A SYSTEMS ANALYSIS OF APPLICATIONS OF EARTH ORBITAL SPACE TECHNOLOGY TO SELECTED CASES IN WATER MANAGEMENT AND AGRICULTURE

Volume II - Technical Report - Appendixes

PLANNING RESEARCH CORPORATION
LOS ANGELES, CALIFORNIA WASHINGTON, D C

A SYSTEMS ANALYSIS OF APPLICATIONS OF EARTH ORBITAL SPACE TECHNOLOGY TO SELECTED CASES IN WATER MANAGEMENT AND AGRICULTURE

Volume II - Technical Report - Appendixes

PRC R-1224

Revised November 1969

Prepared for

National Aeronautics and Space Administration
Washington, D C
Under Contract NASw-1816

By

Planning Research Corporation

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF EXHIBITS

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

LIST OF EXHIBITS
(Continued)

APPENDIX A

USER SENSOR MODEL--HYDROLOGY

I SENSOR ADEQUACY

The principal sensor requirements in the hydrologic application are the detection of snow area and depth, precipitation, albedoes, colors and temperatures over wide areas, soil moisture and surface water areas. As far as the sensor design is concerned, this translates into coordinated observations in the visible and infrared spectrum of elemental areas small enough to be substantially homogeneous. Albedo and color are the principal factors in snow and vegetation surveys. Surface temperature data would be applied in estimates of snow melt, possibly snow presence, rain area and evapotranspiration rate. No sharp thresholds of sensor performance adequacy can be defended, either in terms of resolution area (or lineal resolution) or radiation measurement. However, ranges of interest can be developed and compared to capability. It should be noted that the performance of an entire data collection and processing system can be higher than that of the collector alone by statistical processing of returns. It is also important not to collect too much unneeded or redundant data since this wastes transmission and processing capacity.

The basic problem in hydrology is to estimate water releases to runoff. The test basins are each roughly 1,000 square miles in area and the Columbia River System drains about 260,000 square miles. This river system is divided into basins for computation and management purposes. The degree of subdivision is limited by several factors, among them the incremental amounts of water involved and the accuracy and detail of the data used in the estimates. From a reduction of flow error standpoint, diminishing returns probably set in when the unit of area gets down to 10 square miles. However, physical conditions can vary widely over such an area, especially in mountainous country. Therefore, a temperature range basis was used to determine an acceptable lineal resolution for a benchmark system. Such a system is described in Section II, C, 8, "System Tradeoff Formula, Multi-Spectral Scanner." The principal parameters of the system are

Signal-to-Noise ratio = 1.5 per degree Kelvin

Altitude = 500 n. mi.

Swath Width = 300 n m

Lineal Resolution = 1,820 feet

Detectors per channel = 1

Assuming a reasonable atmospheric lapse rate, a terrain slope of 25 percent or less would have a 1° K temperature range This range should be sufficiently small to obtain uniform snow and vegetational environmental responses This linear resolution would result in about 8 independent readings per square mile, which should suffice to distinguish among meaningful areal elements

The possibility of measuring stream and lake widths was examined as a basis of inferring flow This was rejected partly because of the comparatively extreme resolution and data rate implications

Observation frequency requirements were also addressed The most dynamic parameter is temperature, which routinely ranges 12 - 14°F in a day and several degrees from day to day Mean daily temperature is useful for snow melt estimation The magnitude of the diurnal range is expected to indicate surface wetness and possibly the presence of snow Evaporation cooling of leaves after a rain may indicate the extent of a rainstorm Rain area detection and the desire to take advantage of gaps in the clouds lead to a recommendation for four well spaced observational opportunities per day, and hence for four satellites

Exhibit A-1 is a summary of techniques for data collection in regional water management Information requirements are listed, together with the observed and inferred measurements necessary to produce individual informational factors

II MEASUREMENTS

This section deals with techniques which can be used to quantify or measure hydrological phenomena being observed by the satellite borne sensors It should be emphasized that the great strength of the satellite-assisted system lies in the capability of the sensors to scan large areas frequently Because of this, measurement techniques involve a combination of direct observational measurements and the use of statistical inferences Both of these tools are then supported by a data base accumulated gradually through continuous sensing The result will be greatly increased forecast accuracy and eventually runoff predictions based on well established hydrological and meteorological patterns

A Snow

The most important candidates for satellite measurement deal with snow, both for its importance as a source of later runoff and because rain on snow suffers negligible evapotranspiration (ET) loss (compared to a 70-90 percent loss of rain reaching the ground when it falls on non-snow) In addition, the interval between deposition of snow and release to runoff is measured in months While the timing of melt release may not be forecastable with great long-range accuracy, there is an extended period during which estimates of the water equivalent may be refined Thus there is a chance with snow to realize significant forecasting lead-time advantages by reducing uncertainties about the quantity of runoff, if not the timing. Furthermore, a large share of the annual runoff and the greatest uncertainties in timing and quantity occur during the snow melt season

B Snow-Water Equivalent

As with other hydrologic measurements, there will need to be a reliance on "signatures" in interpreting snow observations A new snow on an old base in open country will appear bright (i e , reflect more of the incident sunshine) for the first three or four days Then, for a

EXHIBIT A-1 SUMMARY OF TECHNIQUES FOR DATA COLLECTION (REGIONAL WATER MANAGEMENT)

Required Information	Inferred Quantities	Observed Quantities	Sensor Problems	Interpretation Problems
Streamflow (antecedent)	River width	Water surfaces in visible, IR, or radar imagery	Resolution	Limited correlation between width and flow
Rainfall	Surface water	Water surfaces in visible, IR, or radar imagery	Resolution	
	Soil moisture	See below		
	Intensity and distribution of rainfall	Non-coherent radar signal strength and range	Resolution, ground clutter, calibration	Intermittent coverage
	Distribution of rainfall	Microwave brightness temperature	Resolution	Temperature discrimination of rain from underlying terrain
Snow area	Snow distribution	TV or multispectral imagery		Distinguish clouds from snow, obscuration by forest cover
		Temperature distribution		
Snow water equivalent	Completness of snow cover	TV or multispectral imagery	Resolution, sensitivity	Forest cover, limited relation between cover and thickness
	Snow thickness	Terrain cross-section in radar imagery	Sensitivity	Relation between signal strength and snow thickness
		Microwave brightness temperature	Resolution	Separation of individual effects
Snow temperature	Same	Thermal IR scanner imagery		Atmospheric effects, separation of surface radiation
		Microwave brightness temperature	Resolution	Separation of individual effects, forest cover
Snow albedo	Directional reflectivity	Radiation in visible and near IR	Calibration	Atmospheric effects
Air temperature	Foliage temperature	Thermal IR scanner imagery	Calibration	Emissivity variations, solar heating, atmospheric effects
		Microwave brightness temperature	Resolution, calibration	Solar heating
Ground temperature	Same	Thermal IR scanner imagery	----	Emissivity variations, atmospheric effects
		Microwave brightness temperature	Resolution	Separation of individual effects

Note Problems underlined are considered most limiting ones Other problems listed may require substantial R&D for satisfactory solution

EXHIBIT A-1 (Continued)

Required Information	Inferred Quantities	Observed Quantities	Sensor Problems	Interpretation Problems
Soil moisture	Surface water	Water surfaces in visible, IR, or radar imagery	Resolution	---
	Vegetation lushness	TV or multispectral imagery		Limited correlation, delay in color effect
	Soil reflectivity	TV or multispectral imagery		Soil variability, vegetation cover
	Diurnal temperature variations	Thermal IR scanner imagery		Emissivity variations, solar heating, vegetation cover
	Water content	Microwave brightness temperature	Resolution	Separation of individual effects
Evapotranspiration	Air temperature Ground temperature Soil moisture Cloud cover	See quantities listed		
Cloud cover	Same	Visible, near IR, or thermal IR		Distinguishing clouds from snow

Note Problems underlined are considered most limiting ones Other problems listed may require substantial R&D for satisfactory solution

PRECEDING PAGE BLANK NOT FILMED

PRECEDING PAGE BLANK NOT FILMED

FOLDOUT FRAME

FOLDOUT FRAME 2

variety of reasons (dust, surface crystal growth, etc), the reflectance or albedo recedes from an initial 80-85 percent to around 60 percent (see Exhibit A-2 from "Snow Hydrology"[1]) Thus, the areal extent of a new snow may be gaged In a forested area snow will be caught in the branches, producing an even more pronounced albedo rise This intercepted snow will be the first to melt or be shaken off by winds, "resetting" the surface to show subsequent falls It may be possible with practice and ground confirmation to tell from such satellite measurements how much snow fell in each event as well as the location Since each area will have its own characteristic behavior, reliance on human interpreters will probably be necessary at the start of such a program. Reports from the TIROS system indicate some ability to make distinctions for up to four inches of snow in open country on bare ground Corresponding performance in forested and mountainous areas may be obtainable with practice This ability may be tied to surface roughness (e g , stubble or plowed ground), where the distinguishable depth would be tied to the fraction of coverage of dark objects The appearance of snow under trees will have to be found by experiment, as well as the effects of terrain slope gradients and azimuthal orientation

A second approach to identifying areas of new snow is to observe the clouds producing the snow This involves the use of an active sensor (radar) which gets a return from the melting or raindrop formation zone in the cloud Rain can be similarly detected, making use of a strong echo strength relation between drop or flake size and radar wave length Some major signal processing problems are anticipated where precipitation and ground returns are superimposed, but some signal gating scheme may be possible even when ground and cloud ranges are close The "snapshot" character of satellite observations must also be considered It can only report on what is going on at the time However, this may be enough to assess storm extent and intensity, to be coupled later with coverage area to assess total snow water equivalent

---

[1] Snow Hydrology, U S Army Corps of Engineers, June 1956

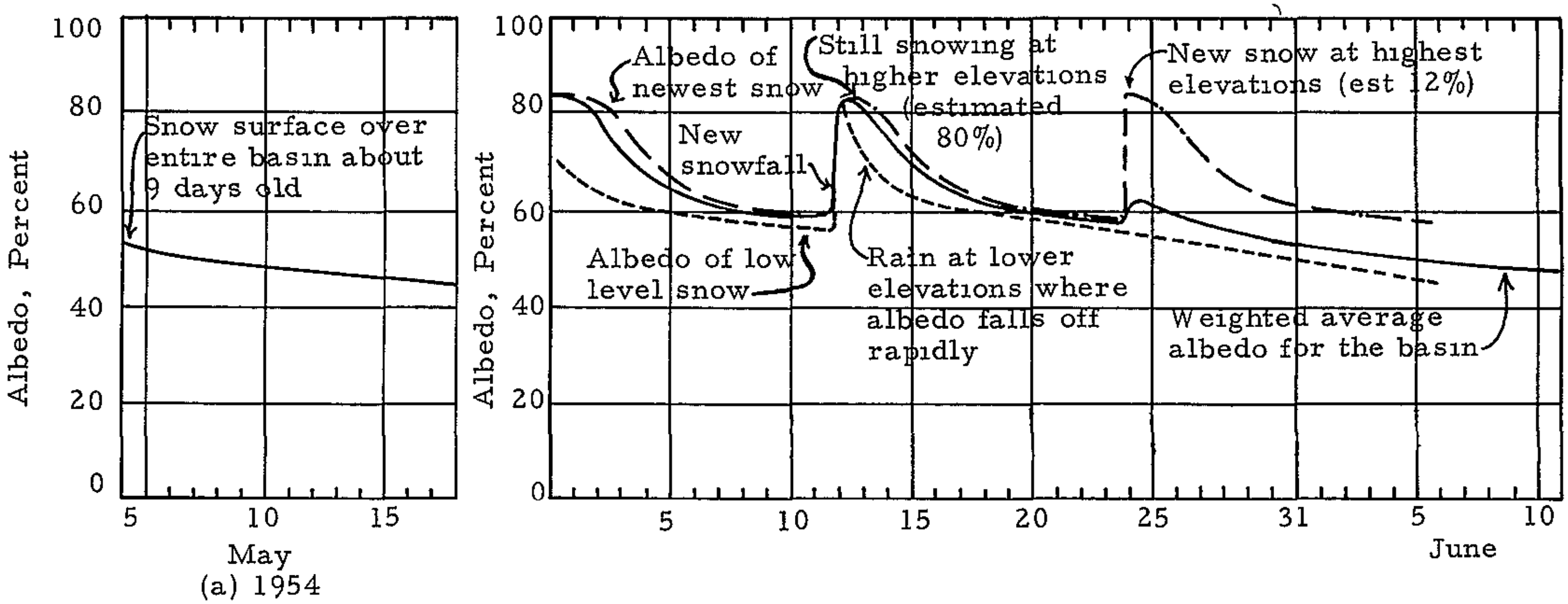


EXHIBIT A-2 ESTIMATES OF SNOW SURFACE ALBEDO-BOISE BASIN

C Snow Area

TV and Multi-Spectral Scanner (MSS) are able to sample the spectrum of reflected light from the earth surface Comparison with known signatures obtained previously can then be used to deduce the snow situation on the ground Of course, snow under trees will look different from snow in the open and north slopes different from south slopes Hence, human interpretation will be needed at least at the start, along with corresponding ground truth observations

Although the total amount of snow will vary from year to year, the build-up and recession patterns display considerable repeatability This pattern can be recognized from the sky and form part of the basin calibration

D Snow Melt

The MSS can also be used to determine ground (or intervening cloud) temperatures It is uncertain just which temperatures would be reported given trees and snow It is speculated that the warmer of the two would dominate, but this would have to be tested and probably no general rule will emerge unless it is a compromise The essential connection which has to be made is a sensed temperature over a given snow covered area with a subsequent outflow Since any basin will contain a range of snow melting regimes at any given time, the sorting-out problem can be quite large, but is a strong point of remote sensing The satellite should make it possible to state how many square miles of snow are within each of several temperature ranges, hence, an ability to estimate the melt production As melt progresses, of course, the snow recedes and therefore the satellite can help keep a running area record The area shrinkage rate should correlate with runoff and enable an inference of the remaining water equivalent

Obviously, the surface or air temperature is not the same over an entire basin Elevation, vegetation, slope orientation, and wind exposure are among the contributors to variation However, differences from point to point should show some stability and this pattern should be measurable from the sky If the satellite then reports a temperature for a weather station as part of a basin observation, the weather station can then use its own readings to correct for any reference temperature bias in the satellite and then use the results over the basin Furthermore, if the temperature difference pattern is reasonably stable, the weather station can suitably process its readings in the absence of a satellite observation

It takes 144 BTU to melt a pound of ice at 32°F. Heat may be applied to snow via radiation (from sun, clouds, and nearby objects), convection, (by winds bringing warm air in contact), conduction (a minor contributor of heat from the ground), water vapor condensation, and warm rain. Melt computation using a heat exchange approach is too difficult to be practical at this time The current method is to say that melt production is equal to the product of a melt rate factor, snow covered area, and the number of degree-days experienced by the snow. Instead of computing degree-days around a 65°F reference as done for home heating purposes, some other reference temperature such as 28°F is used Selection of the reference (average air) temperature (for the day) is done in conjunction with melt rate factor selection so that the observed runoff behavior is reasonably well approximated Temperature is measured at weather stations and extended by approximation over the basin. A long list of shortcomings of this method can be compiled, with the rebuttal that the method is convenient and "works" within limits Also, the air temperature will tend to reflect the combined effect of heat exchanges Satellite measurements of surface temperatures and snow covered areas can likewise be criticized for incomplete treatment of the physical problem, though these observations eliminate some important sources of error in the current approach The strength of the satellite approach lies in the ability to measure snow area and local temperature frequently, rather than to infer them and thus to have a better basis for correlation with runoff

There is a claim that a microwave radiometer can distinguish wet and dry ground When snow melt is occurring, there is a fringe of wet ground which may be observable from the sky. This together with observation that the snow surface is at 32°F could confirm that melt is occurring However, the area resolution capability of the radiometer is something over one square mile, which may be too coarse to be useful for this purpose A field test is needed to find out

E Rain

Falling rain can be seen with radar The strength of the return increases with the intensity of the storm Hence, a connection between echo strength and quantity deposited may be obtainable Cooperation with ground stations will be needed to establish the connection, of course, including corrections for evaporation prior to the drops reaching the ground and variations of radar return with drop size It is also noted that rain and ice are present in thunder clouds even though it may not be raining on the ground

The interception effect was discussed earlier This water will evaporate off the leaves, which will cool them Thus an area which recently received rain will be relatively cooler than one which did not. The leaves sometimes dry out in a few hours, so if the readings cannot be made through clouds, the effect may not be seen very often On the other hand, the soil dries out more slowly, so the chance of observing this process is considerably better. The amount of retained soil moisture depends to a degree on the amount and rate of rain The rate of ET, and hence the temperature depression depends on the available soil moisture This chain of relationships might be used to infer storm extent and amount deposited. Observations of the ET rate prior to a storm would aid in estimating retention losses for the coming storm

While the MSS can measure temperature and the microwave radiometer may be able to distinguish wet or dry soil, the inferential chain to soil moisture estimation has some weak spots The rate of evaporation depends on the vapor pressure gradient at the evaporating surface This can be changed by different wind velocities, humidities, and rates of heat input. In forested areas, the signal may be dominated by trees instead of soil The vapor condition of the intervening atmosphere will also have an effect Methods for handling non-vertical viewing angles and sun aspect angles will be needed

F Visible Water and Ice Surfaces

Lakes, streams, swamps, and ice packs are visible from the sky In some cases their areal extent is associated with basin outflow rate When flow is not restricted or controlled (as by an ice jam or a managed lake), the area (width) of water surfaces may serve as the equivalent of flow gages The readout of this sort of gage could be via satellite. As a practical matter most of the important flow gaging points in the Columbia Basin have gaging stations now Hence the added value of such readings for the Columbia Basin will probably be small However, this sort of measurement could help in initial surveys in ungaged areas. Also, satellites could report on unusual events such as spring flooding in inaccessible areas and ice packs which may be blocking flow

This type of measurement will require a resolution capability in the five foot range if it is to be applied In addition, the number of useful gaging points is sharply limited by fundamental hydrologic considerations and the potential existence of superior measuring devices However, a test of the concept could be part of the experimental program to to see if its value is greater than currently suspected

G Phenological Season and Vegetation Survey

The ET characteristics of an area depend importantly on the type, amount, vigor, and stage of growth of vegetation. This last factor describes the phenological season (dormancy, leafing out, annual growth, fall). While the season is tied roughly to the calendar, it varies for a given point from year to year and also within a region largely because of long-term temperature differences A satellite can report on current conditions and thus enable the selection of appropriate ET and interception factors in runoff computations The satellite can also help maintain a current survey of land use For instance, it can recognize changes in forested area as a result of logging operations and also the current condition of agricultural areas

H Water Release and Measurement

Precipitation is reported by weather stations to the nearest 01 inch of water equivalent Snow accumulation is also reported, but since the packing varies widely (three to ten inches of snow per inch of equivalent water), simple conversions of depth to water are untrustworthy Water equivalent in a snowpack is usually determined by weighing or melting and measuring a core sample This is commonly done for selected snow courses on the first day of February, March, April, and May, and daily at weather stations The amount of precipitation varies considerably within a storm area and with wind and other details around the gaging station, making close analyses of total precipitation difficult based on precipitation gage measurements

Snow courses are areas in a basin where the snow water equivalent is measured on selected standard dates during the melt season Readings at several points are weighted by experience to estimate the remaining snow in the basin On at least one occasion (South Fork of Flathead, early June of 1959), indications within the basin (past snow surveys, temperature history, and flow gage readings) were that the snow was gone This turned out to be wrong and a considerable release from melt in higher elevations occurred This surprise could have been avoided by more comprehensive, frequent, and recent satellite observations It is this sort of event which may be the key to the real value of a satellite system It is very difficult to build a strong economic case for satellite use when the situation is near normal However, warnings of unusual conditions may justify such a system Most of the time a satellite system will be insurance, contributing an intangible increase in confidence to the information users Depending on operational performance, certain of its outputs will probably supplant some of the current measurement systems as the primary data source

I Temperature Measurement

Weather stations have recording thermometers which measure air temperature The mean temperature reported for a day is the arithmetic average of the high and low extremes Measurement accuracy is within a fraction of a degree for these instruments Average diurnal ranges are 6 to 7°F around this mean

The real question about these temperatures is not their accuracy of measurement, but their relevance in hydrologic forecasting These temperatures are measured in an enclosure which protects the instrument from precipitation and radiation and is typically four feet above the ground Knowing this temperature, then one could ask, "What is the temperature of snow under the trees on the other side of the hill?" The trees are doubtless at another temperature, the ground at a third, etc The satellite should be able to measure temperatures to within 1°F, but this is not the real strength of satellites Satellite measurements will deal with areas, not points, and can coordinate observations of snow and temperature with each location in a region, regardless of conditions in the neighboring resolution elements Furthermore, it will measure effects on the ground, trees, and snow which are closer in the hydrologic cycle to runoff than the air and clouds are

J Stream Flow Gaging

There is a wide range of accuracy in stream flow gaging Type of gage, technique, skill, debris, sedimentation, stream profile variation, bottom roughness, etc affect measurement accuracy The table, below, gives the accuracy classification in terms of the error enclosing 95 percent ($\pm 2\sigma$) of the daily discharge measurements and 1σ error The quality of measurements for the test basin gaging points is reported as "excellent", except "good" to "fair" for very low flow rates, and as low as "poor" for very high values, where bank overflow, debris, etc cause uncertainty about the stream profile or where ice effects restrict flow

STREAM FLOW GAUGING ACCURACY (DAILY VALUES)

Classification	$\pm 2\sigma$	σ
Excellent	5%	1-1/4%
Good	10%	2-1/2%
Fair	15%	3-3/4%
Poor	15%	3-3/4%

A brief calculation shows that stream gaging errors are small enough to be negligible with respect to water release estimates Assume a 1,000-square-mile basin, which is representative of the test basins. Also assume a 2,000-cfs flow rate. Assume a 10-percent flow rate measurement error After applying the appropriate conversion constants, this works out to an rms error of 0 0074 inches of runoff per day spread over the basin If "excellent" flow measurements are assumed, the standard deviation (rms error) is more like 0 001 inches per day Precipitation and evapotranspiration estimate errors are easily 20 to 30 times this large In fact, stream flow gaging is probably a better way to measure mean precipitation over a basin than precipitation gaging (except for the uncertainties in estimating evapotranspiration) Another important reason for the superiority of flow gaging in this regard is that it measures the integrated effect over the entire basin, while precipitation gages are necessarily at specific points and may give undue weight (either high or low) to storms

K. Units and Conversion Factors

The English system of dimensions is used in this paper and in much of the U S hydrologic literature Little effort has been made to reduce terminology to a minimum set of basic dimensions, although this is clearly possible Instead, units are used by general agreement as being suitable for particular situations. Since this can be confusing to a new reader, the major units are discussed below

1. Temperature ^{o}F or degrees Fahrenheit
Mean daily temperature is the arithmetic average of the high and low dry bulb air temperatures for the day. Surface wet bulb and dew point temperatures sometimes occur in the calculations

2. Time second, hour, day, month, year.
Seconds appear in flow cubic feet per second. Hours appear in storm durations and stream travel times. A day is frequently used as the time increment for averaging flows, stating temperatures, and in other meteorological records Mean monthly precipitation and water outflow are sometimes tabulated The hydrologic year begins in October, at least in the reference material for this project.

3 <u>Length</u> inches, feet, statute miles, nautical miles Precipitation, melt, soil moisture index, and runoff/ET/interception partitioning computations are frequently handled in inches Feet appears in river stages and cross-sectional dimensions and as part of volume and flow units. Statute mile (5,280 feet), mi., is used for most long surface distance measurements. Nautical mile (6,076 feet), n. mi., is used in orbital descriptions

4. <u>Area</u> acres, square statute miles

640 acres = 1 sq mi

1 acre = 43,560 sq ft

5. <u>Volume</u> cubic foot, acre-foot, inch-square mile, "CFS-day"

Acre-foot (AF) is used to describe reservoir capacity and other volumes associated with reservoir management. It is a volume of one acre in cross section and one foot deep (43,560 cu. ft.). Inch-square mile is used in precipitation, ET, and runoff production calculations (=2,323,200 cu ft = 53.3 AF) "CFS-day" is sometimes expressed as SFD (second foot day) The terminology is not dimensionally descriptive. It means the volume of water represented by a flow of one cubic foot per second for a day There are 24 x 60 x 60 = 86,400 seconds in a day and thus 86,400 cubic feet in a CFS-day.

	cu ft.	acre-ft	inch-sq mi	CFS days
1 acre-foot =	43,560	1	3/160	503
1 inch-sq mi =	2,323,200	52.3	1	26 9
1 CFS-day	86,400	1 985	9/242	1

6 <u>Heats</u> under standard air pressure conditions, the heat of fusion (i e , melting) of ice is 144 BTU per lb , heat vaporization of water 50°F is 1,084 BTU/lb.

Specific Heats, BTU/lb ^{o}F

Water	1
Ice	47
Stone	19- 22
Wood	57- 67
Air	.24

III. SENSOR ANALYSIS

The following section primarily contains detailed technical discussions of the various sensors considered for inclusion in the sensor packages, the multispectral scanner (MSS), television (TV), synthetic-aperture radar, and the microwave radiometer Included also is a brief overview of the state-of-the-art sensor systems and the research and development program necessary for implementation of an operational system.

Altogether, five sensors were given serious consideration for inclusion in the final sensor package. Four of these are discussed in detail in this section The laser altimeter is not discussed since the development of this instrument was not sufficiently advanced for final consideration. Of the group discussed, the MSS, TV, and radar were chosen as the package capable of measuring the parameters required for both the water management and agricultural applications

A Multispectral Scanners

Exhibit A-3 contains a summary of the design and performance characteristics of a multispectral scanner system which could be placed in orbit by 1973 This design achieves a ground resolution of 150 ft over a swath width of 50 n mi , using a rotating mirror to give a circular scan which advances along the ground beneath the satellite The system provides coverage in seven spectral channels ranging from 0.5 through 12 5 microns (including the visible, near IR, and thermal IR regions) The radiation received from each resolution element on the ground is separated into its spectral components in such a way as to maintain registration of the signal outputs of the individual detectors [1] This arrangement for maintaining registration permits the automatic processing of the signal outputs by ground-based data processing equipment to perform detection and identification functions useful for

[1] Braithwaite, J., Dispersive Multispectral Scanning, WRL Report No 7610-5-F, September 1966.

EXHIBIT A-3 MULTISPECTRAL SCANNER DESIGN AND PERFORMANCE CHARACTERISTICS

Design Characteristics

Aperture diameter 20 in

Instantaneous field of view 083 mrad

Type of scan Circular scan

F no of optics 4 8

No of detectors per channel 6

Information bandwidth 4 2 MHz at 30% duty cycle

Sensor Performance

Ground resolution (from 300 n mis) 150 ft

Swath width 50 n mis

Sensitivity

Channel	Detector System	NE$\Delta\sigma$ (for σ = 0 2)	NEΔT
0 5-0 6 micron	S-20 photomultipliers	0051	
0 6-0 7		0057	
0 7-0 8		0076	
0 8-1 2	InSb at 77°K with cooled filter	0066	
1 55-1 75		0058	
2 2-2 4		0056	
10 5-12 5	Ge Hg, Cooled filter and refractive optics with cold-shielded 12° FOV		0 4°K

Size

Weight 350 lbs

Power

agricultural and hydrology applications, as described elsewhere. The sensitivity of each of the visible and near-IR channels is high enough that a change of reflectance in the observed surface from 20 percent to 20 8 percent will produce a signal equal to or greater than the detector noise. This noise level is considered to be small enough that even with additions introduced by tape recording and transmission to the ground, the probability of detection during automatic processing will not be appreciably reduced

The thermal IR channel of the scanner, operating in the region from 10 5 to 12 5 microns, has a net equivalent temperature difference of 0.4° K, assuming that both the filter and any subsequent optics are cooled, and a cold shield is used restricting the field of view to 12 degrees. Without cold filtering and shielding, the NEΔT would be increased to 3 5°K, which would not be good enough for some purposes.

Additional improvement in scanner system performance beyond that described above could be achieved by continued research and development on scanner systems. Technological areas subject to further advances are discussed below It is estimated that by 1980, through the use of larger scanning mirrors, multiple-array detectors, and more sensitive types of detectors, ground resolutions of 100 ft could be achieved for the same sensitivity

The design and performance characteristics shown in the table can be adjusted to meet the needs of specific applications. By trading off one type of performance for another, the system could be modified to provide either a larger number of channels, greater swath width, or improved resolution.

1. <u>Present and Future State-of-the-Art</u>

Several areas of future improvement of optical-mechanical scanning systems have been considered in projecting the future state-of-the-art

(S) One area of technology in which the most substantial improvements can be made is the use of multiple-detector arrays Arrays of several hundred detectors are feasible at the present time and have been used in airborne systems Improvements in microcircuits adaptable to these systems are also being pursued at the present time It seems likely that substantial advances in multiple-detector array technology can be achieved over the next decade which will make possible for space application very lightweight and compact array systems with preamplifiers efficiently incorporated into the detector package The use of increased numbers of detectors per channel eases several design problems and can result in increased performance, either in terms of sensitivity, or other system parameters. For a given total information bandwidth, an increased number of detectors reduces the bandwidth of the individual preamplifier, with a resulting increase in sensitivity, expressed as NE$\Delta\rho$ or NEΔT. However, the fractional change in the sensitivity is inversely proportional only to the square root of the number of detectors per channel Increased numbers of detectors might also be used to trade off for increased spectral or spatial resolution It should be recognized, however, that increasing the number of detectors would increase system complexity and could adversely affect MTBF unless adequate precautions are taken to achieve high reliability in a space environment

Only limited improvements in detector sensitivities beyond present performance are believed possible Photomultiplier and mercury-doped detectors have quantum efficiencies in the neighborhood of 10 to 25 percent. Since sensitivity increases as the square root of increases in quantum efficiency, sensitivity improvement by factors of two or three would be theoretically possible However, various limitations will prevent practical devices from reaching these theoretical limits. For example, in using mercury-doped germanium with cold shielding and cold filtering at low signal levels, the impedance of the preamplifier becomes high, introducing noise into the system which limits the potential improvement in performance of the detector

Improvements in the mechanical aspects of scanner systems are primarily engineering problems Improvements may be expected in making stronger lightweight mirrors using beryllium The introduction of larger scanning mirrors and optical systems will increase system performance

The use of cryogenics systems with high reliability and long lifetime is an important problem, but is not believed to be a critical limitation of system capabilities The use of either mechanical refrigeration or solid cryogens appears to be the most suitable method for missions up to a year or more.[1] The most severe limitations in the use of mechanical refrigerators arise from vibration, reliability, maintenance requirements, and operational duty cycles for extended missions. However, research and development effort is leading to advances in dealing with these problems The use of solid cryogens for missions of long duration is attractive because of the inherent simplicity, reliability, and relatively light weight. The major disadvantages are relatively high cost and complex prelaunch handling requirements

2 Accuracy of Surface Temperature Measurement

In the WRL Report referenced in Section A, the effect of the atmosphere on measurement of surface temperatures in the 10.5 to 12.5 micron region has been studied In the absence of cloud and scattering particles, the absorption in this region is due primarily to the far wings of the intense water vapor lines at both shorter and longer wavelengths Using the U.S Standard Atmosphere, calculations were made to determine the difference between apparent temperature and true temperature of a surface with an emittance of 1. Calculations were made for the vertical path from 0 to 12 km, which contains almost all the water vapor in the vertical column of the complete atmosphere.

It was found that absorption in this vertical path reduces the emittance from the surface by an amount corresponding to a reduction in surface temperature of about 12°C. However, when atmospheric emission is also considered, the error for the example chosen is only about -3° For 100-percent relative humidity in the atmosphere, the error would be increased to about -4 5°, while for zero humidity, it would be zero For temperate surface conditions, even in the absence

[1] Braithwaite, J J J Cook, W Brown, Final Report on Infrared System Studies for the Earth Resource Program, October 1968, UM Report 1059-11-F

of detailed synchronous meteorological information, it would appear to be possible to estimate the path humidity and temperature profiles from seasonal data well enough to predict the error to within about ±1 5° With weather charts, it should be possible to do a good deal better, perhaps ±0 5°

As the true surface temperature varies between 20°C and 10°C, the apparent surface temperature differences are slightly less than the true surface temperature differences (by about 5 or 10 percent) Thus, relative temperature differences are preserved with good accuracy in the thermal mapping of an area Using even crude meteorolgical data, these small errors could probably be cut in half.

The actual water content of the path for a given relative humidity is a steep function of temperature As a direct result, the absorption and emission effects will be reduced in cold weather and toward the poles, while they will be increased in hot weather and toward the equator Errors will be much smaller, and probably negligible, for arctic conditions On the other hand, for tropical conditions, the error will not only be about three times larger but about three times more uncertain, due to the wider range of water vapor contents which can occur

Since the water vapor in the atmosphere is heavily concentrated at the lower levels, the elevation of the terrain may have a marked effect. Over half of the water vapor is in the lowest 2 km layer of the atmosphere Thus, for a terrain elevation of 2 km, the errors would be reduced to less than one-half of those calculated for zero elevation, all other things being equal

The above conclusions are based on the assumption that there is no particulate matter in the vertical path Opaque clouds make measurement of the surface impossible and might be mistaken for snow cover Low altitude haze, though prevalent across continental regions, should present no problem since the absorption due to such haze in the vertical path is insignificant There is much greater question about the effects of thin and often invisible cirrus clouds whose presence has been indicated by results obtained in the TIROS and NIMBUS programs These clouds are believed to have appreciable absorption and to be at altitudes such that their temperatures are well below surface temperatures. Thus, their emission is insufficient to replace an appreciable fraction of the absorbed upwelling radiation This problem is being studied by meteorologists It is possible that there is sufficient spectral information in the upwelling radiation to provide a solution to this problem However, until such a solution is found, the accuracy of infrared measurements of surface temperatures may be degraded from the estimates given above.

The sensitivity of the 10 5 to 12 5 micron channel of the multispectral scanner described above is given as an NEΔT of 0 4°K This is a representation of the ability of the system to detect relative differences of temperature in a scene. The measurement of absolute temperatures is affected not only by the instrument sensitivity just quoted, but by the effects of the atmosphere which are not completely corrected. Based on the analysis of the problem presented above, it is estimated that for observations in the temperate zone and with the aid of meteorological information, absolute temperature measurements within an error of ±2°K should be possible

3 Interpretation of Spectral Data for Hydrology Applications

A series of computations was performed to determine the ability of spectrum matching techniques to discriminate various types of targets from background materials for such purposes as measuring snow area and distinguishing between wet soil and dry soil as a qualitative indication of soil moisture

The computations were intended to find the best channels (of the same nine channels used in the agricultural analysis) and the associated statistics for detecting snow and water against typical background elements. However, because of the paucity of data, the task had to be modified, the calculations were performed for the five wavelengths 0 50 μm, 0.55 μm, 0.73 μm, and 0 90 μm instead of for nine specific channels Since the available data on water were so poor, they were not used as a target. Only the reflectance statistics of the target and background materials were considered Statistics on the transmission and backscatter of the atmosphere and variations in irradiation of the targets and background were not considered

Exhibit A-4 gives the results of these calculations. As expected, snow can be distinguished from various backgrounds with little or no error Also, vegetation can be distinguished from dry soil with an error which approaches zero if three channels are used The task of distinguishing wet soil from dry soil is somewhat more difficult, but with at least three channels, is still good enough to distinguish surface wetness of soil with a high degree of effectiveness Some degradation of the performance indicated in Exhibit A-4 will occur when atmospheric effects are included, but it appears that the ability to distinguish snow and vegetation from other backgrounds will remain highly effective with somewhat lower effectiveness for distinguishing soil wetness.

With more funds and time, a study could be instituted to choose a particular background scene, e g , northern Washington, and to obtain weighting functions for the particular background elements Information concerning the irradiance and transmission statistics would also be obtained. Also, this preliminary study has pointed out the need for more and better data on the reflectance properties of snow.

4. Preliminary Investigations Regarding Project 02261 Multispectral Point Scanner

The following represents a cursory analysis of an optical/mechanical point scanner designed for multispectral operation The design under consideration combines relative simplicity, high efficiency, and state-of-the-art technology It was chosen after consideration of several potentially useful alternative designs, including

Multifaceted Rotating Mirror Wheel

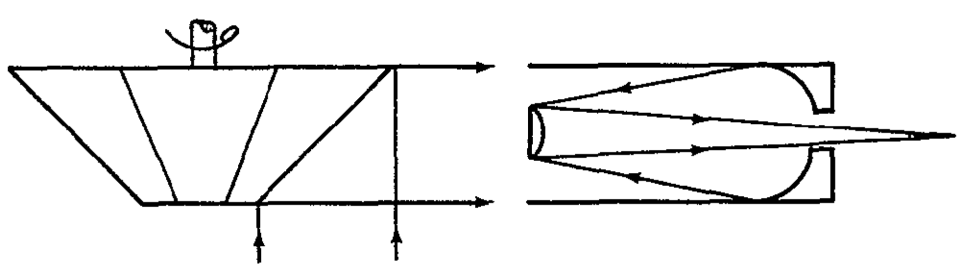
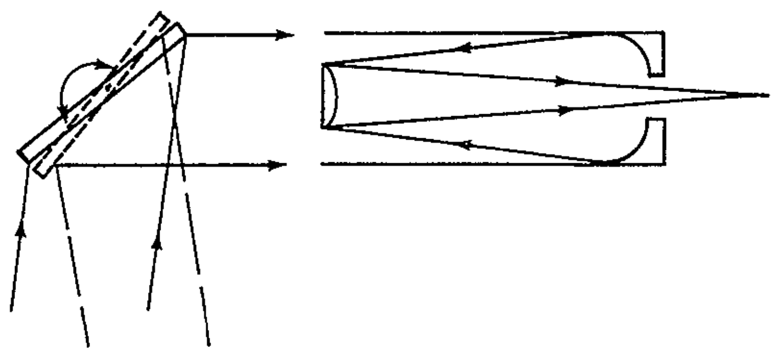


EXHIBIT A-4 DETECTION OF SURFACE TYPES FOR HYDROLOGY APPLICATIONS

TARGET VERSUS BACKGROUND	BEST WAVELENGTHS (μm)	PERCENT PROBABILITIES OF DETECTION	PERCENT PROBABILITIES OF FALSE ALARMS
Snow versus Vegetation	0 50	100 00	0 00
	0 5, 0 55, 0 73	100.00	0 00
	0 5, 0 55, 0 62, 0 73, 0 9	100 00	0 00
Snow versus Wet Soil	0 5	100 00	0 00
	0 5, 0 62, 0 9	100 00	0 00
	0 5, 0 55, 0 62, 0 73, 0 9	100 00	0 00
Snow versus Rocks	0 55	99 36	0 85
	0 55, 0 62, 0 9	99 84	0 30
	0 5, 0 55, 0.62, 0 73, 0.9	99 92	0 13
Wet Soil versus Dry Soil	0 5	91 52	31 52
	0 5, 0 55, 0 9	93 12	14 63
	0 5, 0 55, 0 62 0 73, 0 9	94 54	11 68
Vegetation versus Dry Soil	0 9	98 68	5 65
	0 5, 0 62, 0 73	100 00	0 00
	0 5, 0 55, 0 62, 0 73, 0 9	100 00	0 00

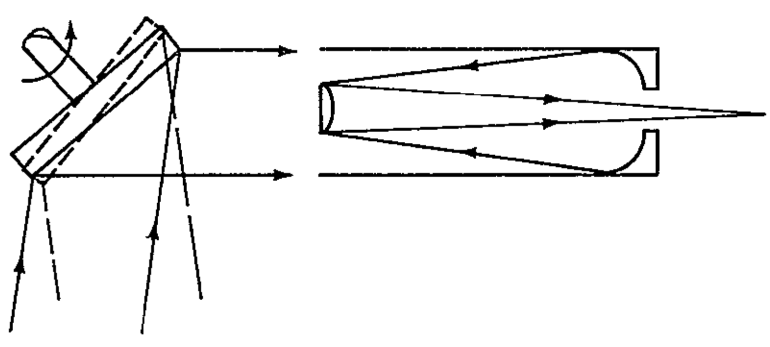
This design was rejected because approximately 24 faces or more are required for a scan efficiency (η_s) of one-third or better, which would cause the maximum dimension of the mirror wheel to be nearly six times the aperture diameter.

