TVA equations are known to be incorrect, it is unclear which coordinates are correct. Similar differences were found for transformations from NAD-27 to X-10. These differences are important for surveying applications, though less significant for mapping (especially at scales larger than 1 in. = 100 ft).
* Conversion procedures for NAD-27 and NAD-83 geodetic data, NAD-27 and NAD-83 TN state plane, and local Oak Ridge grids were documented and compiled. A FORTRAN program called TRANSFORM was written, which performs transformations between the local grids and from local grids to TN state plane. With the exception of GRIDCHG corrections for elevation, TRANSFORM

duplicates the output of GRIDCHG.

* Regression equations (i.e., approximations) were developed for the conversion between the X-10 and ADMIN grids with an error < 0.001 ft [see eqs (4 and 5), Sect. 4.3.2). Regression equations were also developed for conversion of NAD-27 to NAD-83 values for the entire Oak Ridge reservation based on values supplied by the National Geodetic Survey. These equations [Eq (3), Sect. 4.1.3] are accurate to 0.043 m.

* A revised map showing the 264-ft grid and the 298 forest inventory plots was generated. This map is included as Appendix F.

3. WALKER BRANCH WATERSHED REFERENCE GRID GROUND TRUTHING

3.1 PURPOSE

The purpose of the surveying and mapping done on WBW during 1989 was to reconcile actual locations of the 264-ft grid intersections, as observed in the field, with their mapped positions superimposed on the 1987 TVA topographic map. In certain instances, these intersections (marked with a tagged aluminum peg) were mapped on the wrong side of roads or streams. By accurately surveying the coordinates of new control points, and of actual WBW grid points when possible, the placement of the grid in the X-10 system has been established with an accuracy of about plus or minus 5 ft. Concurrently, the relative position of the grid with respect to landmarks is now represented more correctly. The end results are (1) revised coordinates for each grid peg, (2) revised coordinates for 298 permanent research plots, and (3) a revised map of the 264-ft grid. This will allow other watershed features, such as soil types, to be located within the X-10 coordinate system with accuracy of about plus or minus 5 ft.

3.2 PRELIMINARY WORK

Work began in March 1989 with an effort to locate a number of survey monuments from the late 1960s within the watershed. Although a number were eventually found, most were essentially isolated because they had no unobstructed line of sight to an adjacent station. Surveying was hampered by this lack of line-of-sight control points.

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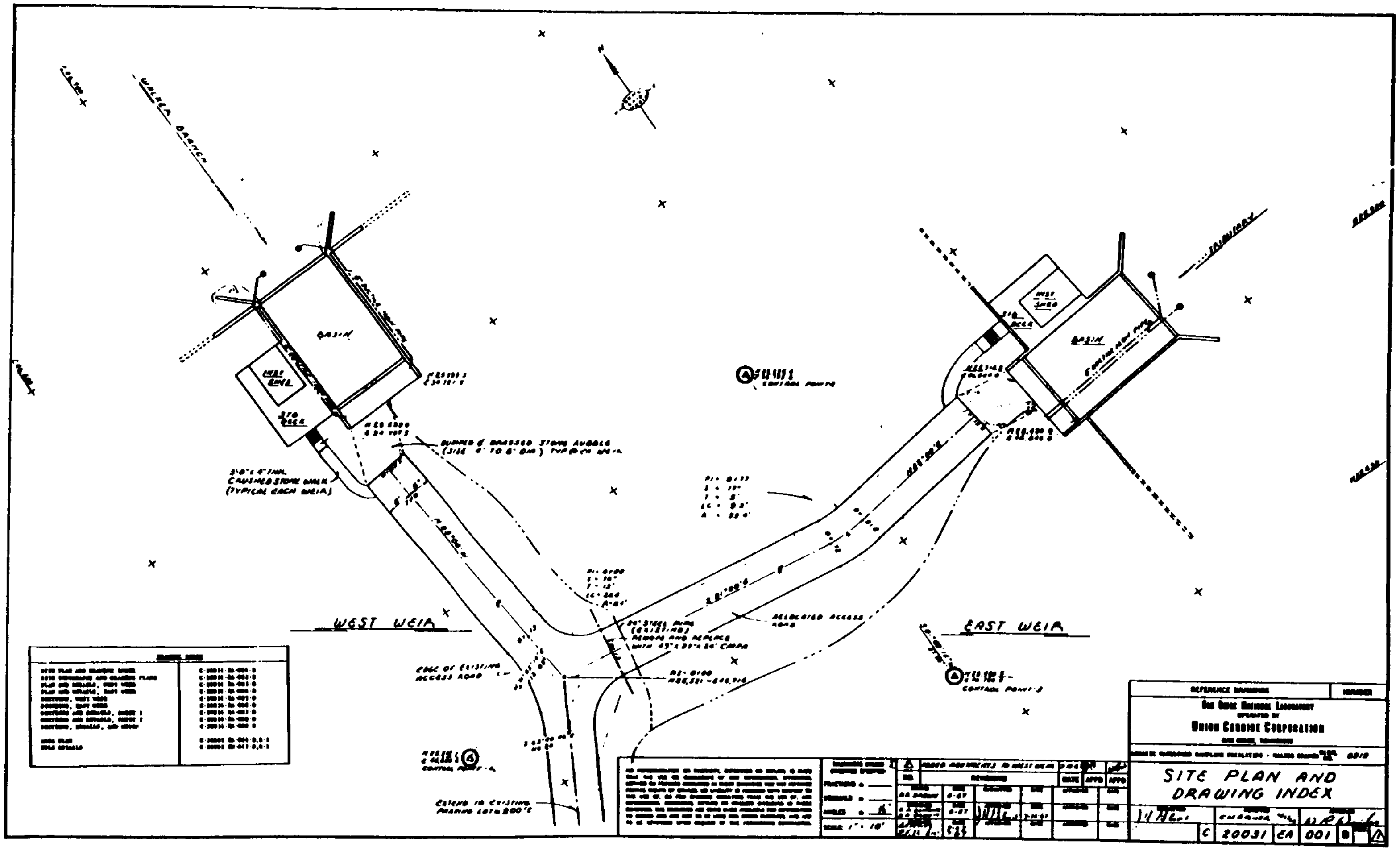

Fig. 4. Site plan and drawing index for the Walker Branch weirs, dated 7-19-67, showing locations of three control points.

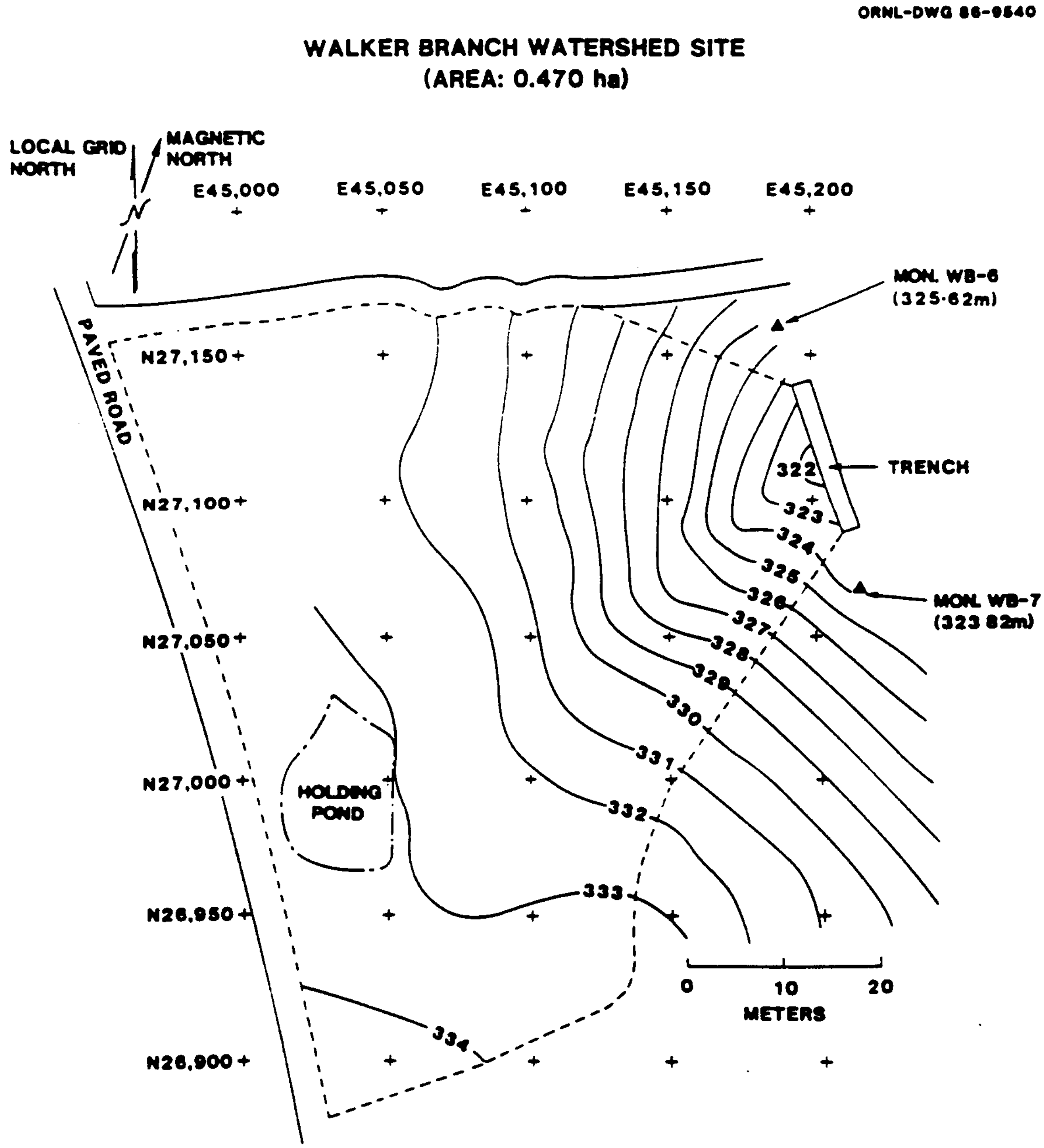

Fig. 5. Topographic map of the Walker Branch Watershed subsurface weir study site showing locations of control points WB-6 and WB-7.

Three control points were identified from a site plan for the weirs dated July 10, 1967 (Fig. 4). These are presumably the monuments from which the 264-ft grid was originally surveyed. A metal detector revealed the remains of an iron spike in the approximate location of control point No. 3. No indication of control points Nos. 1 or 2 was found. Monument WB-7, located at the south end of the trench in the northwest corner of the watershed (see Fig. 5) was never found. What we assumed to be monument WB-6 was located after completion of the project. A control point (spike) in the road adjacent to the trailer near the trench was also found, but its coordinates are not currently known.

A list of five control points in the watershed area was obtained from the Adams, Craft, Herz and Walker surveying company, and the list of photoidentifiable points (recorded in NAD-27-based TN state plane coordinates) for the base map was obtained from TVA. Of these, three points located in the powerline right-of-way along the southeastern edge of the watershed (AC 101, KC-4, and KC-5), and photoidentifiable point 59-2 (NW corner of fence surrounding the radio tower) proved useable. Later, after surveying was initiated on the eastern end of the watershed, another listing of AC control points was obtained of which two (904 and 905) along Jim Diggs Road were located and subsequently used. A site plan for the radio tower facility was also obtained (from Bernie Dykes, Engineering Division) but did not correspond to the TVA information.

Currently, (June 1990), Walker Branch has only three first order control points within line of site: AC 101, KC-4, and KC-5. These positions are reported to within 0.001 ft. AC 904 and the NW fence

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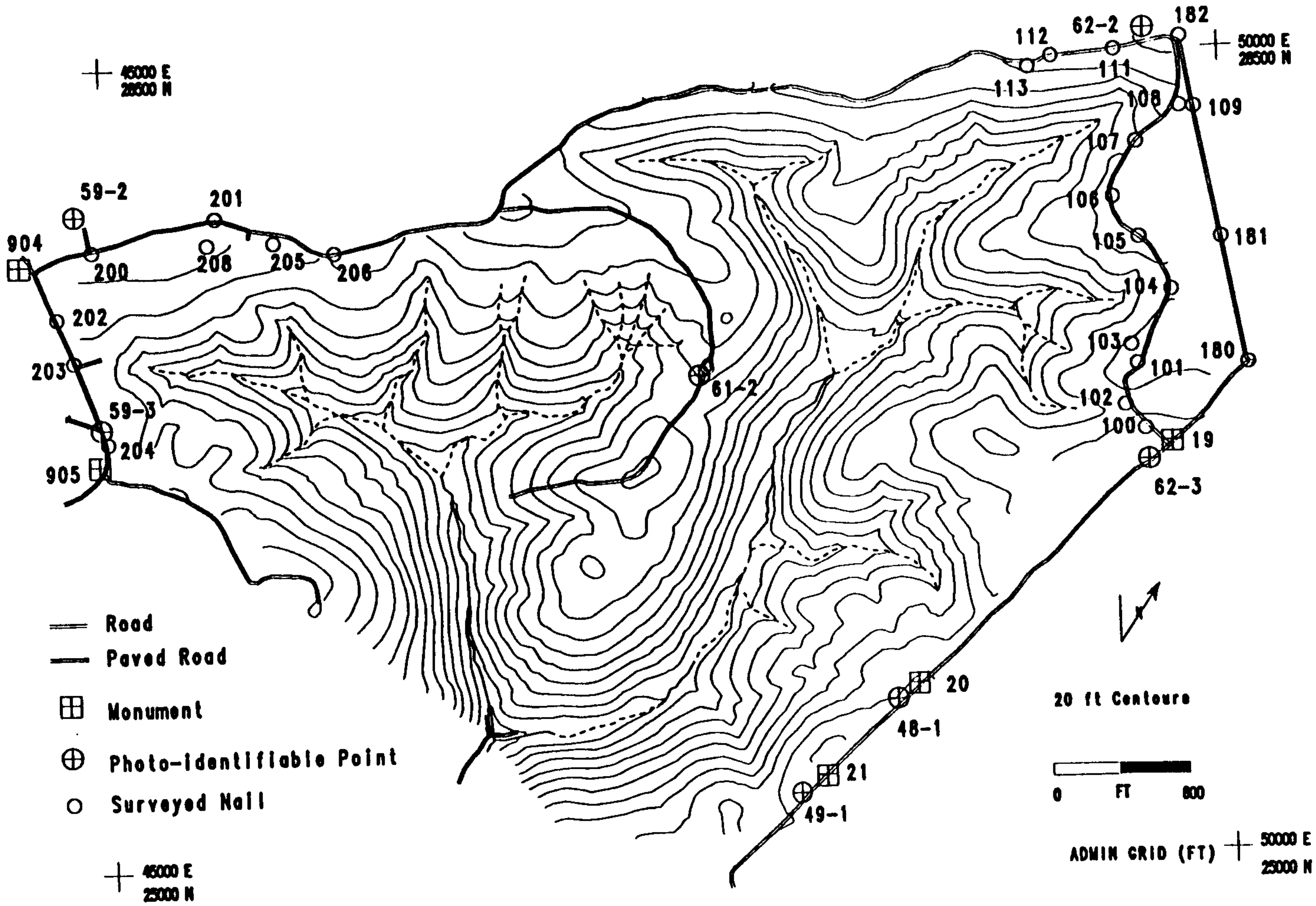

Fig. 6. Existing Walker Branch Watershed monuments, photo-identifiable points, and surveyed nail control points

corner surveyed by TVA (accuracy of 0.1 ft) also have a relatively good line of sight. See Table 3 for control point coordinates.

3.3 SURVEYING AND MAPPING

Norman Farrow (ESD) supplied a Pentax PX-06D electronic distance-measuring theodolite and other equipment used in the surveying portion of this project. Because line-of-sight control existed along the power line, the eastern and southeastern boundaries of the watershed were surveyed first (Fig. 6). Beginning with AC points KC-4, KC-5, and 101, a closed traverse was made along the eastern-most road and the smaller power line running north-south. Closure error for this traverse is about 3 ft. A total of 12 stations was surveyed, and each is marked by a 12 in. nail at ground level and a numbered wooden stake painted red.

Whenever possible (i.e., when sighting was not obstructed), the nearest WBW grid intersection peg was surveyed. Along this eastern traverse, it was possible to survey intersections (49694, 27130), (49694, 27658) and (49694, 27922). Their actual coordinates are included in Table 4. In some instances, the intersection of a line with a road was surveyed in lieu of a peg (e.g., line 28186). Other lines are not currently blazed all the way to the roads; extending these will improve access, particularly for surveying.

Given the existing control points (AC KC-4, KC-5, and 101), the location of 904 and 905 in relation to Jim Diggs Road, and the 12 points along the easternmost traverse, it was possible to overlay the existing WBW map with a transparent grid ("blue-line") corresponding

Table 3. Walker Branch X-10 control point coordinates, units = ft.

Station	Northing	Easting	Source
KC-4	26750.84	49818.43	Adams-Craft
KC-5	25701.32	48669.77	Adams-Craft
101	25305.50	48250.08	Adams-Craft
904	27579.35	44677.60	Adams-Craft
905	26700.62	45020.89	Adams-Craft
100	26806.43	49704.21	Surveyed
101	27092.52	49674.18	Surveyed
102	26910.33	49674.18	Surveyed
103	27174.28	49649.39	Surveyed
104	27415.85	49826.25	Surveyed
105	27648.21	49689.67	Surveyed
106	27825.19	49579.77	Surveyed
107	28063.84	49684.74	Surveyed
108	28216.07	49876.30	Surveyed
109	28209.19	49937.73	Surveyed
111	28466.41	49591.37	Surveyed
112	28444.05	49310.60	Surveyed
113	28297.20	49205.31	Surveyed
200	27639.44	44997.28	Surveyed
201	27784.39	45548.32	Surveyed
202	27347.89	44841.05	Surveyed
203	27156.97	44914.22	Surveyed
204	26798.48	45060.01	Surveyed
205	27673.87	45808.25	Surveyed
206	27626.88	46081.00	Surveyed
207	27654.01	45628.60	Surveyed
208	27665.45	45511.56	Surveyed
18A	27092.23	50152.95	Surveyed
18B	27642.43	50044.81	Surveyed
18C	28515.05	49882.03	Surveyed
Fence corner	27797.33	44923.72	TVA (transformed)

to the revised X-10 coordinates. This was extremely helpful because (1) it allowed subsequent field measurements from grid lines or intersections to reference points (streams, roads, etc.) to be mapped directly and (2) revised coordinates for other points could be easily read from the overlay.

