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Engineering Field Notes

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Engineering Field Notes

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Black Butte Cadastral Survey Using Global Positioning (GPS) & Photogrammetric Technologies for Control

*H. Mike Harbin
Forest Land Surveyor
Mt. Shasta Ranger District
Shasta-Trinity National Forest*

INTRODUCTION

The Washington Office selected the Black Butte cadastral survey to be a "Master Demonstration Project" for using Global Positioning System (GPS) technology. The project was to demonstrate the use of GPS technology in accomplishing a landline project. Provisions were made to have as many staff land surveyors as possible gain exposure to GPS methodology and have hands-on experience under field conditions.

This survey responded to several project requests from the Mt. Shasta Ranger District for landline location activities required by multiple resource activities.

The project included the survey of 42 adjacent sections located in two townships to reestablish a badly deteriorated land net. Because of its size the project not only met the needs of the District but also took advantage of economies of scale and enabled the surveyors to more easily recognize and analyze the work patterns, methods, and idiosyncracies of the original survey. The complexity of the project also was increased because the original surveys were believed to be incomplete or fraudulent surveys associated with the Benson Syndicate land frauds, and fire, logging, and the preparation of plantation sites had obliterated the original survey work to a large extent.

The project combined GPS and photogrammetric methods--GPS forming the basis for subsequent aerial photography and aerotriangulation. Formal contracts were awarded and executed for both these control elements. All other phases of this project are being done by force account.

Global Positioning Theory

A brief overview of GPS theory is required to better understand field procedures and data processing. GPS is the accurate and continuous knowledge of (1) the spatial positions or location of certain satellites or space vehicles (SV's) in Earth orbit and (2) time. Time must be known simultaneously both in the SV and the ground receiver. It is tabulated by an atomic clock in nanoseconds. Four ground control stations of known geodetic position have been established at locations around the world. These ground stations track and send updated orbital parameters (ephemeris data) to SV's constantly via a master station in Colorado Springs, Colorado. When survey data are collected, the exact time is recorded within the receiver from radio signals transmitted from the SV, and a "range" is computed from the difference between time of transmission and the time of reception (multiplied by the speed of light)--and is corrected for ionospheric interferences using two frequencies of reception. Data are recorded simultaneously and continuously from four SV's. The four SV's are called a "constellation." When cadastral accuracy is required for a project, the usual procedure is to establish a "project master station" on a geodetic monument with known geodetic coordinates of latitude (X), longitude (Y), and elevation (Z) in the geodetic network of the United States. The project master station must be located in the vicinity of the project (usually within 20 miles). A receiver is placed on the master station, another receiver is placed on an unknown station, and data are collected. From that data, the X, Y, and Z coordinates of the unknown station can be computed.

This technique is called differential or relative positioning survey. Accuracies between master and remote appear to be in the centimeter range or better. Transmissions, in the Texas Instruments (TI) 4100 system, are recorded on a TI pro-lite computer which functions as a data collector. Data are transferred to a 10-megabyte computer, located in the field office, and undergo several generations of calculations. First-generation results are tabulated in the Department of Defense datum. This datum is called the World Geodetic System 1972 (WGS-72) and is a mathematical model that approximates the Earth's surface and allows computations to be made that take into account the curvature of the Earth.) WGS-72 can be transformed to other datums depending on the flexibility of the software used. Black Butte GPS values were initially done on WGS-72, transformed to the North American datum of 1927

(NAD-27) which is a northern hemispheric reference system that models the Earth's shape more closely to that of the United States, and eventually to California State plane coordinates, Zone 1. This "local" datum allows certain computations to be made that consider elevation and convergency differences within a project area and is readily adaptable to mapmaking work. The accuracy is inherent within the system itself; however, insurance of the values obtained depends on the number of occupations a station receives (redundancy), the constellation configuration (strength of figure), the length of time of data acquisition, and the degree of care in setting up of receiver antennas and height determination.

Preproject Planning

Preproject planning is the critical phase in making a GPS system work and obtaining excellent results.

The crew set up monuments at 18 preselected points to provide stations for the GPS receivers (figure 1). The primary criterion in the initial selection of these GPS stations was to provide adequate coverage for aerotriangulation. The second criterion was to provide primary control stations as part of property line establishment. The third criterion was the selection of property or controlling corners of the public land survey system.

After the above guidelines were met, the following criteria also were considered:

- (1) Access to Stations. Locations generally were within 200 feet of a road that could be negotiated by a four-wheel-drive vehicle. Travel time or transit time (which is the time necessary to disassemble a receiver setup, drive to the next station, and set up the receiver and antennas) was designed to be in the neighborhood of 15 to 20 minutes. Several sites were known to exceed these limits. One required a backpack hike of 1.25 miles. Station descriptions were provided in the contract package to give the potential contractor some concept of the project. The equipment has a degree of portability. The receiver weighs 55 pounds. The 200 feet of special cable, the data collector, and the requisite two 12-volt car batteries require three to four healthy hikers (figure 2). Pack animals and helicopters are most welcome if the site is much greater than 200 feet from road access.

R 5 W

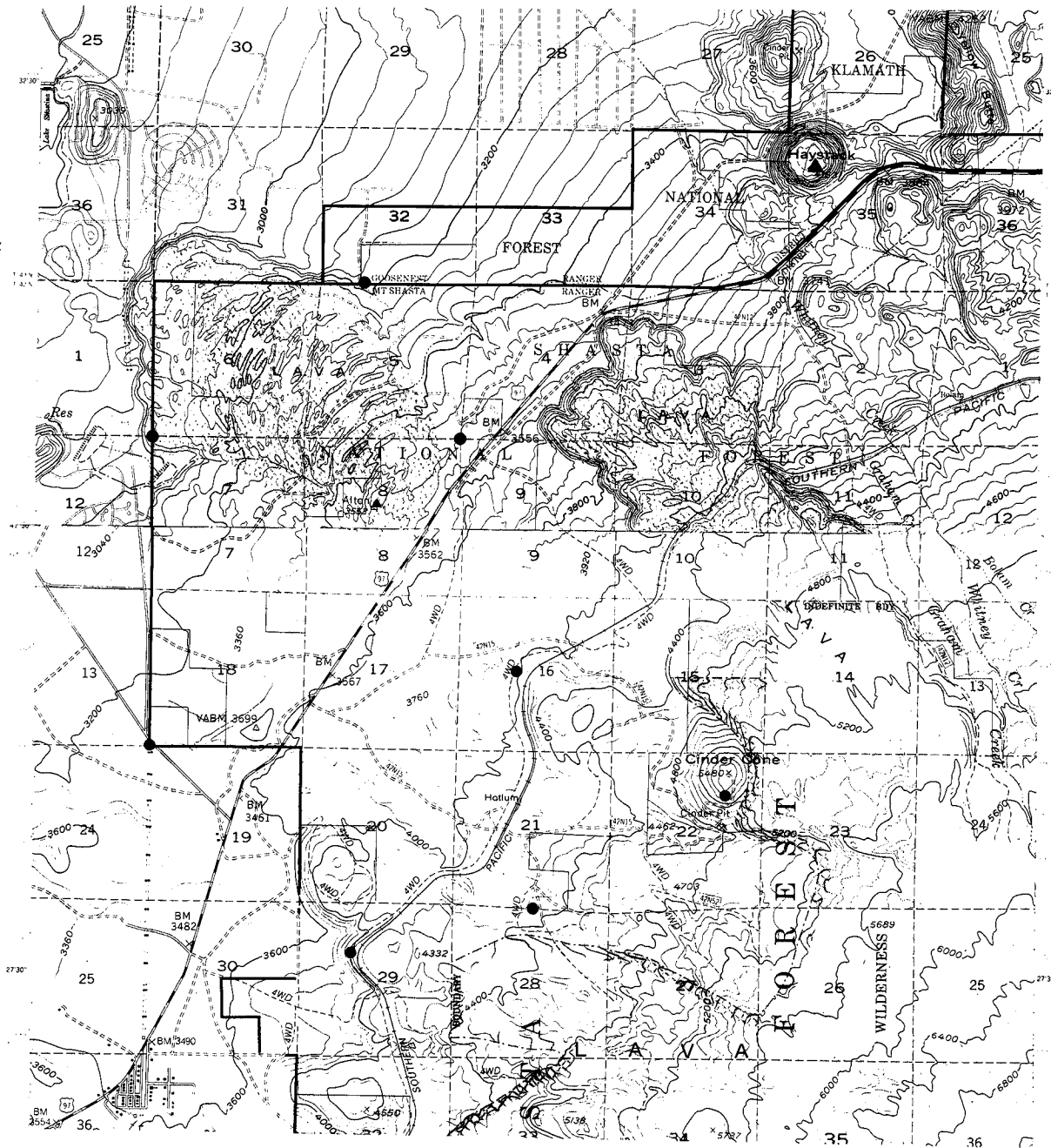
R 4 W

T 43 N

T 43 N

T 42 N

T 42 N



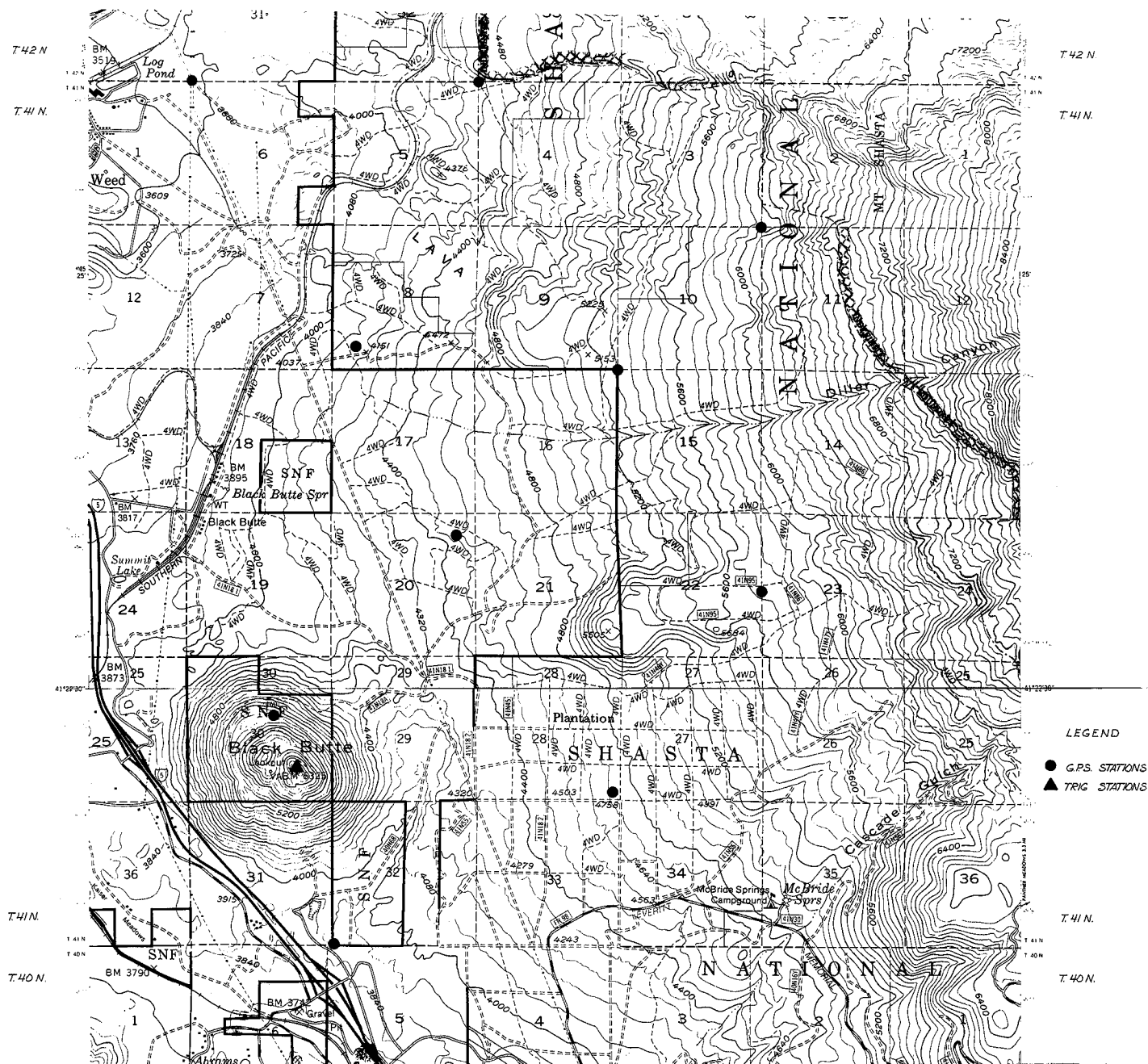


Figure 1.--Location of GPS and trig stations.

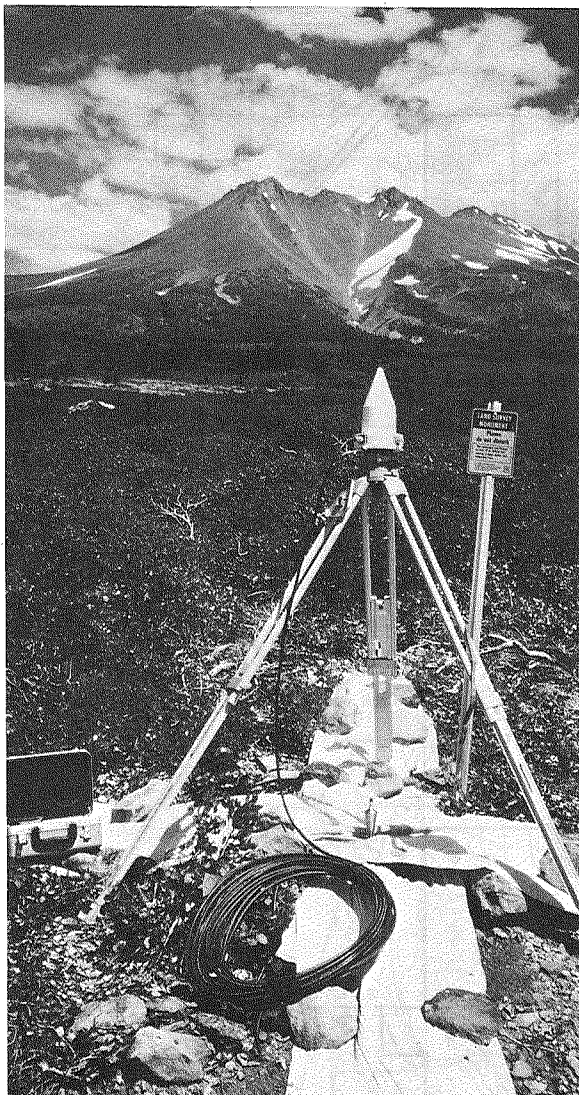


Figure 2.--GPS hardware for stations located more than 200 feet from road access includes two 12-volt batteries, 200 feet of cable, data collector, and antenna setup.