Nodding Mirror



This design was rejected because of the tremendous accelerations required in order to produce nodding at a rate of 7,500 per minute--a requirement for this mission--leading to forces on the order of tons acting upon the system, with all of the attendant vibrations and stresses. Another drawback is the bearing difficulty, associated with nutating motions, produced by the vacuum environment.

Small Circle Scanner



This design was selected for further study because of its relative simplicity (only one rotating part), high efficiency ($\eta_s \approx 0.32$), and because it employs components which are within the current state-of-the-art

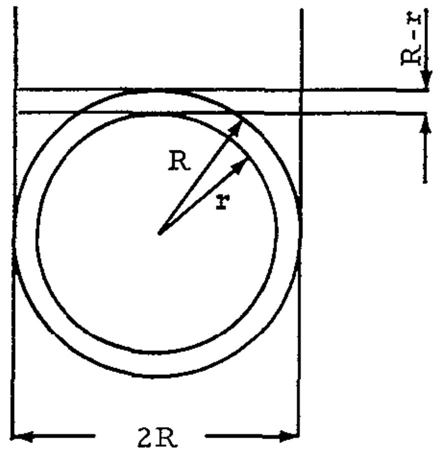
a. Performance Analysis

(1) Scan Efficiency

$$\eta_s = \frac{2R(R-r)}{\pi(R^2-r^2)}$$

$$= \frac{2R}{\pi(R+r)}$$

$$= \frac{2/\pi}{1 + r/R}$$



Because $r \approx R$ for high resolution, we can write

$$\eta_s \approx 1/\pi \approx 0.32$$

(2) Scan Rate

$$\frac{v/h}{\beta}\left(\frac{\text{Radians/sec}}{\text{Radians/scan}}\right)$$

$$\text{Spacecraft Velocity} = \sqrt{k/r} = \sqrt{\frac{62{,}746.8}{3{,}735.864}}$$

$$\text{or } \boxed{v = 4.097 \text{ n. mi. /sec}}$$

$$\text{Ground Patch} = 200 \text{ ft} = \frac{200}{6{,}080.27}\left(\frac{\text{ft.}}{\text{ft /n mi}}\right)$$

$$= \boxed{32.89 \times 10^{-3} \text{ n mi.} = \beta h}$$

Thus, the scan rate is

$$\frac{v}{h\beta} = \frac{4\ 097 \times 10^3}{32\ 89} = \boxed{125\ 47 \text{ scans/second}}$$

which will require a rotation of about $\frac{7,500}{m}$ where m = the number of detector elements per spectral channel

(3) Information Rate

Digital Telemetry Bandwidth/channel $= \Delta f_{tm}$

$$= 6 \frac{\text{bits}}{\text{element}} \times \frac{1}{2} \frac{\text{cycle}}{\text{bit}} \times \frac{v}{h\beta} \frac{\text{scans}}{\text{second}} \times \frac{\pi\theta}{\beta} \frac{\text{elements}}{\text{scan}}$$

Note $\frac{\pi\theta}{\beta} = \frac{50\pi \text{ n. mi. /scan}}{32.89 \times 10^{-3} \text{n. mi. /element}} = \boxed{4{,}775 \ \frac{\text{elements}}{\text{scan}}}$

Therefore, the bandwidth per channel is

$$(3) \times (125) \times (4{,}775) = \boxed{1.79 \text{ MH}_z = \Delta f_{tm}}$$

With m detectors for each spectral channel, the detector bandwidth

$$\frac{1}{2}\left(\frac{\text{cycle}}{\text{element}}\right) \times \frac{v}{h\beta}\left(\frac{\text{scans}}{\text{second}}\right) \times \pi\theta \left(\frac{\text{Radians}}{\text{scan}}\right) \times \frac{1}{\beta}\left(\frac{\text{elements}}{\text{Radians}}\right) \times \frac{1}{m}$$

$$= \frac{\Delta f_{tm}}{6m}$$

$$= \boxed{\frac{0\ 30 \text{MH}_z}{m} = \Delta f_d}$$

and the detector time constant $\lessapprox \frac{1}{2\pi\Delta f_d} = \boxed{0\ 53\ m(\mu\text{sec.}) \geqq \tau_d}$

It appears that m = 1 is feasible at this resolution.

(4) Sensitivity

The system is characterized (in the visible spectrum) by $NE\Delta\rho$ and (in the IR spectrum) by $NE\Delta T$ The equations for these quantities are

$$NE\Delta\rho = 19\ 2 \times 10^{-10} \frac{\sqrt{\theta}}{\beta^2 D_1} \sqrt{\frac{v/h}{\tau\sigma m\eta_s}} \sqrt{\frac{\rho\lambda}{R_c H_\lambda \delta\lambda}}$$

$$NE\Delta T = \frac{4}{\pi} \frac{F_2\sqrt{\theta}}{D_1 \beta^2} \sqrt{\frac{v/h}{2m\eta_s}} \frac{1}{\tau\epsilon\sigma D^*_{\lambda_o}\left(\frac{C_2}{\lambda_o T^2}\right)\int_{\lambda_1}^{\lambda_2} N_\lambda d\lambda}$$

Visible Channels

$$NE\Delta\rho = 19\ 2 \times 10^{-10} \frac{\sqrt{\theta}}{\beta^2 D_1} \sqrt{\frac{v/h}{\tau\sigma m\eta_s}} \sqrt{\frac{\rho\lambda}{R_c H_\lambda \delta\lambda}}$$

$$\theta = \frac{50}{300} \frac{\text{n mi./scanline}}{\text{n mi.}} = \boxed{1/6 \text{ Radian/scanline} = \Theta}$$

$$\boxed{\beta = 0.1096 \text{ mrad}}\ ^*$$

*i e., twice the airy disc for $\lambda = 13.7\mu m$

$$\omega/h = \frac{4\ 097 \text{ n mi /sec}}{300 \text{ n mi}} = \boxed{0.01366 \text{ Rad/sec} = v/h}$$

$$\tau\lambda = 1/2,\ \sigma = 1/\sqrt{2},\ m = 1,\ \eta_s = \frac{1}{\pi} \rightarrow \boxed{\tau\sigma m\eta_s = 0.113}$$

Thus, $$NE\Delta\rho = \frac{124}{D_1(cm)} \sqrt{\frac{\rho\lambda}{R_c H_\lambda \delta\lambda}} \times 10^{-4} \times 10^{-2}$$

Spectral Region	$\rho\lambda$	$\sqrt{\frac{\rho_\lambda}{R_c H_\lambda \delta_\lambda} \times 10^{-4}}$ {S - 20 photomultiplier
0.5 - 0.6μm	0 12	.1225
0 6 - 0 7μm	0 10	1732
0 7 - 0 8μm	0 36	671

With a 1-foot aperture (i e., D_1 = 30 4 cm), the values of NEΔρ are

Δλ	NEΔρ	$\frac{\rho_\lambda}{NE\Delta\rho}$ ("Grey Scales")*
0 5 - 0.6μm	0.0050	24
0.6 - 0 7μm	0 0071	14
0 7 - 0.8μm	0 0275	13

for ρ_λ = 0.20, the values of NEΔρ are

Δλ	NEΔρ (ρ_λ = 0.20)	$\frac{\rho_\lambda}{NE\Delta\rho}$
0 5 - 0 6μm	0 0065	31 ("Grey Scales")
0 6 - 0 7μm	0 0099	20 "
0 7 - 0.8μm	0 0205	10 "

Reflective IR Channels

$$NE\Delta\rho = 4\frac{F_2\sqrt{\theta}}{D_1\beta^2}\sqrt{\frac{v/h}{2m\eta_s(\tau\epsilon\sigma)^2}}\;\frac{1}{\frac{D^*\lambda o}{\lambda o}\int_{\lambda_1}^{\lambda_2}\lambda H_\lambda d\lambda}$$

With a 0 25 mm detector (typical),

$$f_2 = \frac{0.25\text{ mm}}{1.096 \times 10^{-4}\text{RAD}} = 2\ 28\text{ m (i e , 90 inches)}$$

Thus, $F_2 = f_2/D_1$ = 7 5 for a 1-foot aperture.

*This is not a good definition of the number of grey scales actually present, since NEΔρα $\sqrt{\rho_\lambda}$ and since Δ(S/N) = 1 may not be a good criterion for a "Grey Scale " This subject needs further exploration

Detector	λ_o	$D^*_{\lambda_o}$	$D^*_{\lambda_o/\lambda_o}$ $\left(\frac{\text{CM - CPS 1/2}}{\text{watt - }\rho\text{m}}\right)$
Uncooled PbS*	$2\mu m$	1.2×10^n	6×10^{10}
In Sb	$4\mu m$	$0\ 6 \times 10^n$	$1\ 5 \times 10^{10}$

$\Delta\lambda$	$\int_{\lambda_1}^{\lambda_2} \lambda H_n d\lambda$ $\left(\frac{\text{watt - }\mu m}{cm^2}\right)$	$\frac{D^*_{\lambda o}}{\lambda_o} \int_{\lambda_1}^{\lambda_2} \lambda H_n d\lambda$ (cm^{-1} - cps 1/2)
0 8 - 1 $2\mu m$	0 0185	2.77×10^8
1 55 - $1.75\mu m$	0 00354	5.32×10^7
2 2 - 2 $4\mu m$	0 00162	$2\ 43 \times 10^7$

$$NE\Delta\rho = \frac{1\ 41 \times 10^7}{\frac{D^*}{\lambda_o} \int_{\lambda_1}^{\lambda_2} \lambda H_\lambda d\lambda}$$

$\Delta\lambda$	$NE\Delta\rho$ (In Sb)
$0.8 - 1.2\mu m$	0 051
1 55 - $1.75\mu m$	0 264
2 2 - $2.4\mu m$	0 580

With the possible exception of the 0 8 - 1 $2\mu m$ channel, this is clearly unacceptable, The product of τ_λ and D^*_λ could be increased by a factor of 10, however, by using a cooled 0 - 2 $5\mu m$ low-pass filter in front of the InSb detector array, thus improving $NE\Delta\rho$ by the same factor This avenue should be explored further

*It is unlikely that PbS could be used here because of its slow time-constant ($\approx$ 1 - 5 msec) For InSb, $\tau < 1\mu sec$.

Thermal IR Channel (10 5 - 12 5μm)

$$NE\Delta T = \frac{4}{\pi} \frac{F_2\sqrt{\theta}}{D_1 B^2} \sqrt{\frac{v/h}{2mn_s (\tau \epsilon \alpha)^2}} \frac{\lambda_o T^2 C_2}{D^*_{\lambda o} \int_{\lambda 1}^{D^2} N_\lambda d\lambda}$$

$$= 4\ 48 \times 10^6 \frac{\lambda_o T^2 / C_2}{D^*_{\lambda o} \int_{\lambda 1}^{\lambda 2} N_\lambda d_\lambda} = \underline{\underline{36\ 3^\circ K}} \left\{ \begin{array}{l} \text{For} \\ \text{Ge Hg} \end{array} \right.$$

Again, an unacceptable performance is indicated, however, the use of a cold shield could improve this figure by a considerable amount To obtain NEΔT = 0 7°K @ 270°K, however, would require a 50X improvement, which seems unlikely

(In view of the difficulties encountered in most of the channels, it would seem advisable to consider, say a 1-meter aperture--leading to a 10-fold improvement in the IR channels and a 3-fold improvement in the visible channels, sufficient to bring the system up to the desired specifications)

b Performance Summary

Scan Efficiency	32%
Scan Rate	125 Scans/second
Digital Information Rate	12 6MH$_z$(total)
Detector Bandwidth	300 kHz each
Field-of-View (Total)	1/6 Radian
IFOV ("Resolution")	1/9 mrad
v/h	0 01366 Rad/Sec
Swath Width	50 n mi
Ground Resolution	200 ft ($\approx$1 acre)

Performance with 1-foot Aperture

	Channel	NEΔρ	NEΔT
S-20	0 5 - 0 6μm	0 0065	-
	0 6 - 0 7μm	0 0099	-
Photomultiplier	0 7 - 0 8μm	0 0205	-
InSb (77°K) with	0 8 - 1 2μm	0 0051	-
cooled 0-2 5μm	1 55 - 1 75μm	0 0264	-
Filter	2 2 - 2 4μm	0 0580	-
cold-shielded Ge Hg	10 5 - 12 5μm	-	7 5°K

Performance with 1-meter Aperture

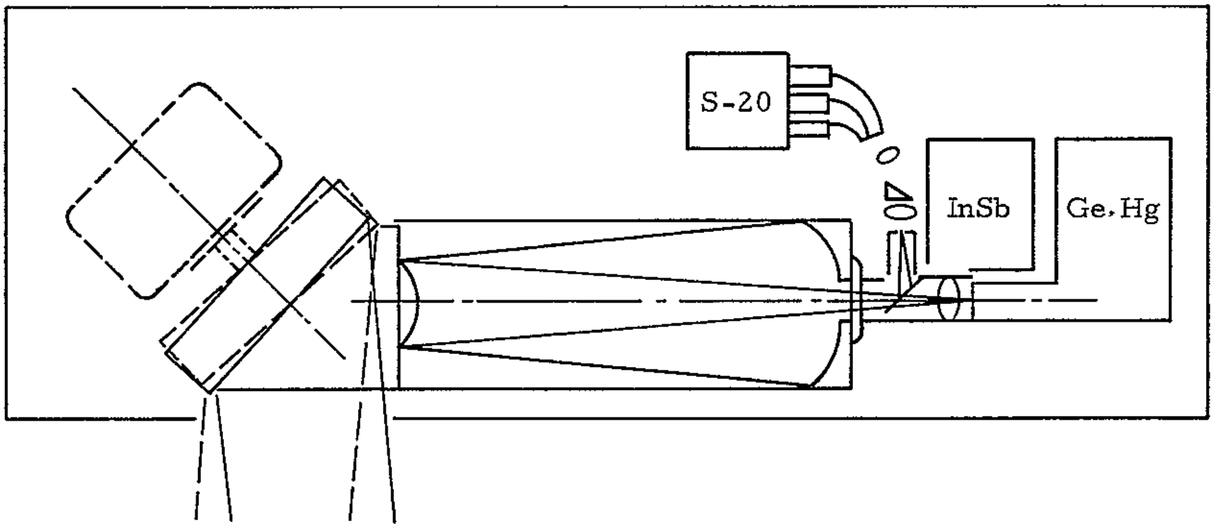
Channel	NEΔρ	NEΔT
0 5 - 0 6μm	0 0020	-
0 6 - 0 7μm	0 0030	-
0 7 - 0 8μm	0 0062	-
0 8 - 1 2μm	0 0005	-
1 55 - 1 75μm	0 0024	-
2 2 - 2 4μm	0 0054	-
10 5 - 12 5μm	-	0 70°K

c Preliminary Layout for System

Mirror and Drive A 400 cps - driven motor provides the drive mechanism, operating at a speed approximating 125 rps The mirror is honeycomb - beryllium, approximately 1/4 as thick as the diameter It must be balanced dynamically as well as statically (because it is cocked 2-1/2 degrees from normal)

Wavelength Separation A dichroic mirror is used to separate the 0 - 0 8 μm radiation from the 0 8 - ∞μm radiation, with a prism used to disperse the recollimated light to fiber optics which lead to 3 S-20 photomultipliers The IR radiation is further divided up into 0 8 - 5μm and 5μm - ∞ with yet another dichroic

Total volume 75 cubic feet (1-foot aperture)
45 cubic meters (1-meter aperture)



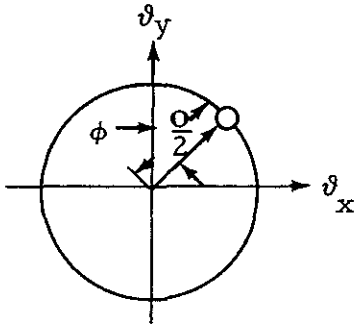
d Weight Considerations (Pounds)

	1-foot System	1-Meter System
Mirror	20	400
Motor Drive	50	100
Telescope	25	50
Electronics	50	50
Power Supply	100	100
Cryogenics	50	50
Frame and Housing	65	150
Total Weight	360#	900#

e Display Considerations

Because of the circular scan pattern, an analog-type display seems desirable (using a rotating cocked mirror with glow modulators and moving film, etc) As the "writing light" traverses the film, however, it will dwell longer at the edges than in the center, according to the relationship

$$\vartheta_x = \frac{1}{2} \Theta \sin\phi$$



where

ϑ_x = X-Deflection

Θ = Total Field-of-view

ϕ = Angular Position of Scanner

The velocity or the sweep is

$$v_x = \frac{d\vartheta_x}{dt} = \frac{1}{2} \Theta \frac{d\phi}{dt} \text{Cos}\, \phi$$

The length of time spent "per line*" on the screen is

$$\Delta_t = \frac{\beta}{v_x} = \frac{2\beta \sec\phi}{\Theta\, d\phi/dt} = \Delta t_o \sec\phi$$

where

$$\Delta t_o = \frac{2\beta}{\Theta\, d\phi/dt} = \frac{2}{(1500)(300\pi)} \cong 1\ 4 \mu sec$$

For uniform exposure on the film, the intensity must be varied according to cos ϕ

$$E = I\Delta t = (I_o \cos\phi)(\Delta t_o \sec\phi) = I_o \Delta t_o = \text{Constant}$$

It should be possible to do this with an appropriate glow-tube driver control circuit

5 System Tradeoff Formula, Multispectral Scanner

An approximate formula relating multispectral scanner (MSS) system, orbit and earth target characteristics is presented The formula developed in this section is based upon coarse assumptions, but serves as a representation of the type of analytical processes which must occur as the system is being engineered The reader is cautioned that this is not presented as final design but merely as an example of the direction in which trade-off analyses must move during the engineering design phase Once the principal system features have been selected, a more detailed design analysis is strongly recommended

*A "line" is one resolution element wide

The basic tradeoff formula is

$$(1) \qquad S/N = \frac{\alpha^2 \, w \, AD\,(R)}{N^* \, a^{1/2} \, (B/m)^{1/2}}$$

where S/N = signal to noise ratio per degree Kelvin temperature difference (S/N should be at least 1 5 for acceptable performance 1° K is 9/5 $^{\circ}$F)

α = angular resolution of the scanner, radians

w = radiating power of the earth target, watts per steradian-sq cm-oK

A = area of the collecting aperture sq. cm. (The infrared aperture diameter should not exceed 60 cm)

D (R) = Atmospheric transmission factor

N* = receiver noise level, watts per (cycle of bandwidth-cm^2)$^{1/2}$

a = detector area, sq. cm.

B = resolution elements covered per second by the scanner (B/m should be less than 10^6 per sec.)

m = number of detectors per channel

Several of the terms in equation 1 are outside the reasonable scope of system tradeoffs. These are w, D (R), N* and a.

w is computed as follows

The total radiation power at 300° K is 50×10^{-4} watts/ster cm^2

250° K is 7×10^{-4} watts/ster cm^2

Radiation power levels in the 8 to 14 micron portion of the spectrum is recommended by WRL as a basis for feasibility analysis. Approximately 37% of the total power for these temperatures falls in this part of the spectrum Therefore,

$$w = \left(\frac{50 \times 10^{-4} - 7 \times 10^{-4}}{300-250}\right) x \;\; 37 = 3\;2\;10^{-5} \text{ watts per } {}^{\circ}\text{K-steradian-cm}^2$$

Atmospheric attenuation and scattering increases rapidly as the path length through the atmosphere increases Since all the orbits being considered are well outside the atmosphere, the relevant path length is determined by the zenith angle of the line of sight at the earth For a zenith angle of 19^{o}, D (R) is approximately 0 1 Transmission is highly dependent on clouds, haze and smoke, as well, so the approximate nature of D (R) should be appreciated

$N^{*} = 2 \times 10^{-10}$ watts/(cps-sq. cm of detector area)$^{1/2}$
a = 01 sq cm

Inserting these values into equation 1 produces

$$(2) \qquad S/N = \alpha^2 A \left(\frac{\dot{m}}{B}\right)^{1/2} \times 1\ 6 \times 10^5$$

α is the angular resolution of the scanning system If we let L = lineal resolution on the earth surface n. mi , and H = orbital altitude, n mi , then

$$(3) \qquad \alpha = L/H$$

Since aperture diameter, d, is a more convenient parameter let

$$(4) \qquad A = \pi d^2/4$$

B is the number of resolution elements scanned per second. As long as $\frac{B}{m}$ is below 10^6 per second, detector response time will not be a system limitation As many as 100 detectors per channel might be possible m = 6 is within the current art If V = satellite velocity measured at the earth surface, n. mi /sec , U = Swath width, n mi

$$(5) \qquad B \approx \frac{UV}{L^2}$$

With these substitutions, equation 2 becomes

$$(6) \qquad S/N = L^3 \left(\frac{m}{UV}\right)^{1/2} \left(\frac{d}{H}\right)^2 \times 1\ 26 \times 10^5$$

Having chosen D (R) and hence the limiting zenith angle of 19°, U is determined by orbital altitude. V is likewise determined by H through the application of orbital formulas. Assuming circular orbits, the orbital period at 300 n.mi is approximately 95 7 minutes and 103 3 minutes at 500 n.mi The earth is approximately 21,600 n.mi in circumference

It is now possible to solve equation 6 for minimum values of lineal resolution, L, to satisfy signal-to-noise requirements and then to use this value of L to see if detector response bandwidth requirements are satisfied, using equation 5

For S/N = 1.5 per °K

H = 500 n mi.

U = 300 n.mi

V = 3 5 n.mi./sec

d = 60 cm.

m = 1

L becomes .3 n mi or about 1820 feet and the corresponding value of $\frac{B}{m}$ is 11,600. Since this value of $\frac{B}{m}$ is well below 10^6, the system will be limited by signal-to-noise restrictions, not by the detector response time The reader is cautioned that there are coarse assumptions used in some of the factor values The calculations should only be used for coarse feasibility studies

B Television Systems

Television systems for space application offer the advantages of being able to provide high resolution imagery, multispectral response (from UV into the IR), sensitivity for nighttime surveillance and an output in an electrical form that is compatible with data link transmission The factors that influence the usefulness of imagery obtained are resolution, coverage (frame dimensions or swath width), sensitivity, and spectral response. These factors are not independent Some of the relationships among the factors are simple (resolution and coverage), while others are quite complex (resolution and sensitivity) The various performance parameters will be discussed individually and the numbers given should be considered optimum, but the inter-relationships should be kept in mind

Two television systems of advanced performance are shown in Exhibit A-5, one of which would be available for space use by 1973 and the other by 1980

1 Resolution

The ultimate ground resolution of a TV system would be limited by the physical size and dimensional tolerances of the optical system However, for the types of system applications we are considering here, the system resolution is determined by the resolution capability of the TV sensing surface.

Current operational systems such as the TIROS camera are typically using 1" vidicons with a .5" x .5" sensing layer format. Typical sensor resolutions are 800 TV lines per frame and 30 line pairs/millimeter

The current state of the art with regard to resolution capability in a laboratory environment is probably best represented by the RCA 2" Return Beam Vidicon.[1] This has a 1" x 1" image format and is capable of 5000 TV line operation. The sensing layer resolving capability is about 100 line pairs/millimeter A distillation of the opinions of industry representatives on when this laboratory device could be operational in a satellite yields a timetable of about 2 years to produce a good prototype model and another 2 years to make it operational in space. This would mean that a 5000 line system could probably be launched in 1973

[1] "Return-Beam Vidicon System Achieves 5000 TV Lines Resolution," Broadcast News, Volume No 138, March 1968.

EXHIBIT A-5 TELEVISION SYSTEMS

Design Characteristics	Advanced Level 1	Advanced Level 2
Type	Vidicon	Vidicon
Lines per frame	5, 000	10, 000
Channels	3	3
Information bandwidth	1 25 MHz/channel	12 5 MHz/channel
F number	2	2
Focal length	8 inch	(1)
Size	1 5 cu ft /channel	5 0 cu ft /channel
Weight	30 lbs /channel	100 lbs /channel
Power	30 watts/channel	100 watts/channel

System Performance		
Ground resolution	50 ft	(1)
Swath width	50 NM	(1)
Dynamic range	100	100
Amplitude response at max resolution	15%	15%

Note (1) Ground resolution and swath width objectives will determine focal length and orbital altitude trade-offs.

Improving the resolution (expressed in TV lines per frame) could be achieved by two methods increasing the size of the sensing layer and improving the resolving capability of the sensing layer. RCA is currently working on a 4 1/2" model of the Return Beam Vidicon with a 2" x 2" sensing layer which could, theoretically, double the number of TV lines of the system to 10,000 with no increase required in sensing layer capability. On certain tubes they have also achieved approximately 120 line pairs/millimeter resolution, but a large increase in the sensing layer resolving power in the near future is not envisioned

However, by combining the increased size of an operational 4 1/2" Return Beam Vidicon with a modest increase in sensing layer resolving power, it is felt that an operational 10,000-12,000 line system could be achieved by approximately 1980 A 10,000-line capability would, for example, permit 100 foot resolution combined with a 200 mile frame size

Image orthicons are more sensitive than vidicons by a factor of 100 to 1000, however, they currently suffer from the disadvantage of being more complex, less rugged, and having lower resolution capabilities. These disadvantages will offset the improved sensitivity for most system applications, so that the vidicon is the preferred sensor However, for some applications in astronomy where very long integration times (minutes) are required, the image orthicon can be the preferred choice.

Improvements of 10 to 100 in sensitivity for both vidicons and orthicons are predicted for the 1980 time period.

Sensing surfaces in current use are able to respond to radiation out to about 0.8 or 0.9 micron, but it seems likely that the spectral range can be extended in the future as far as 1.3 or 1 4 micron without substantial loss in resolution

2 <u>Sensitivity</u>

The sensitivity of the TV sensors is usually specified as the number of foot-candle-seconds required to generate a given signal-to-noise ratio As an indication of the current state of the art for vidicons, the RCA Return Beam Vidicon has a reported sensitivity of 1 foot-candle-seconds for a signal-to-noise ratio of 40 db on a resolution of 4,000 TV lines A S/N of 37 db is reported for 04 foot-candle-seconds The proposed goal for the RCA Return Beam Vidicon is 01 foot-candle-seconds for a S/N ratio of 40 db and 8,000 TV line operation These resolutions normally refer to a scene in which the contrast ratio is 100 1

The dependence of the sensitivity on the resolution requirement can be analyzed by considering the Modulation Transfer Function of the Return Beam Vidicon.[1] An amplitude response of essentially 100% at 30 line pairs/millimeter and a degration of amplitude response down to 15% at 100 line pairs/millimeter have been reported. For a fixed, frequency-independent noise source in the system, the sensitivity will clearly be a function of scene spatial frequencies which correspond to the image spatial frequencies between 30LP/mm and 100LP/mm A reduction in scene contrast ratio below the 100 1 ratio for which resolution figures are quoted will also reduce the attainable resolution For example, the number of TV lines attainable would be reduced by about 25% for scene contrasts of 2 1

3 Dynamic Range

The dynamic range of a system is usually defined as the ratio of saturation-irradiation level to the noise-equivalent-irradiation level Currently, this ratio is approximately 100 for the types of systems under consideration Some types of circuitry have been considered that increase dynamic range by desensitizing a system at higher average irradiation levels, however, these add a degree of complexity to the system. For most earth resources applications a dynamic range of 100 should be adequate

4 Coverage

The relationship between swath width, ground resolution and system resolution was discussed previously To obtain swath widths

---

[1] "The Resolving-Power Functions and Quantum Processes of Television Cameras," O H Schode, Sr , RCA Review, Vol 28, September 1967, pp 460-535.

greater than could be obtained with a single frame, systems have been proposed which would utilize a mechanically scanning image tube This system would index a mirror to generate overlapping frames transverse to the satellite trajectory In such a manner, one could achieve 1500 mile swath width and still have 150 mile frame size. However, since one rarely gets something for nothing, the price paid here would be a reduced frame time as compared to a nonscanning method, and greater mechanical complexity.

If a localized geographic area is the prime area of interest, consideration should be given to a synchronous satellite in an inclined orbit which would have a figure 8 trajectory crossing over at the equator. This would permit a greater percentage of the time to be spent over the area of interest. A synchronous polar satellite would cover the same ground swath on each orbit (once per day), and could thus give better coverage to a specific geographical area than a satellite orbiting at 300 n. mis A ground resolution of 700 ft. could be achieved.

The total cycle time for preparing, exposing, reading, and erasing the sensing layer surface is normally about 20 seconds. During this time, the satellite advances about 100 miles, corresponding to the frame size of a 5,000 TV line system at 100 ft. resolution If smaller frame sizes are needed to achieve higher resolutions, the total cycle time must be reduced accordingly if contiguous longitudinal coverage is to be maintained Some reduction in cycle time can be achieved by accepting somewhat poorer sensitivity and resolution However, if frame sizes of 20 n mis are to be achieved, substantial technological improvements in this area are called for

5 <u>Geometric Fidelity</u>

For applications in which picture distortion must be held to a minimum, a high degree of scan linearity must be achieved Scan linearity achieved at the present time falls in the range of 0 1% to 0 5% Photogrammetric distortions as a percentage of the total frame size on the ground corresponds to the scan linearity figures mentioned

For multispectral television, requiring the use of two or more cameras, it is desirable to be able to maintain registration of the separate images Slight misalignments between the optical axis of two cameras consisting of a few minutes of arc should not cause any appreciable misregistration. However, even scan linearities as low as 0 1% would cause misregistration of identical points on two images If it is important to maintain exact registration, which would be the case if spectrum matching were being used, special methods of processing the individual images to align them throughout the frame probably could be developed This would represent a considerable addition to the data processing load

6 Interrelationships of Performance Parameters

The smallest resolved ground dimension is related linearly to the image frame size through the system resolution expressed in T V lines The coverage can thus be increased or decreased (within limits) depending on the optical configuration

The system resolution is related to the system sensitivity in a complex manner It should be kept in mind that the number of T V lines quoted for system resolution are based on using optimum optical irradiation and furthermore the response has dropped to a value of 10%-15% of its low spatial-frequency value If we specify a minimum signal-to-noise ratio requirement for the system, and in addition have a curve of the Modulation Transfer Function where a normalized signal-to-noise ratio is plotted as a function of the spatial frequency, the relationship between resolution and sensitivity can be established This trade-off can also be achieved by operating at lower frame rates and thus integrating the optical radiation over a longer period of time For continuous coverage, the resolution would thus have to be reduced

For visible systems, the limiting noise will, in all probability be electronic system noise, not optical background noise, therefore, the sensitivity will depend heavily on the signal magnitude, which in turn depends on the spectral region of operation and the optical bandwidth used This means that for multispectral processing, the narrow-optical band systems will be operating at lower signal levels than broad band systems

7 <u>Weights and Powers</u>

The weight and power requirement of the proposed 5000 TV line RCA 2" Return Beam Vidicon has been estimated to be 30 pounds and 30 watts respectively A 10,000 TV line, 4 1/2" version would probably require about 100 pounds of weight and 100 watts to power it Current operational low-resolution systems are typically 15 pound - 15 watt systems Image orthicon systems have proven to be heavier and require greater power than vidicons, with 50 pounds and 50 watts being quoted for 500 line systems (Stratoscope, Tigris)

C Synthetic-Aperture Radar

The fact that much useful information can be gained from a radar sensor in an orbiting satellite is well recognized The feasibility of placing an appropriate radar in a satellite and the design problems involved were the subject of an intensive study conducted by The University of Michigan for the U S Air Force under contract AF 33(616)-8365 The major conclusions and some design specifications are contained in the final report of this contract[1] Furthermore, this report contains a very good bibliography of pertinent reference material Unfortunately, this report and many of the referenced reports are classified However, a recently published set of summer conference notes[2] contains much of the same information, is unclassified, and can be used for radar design guidance

Off-the-shelf equipment and/or well developed technology exists for designing and constructing a focused-synthetic-aperture radar, the only type capable of reasonably fine resolution for satellite-borne operation Once the satellite flight parameters are known and the required resolution and operating frequency of the radar are selected, the remaining parameters of an optimal system are essentially determined by the ambiguity function and recorder and processor limitation Each of these points will be discussed separately

1 Resolution

Just as with optical imagery, higher resolution radar imagery reveals greater details of the surveillance area at an increased

---

[1] Radar Techniques for an Aerospace Vehicle (U), Final Report No AFAL-TR-65-236, Willow Run Laboratories Report No 4563-107-F, Institute of Science and Technology of The University of Michigan, Ann Arbor, Michigan, November 1968 (SECRET)

[2] R O Harger, L J Porcello, A Kozma, E N Leith, A Olte, R K Raney, T B A Senior, L F Sellwig, G L Tyler, Principles of Imaging Radars, Notes of an Intensive Short Course presented at The University of Michigan Engineering Summer Conferences, Ann Arbor, Michigan, July 22 to August 2, 1968

confidence level but requires (and warrants) more careful scrutinization by trained personnel to extract the output data Although resolution can be arbitrarily selected, high resolution can be achieved only at increased cost or significant tradeoffs of the other parameters Therefore, the lowest resolution acceptable for the contemplated use of the imagery should be specified For agricultural observations, where farm fields are generally 600 feet or more on a side, 50 ft resolution appears to be satisfactory Imagery with such coarse resolution does not display crop structural details, such as the rows of corn, but should be adequate for measuring acreage, agricultural activity, and crop backscatter It should also be adequate for hydrologic studies since terrain, glacial and drainage features tend to be of this same size or larger

2 Frequency

Selection of the most appropriate operating frequency for the radar is perhaps the most crucial task in the entire program One would like to maximize the usefulness of the imagery and the probability of successful operations while minimizing the cost of the equipment

For possible crop identification it is desirable to select a frequency which produces maximum dynamic range of the backscatter from the various elements of the farm scene Cosgriff, et al ,[1] concludes that of the three frequencies which they tested (X, Ku and Ka) the Ka-band illumination displays the greatest change between crop types (roughness) and between seasons (dielectric constant) It is probably safe to extrapolate this result and conclude that the use of the highest frequency possible will produce the best results This can be partially substantiated

[1] R L Cosgriff, W H Drake, R C Taylor, Terrain Scatter Properties for Sensor System Design, (Terrain Handbook II), Engineering Experiment Station Bulletin No 181, The Ohio State University, Columbus, Ohio, May 1960

by comparing the Ka-band radar imagery used by Schwarz and Caspall[1] in their crop identification analysis with the X-band imagery produced by The University of Michigan,[2] and finally with the UHF-band imagery obtained by Conductron Corporation[3] Ka-band imagery shows high contrast, X-band imagery shows medium contrast and UHF-band imagery shows almost no contrast

A Ka-band or higher radar would appear to be desirable if one considers only the utility of the imagery, however, there are other factors which oppose its use Signal attenuation due to atmospheric moisture such as dense clouds or rain is barely noticeable at X-band but becomes quite severe at Ka-band and above Thus, use of Ka-band would limit the all-weather capability of the radar, but on the other hand, might provide information to assist in rainfall determination The greatest deterrant, however, is the nonavailability of some of the critical components In particular, ruggedized high-power output amplifiers capable of coherent operation are not readily available for frequencies above X-band This makes X-band a logical choice for the radar frequency

For any given antenna length, D , the achievable azimuthal resolution, ρ_A, of a synthetic aperture radar is given by

$$\rho_A = \frac{D}{2}$$

[1] P E Schwarz, F Caspall, "The Use of Radar in the Discrimination and Identification of Agricultural Land Use," Proceedings of the Fifth Symposium on Remote Sensing of Environment, The Institute of Science and Technology of The University of Michigan, Ann Arbor, Michigan, April 1968

[2] B Larrowe, "Fine Resolution Radar Imagery A Survey of Recent University of Michigan Results (U)," published in the Proceedings of the 14th Annual Tri-Service Radar Symposium, Willow Run Laboratories of The University of Michigan, Ann Arbor, Michigan, December 1968 (SECRET)

[3] Foliage Penetration Radar Flight Program (U), Interim Engineering Report No 5, Conductron Corporation, Ann Arbor, Michigan, April 1966, (SECRET)

which is independent of either frequency or range For 50-ft resolution, a 100 ft antenna could be used An antenna this large would be desirable since it lowers the power requirements, however, this is likely larger than should be carried on a satellite The types of antenna structures which might be applicable to satellite operation are discussed in a report by Larson, et al [1] The slotted waveguide array, which he proposes, appears to be the most appropriate, for the reasons discussed in that report Such an antenna structure does not lend itself to an extendable or inflatable design because of the complexities of feed design, thus would have to be built as a rigid structure For some of the larger satellites which are being discussed in current literature, a rigid antenna 20 feet long as proposed by Larson should not be unreasonable

3 Sampling Rate

For an optimal size antenna, the PRF of the radar need be only great enough to sample the maximum doppler induced by the forward motion of the satellite, which is 250 Hz However, for a smaller than optimum antenna, a wider ground area is illuminated than is required, thus higher doppler frequencies are present For the recommended 20 foot antenna, frequencies as high as 1250 Hz will be present If undersampling of this signal is attempted, ambiguities result which produce multiple imaging in the along-track direction These tend to be very confusing to the interpreter If adequate sampling is provided (2500 PPS) and adequate bandwidth is present in the recorder, imagery with better than the design resolution but displaying less noise can be produced by special processing techniques [2] Some difficulty will be encountered in

---

[1] L J Porcello, N G Massey, R B Innes and J M Marks, "Diversity and Mixed-Integration Processing in Synthetic-Aperture Radar (U)," published in the Proceedings of the 14th Annual Tri-Service Radar Symposium, Willow Run Laboratories of The University of Michigan, Ann Arbor, Michigan, December 1968 (SECRET)

[2] R W Larson, V M Powers, J E Ferris, Antenna Design for a Side-Looking High-Resolution Aerospace Radar System (U)," Report No 4563-41-T, Radiation Laboratory, The University of Michigan, Ann Arbor, Michigan, January 1965 (CONFIDENTIAL)

utilizing the signals generated from targets near the edge of the real beam since the slight offset angle at which they are measured causes their range to be in error by greater than a resolution element The total range change of a point as it traverses the beam can be found from

$$\Delta R \approx \left(\frac{\lambda}{D}\right)^2 R$$

For the 20 foot antenna at X-band, this range walk is 90 feet at a range of 600 n m Note that it would be worse at longer wavelengths, thus pointing again to X-band as the lowest desirable frequency

4 Swath Width

Once the sampling rate of the radar is determined, the nonambiguous ground swath interval can be found from

$$R_g = \frac{c}{2\,(PRF)\,\sin\theta}$$

For our recommended radar this varies from 38 to 66 n m as the depression angle is changed from 30° to 60°

5 Transmitter Power

The required transmitter power can be determined by evaluating the radar range equation A convenient form of this equation for an optimized radar system is found in Greenberg's paper [1]

$$P_{av} = \frac{8\,\pi\,h\,R_g\,\sin\theta\,V\,\rho_x\,(S/N)\,KTL}{D^2\,\lambda\,\delta^2\,\sigma}$$

where h is altitude (feet)

R_g is swath width (feet)

θ is depression angle

[1] J S Greenberg, "A System Look at Satellite-Borne High Resolution Radar," RCA Review, December 1967

V is satellite velocity (feet/second)

ρ_x is azimuth resolution (feet)

S/N is signal/noise ratio

K is Boltzmann's constant ($1\ 3 \times 10^{-22}$ watt-sec/deg)

T is absolute temperature (degrees K)

L is system loss factor

D is antenna length (feet)

λ is wavelength (feet)

δ is illumination efficiency

σ is target cross section (feet^2)