Work then began on a traverse along the east end of Rain Gauge No. 5 Road, where three new stations were surveyed. However, because of leaf cover, the length of time that would be necessary to completely survey this road, and the scarcity of grid pegs within sight of the road, this approach was abandoned. Instead, the distances from a number of pegs throughout the watershed to reference points, such as streams, were measured and used to reposition these points on the map overlay. Table 4 provides a list of each measured peg's revised X-10 coordinates.

Once the coordinates for AC 904 and 905 were obtained, it was possible to survey the northwest corner of the watershed. Three new stations (nails) and lines 27394 and 26866 were surveyed along Jim Diggs Road and marked as before. Unfortunately, no grid pegs were within sight of the control points. Four points and peg 45998, 27658 were surveyed along the west end of Rain Gauge No. 5 Road, and two additional stations were placed in the field adjacent to the road.

3.4 SURVEYING CONCLUSIONS

The locations of 67 pegs throughout the watershed, out of a total of 156, were established in the field. Five of these were surveyed using the theodolite, and measurements to the remaining 62 were made

Table 4. WBW X-10 reference grid nominal coordinates (ft) and actual measurements (ft) to landmarks

Nominal X-10 Northing	Nominal X-10 Easting	How Measured	... N or S from ..[a]	... E or W from .[a]	Actual X-10 Northing	Actual X-10 Easting
25282	47054				25282	47050
25282	47318				25284	47312
25282	47582				25286	47575
25282	47846				25288	47838
25282	48110				25290	48100
25546	46790	(Missing)			25544	46784
25546	47054				25547	47047
25546	47318	Tape	17 S/stream		25550	47310
25546	47582				25554	47573
25546	47846				25558	47836
25546	48110				25562	48099
25546	48374	Tape	134 N/r.o.w.	163 W/20A	25566	48362
25810	46262				25808	46268
25810	46526	Tape		125 W/stream	25808	46550
25810	46790	Tape		109 E/stream	25810	46782
25810	47054				25813	47050
25810	47318				25826	47314
25810	47582				25820	47578
25810	47846				25823	47839
25810	48110				25826	48100
25810	48374	Tape		265 W/nextpin	25830	48362
25810	48638	Tape	144 N/AC-20	186 W/road	25830	48640
26074	45998	Tape	28 S/stream	14 W/stream	26080	45998
26074	46262				26074	46262
26074	46526	Tape		103 W/stream	26074	46538
26074	46790	Tape		107 E/stream	26074	46748
26074	47054				26079	47032
26074	47318				26084	47296
26074	47582				26088	47562
26074	47846	(Missing)	in stream		26090	47838
26074	48110				26092	48088
26074	48374				26095	48356
26074	48638	Tape	162 S/stream	132 W/stream	26098	48620
26074	48902	Tape	213 N/road	233 W/road & 100 W/break in slope	26098	48864
26338	45734	Tape	143 S/road	123 E/road	26338	45730
26338	45998				26339	45984
26338	46262				26340	46246
26338	46526	Tape		57 W/stream	26340	46540
26338	46790	Tape		158 E/stream	26342	46760
26338	47054				26344	47022
26338	47318				26347	47284

Table 4 (continued)

Nominal X-10 Northing	Easting	How Measured	... N or S from ..[a]	... E or W from .[a]	Actual X-10 Northing	Easting
26338	47582				26349	47546
26338	47846				26352	47808
26338	48110	Tape	53 N/stream	136 E/str(jog)	26354	48070
26338	48374	Tape	78 N/stream	138 W/stream	26370	48348
26338	48638	Tape	108 N/stream	127 E/stream	26360	48616
26338	48902	Tape	118 S/stream		26378	48880
26602	45206					
26602	45470	Tape	74 N/road	155 E/road	26610	45430
26602	45734				26610	45704
26602	45998				26612	45974
26602	46262				26618	46236
26602	46526	Tape	50 S/stream		26612	46500
26602	46790	Tape	(line 59 N/end of rd)		26618	46758
26602	47054	Tape	13 N/road		26610	47020
26602	47318	Tape	6 N/road		26614	47284
26602	47582				26614	47545
26602	47846				26616	47808
26602	48110	Tape	52 E/stream		26618	48070
26602	48374				26620	48334
26602	48638				26625	48598
26602	48902				26630	48862
26602	49166				26635	49126
26602	49430				26640	49390
26866	45206	Tape		127 W/road	26850	45162
26866	45470				26854	45426
26866	45734				26858	45691
26866	45998				26863	45956
26866	46262	(Missing)			26868	46220
26866	46526	Tape	178 N/stream		26868	46485
26866	46790				26870	46750
26866	47054	Tape	30 S/stream		26872	47015
26866	47318				26874	47279
26866	47582	Tape		34 W/road	26878	47544
26866	47846				26875	47808
26866	48110	Tape		65 W/str(con)	26880	48050
26866	48374	Tape	200 S/stream		26890	48334
26866	48638				26892	48598
26866	48902				26895	48861
26866	49166				26907	49112
26866	49430	Tape		230 W/ #102	26900	49388
27130	44942					
27130	45206	Tape		231 E/road	27128	45156
27130	45470	Tape	18 N/stream		27128	45420

Table 4 (continued)

Nominal X-10 Northing	Nominal X-10 Easting	How Measured	... N or S from ..[a]	... E or W from . [a]	Actual X-10 Northing	Actual X-10 Easting
27130	45734	Tape	46 N/stream		27130	45684
27130	45998	Tape	124 N/stream		27132	45948
27130	46262				27135	46212
27130	46526				27138	46476
27130	46790	Tape		72 W/stream	27140	46740
27130	47054				27143	47003
27130	47318				27146	47267
27130	47582				27149	47530
27130	47846				27152	47793
27130	48110				27155	48056
27130	48374	Tape	65 N/stream	31 E/str(con)	27138	48320
27130	48638	Tape	32 SW/draw	101 E/str(jog)	27140	48574
27130	48902				27164	48850
27130	49166	Tape		42 E/stream	27168	49115
27130	49430	Tape	22 N/stream	62 W/str	27180	49380
27130	49694	Surveyed			27174	49638
27394	44942	Tape	238 S/road	60 E/road	27380	44878
27394	45206				27383	45142
27394	45470				27386	45405
27394	45734				27389	45669
27394	45998				27392	45932
27394	46262				27395	46196
27394	46526				27398	46460
27394	46790				27401	46723
27394	47054				27404	46987
27394	47318				27407	47250
27394	47582				27410	47514
27394	47846	Tape		35 E/road	27412	47778
27394	48110				27416	48035
27394	48374	Tape		66 E/stream	27420	48292
27394	48638	Tape	(161 N/stream)	96 W/stream	27418	48562
27394	48902	Tape	52 N/stream	186 E/stream	27420	48844
27394	49166	Tape	79 N/str(con)		27426	49098
27394	49430	Tape	19 N/stream		27428	49360
27394	49694	Surveyed			27430	49624
27658	45206	Tape	38 S/road		27632	45138
27658	45470				27635	45402
27658	45734				27638	45667
27658	45998	Tape	32 S/road		27642	45932
27658	46262	Tape	on road		27648	46196
27658	46526	Tape	78 S/road		27650	46458
27658	46790	Tape	104 S/road		27652	46722
27658	47054				27652	46986
27658	47318	Tape	168 S/road		27650	47250

Table 4 (continued)

Nominal X-10		How	... N or S	... E or W	Actual X-10	
Northing	Easting	Measured	from ..[a]	from . [a]	Northing	Easting
27658	47582	Tape	61 S/road	64 W/road	27664	47508
27658	47846				27668	47772
27658	48110				27672	48036
27658	48374				27676	48300
27658	48638				27680	48564
27658	48902				27684	48828
27658	49166				27688	49092
27658	49430	Surveyed (3 W, 10 N)		277 E/road	27692	49356
27658	49694	Surveyed			27698	49620
27922	47054	Tape	90 N/road	170 E/inters.	27910	46984
27922	47318	Tape	98 N/road		27918	47246
27922	47582				27922	47507
27922	47846				27926	47768
27922	48110	Tape	15 S/stream	70 E/str(con)	27930	48030
27922	48374				27936	48296
27922	48638	Tape		75 W/valley	27942	48562
27922	48902			105 E/ridge	27960	48827
27922	49166	Tape	17 S/stream	60 E/stream	27934	49092
27922	49430				27962	49353
27922	49694	Surveyed			27970	49614
28186	47318	Tape	20 S/road		28182	47232
28186	47582				28185	47496
28186	47846				28188	47760
28186	48110				28192	48024
28186	48374				28195	48288
28186	48638				28198	48553
28186	48902				28202	48817
28186	49166				28205	49082
28186	49430				28208	49346
28186	49694	Tape		259 W/ #108	28212	49610

[a] r.o.w. = right-of-way; str = stream (may refer to a flowing stream or to a stream valley-line on the contour map); con = confluence; and inters. = intersection.

with a tape. Twenty-three were measured relative to roads, 34 relative to streams or stream beds, and 5 relative to other features. Three pegs were found to be missing.

In general, the original placement of the grid lines through the forest -- done using a chain and magnetic compass -- was accurate to within 2°. Apparently, surveying began at the weirs and proceeded north. There seems to be an approximate 2° counter-clockwise rotation error with the pivot point near the weirs (Fig. 7). Chaining (interpeg) distances were quite accurate; of those measured, few were more than 1 or 2 ft long. However, in the steepest locations checked (e.g., north of the west branch weir), a few interpeg distances were up to 25 ft short.

For all lines, the average correction required (nominal vs actual coordinates) is 46 ft west and 11 ft north. Maximum differences between the measured positions and the nominal positions are:

24 ft east to 85 ft west offset along lines 45206-49694 (eastings)
40 ft south to 50 ft north offset along lines 25282-28186 (northings).

The largest differences exist in the northeast quadrant of the watershed, and the smallest (or none) exist south of the weirs. Figures 8 and 9 show the distribution of error for all pegs on the final map. It is important to note that because these differences are due primarily to the error in direction, the interpeg distances are still quite accurate overall.

As a result of this work, a revised map of the watershed and 264-ft X-10 reference grid was produced. Sections 3.5.1 and 3.5.2 describe several aspects of generating and testing this map. In summary, the new map

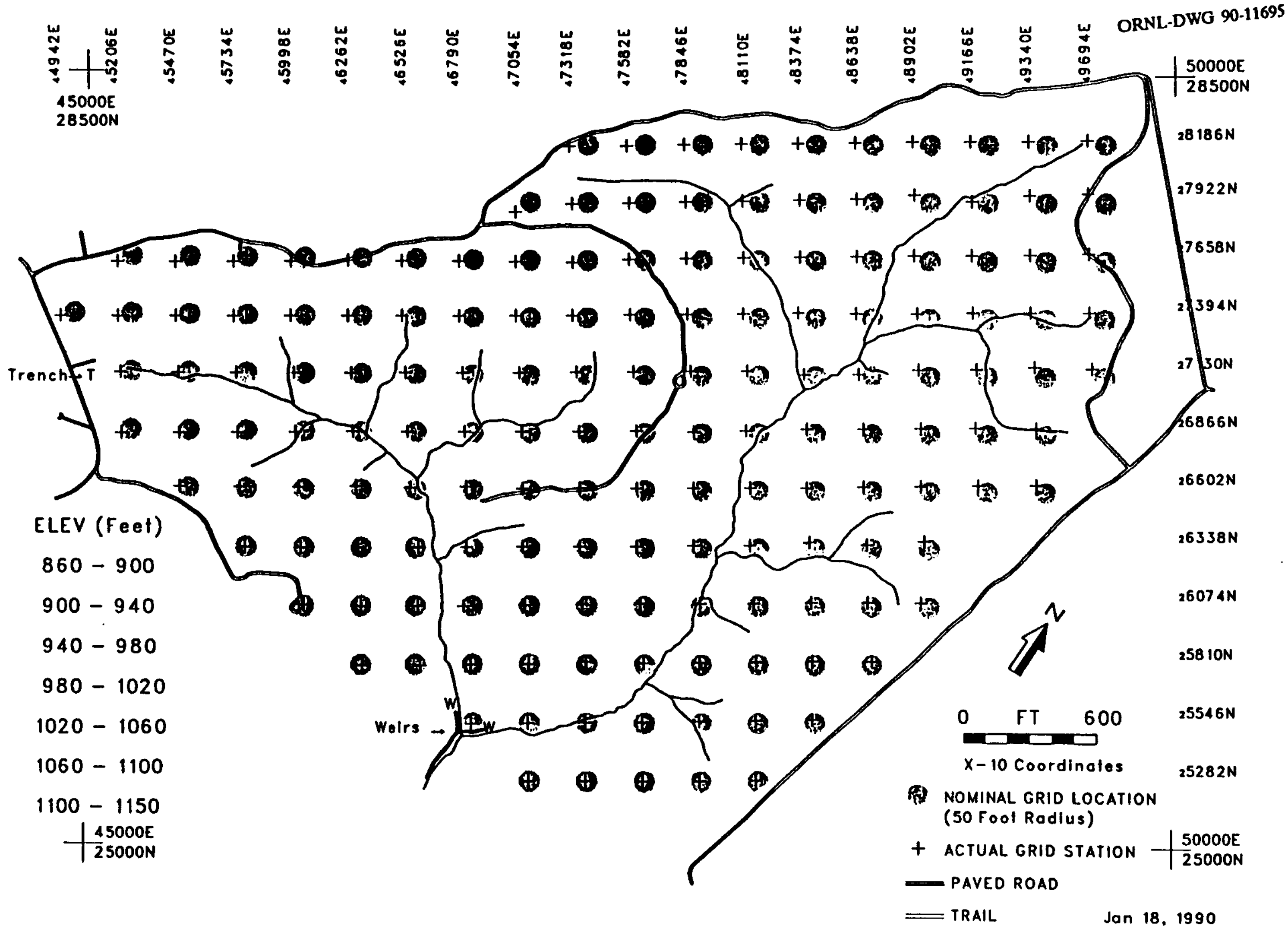

Fig. 7. Comparison of surveyed peg locations (crosses) with nominal (shaded circle) positions.

ORNL-DWG 90-11697

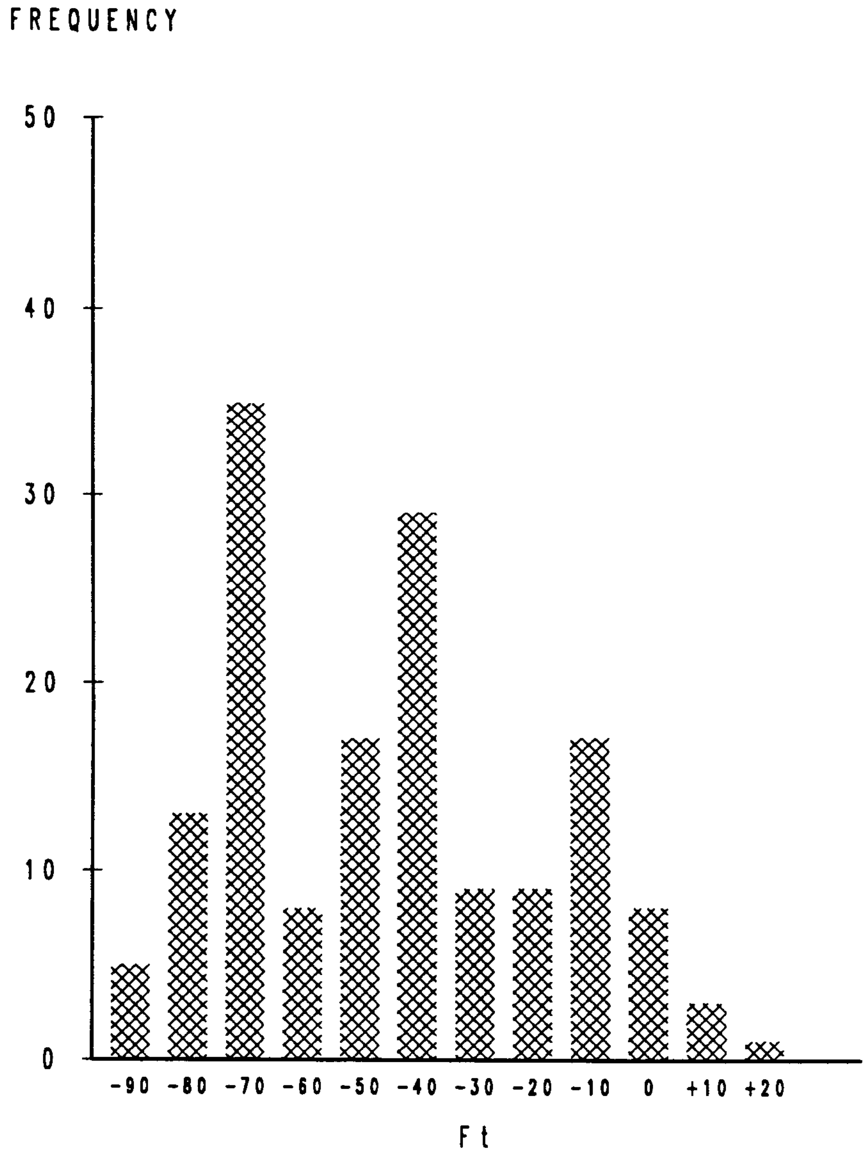

Fig. 8. Difference between nominal and actual grid eastings (in ft).