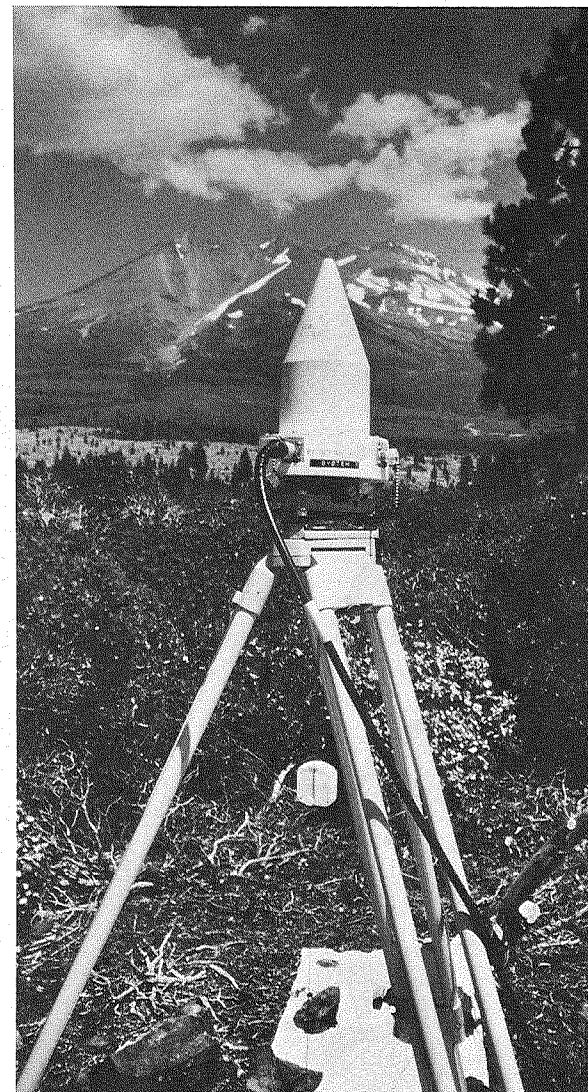


Figure 3.--Ideal GPS setup has a clear view 20 degrees above the horizontal and 360 degrees around the station, but can be modified with SAT-PLAN.

- (2) Horizon. Initially, the most desirable horizon is a clear, unobstructed view 20 degrees above the horizontal in a circle around the point (figure 3). This can be modified with prior knowledge of SV visibility. A satellite availability chart (SAT-PLAN), generated from latitude, longitude, and elevation of project, along with the date of observation will show constellation azimuth and elevation, graphically portraying the positions of SV's as related to the particular station. The SAT-PLAN will provide some information about allowable flexibility in site selection and time of data accumulation. Weather has little effect on field operations as long as temperatures are maintained within the operating range of the receiver. However, radio transmissions, radar emissions, and vibrations from trains or large trucks may have an effect depending upon conditions.

The number of stations that can be measured in a day is a function of the following:

- (1) Transit time between stations (measured in the field prior to startup).
- (2) SV window availability (determined from SAT-PLAN prior to and during the project).
- (3) Number of remote or slave receivers available. For a normal session, with 40 minutes of data acquisition, 40-minute transits, and using four receivers, we could expect to acquire data from 3 to 4 sites per receiver or 9 to 12 stations per day with new values determined, assuming the master/slave technique of differential survey is used, and 4.5 hours of SV window or data acquisition time are available. The baseline (traverse or leapfrog) approach is probably best suited for large projects with impractical transit times for efficient use of receivers. Productivity would be greater with the "leapfrog" approach, but the number of receivers available and the accuracy of the desired survey also enter into the decision of which approach to use.

Field Operations

Before actual field work with a GPS system, it is essential to "recon" the project area with the GPS field party chief. Each station should be looked at, if possible, with strategy on time of day and

horizon potential discussed. If a new station location needs to be selected at this time, it can be done without disturbing the data acquisition plan, which is somewhat inflexible.

As part of the contract, a training session in GPS methodology and procedures was requested for our Staff surveyors. Roughly 20 surveyors attended this 1-day lecture/demonstration, which included an introduction to the field operations. One Forest Service employee was supplied daily as field work progressed to function as a helper-trainer-guide to maximize exposure to GPS use. Forest Service vehicles, along with radio support, supplemented the contractor's resources. Forest Service personnel were allowed to perform all phases of data acquisition and processing, except manipulations during the critical 40-minute acquisition period. In essence, we did the project together, with the contractor responsible for the end results. From this project and conversations with GPS operators, it takes about 1 month of hands-on experience for a person to become reasonably field competent with the system--and an additional month will lead to data processing competence.

Eighteen GPS stations were requested and occupied along with three second-order U.S. Coast and Geodetic Survey (now National Oceanic and Atmospheric Administration (NOAA)) trig stations needed to establish the basis for the California coordinate datum. If first-order trig stations had been accessible, they would have been incorporated. The best control available should be used. Values established within a GPS framework have a relative accuracy to each other; but to a national network, they are no better than the trig stations positioned. The three trig stations were adjusted after occupation, and a project "master" station was selected. This master station was centrally located and readily accessible. All other values were predicated on the master station.

Data Acquisition Processing

For a session to be valid, signals must be received simultaneously by master and remote receivers. If one or both receivers is not operating properly, that portion of the acquisition period is nonusable. Fifteen minutes of data may deliver the desired accuracies. Black Butte used 18 minutes minimum out of the 30- to 40-minute acquisition period attempted. Certain data editing is possible to use the best data at the processing phase.

Several phases of accumulated data can be compared to each other within the overall observation to determine the best segments to be used for final processing.

Results & Audit

Ten stations received multiple occupations (independent setups of tripod and receiver antennas) of either two or three sets of data accumulated in accordance with Federal Geodetic Control Committee (FGCC) specifications for GPS horizontal control. Residuals on these points showed a range of 0.08 foot, with the arithmetic average 0.04 foot, or about 1 centimeter. Work was to be performed to order IV (Feb 86) standards for horizontal control. Dimensional audits using strong third-order Class I procedures and equipment (daytime observations, 1-second theodolite with 12 turns using different sides of the plate, reciprocal vertical angles, and calibrated electronic distance measuring equipment) indicate that these standards were easily met and most likely exceeded. Six baselines were reviewed. The maximum differential across 3.5 miles was 0.4 foot--attributable partly to uncertainty in refractive index. (The speed of light in a "perfect" vacuum differs from ambient conditions in the field. Pressure, temperature, or other variables are measured to obtain an estimated correction for this difference.) Two baselines measured to within 0.01 foot. Short baselines, less than one mile, corresponded closely to the point where the two technologies could not check each other.

Vertical elevations were based on ellipsoidal heights and adjusted from a given benchmark to approximate orthometric heights. This crude approach can be negated by using software that models the geoid with the use of rapp's tables (orthometric heights without extensive vertical control, especially useful when good vertical control is not available). One-meter accuracy is thought to be the relative accuracy of this technique and has been further refined as of January 1987. Trig levels were inadequate to sustain an accurate check. GPS values appear to be just as accurate vertically as horizontally (plus or minus 1 centimeter in X, Y, Z components), with most of the error being associated with eccentricity of setup and antenna height determination.

PHOTOGRAMMETRY

Prephoto Mission Planning

The second control aspect of this project was the application of 1:18,000 vertical aerial photography and aerotriangulation. A root mean square error (RMSE) not to exceed 1 foot was sought to allow setting of 1/16-corners and to enhance the retracement of existing surveys. A photo scale of 1:18,000 clearly is capable of this accuracy, and the number of ground control stations is reduced by one-half over the 1:12,000 scale photography. Ground-determined values from GPS data formulated the basis for controlling the photogrammetric models for aerotriangulation and easily met these requirements (figure 4).

Orthophotos were used to transfer search areas of suspected corner locations onto 1:12,000 resource photography. This single step aided in accessing and placing photo targets that would be used to control the photogrammetric operations. Proposed flight lines were projected onto the orthophotos and guidelines for photo placement were prepared. Horizon requirements (the need for targets to be "seen" from two aerial photos, one each in adjacent,



Figure 4.--GPS ground values formulate the basis for aerial photography.

parallel flight lines) are significantly reduced from the general 45 degree from vertical (1:12,000) to a 30 degree from zenith, when a 1:18,000 scale is used.

A preflight was made 1 to 2 days ahead of the scheduled photography mission to ensure that the targets were visible and still there. One target had to be replaced out of nearly 200--because cows like to eat photo panels.

Preprocessing

Photography at a scale of 1:12,000 with pin-pricked located targets, orthophotos, and GPS values were supplied to the photogrammetrist at various stages to coordinate the work. This close contact resulted in 100 percent target recovery and fostered a genuine team effort.

Computer Analysis Results

A subcontractor did comparator measurements and computer analysis using a WILD BL-1 plotter and a software package called COMBAT II.

The aerotriangulation report shows an RMSE of X=0.39 foot, Y=0.43 foot, and X=0.78 foot, which satisfies the RMSE of 1.0 foot or less of system-determined values versus ground-supplied values. To date, the retracement of $\frac{1}{4}$ - to $\frac{1}{2}$ -mile lines shows relative agreement of 1:10,000 to 1:15,000 closures between field measurements and coordinates!

SUMMARY

Accuracies that normally would be considered overkill for cadastral application are inherent within the GPS technology. Cost analysis of the project shows the following:

<u>ACTUAL</u>	<u>EST. CONVENTIONAL</u>	<u>EST. CONVENTIONAL & PHOTO</u>
PANELING \$ 6,400	PRIMARY \$34,800	PHOTO CONTROL \$15,300
GPS 13,400	SECONDARY 10,300	PHOTO 6,700
PHOTO 6,700		TARGETS 6,400
<u>TOTALS: \$26,500</u>	<u>\$45,100</u>	<u>\$28,400</u>

Cost reductions could result from the following:

- (1) Increasing the number of satellites. More satellites for increased time of coverage and selection of SV would allow greater use and flexibility of operations. By 1991, 18 "Block II" SV's are to be deployed around the Earth. This will provide access to four SV's, 24-hours-a-day, worldwide.

- (2) Reviewing FGCC specifications for GPS surveys. The specifications are an evolving process. Lowering the number of stations requiring multiple occupancy would be a logical step that would not sacrifice project accuracy.
- (3) Minimizing data acquisition time through improved software and processing equipment.
- (4) Improving portability and packaging of GPS field units to allow true "woods" type operations.
- (5) Considering size and composition of projects to amortize mobilization costs. Multiple Forests sharing in a Regional project makes good sense.

Again, the critical phase of GPS use is preproject planning and field review before beginning field operations. We anticipate that the costs will drop as increased satellite coverage becomes available. This technology allows for highly accurate positioning for photogrammetric applications and geodetic control densification of the land net at a price that is usually lower than for conventional survey methodology.

Last Word

As the Forest Service begins to use Graphic Information System (GIS) data, it is becoming increasingly critical to accurately locate National Forest System landlines and resource information both on the ground and on the maps we use in making resource management decisions. GPS technology is a cost-effective tool in meeting our need for accurate geodetic information.

EFN

Getting Ahead Using the Multi-Year Schedule Program

*John T. Chesley
Assistant Forest Engineer
National Forests in North Carolina*

INTRODUCTION

The purpose of this article is to introduce a computer program, called the Multi-Year Schedule Program, developed for the National Forests in North Carolina (NFsNC). This program is used to plan and schedule activities to meet the intent of the National Environmental Policy Act and better implement the "gates" process--that is, the timber sale preparation process.

The Multi-Year Schedule Program is used primarily for estimating and scheduling workloads; tracking costs, targets, and accomplishments; and coordinating among departments. It is also used for storing historical data; maintaining information about past, present, and future program activities; and reporting this information in various formats.

PROGRAM DESCRIPTION

The Multi-Year Schedule Program consists of a series of programs that input, store, manipulate, and retrieve information from five data bases: Planning, Environmental Coordination, Engineering, Timber, and Rights-of-way. The Program resides on the Data General MV 10000 at the Supervisor's Office, is menu driven, and is accessible by all Districts through Deflected Drawer. Information is continually updated by Resource Specialists and District personnel. Users can read any information directly from the CRT or through standard reports. Using information from one or more of the data bases, the program generates 22 standard reports and presents the information in formats that satisfy District, Supervisor's Office, Regional Office, and Washington Office needs (figure 1).

Although the program can track hundreds of pieces of information on each timber sale, only those items that are needed for increased efficiency need be used. For example, if a need exists to track the status of preconstruction activities on the Forest,

10/08/86

SPECIALIST STATUS REPORT--ARCHEOLOGIST
FISCAL YEAR: 87

DIST	PROJECT	SALE DATE	PRIORITY (H,M,L)	DAYS TO COMPLETE	ID TEAM MEETING
CHEO	JOHNSON GAP	10/87	LOW	10	11/ 5/86
	MEETINGHOUSE MT	4/87	HIGH	10	12/30/86
	MURPHY GAP	12/86	HIGH	10	1/10/87
	WESSER		LOW	20	11/10/86
CROA	CEDAR POINT	9/87	HIGH	13	12/ 5/86
	HICKMAN HILL	4/87	LOW	10	11/25/86
	HORSE ISLAND	10/87	HIGH	15	11/ 5/86
	ISLAND CREEK	6/87	LOW	20	12/ 6/86
	LITTLE ROAD	12/86	MODERATE	10	1/10/87
	OYSTER ROAD	2/87	HIGH	12	10/30/86
FREN	CATPEN	11/86	HIGH	15	12/15/86
	MILL CREEK	12/86	LOW	10	12/10/86
GRAM	CAMP ROCK	8/88	MODERATE	12	12/ 3/86
	JARRETT CREEK	6/87	HIGH	10	11/25/86
	YELLOW FORK	2/87	MODERATE	12	1/ 5/87
HIGH	OSTIN KNOB	6/87	HIGH	10	10/ 5/86
PISG	JOEL BRANCH	11/86	HIGH	7	10/20/86
TOEC	BLUE RIDGE COVE	8/87	LOW	10	11/12/86
	DEVIL'S CREEK	11/86	HIGH	5	12/10/86
	FORK MOUNTAIN	12/86	LOW	12	10/ 9/86
	MAPLE CAMP	4/87	HIGH	10	9/10/86
	ROARING FORK		HIGH	4	10/12/86
TUSQ	BUCKBERRY	11/86	MODERATE	13	1/15/87
	GIESKY CREEK	6/87	MODERATE	9	10/ 2/86
	LOWER TUNI	2/87	LOW	10	9/30/86
	PRETTY PINE	12/86	MODERATE	9	11/15/86
	WEBB MILL CREEK	8/88	MODERATE	10	9/13/86
UWHA	WEST POLLY BRAN	11/86	HIGH	12	2/15/87
	YATES PLACE	12/86	LOW	8	2/15/87
WAYA	APPLE TREE	5/87	MODERATE	8	2/16/87
	CLIFF RIDGE	11/86	MODERATE	7	11/15/86
	LAMBERT MNT.	12/86	HIGH	5	1/16/87
	LITTLE LAUREL	9/87	LOW	10	12/15/86

TOTAL DAYS TO COMPLETE: 348

10/8/86

2

SPECIALIST STATUS REPORT

Transportation Planner
Fiscal Year: 87

District	Project	Sale Date	Priority (H,M,L)	Days To Complete	ID Team Meeting	TAU Name	TAU Num
Cheoah	Wesser	8/88	High	20	11/10/86	Big Creek	13
F.Broad	Big Rocky	6/89	Moderate	10	--	Big Rocky	14
G.Father	Camp Rock	8/88	Moderate	10	12/03/86	Laurel Mtn.	4
	Yellow Fork	2/87	Low	10	01/05/87	Yellow Fork	9
Tusq.	Giesky Creek	6/87	High	20	10/02/86	Fleaback Mtn.	11
	Lower Tuni	2/87	Low	40	09/30/86	Tusquitee Mtn.	18
	Potter Br.	3/87	High	30	09/30/86	Cooper Creek	3
	Pretty Pine	12/86	High	30	11/15/86	Shuler Creek	2
	Webb Mill Cr.	8/88	Low	25	09/13/86	Old Mattie Top	8
Wayah	Cliff Ridge	11/86	Moderate	30	11/15/86	Compton Mtn.	9
	Factory Br.	3/87	Low	20	11/15/86	Chestnut Knob	2
	Little Laurel	9/87	Moderate	20	12/15/86	Cowee	5

Total Days to Complete: 265

Figure 1.--Sample reports generated by the Multi-Year Schedule Program.