Using the parameters as proposed for our system this turns out to be 69 watts for a S/N ratio of one However, since we are using an antenna which is 1/5 its optimal length, this power must be multiplied by 25, which gives 1700 watts If a chirped pulse is used to cover the bandwidth required for the desired range resolution, then its length can be somewhat arbitrarily chosen If one chooses 3 microseconds, then the peak power for a PRF of 2500 must be 227 kilowatts For reliable detection of 100 square feet targets, the S/N ratio should be greater than one, preferably as great as 10 This raises the peak power requirements to 2 27 megawatts

6 Data Recording

The radar is designed to produce data continuously (there is no dead time between pulses) at a bandwidth of 15 MHz The only recording media capable of storing large quantities of data at this bandwidth is photographic film Three system implementations can be considered (1) The recorder can be placed on board the satellite and the undeveloped recorded film ejected periodically for ground recovering and processing (2) The recorder can be placed on board the satellite along with a film developer, flying spot scanner and satellite-to-earth data link The radar could collect and store data at the time it is passing an area of interest and transmit this data to the ground at the time it passes a receiving station Neither of these modes of operation is desirable because of the limited supply of expendable film which can be carried aboard the satellite To minimally record the azimuth history on the signal film it must travel at about one-tenth of an inch per second Thus a 5000 foot reel of film would last about 160 hours, which is less than 100 passes around the earth At 300 miles altitude, 18 passes are required to present the entire earth within the viewing constraint of a dual-sided sensor With the recorded swath only 50 miles out of the 600 available, about 50 percent of the earth's surface could be recorded on each 5000 foot reel

Some repetitive coverage can be achieved by restricting the mapped areas to only those of great importance This has the added advantage of permitting a lower bandwidth data link to be used if on-board developing and slow scanning are employed

However, if only limited areas are to be covered, and a wide bandwidth data link is available, the preferred mode of operation becomes feasible In this preferred system, (3), radar data is received and coherently detected in the satellite and the resulting video is used to directly modulate the satellite-to-earth data link The data link must have at least the same bandwidth as the radar and its ground terminal must not be beyond the horizon from the satellite (about 2000 miles) This system also presents the minimum delay in obtaining the data, if that is significant

7 Processor

The recorded signal film should be processed with a coherent optical processor to produce the final output maps[1] The designs of such processors are well covered in the literature and will not be discussed in this report

8 Detection of Precipitation

Radar has been found useful for detecting or measuring precipitation in the atmosphere Operational weather radar systems generally operate at 3 to 10 cm wavelengths At these wavelengths,

---

[1] L J Cutrona, E N Leith, L J Porcello, and W E Vivian, "On the Application of Coherent Optical Processing Techniques to Synthetic-Aperture Radar," Proc IEEE, Vol 54, No 8, August 1966

radar is able to detect the presence of rain in the atmosphere, but is less sensitive to the water content of nonprecipitating clouds At shorter wavelengths of 1 cm and less, the reflected signal and attenuation of the transmitted energy by both rain and clouds increase substantially

Snowfall can also be detected by radar Signal reflection from falling snow has roughly the same strength as for rain with the same precipitation rate in terms of mm/hour of liquid water

In spite of the increased attenuation at wavelengths of 1 cm or less, they appear to offer the best performance for detecting precipitation from orbital altitudes, since rain and snow have greater radar cross-section at these wavelengths and will therefore produce a stronger signal return for a given pulse power Since the direction of viewing from the satellite is nearly vertical, the total round trip distance travelled by the radar pulse through clouds and rain is usually limited to less than a mile. Hence attenuation effects are not likely to have a serious effect on the radar signal return A wavelength of 1 cm, which shows some attenuation from clouds, can therefore be considered suitable for this application

An additional advantage of the shorter wavelength is that the antenna beamwidth can be decreased for a given size of antenna, resulting in smaller resolution element sizes

As an indication of the capability of a precipitation detection radar, a study was made of a radar operating at 1 cm wavelength The radar would use a 4 ft x 4 ft phased-array antenna, capable of scanning laterally over a $\pm$50 degree angle The radar would send out 1 microsecond pulses at a peak power of 15 kw, and a pulse repetition frequency of 200 per second This corresponds to an average output power of 3 watts At an altitude of 300 n mis , the area illuminated by the radar beam at the edge of the swath would be 4 7 by 4 7 n mis If this resolution element were completely filled with rain falling at a rate of 2 5 mm/hour, corresponding to a light to moderate rainfall, the signal return power received by the radar would be 1 4 x 10^{-11} watts, about 10 times above its minimum detectable signal At a pulse repetition frequency of 200 per second, the radar would be able to search over a swath width of 720 n mis If the volume of rain did not completely fill the area illuminated by the radar beam, it could still be detected if the rate of precipitation were greater than the 2 5 mm per hour specified above Greater sensitivity could also be achieved by increasing the average power of the radar

In using an orbiting radar system to detect the areal distribution of rainfall, it will be necessary to avoid confusion between ground clutter and signal return from the precipitation itself For pulses transmitted in a nearly vertical direction, the earliest return representing ground clutter will tend to come from the highest point in the terrain illuminated by the beam By using range gating methods, precipitation which occupies the volume above this highest point can be observed, but clutter will interfere with the signal at lower altitudes At substantial angles from the nadir, ground clutter could interfere with detection of precipitation if the bottom edge of the main beam or its sidelobes contact the ground before the main beam reaches the atmospheric volume to be observed To minimize this effect, the beamwidth of the radar in the vertical plane normal to the satellite velocity should be kept to a minimum This requires an antenna whose aperture normal to the satellite velocity is made as great as possible The design should also aim to reduce sidelobes over the angular region which would cause the most serious trouble

Radar systems have been found to be capable of measuring rainfall rate with fair accuracy under carefully controlled conditions However, it is not believed that quantitative measurements will be possible from an orbiting radar system such as that discussed in this report Satellite coverage of the area will not be continuous, but will consist of repeated sampling at regular intervals determined by the number and spacing of the satellites Also, ground clutter would prevent the detection of rainfall in atmospheric volumes shielded by the clutter Establishing the necessary calibration procedures for accurate measurement of precipitation by radar would also be a sizable problem, but could probably be accomplished if sufficient research is devoted to the problem It is possible, also, that by the use of more than one wavelength, with different capacity for penetrating rain, some ability to distinguish various levels of rain intensity could be achieved. In spite of the limitations mentioned above, the system would be capable of providing frequently repeated coverage of large areas to observe the areal distribution of rainfall and to provide some indication of its intensity

The radar system described above, using a 1-cm wavelength and a 4-ft phased array antenna, could be placed in orbit by 1973. As indicated previously, the ability to detect rain would be restricted, by the attainable resolution, to sizable rain cells and appreciable rates of precipitation. Interpretation of the data would be complicated to some extent in attempting to observe rain at large angles from the nadir, because of poorer resolution and the possibility of ground clutter, but sizable swath widths should still be possible.

By 1980, a system with substantially improved capabilities should be possible. Experience with the 1973 system and additional research in radar meteorology will make possible improved methods of signal interpretation. The use of additional frequencies and the analysis of return echos received at different polarizations would permit better discrimination of ground clutter and of various forms of precipitation, and more quantitative estimates of precipitation rates. Also, increases in available sizes of scanning antennas would improve resolution capabilities. Although the observation of a specific area would still be intermittent, it is possible that the data collected by the radar and other sensors could be used to estimate rainfall occurring between observations.

D Microwave Radiometers

This discussion is confined to radiometer systems operating at frequencies in the range of 10 to 100 GHz, since these frequencies are of major interest for hydrology applications.

In the use of microwave radiometers for satellite application, several performance characteristics of the radiometer system are important From the standpoint of the user's requirements, performance characteristics of major importance include ground resolution, swath width, temperature sensitivity and accuracy The manner in which these requirements are interrelated, and the influence of radiometer equipment characteristics on each of them are discussed below

1. Antenna Design

For antenna sizes capable of producing beamwidths not exceeding 0 5 degrees, scanning is limited to small scan angles, at best As an alternate to scanning, multiple feeds can be used with one antenna and sampled sequentially, by a single receiver, but the total number would be limited to three or four Phased array antennas can also be used in space applications These have high beam efficiencies and allow large scan angles, but are limited to smaller sizes and therefore poorer values of angular resolution

Substantial research and development effort is presently being placed on the problem of putting large antennas in space. It appears possible to automatically erect an antenna up to 100 ft in diameter which will operate efficiently at frequencies up to 6 GHz However, in its packaged form, such an antenna would occupy a volume 10 ft in diameter and 16 ft. long and would weigh about 800 lbs An antenna 30 ft in diameter would probably be usable at higher frequencies, which are of interest in the hydrology application, and would require a package only 3 ft. in diameter, 15 ft long, and 300 lbs. in weight [1]

---

[1] Deep Space Comm. and Nav Study, Vol I, Vol. II, Bell Labs , NAS510293 Whippany, N. J , May, 1968

For parabolic antennas, scanning must be accomplished by moving the entire dish or by moving the feed point. The latter method is preferable, but limits total scan angle As the feed point is moved off the focal axis, sidelobe and gain performance are affected Scanning over as many as 15 elements is believed to be the maximum limit which would be achieved without excessive increase of sidelobe levels and loss of gain.

For satellite applications, it is important to minimize radiation received from near sidelobes, since this radiation will also come from the earth's surface and will affect the accuracy with which measurements can be made

Electronically-scanned phased array antennas also have application to satellite sensor systems. This type of antenna has the advantages of high beam efficiency and small volume requirements. The two-dimensional phased array of realistic dimensions could be flush mounted in the skin of the satellite. Electronic scanning eliminates disturbing torques (which would affect pointing stability) applied to the satellite by mechanical scanning

A phased array antenna used in a 19.35 GHz microwave radiometer system constructed and tested for NASA by Aerojet-General Corporation[1] is typical of the present status of development of these systems. This antenna has a beamwidth of 3° and can be scanned through $\pm 50^{\circ}$ from broadside. The bandwidth is 300 MHz The antenna is nominally 14 in. x 16 in., weighs 10 lbs and occupies 0.5 cu. ft The beam efficiency ranges from more than 90% for scan angles of $\pm 30^{\circ}$, to 84% at the full range of $\pm$ 50 degrees. The array including phase shifters has sidelobe levels of about -20 db It is anticipated that in future systems, sidelobe levels of -30 db can be achieved

Work is presently being done on larger phased array antennas An antenna with 36 in. aperture may be placed in a future Nimbus satellite.

[1] M. E Louapre, "Phased Arrays for Spaceborne Microwave Sensors," Proceedings Fifth Symposium on Remote Sensing of the Environment, pp 59-68, April 1968.

It is believed possible to put a phased array antenna as large as 4 ft in length into space. Increases in size beyond 4 ft. are limited by several factors. A primary limitation is the size of antenna which can be accommodated by the space vehicle itself If the antenna is not folded into a compact configuration, its maximum dimensions are determined by the overall dimensions of the launch vehicle. Attempting to fold the antenna into a package smaller than its normal dimensions and deploy it in space would reduce the antenna performance because of waveguide loss and dimensional tolerances. Tolerance is a fundamental limit of large phased array systems which increases sidelobe levels and reduces beam efficiency

2. Radiometric Receivers

The following discussion of state of the art capabilities refers to the broad band Dicke-system radiometer. This type radiometer provides a measure of the power difference between the source of signal power (the antenna) and a known reference power at a selected fixed frequency. This would be the type most applicable to the collection of data on snow and soil conditions from a satellite.

According to a paper by Ewen, et al ,[1] "These systems currently provide sensitivities of 0 05 deg. K rms from 1 to 20 GHz (assuming an integration time of 1 second) Above 20 GHz, sensitivities degrade .. to 1 5 deg K rms typical of present performance at 100 GHz The most sensitive solid state systems from 1 to 20 GHz are of the TRF type using tunnel diode amplification. Receiver noise figures range from 4 db at 1 GHz to 7 db at 20 GHz. The increase in receiver noise temperature with frequency, however, is offset by the larger increase in pre-detection instantaneous bandwidth which can be obtained. Considerable development effort is currently underway to extend tunnel diode amplifier capabilities to 40 GHz to achieve radiometric sensitivities of 0 1 deg K "

---

[1] H I Ewen, et al, "Microwave Radiometric Capabilities and Techniques," Proceedings Fifth Symposium on Remote Sensing of the Environment, pp. 9-58, April, 1968

For radiometric sensor systems at 60 GHz, "improvements in sensitivity .. will most likely be obtained through improvement in crystal mixer conversion efficiency. Several development programs are currently concentrating on this possibility, a projected improvement of nearly one order of magnitude in sensitivity is anticipated within two years These efforts will have a direct influence on near future sensitivity up to 100 GHz."

Present and near future receiver sensitivities are shown in Exhibit A-6 Because of the usefulness of radiometric systems for meteorology and communications applications, substantial research and development effort is being devoted to this technology It is therefore anticipated that continued substantial improvements in radiometric sensitivity can be expected.

3. System Resolution

The ground resolution R, which can be achieved from a given altitude h (assuming a vertical direction of view) is given by

$$R = \beta h,$$

where β is the angular resolution of the system This angular resolution cannot be better than the theoretical limit imposed by antenna size.

At microwave frequencies, it is possible to build inflatable antennae which approach true diffraction limitations provided certain maximum diameters are not exceeded. The system spatial resolution can then be adequately predicted from the Rayleigh criteriod $\beta = 1.2\lambda/D$, where λ is wavelength and D is antenna diameter. From this equation, and auxiliary data on maximum attainable antenna diameter, the following table summarizes anticipated resolution capabilities.

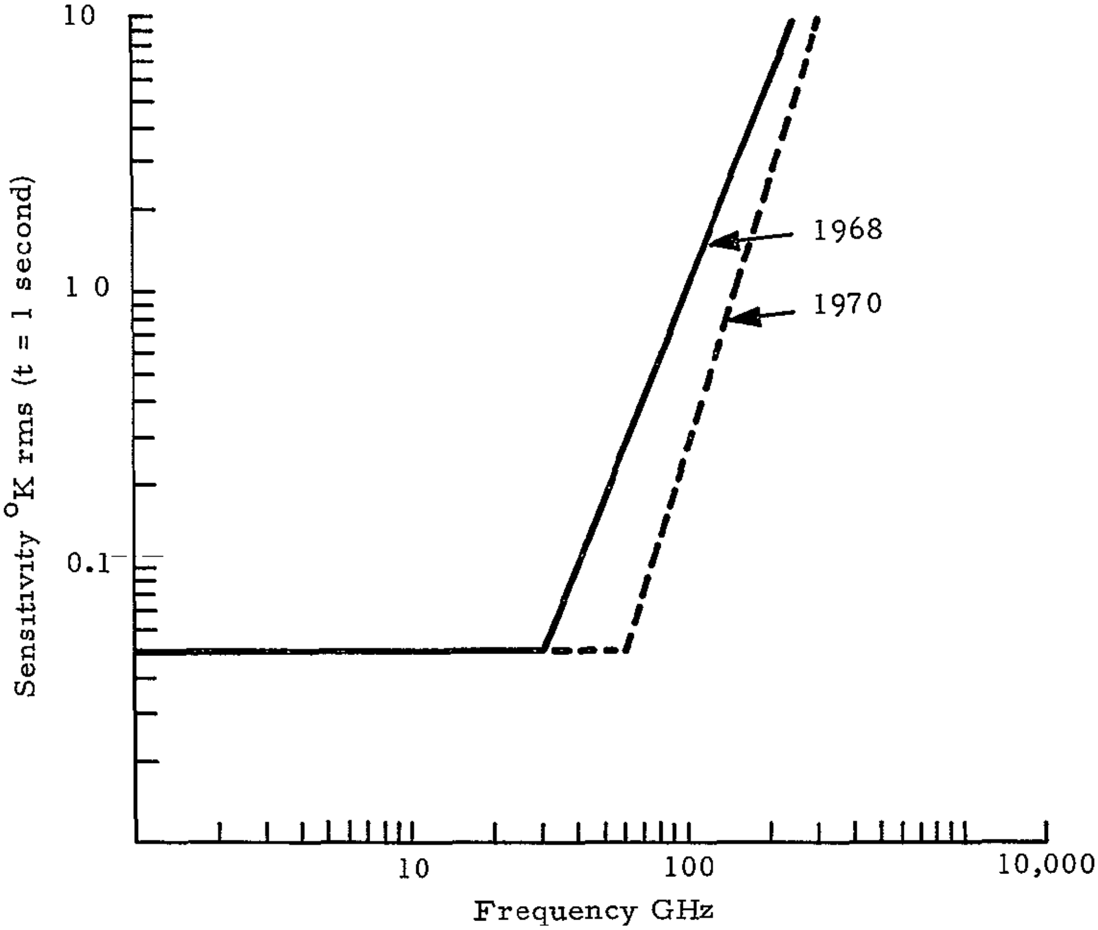


EXHIBIT A-6 PRESENT AND PROJECTED RADIOMETRIC SENSITIVITIES

Resolution Capabilities of Parabolic Antennas

Wavelength (cm)	Frequency (GHz)	Maximum Anticipated Diameter of Spaceborne Antenna (meters)[1]	Angular Resolution (mrad.)	Gnd Resolution from 300 n mi orbit (ft.) (Rayleigh Criterion)	Swath Width (mi)[2]
0.3	100 0	3	1.2	2200	5 4
0.8	37 5	5	1.9	3500	8.6
3	10.0	10	3 6	6600	16 3

If a phased array antenna limited to 4 ft is used, resolution capabilities would be as shown in this table

Resolution Capabilities of 4 ft Phased Array Antenna

Wavelength (cm)	Frequency (GHz)	Angular Resolution (mrad.)	Gnd. Resolution from 300 n. mi orbit (ft.)	Swath[3] Width (n. mi.)
0 3	100 0	3 0	5,500	720
0.8	37 5	8	14,600	720
3	10 0	30	54,800	720

4. Swath Width

The swath width obtainable with a given system is a measure of the total rate of area coverage of the orbiting sensor Several factors limit attainable swath widths.

[1] The maximum anticipated dish diameter is limited by fabrication tolerance. Obviously this becomes more difficult with decreasing wavelengths

[2] The swath width assumes a lateral scanning capability of 15 resolution elements

[3] Based on ± 50 deg scan For additional limitations caused by temperature sensitivity requirements, see text.

If a parabolic antenna is used, scanning normal to the ground track may be accomplished by moving the entire reflector (an impractical solution for large aperture systems on orbiting vehicles) or by moving the antenna feed The latter solution is limited to about 15 resolution elements normal to the ground track, because of the sharp drop in gain as the beam direction moves off axis.[1] If a phased array antenna is used, with electrical rather than mechanical scanning, much larger scan angles can be accommodated. However, this is achieved at the expense of ground resolution, since dimensions of phased array antennas which can be placed in orbit are not as great as those of inflatable antennas

An additional limitation on swath width arises from the interrelationships among angular resolution, scan angle, and temperature sensitivity This subject is discussed below

5 <u>Temperature Sensitivity</u>

A general equation governing the noise performance of a microwave radiometer can be derived from standard noise theory and has been presented in various forms by many authors The form used here illustrates the effects of various parameters on overall system performance.

Sensitivity in the case of the microwave radiometer can be evaluated in terms of a noise temperature, ΔT_{rms} , by defining a signal change (expressed as a change in observed temperature) sufficient to produce an output signal-to-noise ratio of unity (This does not mean that a change in signal strength ΔT_{rms} is necessarily detectable In fact, a value of the order of $3\Delta T_{rms}$ is more realistic as a minimum detectable signal)

$$\Delta T_{rms} = K \frac{T_{eff}}{\sqrt{B_\tau}} + \gamma \left|(T_S - T_R)\right| \qquad (1)$$

[1] R E Hiatt and R W Larson, <u>Survey of High Gain Broadband, Passive Deployable Antennas with Scanning Capabilities for Installation in a Manned Satellite,</u> Internal Memorandum, Report No. 6734-502-M, Willow Run Laboratories, 6 August 1964

where K = a constant for each radiometer depending upon configuration, modulation techniques, etc Varies nominally from 1/2 to 1/16

T_{eff} = total equivalent input noise temperature (^oK)

B = system bandwidth (Hz)

τ = integration time (sec)

γ = short-term gain instability expressed as a percent of overall gain

T_S = equivalent antenna (input) temperature due to signal (^oK)

T_R = equivalent antenna (input) temperature due to reference source (^oK)

For an airborne or spaceborne system, the integration time τ is limited by the dwell time on a single resolution cell. This in turn is determined by the angular resolution, β , of the instantaneous field of view, the angular scan, α, for a scanning system, and the rate of advance of the platform, V/h

$$\tau = \frac{\beta^2}{\alpha(V/h)} \qquad (2)$$

By combining equations (1) and (2), we can isolate the effects of various system parameters on radiometer performance

$$\Delta T_{rms} = K\frac{\left[T_{signal} + T_{system}\right]}{B^{1/2}\ \beta}\left[\frac{\alpha\ V}{h}\right]^{1/2} + \gamma\left|T_{signal} - T_{ref}\right| \qquad (3)$$

where T_{eff} has been replaced by its components T_{signal} and T_{system} The noise component, T_{system}, is a measure of radiometer behavior useful in comparison of various systems. As T_{system} is reduced, the quantity T_{eff} approaches T_{signal} as a lower limit Therefore, a maximum sensitivity exists, dependent upon the <u>magnitude</u> of the observed signal, even for the ideal case of a noiseless system ($T_{system} = 0$) This indicates that in high signal-temperature situations, no significant improvement can be realized through further development of low-noise amplicication beyond that for which $T_{signal} \gg T_{system}$ Current state of the art systems approach this situation for earth observation ($T_{signal} = 300^{o}K$) at microwave frequencies below about 10 GHz However, at higher frequencies, system noise contributions are still comparable to, or several times greater than the signal to be observed (i e , $T_{signal} \leq T_{system}$)

The last term in equation (3) can also affect system sensitivity In practice, quantitative radiometric measurements depend upon the comparison of an unknown signal level (T_{signal}) with a known reference level ($T_{ref.}$) Such a system, which generates an internal reference for quantitative measurement purposes, is usually called a Dicke system, or often a modified Dicke system[1] It is the difference ($T_{signal} - T_{ref}$) which is acted upon by the radiometer's amplification stages and therefore affected by the gain instability term γ By proper design of the system, the effect of gain stabilities can be minimized and usually can be considered negligible The temperature sensitivity problem can then be treated by considering only the first term on the right side of equation (3)

Exhibit A-7[2] gives a tabulation of current state-of-the-art radiometric sensors usable at various frequencies together with their equivalent noise temperatures and bandwidths It should be noted that such devices as masers and paramps are followed (and often preceded) by other more noisy devices in a complete radiometer system, and that T_{system} of equation (1) or (3) is often significantly larger than the values listed in Exhibit A-7 For example, the maser radiometer described by Cook, et al ,[3] seldom achieved a field operational system temperature less than

---

[1] R H Dicke, "The Measurement of Thermal Radiation at Microwave Frequencies," Rev Sci Insts , Vol 17, No 7, p. 268, July 1946

[2] H I. Ewen, State of the Art of Microwave and Millimeter Wave Radiometric Sensors, paper presented at International Symposium on Electromagnetic Sensing of the Earth from Satellites, Miami Beach, Florida, November 1965

[3] J J Cook, M E Bair, L. A Cross, The Ruby Maser, A Practical Microwave Amplifier, The University of Michigan, IST, Willow Run Laboratories, Report No 2900-288-T, September 1961

EXHIBIT A-7 NOISE TEMPERATURE AND PREDETECTION BANDWIDTH OF RADIOMETRIC SENSORS

Frequency	Input Circuit	Noise Temperature $^{\circ}$K (*)	Nominal Bandwidth (Mc)	Remarks
1 - 10 Gc	Maser	10	50 to 100	
	Paramp	250	5% f_o	Uncooled
	Paramp	70	5% f_o	Cooled
	Tunnel Diode	500	Octave	
	TWT	600	Octave	
	Mixer Preamplifier	600*	200	
10 - 20 Gc	Maser	25	100	
	Paramp	350	1000	Uncooled
	Paramp	70	1000	Cooled
	Tunnel Diode	600	500	
	Tunnel Diode	1100	2000	
	TWT	1000	2000	
	Mixer Preamplifier	700*	200	
20 - 40 Gc	Maser	50	200	
	Paramp	1100	1000	Uncooled
	Paramp	200	1000	Cooled
	Tunnel Diode	1400	4000	
	TWT	4200	10, 000	
	Mixer Preamplifier	950*	50	
	Mixer Preamplifier	2500*	1000	
40 - 75 Gc	Mixer Preamplifier	4500*	50	
75 - 100 Gc	Mixer Preamplifier	2500*	2000	
	Crystal Vidio			40°K rms/sec
140 Gc	Mixer Preamplifier	4500*	2000	
230 Gc	Mixer Preamplifier	36000*	2000	
	Bolometer			0 1°K rms/sec

* Dual Channel

50°K and often was measured as high as 100 to 150°K (including all mismatches in waveguide, antenna spillover and backlobes, etc) Thus realistic limits on T_{system} would be perhaps 100°K in the 1-10GHz region, 200°K (10-20GHz), and 300°K (20-40 GHz) Future advances in microwave technology may lower the achievable values of T_{system}, but T_{eff} cannot become less than T_{signal} as a theoretical limit

Bandwidths are somewhat more easily predicted and should probably be expected to range from 100 to 500 GHz throughout the 1-40 GHz range

While these figures are rough estimates, they are sufficient for system noise evaluation and an analysis of the remote sensing capability of microwave radiometers

Performance of present-day systems intended for use in satellites in the near future is represented by the 19 35 GHz phased array scanning system mentioned earlier This has a temperature sensitivity of about 0 5°K and can indicate absolute temperatures with an accuracy of 2°K

In designing a microwave radiometer system for a given space application, values of $\frac{KT_{eff}}{B^{1/2}}$ can be selected which are representative of the present or future state of the art The quantity V/h is a function of orbital altitude, which will presumably be selected on the basis of considerations other than radiometer performance The system can be designed to provide the best tradeoff among temperature sensitivity, ΔT_{rms}, the swath width, αh, and angular resolution, βh

6 Microwave Scanners for Hydrologic Sensing

Based on the previous summary of present and future microwave radiometer performance, the following systems are projected for use at two advanced dates

Operational wavelengths will be chosen to satisfy particular mission goals For surveillance of snow and soil, these wavelengths will coincide with those of high atmospheric transmission, and for this purpose, frequencies of 10 GHz and 37 5 GHz would be useful For detection of rainfall, a frequency of about 20 GHz would be more suitable, since this is more subject to attenuation by rain For the summary of characteristics in Exhibit A-8, frequencies of 10 GHz and 37 5 GHz are assumed

For a system available at the first advanced level, both a deployable antenna and a phased array antenna are shown The deployable antenna is assumed to have a diameter of 30 feet and a nonscanning mode of operation utilizing 5 adjacent feeds The phased array antenna has a dimension of 4 feet Its scanning capability is $\pm$ 50° For both systems, ΔT_{rms} is assumed to be 0 05°K for a 1 second integration time

For a system available at a second advanced level, only the deployable antenna is shown It is assumed to have a diameter of 45 feet, a scanning range of 15 elements, and ΔT_{rms} of 0 04°K

E State-of-the-Art Sensor Systems

Characteristics of sensor systems which represent the present state-of-the-art are shown in Exhibits A-9, A-10, and A-11 These sensors could be placed in orbit without the need for appreciable research and development, and are representative of systems available in a 1970-71 time frame

The sensors covered in the exhibits include the television camera, multispectral scanner, and microwave radiometer A coherent radar is not included in the list Although most of the techniques involved in the design of such radars may be considered within the current state of the art, the special design problems involved indicate that 1973 would be a more suitable launch date

Descriptions of advanced sensor systems have been included in a separate discussion Two advanced levels of performance were identified for each sensor system, one level compatible with a launching date of 1973, the other with a launching date of 1980 For each of the advanced performance levels, a specific sensor design is shown which approximates the highest performance system which might be placed in orbit compatible with requirements of reliability In some cases, these systems are heavy and costly, and will place sizable requirements on subsystem

EXHIBIT A-8 SUMMARY OF CHARACTERISTICS OF PROJECTED SENSOR SYSTEMS

		← ADVANCED LEVEL 1 →				ADVANCED LEVEL 2.	
Type of Antenna		Phased Array		Deployable (5-fixed feeds)		Deployable (15 RE Scanner)	
Antenna Diameter		4'		30'		45'	
Received Sensitivity (ΔT_{rms} for 1 sec. Int time)		$0.05^{\circ}K$		$0.05^{\circ}K$		$0.04^{\circ}K$	
		10GHz	37.5GHz	10GHz	37.5GHz	10GHz	37.5GHz
Angular Resolution (mrad)		30	8	4	2	2.6	1.4
Ground Resolution (from 300 n. mi.)		54,800	14,600	7,300	3,650*	4,750	2,550*
Swath Width (n. mi.)		720	720	6	3	11.7	6.2
Sensitivity (ΔT_{rms})		$0.26^{\circ}K$	$1.05^{\circ}K$	$0.1^{\circ}K$	$0.2^{\circ}K$	$0.4^{\circ}K$	$0.5^{\circ}K$
Size (ft^3)	Electronics	8 (total)		4		4	
	Antenna			150		250	
Weight (#)	Electronics	50 (total)		20		20	
	Antenna			300		500	
Power		50		40		50	

EXHIBIT A-9 SENSOR SYSTEM CHARACTERISTICS - TELEVISION (1970 SYSTEM)

Design Characteristics

Type	2" return-beam vidicon
Lines per frame*	3500
Channels	3
Information bandwidth	470 KHz/channel
F number	2 8
Focal length	6"
Size	1 5 cu ft/channel
Weight	30 lbs/channel
Power	30 watts/channel

System Performance

Ground resolution**	~90 ft
Swath width**	50 nm
Dynamic range	100
Amplitude response at maximum resolution	15%

* For 100 1 Contrast, 0 1 ft-candle-sec exposure

** For 300 nm altitude At 500 nm altitude, ground resolution is 150 ft, and swath width is 83 nm

EXHIBIT A-10 SENSOR SYSTEM CHARACTERISTICS - MULTISPECTRAL SCANNER (1970 SYSTEM)

Design Characteristics

Aperture diameter 4"

Instantaneous field of view 0 6 mrad

Type of scan Circular scan

F no of optics 4

No. of detectors per channel 1

Information bandwidth 6 channels @ 8.3 KHz each

Sensor Performance

Ground resolution (from 300 nm) 1,090 ft

Swath width 43 nm

Sensitivity

Channel	Detector System	NEΔρ	NEΔT
0 5-0.6 micron	S-20 photomultiplier	01	
0 6-0 7		01	
0 8-1 2		01	
1 55-1 75	InSb at 77° K with cooled filter	01	
2 2-2.4		01	
10 5-12 5	Cooled Ge Hg detector		1°K

Size 3 cu ft

Weight 80 lbs

Power 35 watts

EXHIBIT A-11 SENSOR SYSTEM CHARACTERISTICS - MICROWAVE RADIOMETER (1970 SYSTEM)

Type of antenna		Phased array
Antenna size		3 ft x 3 ft
Receiver sensitivity		.05°K
Frequency		10 GHz
Angular resolution (mrad)		40
Ground resolution (from 300 nm)		73, 000 ft
Swath width (nm)		720
Sensitivity (ΔT_{rms})		0. 20°K
Size (ft^3)	Electronics	1 cu ft
	Antenna	2 cu ft
Weight (lbs)	Electronics	25 lbs
	Antenna	15 lbs
Power		25 watts

components, and on launch vehicle capability Accordingly, these sensor systems represent an upper limit aimed at achieving maximum performance rather than a system recommended for particular applications System designs are not necessarily restricted to performance characteristics listed in each table In most cases, it is possible to trade off one type of performance for another within the same limit of size, weight, and power

F Research and Development Program For Implementation Of Operational System

In the following discussion, an R&D program needed to develop an operational capability for the collection and analysis of river management data is described Each of the tasks which make up the total program is discussed, indicating the objectives of the task and the specific activities needed to achieve these objectives for the various sensors and types of data to be collected

The R&D program will be performed in four overlapping phases

- o Equipment design and development
- o Ground-based data collection in laboratory and ground test sites
- o Data collection and analysis using airborne sensors
- o Data collection and analysis using pre-operational satellite

Exhibit A-12 summarizes the tasks comprising the R&D program and the distribution of effort throughout the four phases Final confirmation of R&D results and further refinement of data collection and analysis techniques would also be accomplished after the satellite information system becomes operational, but such activities may be considered as a part of the operational phase of system implementation

1 Equipment Design and Development

The objective of this phase of the work is to develop advanced sensor components and systems with increased resolution, sensitivity, accuracy and coverage, as needed to meet projected operational requirements The development phase of the work extends throughout the R&D program, with airborne and satellite testing being used to check

EXHIBIT A-12 SUMMARY OF RESEARCH AND DEVELOPMENT PROGRAM

R & D TASKS	R & D PHASES: Equipment Design & Development	Ground-Based Data Collection	Airborne Data Collection	Pre-operational Satellite Data Collection
Equipment R & D				
Design and development	X			
Check-out and evaluation			X	X
Collection of ground truth and signature data				
Preparing and operating test sites		X	X	X
Collection of ground truth		X	X	X
Collection of target signature data		X	X	X
Data analysis and interpretation				
Development of automatic processing techniques	X			
Development of interpretation techniques		X		
Analyzing and simulating operational systems		X	X	X
Collecting reference data for operational use		X	X	X

out and confirm sensor performance, including the reliability, stability, and other operational aspects

The performance demanded of each type of sensor depends on its intended use in the operational system For most applications, substantial improvements in sensor performance beyond the existing state of the art will be required to achieve desired operational objectives The technical areas in which sensor improvement is particularly needed have been listed in Exhibit A-13 In addition to improvement of sensor technology, increased performance will also be required for certain auxiliary types of equipment The most critical areas of improvement in performance are also listed in this exhibit

Additional information concerning the need for research and development efforts in specific areas is included in the discussion of the individual sensors contained in other sections of this report Research and development effort is already being devoted to meeting many of the equipment requirements listed in Exhibit A-13

2 Ground-Based Data Collection - Ground Truth And Signature Data

Extensive ground truth data must be collected on hydrologic, meteorological, and illumination conditions in connection with the collection of target signature data and also during airborne and satellite test programs This task must be performed with great care and thoroughness, since it provides information needed for accurate interpretation and evaluation of sensor outputs and for establishing suitable operational procedures for data analysis

A major objective of this phase is to collect and organize comprehensive data on target and background signatures of various types and conditions of snow, ice, soil, vegetation, and other surface materials to provide a foundation for operational methods of interpreting remote sensor data The signature data should cover the visible, IR, and microwave regions of the spectrum and should include polarization and other potentially useful effects Signature data should be collected for various conditions of illumination, viewing angle, weather, time of day or season, and other factors having an influence on target conditions

EXHIBIT A-13 REQUIRED EQUIPMENT R & D

Television

Higher line densities and total number of lines per frame.

Accurate registration of images from different cameras (or ground-based automatic processing of imagery to obtain registration).

Accurate representation of target radiance.

Greater sensitivity of photosensitive surfaces for low light level observations.

Extension of sensitivity to longer wavelengths.

Cycle time of vidicons approaching 5 seconds.

Multispectral Scanner

Large scanning-mirror systems with low distortion of optical surfaces

Large multiple-detector arrays

Higher detector sensitivities

Reliable long-life cryogenic systems

Accurate and consistent calibration methods

Microwave Radiometers

Large scanning antennas with high beam efficiency.

Calibration methods for accurate temperature measurement

Improvements in signal-to-noise ratio of radiometric receivers

Coherent Radar

Calibration methods for accurate measurement of signal strength.

Reduced power requirements

Large antennas (up to 100 ft in length).

Ruggedized high-power output amplifiers capable of coherent operation for frequencies above X-band

Laster Altimeter

Development of lasers with nanosecond pulse lengths and high pulse frequencies

EXHIBIT A-13 (Continued)

Auxiliary Systems or Special Components

Communications

Wide bandwidth data links to handle multichannel or high resolution imagery.

Attitude-Control Systems

Adaptation of high-accuracy attitude measurement systems to provide accurate computation of ground position for imagery

Microwave Antennas

System techniques and mechanical design to provide best capabilities for large apertures, wide scan angles and high beam efficiency, with minimum weight and volume during launch

Power Supply

Large power supply and thermal dissipation capability, particularly needed for coherent radar systems.

Although quantities of laboratory or field data already exist, there are inconsistencies and inadequacies in the collection methods, especially when attempts are made to use the data for research and development of satellite information systems Consequently, data collection programs should be expressly planned to answer questions relating to the use of operational systems, and should provide for collection of all auxiliary data pertinent to the interpretation process

a Preparing and Operating Ground Test Sites

For collecting the ground-based data mentioned above, ground test sites must be prepared and operated by installing field instrumentation and providing personnel and instrument maintenance and calibration facilities

The existing test site at South Cascade Glacier in Washington and possibly hydrology test sites already established by NASA at other locations could be used for laboratory and ground-based testing It is also assumed that the existing network of snow observation stations in Canada and Alaska described by Bilello[1] would be available for supplying ground truth data during aircraft flights and calibration data during satellite flights

It would be desirable to have available as test sites typical areas in a large river basin which is part of a large hydroelectric development, such as areas in the Columbia River basin These test sites could serve not only as a location for collecting ground truth, but would also be used in the later phases of the R&D program to develop and evaluate operational procedures for using remote sensing data Existing instrumentation and methods already in use for collecting operational data would provide ground truth These would be supplemented by additional instrumentation to increase the number of quantities measured

[1] Bilello, Michael, Surface Observations of Snow and Ice for Correlation with Remotely Collected Data

and the density of measurement This test site would also serve as a basis for determining how the forecasting accuracy of existing methods can be improved by the newer remote sensing methods The U S Army Corps of Engineers has described three areas which were used for comprehensive studies of snow hydrology [1] These areas are representative of test sites which might be used for the proposed R&D program

b Collection of Target Signature Data

A large amount of pertinent target signature data has been collected by many workers For example, there is a large amount of pertinent reflectance data in the visible for soils and vegetation There are some radar reflectance data and microwave and IR reflectance and emittance data for the objects of interest in hydrology

Despite the amount of data that has been collected, there are not enough radiance data to permit the evaluation of most of the potential applications of satellites to hydrology More data on snow, ice, water, vegetation, soil, and crops are needed for the following reasons

Measured radiances are influenced by many factors (see Exhibit A-14) For any given object of interest, only a few factors have been systematically studied Many important factors are not reported and not measured Measurements by different workers are not made in similar bands or with instruments having the same spectral resolutions Much of the data are reported in relative rather than absolute terms These and other shortcomings indicate the need for a systematic program of data collection specifically aimed at answering questions pertaining to the use of satellite-borne sensors for various hydrologic applications

[1] Snow Hydrology, U S Army Corps of Engineers, June 1956

Such a measurements program should have the following characteristics Measurements would be made on snow, ice, water, soil, vegetation, and crops The conditions of measurement would include, where applicable

- o Physical condition
- o Viewing conditions
- o Age or maturity
- o Moisture content
- o Geographic location

Objects would be measured by several sensors simultaneously or virtually simultaneously That is, an attempt would be made to measure radiances for all samples in the visible, the IR, and the microwave regions, under the same conditions

Every effort would be made to produce measured spectral radiances having generality and statistical significance Sensors would be calibrated to yield absolute radiances Measurements would be made with instruments of high spectral and geometric resolutions, in the visible and near IR (These high resolution data could be degraded to simulate the outputs of sensors having lower resolution)

The following sensors would be mounted and made transportable to permit measurements in the laboratory and the field

- o Spectrograph
- o IR spectrometer (thermal band)
- o IR radiometer
- o Microwave radiometer (multiband)
- o Color camera

The experimental conditions would be carefully documented For example, in measuring snow samples, the factors in Exhibit A-14 would be known and recorded

3 Airborne Test Program

The airborne test phase of the R&D program for implementing operational earth resources satellites has several distinct objectives

EXHIBIT A-14 FACTORS OF INFLUENCE ON MEASURED RADIANCE FOR SNOW

CONDITIONS OF MEASUREMENT AFFECTING REPORTED REFLECTANCE SPECTRA OF SNOW

(1) Artificial or natural snow

(2) Illumination conditions

- Source of illumination (point or extended)
- Spectral content of illumination (e g., sun, clear sky, overcast sky, glower, lamp)
- Length and quality of air paths.
- Angle of incidence.