ORNL-DWG 90-11698

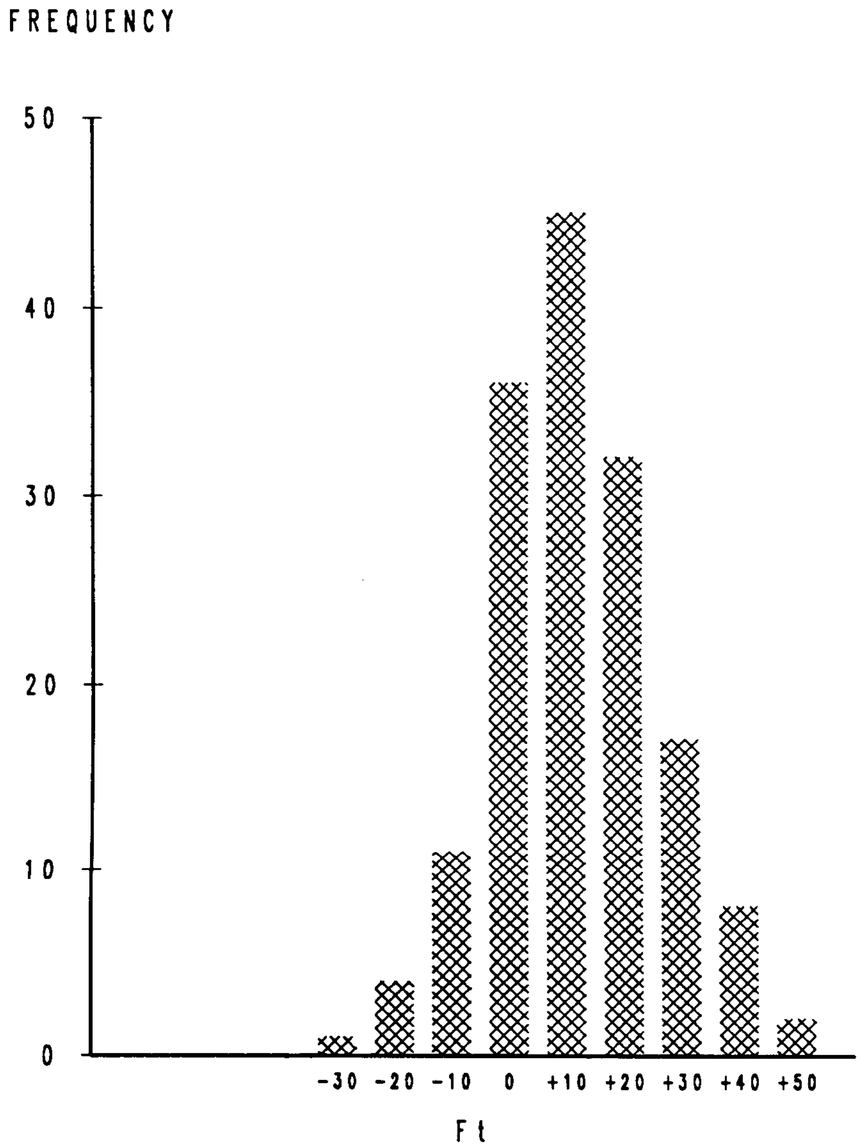

Fig. 9. Difference between nominal and actual grid northings (in ft).

1. is based on NAD-83 control points of confirmed accuracy,
2. shows the newly surveyed control points,
3. indicates which pegs were located in the field,
4. indicates which pegs are known to be missing, and
5. is accurate to within about plus or minus 5 ft.

3.5 USING THE WBW MAP

3.5.1 TVA Map Transformation and Map Registration

The purpose of this section is to describe a problem that occurred in transforming the TVA map of WBW from NAD-27 to the ADMIN grid system, which is the current system for the Walker Branch GIS data base. A consistent difference was observed between ADMIN coordinates calculated from GRIDCHG and coordinates for the same points calculated using the TVA equations (Table 5). This difference, about 3 ft in northing and about -0.4 ft in easting (GRIDCHG value minus TVA value), was also noted on the map itself. We feel this difference can be traced to the benchmark values TVA used for control (Table 6), but we do not know which values are right. This should be taken into account in future applications of the map.

Converting seven of the photoidentifiable points on this map from NAD-27 to ADMIN by way of NADCON, SPCS83, and GRIDCHG (see Sect. 4 for descriptions) yields the differences shown in Table 5. (Note that values quoted for NAD-83 were calculated by the NGS.) Similar differences (3.3 ft northing and -0.35 ft easting) were found by registering the TVA map itself on a digitizer and checking the

Table 5. Comparison of results from GRIDCHG with results from TVA equations for calculating ADMIN coordinates of seven points

(a) GRIDCHG applied to NAD-83 TN Lambert values calculated by NGS from TVA NAD-27 Tn Lambert values (in b).

Station	NAD-83 TN Lambert (m)		ADMIN (ft)	
	Easting	Northing	Easting	Northing
48-1	755641.507	182029.643	48510.5381	25671.0911
49-1	755600.135	181851.855	48063.1586	25272.8888
59-2	754351.521	181937.234	44878.2179	27864.9187
59-3	754540.870	181721.505	44977.4100	26928.3495
61-2	755174.133	182239.224	47654.5449	27117.3902
62-2	755420.530	182961.536	49682.0263	28586.9851
62-3	755747.461	182488.432	49662.8431	26700.2043

(b) TVA equations[a] applied to TVA NAD-27 TN Lambert values

Station	NAD-27 TN Lambert (m)		ADMIN (ft)	
	X	Y	Easting	Northing
48-1	2510623.4	575825.3	48510.955	25668.190
49-1	2510487.7	575242.1	48063.675	25270.014
59-2	2506391.3	575522.2	44878.642	27861.845
59-3	2507012.5	574814.5	44977.905	26925.342
61-2	2509090.1	576512.9	47654.945	27114.414
62-2	2509898.5	578882.6	49682.334	28584.047
62-3	2510971.0	577330.5	49663.202	26697.370

(c) Difference: GRIDCHG output - TVA equation output.

Station	ADMIN via GRIDCHG (ft)		ADMIN via TVA eq.[a] (ft)		Difference (ft)	
	Easting	Northing	Easting	Northing	E	N
48-1	48510.5381	25671.0911	48510.955	25668.190	-0.417	2.902
49-1	48063.1586	25272.8888	48063.675	25270.014	-0.516	2.874
59-2	44878.2179	27864.9187	44878.642	27861.845	-0.424	3.074
59-3	44977.4100	26928.3495	44977.905	26925.342	-0.495	3.007
61-2	47654.5449	27117.3902	47654.945	27114.414	-0.400	2.976
62-2	49682.0263	28586.9851	49682.334	28584.047	-0.308	2.938
62-3	49662.8431	26700.2043	49663.202	26697.370	-0.359	2.834
				Mean	-0.417	2.944

[a] E[ADMIN] = (0.81693049529)*E + (0.576847724702)*N - 2334739.1080
N[ADMIN] = (0.81693049529)*N - (0.576847724702)*E + 1003487.5906
(equations have standard deviation of 0.068 ft)

Table 6. Comparison of control point coordinates provided by TVA (ADMIN grid) with values converted from TN Lambert NAD-27 using program TRANSFORM

Monument	TN Lambert TVA (Appendix E) (ft)	ADMIN TRANSFORM[a] (ft)	ADMIN TVA (Appendix E) (ft)	TRANSFORM - TVA (ft)
1	2476636.11 x	12965.17 E	12965.99 E	0.82 E
	562340.62 y	34261.54 N	34257.19 N	4.35 N
2	2476564.16 x	13279.67 E	13280.46 E	-0.79 E
	562987.68 y	34831.67 N	34827.32 N	4.35 N
231A	2517807.68 x	66331.56 E	66331.359 E[b]	0.20 E
	596543.16 y	38452.27 N	38449.694 N[b]	2.58 N
600	2518534.67 x	67494.38 E	67494.009 E[b]	0.37 E
	597529.31 y	38838.52 N	38835.948 N[b]	3.02 N
300	2525730.77 x	77031.67 E	77031.167 E[b]	0.50 E
	603870.90 y	39868.00 E	39865.755 N[b]	2.25 N
TT-21-W	2500455.6 x	38910.93 E	38911.46 E	-0.53 E
	573584.2 y	29705.93 N	29702.56 N	3.37 N
T-21	2500930.91 x	39246.12 E	39246.67 E	-0.55 E
	573492.13 y	29356.51 N	29353.16 N	3.35 N
RTBP-68	2538037.3 x	84423.74 E	84423.51 E	0.23 E
	599256.8 y	28998.99 N	28997.21 N	1.78 N
RTBP-19	2501725.8 x	35289.39 E	35290.26 E	-0.87 E
	565507.7 y	22374.99 N	22371.65 N	3.34 N
x-13	2501627.33 x	35096.02 E	35096.90 E	-0.88 E
	565311.96 y	22271.89 N	22268.54 N	3.35 N
P-4[c]	2496770.39 x	29388.85 E	29389.82 E	-0.97 E
	562297.06 y	22610.75 N	22607.19 N	3.56 N

[a] Program TRANSFORM uses a regression equation to convert from NAD-27 TN Lambert to NAD-83 TN Lambert with a maximum error of þ 0.15 ft. It then applies equations based on the GRIDCHG program to convert to ADMIN grid (see Appendix D).

[b] These values were surveyed by Adams, Craft, Hertz and Walker and are accurate.

[c] This monument is actually 7W.

difference between nominal and digitized ADMIN cross positions. This checking procedure is described in Sect. 3.5.2.

Currently, our conclusion is that the NAD-27 TN Lambert values from TVA in Tables 1, 5 and 6 are erroneous. However, we believe that the ADMIN coordinates for monuments 231-A, 600, and 300 are correct and the X-10 coordinates for RTBP-19, X-13 and P4(7W) are correct. Because the X-10 monuments were used for survey control and the ADMIN monuments to provide the ADMIN crosses on the TVA map of WBW, we believe the map and the ADMIN crosses on it are correct. However, we do not believe the TN Lambert crosses on the map are correct. Thus, we believe (or hope) that the TVA equations in Appendix E contain self-cancelling errors, although we cannot confirm any of their transformed monument coordinates (Appendix E, DOE Plant Control prepared by TVA, 1985).

3.5.2 WBW Map Registration

When digitizing the WBW map made by TVA, there were problems obtaining accurate registration [minimum root means square (rms) error]. Consequently, an investigation was made to test the map accuracy. This showed the map to be very accurate despite the unresolved ADMIN coordinate problem. At this time, we feel the map is indeed reliable.

This map is on a mylar base at a scale of 1 in. = 100 ft. Production quality is very good, but it does have a splice running east-west; also, the scale bar does not match an engineer's ten scale, and the photoidentifiable points do not have uniform center dots.

The map was produced by traditional means, using aerial photos and field survey of the photoidentifiable points. Seven of these points are on the map itself (see Appendix F), and their coordinates are given in Table 7.

GIS users of this map are faced with a choice of reference points (tics): the photoidentifiable points or the ADMIN grid superimposed on the map. The map quality was tested using the digitizer and the ARC/INFO GIS. Since the photoidentifiable points are the basis for the map and the grid lines are derived, these seven points (see Table 7) were chosen as the primary reference tics for this test.

Table 7. TVA photoidentifiable points in TN Lambert and ADMIN.

		INPUT[a]		OUTPUT[b]	
No.	Description	X	Y	easting	northing
48.1	pole	2510623.4	575825.3	48510.538	25671.091
49.1	south pole	2510487.7	575242.1	48063.159	25272.889
59.2	fence corner	2506391.3	575522.2	44878.218	27864.919
59.3	T-road	2507012.5	574814.5	44977.410	26928.350
61.2	light spot	2509090.1	576512.9	47654.545	27117.390
62.2	lone tree	2509898.5	578882.6	49682.026	28586.985
62.3	pole	2510971.0	577330.5	49662.843	26700.204

[a] TN Lambert (NAD-27 state plane) in ft, reported by TVA (Table 1).
[b] ADMIN coordinates in m, calculated by NGS and the authors using programs NADCON, SPCS83, and GRIDCHG.

When a GIS user registers a map on a digitizer, he or she faces many potential sources of error in measuring positions on the map. Some of these are

1. distortion on the map itself
2. accuracy and repeatibility in the digitizer
3. the user's ability to position the cursor.

It is necessary to be objective in spite of these limitations, and measuring the registration error is the most objective approach.

The ARC/INFO digitizing system (ADS) reports the rms registration error as four or more tics are digitized. This error, in digitizer inches, is the rms difference in position between the nominal values and the digitized values:

$$\text{rms error} = 1/n * \sqrt{\text{sum}^n(xs - xd)^2 + \text{sum}^n(ys - yd)^2} \qquad (1)$$

where xs, ys are the nominal x and y values (scaled to inches),
xd, yd are the digitized x and y values,
and n is the number of tics.

Because the nominal values are not usually in inches, a scalar is automatically calculated by ADS to make the ranges of the two sets of values similar. Values of the rms error below 0.003 in. (approaching the digitizer resolution) are considered very good. Note that since the rms error is derived from a sum of squares, both more tics and/or one or more large errors increase the rms error. Initial tests of the TVA map with all seven photoidentifiable tics produced a large error: 0.010 in., equivalent to 1 ft on the ground. Therefore, tests with fewer tics were tried. The tics identified as the T-road and light spot would be hard to locate on the ground and were removed first. The results were much better when these two tics were omitted (see Table 8).

Table 8. Summary of tics used and the resultant registration errors in digitizing the WBW base map.

Tics used	rms error (digitizer in.)	equivalent ground error (ft)
49.1 59.2 62.2 62.3	< 0.002	0.2
49.1 59.2 59.3 62.2 62.3	0.004	0.4
49.1 59.2 61.2 62.2 62.3	0.004	0.4
49.1 59.2 59.3 61.2 62.2 62.3	0.005	0.5
All seven	0.010	1.0

The result with tics 49.1, 59.2, 62.2, and 62.3, which span the entire WBW map area, is excellent. In absolute terms, the equivalent ground error of 0.2 ft is only twice the resolution of coordinates of the tics themselves.

With the map registered and the photoidentifiable point accuracy verified, it is possible to check other features shown on the map. The ADMIN grid crosses used as tics by K. Dearstone for digitizing the map and most of the WBW GIS library coverages are of particular interest. The measurements in Table 9 were made with tics 49.1, 59.2, 62.2 and 62.3 registered with an rms error of 0.0019275 in. (equivalent ground error = 0.19275 ft).

Table 9. Difference in ft between nominal and digitized coordinates of various points on the WBW base map.

No.	Nominal ADMIN grid position		Digitized ADMIN grid position		Difference dig. - nom.		Best 4 difference	
	E	N	E	N	E	N	E	N
1	50000	28000	49999.963	28003.542	-0.037	3.542		
2	50000	27000	50000.309	27001.454	0.309	1.454	0.309	1.454
3	49000	26000	48998.726	26002.415	-1.274	2.415	-1.274	2.415
4	48000	25000	47998.992	25002.831	-1.008	2.831		
5	47000	25000	46999.321	25003.483	-0.679	3.483		
6	46000	26000	45999.557	26005.223	-0.443	5.223		
7	45000	26000	44999.336	26005.675	-0.664	5.675		
8	45000	28000	45000.668	28002.247	0.668	2.247	0.668	2.247
9	47000	28000	47000.355	28002.746	0.355	2.746	0.355	2.746
10	49000	28000	48999.293	28003.491	-0.707	3.491		
	Average error				-0.348	3.311	0.058	2.216
	Standard deviation				0.641	1.304		
	Equivalent ground rms error					3.329		2.2155
	rms error/tic rms error (0.19275)					17.3		11.5

The digitized ADMIN grid positions are an average of two measurements with repeatablility of 0.5 ft or less. (Actually most had a repeatability of 0.1 ft, except for points 1 and 2, which were close to the edge of the digitizer.) The differences between the nominal values and the digitized positions are quite large compared with the equivalent rms ground error of 0.19275 ft for the photoidentifiable tics. These calculations show clearly that even the best four of these ten ADMIN grid crosses are of secondary accuracy, having an error more than ten times larger than that of four photoidentifiable tics selected for this test.

The reader might view the misplacement of these ADMIN grid crosses, less than 1 ft in easting and about 3 ft in northing, as insignificant. For GIS mapping this may be true, but for surveying this difference is substantial. Thus, this discrepancy should be resolved before any new surveying is done.

4. GUIDE TO MAP TRANSFORMATIONS FOR TENNESSEE STATE PLANE AND LOCAL OAK RIDGE GRID SYSTEMS BASED ON NORTH AMERICAN DATUM 1983

North American coordinate systems are based on a particular standard, or datum, which describes the earth geometrically. This datum is subject to peroidic revision as, for instance, our ability to model the earth improves. There has been one revision since 1927, when the standardized system was instituted. Thus, specification of a point in any particular coordinate system must include the applicable datum--North American Datum 1927 (NAD-27) or NAD-83. The North American Datums are described further in Sect. 4.1. However, it is important to note that the terms NAD-27 and NAD-83 do not represent specific coordinate systems but are descriptors that may be applied to any system.

The standard units are feet for local Oak Ridge grid system coordinates under both NAD-27 and NAD-83. Tennessee state plane values derived under NAD-27 are also in feet, whereas those based on NAD-83 are meters.

Linear transformations convert grid coordinates from one system to another by means of specific mathematical rotation, changes of scale, and translations in the x and y directions (Fig. 10). Projections are non-linear procedures which represent locations on the earth's surface (3-D) by mapping them onto a 2-D surface. Conversions between NAD-27 and NAD-83 are similarly non-linear. Since such a mapping may not be one-to-one, projections are not necessarily reversible.

For simplicity, we shall refer to all conversion procedures as transformations although some are strictly projections. It is also important to note that these mathematical procedures may, as in the case of TN state plane and the North American Datum, be legally described.