ROAD PRECONSTRUCTION STATUS REPORT
FISCAL YEAR: 86

DIST	SALE NAME	SALE DATE	ROAD NAME	ROAD NUMBER	DESIGNER	LOCATOR	LOCATION ACCOMP PLAN		SURVEY ACCOMP PLAN		DESIGN ACCOMP PLAN		ROW CASES
CHEO	CHESTNUT FLATS	9/86	SNOWBIRD	75	BLANK	TYE	4/85	4/85	8/85	8/85	1/86	11/85	
	FRANK'S CREEK	6/88	FRANK'S CREEK	202	WILSON	TYE	4/86	4/86	5/86	6/86	8/86	6/86	
			DEE BRANCH	208A	WILSON	TYE	4/86	4/86	5/86	5/86	8/86	6/86	
			BERT'S CREEK	208	WILSON	TYE	4/86	4/86	5/86	5/86	8/86	6/86	
			SAWMILL BRANCH	208B	WILSON	TYE	4/86	4/86	5/86	5/86	8/86	6/86	
	HAPPY	9/87	COOK BRANCH	419	B. SHELTON	TYE	11/85	11/85	1/86	1/86	2/86	4/86	
	LONG CREEK	9/85	PANTHER ROUGH	2604	BLANK	TYE	12/85	12/85	1/86	1/86	2/86	2/86	
			PAYNE SAWMILL	2607	BLANK	TYE	12/85	12/85	1/86	6/86	2/86	2/86	
CRCA	CAMOOGUE CREEK	9/86	HOPE	3148	B. SHELTON	LEAVITT/VB	12/84	12/84	6/85	11/85	2/85	2/85	
	HERRING RUN	9/86	CEMETARY RD.	3053	B. SHELTON	LEAVITT/VB	12/84	12/84	6/85	11/85	1/86	1/86	
			BLACK BRANCH	3054	B. SHELTON	LEAVITT/VB	12/84	12/84	6/85	11/85	1/86	1/86	
	HOLSTON CREEK	4/86	WEST ROAD	3055	B. SHELTON	V. SHELTON	12/84	12/84	6/85	11/85	1/86	1/86	
	MILLIS SWAMP ROAD		MILLIS ROAD	128	B. SHELTON	LEAVITT	12/84	12/84	6/85	11/85	1/86	1/86	
			PEAK RD.	3091	B. SHELTON	LEAVITT/VB	12/84	12/84	6/85	11/85	1/86	1/86	
FREN	DRY CREEK	4/87	DRY CREEK	111A	B. SHELTON	V. SHELTON	3/86	3/86	8/86	8/86	8/86	7/86	
	LEADLINE RIDGE	4/86	ROCKY BRANCH	3550	B. SHELTON	SHELT/CHMP	6/85	6/85	12/85	10/85	1/86	11/85	
	LITTLE CREEK	6/86	JACK TRAIL MOUN	3527	BLANK	SHELT/CHMP	4/82	4/85	11/85	11/85	2/86	12/85	
			HORSESHE LAUREL	3535	BLANK	SHELT/CHMP	4/85	4/85	11/85	11/85	2/86	12/85	
	MURRAY BRANCH	8/86	POLECAT HOLLOW	468	COLE	V. SHELTON	3/84	3/84	6/84	6/84	8/85	8/85	
GRAN	BAD FORK	6/87	ARMSTRONG EXT.	469	B. SHELTON	CRAWFORD	5/85	5/85	10/85	10/85	5/86	5/86	
	JARRETT CR REPAIRS		JARRETT CREEK	4030	CRR	ORR	1/86	1/86	3/86	3/86	3/86	3/86	
	JARRETT CREEK	6/87	JARRETT CREEK E	7112	B. SHELTON	V. SHELTON	7/85	7/85	12/85	10/85	7/86	6/86	
	JERDON MOUNTAIN	9/86	JERDON MOUNTAIN	4030A	B. SHELTON	HAWK/SHELT	3/86	3/86	1/86	3/86	7/86	8/86	
	REID'S CREEK	6/86	STATE ROAD 1407	1407	CRR	SHELTON	7/86	7/86	7/86	7/86	8/86	8/86	
			LOOSE MOUNTAIN	4097	CRR	SHELTON	4/86	4/86	5/86	5/86	6/86	6/86	
	THUNDERHOLE	7/86	THUNDERHOLE EXT	4071	B. SHELTON	SHELT/BLEV	11/84	11/84	1/85	1/85	2/86	12/85	
	UPPER CREEK	6/85	JOE POORE	4002	CRAWFORD	V. SHELTON	4/85	4/85	5/85	5/85	7/85	7/85	
			BIG CHESTNUT MT	4098	CRAWFORD	V. SHELTON	4/85	4/85	5/85	5/85	7/85	7/85	
			RIPSHIN BRANCH	4074	CRAWFORD	V. SHELTON	4/85	4/85	5/85	5/85	7/85	7/85	
			MORTIMOR PIEDMO	982	CRAWFORD	V. SHELTON	4/85	4/85	5/85	5/85	7/85	7/85	
HIGH	BRUSH CREEK	6/87	BRUSH CREEK RD	4535	BLANK	TYE	2/86	2/86	6/86	3/86	6/86	7/86	
	FALL CLIFF	12/87	TURKEY PEN	323-A	BLANK	TYE	3/86	3/86	6/86	4/86	6/86	6/86	
	PANTHER MTN.	6/89	LOWER BUCK CREE	4591	BLANK	TYE	5/86	5/86	6/86	5/86	8/86	6/86	
	TERRAPIN MTN.	5/86	BULL PEN	117B	CRR	TYE	5/85	5/85	11/85	9/85	2/86	2/86	
			BRUSHY MTN.	4568	CRR	TYE	5/85	5/85	11/85	9/85	2/86	2/86	
			FOWLER CREEK	4566	CRR	TYE	5/85	5/85	11/85	9/85	2/86	2/86	
PISG	BEAVERDAM	10/87	BEAVERDAM CREEK	5005	WARBRITTON	SHELT/JACK	12/85	12/85	3/86	2/86	6/86	6/86	
			YOUNG PISGAM MT	5006	WARBRITTON	SHELT/JACK	12/85	12/85	3/86	2/86	6/86	6/86	
			HARRIET COVE	5011	WARBRITTON	SHELTON	12/85	12/85	3/86	2/86	6/86	6/86	
	CRADLE PAVING		CRADLE ENTRANCE	812	CRR	ORR	3/86	3/86	3/86	3/86	3/86	3/86	
	FLETCHER CREEK #2	5/86	FLETCHER CREEK	5097	WARBRITTON	SHELT/JACK			6/85	6/85	2/86	1/86	
	KING CREEK	12/85	HORSE COVE	475C	CRR	SHELT/JACK	5/85	5/85	10/85	10/85	11/85	11/85	
	LONG BRANCH	6/88	SPICE COVE	5073	CRR	SHELTON	7/86	7/86	7/86	7/86	7/86	7/86	
			LONG BRANCH	5074	CRR	SHELT/JACK	7/86	7/86	7/86	7/86	7/86	7/86	
	TURKEY CREEK	11/86	LOWER TURKEY CR	506C	CRR	SHELT/JACK	4/85	4/85	6/85	4/86	2/86	7/86	
			TURKEY CREEK	5099	CRR	SHELT/JACK	4/85	4/85	6/85	11/85	2/86	12/85	
TOEC	YELLOW GAP	5/86	YELLOW GAP	1206	CRR	N/A	11/84	11/84	11/84	11/84	2/86	11/84	
	BEAR-WALLOW	1/87	BEAR WALLOW	5501	CRR	V. SHELTON	11/85	11/85	1/86	1/86	2/86	2/86	
	ROAN MT EST		ROAN MT PARKING	00000	CRR	ORR	3/86	3/86	3/86	3/86	4/86	4/86	
	WHITE OAK	6/86	WHITE OAK EXT.	5570	B. SHELTON	V. SHELTON	4/85	4/85	10/85	10/85	4/86	4/86	
TUSG	BARNETT CREEK	8/86	BARNETT CREEK	6236	BLANK	TYE	3/85	3/85	8/85	9/85	5/86	11/85	
			BRUCE RIDGE	6237	BLANK	TYE	3/85	3/85	8/85	9/85	5/86	11/85	
	DAVIS CREEK	9/86	LITTLE CREEK	6265	CRR	TYE	10/85	10/85	11/85	10/85	3/86	2/86	
	DOCKERY CREEK	7/86	DOCKERY CREEK	6273	BLANK	TYE	2/85	2/85	10/85	9/85	3/86	1/86	
			WEST PRONG GRAP	6278	BLANK	TYE	2/85	2/85	10/85	9/85	3/86	1/86	
	GARRETT CREEK	9/86	DAVIS CREEK	420	BLANK	TYE	11/85	11/85	3/86	2/86	5/86	3/86	
			TIPTON CREEK BY	420A	BLANK	TYE	2/86	2/86	3/86	2/86	5/86	7/86	
	PEACHTREE		PEACHTREE EXT.	6176	BLANK	TYE	12/85	12/85	4/86	3/86	6/86	8/86	
	SHOOTING CREEK	4/86	VINEYARD CR.	6226	BLANK	TYE	11/85	11/85	1/86	1/86	2/86	2/86	
UWPA	DENSON CREEK	5/86	DENSON CREEK RD	6648	B. SHELTON	V. SHELTON	10/85	10/85	11/85	11/85	2/86	12/85	
	LITTLE ISLAND CREEK	9/86	WOODRUN ROAD	517	CRR	V. SHELTON	11/85	11/85	12/85	12/85	3/86	1/86	
			LITTLE ISLAND C	518	CRR	V. SHELTON	11/85	11/85	12/85	12/85	3/86	1/86	
			WOODRUN EXT.	517-1	CRR	V. SHELTON	11/85	11/85	12/85	12/85	3/86	1/86	
	TOM MARKS	7/86	BADIN LAKE	597	CRR	V. SHELTON	11/85	11/85	1/86	1/86	3/86	4/86	
WAYA	FACTORY BRANCH	3/87	ROARING FORK RI	7167	BLANK	LYNCH/TYE	10/85	10/85	4/86	4/86	5/86	5/86	
	LAMBERT MNT.	12/86	JUNULUSKA GAP	727C	BLANK	TYE	2/86	2/86	1/86	2/86	3/86	8/86	
	MICA CITY	11/85	FED COVE	7071	CRR	V. SHELTON	3/85	3/85	3/85	3/85	5/85	5/85	
			BROWN CREEK	7072	CRR	V. SHELTON	3/85	3/85	3/85	3/85	5/85	5/85	
	POL MILLER	7/87	TRIMONT GAP	713A	CRR	TYE	11/85	11/85	4/86	3/86	4/86	8/86	
	RAY BRANCH	5/86	SHINGLETREE BRA	713	CRR	SHELT/LYNC	10/85	10/85	2/86	2/86	5/86	5/86	
			RAY BRANCH EXTE	7279	CRR	SHELT/LYNC	10/85	10/85	2/86	2/86	3/86	3/86	
	WINE SPRINGS	9/86	ROCKY BALD BRAN	7132	B. SHELTON	TYE	3/85	3/85	10/85	9/85	2/86	11/85	

Figure 1. (cont.)--Sample reports generated by the Multi-Year Schedule Program.