(3) Viewing angles

- Angle of reflection.
- Azimuth (when incident ray, reflected ray, and zenith do not lie in the same plane)

(4) Instrumentation.

- Reflectance standard (MgO, $MgCO_3$, S, paper, or none when reflected energy is compared to illumination)
- Means of achieving dispersion (filters, prism, grating).
- Spectral response of dispersing medium
- Detector (spectral response and sensitivity for, e.g , thermistor, photovoltaic material, photomultiplier tube, photographic plate)
- Detector temperature (for thermal bands).
- Amplifiers and recording media (e g , linearity, bandwidth, dynamic range)

(5) Sampling methods

- Number of replications
- Method of averaging measurements (over an area or a time interval)

PARAMETERS DESCRIBING PHYSICAL FORM OF SNOW

- Density
- Particle size
- Wetness
- Purity

Extent of sintering

Surface roughness

Surface ice and water

FACTORS INFLUENCING THE PHYSICAL FORM OF SNOW

Temperature of snow

Temperature of air

Age

Winds

Sunlight

Dust and smoke in air

- To check out and evaluate sensor equipment
- To provide experience with data interpretation methods, and associated data processing techniques and equipment.
- To collect ground truth and target signature data useful for operational purposes

To a considerable extent, these same objectives can be achieved by the use of a pre-operational satellite test program, or during the initial use of the operational satellite system itself The exact distribution of R&D effort among the various phases of the program can be decided after a more detailed program is prepared, but it is believed that a substantial and balanced effort in the various phases of the program will be required for system implementation

a Sensor Checkout and Evaluation

In this task sensor performance will be checked out and evaluated in airborne and satellite tests to confirm anticipated performance This evaluation will cover not only accuracy, sensitivity and resolution of the sensor outputs, but the reliability, stability, and other operational aspects of sensor performance

Airborne tests can provide much useful information concerning sensor performance, but final evaluation will come from the use of sensor equipment in satellite systems

b Collection of Ground Truth During Airborne Tests

In the airborne testing program, data should be gathered by obtaining repeated coverage over the ground test sites for different seasons, time of day, surface temperatures, and target conditions Simultaneous coverage with more than one type of airborne sensor would further increase the value of the information Comprehensive efforts should be made to collect all necessary ground truth at the same time as the airborne coverage Extending the same concept to pre-operational or operational satellites, simultaneous coverage should be obtained with airborne systems and ground truth collection to facilitate the analysis and interpretation of the satellite data c Data Analysis and Interpretation

Relationships must be established between signature data and surface type and condition to allow reliable interpretation of sensor outputs identifying and measuring hydrologic variables Exhibit A-15 lists a number of specific studies which should be carried out to develop the necessary interpretation methods

Methods must also be developed for automatic processing of sensor outputs to alleviate the high cost and time requirements associated with human photointerpretation Important interpretation problems which require automation are included in the exhibit This subject is also discussed in the section on ground data processing

d Analyzing and Simulating Operational Systems

Using laboratory and field test data, and in a later phase, outputs of airborne and pre-operational satellite testing, the performance of operational satellite information systems can be analyzed

For purposes of comparison, the laboratory and ground-based data can be extrapolated to satellite altitudes by taking into account the effects of varying illumination and atmospheric absorption and scattering and the sensitivity and resolution characteristics of the operational sensor Frequency of obscuration by cloud cover can also be taken into account analytically These same general methods can also be used in the evaluation of airborne systems intended for later operational application

The effectiveness of the remote sensor system can be expressed in terms of such factors as

- o Probability of detection and probability of false alarm in identifying snow or other surface materials
- o Accuracy of measuring area, albedo, or other physical variables
- o Total rate of coverage, expressed in square miles per hour or day, or in frequency of looks at a specified area

Further analysis can be used to convert this type of information to estimates of the accuracy of predicting volume of snowpack, stream-flow or other hydrologic conditions

Television

Interpret imagery of snow-covered areas to estimate snow thickness, measure snow-covered area or surface water, distinguish wet soil from dry soil, etc

Determine ground resolution needed for various tasks.

Multispectral Scanner

Determine best spectral bands for differentiating snow covered areas from soil, rocks, or vegetation, wet soil from dry soil, etc

Develop precise measurement of snow albedo, for heat budget studies, identifying snow characteristics, etc

Distinguish snow from cloud cover.

Investigate effects of ground resolution on signature data.

Develop correction methods for atmospheric effects on signatures and temperature measurements.

Establish relation of evaporation or transpiration to surface temperature for vegetation, water, or soil or other measured variables

Calculate heat absorbed and radiated by snow as a function of measured reflectances in bands containing solar energy

Provide accurate area measurement techniques.

Microwave Radiometer

Relate apparent brightness temperature data for snow, ice, soil and other surface materials to various surface and environmental conditions.

Investigate atmospheric attenuation and scattering effects on microwave measurements

Analyze apparent brightness temperatures of rain, snow, and other forms of precipitation

Investigate effects of ground resolution on data interpretation process

Coherent Radar

Investigate relationships of signal return strength to snow thickness for various types and conditions of snow cover.

Laser Altimeter

Develop techniques for snow thickness measurement e Collecting Reference Data for Operational Use

A bank of reference data and imagery will be collected and stored in photographic files or in computer memory banks for operational use The required data include maps and photography of river basins and agricultural areas for various seasons Also, soil and vegetation types and characteristics, terrain slope and orientation, canopy density, distribution of rivers, lakes, and other bodies of water will be stored by geographic location for use in computer analysis and interpretation of operational data The stored information for each geographic area will include data on reflectances and emittances of surface materials in various spectral regions, as needed for data interpretation

The collection of data as described above will take place throughout the entire R&D program, but will be concentr ted particularly in the airborne and satellite phases

4 Satellite Test Program

The objectives of the final phase of the R&D program are to use data obtained from a pre-operational satellite to evaluate and confirm predicted satellite sensor performance Specific areas of investigation include the performance of the sensors and auxiliary satellite systems, performance of the ground data processing system, and effectiveness and accuracy of the data analysis and interpretation procedures for predicting river management conditions

Results of satellite testing will be used to confirm system performance predicted from system analytical and simulation studies and to modify and improve system operating procedures, where necessary

The objectives of the satellite test program are basically similar to those of the airborne test program, and the use of a pre-operational satellite may obviate the need for some of the airborne tests In general, the results of the satellite test program provide experience under conditions which are most representative of operational conditions, even though the final operational equipment or procedures may not be fully employed

The test program described under airborne testing is in large part applicable to satellite testing, but detailed procedures will be affected by the operational environment Collection of data by satellite should be accompanied by simultaneous collection of airborne data and ground truth data

In the early portion of the satellite test program, primary emphasis will be placed on analyzing sensor outputs to determine spectral, polarization, or other characteristics of the incoming radiation and their relationship to the various types of surface materials, and atmospheric and illumination conditions This type of analysis will permit the improvement of interpretation techniques for operational application

In the latter stages of the test program, the emphasis will shift to demonstration and improvement of system performance For these tests, data collected by satellite sensors will be used in a manner simulating operational procedures as closely as conditions permit Data reduction and analysis procedures will be applied to the sensor output data and imagery, and the resulting estimates and forecasts of hydrologic variables compared with ground truth taken during the same test program

APPENDIX B

HYDROLOGICAL MODELS

I HYDROLOGIC DATA

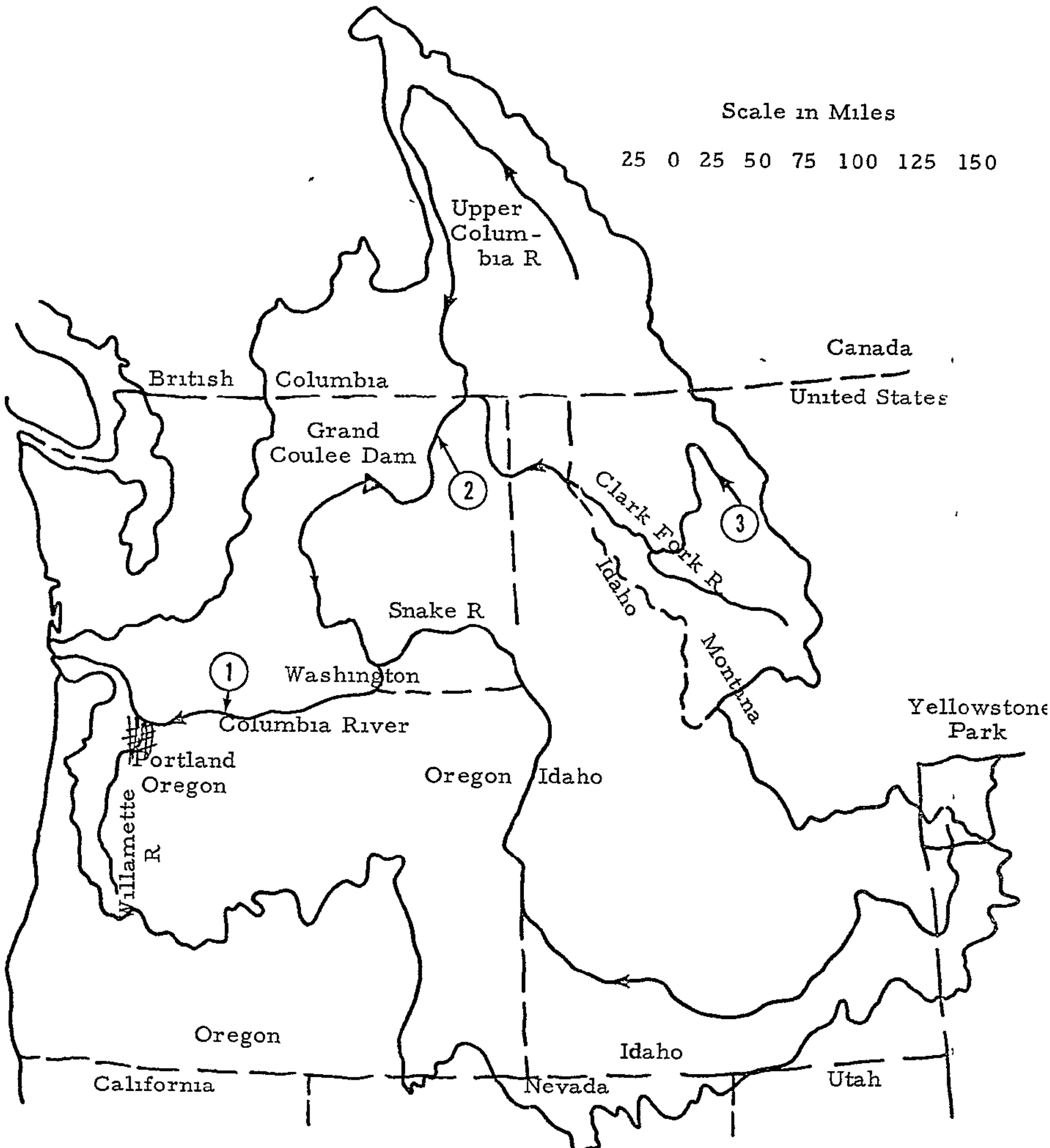
On the basis of their peculiar characteristics, the following subbasins of the Columbia River System were selected for study of hydrological data (1) the Klickitat River Basin, (2) the Colville River Basin, and (3) the South Fork Flathead River Basin upstream from Hungry Horse Dam The illustrations in this part of the hydrology appendix show detailed information on the three selected subbasins Three years of water-year records (1958-59, 1959-60, and 1960-61) were selected for study These years were chosen because they represented relatively wet, dry, and average years of record in the subbasins and total basin

The locations of the three "study basins" are shown in Exhibit B-1 Some major considerations leading to their selection are shown in Exhibit B-2 Average June river travel times from the subbasins and major tributaries of the Columbia River System downstream to Portland, Oregon, are shown in Exhibit B-3

Exhibits 4, a, b, and c, and 5, a, b, and c, are detailed topographic maps of the study basins showing basin boundaries, location of stream gages and weather stations, subdivisions of the basins, and current land use Exhibit B-6 gives geographic characteristics of the three study basins and Exhibit B-7 shows basin subdivisions and their hydrologic characteristics

Exhibit B-8 and Exhibits B-9, a, b, and c, are relevant to the study of basin subdivision, location of snowfall-rainfall areas from a storm over a basin, and to the calculation of snowmelt Exhibit B-8 gives the area-elevation relation from which areas of snow and rain can be determined when the freezing elevation is known Exhibits B-9, a, b, and c, assist in determining the rate of snow melt in each of the study basins

The unit hydrographs for the three basins are shown in Exhibits B-10, a, b, and c



Selected Study Basins

(1) Klickitat River Basin

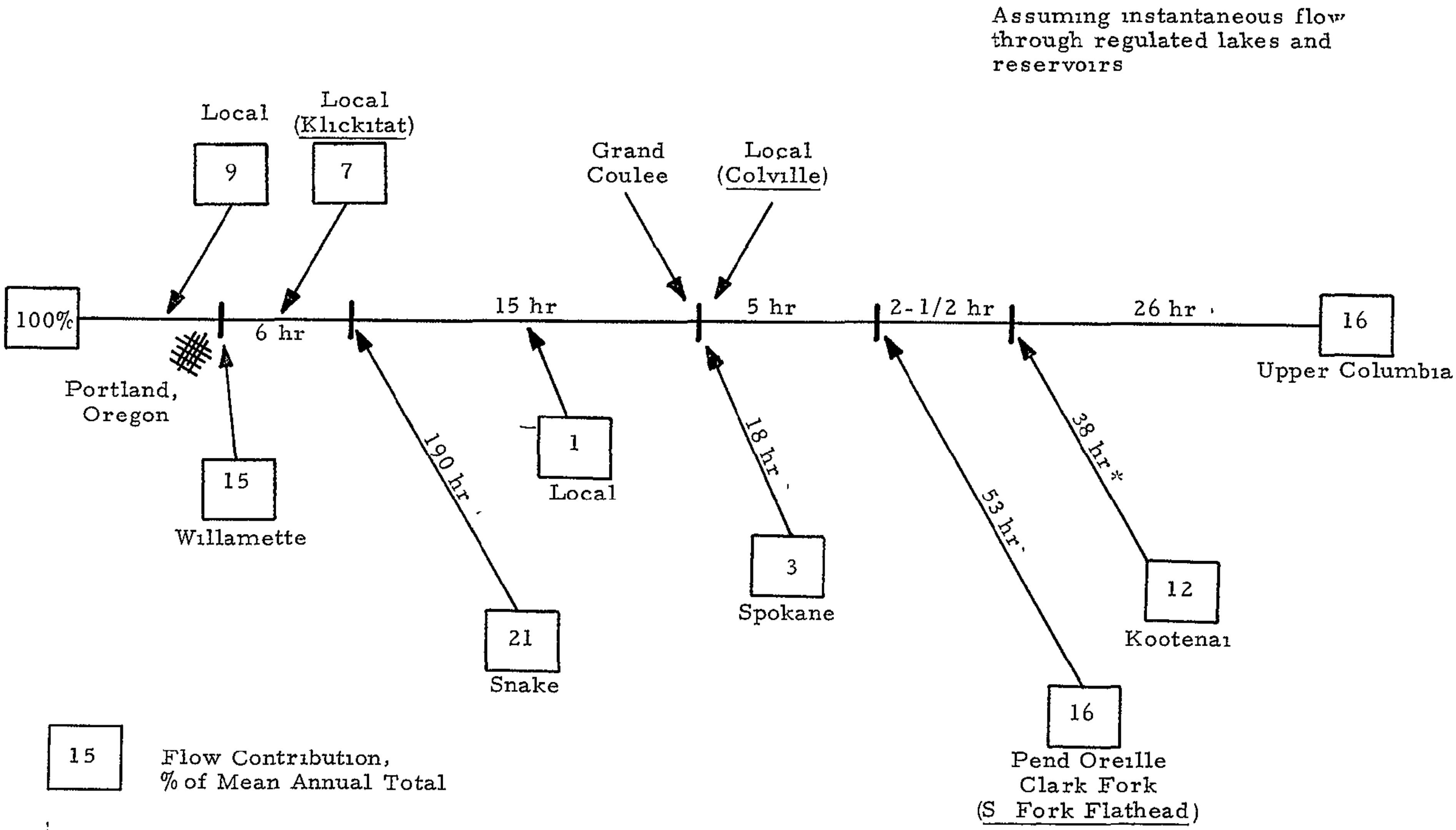
(2) Colville River Basin

(3) South Fork Flathead River Basin (Above Hungry Horse Dam)

EXHIBIT B-1 COLUMBIA RIVER BASIN

EXHIBIT B-2 SUBBASIN SELECTION FACTORS

Klickitat	Colville	South Fork Flathead
Climate of western section	Climate of plateau-central section	Climate of eastern section
Snow and rain, major winter rain runoff	Low precipitation and runoff	Heavy seasonal snow with major spring melt runoff
Tributory to a run-of-the river reservoir	Tributary to an annual reservoir	Tributary to a cyclical reservoir
Winter floods sizeable	Low flood potential	Major contributor to spring floods
Tributary to navigable reach of Columbia River	Contributes local flow to Grand Coulee Dam where recreation, power, and agriculture make demands on the water supply	Major headwaters Power dam on stream



*Tributary travel times are from Headwaters

EXHIBIT B-3 COLUMBIA RIVER AND MAJOR TRIBUTARY TRAVEL TIMES FOR MEAN JUNE FLOWS, 1951-60 AVERAGE

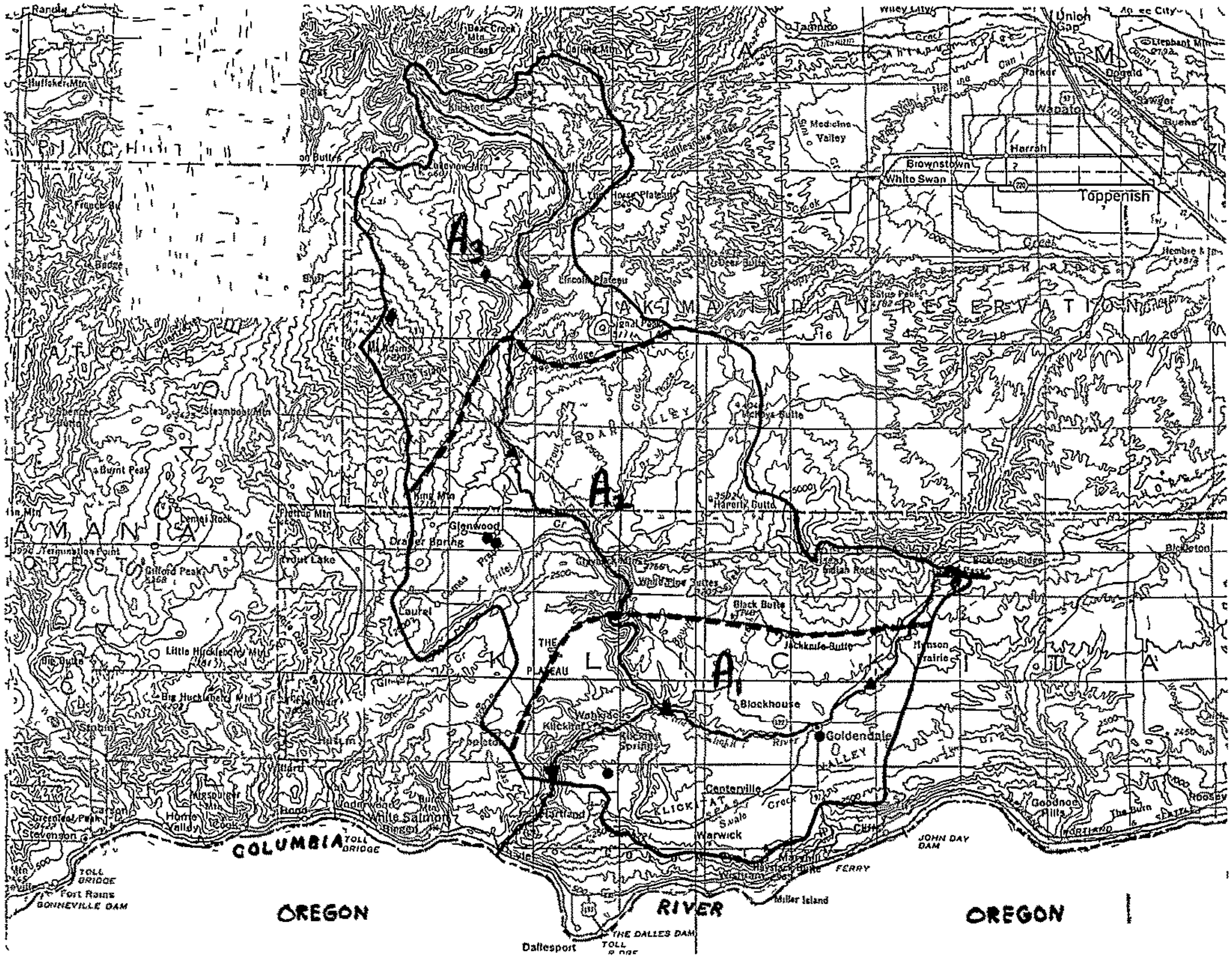


EXHIBIT B-4-a TOPOGRAPHIC MAP OF THE KLICKITAT RIVER BASIN

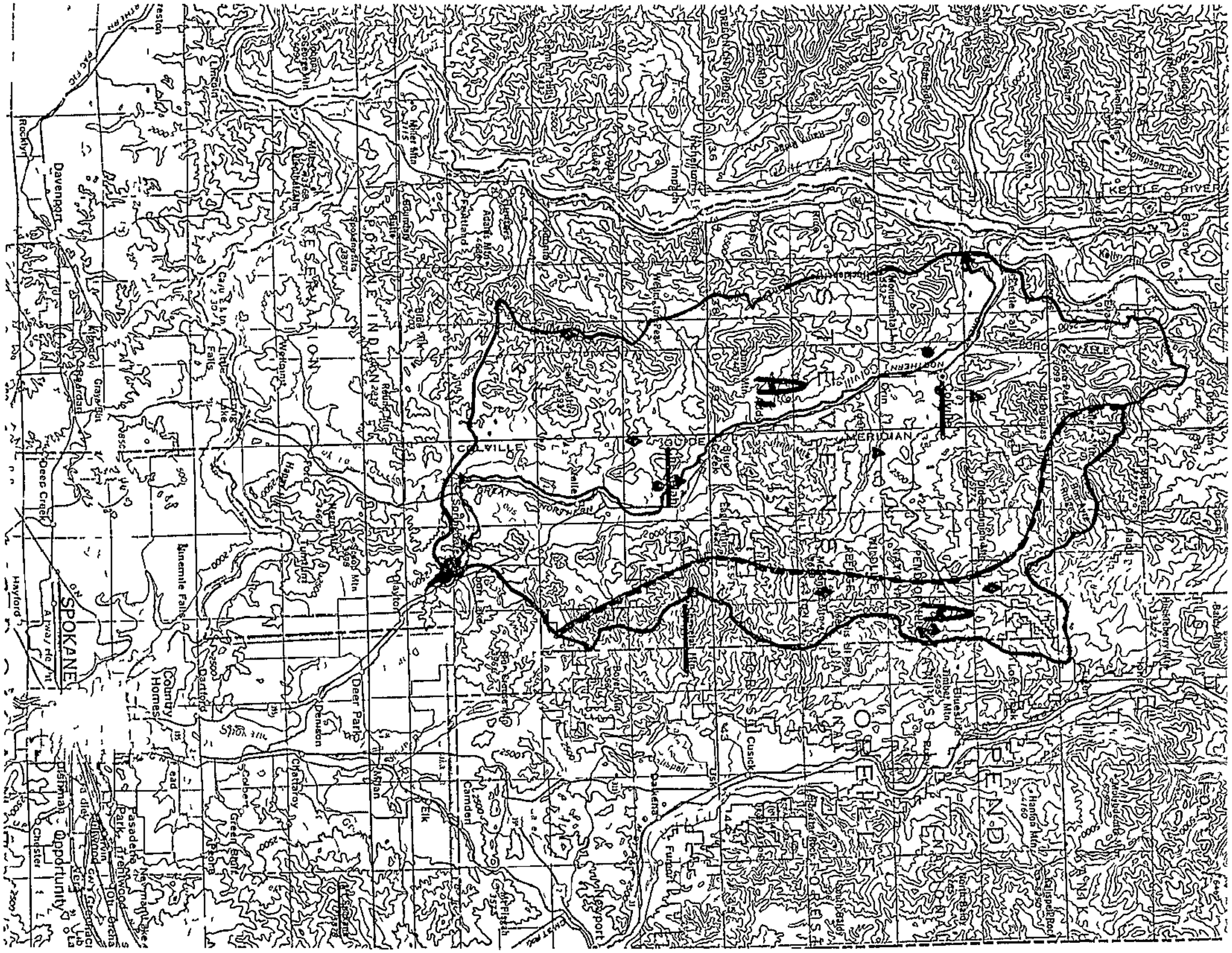


EXHIBIT B-4-b TOPOGRAPHIC MAP OF THE COLVILLE RIVER BASIN

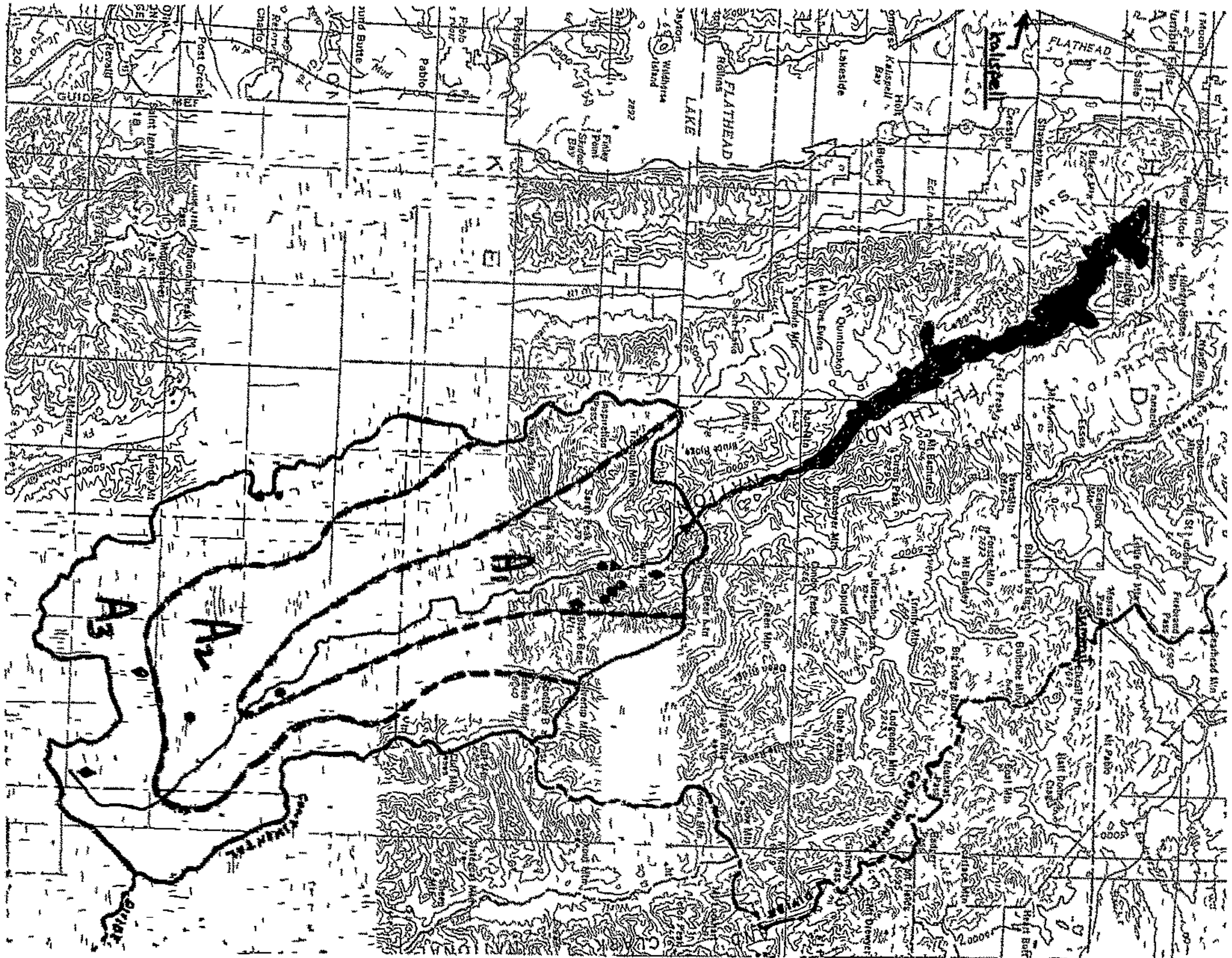


EXHIBIT B-4-c TOPOGRAPHIC MAP OF THE SOUTH FORK RIVER BASIN
(Above Hungry Horse Dam)

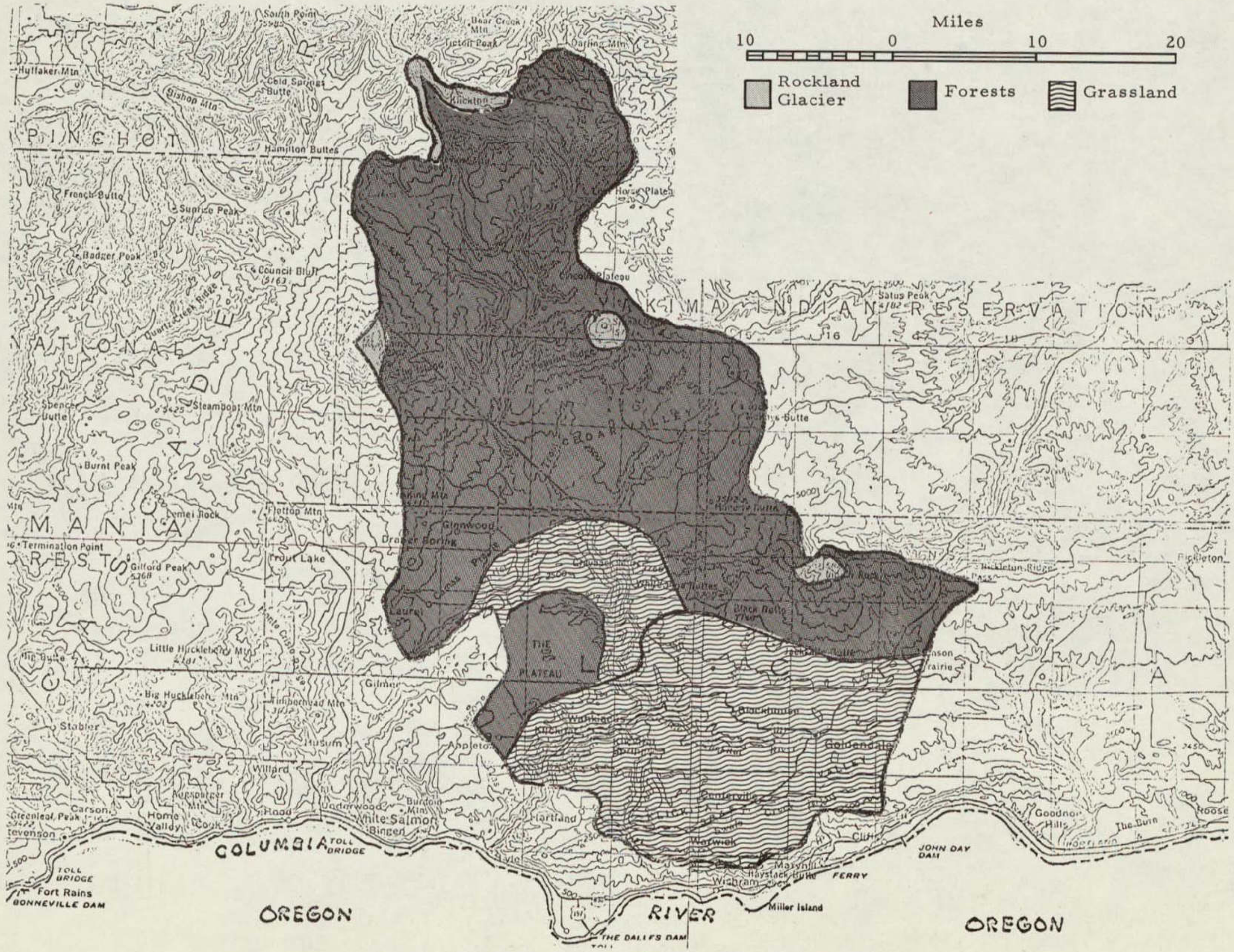


EXHIBIT B-5-a LAND USE - KLICKITAT

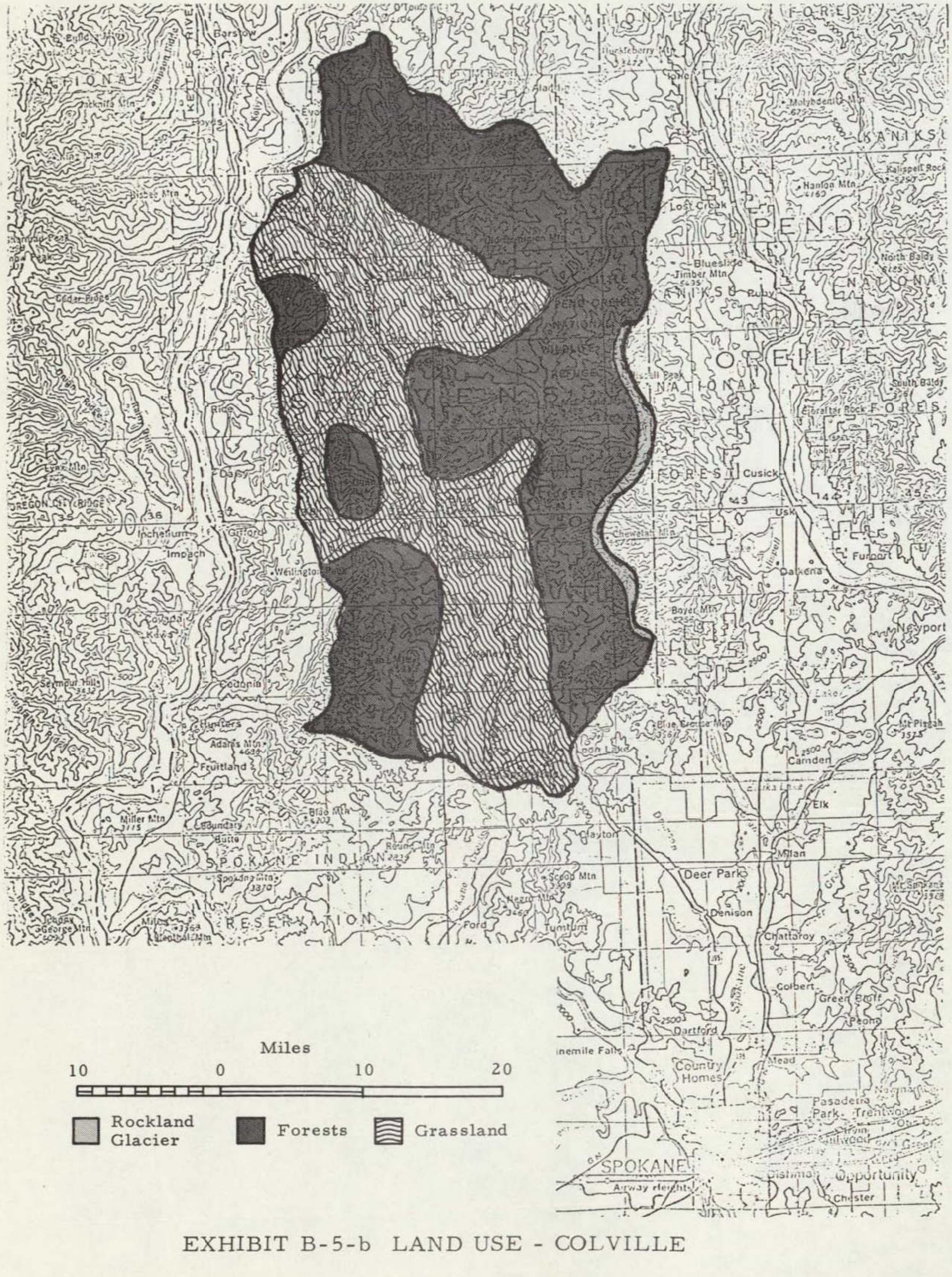


EXHIBIT B-5-b LAND USE - COLVILLE

EXHIBIT B-5-c LAND USE - FLATHEAD

EXHIBIT B-6 GEOGRAPHIC STATISTICS OF SELECTED RIVER BASINS

	Basin		
	Klickitat	Colville	S.F. Flathead
<u>Characteristic</u>:			
(1) Size (Mi^2)	1,290	1,007	958
(2) Land use %			
Forest	81	83	97
Cropland	15	13	1
Grass	3	4	--
Other	1	--	2
(3) Geology	Columbia River Basalts and Cascade Andesite	75% Silurian and Ordovician Limestone 25% Granites and Diorites	Cambrian-Devonian Sediments: shale, limestone, etc.
(4) Soils: All basins are in the "cool to cold, subhumid and humid forested" soils regions	Western Brown Forest	Brown Podzolic Gray Wooded Western Brown Forest	Grey Wooded Brown Podzolic Rockland
(5) Availability of groundwater	Generally unknown, some yields near Goldendale of 100-500 gpm	Mountain areas unknown, valley floor area in north yield 100-500 gpm and in the south yield 500-2,000 gpm	Generally unknown. Some yields on valley floor of 1-20 gpm.
(6) Maximum contribution to stem flow	~10% during large winter storm	≃10% in spring melt	~6% during spring melt at Grand Coulee
(7) Elevation	1,000-12,000 ft.	2,000-5,500 ft.	4,000-8,000 ft.