ORNL-DWG 90-11699

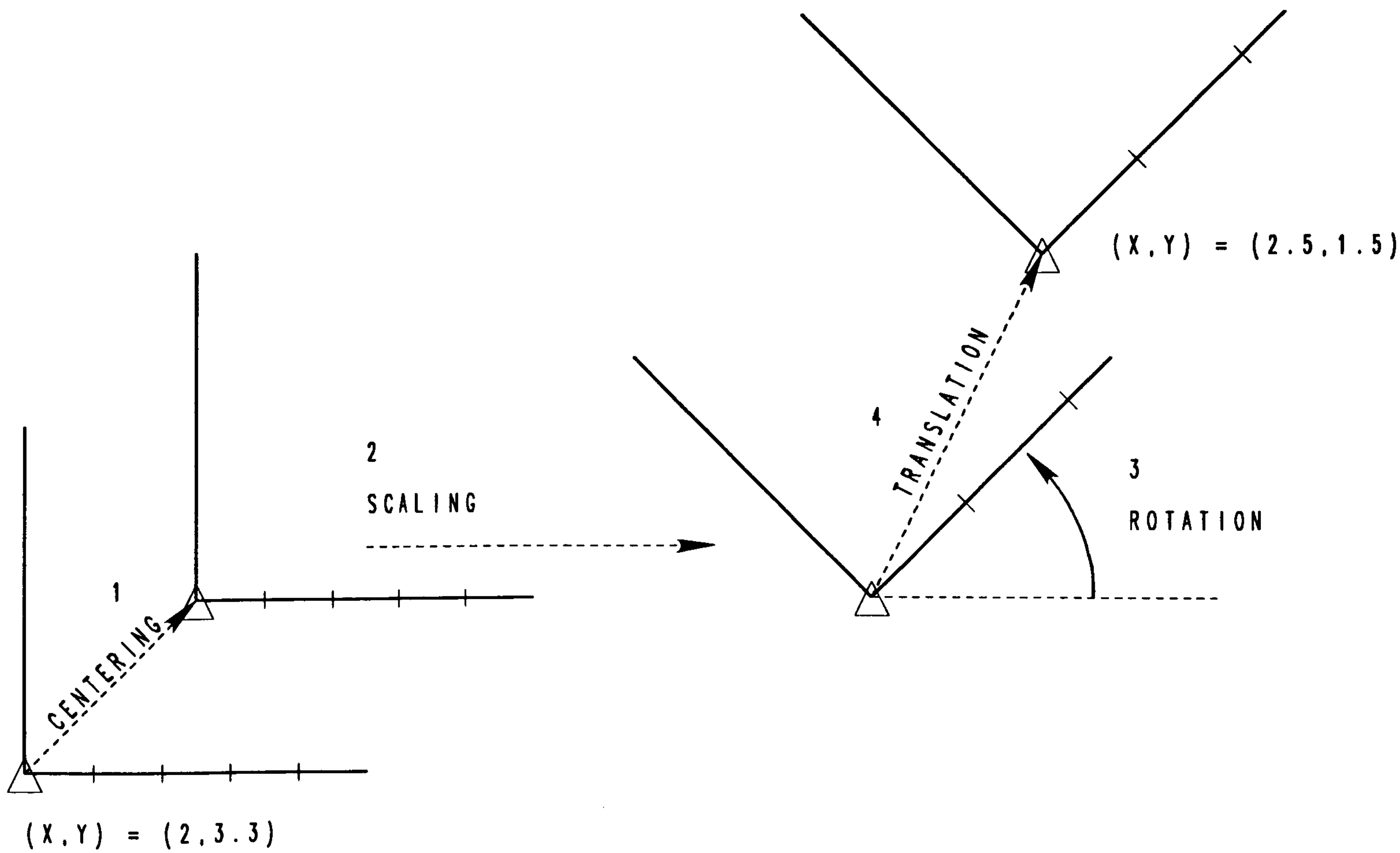

Fig. 10. Exampe 2-D transformation illustrating centering, scaling, rotation, and translation. The triangle represents a single, fixed point.

Thus, to reliably transform coordinates, one must (1) know the input data's coordinate system, including the datum on which they are based; (2) confirm the reliability of these input coordinates; (3) have access to and understand the transformation programs or algorithms required; (4) ensure that the data conform to the assumptions underlying each transformation procedure; and (5) make sure any reverse transformations which may be necessary are appropriate and do not introduce significant error.

This section is intended to provide an overview of the available computer programs (GRIDCHG, SPCS83, NADCON, and TRANSFORM) and to serve as a guide in addressing the three basic transformation problems that arise:

1. Conversion of geodetic positions (latitude, longitude) from NAD-27 (North American Datum 1927) to NAD-83
2. conversion of NAD-83 geodetic positions or NAD-27 state plane (TN Lambert) to NAD-83 state plane coordinates, and
3. transformation of coordinates between state plane and/or local Oak Ridge grid systems.

Any of the above tasks can be accomplished using the procedures and computer programs outlined herein. Assumptions are stated explicitly, and examples are provided with the discussion whenever possible. Documentation for GRIDCHG and SPCS83 is available in Adams et al. (1988).

4.1 CONVERSION FROM NAD-27 TO NAD-83

4.1.1 The 1983 Adjustment

The North American Datum is the reference system used to position the nation's horizontal control network relative to the shape (curvature) and center of the earth. Two components are involved: (1) a geoid, and (2) its mathematical representation, a reference ellipsoid. In 1927 a reference system (known as NAD-27) was developed using the Clarke Ellipsoid of 1866. This system provided adequate horizontal control and accuracy for a number of years (Wade 1986).

During the following decades, however, the addition of tens of thousands of new stations to the network and vast improvements in surveying technology uncovered weaknesses in the NAD-27. Serious problems soon arose in tying new surveys to this network, making an adjustment to the control network necessary. In 1983 a new datum for North America (NAD-83) was established based on a revised geoid and reference ellipsoid -- the Geodetic Reference System of 1980. In addition, the system of measurement used for the network was changed to the SI (metric) system at this time. The new framework eliminated much of the distortion inherent in NAD-27 and is accurate within about 1 part in 100,000 with current satellite-based positioning data (Wade 1987).

The distinction between NAD-27 and NAD-83 must be recognized and taken into account when projecting coordinates. [By convention, NAD-83 values are specified as eastings and northings (in meters) vs NAD-27, which uses xs and ys (in feet).] Many surveys based upon NAD-27 have not been converted to the corresponding NAD-83 values; unless care is taken in checking coordinates before transforming them, the potential exists for bypassing this very necessary conversion. Because NAD-27 and NAD-83 coordinates for Walker Branch differ by about 11 m, serious errors can result.

Sections 4.1.2 and 4.1.3 describe methods for transforming both geodetic positions and state plane coordinates. More detailed discussions of the 1983 adjustment, including descriptions and examples of transformation methods, can be found in Dracup (1990), Wade (1987, 1986), Wade and Doyle (1987), and Vogel (1983).

4.1.2 Conversion of NAD-27 Geodetic Positions Using NADCON

One possible approach to the NAD-27 to NAD-83 conversion problem is to enlist the help of the NGS directly. This group, from which we have had excellent service, offers technical assistance of various types and will convert coordinates submitted by users.

Alternatively, Dracup (1990), Vogel (1983), and Wade and Doyle (1987) describe several methods for converting NAD-27 geodetic positions, as well as state plane or other rectangular coordinates, to NAD-83. The NGS also offers computerized conversion programs. NADCON, which converts NAD-27 geodetic data to NAD-83 (or vice versa), is available for about $30.

4.1.3 Conversion of NAD-27 State Plane Coordinates

As with geodetic data, NAD-27-based state plane coordinates may be submitted to the NGS for conversion to NAD-83. Alternatively, conversions can be performed using differences between NAD-27 and NAD-83 values for a single point, or preferably, regressions using three or more points. Ideally, these points should be as close as possible to the region of interest to minimize the error (see Sect. 4.3.2). See Dracup (1990) for a description of a weighted mean shift method.

For example, the following simplified transformation is based on differences for a single point. Melton, the nearest control point in the national network, is about 7000 ft south and 2500 ft west of WBW. The shifts between TN state plane NAD-83 and NAD-27 are computed:

	Melton coordinates	
	X	Y
NAD-27	2501859.600(ft)	556725.490(ft)
NAD-27*12/39.37	762568.331(m)	169690.269(m)
NAD-83	752970.309(m)	176207.838(m)
NAD83 - NAD27 Difference:	- 9598.022(m)	6517.569(m)

This difference is as an approximate shift for all points in the vicinity of WBW that can be added to NAD-27 state plane values to get NAD-83 values in meters. (Note in converting feet to meters always use North American conversion factor 12/39.37, not the international conversion factor 12*2.54/100.) Table 10 lists the coordinates of the WBW photoidentifiable points obtained by applying this shift. The computed differences are accurate to < 0.05 m in easting and 0.2 m in northing.

Table 10. WBW photoidentifiable points in NAD-83 state plane obtained by using an average shift method. All values are given in meters.

Point	TN lambert NAD-27	Approximate NAD-83	TN lambert NAD-83	Error[a]
48.1	X 2510623.4	E 755641.521	E 755641.508	-0.013
	Y 575825.3	N 182029.472	N 182029.643	0.171
49.1	X 2510487.7	E 755600.159	E 755600.135	-0.024
	Y 575242.1	N 181851.712	N 181851.855	0.143
59.2	X 2506391.3	E 754351.574	E 754351.521	-0.053
	Y 575522.2	N 181937.087	N 181937.234	0.147
59.3	X 2507012.5	E 754540.916	E 754540.870	-0.046
	Y 574814.5	N 181721.379	N 181721.505	0.126
61.2	X 2509090.1	E 755174.170	E 755174.133	-0.037
	Y 576512.9	N 182239.052	N 182239.224	0.172
62.2	X 2509898.5	E 755420.571	E 755420.530	-0.041
	Y 578882.6	N 182961.339	N 182961.536	0.197
62.3	X 2510971.0	E 755747.469	E 755747.461	-0.008
	Y 577330.5	N 182488.258	N 182488.432	0.174
			Mean	E -0.032
				N 0.161

[a] Error = true NAD-83 minus approximate NAD-83.

We can then use these errors to calculate an average correction for WBW similar to method 3 of Wade (1985). This permits us to approximately convert points on WBW from NAD-27 to NAD-83. Adjusting the difference from Melton by the average errors we obtain an average correction in meters of -9598.054 E, and 6517.730 N. This simplified transformation has an error of þ 0.1 m on WBW.

A better aproximation for WBW is to use the following regression equation which is accurate to 0.015 m. It was derived by regressing NAD-83 TN state plane values on NAD-27 values for the seven TVA photo-identifiable points on WBW (see Appendix B). This equation produces NAD-83 eastings and northings in meters from NAD-27 x and y in feet:

(2)

E = 0.304810152011278 * x - 0.000003857390399 * y - 9619.774732

N = 0.304814624296977 * y + 0.000002840107391 * x + 6502.527601

The next formula, based on a regression of eight points (see Table 2 and Appendix B), spans the entire Oak Ridge Reservation and has an accuracy of 0.05 m:

(3)

E = 0.304808733909068 * x - 0.0000043972060 * y - 9615.934956

N = 0.304809697719075 * y + 0.0000041562824 * x + 6502.067784

Note that neither of these two sets of equations is absolutely correct, although they produce very precise results. This is because their coefficients were derived by regression rather than using the rigorous, legal descriptions embodied in programs SPCS83 and NADCON.

4.2 CONVERSION OF NAD-83 GEODETIC POSITIONS TO STATE PLANE GRID

One conversion common to many applications is that from latitude, longitude to the state plane system. For instance, state plane coordinates are a necessary intermediate in converting geodetic positions (degrees, minutes, seconds) to one of the local grids. SPCS83 [see Adams et al. (1988)] is a simple-to-use program for making this NAD-83 geodetic to state plane conversion (or vice versa). The program is well-documented and provides a number of options for both input and output. The only information needed, aside from the positions to be transformed, is a zone code identifying the appropriate state and region (TN is zone 4100). These codes are included in the program documentation.

An example of the output from the NGS program GPPC83, v.1, using the 1983 Datum is shown below for three stations. The degrees, minutes, and seconds were input at the appropriate prompts, and an output filename was specified. Note that northings and eastings are output for NAD-83 in meters.

	Input		Output	
Name	Latitude	Longitude	Northing	Easting
48-1	35 57 41.84700	84 16 28.02300	182029.643	755641.508
49-1	35 57 36.10300	84 16 29.79900	181851.855	755600.135
59-2	35 57 39.58400	84 17 19.56300	181937.234	754351.521

4.3 TRANSFORMATIONS BETWEEN LOCAL GRID SYSTEMS

4.3.1 GRIDCHG

Given coordinates in state plane (based on NAD-83) or one of the four local grids, conversions can be made between any pair. The recommended and most accurate approach is to use the program GRIDCHG [see Adams et al. (1988)]. Any transformation directly to or from state plane coordinates (referred to in the program as NAD-83) requires only one pass through GRIDCHG. Transformations between any two local grids (X-10, Y-12, K-25, or ADMIN) use state plane as an intermediate step and thus require two passes.

In using GRIDCHG one must decide on the mode of input, mode of output, and whether to compute or input two transformation-specific parameters: rotation angle and scale factor. For most applications involving local grids, simply inputting these numbers directly from the program documentation is sufficient. Input and output may be either keyboard to screen, keyboard to file, or file to file. For any transformation between local grids, it is best to output the intermediate (state plane) coordinates to a file that can then be used as input for the final computations. (Note: GRIDCHG has no provision for processing NAD-27 values.)

For example, suppose the following X-10 coordinates (in feet) are to be converted to ADMIN.

Station	X-10 Easting	X-10 Northing
48-1	48573.1744	25631.9321
49-1	48128.9127	25230.2332
59-2	44923.7197	27797.3333

Because no direct transformation is provided, GRIDCHG must first be used to obtain state plane values (in meters, based on NAD-83). Using GRIDCHG and inputting the rotation angle and scale factor provided in the program documentation (+34 46 40.5817 and 0.30476866322, respectively) we obtain:

	X-10 input		NAD-83 output	
Station	Easting	Northing	Easting	Northing
48-1	48573.1744	25631.9321	755641.508	182029.643
49-1	48128.9127	25230.2332	755600.135	181851.855
59-2	44923.7197	27797.3333	754351.521	181937.234

When an output file is specified, these values can be read directly for the second GRIDCHG execution. By again specifying the appropriate rotation angle (-35 13 41.9198) and scale factor (3.28109950844), the desired results in ADMIN coordinates (feet) are produced (see below).

If no output file were created in the first run, the intermediate NAD-83 values would have to be entered from the keyboard. This is an unnecessary task and a potential source of error, especially for a large number of stations. Also, when an output file is used, the rotation angle and scale factor entered by the user are automatically recorded with the output coordinates.

	NAD-83 input		ADMIN output	
Station	Easting	Northing	Easting	Northing
48-1	755641.508	182029.643	48510.5381	25671.0911
49-1	755600.135	181851.855	48063.1586	25272.8888
59-2	754351.521	181937.234	44878.2179	27864.9187

4.3.2 Transformation Equations and TRANSFORM

Program GRIDCHG was written to perform specific mathematical transformations between NAD-83 control points on the geoid and the local grid systems. Sixteen NAD-83 control points were obtained by use of a Global Positioning System (GPS) in 1987 by Geophysical Service, Inc. (Adams et al. 1988). These points all have quoted values in both NAD-83 and the local grid systems to the nearest 0.001 ft. Certain of these points (known as pivot points) were chosen to be the origin for a particular local grid system. The pivot point coordinates along with the rotation angle and scale factor can be used to derive the transformation equations in program GRIDCHG. These equations (Appendix C) have been incorporated into a FORTRAN program called TRANSFORM.

Program TRANSFORM (Appendix D) performs

1. conversions of feet to meters or vice versa,
2. conversions from NAD-27 TN state plane to NAD-83 state plane,
3. conversions between local grid systems, and
4. conversions to/from local grid systems and NAD-83 TN state plane.

TRANSFORM has one advantage over GRIDCHG in that it converts directly between local grid systems in a single step (intermediate state plane coordinates are omitted). The equations incorporated into TRANSFORM are described in the following.

The mathematical formula for a 2-D transformation of an x,y pair requires a multiplication by a matrix with the necessary form. Coordinates are, first, centered about the pivot point of the old system; second, rotated to the orientation of the new grid system; third, compressed or expanded by a scale change; and finally, translated by their distance from the new origin (Fig. 10). We will illustrate this procedure with a particular formula with values taken from the GRIDCHG documentation.

For example, to obtain NAD-83 from X-10 coordinates:

$$\left| \begin{matrix} E(NAD83) \\ N(NAD83) \end{matrix} \right| = \left| EC(X\text{-}10) \;\; NC(X\text{-}10) \;\; 1 \right| * \left| \begin{matrix} \cos A & \sin A & 0 \\ -\sin A & \cos A & 0 \\ Te & Tn & 1 \end{matrix} \right| \qquad (4)$$

or

$$E(NAD83) = \cos A * EC(X\text{-}10) - \sin A * NC(X\text{-}10) + Te,$$
$$N(NAD83) = \sin A * EC(X\text{-}10) + \cos A * NC(X\text{-}10) + Tn,$$

where

EC(X-10) = centered X-10 easting,
= SF* (X-10 - 32687.878),

NC(X-10) = centered X-10 northing,
= SF* (X-10 - 22255.884),

SF = scale factor to convert from X-10 to NAD-83 (0.30476866322),

A = rotation angle from X-10 to NAD-83 (34°, 46′, 48.5817″),

Te = E translation of pivot point from NAD-83 origin (752252.011 meters),

Tn = N translation of pivot point from NAD-83 origin (178422.906 meters).

The matrix performs a four-step process. Centering about the pivot point is accomplished by the use of centered coordinates based on the

X-10 to NAD-83 pivot point (C008) with coordinates 32687.878 E and 22255.884 N. Then, these centered values are rotated by angle A to the new coordinate system. Finally, these rotated values are scaled and translated to their correct position by (Te,Tn), the pivot point's NAD-83 coordinates.

The presence of the scale factor changes the matrix multiplication from a strictly 2-D process to a 3-D projection. The scale factor [defined by Cross et al. (1980) as the ratio of a geodesic to its projected length] compensates for the earth's shape at the pivot point. This scale factor is very close to 1. In this matrix the scale factor also includes the foot-to-meter conversion factor (or its reciprocal). Hence, the scale factor is close to 39.37/12 = 3.2803333.. or its reciprocal 0.304800610... but never exactly equal to either of these.

The matrix equation [Eq.(4)] above can be simplified to:

(5)

E(NAD83) = 0.2503207562*E(X-10) - 0.1738489490*N(X-10) + 747938.7187 ,

N(NAD83) = 0.1738489490*E(X-10) + 0.2503207562*N(X-10) + 167169.0431 ,

where the added constants now include the centering amounts.

To transform from NAD-83 to ADMIN, we need a matrix equation using the pivot point 2009 and the rotation angle and scale factor from NAD-83 to ADMIN

(6)

E(ADMIN) = cos Q*EC(NAD83) - sin Q*NC(NAD83) + TE ,

N(ADMIN) = sin Q*EC(NAD83) + cos Q*NC(NAD83) + TN ,

where Q is the rotation angle from NAD83 to ADMIN (-35°, 13', 41.9198"),

TE = easting translation of pivot point from ADMIN origin (72791.453 ft),

TN = northing translation of pivot point from ADMIN origin (42601.023 ft).