10/28/86

ENGINEERING ROAD PROGRAM--PURCHASER CREDIT
FISCAL YEAR: 86

DIST	SALE NAME	ROAD NAME	ROAD NUMBER	ROW CASES	CONSTR CLASS C MILES	RECONSTR CLASS C MILES	CONSTR CLASS D MILES	RECONSTR CLASS D MILES	PLANNED COST (\$1000)	PLANNED AUGMEN (\$1000)	COST/ MBF \$	COST/ MILE (\$1000)
CHCO	CHESTNUT FLATS LONG CREEK	SNOWBIRD PANTHER ROUGH PAYNE SAWMILL	75 2604 2607		1.15 0.00 0.00	0.00 0.00 1.21	0.00 0.00 1.57	0.00 3.52 0.00	16 5 55	0 0 0	9.28 3.35 18.09	14 1 20
				TOTAL:	1.15	1.21	1.57	3.52	76	0	12.15	10
CRCA	CAMOOGUE CREEK HERRING RUN HOLSTON CREEK MILLIS SWAMP ROAD	HOPE CEMETARY RD. BLACK BRANCH WEST ROAD MILLIS ROAD PEAK RD.	3148 3053 3054 3055 128 3091		0.00 0.40 0.52 0.36 0.00 0.54	2.45 0.00 0.00 0.00 2.80 0.00	0.00 0.00 0.00 0.00 0.00 0.00	0.00 0.00 0.00 0.00 0.00 0.00	50 19 38 25 22 36	0 0 0 0 0 0	0.00 182.86 109.76 112.81 27.62 95.28	20 48 73 69 8 67
				TOTAL:	1.82	5.25	0.00	0.00	190	0	102.92	26
FREN	LEADMINE RIDGE LITTLE CREEK HORSE LAUREL MURRAY BRANCH	ROCKY BRANCH JACK TRAIL MOUN POLECAT HOLLOW	3550 3527 3535 468		0.00 0.00 0.00 0.00	0.00 0.00 0.00 0.00	0.00 0.32 0.00 0.00	0.84 0.00 2.80 5.65	30 35 30 5	5 0 0 0	27.07 30.85 46.83 2.02	36 109 11 1
				TOTAL:	0.00	0.00	0.32	9.29	100	5	18.69	10
GRAN	JERDON MOUNTAIN REID'S CREEK THUNDERHOLE UPPER CREEK	JERDON MOUNTAIN STATE ROAD 1407 LOOSE MOUNTAIN THUNDERHOLE EXT JOE POORE BIG CHESTNUT MT RIPSHIN BRANCH MORTIMOR PIEDMO	4030A 1407 4097 4071 4002 4098 4074 982		0.00 0.10 0.00 0.00 0.73 0.00 0.00 0.00	0.00 0.00 0.00 1.00 0.29 2.93 0.00 0.00	1.00 0.00 0.00 2.55 0.00 0.00 2.38 0.00	0.00 0.00 1.30 0.00 0.00 0.58 0.00 4.10	25 10 8 110 25 31 50 15	0 0 0 0 0 0 0 0	55.06 5.50 4.40 44.29 21.09 68.99 42.19 12.65	25 100 6 31 25 23 21 4
				TOTAL:	0.83	4.22	5.93	5.98	324	0	28.64	19
HIGH	TERRAPIN MTN.	BULL PEN BRUSHY MTN. FOWLER CREEK	1178 4568 4566		0.00 0.00 0.00	0.40 0.00 0.00	0.00 0.75 0.42	0.00 0.00 0.00	2 25 11	0 0 0	0.00 20.00 31.07	6 33 26
				TOTAL:	0.00	0.40	1.17	0.00	38	0	23.69	24
PISG	FLETCHER CREEK #2 KING CREEK YELLOW GAP	FLETCHER CREEK HORSE COVE YELLOW GAP	5097 4750 1206		1.82 0.00 0.00	0.28 7.00 3.94	3.03 0.00 0.00	7.00 0.00 0.00	140 0 18	0 0 0	40.06 0.00 0.00	12 0 5
				TOTAL:	1.82	11.22	3.03	7.00	158	0	45.22	6
TOEC	WHITE OAK	WHITE OAK EXT.	5570		0.00	0.00	0.00	0.87	30	0	41.03	34
				TOTAL:	0.00	0.00	0.00	0.87	30	0	41.03	34
TUSG	BARNETT CREEK DAVIS CREEK DOCKERY CREEK GARRETT CREEK PEACHTREE SHOOTING CREEK	BARNETT CREEK BRUCE RIDGE LITTLE CREEK DOCKERY CREEK WEST PRONG GRAP TIFTON CREEK BY PEACHTREE EXT. VINEYARD CR.	6236 6237 6265 6273 6278 420A 6176 6226		0.15 0.00 0.82 0.23 0.07 0.00 0.00 0.00	0.90 0.00 0.00 0.00 0.00 0.00 0.00 0.00	0.47 2.53 0.00 0.00 0.00 1.20 6.22 4.86	0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	60 60 25 8 8 25 165 50	0 30 0 0 0 0 15 0	183.48 53.48 29.79 10.49 21.12 62.50 99.66 0.00	39 24 30 35 114 21 27 10
				TOTAL:	1.27	0.90	15.28	0.00	401	45	73.11	22
JWPA	DENSON CREEK LITTLE ISLAND CREEK TOM MARKS	DENSON CREEK RD WOODRUN ROAD LITTLE ISLAND C WOODRUN EXT. BADIN LAKE	6648 517 518 517-1 597		0.00 0.00 0.00 0.00 0.00	0.00 0.00 0.00 0.00 0.70	0.00 0.00 0.58 0.46 0.00	1.20 4.60 0.00 0.00 0.00	25 40 15 0 10	0 0 0 0 0	16.04 66.55 45.26 0.00 19.21	21 9 26 0 14
				TOTAL:	0.00	0.70	1.04	5.80	90	0	29.89	11
WAYA	LAMBERT MNT. MICA CITY RAY BRANCH WINE SPRINGS	JUNULUSKA GAP FED COVE BROWN CREEK SHINGLETREE BRA RAY BRANCH EXTE ROCKY BALD BRAN	7270 7071 7072 713 7279 7132		0.00 0.31 0.59 0.00 1.19 0.31	0.00 0.00 0.00 3.40 0.00 2.52	1.50 0.00 0.00 0.00 1.08 1.76	0.50 0.00 0.00 0.00 1.53 0.00	36 20 40 5 80 90	0 0 0 0 0 0	26.18 0.00 0.00 8.07 31.09 44.99	18 65 68 1 21 20
				TOTAL:	2.40	5.92	4.34	2.03	271	0	41.26	18
TOTAL CONSTRUCTION MILES CLASS C:					9.29							
TOTAL RECONSTRUCTION MILES CLASS C:					29.82							
TOTAL CONSTRUCTION MILES CLASS D:					32.68							
TOTAL CONSTRUCTION MILES CLASS D:					34.49							
TOTAL PLANNED COST:					\$1,679,252.50							
TOTAL AUGMENTATION:					\$50,000.00							
TOTAL AVG COST/MBF:					\$36.78							
TOTAL AVG COST/MILE:					\$15,800.27							

Figure 1. (cont.)--Sample reports generated by the Multi-Year Schedule Program.

then only the second screen of the engineering data base might be used. Scheduling program activities to increase efficiency and meet specified time frames is possible using the "Critical Path Method" option (figure 2).

APPLICATIONS on the NFsNC

The program on the NFsNC has been loaded with information about timber sales and road projects for all sales from 1981 to 1988. Information for future sales is added as it becomes available. Currently, there are more than 350 timber sales and more than 500 road projects in the data base. The information for years 1981 to 1984 has been archived, but is easily accessible. A summary of some of the applications used by the various departments follows.

The Planning Shop is able to track the status of all projects through gates 1 and 2. Information is input into the data base by the Districts to produce a "position statement" that is reviewed by the Forest Supervisor and Staff before a project is approved (that is, passed through gate 1). The status of the writing and approval of the environmental analysis is tracked by the Planning Shop and reported to the Forest through the "Gates Status Report" generated by the program.

The Timber Shop is able to keep the timber industry informed about future sales by generating a "Timber Report" with the program. The status of all timber sales is tracked by the program through gate 6.

The Engineering Shop uses the program to track road mileage, unit costs, and the status of the road program (both purchaser credit and public works) from inception to contract completion. Standard reports are used to keep others on the Forest informed of what is happening in the road program.

The Lands Shop uses the program to track both the rights-of-way and landline programs, as well as to inform others on the Forest about the status of these programs.

The Districts use the program as a communication tool with other shops and Staff on the Forest by continually updating information about the timber sale program as better data become available.

The strong point of the program is that each department can use its section of the data base to keep track of its program of work, and at the same time

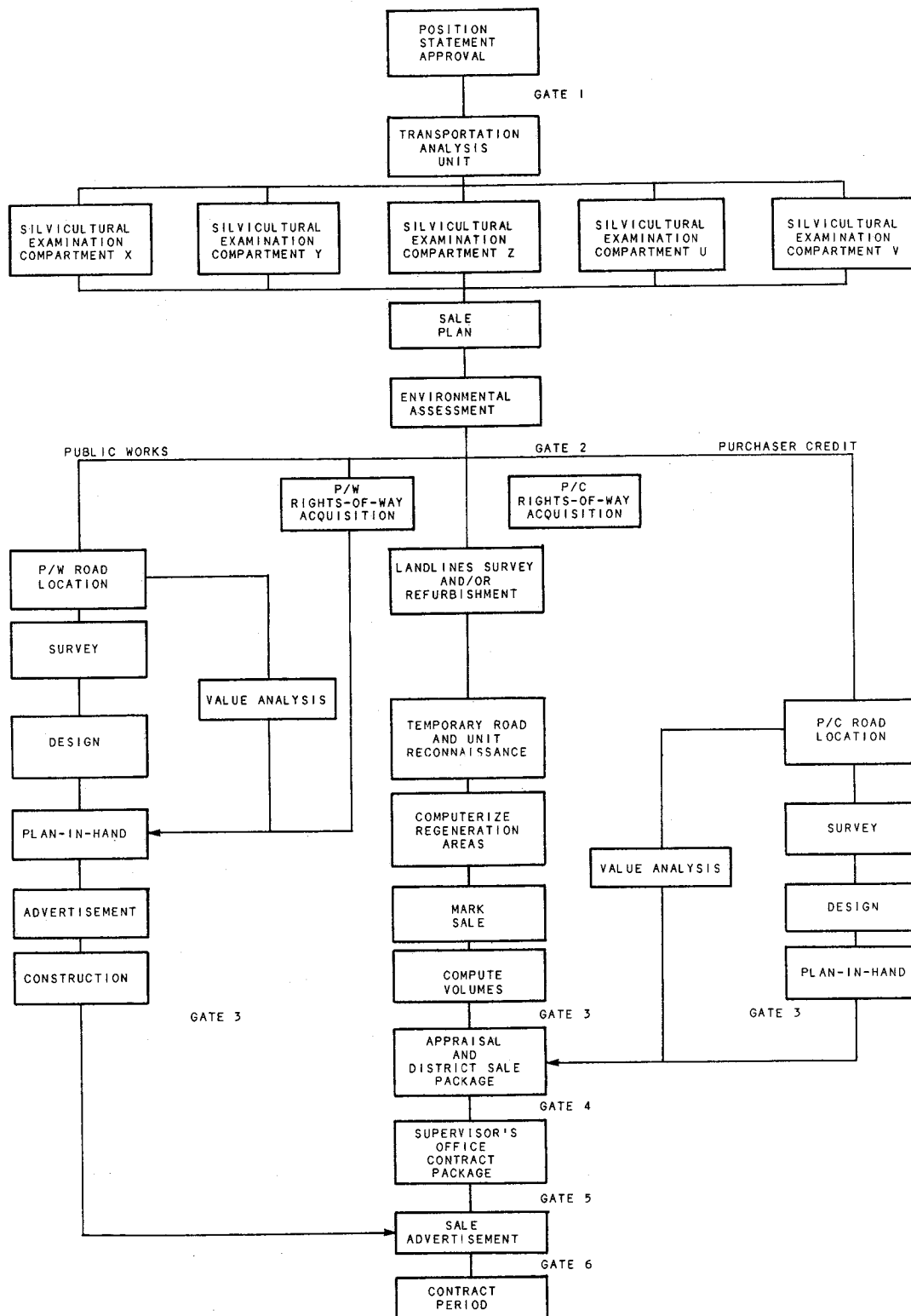


Figure 2.--The Critical Path Method.

be tied in with all the other activities that make up the total timber sale program.

A comprehensive 130-page user's guide that describes all features of the Multi-Year Schedule Program task can be acquired by dropping a request on the Data General to J.CHESELEY:R08F11A.

EFN

An Analysis of Space Shuttle Large Format Camera Coverage of National Forests in the United States

*Jerry D. Greer
Project Leader
Nationwide Forestry Applications Program*

The MISSION

On October 5, 1984, the space shuttle Challenger was launched into an Earth orbit that took the shuttle over that part of the Earth's surface that is between latitude 57 degrees north and latitude 57 degrees south. This orbit permitted the shuttle to pass over most of the Earth's surface.

For the mission designated as STS 41-G, such an orbit was critical. This shuttle carried a large format camera (LFC) in an experiment to collect high resolution images of the Earth on a variety of film emulsions.

The shuttle also carried the Feature Identification and Location Experiment, the Measurement of Air Pollution from Space Experiment, and the Shuttle Imaging Radar (SIR-B) Experiment. The crew on this mission also launched the Earth Radiation Budget Experiment Satellite into an independent orbit.

The Forest Service, acting through the Nationwide Forestry Applications Program, was a participant along with other agencies in this experiment. Desirable test sites (for the collection of imagery) were recommended and were accepted in the mission plan. This article represents the final stage of Forest Service participation in this experiment.

The LARGE FORMAT CAMERA EXPERIMENT

The camera carried on this flight of the space shuttle produces a 9-inch by 18-inch photographic image. Forward motion compensation is used to maintain image sharpness. The camera unit was specially configured and housed for operation in space. Otherwise, it functioned similarly to any aerial camera. The camera carried 4,000 feet of 9.5-inch-wide film.

The film actually consisted of four separate emulsions and was specially prepared by Kodak. Table 1 lists these film types.

Table 1.--Film types used in the LFC mission.

Kodak Film Type	Description
3414	High-Definition Aerial
3412	Panatomic-X Aerocon II
S0-131	High-Definition Aerochrome Infrared
S0-242	Aerial Color

During operation, a total of 12 fiducial marks are projected onto the image distributed around all sides of the frame. In addition, 45 reseau projectors are flashed. Their purpose is to aid in the analysis of errors in either original or duplicate imagery that may result from film instabilities.

Each image also is marked with a serial number, the day, hour, minute, second, and millisecond of exposure, the mission number, and the sequential frame number. A direction-of-flight arrow is also on each image, but it is reversed from what it should be.

The lens for the camera was specially designed and fabricated to remain stable in the space environment. The lens has an effective focal length of 12 inches. The glass lens assembly weighs almost 120 pounds and the full assembly approaches 158 pounds. An antivignetting filter was used.

The large format camera system included a stellar camera array, which is a 70 mm camera system rigidly mounted to the LFC assembly. Each time a frame of film was exposed in the LFC, two different star fields were photographed by the stellar camera. These auxiliary images permit the precise determination of the relationship between the LFC optical axis and the Earth nadir point. The LFC was designed and manufactured by Itek Optical Systems.

EXPERIMENT RESULTS

It was both unexpected and unfortunate that an unusually large number of very broad and significant weather systems covered much of the Earth's surface during this mission. The problem was especially bad

in North America and Europe. One of the astronauts observed that the Earth had an estimated 70 percent cloud cover, whereas it normally has about 30 percent.

The Forest Service had recommended a number of test sites in the United States that were included in the mission plan. Other primary test sites were located in Canada and Europe. Because of the cloud cover, up to 90 percent of the data passes (that is, photography of the test sites) over primary test sites had to be canceled. In the final analysis, most photographs were of secondary test sites that lay between latitude 28.5 degrees north and latitude 28.5 degrees south.

Despite this significant problem, 2,143 images of the Earth's land, oceans, and clouds were acquired during daylight passes. An estimated 40 percent were rated from unacceptable to marginal for use by persons interested in the Earth's land surface. Sixty percent were classified as acceptable. In the "acceptable" group, there were a number of nearly cloud-free images that are unusable because they fall on an emulsion splice or because the forward motion compensation mechanism failed to operate properly.

It turned out that many of the images that have either significant or total cloud cover are proving to be of extreme interest to researchers in oceanography and in the atmospheric sciences.

Most of the National Forests that were test sites in the original mission plan were cloud-covered during the flight of the Challenger. Imagery was frequently acquired on data passes over cloud-covered areas in order to advance the film to a scheduled change in the emulsion type during the mission.

On the images over the United States, there are a few notable places free of clouds that are of interest to the Forest Service. The quality and resolution of the images varies with the emulsion. Table 2 lists the number of images collected over the United States by film type. Table 2 also gives the total number of images that are usable and that have 15 percent or less of cloud cover. (Selecting 15 percent for this table was arbitrary and serves only to give users an idea of the cloud cover problem. Many frames that exceed 15 percent cloud cover are very useful.)

Table 2.--Images collected over the United States.

Kodak Film Type	Number of Images	Number of Frames with 15 Δ or Less of Cloud Cover
3414	123	51
3412	58	8
S0-131	33	17
S0-242	66	4
All kinds	280	80

Film type 3412 provided the highest resolution. Portions of some of these frames have been enlarged up to 100 times. At that magnification, the number of engines on jet aircraft in flight could be counted.

Film type 3414 provided a large number of very good images. Type S0-131 is probably the lowest quality from the standpoint of ground resolution. The images are, however, entirely acceptable for regional studies of gross vegetative patterns or geologic features.

The few U.S. images acquired with film type S0-242 are very good. Resolution is superior to the S0-131, but it is quite inferior to the two black-and-white emulsions.