EXHIBIT B-7 BASIN RUNOFF CHARACTERISTICS

Basins	Range in Elevation, feet	Percent of Basin Data	Unit Graph Peak	Time to Peak	Recession Time Constants, days: Surface Flow	Snow-melt Season	Base Flow	Seasonal Snowmelt	Recession	Fall and Winter Precip
I Klickitat			18,000 cfs at Pitt	1 day	2-3	50	61	Apr - June	July-Oct	Nov - March
Sub-basin A_1	1,000-2,500	29	5,820 cfs	18 hr						
A_2	2,500-4,000	44	7,920 cfs	18 hr						
A_3	3,500-12,000	27	5,460 cfs	24 hr						
II Colville			3,870 cfs at Kettle Falls	4 days	15	26	63	Apr - May	June-Dec	Jan-March
Sub-basin A_1	2,000-4,500	83	3,210 cfs	4 days						
A_2	3,500-5,500	17	660 cfs	4 days						
III Flathead			12,700 cfs at Spotted Bear	1 day	2	19	38	Apr - June	July-Nov	Dec - March
Sub -basin A_1	4,000-6,000	24	2,730 cfs	12 hr						
A_2	5,000-7,000	39	4,950 cfs	24 hr						
A_3	6,000-8,000	37	5,200 cfs	24 hr						

(Column group heading: Basin and Sub-basin Unit Graphs)

Evapotranspiration Recession Factors - all basins 98 Dec, Jan, 94 Feb, Mar, Oct, Nov, 90 Apr, May, Aug, Sept, 85 Jun, July

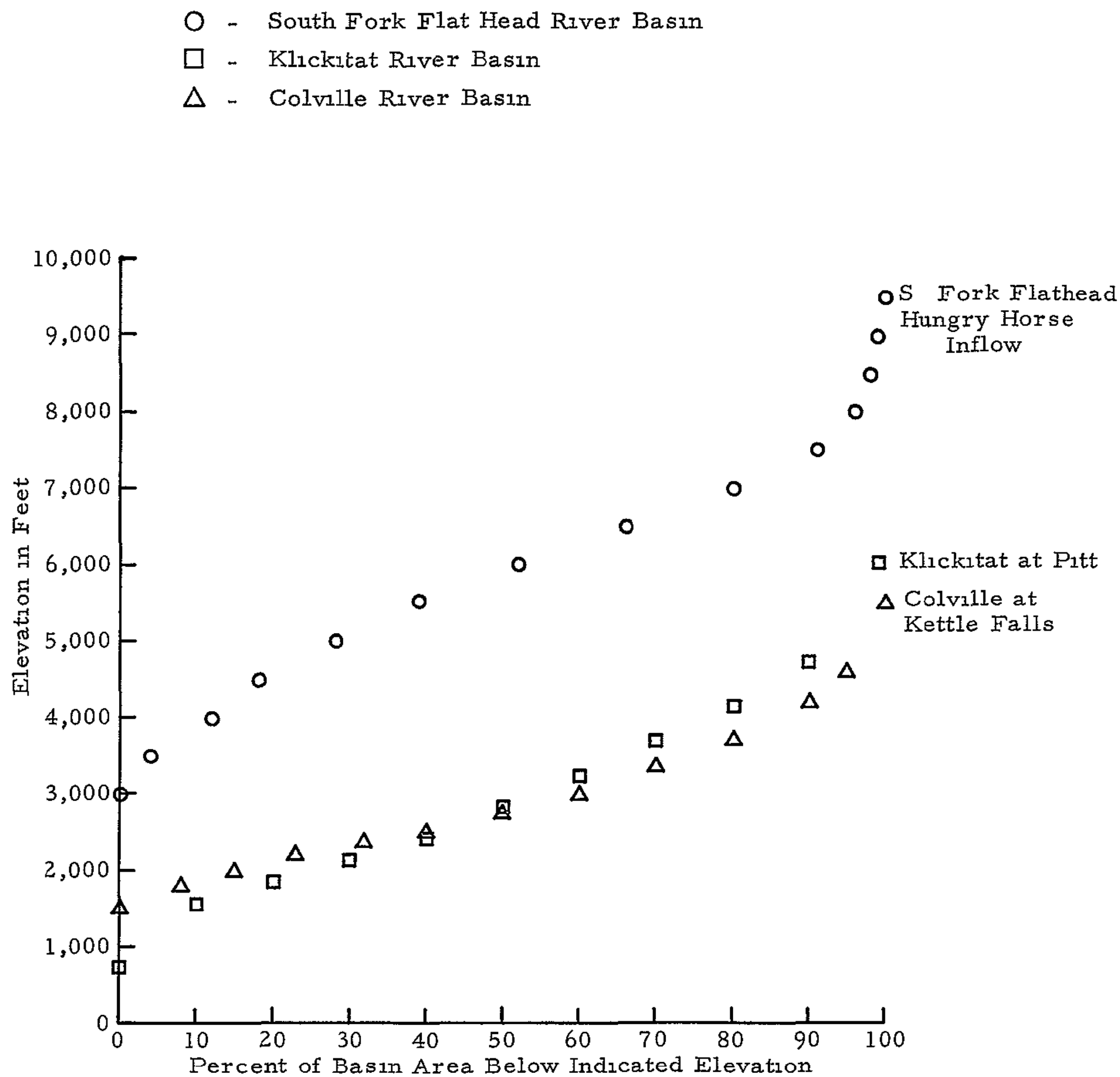


EXHIBIT B-8 AREA-ELEVATION RELATIONSHIPS IN THE STUDY BASINS

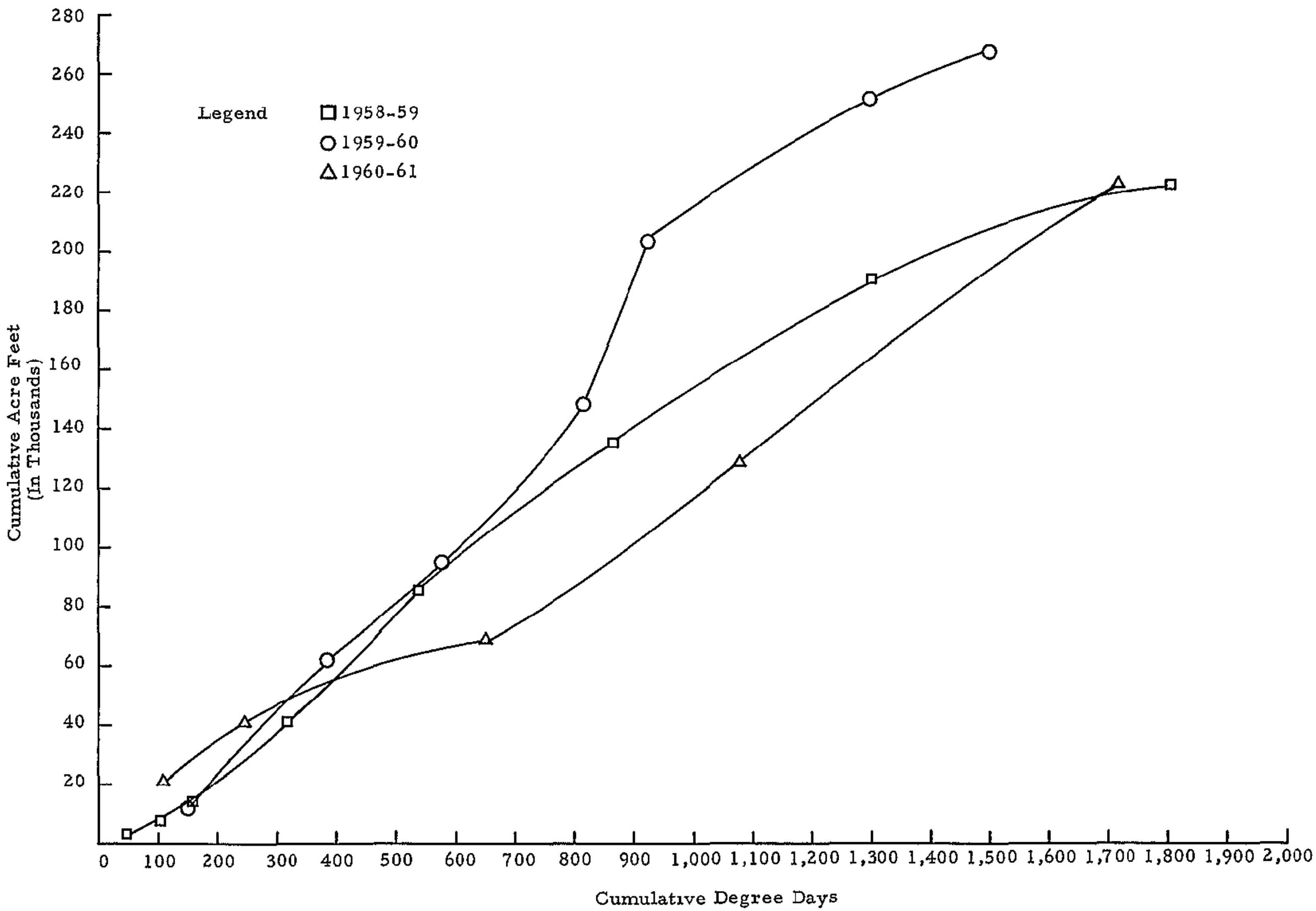


EXHIBIT B-9-a RATE AND AMOUNT OF SNOW MELT - KLICKITAT RIVER BASIN

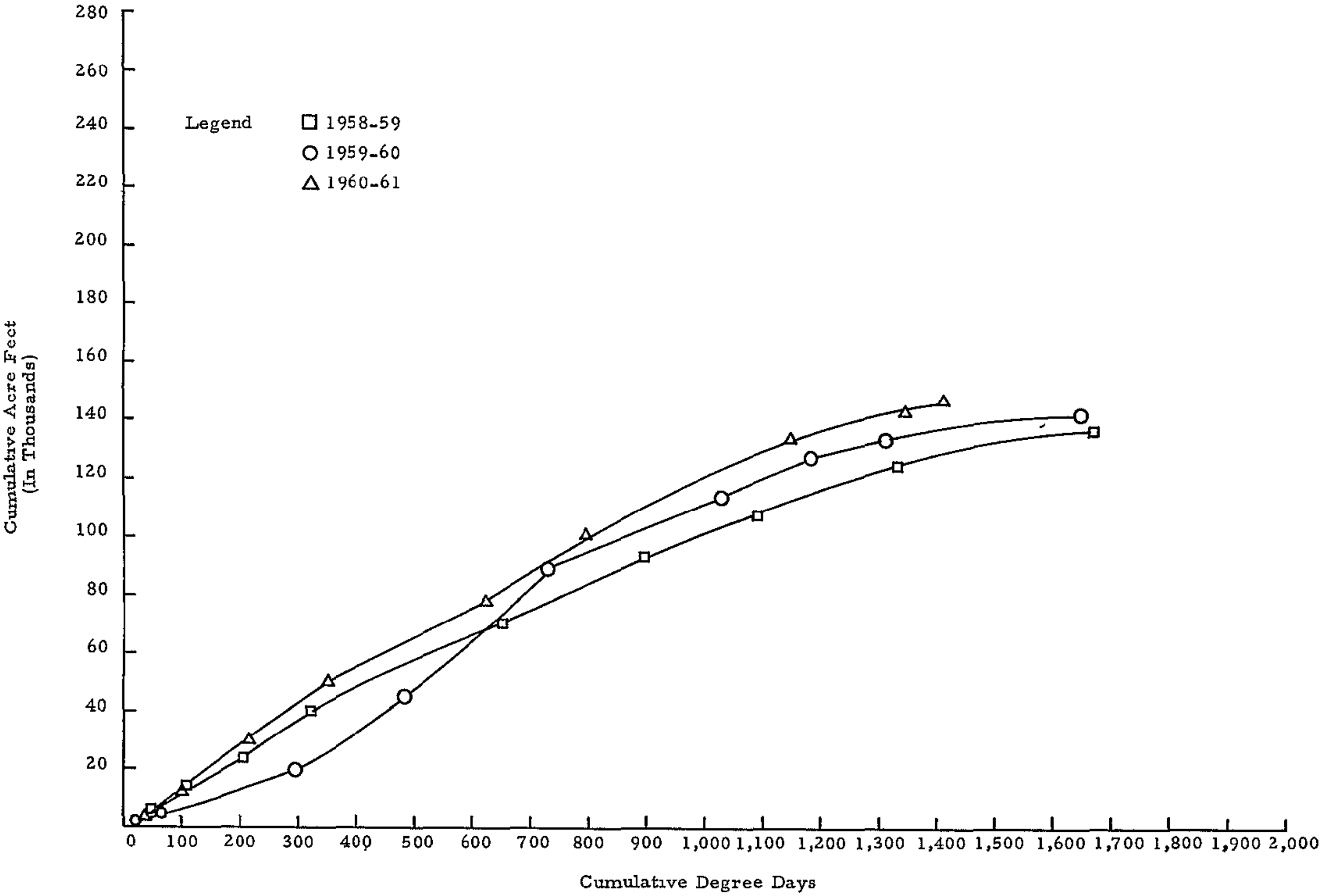


EXHIBIT B-9-b RATE AND AMOUNT OF SNOW MELT - COLVILLE RIVER BASIN

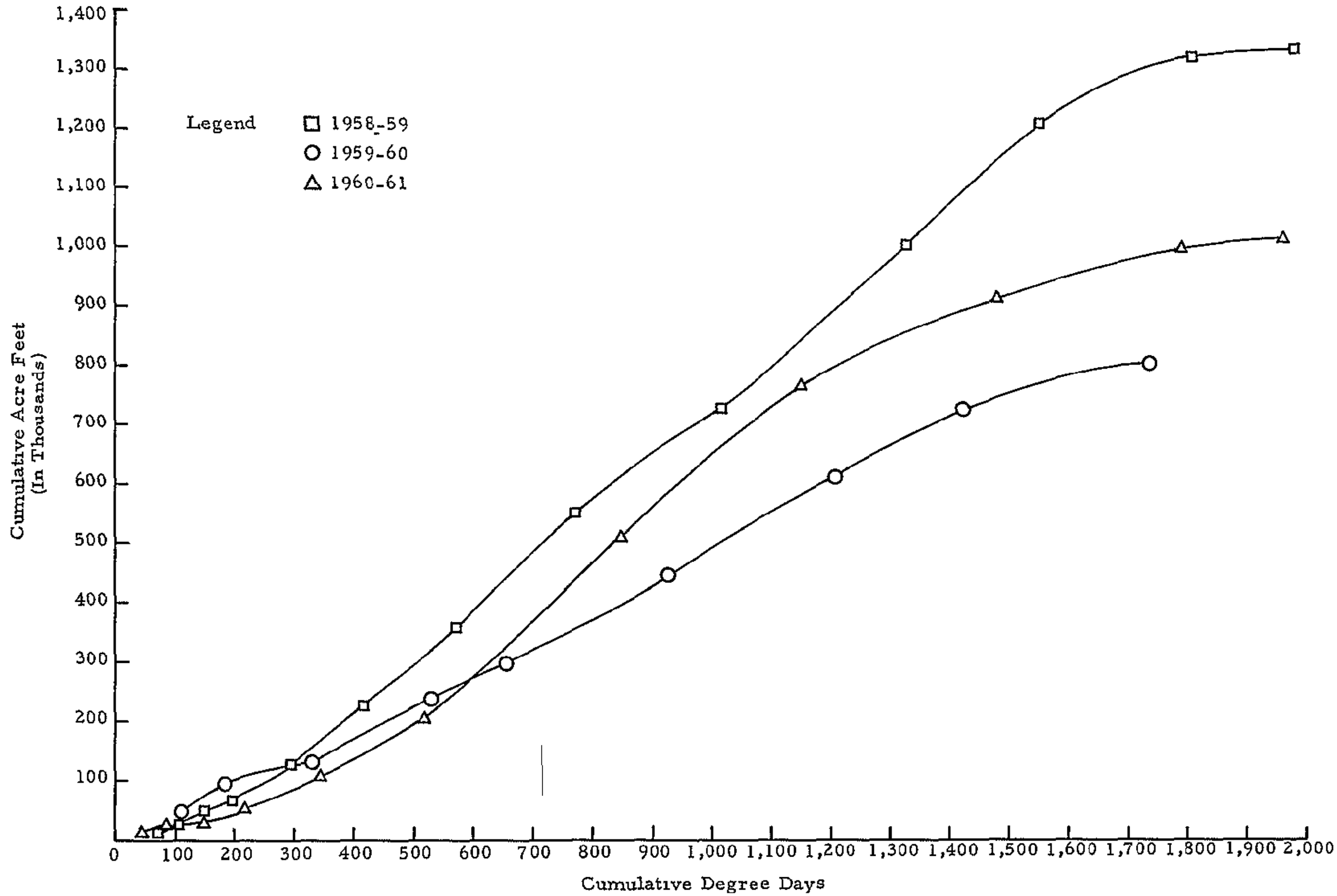
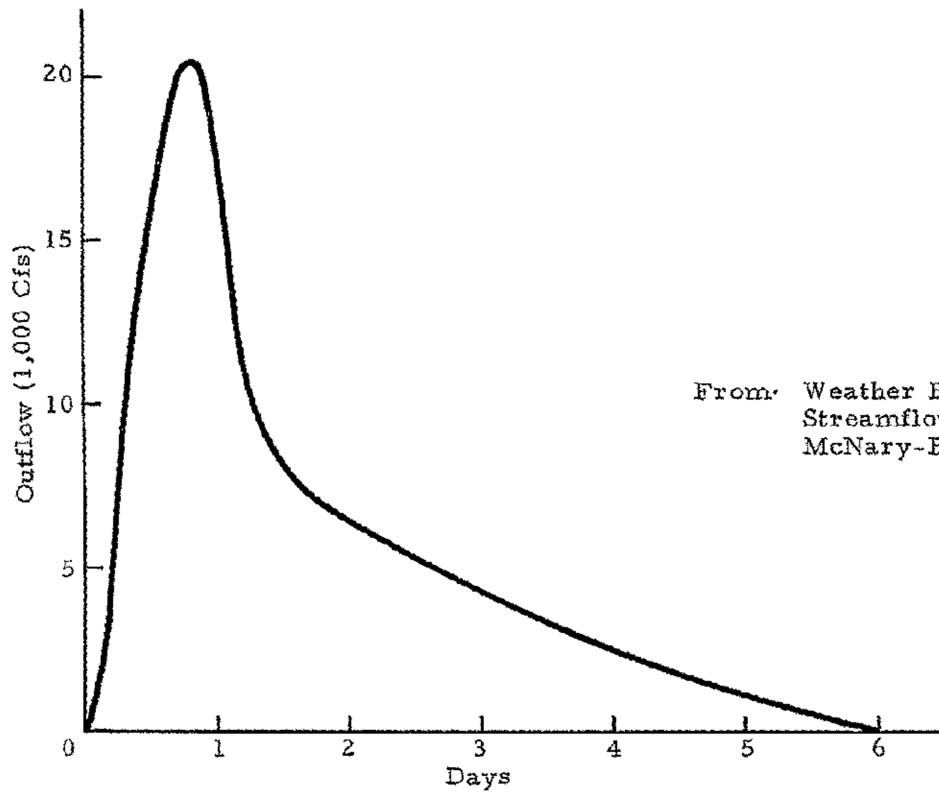


EXHIBIT B-9-c RATE AND AMOUNT OF SNOW MELT - SOUTH FORK FLATHEAD RIVER BASIN



From: Weather Bureau Forecasting Streamflow Study of Local Inflow, McNary-Bonneville, 1963

EXHIBIT B-10-a UNIT HYDROGRAPH - KLICKITAT NEAR PITT

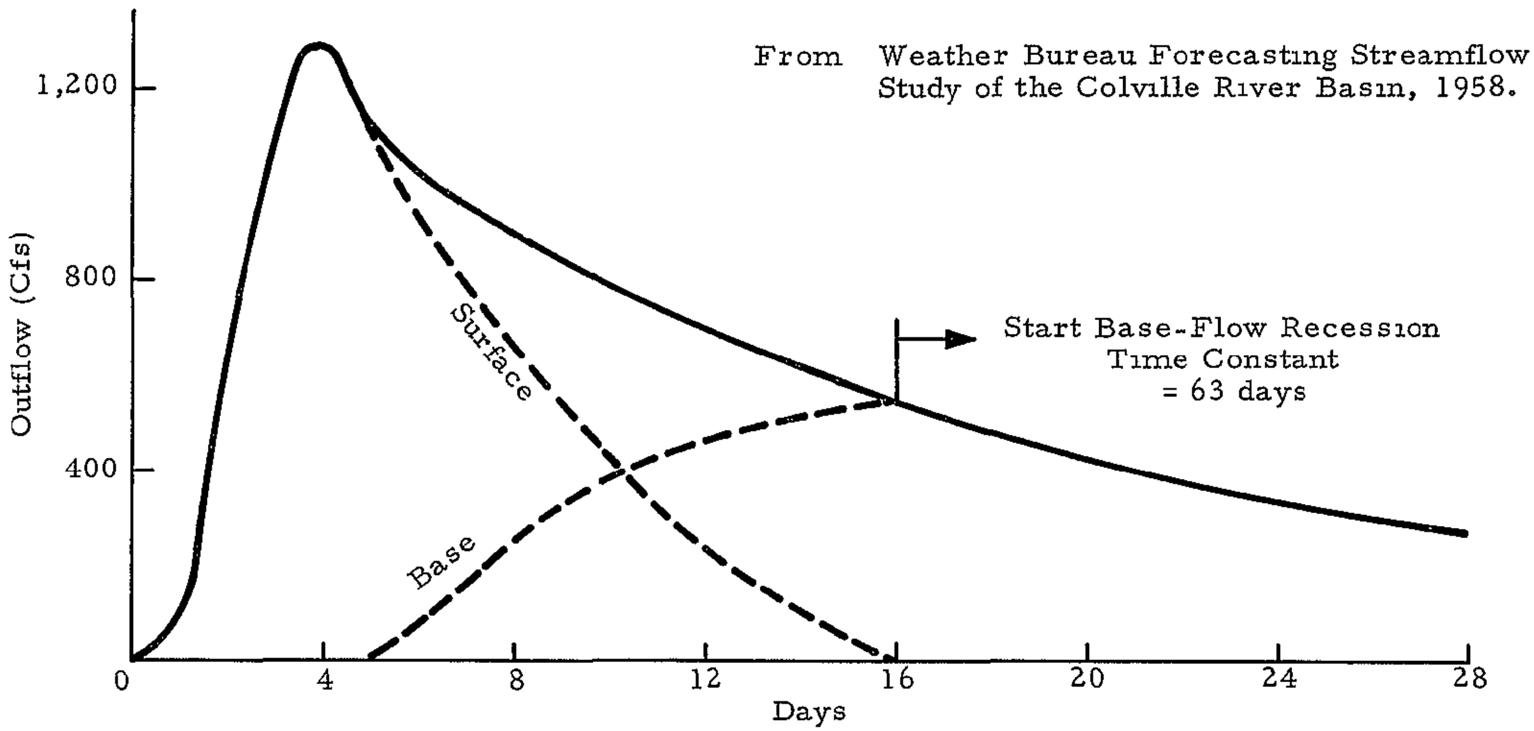


EXHIBIT B-10-b TOTAL AND UNIT HYDROGRAPH - COLVILLE RIVER AT KETTLE FALLS
(24-Hour Storm)

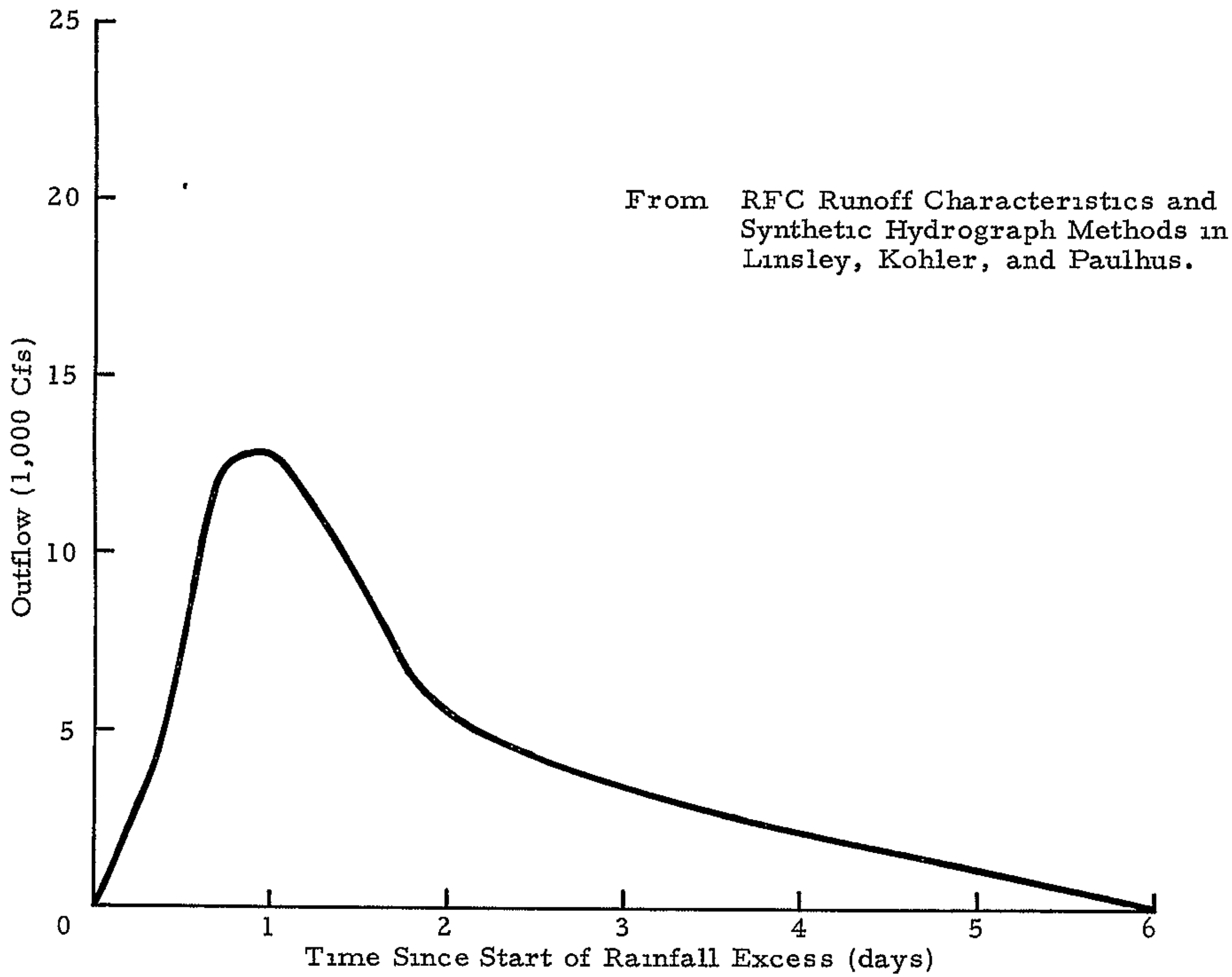


EXHIBIT B-10-c SYNTHESIZED UNIT HYDROGRAPH - SOUTH FORK FLATHEAD RIVER AT SPOTTED BEAR

The unit graphs for the Klickitat and Colville River Basins were obtained from forecasting procedure studies done by the U. S Weather Bureau for the Bonneville Power Authority in Portland, Oregon It was necessary to synthesize the unit graph for the South Fork of the Flathead River Basin because no literature contained such an analysis and no unit storms occurred during the three years of study that produced a significant response on the hydrograph

The synthetic unit hydrograph was developed through the use of the basin routing constants of the Columbia River Forecast Center in Portland, Oregon, for the South Fork of the Flathead River The routing constants of the surface and subsurface components of flow were then used in conjunction with a dimensionless unit hydrograph[1] to obtain an estimated unit hydrograph

Recent summaries of streamflow out of the selected study basins are given in Exhibits B-11, a, b, and c These data are from the surface water records of the U S. Geological Survey appearing in Water Supply Papers, numbers 1736 and 1738

An approximate disposition of the annual precipitation in each of the three study basins is shown in Exhibits B-12, a, b, and c

Exhibits B-13, a, b, and c, show the hydrologic data in each study basin that appear in the Hydromet summary charts, Exhibits B-14 a, b, and c, and B-15, a, b, and c, and B-16, a, b, and c

Data for the hydrographs appearing in these Hydromet summary charts were obtained from the Surface Water Records of the U S Geological Survey

Daily streamflow records were available for eight of the nine basin-years of the study, the exception being the 1958-59 water year for the South Fork of the Flathead River at Spotted Bear The missing

---

[1] R K Linsley, M A Kohler, and J L Paulhus, Hydrology for Engineers, page 208, McGraw-Hill, New York, 1958

EXHIBIT B-11-a STREAMFLOW-KLICKITAT

1130 Klickitat River near Pitt, Wash

Location --Lat 45°45'30" long 121°12'30" in SW¼ sec 8 T 3 N , R 13 E on left bank 3½ miles south of Pitt, 5 miles upstream from Silvias Creek and 7 miles upstream from mouth at Lyle

Drainage area --1,290 sq mi approximately

Records available --July 1909 to January 1912 October 1928 to September 1960 Published as "at Klickitat" 1909-12 and as "at Pitt" 1928-35

Gage --Water-stage recorder Datum of gage is 288 9 ft above mean sea level (river-profile survey) July 3 1909 to Jan 31, 1912 staff gage at Klickitat just downstream from Snider Creek 7 miles upstream at different datum Oct 1 1928 to Sept 30, 1935 staff gage at site 175 ft downstream from highway bridge at Pitt 3 5 miles upstream from present site at different datum

Average discharge --34 years (1909-11 1928-60), 1 591 cfs (1 152 000 acre-ft per year)

Extremes --1909-12 1928-60 Maximum discharge 25,500 cfs Dec 22, 1933 (gage height, 12 50 ft site and datum then in use from graph based on gage readings), from rating curve extended above 3 400 cfs on basis of velocity-area study and gage-height curve of relation, minimum, 466 cfs Feb 4, 1937

Remarks --Several small diversions above station for irrigation of about 7,500 acres, mostly in vicinity of Glenwood The largest of these is Hellroaring Irrigation Canal which at times diverts the entire flow of Hellroaring Creek a tributary of Big Muddy Creek No regulation Records of water temperatures are published in reports of Geological Survey

Monthly and yearly mean discharge in cubic feet per second

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	1 069	1 856	3 973	3 800	4 341	2 858	4 161	3 957	2 416	1 342	981	896	2 665
1952	1 109	1 116	1 700	1 097	3 352	1 906	3 173	3 042	1 899	1,216	901	778	1 766
1953	744	766	831	4 210	3 250	1 6[illegible]	1 943	2 861	2 195	1 385	868	748	1 781
1954	747	870	1 510	1 75	2 941	2 779	3 398	3 348	2 619	1 833	1 041	874	1 969
1955	904	1 047	936	932	935	1 018	1 478	2 025	2 539	1 335	844	763	1 230
1956	972	1 825	4 231	3 773	1 940	3 030	4 926	5 235	3 595	1 963	1,208	1 027	2 815
1957	903	915	1 175	867	1 214	2 730	2 498	2 926	1 519	967	769	711	1 435
1958	796	766	1 204	2 072	3 889	2 036	2 361	3 374	1 928	1 097	842	764	1 747
1959	789	1 400	1 700	2,655	1 757	1 676	2 201	2 099	1 876	1 113	800	867	1 576
1960	1 118	1 1[illegible]	974	803	1 562	1 857	2 [illegible]56	2 470	2 140	1 075	785	712	1 437

Monthly and yearly discharge in acre-feet

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	65 700	110 400	244 300	233 700	268 900	175 700	247 600	243 300	143 700	82 490	60 290	53 340	1 929 000
1952	68 160	6[illegible] 390	[illegible]04 500	[illegible]7 440	192 800	[illegible]17 200	168 800	187 0[illegible]	[illegible]13 000	74 800	55 420	46 270	1 282 000
1953	45 770	45 590	51 [illegible]	258 900	190 [illegible]	102 200	[illegible]5 600	75 900	[illegible] 600	85 170	53 [illegible]	44 530	1 289 000
1954	45 910	51 740	92 970	108 000	163 300	70 900	202 200	205 900	[illegible]5 800	12 700	64 020	51 990	1 425 000
1955	55 600	62 270	57 540	57 320	51 950	62 610	87 930	124 500	151,100	32 060	51 910	45 390	890 200
1956	59 760	108 600	260 200	232 000	111,600	186 300	293 100	321 900	213 900	120 700	74 260	61 110	2 043 000
1957	55 5[illegible]0	54 450	72 250	53 280	67 420	167 900	148 700	179 900	90 330	59 [illegible]90	47 270	42 [illegible]00	1 039 000
1958	48 950	45 570	7[illegible] 030	127 400	216 000	125 200	140 500	207 500	[illegible]14 700	67 460	51 760	45 470	1 265 000
1959	48 510	83 310	104 500	[illegible]63 200	97 590	103 100	131 000	129 100	11[illegible] 600	68 410	49 180	51 580	1 [illegible]41 000
1960	68 760	67 220	59 900	49 400	89 830	114 200	153 [illegible]	151 900	127 300	66 110	48 260	42 360	1 043 000

Yearly discharge in cubic feet per second

Year	WSP	Water year ending Sept 30							Calendar year		
		Momentary maximum		Minimum day	Mean	Per square mile	Runoff		Mean	Runoff	
		Discharge	Date				Inches	Acre-feet		Inches	Acre-feet
1950	-	-	-	-	-	-	-	-	2 332	24 [illegible]4	1 [illegible]39 000
1951	1218	12 400	Feb 1 1951	770	2 665	2 07	28 05	1 929,000	2 415	25 43	1 748 000
1952	1248	13 500	Feb 4 1952	742	1 766	1 37	18 63	1 282 000	1 633	17 22	1 [illegible]55 000
1953	1288	10 900	Jan 9 1953	697	1 781	1 38	18 75	1 289 000	1 847	19 45	337 000
1954	1348	7 980	Feb 21 1954	71[illegible]	1 969	1 53	20 72	1 425 000	1 948	20 51	1 4[illegible]0 000
1955	1398	4,020	June 1 1955	702	1 230	953	12 95	890 200	1 579	16 62	1 143 000
1956	1448	19,800	Dec 22 1955	728	2 815	2 18	29 70	2 043 000	2 476	26 12	1 797 000
1957	1518	6,800	[illegible] 9 1957	673	1 4[illegible]5	1 11	15 09	1 039 000	1 416	14 89	1 025 000
1958	1568	7,410	Feb 16 1958	693	1 747	1 35	18 38	1 265 000	1 840	19 37	1 332 000
1959	1638	6,470	[illegible] 12 1959	719	1 576	1 22	16 58	1 41 000	1 520	15 99	1 101 000
1960	1718	5,530	Mar 30 1960	676	1 437	1 11	5 18	1 043 000		-	-

Note U S G S Water Supply Paper No 1738

EXHIBIT B-11-b STREAMFLOW-COLVILLE

4090 Colville River at Kettle Falls, Wash

Location --Lat 48°35'40" long 118°03'30" in sec 29 T 36 N , R 38 E on right bank 600 ft downstream from Washington Water Power Co 's plant (revised) at foot of Meyers Falls, half a mile south of town of Kettle Falls, and 2 miles upstream from Franklin D Roosevelt Lake

Drainage area --1 007 sq mi (revised)

Records available --October 1922 to September 1960 Published as "at Meyers Falls" 1922-38

Gage --Water-stage recorder Altitude of gage is 1 500 ft (from topographic map) Prior to Oct 21, 1932 staff gage at site 500 ft upstream at different datum Oct 21, 1932 to Sept 19, 1938 staff gages at site 200 ft upstream at different datum Sept 20 1938 to Mar 20, 1949, staff gage at present site and datum

Average discharge --38 years (1922-60) 297 cfs (215 000 acre-ft per year)

Extremes --1922-60 Maximum discharge 3 230 cfs Apr 23 1956 (gage height 10 17 ft), minimum observed 0 5 cfs Aug 15 1930

Remarks --Several ditches above station divert water for irrigation Prior to Apr 30, 1960 slight regulation for power by small reservoir above falls

Monthly and yearly mean discharge in cubic feet per second

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	157	233	385	455	727	823	1 801	1 098	388	184	113	129	538
1952	192	201	266	259	405	642	1 878	1,083	398	232	133	128	483
1953	137	157	194	338	328	348	581	904	589	208	114	113	334
1954	126	149	184	163	319	420	653	648	385	175	95 1	128	286
1955	127	156	144	151	149	183	554	867	420	272	121	96 5	271
1956	137	140	205	341	269	725	2 128	1 137	380	199	136	132	493
1957	147	149	161	141	202	395	477	787	447	159	98 3	88 6	271
1958	137	152	178	223	608	895	1 421	849	321	168	85 1	99 5	426
1959	126	158	180	392	296	540	1,006	947	580	197	110	154	390
1960	183	205	218	199	338	590	1 459	1 074	553	189	136	134	439

Monthly and yearly discharge in acre-feet

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	9 660	13 870	23 650	27 950	40 350	50 620	107 200	67 530	23 110	11 280	6 950	7 680	389 800
1952	11 780	11,940	16 360	15 950	23 280	39 470	111,800	66 610	23 660	14 250	8 150	7 620	350 900
1953	8,450	9 370	11 920	20 800	18 210	21 420	34 570	55 580	35 020	12,800	6 980	6 720	241,800
1954	7,760	8 890	11 320	10 020	17 710	25 830	38 860	39 850	2_ 900	10 760	5 850	7 590	207,300
1955	7,830	9 290	8 850	9 290	8 270	11 250	32 950	53 290	24 980	16 730	7 430	5 740	195,900
1956	8,440	8 350	12 630	20 990	15 480	44 560	126 600	69 920	22 630	12 250	8 360	7 830	358 000
1957	9 020	8 8°0	9 920	8 660	11 200	24 270	28 380	48 370	26 600	9 760	6 050	5,270	196 400
1958	8 430	9 030	10,930	13 720	33 780	55 050	84 560	52 200	19 120	10,320	5 230	5 920	308,300
1959	7 750	9 420	11 080	24 090	16 420	33 220	59 870	58 240	34 490	12 120	6 730	9 140	282 600
1960	11 230	12 190	13 400	12 250	19 420	36 2-0	86 840	66 010	32 890	11 640	8,350	7 950	318,400

Yearly discharge in cubic feet per second

Year	WSP	Water year ending Sept 30					Calendar year	
		Momentary maximum		Minimum day	Mean	Acre-feet	Mean	Acre-feet
		Discharge	Date					
1950	-	-	-	-	-	-	390	282,_00
1951	1216	2,240	Apr 14 15 1951	85	538	389 800	529	382 800
1952	1246	2 550	Apr 21 1952	110	483	350 900	469	340 500
1953	1286	1 660	Apr 30, 1953	95	334	241 800	332	240 100
1954	1346	1 050	May 13 1954	58	286	207,300	284	205,300
1955	1396	990	May 22 1955	78	271	195 900	275	199,400
1956	1446	3 230	Apr 23 1956	81	493	358 000	491	356 400
1957	1516	1 590	May 21 1957	78	271	196 400	272	197 000
1958	1566	1 750	Mar 2 1958	66	426	308 300	426	308,200
1959	1636	1 120	Apr 15 1959	75	390	282 600	402	291,100
1960	1716	2 300	Apr 29 1960	112	439	318,400	-	-

Note U S G S Water Supply Paper No 1736

EXHIBIT B-11-c STREAMFLOW-SOUTH FORK FLATHEAD

3590 South Fork Flathead River at Spotted Bear ranger station near Hungry Horse Mont

Location --Lat 47°55'20" long 113°31'25" in SE¼SW¼ sec 17 T 25 N R 15 W , on left bank 600 ft south of Spotted Bear ranger station 1 000 ft upstream from Spotted Bear River, and 40 miles southeast of Hungry Horse

Drainage area --958 sq mi

Records available --August 1948 to September 1957, August 1959 to September 1960

Gage --Water-stage recorder Altitude of gage is 3,670 ft (from river-profile map)

Average discharge --10 years (1948-57 1959-60) 1,954 cfs (1 415,000 acre-ft per year)

Extremes --1948-57, 1959-60 Maximum discharge 21,200 cfs June 2, 1956, maximum gage height 12 75 ft May 20 1954, minimum discharge, less than 121 cfs Dec 26, 1952 (stage below intake pipes)
Flood in May to June 1948 reached a stage of 14 00 ft about May 22 (discharge, 22,000 cfs by slope-area measurement of peak flow)

Remarks --No regulation or diversion above station

Monthly and yearly mean discharge in cubic feet per second

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	977	1,175	1 011	672	883	488	2 473	7 996	6 210	3 993	961	682	2 284
1952	956	635	464	352	323	320	3 331	7 469	4 732	1 450	558	337	1,746
1953	237	197	202	393	385	354	1 398	5 510	9 776	3 466	773	390	1,925
1954	271	282	290	241	303	390	1 305	9 171	8 535	5 362	962	594	2,321
1955	739	628	398	282	235	236	610	4,405	8 862	3 125	743	374	1 722
1956	489	427	459	382	284	390	2 484	8,878	8 716	2,027	678	394	2 135
1957	386	369	401	262	271	303	926	8 817	5 356	1,243	482	294	1 602
1958													
1959	-	-	-	-	-	-	-	-	-	-	-	941	-
1960	2,217	1 365	863	485	383	760	2 560	4 271	7 617	2 167	655	399	1 976