Equation (6) can be simplified to

$$E(ADMIN) = 2.6801988500*E(NAD83) + 1.8926563631*N(NAD83) - 2321278.52477 ,$$
$$N(ADMIN) = -1.8926563631*E(NAD83) + 2.6801988500*N(NAD83) + 967965.15966 . \tag{7}$$

To perform transformations between two local grid systems, it is necessary to perform the matrix multiplications by Eqs. (5 and 7), successively. Because matrix multiplication is not commutative, there is no shortcut. Thus, to create ADMIN coordinates from X-10 coordinates, we must first generate NAD-83 coordinates by Eq.(5) and convert these to ADMIN coordinates by Eq.(7). A complete set of equations for local grid system transformations derived from the definitions used in GRIDCHG are given in Appendix C. These duplicate the behavior of GRIDCHG, except for correcting for elevation, and therefore, supercede any regression equations.

4.3.3 Approximate Regression Equations

Linear transformations may be estimated using SAS procedure REG (SAS 1985). However SAS solves the equations for easting and northing independently as it attempts to find the best least-squares fit. Also, it does not use NAD-83 as an intermediate system as does GRIDCHG. Consequently, SAS does not produce equations with the correct mathematical form for 2-D rotation and translation. Such equations may be sufficiently accurate for mapping purposes if the coordinates to be converted are near the points used in the regression. Because they do not have the correct mathematical form, regression equations should be assessed on the basis of their residuals rather than their coefficients.

For conversion to/from NAD-83 values, there is little incentive to use regression equations since they are less accurate than GRIDCHG and offer no shortcut. For direct conversion from one local system to another, linear regressions can provide a shortcut at the expense of somewhat reduced accuracy. We recommend these formulas be used only for mapping purposes.

For example, a linear regression applied to the C008 (X-10), C011 (Y-12), and 2009 (ADMIN) reservation rotation points was derived for the direct X-10 to ADMIN conversion:

(8)

E[ADMIN]= 0.9999458184*E[X-10]+0.00782127127*N[X-10] -260.4782190 ,

N[ADMIN]= -0.0078214628*E[X-10]+0.9999458170 *N[X-10] +420.4609099 .

The error for this equation on WBW is less than 0.001 ft.

The ADMIN to X-10 conversion is given by

(9)

E[X-10]= 0.999993005*E[ADMIN] -0.00782164138*N[ADMIN] +263.7651003 ,

N[X-10]=.00782183173*E[ADMIN] + 0.9999930058*N[ADMIN] -418.4205385 .

The error in this case is also < 0.001 ft. These equations were calculated to extended precision using an orthogonal factorization program on an HP15c calculator (HP15c Advanced Functions Handbook, 1984, p. 143). Note the approximate symmetry in these equations.

Two caveats should be given regarding the accuracy and precision of these equations. The first is that coordinates may be calculated from these equations to a greater precision (0.001 ft) than the coordinates from which they are derived. Thus, the precision of the original coordinates places an upper limit on the conversion precision. A second is that a potential loss of accuracy exists for coordinates not "near" the values used to derive the equations. Thus, when possible, values derived from regression equations should be checked against GRIDCHG or TRANSFORM with points in the region of interest.

Four "rules of thumb" accurate to the nearest foot on WBW, and thus suitable for use in ARC/INFO applications, are

(10)

E[ADMIN] = E[X-10] + 0.0078*N[X-10] - 263 ,

N[ADMIN] = -0.0078*E[X-10] + N[X-10] + 418 .

and

(11)

E[X-10] = E[ADMIN] - 0.0078*N[ADMIN] + 263 ,

N[X-10] = 0.0078*E[ADMIN] + N[ADMIN] - 418 .

The constants for these equations were calculated using 'average' coordinates for WBW. Therefore, (10) is similar to (8), and (11) is similar to (9).

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APPENDIX A

INVENTORY PLOT COORDINATES AND MAP

Table A.1. Walker Branch permanent forest inventory plots' revised X-10 coordinates. These were derived using original placement notes (directed distances from grid lines) and revised grid line coordinates.

PLOT	X	Y	PLOT	X	Y
1	47013	27630	51	45958	26405
2	47118	27674	52	46827	26008
3	47382	27716	53	46756	25832
4	44878	27280	54	46537	27650
5	45010	27402	55	45763	27064
6	45221	27483	56	46819	27118
7	45326	27486	57	46767	27206
8	45484	27486	58	45975	27286
9	45535	27549	59	46064	27502
10	45694	27513	60	46117	27505
11	45379	27486	61	46223	27417
12	47323	26457	62	46275	27329
13	47205	26592	63	46223	27590
14	47014	27294	64	46379	27622
15	47325	27808	65	45932	27574
16	45552	27062	66	45748	27323
17	46943	26410	67	47518	27664
18	46210	26552	68	47482	27598
19	46220	26406	69	45959	27194
20	45400	26744	70	46344	27289
21	47346	27036	71	45136	26916
22	47399	27036	72	45400	26920
23	47399	27080	73	46001	26632
24	46941	26632	74	46421	26590
25	47147	26764	75	46368	26546
26	47258	26413	76	46273	26362
27	47205	26325	77	46273	26450
28	47154	26454	78	46325	26318
29	47465	26944	79	45922	27110
30	47557	27215	80	45869	27066
31	47111	26189	81	45975	27066
32	47224	27473	82	45823	26836
33	46732	26508	83	45235	27194
34	46679	26464	84	45288	27018
35	46724	26848	85	45288	27238
36	46734	26408	86	47013	27762
37	46787	26408	87	46907	27674
38	46053	26632	88	46106	26720
39	47435	27388	89	46210	26772
40	47541	27432	90	45763	27240
41	45721	27489	91	45816	27196
42	45830	27492	92	45235	27258
43	45505	26700	93	45552	27194
44	46802	27467	94	45499	27238
45	46555	27028	95	46088	26841
46	47135	27165	96	47188	27124
47	47099	26632	97	47082	27077
48	46809	25744	98	46564	26758
49	46011	26361	99	46512	26802
50	46104	26552	100	47200	26940

Table A.1 (continued).

PLOT	X	Y	PLOT	X	Y
101	46638	26364	151	47910	27302
102	46627	26274	152	49191	26834
103	46378	26274	153	48588	27352
104	45130	27228	154	48495	27030
105	46186	27025	155	48399	27248
106	46133	27025	156	48294	27028
107	45558	26744	157	48241	27072
108	46352	26978	158	48044	26596
109	46527	26678	159	48149	26640
110	46474	26634	160	48096	26640
111	46559	26634	161	47782	26374
112	46669	26184	162	47676	26462
113	46670	26184	163	47834	26418
114	46699	26052	164	48843	28252
115	46577	25830	165	48548	27030
116	46682	25830	166	48413	26780
117	46713	25744	167	47024	25879
118	46703	25700	168	48541	26208
119	49152	26701	169	48646	26208
120	49258	26706	170	48371	27530
121	47325	27896	171	48326	27786
122	47428	27856	172	48382	26161
123	47084	27910	173	48020	25540
124	47010	27875	174	48073	25672
125	48888	26696	175	47970	25354
126	48888	26652	176	49386	27362
127	47819	27262	177	48466	27002
128	47804	27302	178	47217	26062
129	48765	27442	179	49459	27070
130	48818	27398	180	48876	27186
131	47956	27394	181	49531	28322
132	48838	26208	182	48960	27824
133	47872	27042	183	48960	27868
134	47819	27086	184	48738	28092
135	47641	26198	185	48653	27118
136	47466	26504	186	48641	27396
137	47571	26504	187	48044	26728
138	47571	26724	188	49372	28274
139	47623	26768	189	48802	27794
140	47940	26682	190	49500	28366
141	47887	26682	191	49636	28366
142	47676	26242	192	49636	28278
143	47940	26765	193	49594	27588
144	47729	26897	194	48887	26961
145	48959	26352	195	48966	27492
146	48801	26400	196	49019	27536
147	49725	28278	197	47182	25172
148	48890	26164	198	47654	25176
149	47819	26966	199	49386	27450
150	47598	26812	200	49406	27290

Table A.1 (continued).

PLOT	X	Y	PLOT	X	Y
201	49406	27246	251	47742	27992
202	48771	27054	252	47689	28036
203	49320	28098	253	49531	28190
204	49267	28142	254	47652	25488
205	48050	28242	255	47444	25174
206	48367	28235	256	47391	25394
207	48579	28203	257	47375	26194
208	49171	27666	258	47782	26242
209	49118	27798	259	47375	25974
210	48548	27162	260	47694	26066
211	48114	26114	261	47483	26022
212	48114	25982	262	47483	26198
213	49535	27992	263	47467	26283
214	49274	27984	264	47467	26371
215	48642	26338	265	48294	27248
216	48642	26470	266	48294	27160
217	48730	26515	267	47940	26462
218	48336	25720	268	48266	27310
219	48336	25852	269	47971	26814
220	48074	25936	270	49414	27010
221	47206	28116	271	49414	26966
222	47596	28235	272	47182	25703
223	49171	27912	273	47340	25936
224	49372	28362	274	47389	25484
225	48508	25852	275	47494	25488
226	49330	27626	276	48632	28088
227	49559	27284	277	48906	27982
228	48853	27894	278	48906	28026
229	49171	27578	279	47442	25572
230	49244	27010	280	47336	25660
231	49089	27190	281	47951	27820
232	48322	27914	282	48056	27820
233	48428	28046	283	48056	27864
234	49689	28146	284	47951	28040
235	48527	28088	285	48004	27952
236	47533	27856	286	48062	27694
237	49650	27540	287	48168	27606
238	48114	26158	288	47945	28126
239	48220	25982	289	48801	27938
240	48748	26250	290	47417	28075
241	48537	26250	291	47470	28163
242	48388	25896	292	47786	28210
243	48441	25720	293	48641	27832
244	48488	25985	294	48538	27790
245	48488	26161	295	47499	25798
246	48021	25716	296	47552	25842
247	49267	28362	297	47552	25710
248	48374	26392	298	47311	28160

ORNL-DWG 90-11696

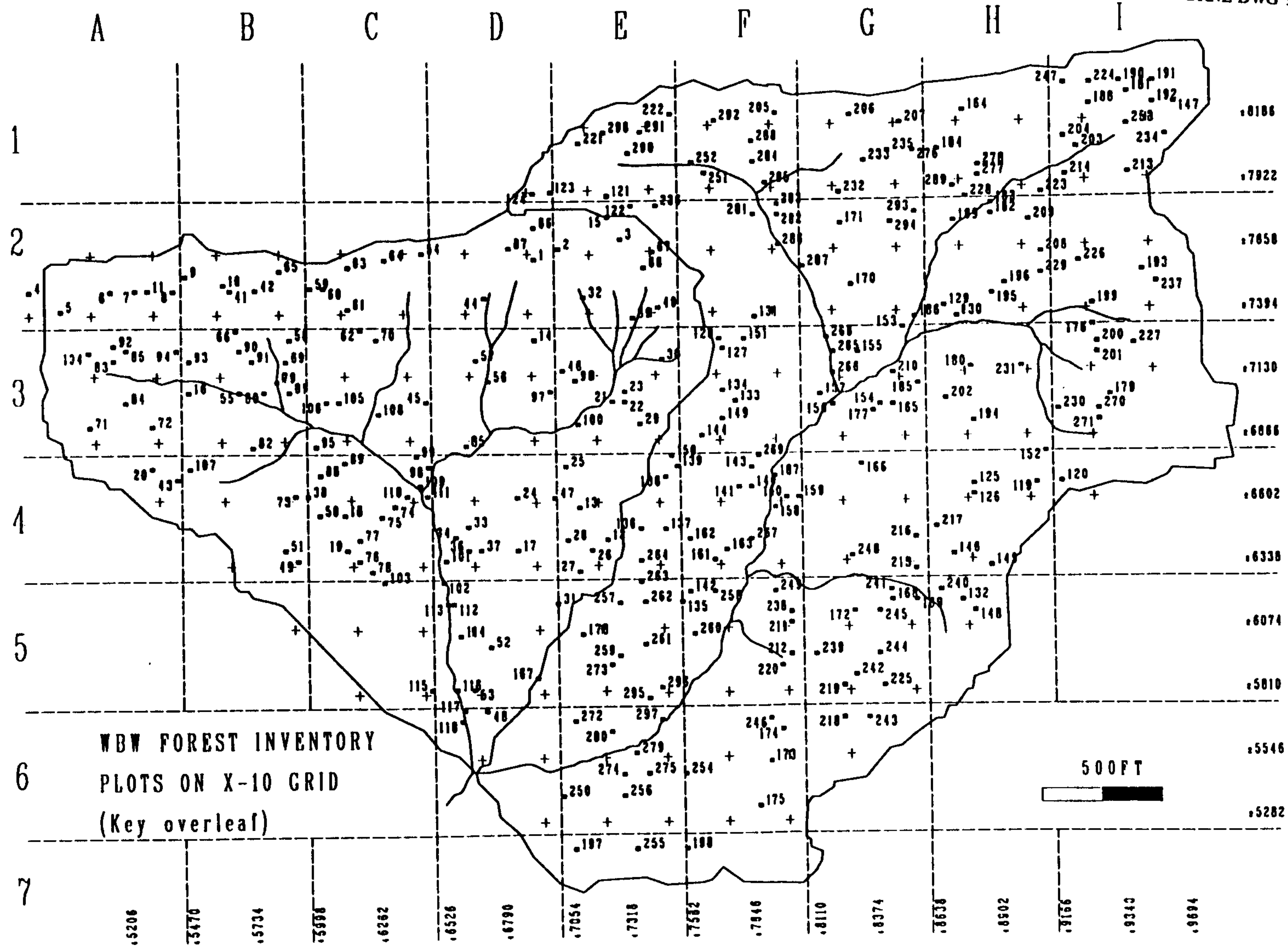

Fig. A.1. 298 permanent forest inventory plots were established on the watershed in 1967 using the reference grid.

APPENDIX B

EXAMPLE REGRESSION (SAS)

REGRESSION ON 8 NAD27 POINTS SPANNING ENTIRE S16A MAP TO NAD83

SAS input 'program' to find a straight line equation (regression) relationship between NAD27 values and NAD83 values

Final result (for input NAD27 X and Y in feet)

```
E (m) = 1.0000266545*12/39.37*X - 0.0000043972060*Y - 9615.934956
N (m) = 1.0000298166*12/39.37*Y + 0.0000041562824*X + 6502.067784
```

```
OPTIONS PS=60 LS=72;
LIBNAME OUT '[STQ.SAS]';

DATA OUT.A1;
  INPUT  X Y E N ;
  FORMAT X Y E N 12.4;
  CARDS;
  2460000     560000      740211.070 177205.720
  2490000     600000      749355.183 189398.246
  2520000     610000      758499.375 192446.433
  2550000     580000      767643.773 183302.295
  2510000     540000      755451.618 171109.731
  2490000     530000      749355.459 168061.532
  2501859.60  556725.49   752970.309 176207.838
  2500930.91  573492.13   752687.150 181318.425
  ;
  data out.a1; set out.a1;
  XM = X * 12. / 39.37; YM = Y * 12. / 39.37;
  FORMAT XM YM 12.4;
  run;
  PROC PRINT DATA=OUT.A1;
  PROC REG DATA=OUT.A1;
    VARIABLES XM YM E N;
    MODEL  E =XM YM/P R CLM CLI;
    OUTPUT OUT=E PREDICTED=PE RESIDUAL=RE ;
    MODEL  N =XM YM/P R CLM CLI;
    OUTPUT OUT=N PREDICTED=PN RESIDUAL=RN;
  TITLE 'REGRESSION ON 8 NAD27 POINTS SPANNING ENTIRE S16A MAP TO NAD83';
  RUN;
  DATA E ;
    SET E;
    FORMAT PE 12.4 RE 12.9;
  RUN;
  DATA N ;
    SET N;
    FORMAT PN 12.4 RN 12.9;
  RUN;
  PROC PRINT DATA=E;
  PROC PRINT DATA=N;
  PROC PLOT  DATA=E;
    PLOT RE*XM;
    TITLE 'RESIDUAL NAD83 EASTING AS FUNCTION OF X IN METERS';
  RUN;
  PROC PLOT  DATA=N;
    PLOT RN*YM;
    TITLE 'RESIDUAL NAD83 NORTHING AS FUNCTION OF Y IN METERS';
  RUN;

  RUN;
```

		Input NAD27 (ft)		NAD83 (m)
	OBS	X	Y	E
Eight	1	2460000.0000	560000.0000	740211.0700
points	2	2490000.0000	600000.0000	749355.1830
on	3	2520000.0000	610000.0000	758499.3750
S16A	4	2550000.0000	580000.0000	767643.7730
map	5	2510000.0000	540000.0000	755451.6180
	6	2490000.0000	530000.0000	749355.4590
Melton	7	2501859.6000	556725.4900	752970.3090
T-21	8	2500930.9100	573492.1300	752687.1500

		NAD83 (m)	Input NAD27 (m)	
	OBS	N	XM	YM
Eight	1	177205.7200	749809.4996	170688.3414
points	2	189398.2460	758953.5179	182880.3658
on	3	192446.4330	768097.5362	185928.3719
S16A	4	183302.2950	777241.5545	176784.3536
map	5	171109.7310	765049.5301	164592.3292
	6	168061.5320	758953.5179	161544.3231
Melton	7	176207.8380	762568.3312	169690.2687
T-21	8	181318.4250	762285.2659	174800.7508

REGRESSION ON 8 NAD27 POINTS SPANNING ENTIRE S16A MAP TO NAD83 2
14:20 WEDNESDAY, JANUARY 3, 1990

DEP VARIABLE: E

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	440325750.91	220162875.45	999999.990	0.0001
ERROR	5	0.003232678	0.0006465357		
C TOTAL	7	440325750.91			

ROOT MSE	0.02542707	R-SQUARE	1.0000
DEP MEAN	753271.7	ADJ R-SQ	1.0000
C.V.	.00000337555		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-9615.934956	0.92812762	-10360.574	0.0001
XM	1	1.0000266545	.00000126962	99999.999	0.0001
YM	1	-.0000144265	.00000119203	-12.102	0.0001

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT
1	740211.1	740211.1	0.018286	740211.0	740211.1	740211.0
2	749355.2	749355.2	.0163676	749355.1	749355.2	749355.1
3	758499.4	758499.4	.0170254	758499.3	758499.4	758499.3
4	767643.8	767643.8	.0196462	767643.7	767643.8	767643.7
5	755451.6	755451.6	.0146651	755451.6	755451.7	755451.5
6	749355.5	749355.5	.0161935	749355.4	749355.5	749355.4
7	752970.3	752970.3	.0099567	752970.2	752970.3	752970.2
8	752687.2	752687.1	.0092229	752687.1	752687.2	752687.1