UNITED STATES COVERAGE

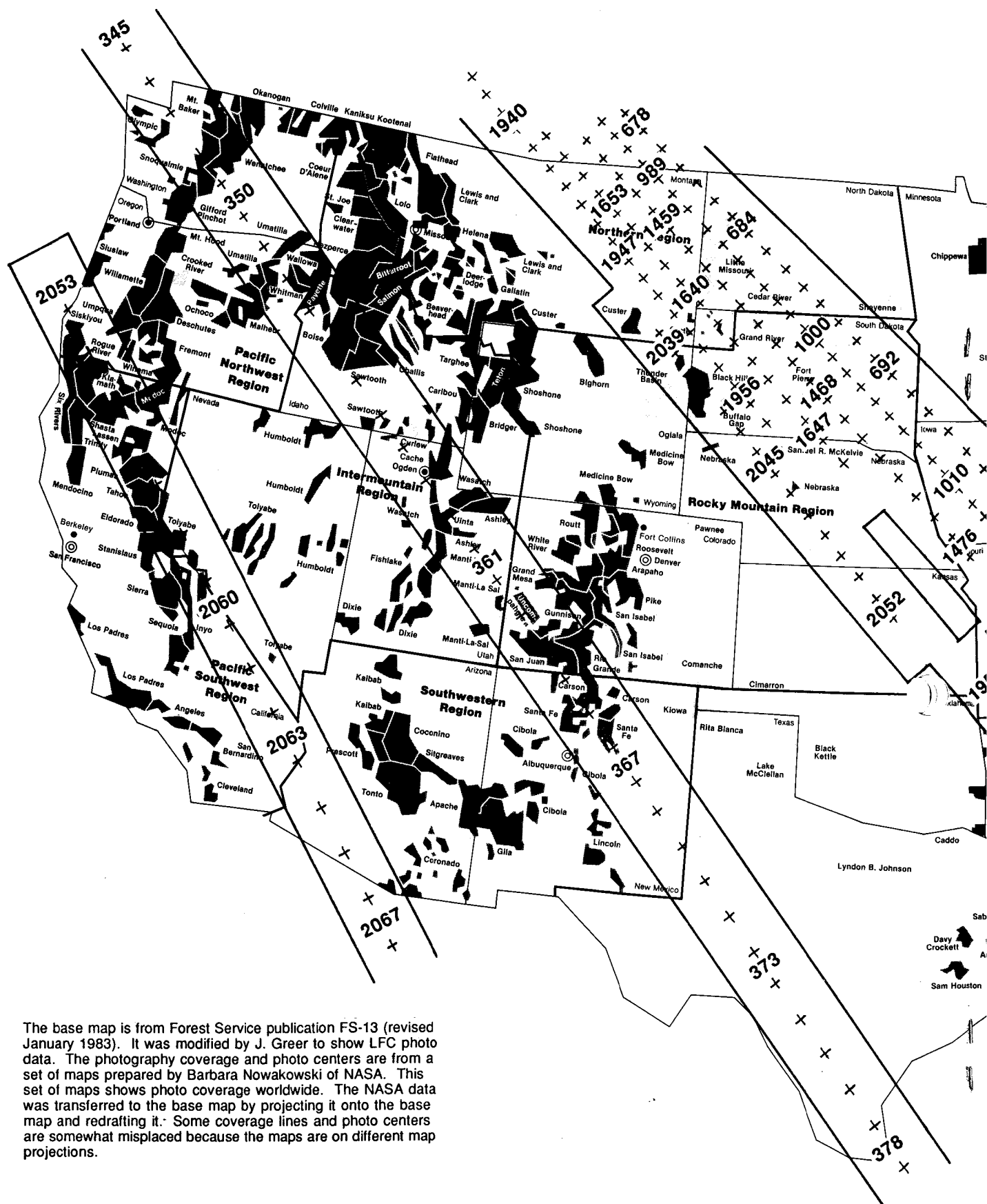
Table 3 presents a summary of the frames acquired and the areas of the United States covered. Figure 1 is a map that shows the areas covered by imagery. Areas listed refer to ground track coverage. Most land areas are obscured by clouds, and the images are not usable for resource inventories or as illustrative materials. All technical information about the images is included in a mission ephemeris. A few sample lines from this document are shown in figure 2.

Table 3.--Orbit pass, frame numbers, and land areas covered with LFC imagery.

Orbit	Frames	Film	Areas
21	276-279	3414	Vermont, New Hampshire, Maine
23	347-378	3414	Washington, Idaho, Utah, Colorado, New Mexico, Texas
37	657-667	3412	New York, Massachusetts, Connecticut
38	679-725	3412	Dakotas, Iowa, Illinois, Indiana, Kentucky, Tennessee, Alabama, Florida
54	988-1053	SO-242	Montana, Dakotas, Iowa, Missouri, Kentucky, Tennessee, Alabama, Florida
70	1454-1476	3414	Montana, Dakotas, Nebraska, Iowa, Missouri
86	1630-1662	SO-131	Montana, Dakotas, Nebraska, Florida
102	1940-1974	3414	Montana, Black Hills, South Dakota, Missouri, Alabama, Florida, Panhandle
118	2038-2052	3414	Montana, Black Hills, Nebraska, Kansas
119	2053-2066	3414	California, Nevada

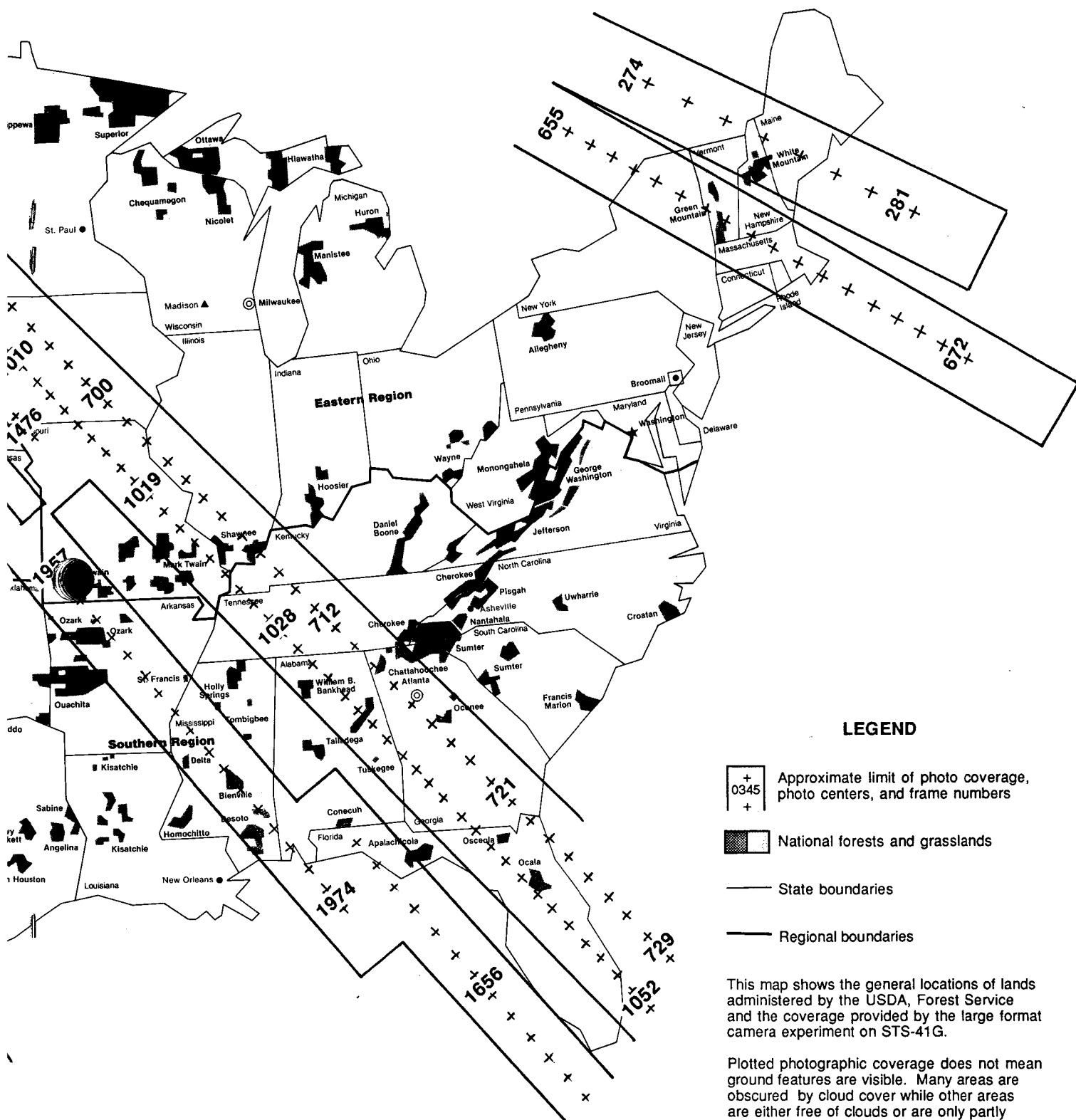
IMAGE CHARACTERISTICS

The space shuttle flies in an elliptical orbit. Parts of the orbit are closer to Earth, and others are farther away. During large format camera data passes, images were acquired from a high point of 366.78 kilometers and a low point of 221.50 kilometers. Nearly all images in a series have a slightly different scale. This poses no problems in stereo use of the photography when sequential frames from a single flight line are used. The maximum frame-to-frame difference in altitude is in the magnitude of



The base map is from Forest Service publication FS-13 (revised January 1983). It was modified by J. Greer to show LFC photo data. The photography coverage and photo centers are from a set of maps prepared by Barbara Nowakowski of NASA. This set of maps shows photo coverage worldwide. The NASA data was transferred to the base map by projecting it onto the base map and redrafting it. Some coverage lines and photo centers are somewhat misplaced because the maps are on different map projections.

Figure 1.--Areas of the United States covered by imagery.



ORBIT NO. 17

PASS NO. 17.0

OCPS LARGE FORMAT CAMERA

4-APR-85

MEG	COORDINATES		TIME (GMI)		ALTITUDE (DEG)			RATES (MRAD/S)			ALTITUDE (MRAD)	V/H	OVR	FI	EXP	SOLAR	CL
NO.	LAT.	LONG.	DAY/HR:MIN: SEC	YAW	PITCH	ROLL	YAW	PITCH	ROLL	(KM)	/SEC	(%)	TYPE	ER	(MS)	(DEG)	(%)
203	56.60N	15.15W	280/11:48:11.028	0.03	0.04	0.05	.02	-.01	.01	366.78	20.00	80	3414	-B	31.4	27.04	90
204	56.43N	13.51W	280/11:48:25.667	0.04	0.04	0.08	.01	.00	.02	366.76	20.00	80	3414	-B	31.4	27.47	80
205	56.22N	11.80W	280/11:48:41.114	0.06	0.03	0.08	.01	-.01	.00	366.74	20.00	80	3414	-B	31.4	27.91	70
206	56.00N	10.20W	280/11:48:55.747	0.07	0.01	0.08	.01	-.01	.01	366.72	20.00	80	3414	-B	31.4	28.32	60
207	55.74N	8.52W	280/11:49:11.189	0.09	0.01	0.10	.01	.00	.01	366.67	20.00	80	3414	-B	31.4	28.75	60

Figure 2.--A representative part of the photographic log in the mission ephemeris for 41-G.

about 0.13 kilometers (130 meters, or about 425 feet). This change is negligible when working from these altitudes.

More significant differences in scale may be encountered when using adjacent images from different orbit paths. In many cases, the scale of the photo would have to be changed before it could be used. Table 4 lists some maximums and minimums for the variation in scale.

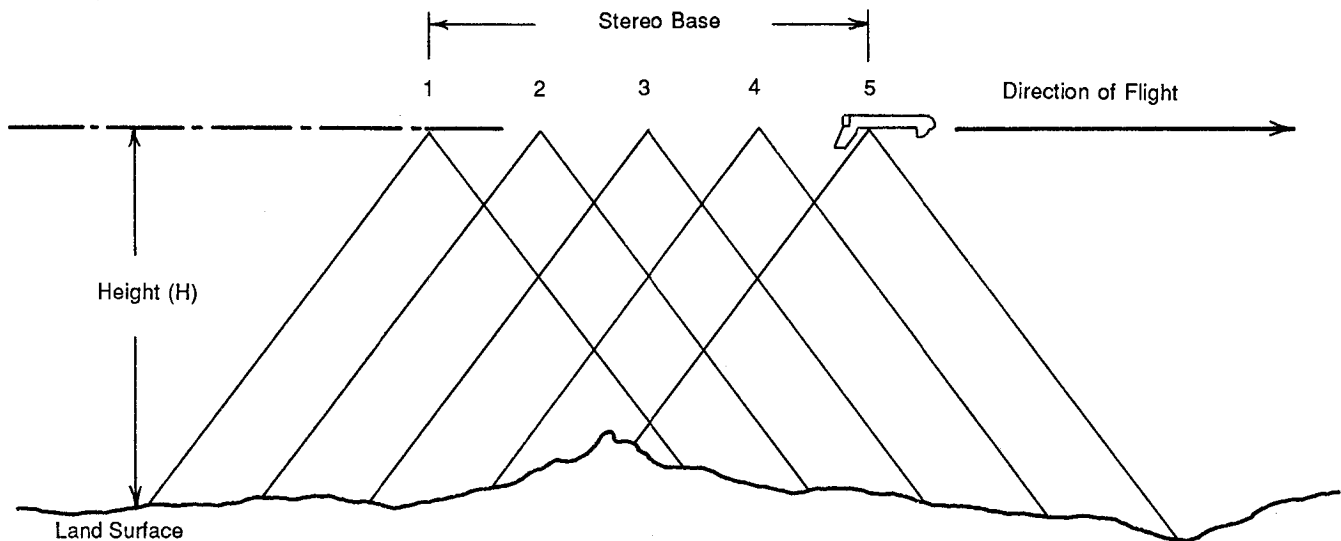
During the mission, the camera timing was variably set to acquire images with 60, 70, or 80 percent overlap. All data passes over the United States provided 80 percent overlap except for orbit 23 with 70 percent and orbit 119 with 60 percent.

Figure 3 illustrates how the vertical exaggeration changes with different pairs of images on a data pass. Potential users can use this information to determine how they might choose a set of frames for stereo coverage of an area of land.

Figure 4 compares the orientation of images acquired by the shuttle LFC with large format camera images acquired by the NASA U-2 or ER-2. In the space shuttle camera, the image overlap is end to end with the film transport parallel to the direction of flight. The LFC in the U-2 aircraft is mounted to cover more land area across track, and the film transport is perpendicular to the direction of flight.

Table 4.--Some minimums and maximums for the large format camera imagery.