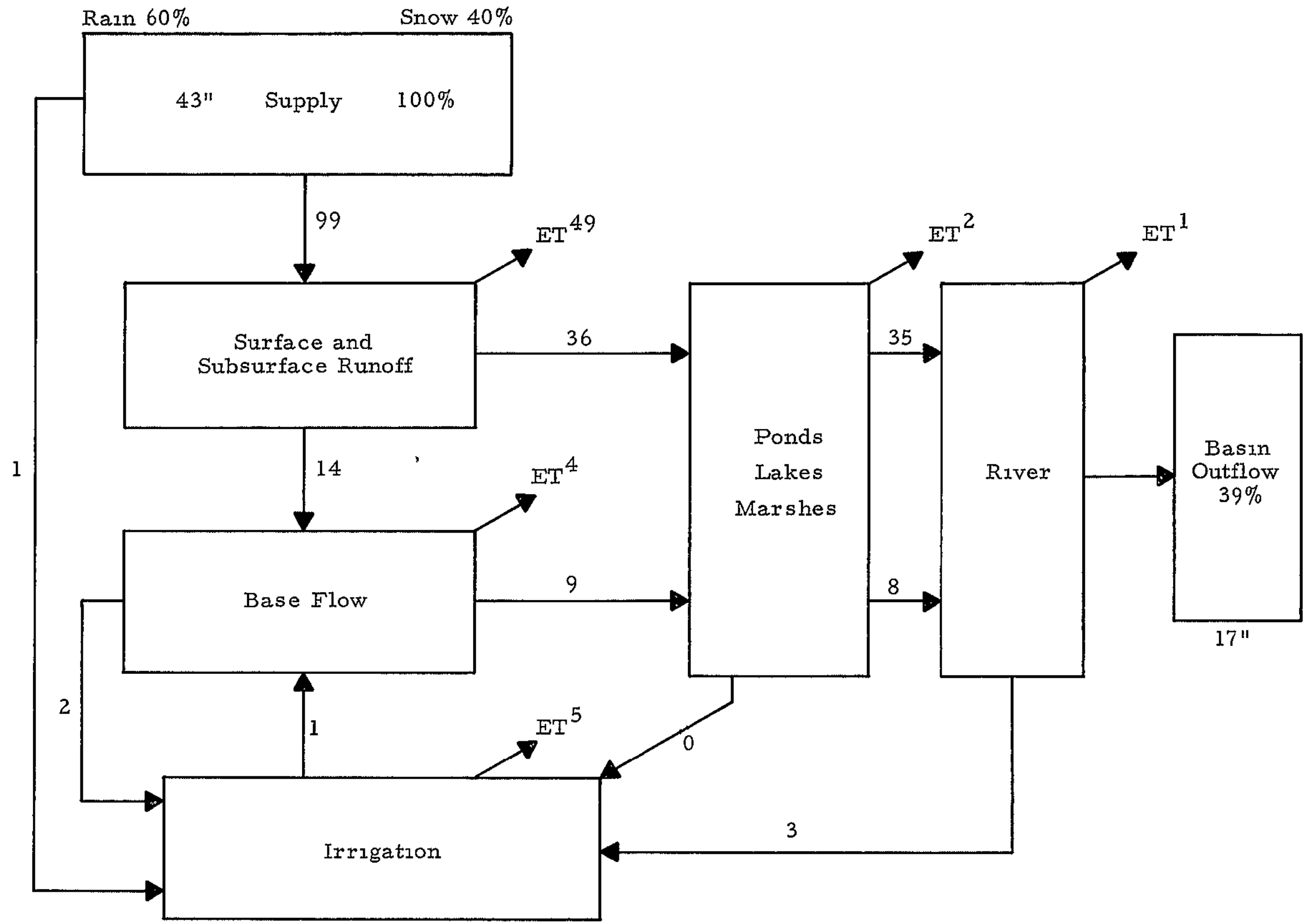
Monthly and yearly discharge in acre-feet

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	The year
1951	60 070	69 930	62 180	41 350	49 020	29 990	147 100	491 700	369 500	23 200	59 070	40 600	1 654 000
1952	58 770	37,770	28 530	21 640	18 600	19 680	198 200	459 300	281 600	89 150	34 330	20 050	1 268 000
1953	14 580	11 730	12 430	24 170	21 390	21 790	83 170	338 800	581 700	213 100	47,550	23 200	1 394 000
1954	16 670	16,780	17 840	14 790	16 850	24 000	77 670	563 900	507 900	329 700	59 150	35 370	1 681 000
1955	45 470	37 350	24 460	17 320	13 040	14 530	36 270	270 800	527,300	192 200	45,680	22 240	1,247 000
1956	30 090	25 410	28 220	23 500	16 340	23 980	147 800	545,900	518 700	124,700	41 680	23 410	1 550 000
1957	23 700	21,930	24,680	16 110	15 070	18 630	55 110	542 100	318,700	76 450	29 650	17 470	1 160 000
1958													
1959	-	-	-	-	-	-	-	-	-	-	-	55 970	-
1960	136,300	81 220	53 040	29,820	22 040	46 760	152 300	262 600	453 200	133 200	40 250	23,730	1 434,000

Yearly discharge in cubic feet per second

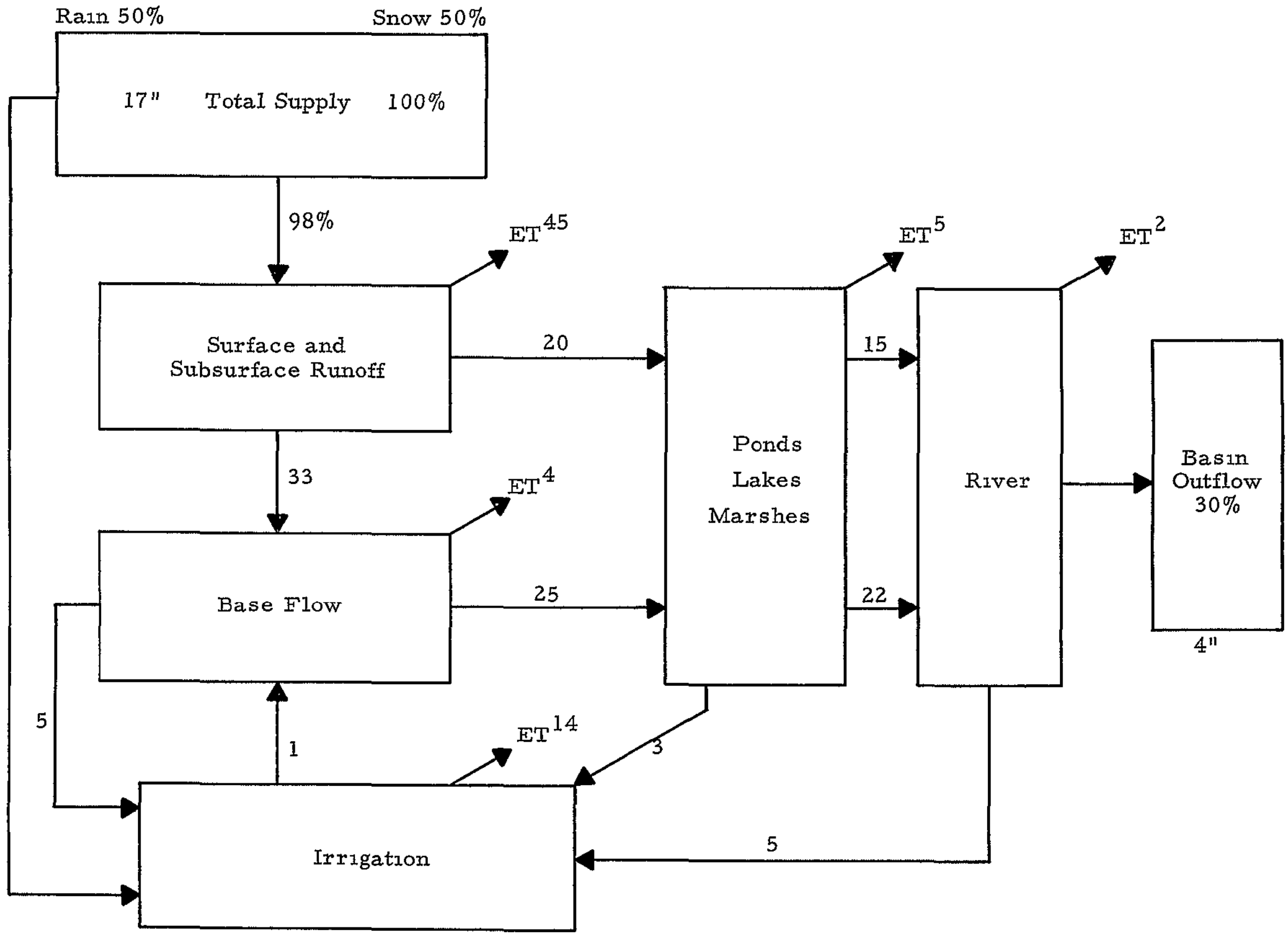
Year	WSP	Water year ending Sept 30								Calendar year		
		Momentary maximum		Minimum day	Mean	Per square mile	Runoff			Mean	Runoff	
		Discharge	Date				Inches	Acre-feet			Inches	Acre-feet
1950	-	-	-	-	-	-	-	-		2 502	35 43	1 811 000
1951	1216	14 200	May 12 1951	280	2 284	2 38	32 37	1 654 000		2 192	31 05	1 587 000
1952	1246	12 000	Apr 28 1952	240	1 746	1 82	24 80	1 268 000		1 627	23 10	1 181 000
1953	1286	17 700	June 13 1953	130	1 925	2 01	27 26	1 394 000		1 942	27 52	1 406 000
1954	1346	21,000	May 20 1954	150	2 321	2 42	32 90	1 681 000		2 399	33.99	1 737 000
1955	1396	13 800	June 14, 1955	170	1 722	1 80	24 40	1,247,000		1 689	23 94	1 223 000
1956	1446	21,200	June 2 1956	170	2 135	2 23	30 33	1 550 000		2 116	30 06	1 536 000
1957	1516	13 200	May 5 1957	220	1 602	1 67	22 70	1 160,000		-	-	1,536 000
1958												
1959	1716	-	-	-	-	-	-	-		-	-	-
1960	1716	16 200	June 4 1960	250	1 976	2 06	28 08	1 434 000		-	-	-

Note U S G.S Water Supply Paper No 1736



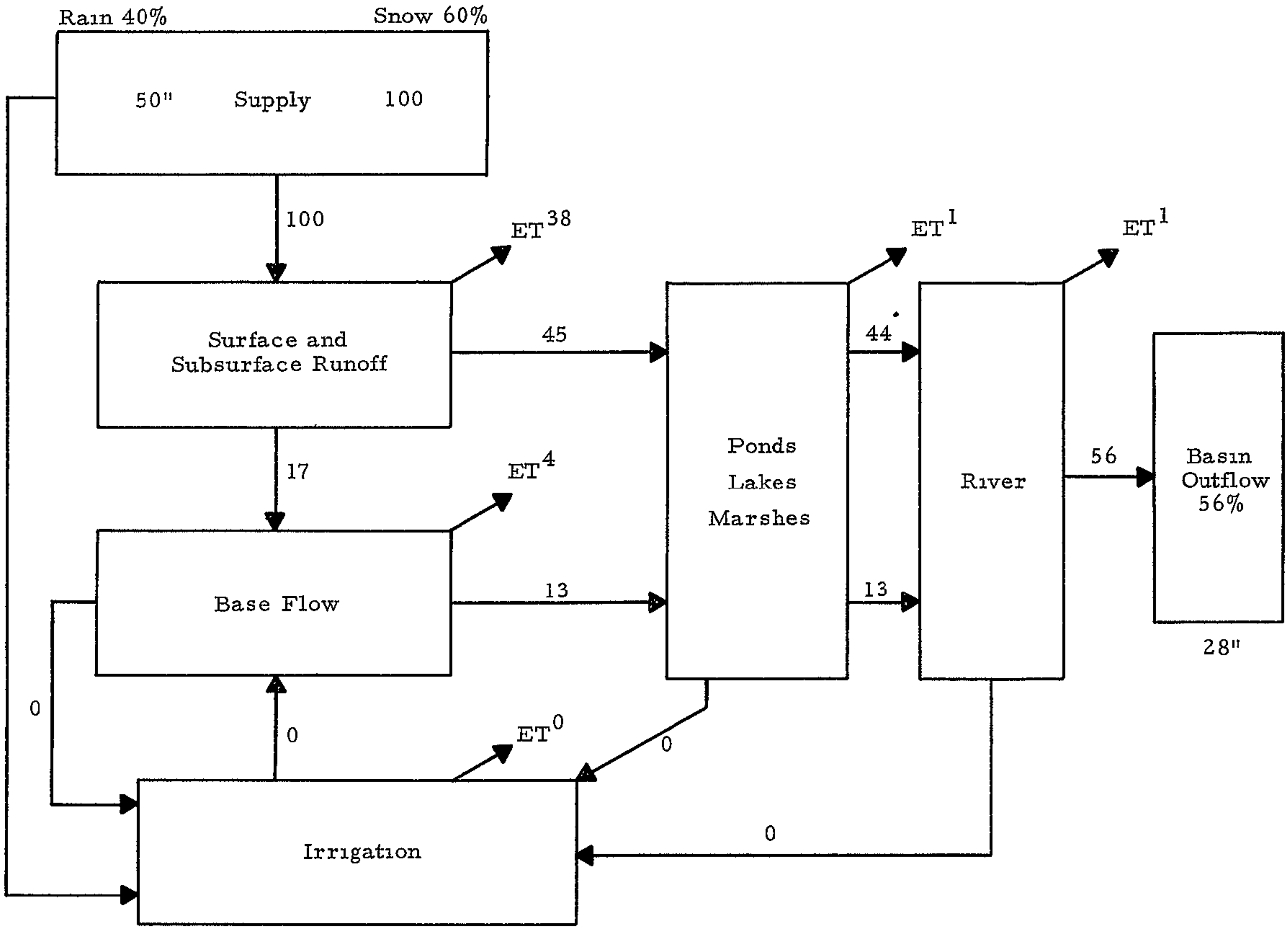
Note Numbers denote percent of total annual precipitation for the basin.

EXHIBIT B-12-a PRECIPITATION DISPOSITION - KLICKITAT RIVER BASIN



Note Numbers denote percent of total annual precipitation for the basin.

EXHIBIT B-12-b PRECIPITATION DISPOSITION - COLVILLE RIVER BASIN



Note Numbers denote percent of total annual precipitation for the basin

EXHIBIT B-12-c PRECIPITATION DISPOSITION - SOUTH FORK FLATHEAD RIVER BASIN

EXHIBIT B-13-a HYDROLOGIC DATA KLICKITAT RIVER BASIN, WASHINGTON

Information for daily values shown on Annual Basin Charts, Exhibits B-14-a, b, c

Measurement	Location	Elevation (ground)
Streamflow Thousand cubic ft/second day	Pitt, Wash	289
Precipitation (Tenths of inch)	Status Pass, Wash.	3095
Snow Depth (Inches)	Status Pass, Wash	3095
Snow Survey Data (Inches)	Status Pass Mtns	4030
Temperatures (Deg Fahr)		
Maximum	Status Pass	3095
Minimum	Status Pass	3095
Number Days Ground Visible from satellite (more than 75% probability)	Portland, Ore	21
Additional Days Ground Visible through clouds (8, 9, or 10/10ths Mean Cloudiness and 30% or more possible sunshine)	Portland, Ore	21

EXHIBIT B-13-b HYDROLOGIC DATA· COLVILLE RIVER BASIN, WASHINGTON

Information for daily values shown on Annual Basin Charts, Exhibits B-15-a, b, c

Measurement	Location	Elevation (ground)
Streamflow (Thousand cubic feet per second)	Kettle Falls, Wash	1500
Precipitation (Tenths of inch)	Chewelah, Wash	1635
Snowfall (Tenths of inch)	Mount Spokane Summit, Wash	5590
Snow Survey Data (Inches)	Chewelah Mountain	4925
Temperature (Deg Fahr)		
Maximum	Chewelah, Wash	1635
Minimum	Chewelah, Wash	1635
Number Days ground visible from satellite (More than 75% probability)	Spokane, Wash	2357
Additional days ground visible through thin clouds (8 to 10/10th cloudiness with 30% or more possible sunshine)	Spokane, Wash	2357

EXHIBIT B-13-c HYDROLOGIC DATA SOUTH FORK OF THE FLATHEAD RIVER BASIN, MONTANA

Information for daily values shonw on Annual Basin Charts, Exhibits B-16-a, b, c

Measurement	Location	Elevation (ground)
Streamflow (Thousand cubic feet per second)	Spotted Bear, Mont.	3670
Precipitation (Tenths of inch)	Hungry Horse Dam, Mont	3160
Snow Depth (Inches)	Summit, Mont	5213
Snow Survey Data (Inches)	Spotted Bear Mountain	7000
Temperatures (Deg Fahr)		
Maximum	Hungry Horse Dam	3160
Minimum	Hungry Horse Dam	3160
Number Days ground visible from Satellite (more than 75% probability)	Kalispell, Mont	2965
Additional Day ground visible through clouds. Days with .8 or more clouds at both Kalispell and Missoula and 30% or more possible sunshine at Missoula	Kalispell Missoula, Mont	2965 3200

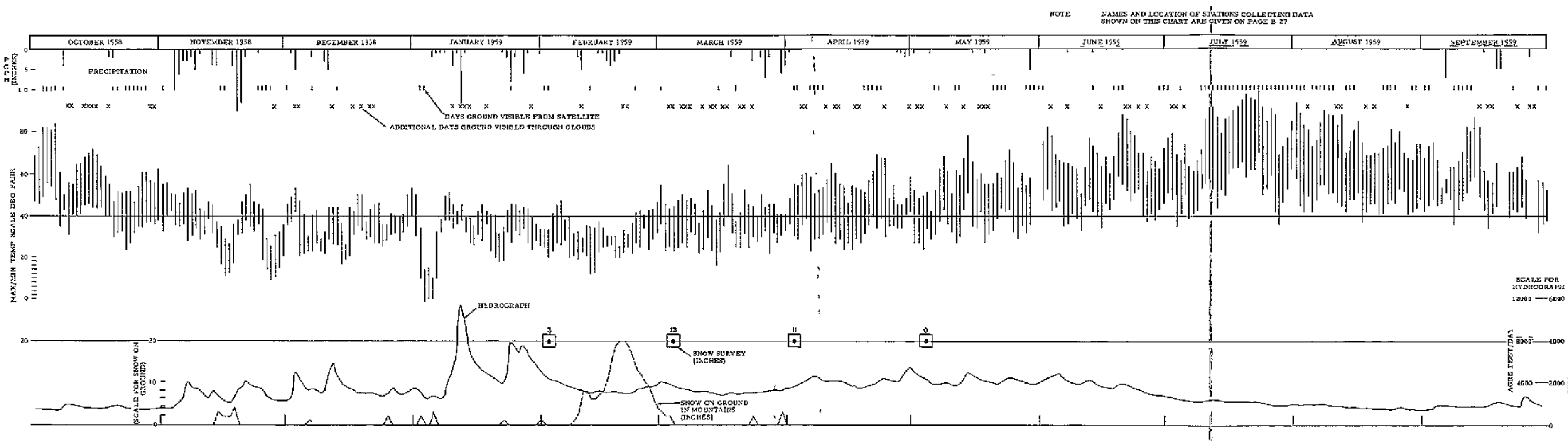


EXHIBIT B-14-a HYDROLOGIC/ METEOROLOGIC DATA - KLICKITAT RIVER BASIN, October 1968 through September 1959

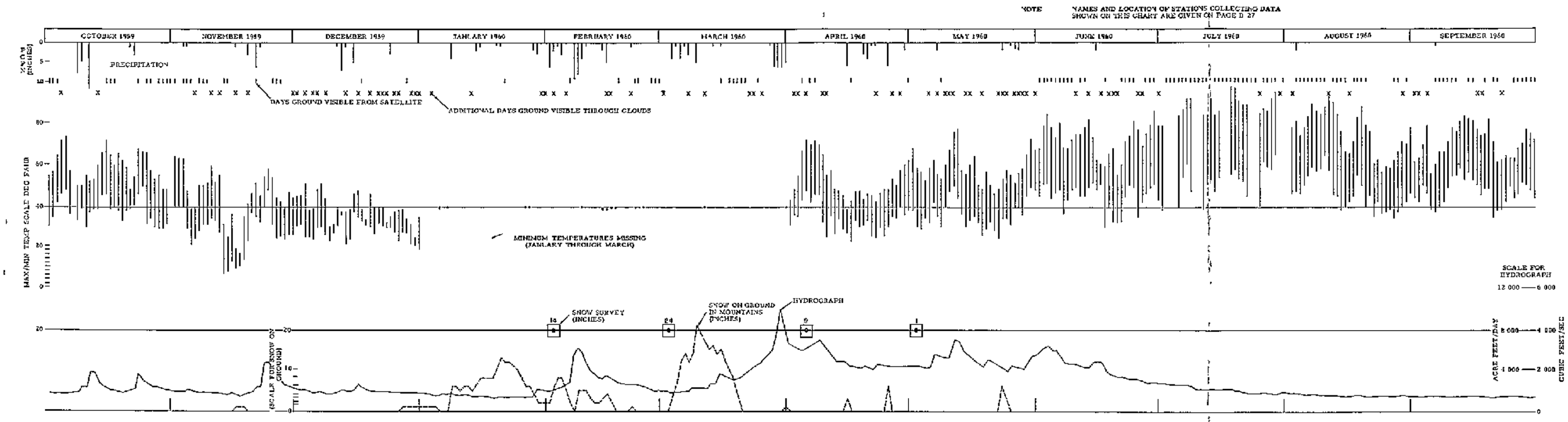


EXHIBIT B-14-b HYDROLOGIC/ METEOROLOGIC DATA - KLICKITAT RIVER BASIN, October 1959 through September 1960

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED

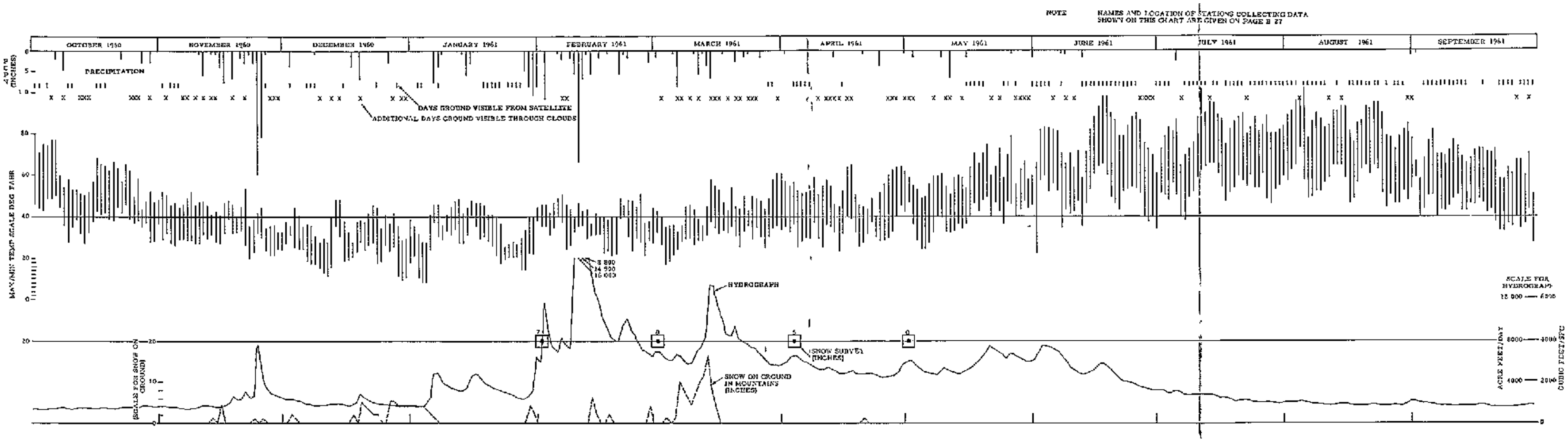


EXHIBIT B-14-c HYDROLOGIC/ METEOROLOGIC DATA - KLICKITAT RIVER BASIN, October 1960 through September 1961

FOLDOUT FRAME

FOLDOUT FRAME

PRECEDING PAGE BLANK NOT FILMED

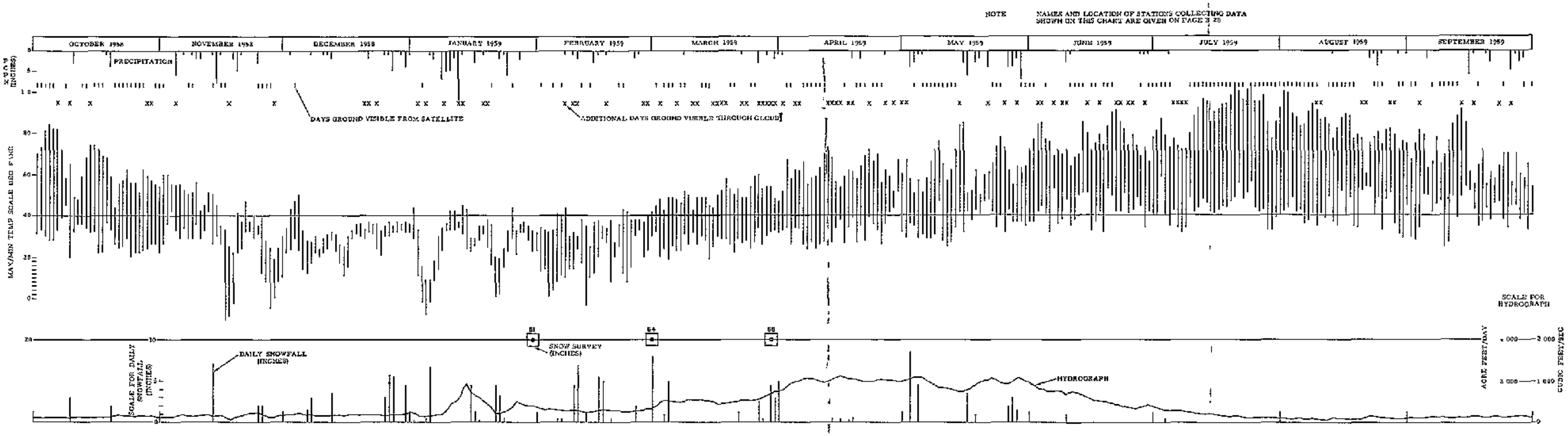


EXHIBIT B-15-a HYDROLOGIC/ METEOROLOGIC DATA - COLVILLE RIVER BASIN, October 1958 through September 1959

FOLDOUT FRAME 1

FOLDOUT FRAME A-127 2

NOTE NAMES AND LOCATION OF STATIONS COLLECTING DATA SHOWN ON THIS CHART ARE GIVEN ON PAGE B 28

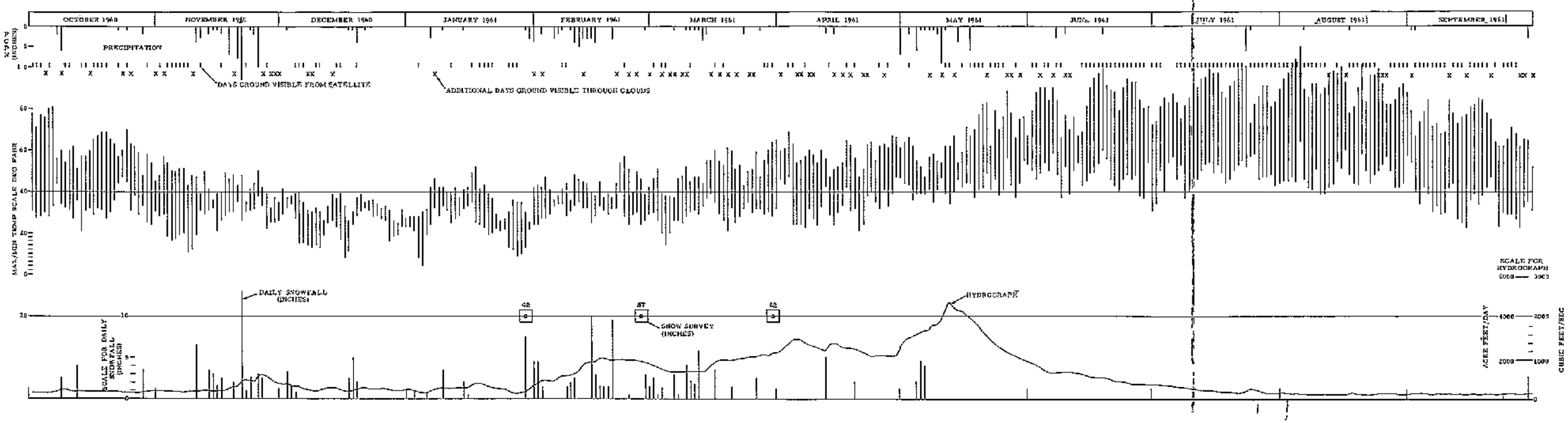


EXHIBIT B-15-c HYDROLOGIC/ METEOROLOGIC DATA - COLVILLE RIVER BASIN, October 1960 through September 1961

FOLDOUT FRAME 2

FOLDOUT FRAME 1

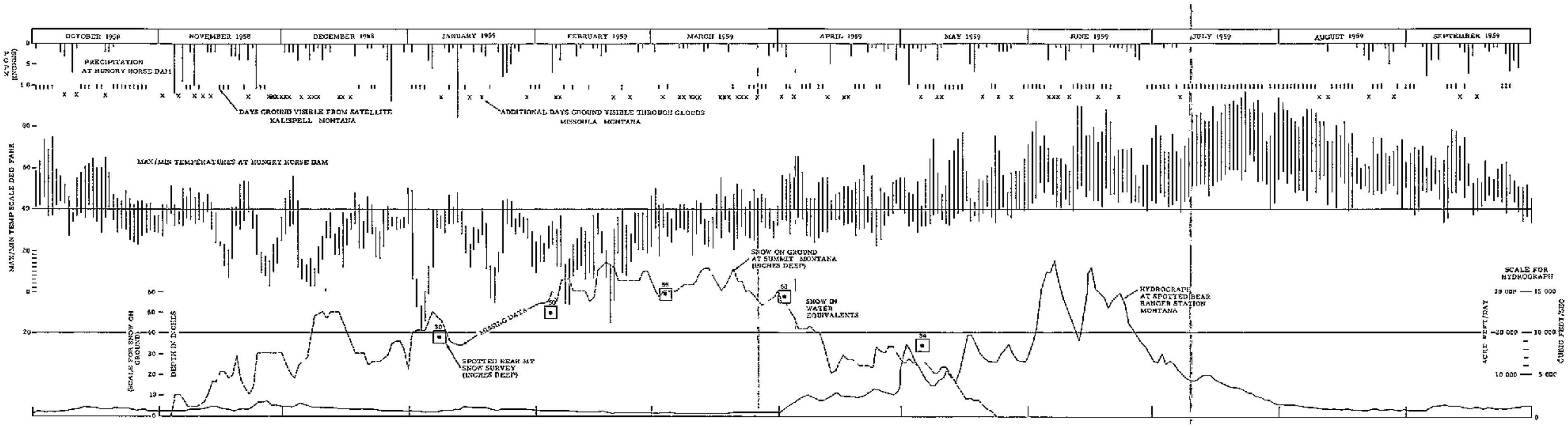


EXHIBIT B-16-a HYDROLOGIC/ METEOROLOGIC DATA - SOUTH FORK OF THE FLATHEAD RIVER, October 1958 through September 1959

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED

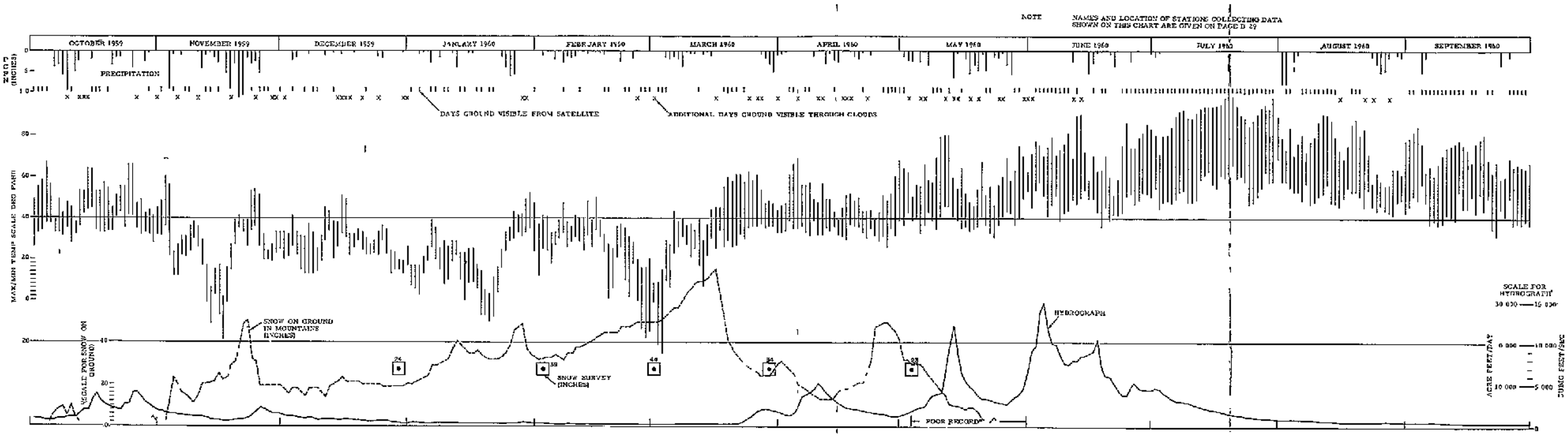
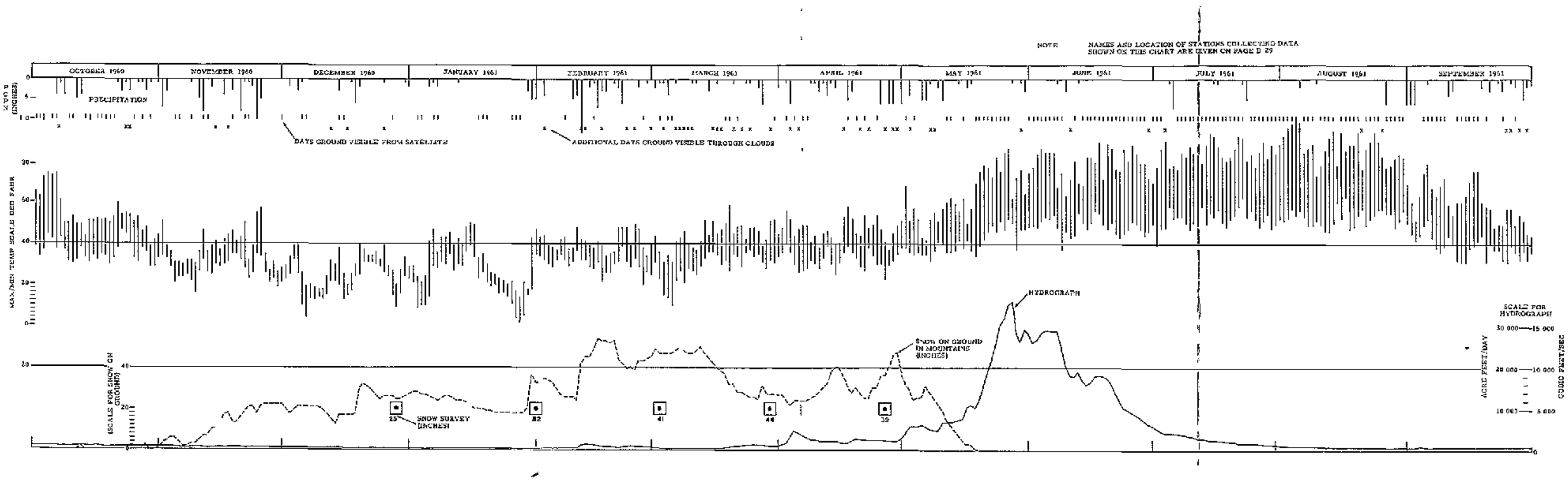


EXHIBIT B-16-b HYDROLOGIC/ METEOROLOGIC DATA - SOUTH FORK OF THE FLATHEAD RIVER, October 1959 through September 1960

FOLDOUT FRAME

PRECEDING PAGE BLANK NOT FILMED

FOLDOUT FRAME 2



FOLDOUT FRAME

FOLDOUT FRAME

2

EXHIBIT B-16-c HYDROLOGIC/ METEOROLOGIC DATA - SOUTH FORK OF THE FLATHEAD RIVER, October 1960 through September 1961 hydrograph data were synthesized through correlation of the streamflow in the Middle Fork of the Flathead with that at Spotted Bear for several years of record There is a high degree of correlation between the streamflow in these two adjacent basins About 95 percent of the variance in the streamflow at Spotted Bear is accounted for by the flow in the Middle Fork This correlation, and the 1958-59 streamflow records for the Middle Fork, gave the corresponding estimated flow at Spotted Bear during 1958-59

A Hydrology of the Study Basins and Potential Forecast Improvements

The following study area discussions reference the hydrology and meteorology portrayed in Exhibits B-14, B-15, and B-16, and relate the important periods of runoff in each basin to promising satellite observations that would aid forecasting procedures

1 Klickitat River Basin

The most significant period of runoff in the Klickitat River Basin is the time of winter rainfall from January through March During this time major rainfall occurs when the soil moisture deficiency and evapotranspiration are low, which results in a high percentage of the rainfall running off This is particularly evident in the 11 February 1961 runoff

The average runoff of the Klickitat Basin is small when compared to the flow of the Columbia River However, during times of maximum runoff in the Klickitat, as noted above, the contribution of this small basin to the total Columbia flow at that point may be as large as 10 percent The contribution of several such basins in the lower Columbia area is important indeed If large storms and resulting runoff could be forecast at least 28 hours in advance (the winter river travel time from Grand Coulee to Bonneville), then some of the valuable upstream water at Grand Coulee could be saved and a higher head maintained

The impact of antecedent conditions on runoff is strikingly apparent when comparing the storms and runoff of 24 November 1960 and 11 February 1961. The fifteen day period preceding and including each peak runoff produced about 9 inches of rain. In November there were 3.6 inches of rain preceding the day of the major storm and runoff, and in February there were 4.8 inches. The resulting maximum flow rates were 3,700 cfs in November and 18,000 cfs in February.

The February discharge was nearly five times the November flow because of the relatively wet conditions preceding the heavy rainfall event. The November rainfall preceding the large storm was lost largely to evapotranspiration and soil moisture deficiency from the previous dry summer and fall period. The impact of the major November storm also must have been lowered substantially by continuing soil moisture deficiency and evapotranspiration losses. The February storm, however, occurred when the surface was well wetted after three or four months of rain and when the evapotranspiration was quite low.

Rainfall and runoff in the other years of this study also reflect this reasoning but to a lesser degree.

Lesser amounts of rain substantially increase runoff in the Klickitat Basin when they fall on low lying snow during a period of rising temperatures. Note the hydrograph peak of 23-24 November 1959.

Satellite sensors can make three important data contributions to the forecasting of streamflow in the Klickitat Basin. These are (1) the distribution and intensity of rainstorms, (2) the areal extent of low lying snow, and (3) the antecedent soil moisture and temperature conditions. A look at the ground observation data for this area shows that most of the satellite observations during the important periods of stream flow will have to be made through the clouds.

The most important forecast parameter during the winter period is the rainfall intensity and its duration for a twelve to 28 hour period. This is the lead time required for water release decisions to be made at Grand Coulee to control flow at Bonneville. The forecast period must be lengthened if the release decisions are to be made farther upstream than the Grand Coulee.