OBS	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2 -1 0 1 2
1	740211.2	-.018051	0.017668	-1.0217	| **| |
2	749355.3	.0088197	.0194586	0.4533	| | |
3	758499.5	-.017226	.0188858	-.912106	| *| |
4	767643.9	-0.01316	.0161419	-.815252	| *| |
5	755451.7	.0053087	.0207718	0.2556	| | |
6	749355.6	-.022985	.0196038	-1.1725	| **| |
7	752970.3	.0348718	.0233966	1.4905	| |** |
8	752687.2	.0224213	.0236955	0.9462	| |* |

SUM OF RESIDUALS	-1.60071E-10
SUM OF SQUARED RESIDUALS	0.003148786
PREDICTED RESID SS (PRESS)	0.007587343

REGRESSION ON 8 NAD27 POINTS SPANNING ENTIRE S16A MAP TO NAD83 4
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DEP VARIABLE: N

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	499523753.22	249761876.61	999999.990	0.0001
ERROR	5	0.003255419	0.0006510839		
C TOTAL	7	499523753.22			

ROOT MSE	0.02551635	R-SQUARE	1.0000
DEP MEAN	179881.3	ADJ R-SQ	1.0000
C.V.	0.0000141851		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6502.067784	0.93138645	6981.063	0.0001
XM	1	.00001363607	.00000127408	10.703	0.0001
YM	1	1.0000298166	.00000119622	99999.999	0.0001

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT
1	177205.7	177205.7	.0183502	177205.7	177205.8	177205.6
2	189398.2	189398.2	.0164251	189398.2	189398.3	189398.2
3	192446.4	192446.5	.0170852	192446.4	192446.5	192446.4
4	183302.3	183302.3	.0197152	183302.2	183302.3	183302.2
5	171109.7	171109.7	.0147166	171109.7	171109.8	171109.7
6	168061.5	168061.6	.0162503	168061.5	168061.6	168061.5
7	176207.8	176207.8	.0099917	176207.8	176207.8	176207.7
8	181318.4	181318.4	.0092553	181318.4	181318.4	181318.4

OBS	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2 -1 0 1 2
1	177205.8	-.002967	0.01773	-0.16736	| | |
2	189398.3	.0104351	.0195269	0.5344	| |* |
3	192446.5	-.024231	.0189521	-1.2785	| **| |
4	183302.4	.0040127	.0161986	0.2477	| | |
5	171109.8	-.005827	.0208448	-.279537	| | |
6	168061.6	-.024724	.0196726	-1.2568	| **| |
7	176207.9	.0434557	.0234787	1.8509	| |*** |
8	181318.5	-1.5E-04	.0237786	-.006507	| | |

SUM OF RESIDUALS	4.72937E-11
SUM OF SQUARED RESIDUALS	0.003254568
PREDICTED RESID SS (PRESS)	0.00682426

REGRESSION ON 8 NAD27 POINTS SPANNING ENTIRE S16A MAP TO NAD83 6
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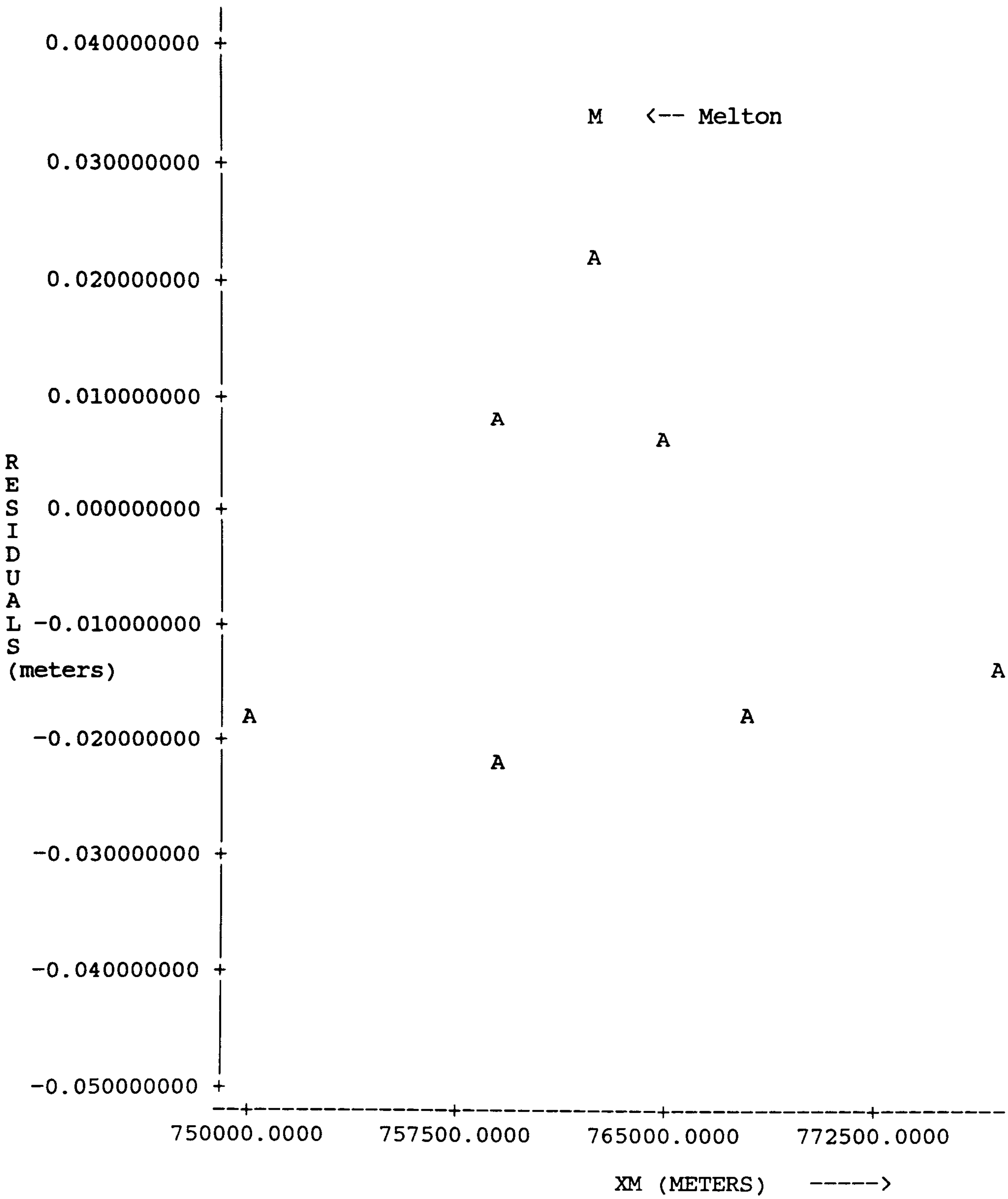
OBS	X	Y	E	N
1	2460000.0000	560000.0000	740211.0700	177205.7200
2	2490000.0000	600000.0000	749355.1830	189398.2460
3	2520000.0000	610000.0000	758499.3750	192446.4330
4	2550000.0000	580000.0000	767643.7730	183302.2950
5	2510000.0000	540000.0000	755451.6180	171109.7310
6	2490000.0000	530000.0000	749355.4590	168061.5320
7	2501859.6000	556725.4900	752970.3090	176207.8380
8	2500930.9100	573492.1300	752687.1500	181318.4250

	NAD27 X (m)	NAD27 Y (m)	Predicted East (m)	Residual East (m)
OBS	XM	YM	PE	RE
1	749809.4996	170688.3414	740211.0881	-0.018051071
2	758953.5179	182880.3658	749355.1742	0.008819693
3	768097.5362	185928.3719	758499.3922	-0.017225824
4	777241.5545	176784.3536	767643.7862	-0.013159715
5	765049.5301	164592.3292	755451.6127	0.005308725
6	758953.5179	161544.3231	749355.4820	-0.022984962
7	762568.3312	169690.2687	752970.2741	0.034871811
8	762285.2659	174800.7508	752687.1276	0.022421342

	NAD27 X (m)	NAD27 Y (m)	Predicted North (m)	Residual North (m)
OBS	XM	YM	PN	RN
1	749809.4996	170688.3414	177205.7230	-0.002967295
2	758953.5179	182880.3658	189398.2356	0.010435123
3	768097.5362	185928.3719	192446.4572	-0.024230635
4	777241.5545	176784.3536	183302.2910	0.004012705
5	765049.5301	164592.3292	171109.7368	-0.005826886
6	758953.5179	161544.3231	168061.5567	-0.024723956
7	762568.3312	169690.2687	176207.7945	0.043455675
8	762285.2659	174800.7508	181318.4252	-0.000154731

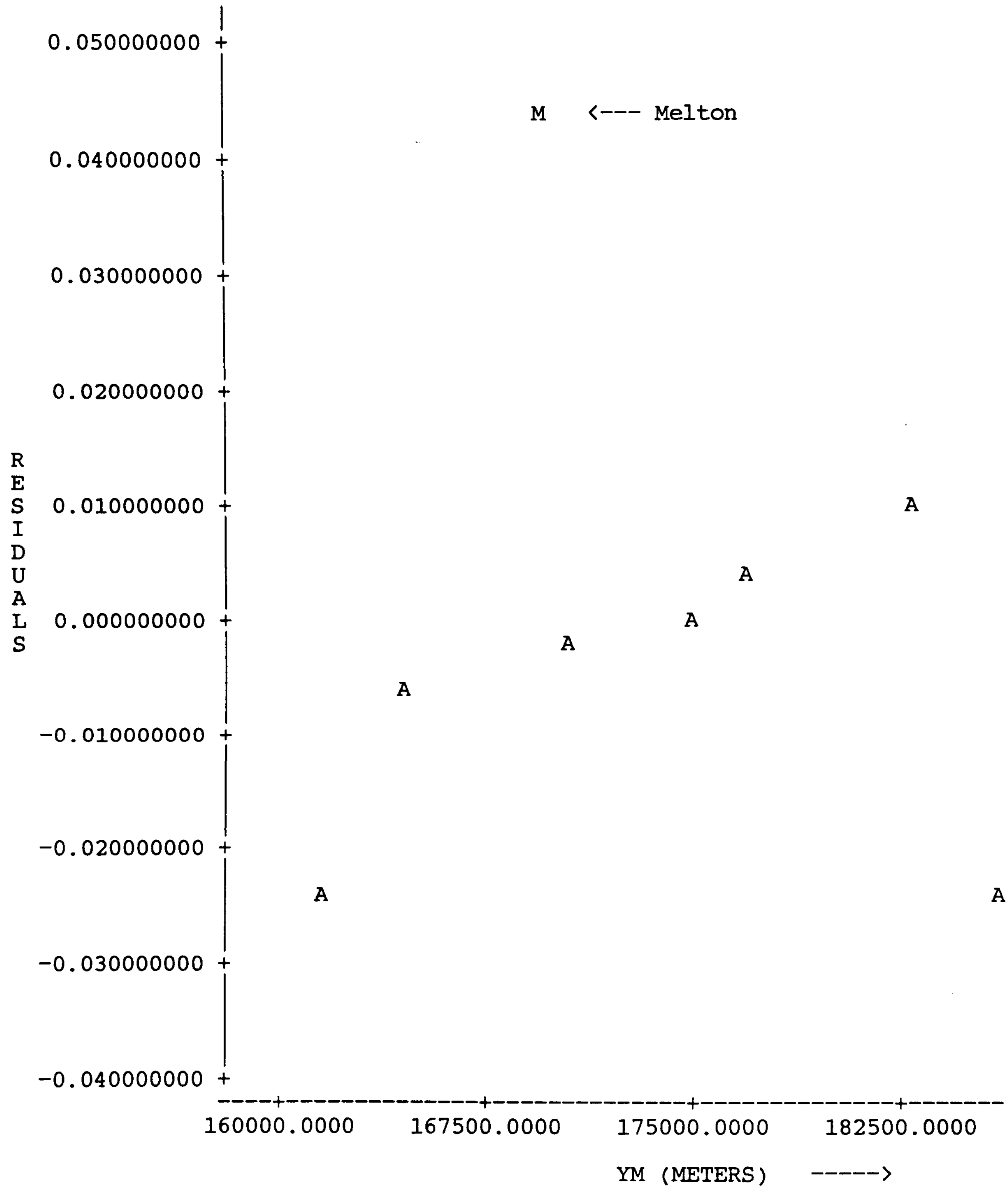
RESIDUAL NAD83 EASTING AS FUNCTION OF X IN METERS 8
14:20 WEDNESDAY, JANUARY 3, 1990

PLOT OF RE*XM LEGEND: A = 1 OBS, B = 2 OBS, ETC.



RESIDUAL NAD83 NORTHING AS FUNCTION OF Y IN METERS 9
14:20 WEDNESDAY, JANUARY 3, 1990

PLOT OF RN*YM LEGEND: A = 1 OBS, B = 2 OBS, ETC.



APPENDIX C

TRANSFORMATION EQUATIONS

APPENDIX C

EQUATIONS TO/FROM LOCAL OAK RIDGE GRID SYSTEMS AND NAD-83

Transformation equations derived from Definitions for Program GRIDCHG (page 22 of GRIDCHG documentation)

(Note: to go from a local grid system to another local system, it is necessary to calculate NAD-83 E and N first, then calculate new grid system X and Y values.)

TRANSFORMATION EQUATIONS FROM LOCAL GRID SYSTEMS TO NAD-83

(Input local grid X and Y values are in feet, output NAD-83 E and N values are in meters)

```
from ADMIN
   E = 0.2489592190*X(ADMN) -0.1758057056*Y(ADMN) + 748077.48662
   N = 0.1758057056*X(ADMN) +0.2489592190*Y(ADMN) + 167110.15882

from K-25
   E = 0.3029123485*X(K-25) -0.0336026312*Y(K-25) + 744322.97774
   N = 0.0336026312*X(K-25) +0.3029123485*Y(K-25) + 186597.78622

from X-10
   E = 0.2503207562*X(X-10) -0.1738489490*Y(X-10) + 747938.71870
   N = 0.1738489490*X(X-10) +0.2503207562*Y(X-10) + 167169.04305

from Y-12
   E = 0.2496716913*X(Y-12) -0.1747867025*Y(Y-12) + 747982.60738
   N = 0.1747867025*X(Y-12) +0.2496716913*Y(Y-12) + 167159.44602
```

TRANSFORMATION EQUATIONS FROM NAD-83 TO LOCAL GRID SYSTEMS

(input NAD-83 E and N values are in meters, output local grid X and Y values are in feet)

```
to ADMIN
   X(ADMN)=  2.6801988500*E +1.8926563631*N -2321278.52477
   Y(ADMN)= -1.8926563631*E +2.6801988500*N + 967965.15966

to K-25
   X(K-25)=  3.2611536654*E +0.3617658520*N -2494856.31419
   Y(K-25)= -0.3617658520*E +3.2611536654*N - 339253.41826

to X-10
   X(X-10)=  2.6949843148*E +1.8716793520*N -2328569.96149
   Y(X-10)= -1.8716793520*E +2.6949843148*N + 949383.50746

to Y-12
   X(Y-12)=  2.6879267545*E +1.8817265645*N -2325070.83240
   Y(Y-12)= -1.8817265645*E +2.6879267545*N + 958186.39485
```

APPROXIMATE REGRESSION EQUATIONS

FOR SPECIAL PURPOSES

NAD-27 TO NAD-83 conversion for entire S16A map
accuracy better than plus or minus .05m

(from SAS regression on 8 points spanning the
Oak Ridge reservation, see appendix H)

(Input NAD-27 X and Y values in feet,
output NAD-83 E and N values in meters)

```
to NAD-83
  E = 1.0000266545*12/39.37*X -0.0000043972060*Y -9615.934956
  N = 1.0000298166*12/39.37*Y +0.0000041562824*X +6502.067784
```

NAD-27 TO NAD-83 for WBW watershed
accuracy better than plus or minus .015m

(from SAS regression on 7 photo-identifiable points
on WBW in table 5)

(Input NAD-27 X and Y values in feet,
output NAD-83 E and N values in meters)

```
to NAD-83
   E = 1.000031307057*12/39.37*X - 0.000003857390399*Y
       -9619.774732

   N = 1.000045979881*12/39.37*Y + 0.000002840107391*X
       +6502.527601
```

APPROXIMATE REGRESSION EQUATIONS FOR SPECIAL PURPOSES

X-10 to ADMIN on WBW watershed
(error less than plus or minus 0.001 foot)

(from regression on C008, C011 and 2009 pivot points)

(both input and output are in feet)

to ADMIN

```
E[ADMIN]=  0.9999458184*E[X-10]+0.00782127127*N[X-10]
          -260.4782190

N[ADMIN]= -0.0078214628*E[X-10]+0.9999458170 *N[X-10]
          +420.4609099
```

ADMIN to X-10 on WBW watershed
(error less than plus or minus .001 foot)

(from regression on C008, C011 and 2009 pivot points)

(both input and output are in feet)

to X10

```
E[X-10]= 0.999993005*E[ADMIN] -0.00782164138*N[ADMIN]
         +263.7651003

N[X-10]=.00782183173*E[ADMIN] + 0.9999930058*N[ADMIN]
         -418.4205385
```

These equations were calculated to extended precision using an orthogonal factorization program on an HP15c calculator.