	Altitude (km)	Scale (R.F.)	On-track distance	Cross-track distance	Area coverage
Maximum	366.78 km 227.90 mi	1:1,202,557	549.8 km 341.6 mi	274.9 km 170.8 mi	151,140 sq km 58,345 sq mi
Minimum	221.47 km 137.61 mi	1:726,131	332.0 km 206.3 mi	166.0 km 103.1 mi	55,112 sq km 21,270 sq mi



Selected Frames	1&2	1&3	1&4	1&5
Forward Overlap (in percent)	80	60	40	20
Base/Height Ratio (B/H)	0.3	0.6	0.9	1.2
Stereo Base	$0.3 \times H$	$0.6 \times H$	$0.9 \times H$	$1.2 \times H$
Vertical Exaggeration Factor	1.4	2.8	4.2	5.5

Figure 3.--This drawing is adapted from Schardt and Mollberg. This illustration shows the image acquisition in the 80 percent forward overlap mode. The shuttle Challenger (flying "upside down") at a height "H" holds the camera assembly in proper orientation to acquire near-vertical photographs. In this sketch, an image is acquired at the points labeled 1, 2, 3, 4, and 5. The field of view is 74 degrees along track and 41 degrees across track.

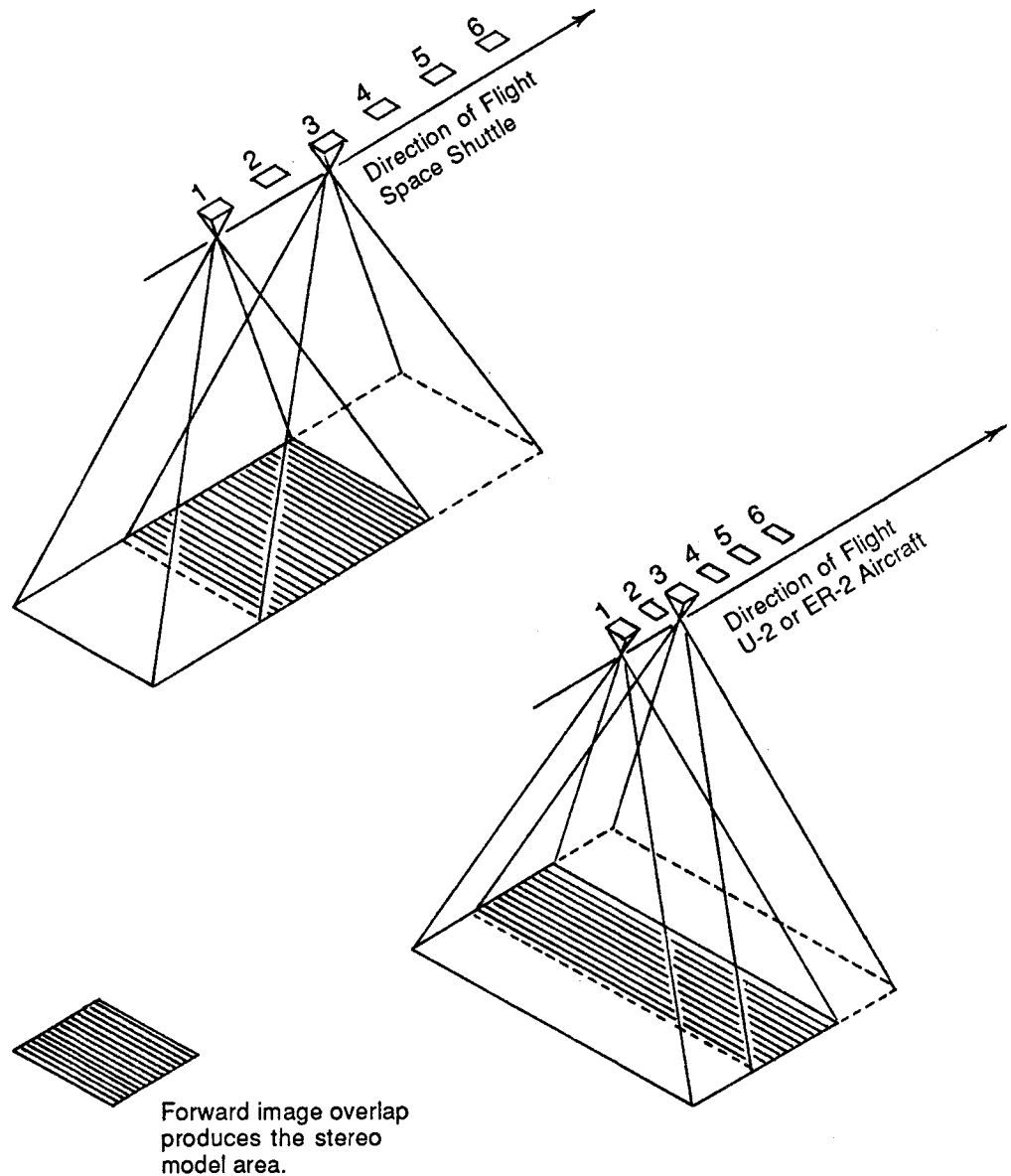


Figure 4.--A comparison of image orientation in the space shuttle large format camera and the LFC carried in the U-2 and ER-2 aircraft. In the space shuttle, images are acquired end to end. In the LFC carried on the U-2 and the ER-2, images are acquired as the film is advanced perpendicular to the aircraft's flight path.

CURRENT & POTENTIAL USES of the IMAGERY

The imagery has not been available long enough to have been used for many applications. There have been some significant uses made in other countries, however. Both the Australians and Chinese have made use of the imagery to map and explore vast, unknown

reaches in the western parts of their countries. The Australians, perhaps more than any others, are making extensive use of the imagery.

In the United States, Forest Service Region 9 produced an orthophoto of the White Mountain National Forest using two frames from this mission. The orthophotograph was created at the Geometronics Service Center, Salt Lake City, Utah. Representative form lines were computed by Jim Colborn in Milwaukee. These lines were overlaid on the image and represent 200-foot contours.

For all areas covered, this imagery (like all other photography) provides a unique archive of the conditions existing at the time of the mission. It is unfortunate that the camera will not be flown again on the shuttle in the near future. The images on hand represent a one-shot pass over the Earth; without more missions, they cannot easily be used for detecting change.

Since the imagery covers such broad areas, its most attractive use will be for the study of geologic features and perhaps to assess the vegetative cover in unexplored countries. According to Bernie Mollberg (the NASA Principal Investigator), there already have been some significant discoveries in geology from the imagery.

The imagery surely will prove valuable for other uses that have not yet been conceived. For now, it is important that the imagery be recognized as a valuable data source. Members of the Forest Service will undoubtedly find applications for this unique resource.

SOURCES of IMAGERY

Agencies of the Federal Government and members of cooperative research programs may order products made from the LFC photography through the Geological Survey, EROS Data Center in Sioux Falls, South Dakota. The original imagery is archived at EROS, but purchasers will receive products made from a reproducible master duplicate (a first-generation copy). The EROS Data Center will not provide reproductions to persons who desire to make commercial use of the data. Call EROS at FTS 784-7151 or (605) 594-6151 for information or to request order blanks.

Other persons who want LFC reproductions and products may order them from the LFC Department of

Chicago Aerial Survey, Inc., in Des Plaines, Illinois. The photographic products are also made from a master duplicate of the original LFC film. The prices at Chicago Aerial Survey are significantly higher than at EROS. Call Chicago Aerial Survey at (312) 298-1480 for ordering information or to request order blanks.

SUMMARY

Taking aerial photographs from space is very much like taking aerial photos from aircraft. Controlling the attitude of the spacecraft to ensure that the photographs are vertical is different. Also, the space shuttle, from the perspective of an observer on Earth, actually flies upside down with the shuttle cargo bay directed toward Earth. The camera is mounted firmly in the shuttle's cargo bay.

As in more mundane aerial photography, the images are acquired as the spacecraft travels along the orbit path. During the mission, the timing interval between sequential exposures was computed by the camera's electronic system. Timing was based on calculated velocity-to-altitude ratios that were determined at the Johnson Space Center and were transmitted to the space shuttle. The camera was operated without astronaut assistance.

The Principal Investigator and the mission scientists have concluded that the experiment was "very satisfactory." Nearly all objectives were accomplished and more than 2,000 photographs were collected.

From the standpoint of the Forest Service, cloud-free imagery acquired over National Forest test sites was insufficient for a full assessment of resolution, quality, and potential uses. While the limited number of images will prove useful, the real accomplishment should be remembered as the first use of a precision cartographic camera in space. These are the pioneer years in the use of cameras from space and the future will see more. If a "free-flyer" (that is, an independent orbiter) is created as a companion to the space station, resource managers nationwide and worldwide will have the opportunity to use imagery acquired from space in a scheduled manner.

Five photographs (figures 5 through 9) are included with this article. They illustrate some of the National Forest areas photographed during the mission. These reproductions were made from negatives

produced with a Polaroid copy camera. Each print is only a small part of a full frame.

The duplicate images were produced with the assistance of Bernie Mollberg, Ron Merkel, and John Salmon of NASA's Johnson Space Center. These people provided excellent support for the preparation of this paper.

REFERENCES

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4. Schardt, Bruton B. and Bernard H. Mollberg. Monitoring Earth's Ocean, Land and Atmosphere from Space--Sensors, Systems, and Applications. Progress in Astronautics and Aeronautics, 1985. American Institute of Aeronautics and Astronautics, Inc. Vol. 97:684-709 and Plates 17 to 21. (1985).
5. STS 41-G Large Format Camera Photographic Footprints. A draft copy of a worldwide set of maps showing areas of coverage and numbered frame centers. Drafted on DMAAC 1:10,000,000 scale maps by Barbara Nowakowski.

Figure 5.--Table Rock Lake in southwestern Missouri occupies a rare, cloud-free space on frame 1958. Water stands in contrast to adjacent vegetation. Clouds are easy to identify by their associated shadows. Nearly all of the Cassville Ranger District of the Mark Twain National Forest is included in this duplicate. (Film type 3414. Taken from an altitude of 228 kilometers. Enlarged 2x.)

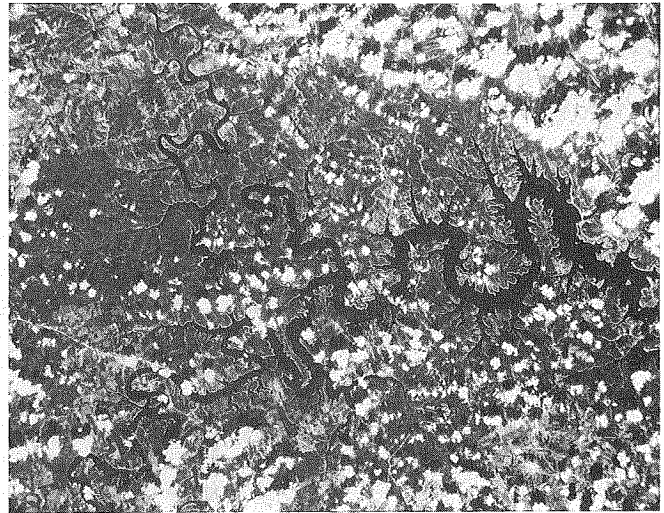


Figure 6.--Only thin wisps of cloud obscure parts of an otherwise clear image of western New York and Vermont. Water, vegetation, farm patterns, and roads are clearly seen on frame 0662. The lake along the left side of this photograph is Lake George in the Tongue Mountain Range of western New York. The smaller lake just above photo's center is Lake Bomoseen. Rutland, Vermont, is in the upper right quadrant of this picture. Chittenden Lake is visible above Rutland near the top photo edge in the Green Mountain National Forest. The Green Mountain National Forest with Mt. Tabor occupies much of the land in the lower right quadrant of the photo. (Film type 3412. Taken from an altitude of 232 kilometers. Enlarged 1x.)

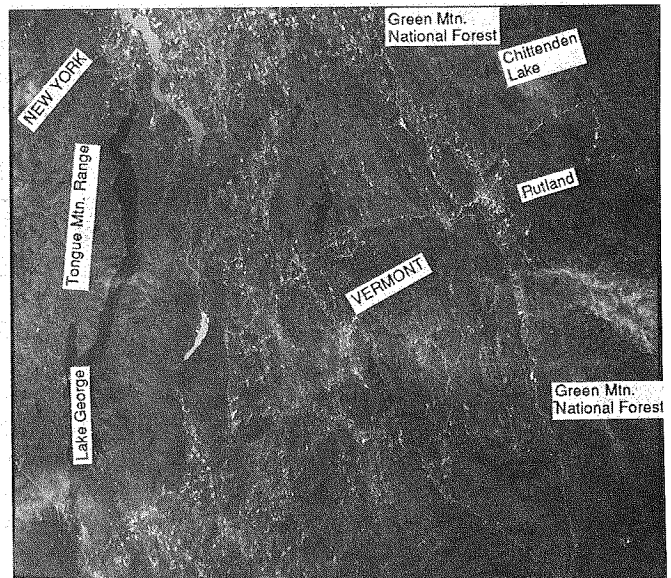


Figure 7.--A portion of the Black Hills National Forest from LFC frame 1952 is shown in this photograph. Roadways, cleared lands, and some vegetative differences are obvious on this image. Frame 1952 was free of cloud cover. It provides a fairly high resolution image of the entire National Forest. Deerfield Lake is in the lower center of the photo between the prominent road and the large clearing that is within Township 1 north and Range 3 east. (Film type 3414. Taken from an altitude of 230 kilometers. Enlarged 4.5x.)

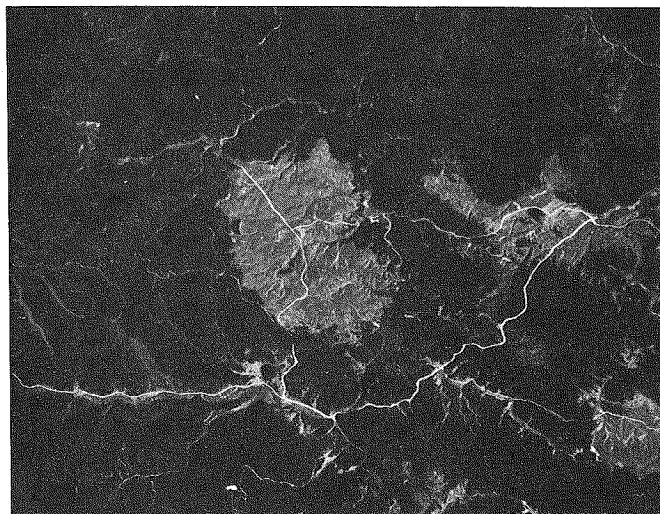


Figure 8.--The arrangement of streets and highways in Albuquerque, New Mexico, is easy to see in this portion of frame 0366. The dark area from the center of the photo to the lower right corner is vegetation from the pinyon-juniper type up to the mixed conifer type on the Sandia and Manzanita Mountains. The entire Sandia Ranger District of the Cibola National Forest is within this photograph. A large, rapidly building cumulus cloud is centered over Sandia Crest. Notice the center-pivot irrigation fields at the right-center edge of the photograph. (Film type 3414. Taken from an altitude of 264 kilometers. Enlarged 1x.)



Figure 9.--The east half of the Great Salt Lake, Salt Lake City, and the Wasatch Mountains are shown in this duplicate taken from frame 0357. The Wasatch National Forest is located on the mountains that bisect the photograph from top to bottom. A few clouds obscure parts of Antelope Island. Cumulus clouds build over the lands on the right side (east of the Wasatch Mountains) of the photograph. (Film type 3414. Taken from an altitude of 266 kilometers. Enlarged 1x.)