The forecast of future rainfall in conjunction with satellite observations of the potential for runoff (antecedent conditions) should give an excellent estimate of the runoff to be expected Due to the major importance of rainfall in this basin, the observation of the antecedent conditions alone (without weather forecast) would not contribute significantly to the management of water for power at Bonneville Dam

2 Colville River Basin

The major runoff in the Colville Basin is from snow melt and rain during April and May The contribution of the Colville Basin to the main stem of the Columbia River at this time is generally less than one percent of the total flow

The April-May streamflow is very dependent upon temperatures as can be seen in the Hydromet charts The hydrographs also show the basin's relatively slow reaction time to rainfall

Winter runoff in the Colville and other basins in this area is probably more interesting than the higher spring flow because of the water demands for hydroelectric power The Colville Basin reacts to some major rainfall but this does not appear to be as important as the substantial retarding of the streamflow due to severe below freezing temperature periods An example of low flows due to low temperatures is found on January 3 and 4, 1959 It should be noted, however, that the streamflow quickly recovers when the temperature rises again

Satellite sensing of snow covered areas and ground temperatures would be an important input to forecast procedures for the Colville River

Snow area observations during the melt season are not limited by clouds The winter critical period is quite cloudy and would definitely require sensor penetration through the clouds

3 South Fork Flathead River Basin

Runoff in the South Fork of the Flathead River Basin is concentrated in the spring snow melt season This basin typifies the high elevation, seasonal snow pack areas in the east and northeast portions of the Columbia River Basin The winter flow is a small percentage of the spring flow--about three percent Spring melt contributes about 6 percent of the flow at Grand Coulee

Precipitation in the basin falls largely as snow from November through March Rainfall during the remainder of the year does not significantly affect the runoff An exception to this is concentrated rain during the snow melt season which could significantly raise the peak discharge This exception did not occur during the three years selected in this study The summer and fall rainfall is usually lost to evapotranspiration unless there is a period of rainfall long enough to satisfy soil moisture requirements which would permit a high percentage of subsequent rain to run off Note wet September 1959, followed by the significant October 1959 rainfall-runoff, and compare to other years

Rain on snow and the resulting priming of the pack during the spring is somewhat analogous to summer rainfall being used to satisfy soil moisture deficiencies When the snow pack is primed, a unit of melt will produce a unit of water excess for runoff and evapotranspiration.

The spring snow melt runoff is almost entirely a function of the incoming solar radiation and the resulting rise in air temperatures It appears that minimum daily temperatures of 40°F or more at the Hungry Horse Dam valley station induce steep rises in the hydrograph This is particularly well noted in the periods of June 1 to 6 and 12 to 15, 1959 Minimum temperatures falling below the 40°F mark cause steep recessions in the runoff hydrograph The final recession of the spring melt is obviously due to the lack of supply and the temperature is no longer the driving function. At that time, high temperatures cause steeper recession through increased loss of potential runoff to evapotranspiration

Both the seasonal and daily forecasts of snowmelt runoff are important in basins of this type The primary factors in making the seasonal forecast are the knowledge of the areal extent and water equivalent of the snow pack at the time of forecast, the antecedent soil moisture conditions, and an estimate of the precipitation yet to come in the season Satellite sensors should be able to provide excellent data on the areal extent of the snow pack and good data on precipitation and the antecedent soil moisture conditions Water equivalent data is questionable The forecast of future precipitation is the most important parameter early in the season As the season progresses, the areal extent and water equivalent of the snow pack become the most important

The forecasts of daily runoff rates are almost wholly dependent upon future air temperatures Satellite observations of the snow area, area of active melt, and the soil moisture conditions would give the melt runoff potential on which the temperatures would act

Cloud penetration by the satellite sensors is not important in the South Fork of the Flathead Basin There are numerous cloudy days during the snow accumulation period but there appears to be a time of ground visibility between the major storms The skies become almost entirely cloud free during the snow melt season Note April, May, June periods on charts

The major contributions of the satellite sensor system in basins of this climate are first, the areal extent and depth of the snow pack and, second, the ground and air temperatures

II CLOUD COVER

In order for the sensors on a satellite to record the reflectance in the visible and near infrared spectrum and radiation intensity at longer wavelengths from the surface of the earth, the line-of-sight from the satellite to the surface must not be intercepted by obscuring clouds, fog, haze, smoke, and other pollutants Furthermore, the clear zone in the space between the clouds must have a certain minimum horizontal extent in order that pattern recognition techniques may be utilized effectively Obviously, clouds accompany precipitation and such clouds are opaque in the visible and much of the longer wavelength spectrum Many other clouds are correspondingly opaque For the passive sensors it is assumed that such clouds will prevent effective ground observations There is a continuum of opacity or transparency ranging from the clouds mentioned above, through thin clouds, to clear sky There is a corresponding continuum of the quality of sensor observations Thin clouds superimpose returns of their own and attenuate and scatter returns from the earth surface These effects produce blurring and reduction of image contrast However, it is possible to obtain useful information from a satellite even though a weather station might be reporting overcast conditions

A Cloud Cover Data for the Study Basins

Three years of cloud data were examined for the test basins in the Columbia River System (Colville, Klickitat, and Flathead) in terms of the number of days when a satellite could be expected to see the ground. The results are given in Exhibit B-17 Exhibit B-18 presents some data on cloud-free line of sight probabilities taken from weather station records at Spokane, Washington, and Portland, Oregon Diurnal variations in cloud cover at Spokane are reported in Exhibit B-19 Elaborate cautions are in order in using the figures in these exhibits, but some basic conclusions can be derived One important factor is that the windward sides of mountain ranges tend to have more cloud cover because

EXHIBIT B-17 GROUND SIGHTING DAYS THREE BASINS, THREE YEARS

Hydrologic Year	Sighting* Condition	O	N	D	J	F	M	A	M	J	J	A	S	Annual
South Fork, Flathead River Basin, Montana														
1958	A	20	9	3	9	5	7	12	13	17	28	20	10	153
to	B	3	10	9	5	4	13	5	6	6	1	4	2	69
1959	C	23	19	12	14	9	20	17	19	23	29	24	12	222
1959	A	11	12	6	14	10	9	11	10	21	30	15	22	171
to	B	6	6	9	2	2	6	7	12	13	0	4	2	59
1960	C	17	18	25	16	12	15	18	22	24	30	19	24	230
1960	A	17	9	5	10	3	7	8	16	26	27	25	15	168
to	B	4	2	5	4	8	13	9	4	2	1	3	4	59
1961	C	21	11	10	14	11	20	17	20	28	28	28	19	227
Colesville River Basin, Washington														
1958	A	21	10	1	3	6	13	15	16	15	26	21	12	159
to	B	5	3	3	6	6	15	13	5	12	5	6	4	83
1959	C	26	13	4	9	12	28	28	21	27	31	27	16	242
1959	A	11	12	4	7	8	9	13	9	23	28	16	21	161
to	B	4	3	4	2	10	14	8	13	5	3	11	6	83
1960	C	15	15	8	9	18	23	21	22	28	31	27	27	244
1960	A	15	11	8	10	2	10	8	13	23	27	23	21	171
to	B	6	7	3	2	6	11	11	7	4	0	6	7	70
1961	C	21	18	11	12	8	21	19	20	27	27	29	28	241
Klickitat River Basin, Washington														
1958	A	16	7	4	3	4	3	11	12	7	25	13	10	115
to	B	9	1	7	6	3	13	9	7	7	3	6	6	77
1959	C	25	8	11	9	7	16	20	19	14	28	19	16	192
1959	A	14	13	2	1	8	7	5	1	19	27	19	17	133
to	B	2	6	16	4	5	6	8	16	9	2	4	6	84
1960	C	16	19	18	5	13	13	13	17	28	29	23	23	217
1960	A	9	5	7	13	0	3	6	9	20	25	22	20	139
to	B	9	12	7	0	2	15	11	12	7	3	5	2	85
1961	C	18	17	14	13	2	18	17	21	27	28	27	22	224

*A = unconditional sighting of the ground At least 75% climatological mean probability of a cloud-free line-of-sight to the ground, based on McCabe

B = conditional sighting of the ground At least 75% climatological mean probability of a visual line-of-sight to the ground through "thin" clouds (bright sunshine recorded at the ground) when total sky cover 8/10 - 10/10

C = A + B

EXHIBIT B-18 CLIMATOLOGICAL MAXIMUM, MINIMUM, AND AVERAGE MONTHLY PROBABILITY OF A CLOUD-FREE LINE-OF-SIGHT TO THE GROUND, SUNRISE TO SUNSET (0° NADIR ANGLE)

	Months												
	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Spokane, Washington - 1949-1967													
Maximum	91	80	92	95	88	93	97	97	97	96	81	61	85
Year (19-)	49	67	65	51	49	62	52 67	67	50	52	67	49	49 67
20-Year Average	54	63	72	77	81	85	96	94	92	81	63	41	82
Minimum	14	48	51	72	57	75	96	90	86	34	14	14	78
Year (19-)	65	62	50	50	62	50	66	65	49	50	65	52	62
Portland, Oregon - 1949-1967													
Maximum	83	83	88	91	82	93	97	97	94	89	85	54	80
Year (19-)	49	64	65	51	66	61	60	58	67	52	56	55	51
19-Year Average	41	48	54	69	73	79	93	90	89	73	57	33	74
Minimum	11	2	27	31	27	45	78	61	61	31	23	5	67
Year (19-)	67 60 53	61	59	53	60	53	55	54	59	50	53 51	66	53

EXHIBIT B-19 MEAN HOURLY SKY COVER (TENTHS), SPOKANE, WASHINGTON (1948-1957)

Hours (LST)	J	F	M	A	M	J	J	A	S	O	N	D	Annual
						Months							
01	7.4	7 0	5 7-	5.0	4.7	4.9	2 4	2 7	2.9	5 0	6.9	7 7	
02	7 5	7 1	5 7	5.2	4.7-	4 6-	2.3	2 6-	3.0-	5 1	7 0	7.9	
03	7 6	7 1	6 0	5.2	5.0	4 8	2 5+	2.7	2 9	5 2	7 1	7 9	
04	7.6	7 0	6 0	5 2-	5 5	5.2	2.9	2.8	2 9	5 4	7 0	8 1	
05	7.6	7 1	6 1	5 6	5 9	5.4	3 2	3.5	3.1	5.7	7.0	8 0	
06	7 6	7 1	6 6	6.1	6 2+	5.5	3.3	3 8	3.9	6.3	7.3	8 2	
07	7.7	7 7	6.9	6.2	6.0	5.4	3.1	3 9+	4 3	6 9	7.6	8 2	
08	8 2	8 0	7 2	6 4	6 1	5.4	3 0	3 8	4 3	7 0	7 9+	8 6	
09	8 3+	8 0	7.1+	6.4	6 0	5 6	2 9	4 0	4 2	6.9+	7 8	8 7	
10	8 3	8 1+	7 2	6.6	6.1	5 9	3.0	3 8	4 2	6 5	7.8	8 6	
11	8 1	7 9	7.3	7.0	6 5	6.4	3.1	3.8	4 2	6 4	7 8	8 6	
12	8 0	7 9	7 4	7.2+	7.0	6 7	3.5	3.9	4 6	6 5	7 7	8 6	
13	8 0	8 0	7.5	7 4	7 2	7 0	3 7	4.1	4 7	6 5	7.8	8 6+	
14	8 0	8 1	7.6	7.5	7.2	7 1+	3 7	4.1	4.9+	6 6	7.6	8.4	
15	8.0	7.8	7 7	7 5	7.2	6 9	3 7	4.3	4 9	6.5	7.5	8 4	
16	8 0	7 8	7.8	7.4	7.1	6 9	3.6	4 4	4.7	6 3	7.5	8.2	
17	8 0	7.8	7 6	7.3	7.2	6 9	3.3	4 3	4 7	6.3	7.3	8.2	
18	7 7	7 5	7 2	6 9	6 9	6.7	3 2	4.0	4.5	6.0	7 2	7 8	
19	7 5	7.1	6.9	6 7	6.5	6 3	3 0	3 8	4 3	5 5	7.0	7 7	
20	7.2	6.9	6 2	6.3	6 2	6.0	2 9	3 7	4 0	5 1	6 7	7 6	
21	7 3-	6 9	5.8	5.7	5 8	5 7	2.7	3 2	3 7	5 1	6 8	7 7	
22	7 4	6 8	5.7	5 3	5 4	5.4	2.6	2.8	3.3	5 0	6 8	7 6	
23	7 4	6 8-	5 6	5 3	5 0	4.9	2 3	2.7	3 1	5 0-	6 9-	7 5-	
24	7 5	6 7	5.7	5.3	4.6	5.0	2 3-	2 6	3 1	4.9	7.2	7.7	
Mean	7.7	7 4	6 7	6.3	6 1	5 9	3.0	3.6	3.9	5 9	7 3	8 1	
% Clear Skies	14	14	17	19	19	19	48	41	41	25	16	10	23
% Overcast Skies	66	60	47	39	37	32	11	15	20	40	60	69	42

- Hour with maximum frequency of clear skies

+ Hour with maximum frequency of overcast skies of orographic lifting of moist air (The terrain forces moving air to cooler elevations, thus encouraging cloud formation) Weather stations are frequently at airports and hence tend to be at the lower elevations within a region Therefore, their cloudiness reports will tend to understate the situation for higher elevations

1 Diurnal Variations in Cloudiness

In general, throughout the Basin, sky cover decreases during the period from sunset to sunrise This is illustrated in Exhibit B-19, which shows the mean hourly sky cover at Spokane, Washington Thus, the climatological probability of sighting the ground will be significantly greater during the nighttime, particularly 2300 - 0200 LST, as compared to the daytime period

Because of the significance of the contribution to streamflow of the mountainous sections of the Basin, it should be noted that in mountain areas, valleys are generally clearer than peaks during the day, the reverse being true at night These may be superimposed on the normal diurnal trend of maximum cloudiness around sunrise and in the afternoon, with late morning and night exhibiting minima

2 Sky Cover Conditional Probabilities

Sky cover probability data for the interior part of the Columbia River Basin provides interesting information on the change in sky cover to be expected at 24-hour intervals and at places 200 nautical miles apart

Satellite observed cloud amounts were used to derive the 200 nautical miles spatial conditional probabilities statistics See Exhibit B-20 The "summer" sample consists of all the available observations during June, July, and August 1966 for the NIMBUS II AVCS photography (resolution 0 5 nautical miles, but poor picture quality), and a limited data sample for June, July, and August 1967 from the ESSA-5 satellite (resolution 2 nautical miles)

The "winter" sample consists of photographic observations taken during December 1966, and January and February 1967 by the ESSA-3 satellite (resolution 2 nautical miles)

EXHIBIT B-20 200 NAUTICAL MILE SPATIAL CONDITIONAL PROBABILITIES OF SKY COVER (TENTHS), EAST-WEST DIRECTION IN THE INTERIOR OF THE COLUMBIA RIVER BASIN (DERIVED FROM SHERR, 1968)

December 1966, January and February 1967

Given Sky Cover \ Observed Sky Cover	0/10	1,2,3/10	4,5/10	6,7,8,9/10	10/10
0/10	41	11	21	16	11
1,2,3/10	13	25	25	12	25
4,5/10	10	20	20	30	20
6,7,8,9/10	00	08	25	42	25
10/10	00	02	05	23	70

June, July and August 1966 and 1967

Given Sky Cover \ Observed Sky Cover	0/10	1,2,3/10	4,5/10	6,7,8,9/10	10/10
0/10	60	20	13	07	00
1,2,3/10	45	18	10	27	00
4,5/10	20	15	30	20	15
6,7,8,9/10	07	14	08	50	21
10/10	00	00	10	30	60

In considering the spatial probabilities, one must keep in mind that the satellite observations may underestimate cloud cover, especially because small cumulus cells in particular cannot be detected at the camera resolution of 2 nautical miles

Spatial conditional points for computation of the 200 nautical mile spatial conditional probabilities were oriented in an east-west direction Thus, they may not be representative of the basin because cloudiness varies considerably in the north-south direction

From the spatial conditional distributions, the cloud amount probability distribution for a location 200 nautical miles distance from a base location can be determined for a given cloud amount at the base location

Exhibit B-20 indicates sky cover is related to storms in which the same sky cover amounts prevail over long distances in an east-west direction. For example, if the sky cover is overcast at a given location, there is a 70 percent probability in winter and a 60 percent probability in summer that the sky cover is overcast 200 nautical miles away, in an east-west direction

3 Sky Cover 24-Hour Temporal Conditional Probabilities

Interesting information on the change in sky cover to be expected in the southern part of the interior of the Columbia River Basin from one day to the next is contained in Exhibit B-21, which is based on a 20-year record of sky cover observations at Mountain Home AFB, Idaho, located in the southern interior part of the Basin. Since there was little conditionality past 24 hours, only the 24-hour probabilities were included

From the temporal conditional distribution shown in Exhibit B-21, the cloud amount probability for "tomorrow" can be determined given a cloud amount "today."

Exhibit B-21 indicates that when overcast skies are present at Mountain Home AFB, they are likely to be present 24 hours later both summer (35 percent) and winter (54 percent)

With regard to clear skies, the picture is not so simple If the sky is clear at Mountain Home AFB, there is a probability of 31 percent it will be clear and 41 percent it will be overcast in the next 24 hours

EXHIBIT B-21 24-HOUR TEMPORAL CONDITIONAL PROBABILITIES OF SKY COVER AT MOUNTAIN HOME AFB, IDAHO (DERIVED FROM SHERR, 1968)

November - April

Given Sky Cover \ Observed Sky Cover	0/10	1, 2, 3/10	4, 5/10	6, 7, 8, 9/10	10/10
0/10	31	09	06	13	41
1, 2, 3/10	16	11	15	20	38
4, 5/10	14	14	14	19	39
6, 7, 8, 9/10	09	09	08	22	52
10/10	10	03	08	25	54

May - October

Given Sky Cover \ Observed Sky Cover	0/10	1, 2, 3/10	4, 5/10	6, 7, 8, 9/10	10/10
0/10	53	13	10	15	09
1, 2, 3/10	38	14	15	23	10
4, 5/10	35	19	08	27	11
6, 7, 8, 9/10	43	11	09	20	17
10/10	22	11	10	22	35

during winter, during summer, the probability is 53 percent for clear and only 9 percent for overcast conditions following clear conditions

The implications regarding the probability of sighting the ground on successive passes of the satellite 24 hours apart are obvious.

4 Hourly Changes in Cloud Amounts

The unconditional probabilities of sky cover at Mountain Home AFB, Idaho, are presented in Exhibit B-22 to show how the same sky cover categories vary during the day in January, the cloudiest month (7 5 tenths sky cover), and July, the least cloudy month (2 5 tenths sky cover). It is noteworthy that overcast skies (10/10 sky cover) are the most frequent category of sky cover during January throughout the day (more than 50 percent probability), whereas clear skies (0/10 sky cover) prevail during July In both months, sky cover is less during the night

5 Dimensions of the Ground Area Sighted Through Spaces Between the Clouds

In order for the passive sensors on the satellite to observe the surface of the earth, the line-of-sight from the satellite to the surface must not be intercepted by obscuring clouds Furthermore, the clear zone sighted through spaces between the clouds must have a minimum horizontal extent of a few thousand feet on the earth's surface in order that most pattern recognition interpretation techniques can be employed successfully

Coverage by radiometers or radars will be limited by the interaction of the wings of the acceptance beam (beyond the half-power points) with clouds If characteristic earth surface sizes compare with intercloud gaps, the fraction of the available surface uncontaminated by clouds may be smaller than the cloud cover would indicate

Information on the spacing of clouds is extremely sparse, and the information available is limited in scope and applicability to the Columbia River Basin

Lund (1965) computed the average spacing of cumulus clouds during each hour of the day for August at Tampa, Florida, using high resolution U-2 photographs from 50,000 feet The cloud spacing shown in Exhibit B-23 (and others available from satellite photography for the

EXHIBIT B-22 - UNCONDITIONAL PROBABILITIES OF SKY COVER AT MOUNTAIN HOME AFB, IDAHO (DERIVED FROM SCHERR, 1968)

January - cloudiest month

Sky Cover	Time (LST) 01	04	07	10	13	16	19	22
0/10	20	18	13	07	07	08	12	18
1, 2, 3/10	09	10	11	11	13	13	11	10
4, 5/10	04	05	05	05	05	05	07	05
6, 7, 8, 9/10	15	14	20	21	23	21	18	16
10/10	52	53	51	56	52	53	52	51

July - least cloudy month

Sky Cover	Time (LST) 01	04	07	10	13	16	19	22
0/10	66	59	47	51	44	39	41	51
1, 2, 3/10	15	18	25	23	27	26	25	22
4, 5/10	07	06	07	07	04	10	08	08
6, 7, 8, 9/10	08	11	16	15	16	21	21	14
10/10	04	06	05	04	04	04	05	05

EXHIBIT B-23 CLOUD SPACING (FEET), TAMPA, FLORIDA, AUGUST (AFTER LUND, 1965)

Local Standard Time	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530
Cloud Spacing (feet)	300	500	1000	1800	2800	4400	5500	6500	7600	8000	7500

Local Standard Time	1630	1730	1830	1930
Cloud Spacing (feet)	6800	5700	4600	3500

Tampa Area), suggest that with these types of clouds and cloud patterns, the spacing will be in the order of thousands of feet The average total sky cover (sunrise to sunset) in August at Tampa is 6 7 tenths Unfortunately, these convective cloud types are not duplicated precisely in the Columbia River Basin, even during the summer season, so that these values may not be fully applicable to the Basin

III BASIN RUNOFF MODEL

The Basin Runoff Model (BRM) calculates the streamflow output from a watershed or a sub-area of a watershed when given a daily precipitation and surface air temperature sequence and basin-related geographic and hydrologic constants A descriptive flow diagram of the model is shown in Exhibit B-24

The following text discusses the methodology, inputs, and output of the Basin Runoff Model The functional relationships between variables are shown by mathematical equations and the pertinent assumptions are discussed The detailed operation of the model in computational form is given in the computer program documentation

A Inputs

The daily inputs, temperature, and precipitation, which drive the model may be either generated by random number process or forced by using real data By forcing observed data for a basin through the model, the model-generated streamflow may be compared to that which was observed This comparison will assist in determining the appropriate values of the basin constants

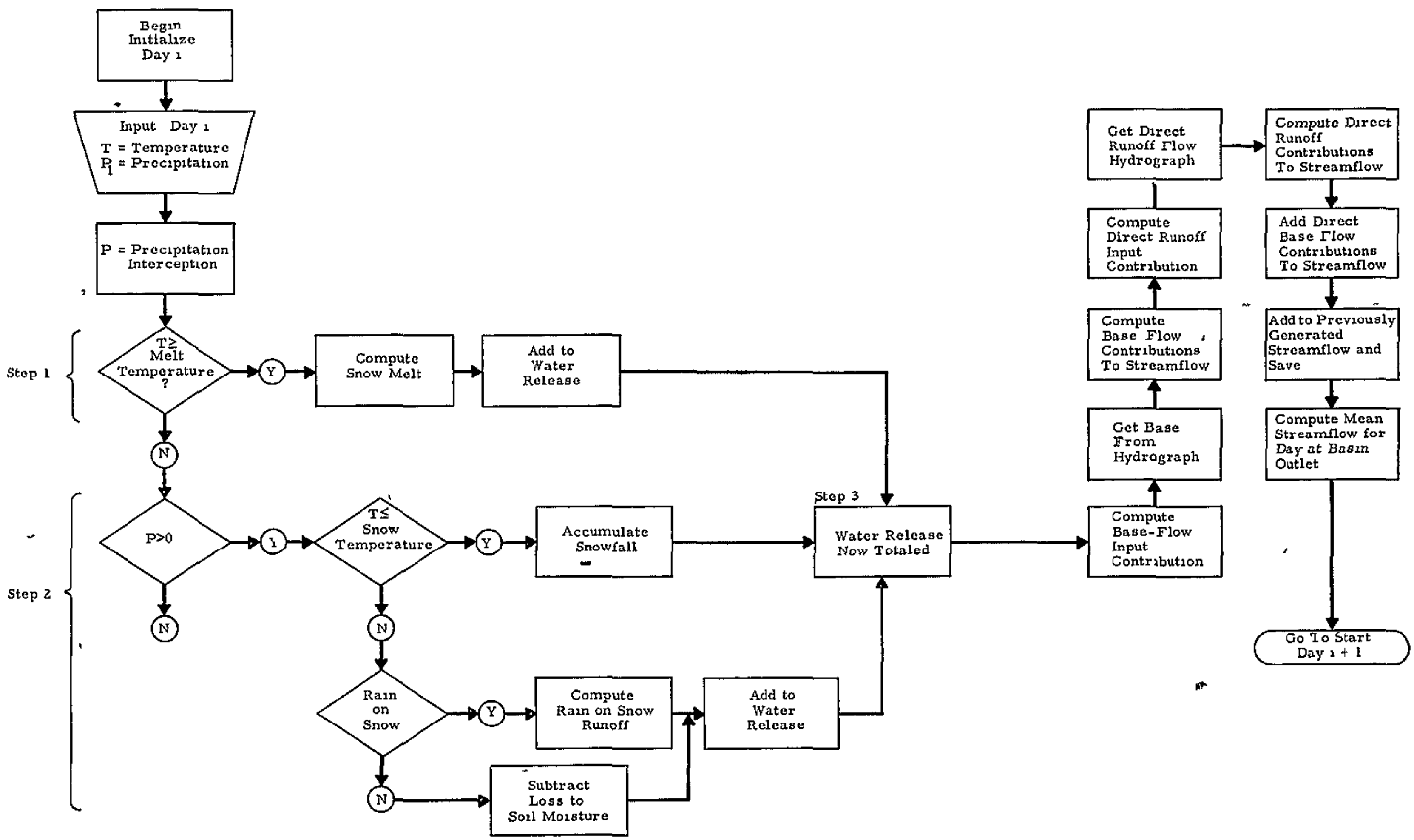
1 Generated Temperature

Generated temperature input is accomplished by a random walk process The random walk table (see program documentation) is based on the probability that the daily departure from the mean temperature will be in a specified range given the preceding day's departure from the mean Thus, knowing a given day's temperature and its departure from the mean, a random number is drawn to determine the following day's departure from the mean

2 Generated Precipitation

Generated precipitation is based on the mean monthly probability of cloudiness, the probability of precipitation, given that

EXHIBIT B-24 BASIN RUNOFF MODEL



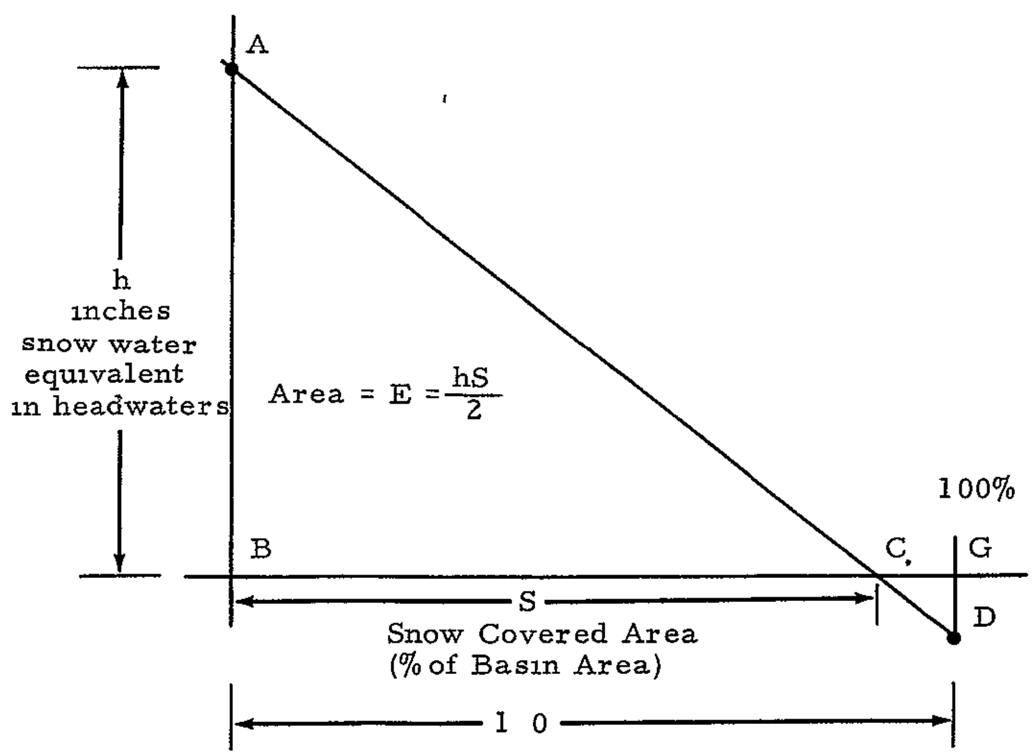
A-157

clouds occur, the mean monthly size of precipitation events, and the probability of deviation from the mean event size Random numbers are used in conjunction with the probabilities to determine first, whether there are clouds, second, if there is precipitation, given clouds, and finally, the deviation in the size of the precipitation event from the mean, given the occurrence of precipitation.

The daily precipitation amounts (forced or generated) are reduced by an interception factor before being inputed to the Basin Runoff Model This reduction factor, C_3, is not limited only to interception loss estimates It may also be used to compensate for nonrepresentative basin precipitation measurements, losses through ground water leakage, or any other gains or losses which can be reflected in the total water supplied to the watershed by precipitation

3 Snow/Water Equivalence

The basic relationship assumed between water equivalents of snow in the basin, E, and the fraction of snow covered area, S, of the basin are shown in the figure below Related equations derived from this graphical relationship are used in Steps 1 and 2 of the model



The relationship between h and S for any h is found by pivoting the line AD around point D S equals C, the point of intersection of AD with BG Point G corresponds to S = 100%.

The Basin Runoff Model assumes that AD is a straight line and that ten percent of the basin area is without snow when h is ten inches of snow water equivalent This was a necessary simplifying assumption because of the lack of historic data on snow covered area and the relation of the snow area to the snow water equivalent at some point in a basin Each basin or sub-area to be modeled would have to be calibrated (i e , vary the length of GD and/or the shape of AD) by observing h and S during the snow accumulation and melt period

It should be noted that the assumptions made for this model limit the snow covered area to less than 100% ($h \rightarrow \infty$ as $S \rightarrow 100\%$) This may be true depending upon the topography, size, and climate of a particular basin As previously noted, individual basin calibration is necessary to obtain the correct relationship

The geometry of the figure and the assumption of the h and S relation yield equations (2), (3), and (4) which appear in Figures B-25 and B-26

$$S = \frac{9h}{10 + 9h} \qquad (2)$$

$$E = \frac{hS}{2}$$

$$= \frac{9h^2}{2(10 + 9h)} \qquad (3)$$

solving the above for h

$$h = E\left(1 + \sqrt{1 + \frac{20}{9E}}\right) \qquad (4)$$

where E = the inches of snow water equivalent spread evenly over the entire basin area (triangle ABC)

The subscripts, i, appearing in Exhibits B-25 and B-26 denote the time dependence of these variables by Julian date

This model relating snow covered area and snow-water equivalent is just one of an infinity of possible models It was selected as expedient for computer application and as somewhat representative of the physical behavior of snow cover In fact, each drainage basin has its own characteristic snow buildup and recession pattern Even this pattern will vary from year to year as a result of logging operations, other long-term effects and the pattern of snow-deposition It is preferable by far to use data (curves, factors and the like) which have derived from previous analyses of the basin being studied However, snow area recession data was not available to help in model construction

A satellite could report snow covered area on a regular basis, thus supplying a fundamental piece of information There is some hope that snow depth or even the water equivalent might be deduced directly using satellite observations Rather than rely too heavily on a tenuous chain of physical reasoning, a regression analysis approach to snow water equivalent estimation is recommended (e g x melt degree-days exposed y square miles and produced z cfs-days of melt runoff) The regression might even be conducted between flow and area change as seen by the satellite This would bypass many measurements and calculations It is also noted that any number of other regressions could be conducted in parallel, relying on operational performance to make an eventual choice of the tools to be used

B Major Steps in Basin Runoff Model

Exhibits B-25, B-26, and B-27 show flow diagrams in equation form for the three major steps in the Basin Runoff Model These steps are Snowmelt, Precipitation, and Streamflow An explanation of the symbols is given here for convenience and a discussion of the functions in each step follows the exhibits

Symbols

C_1 = Basin snow melt rate constant in degree days per inch (50 - 150)

C_2 = Basin soil moisture loss constant (8 - 9)

C_3 = Interception factor applied to P_i

E_i = Snow water equivalent in inches of h_i spread evenly over the entire basin

ΔE_i = Snow accumulation or melt on day i spread over the entire basin, inches In the case of snowfall accumulation $\Delta E_i = R_i$

${}^{F}D_{ij}$ = Direct Runoff component of streamflow in cubic feet per second at end of day j from water released on day i

${}^{F}B_{ij}$ = Base runoff component of streamflow in cubic feet per second at end of day j from water released on day i

F_j = Total streamflow at end of day j at mouth of basin

h_i = Model value for snow water equivalent of deepest snow in basin at end of day i, inches

h_o = Initial h_i for first calculation

$\bar{h}_i$ = Average value of h between i and (i - 1)

m_i = Fraction of rain in day i on nonsnow areas that is available for runoff

M_i = Snow melt on day i in inches

P_i = Precipitation input on day i

R_i = Net precipitation after interception on day i, inches

$\bar{R}_i$ = Sum of the net precipitation for the last γ days, inches

ΔR_{S_i} = Water release from rain on snow on day i

ΔR_{NS_i} = Water release from rain on nonsnow areas on day i

S_i = Snow covered fraction of total basin area

$\overline{S}_i$ = Average S_i corresponding to $\overline{h}_i$.

T_i = Mean surface air temperature for day i in ^oF

T_M = Temperature at which snow melts , ^oF

T_S = Temperature at or below which precipitation falls as snow, ^oF

$U_{D_{ij}}$ = Coordinates of direct runoff unit hydrograph in cubic feet per second at time j from water released on day i

$U_{B_{ij}}$ = Coordinates of base runoff unit hydrograph in cubic feet per second at time j from water released on day i

W_i = Total water release in inches on day i available for runoff

W_{D_i} = Direct runoff component of W_i .

W_{B_i} = Base runoff component of W_i .

τ = Seasonal evapotranspiration time constant in days (10 - 50)