APPENDIX D

FORTRAN PROGRAM TRANSFORM CODE

APPENDIX D: PROGRAM TRANSFORM

```
      program transform
c     ---------------------------------------------------------------
c    |         author: SIDEY TIMMINS, ORNL, PO Box 2008
c    |                 Bldg 1505, Oak Ridge, TN 37831-6038
c    |
c    |        Purpose: perform transformations between Oak Ridge
c    |                 local grid systems
c    |
c    |    based upon:  Adams, Craft, Hertz & Walker documentation
c    |                 for program GRIDCHG (by Tom Pidgeon, GSI).
c    |
c    |        tested: for local to local with coordinates from
c    |                Final Report, Adams, Craft, Hertz & Walker
c    |                GPS Survey, Oak Ridge TN, Oct 28,1988 and
c    |                for NAD27->NAD83 with coordinates from NGS.
c     ---------------------------------------------------------------
c
      character*80 card,card2,format
      character*1  do
      logical      to adm, to k25, to x10, to y12, to nad27, to nad83
      logical      fr adm, fr k25, fr x10, fr y12, fr nad27, fr nad83
      logical      fr local, to local, input,outfile
      integer      ifld(2,20)
      real*8       theta,cos0,sin0,const1,const2,sinq,cosq
      real*8       sf,x,y,e,n,xx,yy

     write(*,1) ' TRANSFORM:  does meter or feet conversions'
     write(*,1) ' (Jan 90)    with N American ft = 12/39.37m,'
     print *
     write(*,1) '     or      transforms local Oak Ridge Grid system'
     write(*,1) '             coordinates to/from TN state plane,'
     print *
     write(*,1) '     or      transforms local Oak Ridge Grid'
     write(*,1) '             to each other,'
     print *
     write(*,1) '     or      does arbitrary coord rotations.'

c
     write(*,'(/A/)')
    *         ' Note 1)  <CR> skips to next prompt, <ctrl z> backs u
     write(*,1)'      2)  for transformations, units are feet except'
     write(*,3)'          NAD83 (meters). Order is always x,y or E,N.
     write(*,3)'      3)  Numbers do not contain commas!'
     write(*,1)'      4)  All results match GRIDCHG (except for elev'
     write(*,1)'          correction) and are accurate to .001ft or m
     write(*,3)'          except NAD27 to NAD83 (.015m)'

     write(*,1)'$Continue? :'
```

```
      read *
1     format(A)
2     format(1X,4F14.4)
3     format(A/)
      lu = 7
100   write(*,'(/A)') ' Choose to convert coordinates (M or FT)'
      write(*,1) ' or do arbitrary coordinate rotation (R)'
      write(*,1) ' or transform coordinates(input, output systems)'
      write(*,'(A/A/A)')
     * '                           e.g. ADM, X10    ',
     * '                           or   Y12, K25    ',
     * '$                          or   NAD27, NAD83: '
      close(lo,err=110)
110   close(lu,err=120)
120   lu = 5
      read(*,1,end=999,err=100) card2
      nofs = nfld(card2,ifld)
      if(nofs.eq.0) goto 999
      i = ifld(1,1)
      j = ifld(2,1)
      do = card2(i:i)
      input    = .false.
      outfile  = .false.
c                          input file/output file

140   write(*,1) ' Choose interactive (<CR>)'
      write(*,1) '$or enter input and output files: '
      read(*,1,end=100) card
      nof = nfld(card,ifld)
      if(nof.eq.1) goto 140
      if(nof.eq.2) then
c                       check for user jumping the gun
        read(card,*,err=150) x,y
        goto 160
150     lu = 7
        lo = 8
        i = ifld(1,1)
        j = ifld(2,1)
        open(lu,file=card(i:j),status='old')
        i = ifld(1,2)
        j = ifld(2,2)
        open(lo,file=card(i:j),status='NEW',CARRIAGECONTROL='LIST')

        write(*,1) ' Enter FORTRAN format for input x or x,y'
        write(*,1) '$or    choose default * (<CR>): '
        read(*,1,end=100) format
        nof = nfld(format,ifld)
        if(nof.ne.0) input = .true.
        outfile = .true.
      endif
```

```
C                          unit conversions or arbitrary rotation
160     continue
        nofs = nfld(card2,ifld)
        i = ifld(1,1)
        j = ifld(2,1)
        if(do.eq.'m'.or.do.eq.'M') goto 200
        if(do.eq.'f'.or.do.eq.'F') goto 300
        if(do.eq.'r'.or.do.eq.'R') goto 900
        if(nofs.eq.1) go to 100

        fr adm = do.eq.'a'.or.do.eq.'A'
        fr k25 = do.eq.'k'.or.do.eq.'K'
        fr x10 = do.eq.'x'.or.do.eq.'X'
        fr y12 = do.eq.'y'.or.do.eq.'Y'
        fr nad27 = card2(i:j).eq.'nad27'.or.card2(i:j).eq.'NAD27'
        fr nad83 = card2(i:j).eq.'nad83'.or.card2(i:j).eq.'NAD83'
        fr local = fr adm .or. fr k25 .or. fr x10 .or. fr y12

        i = ifld(1,2)
        j = ifld(2,2)
        do = card2(i:i)
        to adm = do.eq.'a'.or.do.eq.'A'
        to k25 = do.eq.'k'.or.do.eq.'K'
        to x10 = do.eq.'x'.or.do.eq.'X'
        to y12 = do.eq.'y'.or.do.eq.'Y'
        to nad27=card2(i:j).eq.'nad27'.or.card2(i:j).eq.'NAD27'
        to nad83=card2(i:j).eq.'nad83'.or.card2(i:j).eq.'NAD83'
        to local = to adm .or. to k25 .or. to x10 .or. to y12

C===============================================================
C           from local to NAD83
C           from NAD83 to local
C           from local to local
C           from NAD27 to NAD83
C           from NAD27 to local
C===============================================================

        if(fr local  .and. to nad83) goto 400
        if(fr nad83  .and. to local) goto 500
        if(fr local  .and. to local) goto 600
        if(fr nad27  .and. to nad83) goto 700
        if(fr nad27  .and. to local) goto 800
```

```
c
c                       unit conversion (feet or meters)
c
200   write(*,1) '$Enter coordinates to convert to meters:'
      read(lu,1,end=100) card
      nof = nfld(card,ifld)
      if(nof.eq.0) goto 300

      if(nof.eq.2) then
        if(input)      read(card,format,err=200) x,y
        if(.not.input)      read(card,*,err=200) x,y
      else
        if(input)      read(card,format,err=200) x
        if(.not.input)      read(card,*,err=200) x
      endif

      E=  x*12.d0/39.37d0
      N = y*12.d0/39.37d0
      print *,'meters E:', E
      if(nof.eq.2) print *,'meters N:', N
      if(outfile.and.nof.eq.1)      write(lo,2) E
      if(outfile.and.nof.eq.2)      write(lo,2) E, N
      goto 200

300   write(*,1) '$Enter coordinates to convert to feet:'
      read(lu,1,end=100) card
      nof = nfld(card,ifld)
      if(nof.eq.0) goto 100

      if(nof.eq.2) then
        if(input)      read(card,format,err=300) x,y
        if(.not.input)      read(card,*,err=300) x,y
      else
        if(input)      read(card,format,err=200) x
        if(.not.input)      read(card,*,err=200) x
      endif

      E=  x*39.37d0/12.d0
      N = y*39.37d0/12.d0
      print *,'feet x:', E
      if(nof.eq.2) print *,'feet y:', N
      if(outfile.and.nof.eq.2) write(lo,2) E
      if(outfile.and.nof.eq.1) write(lo,2) E, N
      goto 300
```

```
c
c                    from local X,Y to NAD-83 conversions
c
400     continue
         if(fr adm)write(*,1) '$Enter ADM X,Y to convert to NAD-83:'
         if(fr k25)write(*,1) '$Enter K25 X,Y to convert to NAD-83:'
         if(fr x10)write(*,1) '$Enter X10 X,Y to convert to NAD-83:'
         if(fr y12)write(*,1) '$Enter Y12 X,Y to convert to NAD-83:'

         read(lu,1,end=100) card
         nof = nfld(card,ifld)
         if(nof.eq.0) goto 100
         if(input)      read(card,format,err=400) x,y
         if(.not.input)      read(card,*,err=400) x,y

         if(fr adm) call adm (.true.,x,y,E,N)
         if(fr k25) call k25 (.true.,x,y,E,N)
         if(fr x10) call x10 (.true.,x,y,E,N)
         if(fr y12) call y12 (.true.,x,y,E,N)

         print *,'meters E:',E,' N:',N
         if(outfile)     write(lo,2) E, N
         goto 400
c
c                   from NAD-83 E,N to local grid X,Y
c
500     continue
         if(to adm) write(*,1) '$Enter NAD83 E,N to convert to ADMIN:'
         if(to k25) write(*,1) '$Enter NAD83 E,N to convert to K-25:'
         if(to x10) write(*,1) '$Enter NAD83 E,N to convert to X-10:'
         if(to y12) write(*,1) '$Enter NAD83 E,N to convert to Y-12:'

         read(lu,'(A)',end=100) card
         nof = nfld(card,ifld)
         if(nof.eq.0) goto 100
         if(input)      read(card,format,err=500) e,n
         if(.not.input)      read(card,*,err=500) e,n

         if(to adm) call adm (.false.,X,Y,e,n)
         if(to k25) call k25 (.false.,X,Y,e,n)
         if(to x10) call x10 (.false.,X,Y,e,n)
         if(to y12) call y12 (.false.,X,Y,e,n)

         print *,'feet X:',X,' Y:',Y
         if(outfile)     write(lo,2) X,Y
         goto 500
```

```
c
c               from local x,y to local X,Y
c
600    continue
        if(to adm) write(*,1) '$Enter X,Y to convert to ADMIN:'
        if(to k25) write(*,1) '$Enter X,Y to convert to K-25:'
        if(to x10) write(*,1) '$Enter X,Y to convert to X-10:'
        if(to y12) write(*,1) '$Enter X,Y to convert to Y-12:'

        read(lu,'(A)',end=100) card
        nof = nfld(card,ifld)
        if(nof.eq.0) goto 100
        if(input)      read(card,format,err=600) x,y
        if(.not.input)      read(card,*,err=600) x,y

        if(fr adm) call adm (.true.,x,y,E,N)
        if(fr k25) call k25 (.true.,x,y,E,N)
        if(fr x10) call x10 (.true.,x,y,E,N)
        if(fr y12) call y12 (.true.,x,y,E,N)

        if(to adm) call adm (.false.,XX,YY,e,n)
        if(to k25) call k25 (.false.,XX,YY,e,n)
        if(to x10) call x10 (.false.,XX,YY,e,n)
        if(to y12) call y12 (.false.,XX,YY,e,n)

        print *,'feet X:',XX,' Y:',YY
        if(outfile)      write(lo,2) XX,YY
        goto 600
c
c                 from NAD-27 X,Y to NAD-83
c
700     continue
        if(to nad83)write(*,1) '$Enter NAD27 X,Y to convert to NAD83:'

        read(lu,1,end=100) card
        nof = nfld(card,ifld)
        if(nof.eq.0) goto 100
        if(input)      read(card,format,err=700) x,y
        if(.not.input)      read(card,*,err=700) x,y

        call nad2783 (.true.,x,y,E,N)

        print *,'meters E:',E,' N:',N
        if(outfile)      write(lo,2) E,N
        goto 700
```

```
c
c                   from NAD-27 X,Y to local grid X,Y
800     continue
        if(to adm) write(*,1) '$Enter NAD27 X,Y to convert to ADMIN:'
        if(to k25) write(*,1) '$Enter NAD27 X,Y to convert to K-25:'
        if(to x10) write(*,1) '$Enter NAD27 X,Y to convert to X-10:'
        if(to y12) write(*,1) '$Enter NAD27 X,Y to convert to Y-12:'

        read(lu,'(A)',end=100) card
        nof = nfld(card,ifld)
        if(nof.eq.0) goto 100
        if(input)       read(card,format,err=800) x,y
        if(.not.input)       read(card,*,err=800) x,y

        call nad2783 (.true.,x,y,E,N)
        if(to adm) call adm (.false.,XX,YY,e,n)
        if(to k25) call k25 (.false.,XX,YY,e,n)
        if(to x10) call x10 (.false.,XX,YY,e,n)
        if(to y12) call y12 (.false.,XX,YY,e,n)

        print *,'feet X:',XX,' Y:',YY
        if(outfile)      write(lo,2) XX,YY
        goto 800
c                   rotate x,y coordinates by a general rotation
c
900     continue
        write(*,1) ' Enter rotation angle (in decimal degrees)'
        write(*,1) '                          (anti-clockwise is +ve): '
        read(lu,1,end=100) card
        nof = nfld(card,ifld)
        if(nof.eq.0) goto 100
        read(card,*,err=900) theta
        cos0 = dcosd(theta)
        sin0 = dsind(theta)

910     write(*,1)' Enter E translation, N translation, scale factor: '
        write(*,1)'$         (                    defaults are 0,0, 1.0): '
        read(lu,1,end=900) card
        nof = nfld(card,ifld)
        const1 = 0.0d0
        const2 = 0.0d0
        sf     = 1.0d0
        if(nof.lt.2) goto 910
        if(nof.eq.2) read(card,*,err=910) const1,const2
        if(nof.eq.3) read(card,*,err=910) const1,const2,sf

950     write(*,1) '$Enter coordinates (x,y) to rotate: '
        read(lu,1,end=900) card
        nof = nfld(card,ifld)
        if(nof.eq.0) goto 100
        read(card,*) x,y
        if(input)       read(card,format,err=950) x,y
        if(.not.input)       read(card,*,err=950) x,y
          E = x*cos0 - y*sin0 + const1
          N = x*sin0 + y*cos0 + const2
        print *,'new X:',E,'new Y:',N
        if(outfile)      write(lo,2) E, N
        goto 950

999     stop
      end
```

```
      subroutine adm(to nad83,x,y,E,N)
      logical  to nad83
      real*8   theta,cos0,sin0,sinq,cosq
      real*8   a,b,c,d,x,y,e,n
      data     a,b,c,d/758710.087d0 ,190513.229d0
     *                  72791.453d0 ,42601.023d0/
C
C                   ADMIN
C
400   theta = 35.d0 + 13.d0/60.d0 +41.9198d0/3600.d0
      cosq =  dcosd (theta)
      sinq =  dsind (theta)
      cos0 =  cosq*0.30477588303d0
      sin0 =  sinq*0.30477588303d0

      if(to nad83) then
        E = x*cos0 - y*sin0 + a - cos0*c +sin0*d
        N = x*sin0 + y*cos0 + b - sin0*c -cos0*d
      else
        cos0 =   cosq*3.28109950844d0
        sin0 =  -sinq*3.28109950844d0
        x = E*cos0 - N*sin0 + c  -cos0*a +sin0*b
        y = E*sin0 + N*cos0 + d - sin0*a -cos0*b
      endif
      return
      end

      subroutine k25(to nad83,x,y,E,N)
      logical  to nad83
      real*8   theta,cos0,sin0,sinq,cosq
      real*8   a,b,c,d,x,y,e,n
      data     a,b,c,d/745096.796d0, 178398.283d0,
     *                  -442.760d0  -27019.781d0/
C
C                               K-25
C
      theta = 6.d0 + 19.d0/60.d0 +48.1679d0/3600.d0
      cosq =  dcosd (theta)
      sinq =  dsind (theta)
      cos0 =  cosq*0.30477045079d0
      sin0 =  sinq*0.30477045079d0

      if(to nad83) then
        E = x*cos0 - y*sin0 + a - cos0*c +sin0*d
        N = x*sin0 + y*cos0 + b - sin0*c -cos0*d
      else
        cos0 =   cosq*3.28115799085d0
        sin0 =  -sinq*3.28115799085d0
        x = E*cos0 - N*sin0 + c  -cos0*a +sin0*b
        y = E*sin0 + N*cos0 + d - sin0*a -cos0*b
      endif
      return
      end
```

```
      subroutine x10(to nad83,x,y,E,N)
      logical  to nad83
      real*8   theta,cos0,sin0,sinq,cosq
      real*8   a,b,c,d,x,y,e,n
      data     a,b,c,d/752252.011d0,  178422.906d0,
     *                 32687.878d0,   22255.884d0/
C
C                           X-10
C
      theta = 34.d0 + 46.d0/60.d0 +48.5817d0/3600.d0
      cosq =  dcosd (theta)
      sinq =  dsind (theta)
      cos0 =  cosq*0.30476866322d0
      sin0 =  sinq*0.30476866322d0
      if(to nad83) then
        E = x*cos0 - y*sin0 + a - cos0*c +sin0*d
        N = x*sin0 + y*cos0 + b - sin0*c -cos0*d
      else
        cos0 =   cosq*3.28117723595d0
        sin0 =  -sinq*3.28117723595d0
        x = E*cos0 - N*sin0 + c  -cos0*a +sin0*b
        y = E*sin0 + N*cos0 + d - sin0*a -cos0*b
      endif
      return
      end

      subroutine y12(to nad83,x,y,E,N)
      logical  to nad83
      real*8   theta,cos0,sin0,1,2,sinq,cosq
      real*8   a,b,c,d,x,y,e,n
      data     a,b,c,d/755685.060d0 , 184117.408d0
     *                 52613.876d0 ,  31087.850d0/
C
C                           Y-12
C
      theta = 34.d0 + 59.d0/60.d0 +40.4313d0/3600.d0
      cosq =  dcosd (theta)
      sinq =  dsind (theta)
      cos0 =  cosq*0.30477261161d0
      sin0 =  sinq*0.30477261161d0

      if(to nad83) then
        E = x*cos0 - y*sin0 + a - cos0*c +sin0*d
        N = x*sin0 + y*cos0 + b - sin0*c -cos0*d
      else
        cos0 =   cosq*3.28113472769d0
        sin0 =  -sinq*3.28113472769d0
        x = E*cos0 - N*sin0 + c  -cos0*a +sin0*b
        y = E*sin0 + N*cos0 + d - sin0*a -cos0*b
      endif
      return
      end
```

```
      subroutine nad2783(to nad83,x,y,E,N)
      logical  to nad83
      real*8   sf,x,y,e,n
C
C                NAD27 to NAD83 for Oak Ridge reservation
C

      if(to nad83) then
        sf = 12.d0/39.37d0
        E = 1.0000266545d0*sf*x - 0.0000043972060*y - 9615.934956d0
        N = 1.0000298166d0*sf*y + 0.0000041562824*x + 6502.067784d0
      else
        print *,'nad83 to nad27 not implemented yet'
c        x =
c        y =
      endif
      return
      end
```

```
C+     NAME               NFLD.FOR
C      PURPOSE            COUNTS NUMBER OF FIELDS ON A CARD
C      LANGUAGE           FORTRAN (F77)
C      AUTHOR             SIDEY TIMMINS
C      DATE               OCT 20, 1986
C-     FIRST USED ON      VAX 11-785, College Of Geographic Sciences
C=================================================================
C DESCRIPTION
C      COUNTS          #OF THINGS (FIELDS) ON A CARD
C                      Fields are separated by commas, blanks or ;
C      FOR EXAMPLE; THERE ARE, 10 FIELDS ON THIS CARD
C1     2  3            4     5    6  7       8  9    10
C=================================================================
C VARIABLE DEFINITION SECTION
C      ARGUMENTS          INPUT   ----CARD  CHARACTER BUFFER TO SEARCH
C              OUTPUT  ----IFLD  START,STOP COLUMN OF EACH FIELD
C                         ----NFLD  NUMBER OF FIELDS
C      LOCAL VARIABLES ----I  DO LOOP INDEX
C                         ----CURRENT  CURRENT COLUMN VALUE ON CARD
C                         ----N  COUNT OF NUMBER OF FIELDS
C=================================================================
C DECLARATIONS
      FUNCTION NFLD(CARD,IFLD)
      CHARACTER*(*) CARD
      CHARACTER*(1) CBLANK,COMMAA,CSEMII
      INTEGER       CURRENT,IFLD(2,1)
      DATA          CBLANK/' '/,COMMAA/','/,CSEMII/';'/
C=================================================================
C PROCESS
      N=0
      CURRENT=0
      DO 100 I=1,LEN(CARD)
C         found a terminator
         IF(CURRENT.NE.0.AND.(CARD(I:I).EQ.CBLANK.OR.
     &      CARD(I:I).EQ.COMMAA.OR. CARD(I:I).EQ.CSEMII)) THEN
            N = N +1
            IFLD(1,N) = CURRENT
            IFLD(2,N) = I
            IF(CARD(I:I).EQ.CBLANK) IFLD(2,N)=I-1
            CURRENT=0
         ENDIF
C         non terminator, so increase current column
         IF(CURRENT.EQ.0.AND.CARD(I:I).NE.CBLANK.AND.
     &      CARD(I:I).NE.COMMAA.AND.CARD(I:I).NE.CSEMII) CURRENT=I
C         reached end of card, so terminate current field
         IF(CURRENT.NE.0.AND.I.EQ.LEN(CARD)) THEN
            N = N + 1
            IFLD(1,N) = CURRENT
            IFLD(2,N) = I
         ENDIF
100   CONTINUE
C         set # fields
      NFLD = N
      RETURN
      END
```