ROad Analysis & Display System (ROADS)

*Chris Schwarzhoff
Civil Engineer
Washington Office Engineering*

Management of the National Forest System road program has been, and will continue to be, of major interest to Forest Service managers and the public. As the single largest Forest Service budget line item, it naturally attracts significant attention. Focus is further increased as Congress releases unroaded areas, once considered for wilderness, to the Forest Service for multiple-use management. As pressure is maintained or increased for managers to sustain high timber outputs across the country, it is inevitable that these released areas will give rise to continued debate on the role of the national road program and its relationship to the provision of resource outputs in the years ahead. Further, the issues, concerns, and opportunities identified in Forest Plans, along with a sustained, high-level Federal deficit, combine to necessitate effective management of road program costs.

To ensure that Forest Service managers have adequate information and controls to address these issues, the Chief directed a review of the situation. In September 1986, a six-member, interdisciplinary working group was charged with performing an indepth analysis of the situation.

Specifically, the working group was charged with the following:

- (1) Developing measurable criteria for the Chief to use in monitoring and evaluating the efficiency of the road program. These criteria will be expressed as costs per unit of output--to the degree possible. These criteria will be used along with other considerations to evaluate the effectiveness of each Region, to make comparisons between Regions and Forests, and to track trends in road program costs.

- (2) Developing recommendations on how the data elements necessary for the evaluation criteria will be tracked, and how the evaluations and comparisons between units will be made. The recommendations must result in a process that provides for an objective measurement of Regional and Forest progress in managing road program costs.

The recommendations of the working group were presented to, and accepted by, the Chief in February 1987. The team's report, "Road Analysis & Display System (ROADS)," was transmitted to the Regions on February 19, 1987. The working group's recommendations were built, in large measure, upon the efforts of another ad hoc team--Road Technology Improvement Program (RTIP) Team 2. The RTIP Team 2 had developed a lot of information and proposals in this area, but was not quite as broadly focused as the roads working group.

Implementation of ROADS includes (1) the 7 "key indicators" for use by the Chief, (2) the 21 other indicators for use by managers at Regional and Forest levels, and (3) the 2 data-base spreadsheets that involve amending and standardizing the use of the current "In Support of" Form D and the new Forest Project Listing. This will provide the needed framework for analyzing the road program and displaying information on efficiency, performance, presentation, and project selection.

The seven key indicators to be tracked on a Service-wide basis are the following:

- (1) Present Program Change (1A)

$$\frac{\text{Announced Miles Constructed/Reconstructed (C/R) Accomplished}}{\text{Announced Miles Constructed/Reconstructed}}$$

- (2) Timber Sale Volume Change (1B)

$$\frac{\text{Volume Sold in Announced Sales}}{\text{Volume Planned in Announced Sales}}$$

- (3) Total Transportation Costs per MBF (2A)

$$\frac{\text{C/R + Reconst + Maint + Haul + Yard/Skidding + Temp Road Cost}}{\text{MBF}}$$

(4) Percent Roadless Areas Accessed (2B)

$$\frac{\text{Acres Accessed}}{\text{Total Acres of Released Areas}}$$

(5) Planned Construction Costs Per Mile by Functional Class (3A)

$$\frac{\text{Construction \$ (FRP + PCP + PEP)}}{\text{Constructed Miles (FRP + PCP + PEP)}}$$

(6) Support Costs Per Mile--Timber System (3D)

$$\frac{\text{Preconst Eng \$ (FRP + PCP) + CE \$ (FRP + PCP + PEP) + PM \$ + PS \$}}{\text{Miles Constructed/Reconstructed (FRP + PCP + PEP)}}$$

(7) Support Costs to all Costs--Timber System (3E)

Same as #6, above, expressed over all dollars
(FRP + PCP + PEP)

Much of the data needed to track these indicators was already being collected; therefore, implementation of ROADS should not be too burdensome. In addition to the seven key indicators, the system provides for a road project listing that allows for Service-wide aggregation of all road projects.

The report includes a "first cut" identification of comparable units (these are Forests with similar characteristics and program demands). Thus, managers will have a basis of comparison when analyzing their key indicators. It is expected that these indicators will be used in the management review process at all levels.

Successful implementation of ROADS and continued efficient management of the national road program will require complete support from Regional Foresters and Forest Supervisors. It is recognized that the system is not perfect, but the intent is to implement, review, and refine as needed. The use of "comparable units" is one example of this. The Forest groupings are a first cut at defining organizational units that may be expected to have similar costs. These will be tested and revised to ensure an equitable process, with an overall emphasis placed on the individual unit and its ability to improve management.

For more details on ROADS, please refer to the full report from the working group, which also contains a "How To Do It" chapter and a detailed implementation action plan.

EFN

Computer Spreadsheets in Geotechnical Design

Michael D. Remboldt
Region 4 Regional Office

The increasing availability of low-cost personal computers and software, combined with the minimum time required to become skilled in using spreadsheets, makes the personal-computer-based spreadsheet a powerful and efficient tool for the geotechnical engineer.

Spreadsheet software offers relief from time-consuming iterative calculations; provides clear, easy-to-read reports automatically; virtually eliminates the need for time-consuming programming for sensitivity studies; and can be integrated with government agency analysis standards documentation to provide quick design review for contract design work.

Spreadsheets have numerous applications. For example, they can be used to analyze the bearing capacity of spread footings and piles, to help design retaining walls, and to perform economic analyses. Examples of spreadsheets for these applications are detailed and discussed in this article.

WHAT is a SPREADSHEET?

Spreadsheets are groups of information (cells) arranged in a matrix of rows and columns. We have all seen balance sheets and financial statements arranged in spreadsheet fashion. Indeed, people traditionally familiar with spreadsheets, as most of us know them, are accountants and bookkeepers.

The cells of a computer spreadsheet can contain text, numbers, logical functions, and formulas. This provides the capability of performing complex operations on information in other cells and displaying the results on the same spreadsheet.

The user can input the contents of any cell from the keyboard simply by moving the cursor to that cell location on the screen and typing in the desired contents. Cells or groups of cells can be easily

edited, moved, deleted, and recalculated, making it easy to customize a particular application.

Many spreadsheet software packages can handle graphics and are designed to accept data from other software, such as data-base and word-processing programs, as well as to export data to those programs.

Learning to use a computer spreadsheet is easy; using it can save time and be cost-effective. Spreadsheets provide an opportunity to do many of those things that used to be difficult--if not impossible--because of a lack of time and programming skills.

Computer spreadsheets include these advantages:

- (1) Ease of use. Inputting data, text, formulas, and logical expressions is easy because they are placed exactly where the user wants them.
- (2) Flexibility. The user can change input data or formulas at will without the frustrating "debugging" required in more conventional programming.
- (3) Power. The spreadsheet incorporates mathematical, trigonometric, and logical functions that can be duplicated and recalculated with one stroke. This makes spreadsheets ideal for sensitivity studies ("what if" type questions).
- (4) Cost-effectiveness. Using spreadsheets for repetitive calculations results in work that can be done in a fraction of the time required to perform identical calculations by hand. Initial setup of spreadsheet templates takes much less time than conventional programming and debugging. A bonus of the spreadsheet is that the output can be structured easily into an attractive and organized report. The spreadsheet (and its contents) is ready to be filed in compact form (digital mass storage) for future documentation or re-use.
- (5) Portability. Users of identical spreadsheet software can exchange "templates" (spreadsheets structured for specific purposes) to avoid duplication of effort and to achieve consistency in technology application.

SPREADSHEET USE in GEOTECHNICAL ENGINEERING

Applications

Computer spreadsheets offer the engineer an easy-to-use tool for performing a broad spectrum of calculations and for providing professional-looking reports. Some of the uses to which the Region 4 Materials Engineering Group has put spreadsheets follow:

- (1) Slope stability sensitivity analysis.
- (2) Bearing capacity analysis.
- (3) Retaining wall design.
- (4) Economic projections and cost analysis.
- (5) Earthwork quantity calculations.
- (6) Statistical analysis, including regression.
- (7) Static pile capacity evaluation.
- (8) Pavement design.
- (9) Materials testing calculations and reports.

Following is a brief discussion of two spreadsheets designed by the author. These spreadsheets are not technically complex and do not involve new technical concepts. Hopefully, these examples will suggest other potential uses of computer spreadsheets.

Analysis of the Static Bearing Capacity of Piles

The method used in this application is based on Nordlund (4) and is discussed in the FHWA "Manual on Design and Construction of Driven Pile Foundations" (5) and by Bowles (1). Figure 1 sketches the geometric assumptions and outlines the general equation.

Manually calculating bearing capacity using this method is tedious at best. This is because of the need to refer to numerous charts and to interpolate between them. One way to get around this obstacle is to use a powerful feature called the lookup function. This is essentially a command for the computer to return a "y" value for a given "x" from a specified table of "x-y" values residing in the spreadsheet. Several lookup tables were easily constructed by reading the charts and entering the values in the template. The tables then were expanded--using the spreadsheet to do the work, of course--by inserting blank rows and columns and filling them with calculated interpolations.

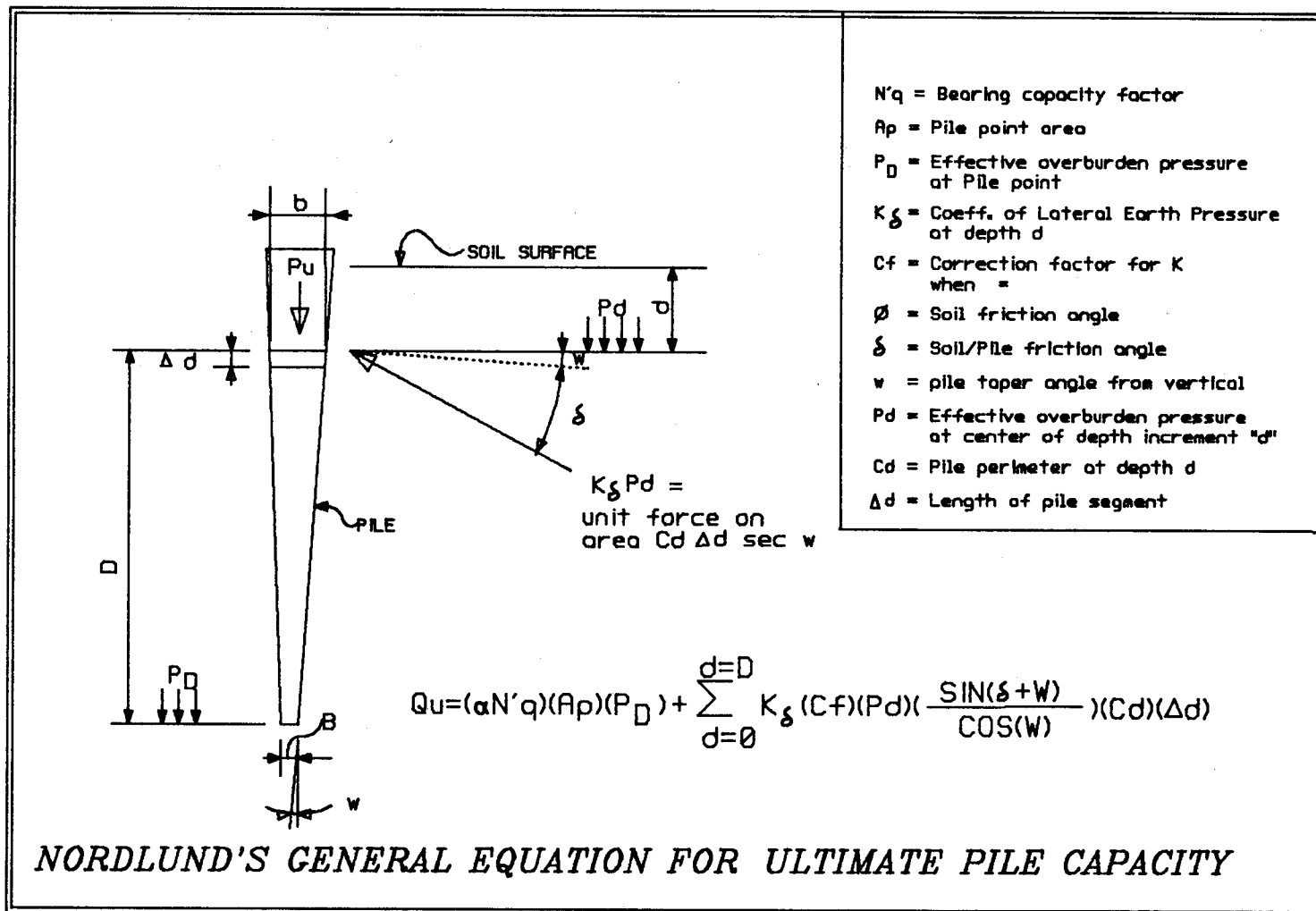


Figure 1.--Nordlund's general equation for ultimate pile capacity.

Figure 2 shows the initial template before any data were entered. Cells into which data must be placed before calculation contain "???" This reduces confusion as to what and where input information is required. If data are not entered into the "???" cells, then the "???" cells will be interpreted as having zero values and calculations will result in zeros and "ERR" (error) messages. Recalculation of the spreadsheet with the "???" cells replaced with appropriate numerical values will result in meaningful contents in the remaining cells.

The first part of the template is for basic input data, such as pile geometry and location. In the second part of the template, column 1 is where data about depth (of layer interfaces) are entered, while columns 3 through 5 are for input data about soil friction angle, effective soil mass density, and pile type. (Codes for pile types, including a "no pile" option for piles below ground, are listed in the table at the top-right of the template.) Once these data are entered, the spreadsheet can calculate skin and tip ultimate static capacity, showing intermediate calculations and parameters.

Figure 3 is a printout of a sample problem (from the FHWA manual, pp. 177-185). The lookup tables were not printed because of their large size.

Retaining Wall Design

This template was designed for a review of a design for a 38,400-square-foot mechanically stabilized embankment (welded wire wall). There were eight different wall geometries, with a maximum height of 26 feet. A tool was needed to efficiently check the design and analyze the effect of various design parameters. Figure 4 is a sketch of a typical wall section showing the geometric assumptions.

Figures 5, 6, and 7 are printouts of the spreadsheet analysis for a specific wall geometry.

As shown in figure 5, the data required for analyzing wall design include external geometry, soil parameters, loading geometry, and corrosion reduction requirements. Once these data are entered, the spreadsheet can determine external stability by calculating vertical and horizontal loads and moments, factors of safety against sliding and overturning, location of vertical resultant at the toe, and toe pressure (figure 6).

**STATIC ULTIMATE PILE CAPACITY FOR COHESIONLESS SOILS
NORDLAND METHOD**

BASIC INPUT DATA

Pile Perimeter at Point, in. =	???	Pile Taper, inches/ft.	???
Effective Pile Point Diameter, in. =	???	Depth of Pile Tip From Surface, ft. =	???

Pile Tip Area = ERR sq.ft.
Pile Taper Angle = 0.00 radians
Pile Taper Angle = 0.00 degrees

PILE TYPES

(0) No Pile
(1) Pipe piles, non-tapered portion of monotube piles
(2) Timber piles
(3) Precast concrete piles
(4) Raymond step-taper piles
(5) Raymond uniform taper piles
(6) H-piles and augercast piles

PILE CAPACITY WORKSHEET

Depth Ft.	Segment Thickness Ft.	Soil Friction Angle deg.	Effective Soil Density pcf	Pile Type (see above)	Average Specific Pile Volume, V cu.ft./ft.	Soil/ Pile Friction Angle deg.	Lateral Earth Pressure Coeff. K	Effective Overburden Press. at Pile Point psf	Effective Overburden Press. at Segment psf	Alpha Coeff.	Ultimate Segment Qs tons	Sum Ultimate Qs tons	Ultimate Pile Qp tons	Ultimate Capacity Qs + Qp tons
???	ERR	???	???	???	ERR	ERR	ERR							
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR
???	ERR	???	???	???	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR

Figure 2.--Initial template for analysis of static bearing capacity of piles.

**STATIC ULTIMATE PILE CAPACITY FOR COHESIONLESS SOILS
NORDLAND METHOD**

BASIC INPUT DATA

Pile Perimeter at Point, in. =	48	Pile Taper, inches/ft.	0	(0) No Pile
Effective Pile Point Diameter, in. =	13.54	Depth of Pile Tip From Surface, ft. =	38	(1) Pipe piles, non-tapered portion of monotube piles
Pile Tip Area =	1.00 sq.ft.			(2) Timber piles
Pile Taper Angle =	0.00 radians			(3) Precast concrete piles
Pile Taper Angle =	0.00 degrees			(4) Raymond step-taper piles
				(5) Raymond uniform taper piles
				(6) H-piles and augercast piles

PILE CAPACITY WORKSHEET

Depth Ft.	Segment Thickness Ft.	Soil Friction Angle deg.	Effective Soil Density pcf	Pile Type (see above)	Average Specific Pile Volume, V cu.ft./ft.	Soil/ Pile Friction Angle deg.	Lateral Earth Pressure Coeff. K	Effective Overburden Press. at Pile Point psf	Effective Overburden Press. at. Segment psf	Alpha Coeff.	Ultimate Segment Qs tons	Sum Ultimate Qs tons	Ultimate Pile Qp tons	Ultimate Pile Qs + Qp tons
0	6	34	105	0	0.00	0.0	0.00							
6	2	34	42.6	3	1.00	25.5	1.68	630	315	0.66	0.0	0.0	11.2	NA
8	18	34	42.6	3	1.00	25.5	1.68	715	673	0.66	1.9	1.9	12.7	NA
26	12	40	60.6	3	1.00	30.0	3.00	1482	1099	0.66	28.6	30.6	86.1	NA
38								2209	1846	0.75	66.4	97.0	128.4	225.4

Figure 3.--Printout of completed analysis for sample problem.

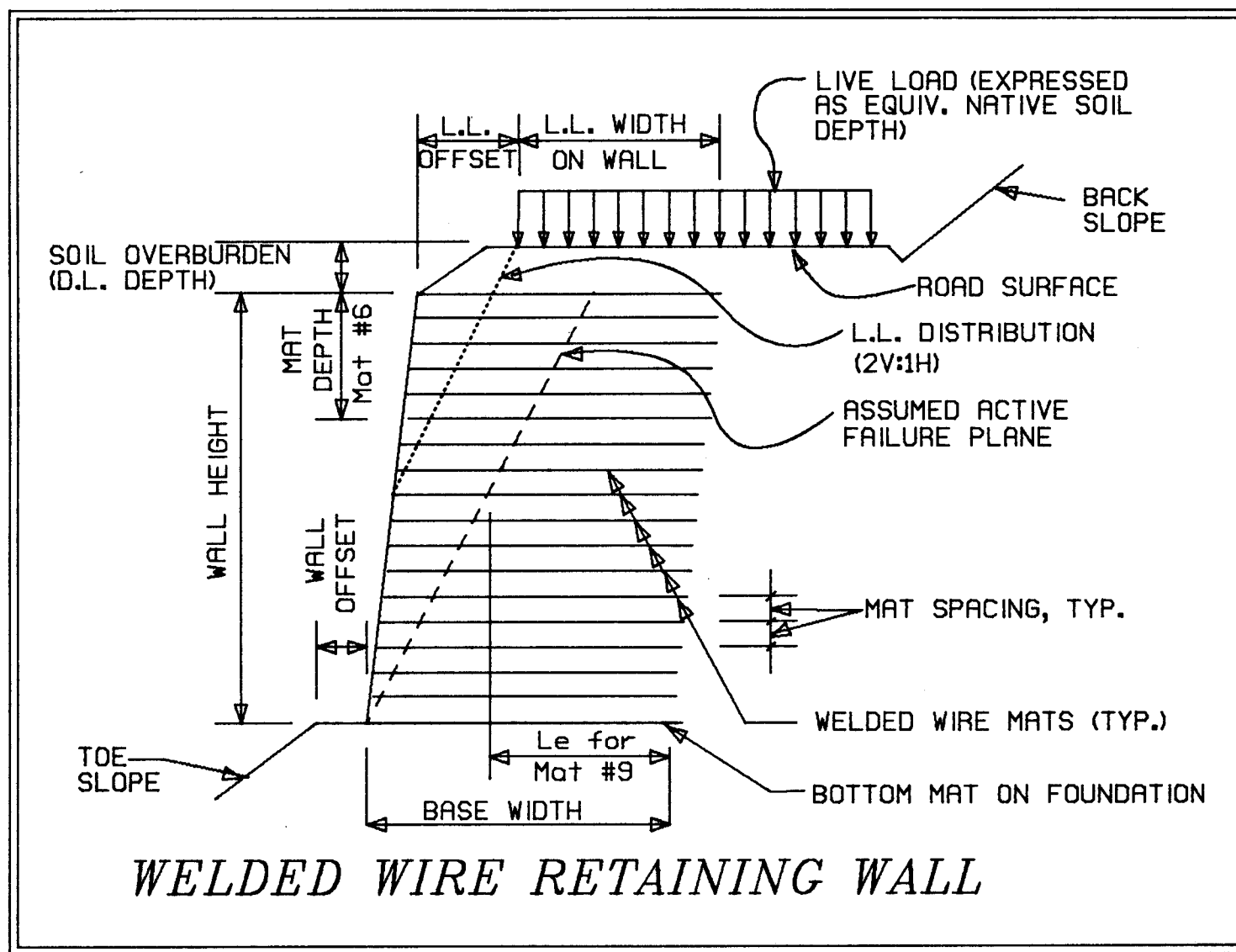


Figure 4.--Typical section of welded wire retaining wall.

BASIC INPUT DATA:**Soil and Geometry**

Wall Height, Feet.	25.5	PHI Soil Wall, deg.	34	DENSITY soil Wall, k/cu.ft.	0.125	Ka Coefficient Behind Wall	0.333
Base Width, Feet.	18	PHI Soil Native, deg.	30	DENSITY soil Native, k/cu.ft.	0.125		

* LOADING *	Soil Depth (Equiv.) ft.	Offset From Wall Edge ft.	Width Above Wall ft.	* WIRE *	Soil/Wire Friction Angle, deg. =	20
					Dia. Reduction for Corrosion, in. =	0.026
***LIVE LOAD:	2	4	14			
***DEAD LOAD:	2.67	2	16			

Figure 5.--Section of spreadsheet containing input data for retaining wall analysis.

For the spreadsheet to calculate internal stability, the user must input mat spacing, mat depths, wire sizes, and wire spacing (figure 7). The spreadsheet then calculates reduced wire area (for corrosion), longitudinal wire stress, length of wire embedment (behind assumed failure plane), and factors of safety against pullout for each mat for three different soil types. Factors of safety against pullout were calculated after Nielson and Anderson (3).

It takes an experienced wall designer about 12 hours to design a spreadsheet like this. Setting up and recalculating the spreadsheet template to accommodate different conditions takes about 10 minutes. Calculating and printing the results for 8 different conditions takes less than 2 hours and includes 39 calculations per layer, or 3,120 calculations for the whole job. This compares to an estimated 32 hours of hand calculation with no printed report.

**COST/BENEFIT
RATIO**

The cost/benefit ratio of using computer spreadsheets depends on how much the system is used, as well as on the cost of the hardware and software. The author's experience indicates that analyses using a computer spreadsheet take about one-fourth the time

EXTERNAL STABILITY

Vertical Loading:

DESCRIPTION	LOAD K/FT	MOMENT	
		ARM FT/FT	MOMENT K-FT/FT
WALL DEADLOAD	57.38	9.00	516.38
DEADLOAD SURCHARGE	5.34	10.00	53.40
LIVELOAD SURCHARGE	3.50	11.00	38.50
TOTALS	66.22	30.00	608.28

Horizontal Loading:

DESCRIPTION	LOAD K/FT	MOMENT	
		ARM FT/FT	MOMENT K-FT/FT
LAT. SOIL PRESS. BEHIND WALL	16.52	9.39	155.08
LIVELOAD INDUCED LAT. PRESS.	2.35	14.09	33.03
TOTALS	18.86	23.48	188.11

***MIN. OVERTURNING F.S. = 3.03 <-----

***MIN. SLIDING F.S. = 1.92 <-----

MAX. DISTANCE OF VERT. RESULTANT FROM TOE =	6.09 FT.
ECCENTRICITY =	2.91 FT.
MAXIMUM ALLOWABLE ECCENTRICITY =	3.00 FT.
MAXIMUM TOE PRESSURE =	11.46 KSF

Figure 6.--Section of spreadsheet for evaluating the external stability of retaining wall.

INTERNAL STABILITY

MAT #	MAT DEPTH FROM TOP OF WALL FT.	--LOADING--		--WIRE SIZE--		--CORRODED WIRE SECTION PROPERTIES--				LONG. SPACING IN.	TRANS. SPACING IN.
		VERT. KSF	HORIZ. KSF	LONG. (Wxx.X)	TRANS. (Wxx.X)	--LONGITUDINAL-- AREA SQ. IN.	DIA. FT.	--TRANSVERSE-- AREA SQ. IN.	DIA. FT.		
1	0.0	0.52	0.34	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
2	1.5	0.69	0.45	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
3	3.0	0.85	0.56	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
4	4.5	1.05	0.68	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
5	6.0	1.24	0.81	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
6	7.5	1.43	0.93	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
7	9.0	1.62	1.05	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
8	10.5	1.80	1.17	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
9	12.0	1.99	1.29	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
10	13.5	2.18	1.42	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
11	15.0	2.37	1.54	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
12	16.5	2.55	1.66	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0
13	18.0	2.74	1.78	7.0	3.5	0.058	0.023	0.027	0.015	6.0	9.0
14	19.5	2.93	1.90	7.0	3.5	0.058	0.023	0.027	0.015	6.0	9.0
15	21.0	3.12	2.03	7.0	3.5	0.058	0.023	0.027	0.015	6.0	9.0
16	22.5	3.30	2.15	7.0	3.5	0.058	0.023	0.027	0.015	6.0	9.0
17	24.0	3.49	2.27	7.0	3.5	0.058	0.023	0.027	0.015	6.0	9.0
18	25.5	3.68	2.39	4.5	3.5	0.036	0.018	0.027	0.015	6.0	9.0

MAT #	NO. LONG. WIRES / FOOT	NO. TRANS. WIRES / FOOT	LONG. WIRE STRESS KSI	S. SAND PULLOUT Le FT.	S. SAND RESIST. KIPS/FT.	W. SAND PULLOUT F.S. KIPS/FT.	W. SAND PULLOUT F.S. KIPS/FT.	PEA GRAV. PULLOUT F.S. KIPS/FT.	PEA GRAV. PULLOUT F.S. KIPS/FT.
1	2.00	1.33	7.12	4.44	1.811	3.56	2.459	4.83	2.601
2	2.00	1.33	9.38	5.24	2.812	4.19	3.469	5.17	3.645
3	2.00	1.33	11.65	6.04	4.028	4.83	4.696	5.63	4.913
4	2.00	1.33	14.37	6.83	4.970	4.84	6.302	6.14	6.574
5	2.00	1.33	16.92	7.63	5.862	4.84	8.091	6.69	8.423
6	2.00	1.33	19.48	8.43	6.872	4.93	10.114	7.26	10.515
7	2.00	1.33	22.03	9.23	7.998	5.08	12.374	7.85	12.851
8	2.00	1.33	24.59	10.02	9.243	5.26	14.868	8.46	15.431
9	2.00	1.33	27.15	10.82	10.604	5.46	17.599	9.07	18.254
10	2.00	1.33	29.70	11.62	12.083	5.69	20.564	9.68	21.320
11	2.00	1.33	32.26	12.42	13.680	5.93	23.765	10.30	24.630
12	2.00	1.33	34.82	13.21	15.394	6.18	27.202	10.93	28.183
13	2.00	1.33	22.91	14.01	17.550	6.57	31.199	11.67	32.305
14	2.00	1.33	24.47	14.81	19.541	6.84	35.149	12.31	36.387
15	2.00	1.33	26.04	15.61	21.652	7.13	39.336	12.95	40.716
16	2.00	1.33	27.61	16.40	23.883	7.41	43.762	13.59	45.290
17	2.00	1.33	29.17	17.20	26.233	7.71	48.426	14.23	50.111
18	2.00	1.33	25.08	18.00	28.144	15.69	52.767	29.42	54.617

Figure 7.--Section of spreadsheet for calculating the internal stability of retaining wall.

they take when done by hand. In addition, it seems that the spreadsheet is used approximately 5 to 10 percent of working hours. When usage increases just a small amount, the cost recovery time decreases very quickly. When used by upper level designers and managers, computer spreadsheets are even more cost-effective.

SUMMARY

Geotechnical engineers can greatly improve their efficiency and reduce design costs by using computer spreadsheets. In addition to allowing cost savings, spreadsheets offer freedom to explore variations in design and encourage creativity while giving an added element of neatness and organization. As Kleiner (2) states, "engineers . . . must further explore the usefulness of the electronic spreadsheet, a truly remarkable, powerful and flexible tool with unlimited applications."

Of course, the use of spreadsheets is not limited to design for the geotechnical engineer. For example, it has been of great value in the soils laboratory. It is ideal for such applications because of the reportlike format and ability to "program" it to do required calculations. In addition, the spreadsheet software (if so designed) can illustrate results (such as moisture-density relationships) in graphical form.

The spreadsheets discussed in this article were designed using Lotus 1-2-3®. For additional information or copies of the described spreadsheet templates contact Michael Remboldt. The telephone number is (801/FTS) 625-5238; the Data General address is M.REMBOLDT:R04A.

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1. Bowles, Joseph E. Foundation Analysis and Design. McGraw-Hill. San Francisco, CA. (1977).
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SOFTWARE COMPANIES (SPREADSHEETS)

LOTUS 1-2-3: Lotus Development Corp.
55 Cambridge Parkway
Cambridge, MA 02142

SuperCalc: Computer Associates
2195 Fortune Dr.
San Jose, CA 95121
(408) 942-1727

RECOMMENDED READING

Using 1-2-3, Second Ed. LeBlond, Geoffrey T. and Thomas W. Carlton. Que Corporation, Indianapolis, Indiana. (1985).

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