APPENDIX E

TVA REGRESSION EQUATIONS AND DOE PLANT CONTROL VALUES

OAK RIDGE, TENNESSEE
DEPARTMENT OF ENERGY PLANT CONTROL
COORDINATE TRANSFORMATIONS AND RELATED FORMULAE

Prepared By:
TENNESSEE VALLEY AUTHORITY
MAPPING SERVICES BRANCH
COMPUTING UNIT

6 November 1985

TENNESSEE VALLEY AUTHORITY
DATA SERVICES BRANCH
AND MAPPING SERVICES BRANCH

OAK RIDGE TENNESSEE
DOE PLANT CONTROL
(Field Book: ESS-3115 Pages 1-20)

Monument	Tenn. Lambert Coordinates (Feet)	Geodetic Position (Deg-Min-Sec)	UTM Coordinates (Meters)	Grid Zone
1	X= 2,476,636.11	35-55-33.9500	E 735,474.08	16
	Y= 562,340.62	84-23-24.3775	N 3,978,699.34	
2	X= 2,476,564.16	35-55-40.3603	E 735,450.11	16
	Y= 562,987.68	84-23-25.1228	N 3,978,896.40	
231A	X= 2,517,807.68	36-01-05.1673	E 747,919.50	16
	Y= 596,543.16	84-14-56.4172	N 3,989,257.18	
600	X= 2,518,534.67	36-01-14.7898	E 748,138.05	16
	Y= 597,529.31	84-14-47.3540	N 3,989,560.16	
300	X= 2,525,730.77	36-02-16.2122	E 750,312.17	16
	Y= 603,870.90	84-13-18.3651	N 3,991,516.51	
TT-21-W	X= 2,500,455.6	35-57-21.1598	E 742,701.15	16
	Y= 573,584.2	84-18-32.4404	N 3,982,202.24	
T-21	X= 2,500,930.91	35-57-20.1682	E 742,846.36	16
	Y= 573,492.13	84-18-26.6792	N 3,982,175.66	
RTBP-68	X= 2,538,037.3	36-01-28.3507	E 754,079.20	16
	Y= 599,256.8	84-10-49.5915	N 3,990,148.51	
RTBP-19	X= 2,501,725.8	35-56-01.0786	E 743,113.81	16
	Y= 565,507.7	84-18-18.6938	N 3,979,743.71	
X-13	X= 2,501,627.33	35-55-59.1599	E 743,084.40	16
	Y= 565,311.96	84-18-19.9322	N 3,979,683.72	
P-4	X= 2,496,770.39	35-55-30,1747	E 741,612.99	16
	Y= 562,297.06	84-19-19.6122	N 3,978,749.24	

Monument	Administrative Coordinates (Feet)	Y-12 Coordinates (Feet)	ORNL (X-10) Coordinates (Feet)	ORGDP (K-25) Coordinates (Feet)
1	E 12,965.99 N 34,257.19	E 13,016.30 N 34,027.02	E 12,964.26 N 33,948.29	9 W* 286+51 S
2	E 13,280.46 N 34,827.32	E 13,328.66 N 34,597.61	E 13,274.34 N 34,520.75	9 W* 280+00 S
231A	E 66,331.359* N 38,449.694	E 66,317.82 N 38,385.81	E 66,291.16 N 38,547.42	446+86.95 E 7+89.83 N
600	E 67,494.009* N 38,835.948	E 67,478.27 N 38,775.44	E 67,450.86 N 38,942.53	455+18.41 E 16+89.53 N
300	E 77,031.167* N 39,865.755	E 77,003.05 N 39,834.69	E 76,978.93 N 40,044.96	533+70.68 E 71+96.59 N
TT-21-W	E 38,911.46 N 29,702.56	E 38,951.48* N 29,559.54	E 38,941.36 N 29,592.16	249+05.32 E 201+09.31 S
T-21	E 39,246.67 N 29,353.16	E 39,288.12* N 29,211.41	E 39,279.19 N 29,245.36	253+67.51 E 202+53.34 S
RTBP-68	E 84,423.51 N 28,997.21	E 84,423.09* N 29,000.00	E 84,453.31 N 29,234.12	650+91.04 E 12+51.15 N
RTBP-19	E 35,290.26 N 22,371.65	E 35,357.41 N 22,223.93	E 35,376.531* N 22,234.517	252+75.15 E 282+76.11 S
X-13	E 35,096.90 N 22,268.54	E 35,164.56 N 22,120.30	E 35,183.968* N 22,129.914	251+55.66 E 284+59.76 S
P-4	E 29,389.82 N 22,607.19	E 29,461.79 N 22,440.43	E 29,475.00 * N 22,425.00	199+95.66 E 309+19.25 S

Note: Coordinates marked by an asterisk (*) are the monuments which were used as the basis for the transformation in the particular system.

200 Haney Building

February 13, 1986

Mr. R. O. Daugherty
Martin Marietta Energy Systems, Inc.
P. O. Box P
Oak Ridge, Tennessee 37831

Dear Mr. Daugherty:

As requested in your letter of January 28, 1986, enclosed please find the formulae to convert coordinates from the Oak Ridge administrative grid to the three plant grids (ORGDP, Y12, and ORNL), and from the three plant grids to the administrative grid.

These formulae were developed through algebraic manipulation of the formulae sent to you on November 6, 1985. Therefore, their accuracy should be the same as the parameters listed with these formulae.

Please let me know if we can be of any further service.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

Robert H. Chappell, Chief
Mapping Services Branch

AWV:GG
Enclosure
bc: D. S. Andrews, 200 HB-C
A. W. Voss, 200 HB-C

MSB-0201L

OAK RIDGE, TENNESSEE
DEPARTMENT OF ENERGY PLANT CONTROL
COORDINATE TRANSFORMATION FORMULAE
ADDENDUM - FEBRUARY 1986

Prepared By:
TENNESSEE VALLEY AUTHORITY
MAPPING SERVICES BRANCH
COMPUTING UNIT

TENNESSEE VALLEY AUTHORITY
MAPPING SERVICES BRANCH

OAK RIDGE, TENNESSEE
DOE PLANT CONTROL
FORMULAE FOR TRANSFORMATIONS-ADDENDUM

Use the following equations for coordinate transformations:

1. From ORGDP (K-25) to Administrative Grid:

   E[Admn]= (0.875773125337)EK + (0.483063897613)NK + 26814.1338

   N[Admn]= (0.875773125337)NK - (0.483063897613)EK + 59344.6216

   Where: EK= ORGDP Easting NK= ORGDP Northing

   From Administrative Grid To ORGDP (K-25) Grid:

   E[K25]= (0.875484834073)EA - (0.482904880806)NA + 5182.44

   N[K25]= (0.875484834073)NA + (0.482904880806)EA - 64903.99

   Where: EA= Administrative Grid Easting
   NA= Administrative Grid Northing

2. From Y-12 Grid To Administrative Grid:

   E[Admn]= (1.00093544737)EY + (0.003196682653)NY - 171.2641

   N[Admn]= (1.00093544737)NY - (0.003196682653)EY + 239.9513

   Where: EY= Y-12 Grid Easting NY= Y-12 Grid Northing

   From Administrative Grid To Y-12 Grid:

   E[Y12]= (0.999055236531)EA - (0.003190677834)NA + 171.8679

   N[Y12]= (0.999055236531)NA + (0.003190677834)EA - 239.182

   Where: EA= Administrative Grid Easting
   NA= Administrative Grid Northing

3. From ORNL (X-10) Grid TO Administrative Grid:

$$E[Admn] = (1.00006207038)EX + (0.007630810369)NX - 258.1265$$

$$N[Admn] = (1.00006207038)NX - (0.007630810369)EX + 405.720$$

Where: EX= ORNL Easting NX= ORNL Northing

From Administrative Grid To ORNL (X-10) Grid:

$$E[X10] = (0.999879718337)EA - (0.007629418959)NA + 261.1912$$

$$N[X10] = (0.999879718337)NA + (0.007629418959)EA - 403.701$$

Where: EA= Administrative Grid Easting
NA= Administrative Grid Northing

Note: All equations above were developed using transformation equations dated 6 November 1985. Therefore, their accuracies should be within the parameters published at that time.

ORNL-DWG 91-6242

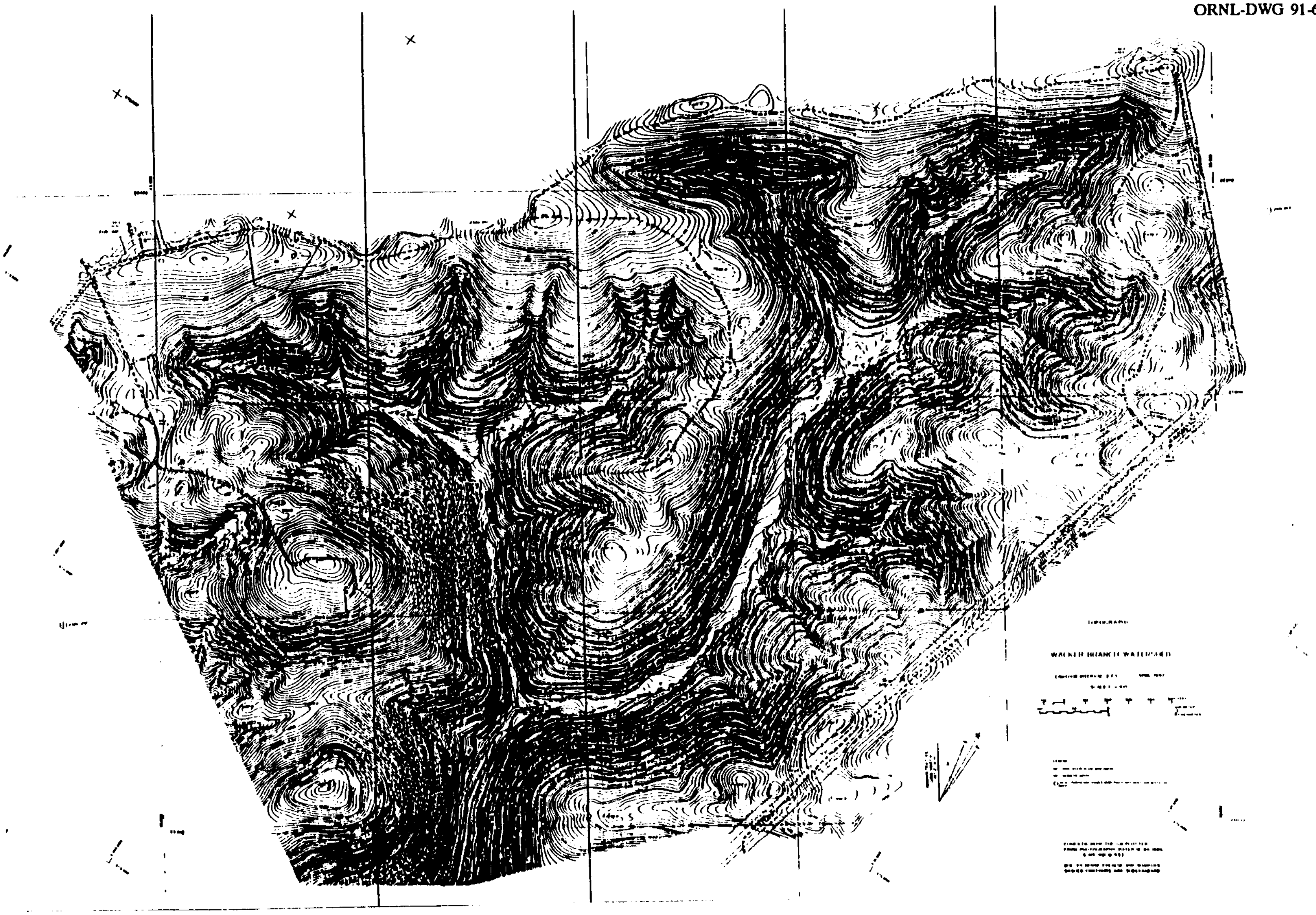
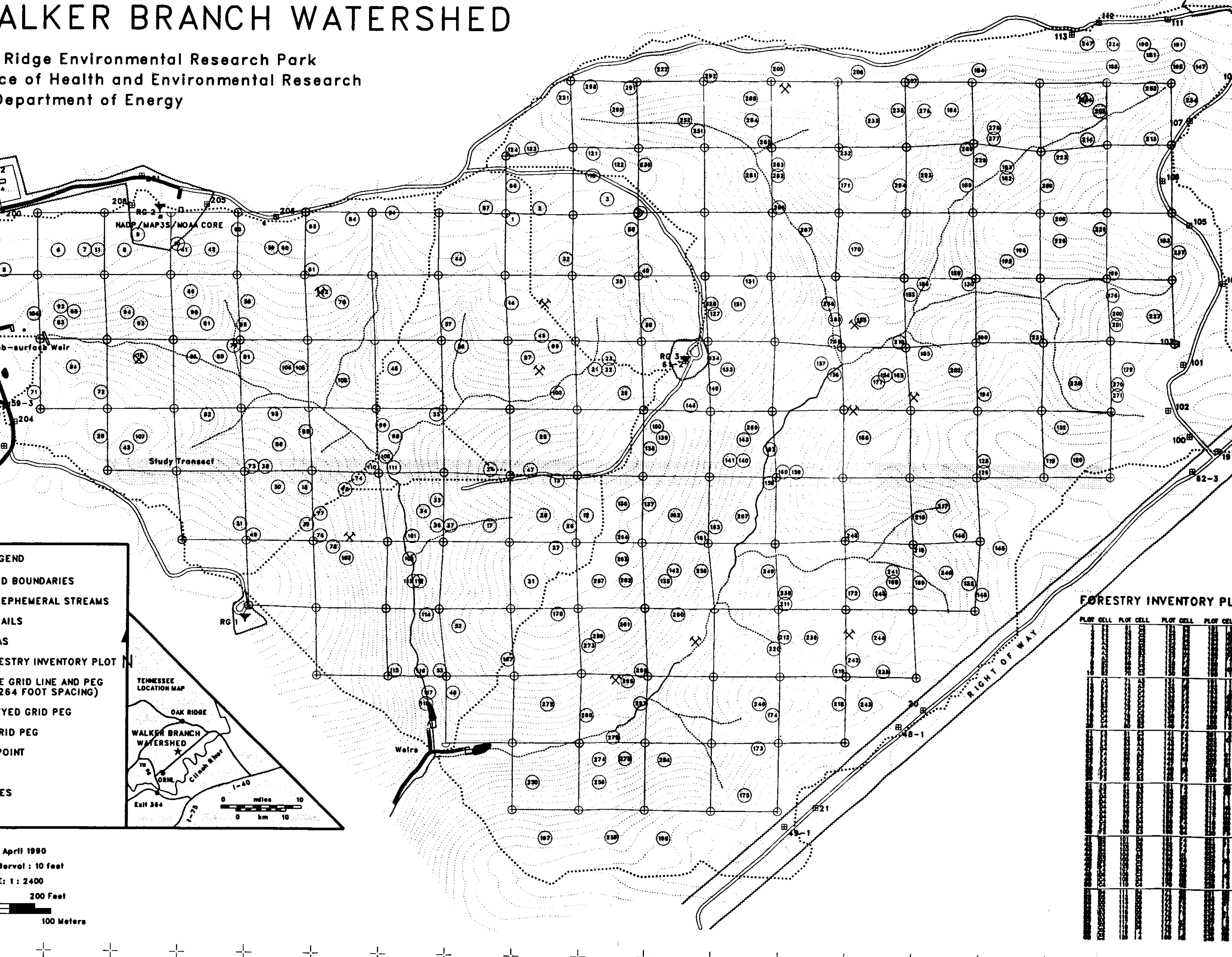


Fig. E.1. The 1987 2-ft contour map of WBW was made by TVA at an original scale of 1 in = 100 ft.

APPENDIX F

REVISED WBW MAP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Ridge Environmental Research Park
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Department of Energy
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EPHEMERAL STREAMS
AILS
AS
ESTRY INVENTORY PLOT
E GRID LINE AND PEG
264 FOOT SPACING)
YED GRID PEG
RID PEG
POINT
ES
April 1990
terval : 10 feet
E: 1 : 2400
200 Feet
100 Meters
TENNESSEE LOCATION MAP
OAK RIDGE
WALKER BRANCH WATERSHED
ORNL
Clinch River
I-40
I-75
Exit 364
miles
km
NADP/MAP3S/NOAA CORE
Sub-surface Weir
Study Transect
Weirs
RIGHT OF WAY
FORESTRY INVENTORY PL
PLOT CELL

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