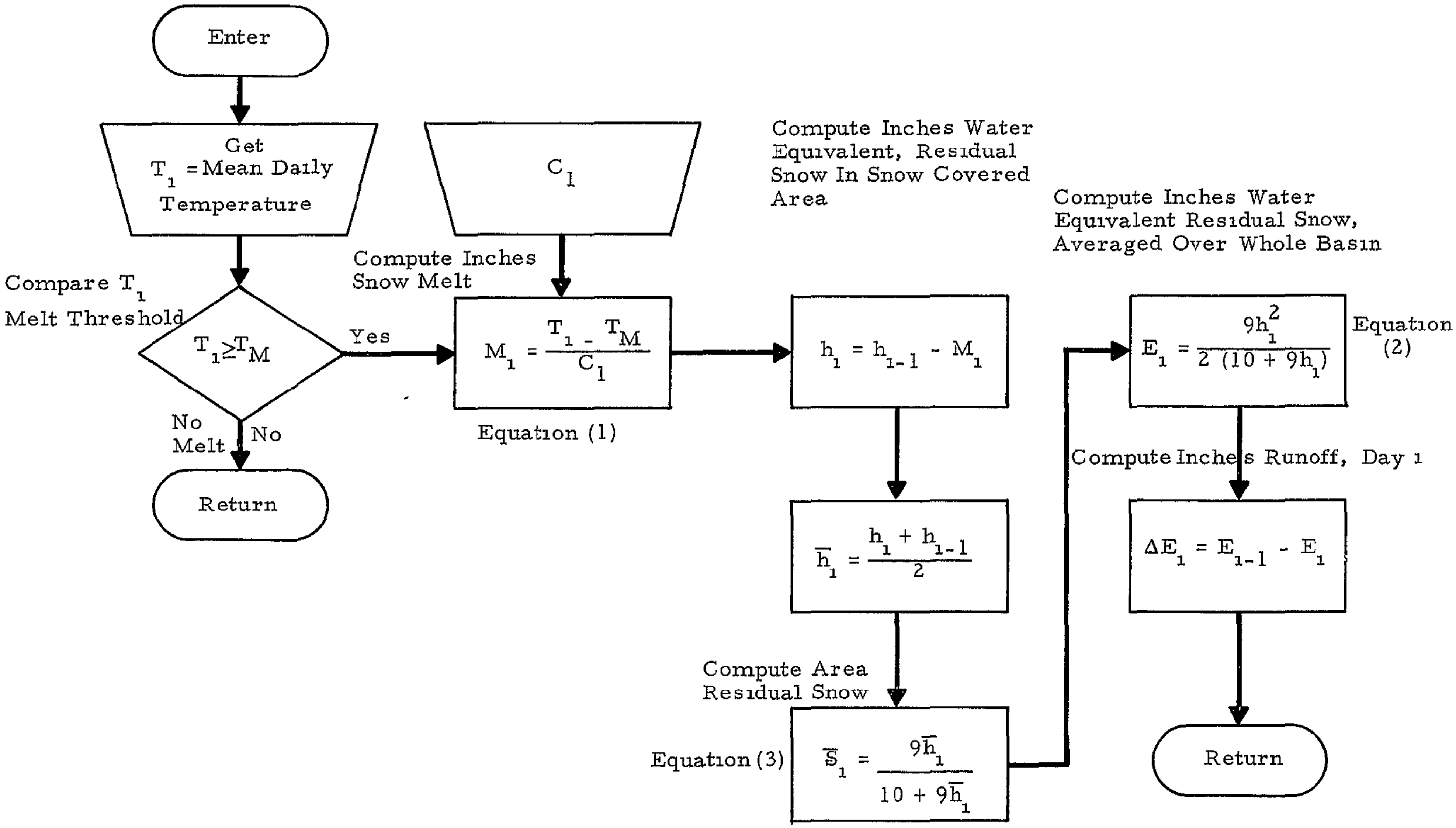


EXHIBIT B-25 BASIN RUNOFF MODEL - SNOW MELT RUNOFF

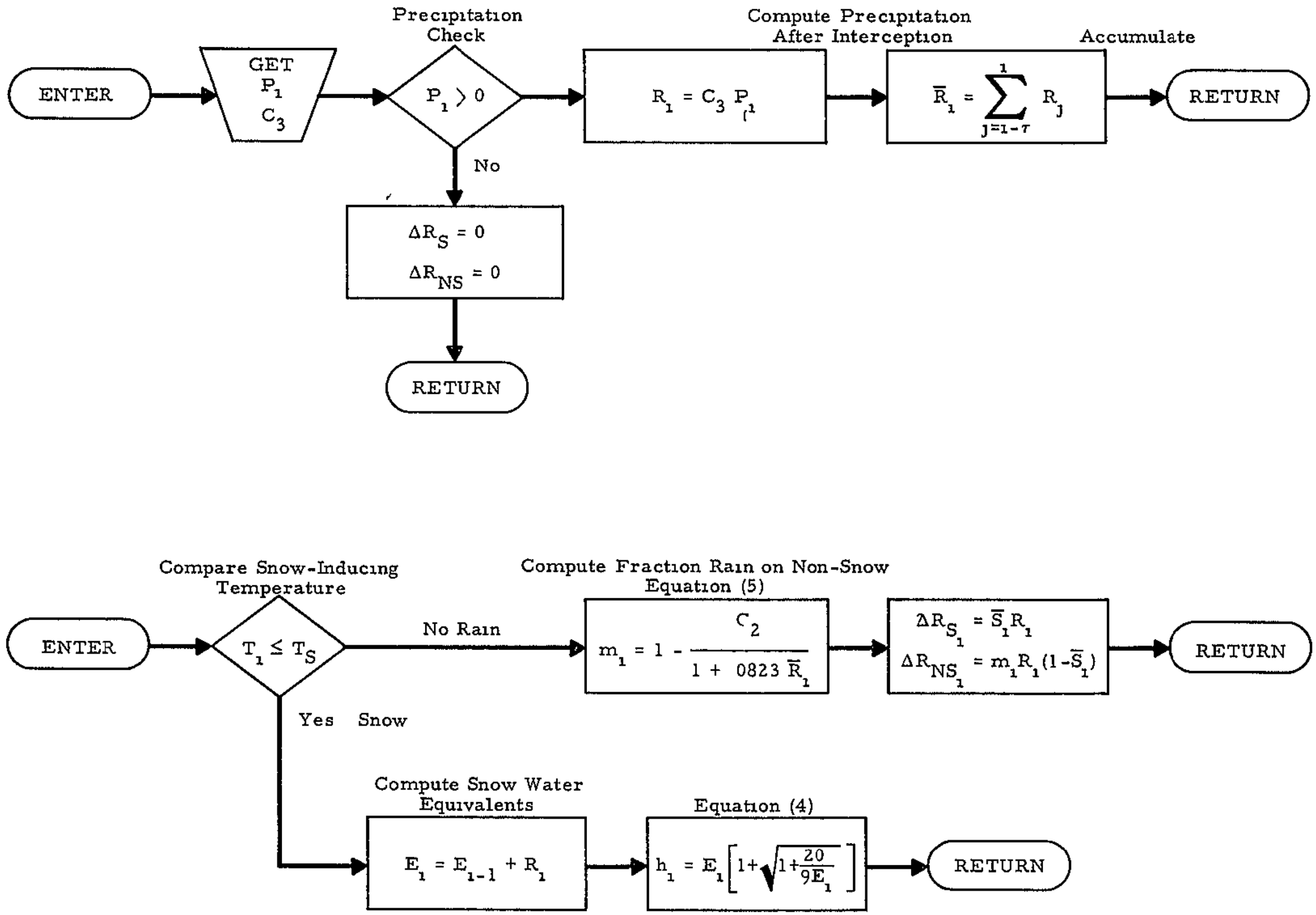


EXHIBIT B-26 BASIN RUNOFF MODEL - PRECIPITATION RUNOFF, SNOW-RAIN DIVISION

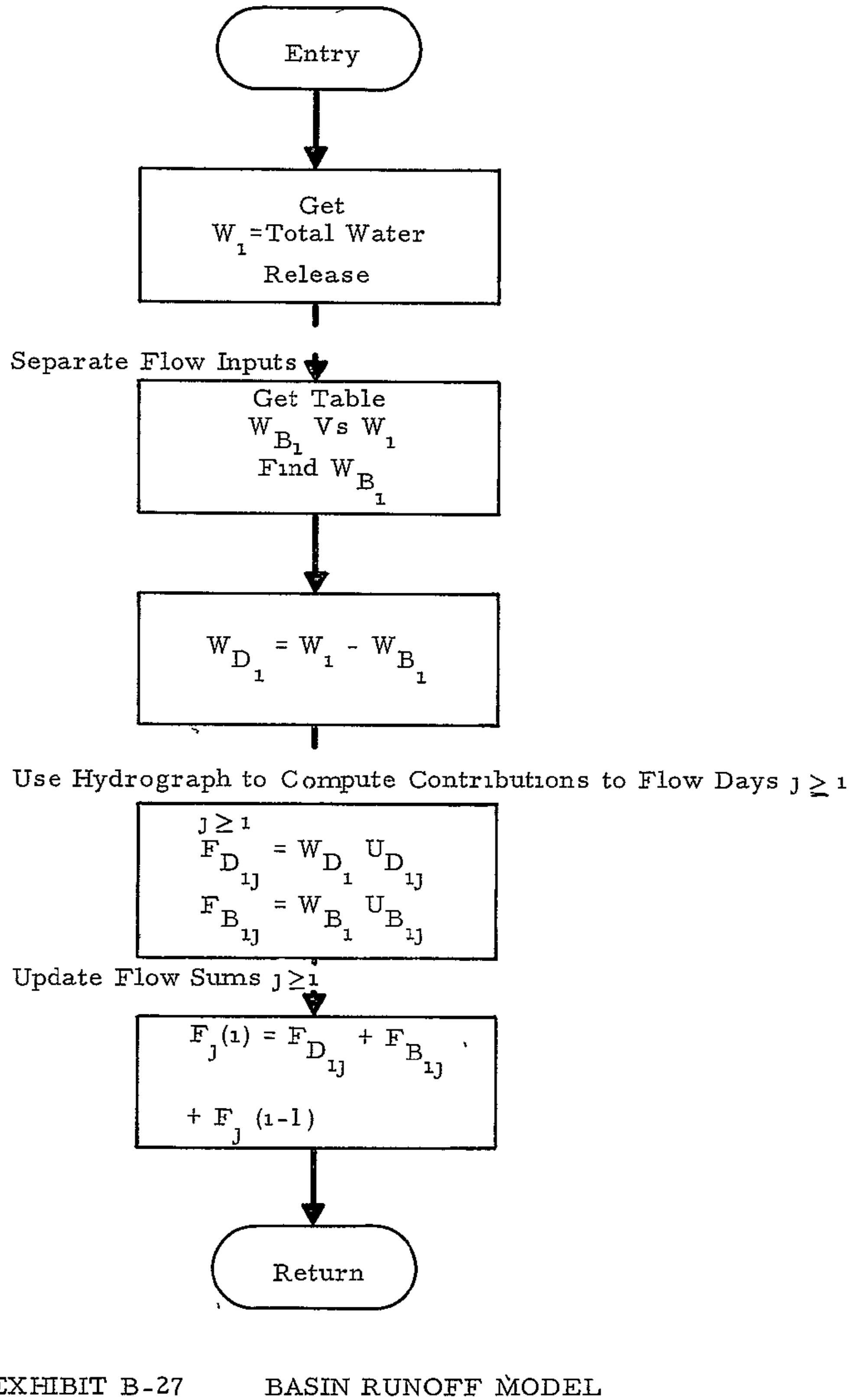


EXHIBIT B-27 BASIN RUNOFF MODEL

1 Step 1 Snowmelt

The basin runoff model first compares the period input temperature, T_i, with the temperature of melt, T_M, to check for snowmelt If $T_i \geq T_M$, melt occurs, providing $h_i > 0$, and the water release is

$$M_i = \frac{T_i - T_M}{C_1} \quad (1)$$

$$h_i = h_{i-1} - M_i$$

$$E_i = \frac{9h_i^2}{2(10 + 9h_i)} \quad (2)$$

$$\Delta E_i = E_{i-1} - E_i \qquad \text{knowing } h_{i-1} \text{ and } h_i$$

where M_i = water equivalent increment in inches of melt for the deepest snow in the basin

C_1 = Deepest snow melt rate in degree days per inch of melt

i = Julian date

h_i = snow water equivalent in inches of deepest snow in the basin at end of day i

ΔE_i = water equivalent increment in inches, over the entire basin area in period i

ΔE is the effective water release from the snowmelt in Step 3

If $T_i < T_M$

then $\Delta E_i = 0$

Equation (1) relates the surface air temperatures to the amount of snowmelt to be expected in a particular basin Constant No 1, C_1, is the melt rate expressed in degree days per inch. This factor is approximated by taking the slope of the cumulative melt runoff versus cumulative degree days curves for the individual basins, see Exhibits B-9, a, b, and c It is then adjusted by using observed input data and fitting the calculated to the observed streamflow for the basin

It should be noted that this equation is only an approximation of a more detailed heat balance snowmelt relation, see Snow Hydrology, U S Corps of Engineers Such a simple relation is commonly used, however, as it does yield a relatively good approximation of snowmelt using a commonly measured variable

2 Step 2 Precipitation

The precipitation input is now introduced If

$$R_i = 0$$

then $W_i = \Delta E_i$ in Step 3

where W_i = basin water release, in inches, in period i

If precipitation did occur, then the input temperature is compared with the temperature of snow, T_S, to determine whether the precipitation was rain or snow

If $T_i \leq T_S$, then snow occurs and the snowpack accumulates in the following manner

$$E_i = E_{i-1} + R_i$$

and h_i is calculated from equation (4)

If $T_i > T_S$, then rainfall occurs The rain falling on snow must be treated differently than that on snow-free areas Virtually all of the rain falling on snow is available for runoff, whereas, rain on non-snow areas is subject to evapotranspiration losses

The snow covered area, $\overline{S}$, in percent of total basin area is calculated by

$$\overline{S}_i = \frac{9\overline{h}_i}{10 + 9\overline{h}_i} \qquad (3)$$

where

$$\bar{h} = \frac{h_i + h_{i-1}}{2}$$

The incremental runoff, in inches, from rain on snow is then

$$\Delta R_{S_i} = S_i \; R_i$$

From equation (2) follows

$$h_i = E_i \left[1 + \sqrt{1 + \frac{20}{9E_i}} \right] \qquad (4)$$

for snow depth

The rain falling on nonsnow areas must be decreased by the current deficit in soil moisture The proportion of rainfall available for runoff at time i is given by the following equation which is derived on page 72 of this appendix

$$m_i = 1 - \frac{C_2}{1 + 0.0823 \; \bar{R}_i} \qquad (5)$$

where m_i = fraction of rainfall at time available for runoff

C_2 = constant related to evapotranspiration in the basin

and

$$\bar{R}_i = \sum_{j=i-\tau}^{i} R_j$$

τ = monthly evapotranspiration recession time constant in days

The increment of runoff from rain falling on nonsnow area is then

$$\Delta R_{NS_i} = m_i \; R_i \; (1 - S_i)$$

3 Step 3 Streamflow

The total daily increment, W_i, of water input to runoff is the sum of the snowmelt and rainfall contributions from Steps 1 and 2

$$W_i = \Delta E_i + \Delta R_{S_i} + \Delta R_{NS_i}$$

The total water release is partitioned into two components of runoff, direct and base The direct runoff is a more immediate flow from surface and subsurface runoff while the base component is a much slower reacting flow coming from precipitation-supplied ground water The separation is based on the size of the total water release for that day Tabular values of total water release and corresponding amounts going to base flow, W_B, are derived for the basin by analysis of the hydrograph W_B reaches some maximum amount limited by the local geology The direct runoff water release is $W_i - W_{B_i}$

The total water release is divided into two components with different timing to provide a better fit to the observed hydrographs The division of runoff could be made into several components with different timing to further approximate the actual hydrographs The two component runoff system yielded a good approximation of the hydrograph for the purposes of this model

The water releases over the basin are translated into streamflow at the mouth of the basin through the use of unit hydrographs for each component The daily streamflow values of the unit hydrograph are tabulated for each component and these values are proportioned by the size of the actual water release for the particular event relative to the one inch release-runoff relation of the unit hydrograph

$$F_{D_{ij}} = W_{D_i} \quad U_{D_{ij}}$$

where $F_{D_{ij}}$ = Direct component of streamflow (in cubic feet per second) at the end of day j resulting from water released on day i

W_{D_i} = Direct flow water release component on day j

$U_{D_{ij}}$ = Unit hydrograph direct streamflow at end of day j in cubic feet per second per inch of release on day i

The same equation holds for base flow by substituting "B" for "D" in the above It should be noted that the streamflow on the end of the same day of the water release is for $i = j$ as shown in Step 3 of the model

Total daily stream flow out of the basin is then the sum of the current days input plus all the contributions of prior water releases appearing in the stream on that day This is shown in the last equation in Step 3

4 Derivations

Equation (5) partitions rainfall on nonsnow covered areas into that available for runoff and that lost to evapotranspiration. The evapotranspiration loss is that part of the rainfall that goes to satisfy the current deficit in soil moisture The fraction of rain available for runoff, m, is then a function of the wetness of the soil.

The U.S. Weather Bureau and Corps of Engineers at the Portland, Oregon, Columbia River Forecast Center have approximated the soil moisture content versus runoff relationships in their "SSARR" model. A sample relationship is provided on a graph in their SSARR model program description. The graph indicates that all of a rainfall will run off where the soil moisture variable is above 8.5 inches

The SSARR soil moisture versus runoff loss curve is reasonably well fitted by

$$\begin{aligned} g &= a - bD - cD^2 \\ &= 0.9 - 0\ 0823D - 0\ 00277D^2 \end{aligned} \qquad (6)$$

where g = fraction of rain fall not available for runoff

D = soil moisture index in equivalent depth of water in inches just prior to the rainfall

If D_1 represents average moisture conditions just before a rain and D_2, the conditions just after the rain, then

$$D_2 = D_1 + gR \tag{7}$$

The decrease in soil moisture between rains is generally thought to follow an exponential decay function, ref Linsley, Kohler, and Paulhus, the rate of decay depending essentially upon the season and the soil and vegetation characteristics. Decay time constants of 10 and 50 days are commonly used for active and dormant vegetation seasons, respectively If Δt is the time between rains, then it follows that

$$\frac{D_1}{D_2} = e^{-K\Delta t}$$

where

$$K = \frac{1}{\tau}$$

τ = Soil moisture recession time constant

If the rains are random events in time, the average value of D_1/D_2 is

$$(\overline{D_1/D_2}) = \frac{1/\Delta t}{K + 1/\overline{\Delta t}} = \frac{1}{K\overline{\Delta t} + 1}$$

Combining this result with equation (7) gives the average condition just before a rain to be

$$\overline{D}_1 = \left(\frac{\overline{g}}{K}\right) \quad \left(\frac{\overline{R}}{\Delta t}\right)$$

$(R/_{\Delta t})$ is the average amount of rain per day Thus, the actual statistical distribution of rain amount and spacing is not important The relevant statistic can be found by dividing the season precipitation by the length of the season Since K is also a seasonal characteristic, a composite seasonal descriptor, p, can be computed where

$$p = \frac{(\overline{R})}{K\Delta t}$$

This result can be used in equation (6) to produce

$$g = a - bpg - cp^2 g^2$$

Solving for g in this equation by using a combination of the quadratic formula solution and the following approximation

$$(1 \pm X)^A \approx 1 \pm AX$$

with

$$A = \frac{1}{2}$$

and

$$X = 4\, acp^2/(bp + 1)^2$$

yields

$$g = \frac{a}{1 + bp}$$

The seasonal descriptor, p, is actually the sum of all the daily rainfall over the past τ days.

$$p = \overline{R}_i = \sum_{j = i - \tau}^{i} R_j$$

From the definition of m

$$m_i = 1 - g_i$$

$$m_i = 1 - \frac{a}{1 + b\,\overline{R}_i}$$

For the purposes of this model, "a" has been chosen to be a constant for each basin depending upon local climate, etc The value of b remains that which was derived earlier

Thus

$$m_1 = 1 - \frac{C_2}{1 + 0\ 0823\ \overline{R}_1}$$

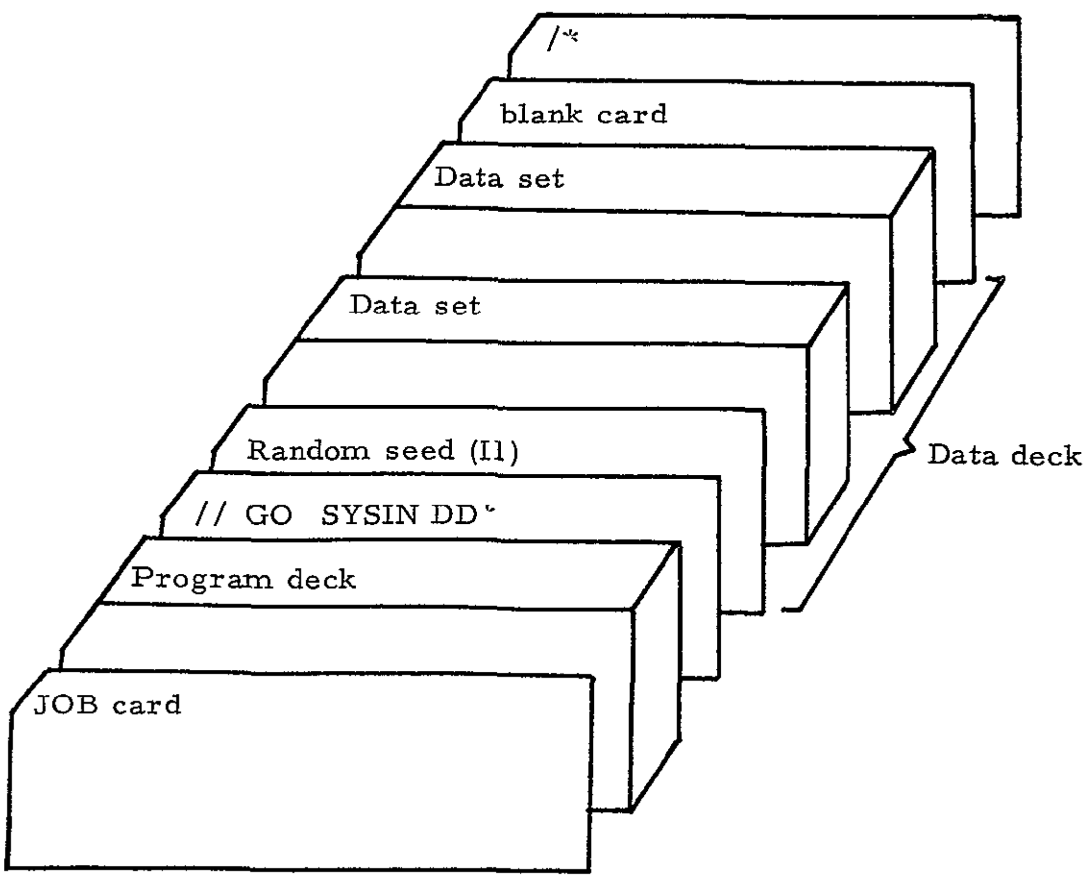
C_2 is about 0.9 but each basin will have this characteristic adjusted to fit observed runoff relationships

IV. COMPUTER PROGRAM USAGE

A General Description

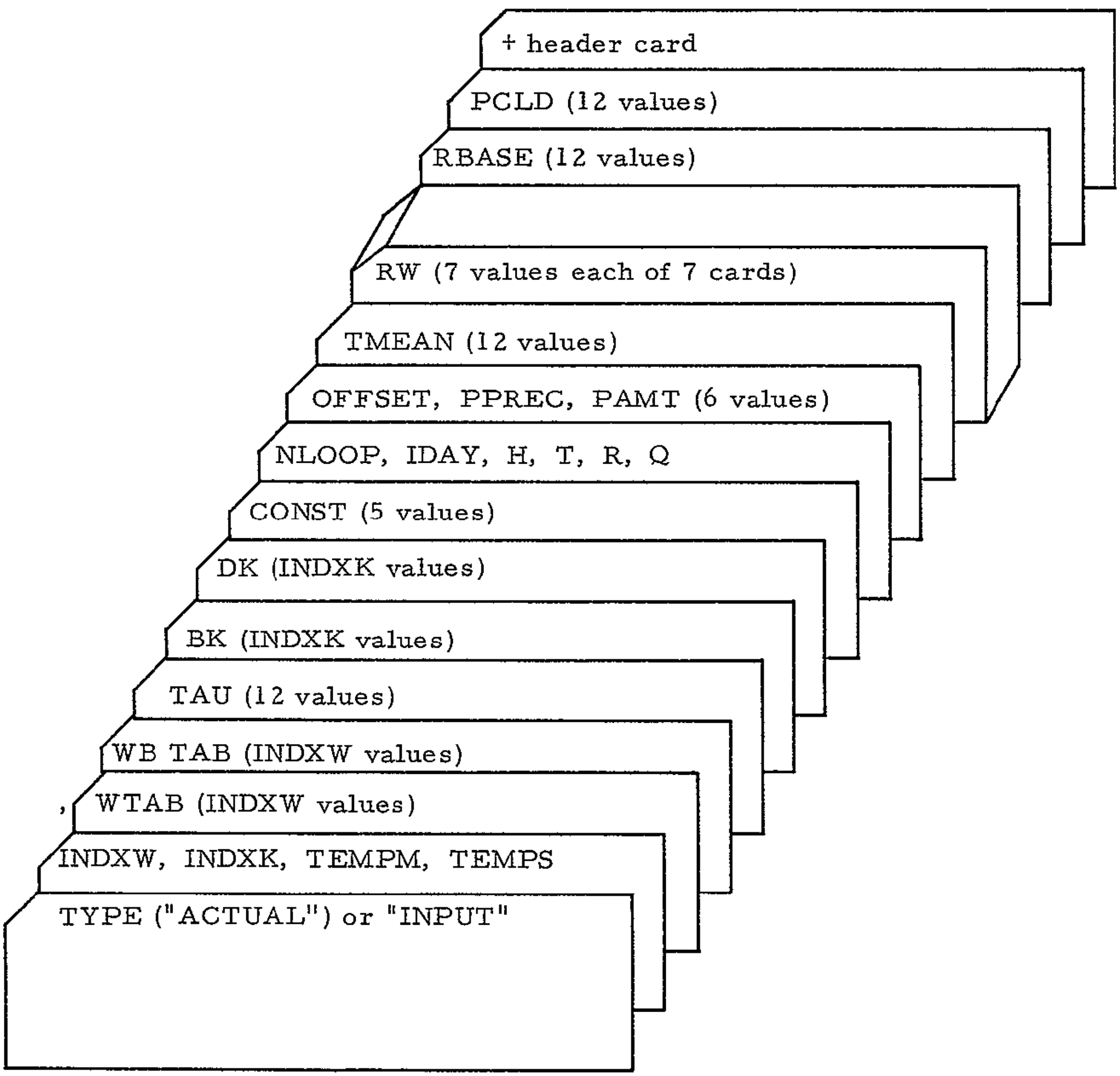
The Basin Runoff Model (BRM) program uses two separate input techniques to produce similar printed output. The "actual" input routine uses initial values for temperature and precipitation and generates, by random selection, a sequence of temperatures, cloudiness, and precipitation The forced input routine, referred to as "input" expects all temperatures and precipitation to be read from data cards The BRM routine, a third portion of the program, uses each successive pair of temperature and precipitation to calculate change in level of snow (if any), the amount of water (in inches) released by snow melt or rainfall, and the accumulated flow of water (in CFS-days), based on the water release of the last several (TAU) days The input and calculated values are then printed along with a successive sum of the flow

1. Deck Setup

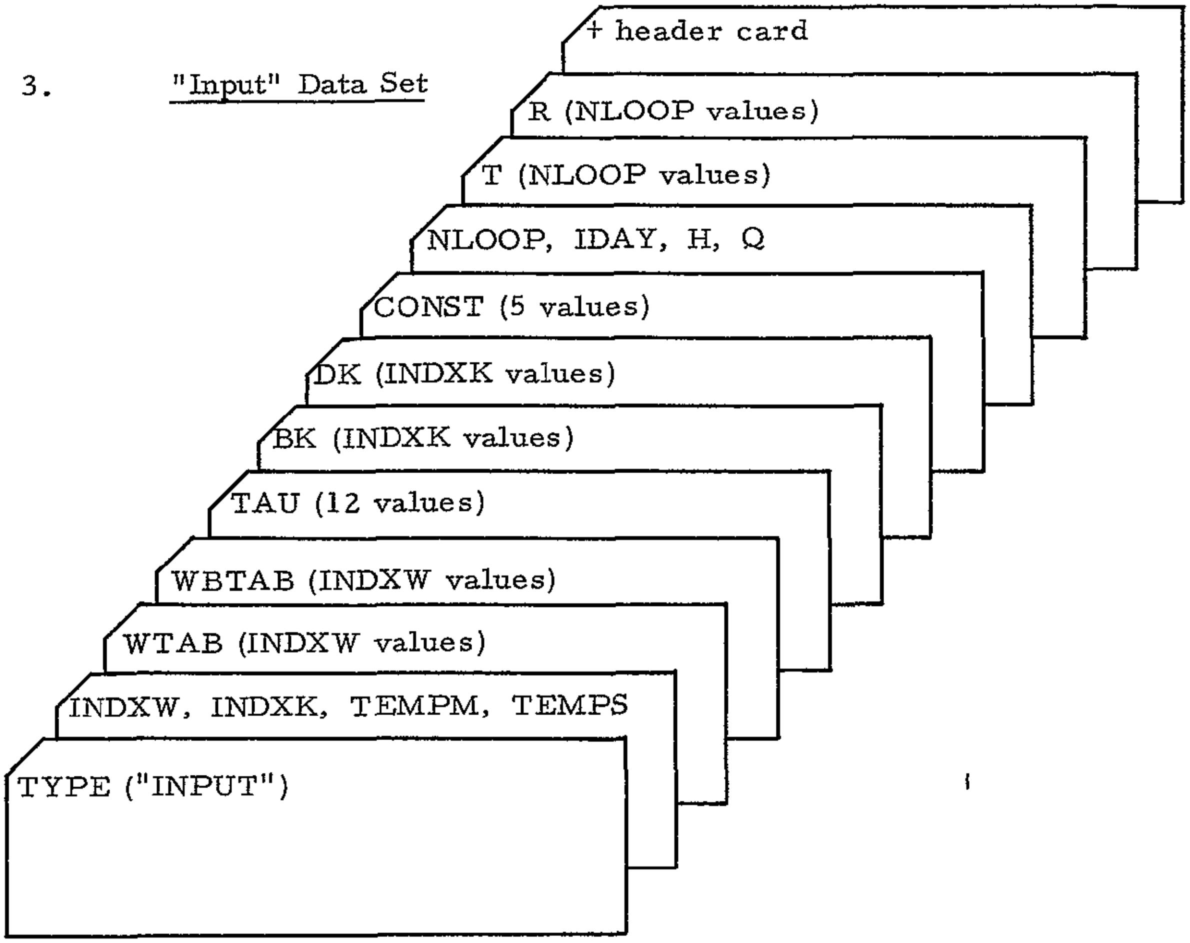


As illustrated, the data deck follows the "GO" system control card The first data card, containing the seed for the random number generator, must be present regardless of the type of input requested Each data set begins with a type card and ends with a header card There may be as many data sets as desired The blank card following the last data set terminates the program The last card in the deck must be the system control card with "/ " (slash, asterisk) punched in columns 1 and 2

2 "Actual" Data Set



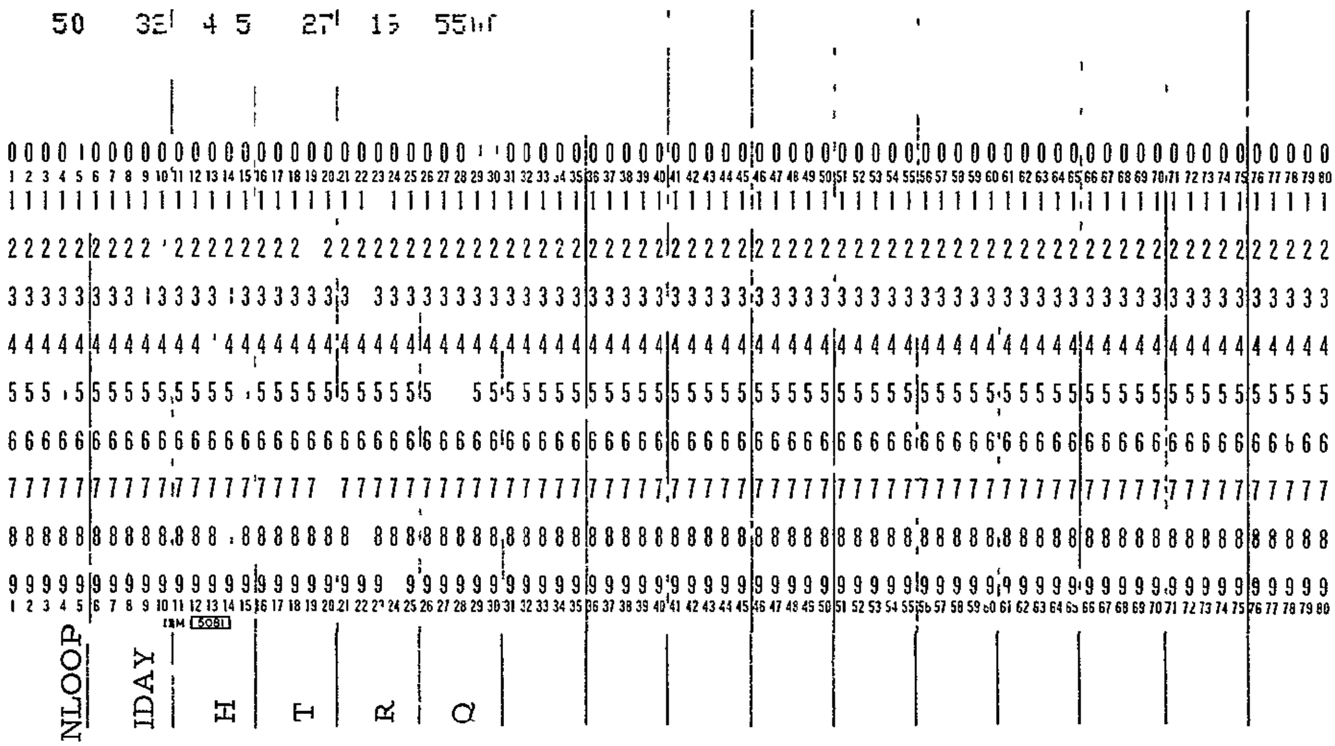
3. "Input" Data Set



4. Card Formats

With the exceptions of the type card, header cards, and the random seed, all input data cards are divided into 5-column fields Integer values are right adjusted, that is, the one's digit must be in the fifth column of the field For fractional numbers, the decimal point must be punched and the number may be placed anywhere in the field (columns 1 through 5), and each value thereafter in the next adjacent field. When there are more than 16 values in a list (as for T and R when NLOOP is more than 16), the seventeenth value goes into the first field of a new card. No special consideration is necessary since the values of NLOOP, INDXW, and INDXK determine the number of values to be read

An example follows



In this example, 50, 32, 27, and 5500 are integer values, right adjusted in their fields Values 4 5 and .19 illustrate two possible positions for fractional numbers in their fields

5 Data Definitions

The variable names are listed here in alphabetical order for easier reference The names used are those listed in the deck setups in this section and are the same names used by the program. Note All probabilities are positive values of 1 or less

BK — Table of constant factors used in determining the portion of base water release (W_B) contributing to the total flow on a given day

CONST — Table of five constants used in calculation In the following equations, C_1 indicates $CONST_1$

$$h_i = h_{i-1} - \left(\frac{T_i - TEMPM}{C_1} \right)$$

$$m_i = 1 - \left(\frac{C_2}{1 + 0823 \times \overline{R}} \right)$$

C_3 is the precipitation interception factor For no interception, $C_3 = 1$

$$Q_i = Q_i - 1 \quad 1 - \frac{1}{C_4} \quad + C_5 \ W_B(i)$$

C_4 = base flow recession time instant in days

C_5 = 26 9 (Basin area, sq mi) - $\frac{15}{1}$ K_B, cfs days per inch

DK Table of constant factors used in determining the portion of direct water release (W_Δ) contributing to the total flow on a given day.

H The initial snow depth in inches on IDAY

header card The information in 79 columns of the header card is printed at the beginning of the output set, followed by the notation "input" or "actual " For consistent output, column 1 of this card should contain a "+" sign The "+" is a printer carriage control character and will not appear as output

IDAY The starting day, in Julian, corresponding to the initial input values

INDXK The number of entries in each of the BK and DK tables. INDXK should not exceed 20

INDXW The number of entries in each of the WBTAB and WTAB tables INDXW should not exceed 20

NLOOP The number of days desired for the output set, including IDAY For type "input," NLOOP is also the number of entries in the lists of T and C NLOOP should not exceed 365.

OFFSET The sub-basin temperature offset in degrees F

PAMT	A probability/normality table of six values used in random selection of precipitation:

	above	normal	below
Probability	1	2	3
Factor	4	5	6

	where the Factor is multiplied by the appropriate RBASE value to find precipitation for each day.
PCLD	Table of probabilities of cloudiness, one value for each month.
PPREC	The probability of precipitation given cloudiness. (One value)
Q	The initial quantity of water, in inches, which is released from snow or rainfall but has not yet entered the flow Q is maintained by the program as an imaginary cummulative total of base water release and decreased according to the equation listed under CONST.
R	The initial value (or list of values), in inches, of precipitation on IDAY (or successive days) For type "actual," subsequent values of R are generated by the program
Random Seed	Initial seed value for random number generator. This value may be any odd integer of 9 digits or less. The input value is printed at the beginning of the run and a seed which may be used for the next run is printed at the end. Any single seed will generate the same sequence of random numbers Therefore, previous output may be duplicated
RBASE	Table of monthly mean precipitation per day These values are adjusted by the factor in the PAMT table
RW	The random walk table of 49 values, used in determining daily temperature offset

	+15°	+10°	+5°	0	-5°	-10°	-15°
+15°	1	8	15	22	29	36	43
+10°	2	9	16	23	30	37	44
+ 5°	3	10	17	24	31	38	45
0	4	11	18	25	32	39	46
- 5°	5	12	19	26	33	40	47
-10°	6	13	20	27	34	41	48
-15°	7	14	21	28	35	42	49

Note When punching these cards, use seven fields on each of seven cards To use this table, first determine offset of yesterday's temperature Enter the appropriate row and, by comparing the probabilities with a random number, determine the offset to be added to the monthly mean for today's temperature

T — The initial value (or list of values), in degrees F , of temperature on IDAY (or successive days) For type "actual," subsequent values of T are generated by the program

TAU — Table of 12 integer values, a number of days, used as an index in summing previous rainfall, ($\overline{R}$ in equation under CONST) for calculation of the soil moisture factor.

TEMPM — Critical temperature for snow melt, in degrees F. Melt occurs when temperature is equal to or greater than TEMPM

TEMPS — Critical temperature for snowfall in deg F Any precipitation is snowfall when the temperature is equal to or less than TEMPS

TMEAN — Table of monthly mean temperatures for the desired region. These are corrected for sub-basin by the OFFSET

type card — Column 1 of this card determines the type of input desired. The words "INPUT" or "ACTUAL" may be punched but only column 1 will be examined by the program The symbols "I", "A", "F", and "blank" are recognized Any other symbol will cause an error termination of the program A blank causes normal termination Recognition of "F" is supplied for future modification of the program. An "F" type card will not generate information

WBTAB Table of base water release values corresponding to WTAB

WTAB Table of net water release values corresponding to WBTAB The tables WTAB and WBTAB may be any tabulation of relationships between W and W_B suitable for linear interpolation Each table may have up to 20 entries

B Computer Program Description

The BRM program is composed of the following basic subroutines

MAIN Reads the random seed and type cards By comparison with the first letter of each type card, control goes to INPUT 1, INPUT 2, or INPUT 3

INPUT 1 Reads an "input" type data set, calls BRM in a loop on NLOOP, and prints the filled arrays

INPUT 2 Reads an "actual" type data set In a loop on NLOOP, it generates by random selection at T and at R and calls BRM It then prints the filled arrays

INPUT 3 A dummy subroutine which may be used for future modification. It is called when an "F" type card is recognized

BRM Does calculations on intial values (indexed I-1 in arrays) to determine H, E, W, FLOW and SUMF (indexed I) for one day

Supporting subroutines are these

SETUP Initializes C, E, W, FLOW, and SUMF

DATE Determines the month corresponding to the Julian date IDAY (1)

DAYINC Increments IDAY, MONTH when necessary, and resets IDAY and MONTH to 1 for change in year.

READ 1 Reads tables and constants common to both INPUT 1 and INPUT 2

PRINT 1 — Prints header card and arrays IDAY, T, C, R, H, E, W, WB, WD, FLOW, and SUMF. It counts 50 lines per page for new column headings

PRINT 2 — Prints input data ready by READ 1

PRINT 3 — Prints probability tables and other input values used by INPUT 2

RANDU — The random number generator, a copy of one of the HASP system library routines

Much data is stored in COMMON blank COMMON, labeled CAST, and labeled PROB Except MONTH, WB, and WD, data entries are described in the next section WB and WD are the base and direct water release values found from the calculated W MONTH is an integer from 1 to 12.

Important local variables are these

I — Index on the CAST arrays incremented after each call to BRM

I1, I2, Y — Used in RANDU calling sequence. I1 is the input seed, I2 the new seed, and Y the random number between 0 and 1

DELTAE, DELRNS, DELRS, — Intermediate variables used in BRM

A, F1, F2, S — A is the soil moisture factor, m

MUNTH — Data array consisting of Julian date of last day of each month

C Flowcharts and Program Listing

Flowcharts for the program are presented in Exhibit B-28, starting on the next page A sample computer model output follows in Exhibit B-29 A copy of the computer program listing is included as an attachment to this appendix

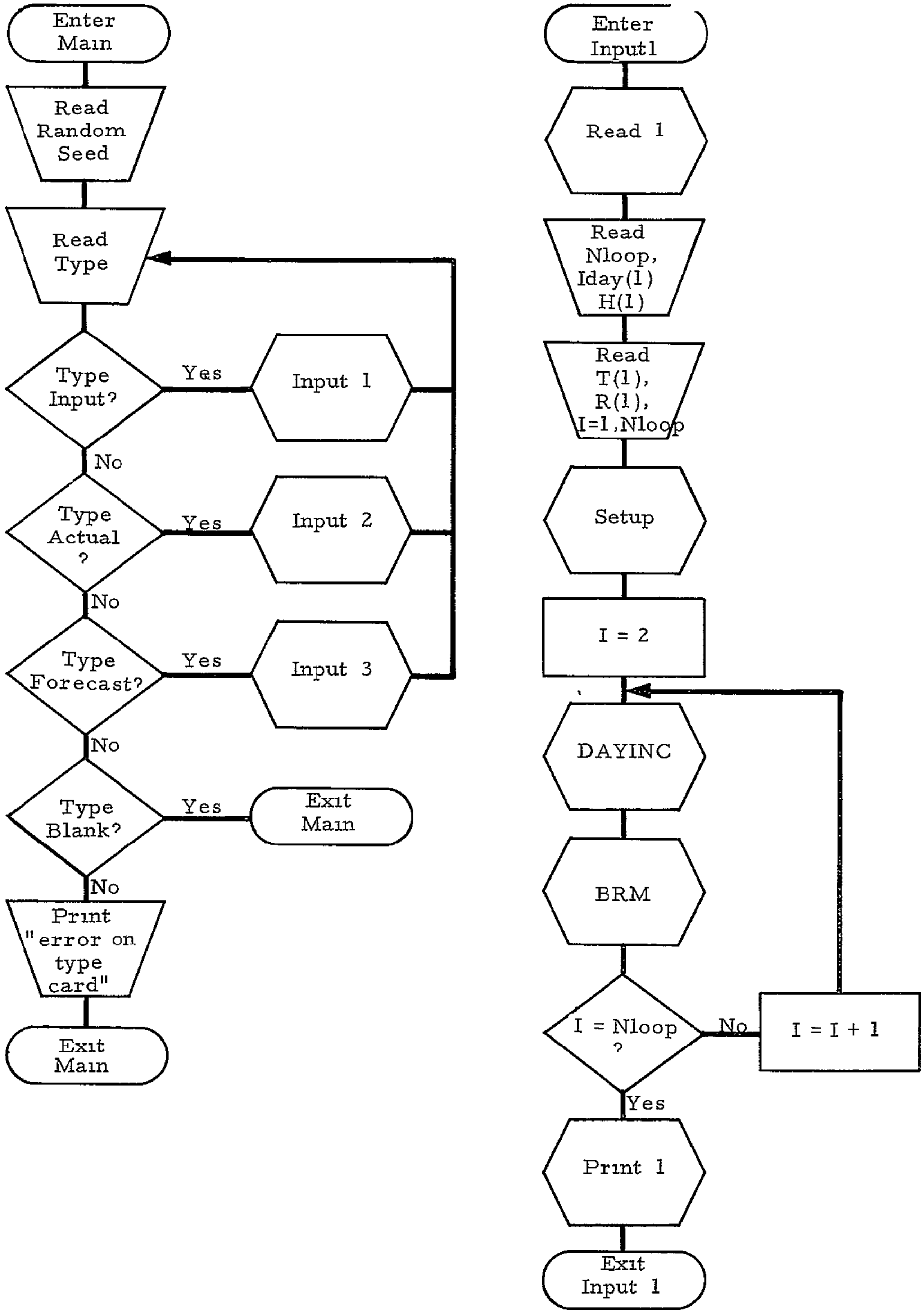


EXHIBIT B-28 BASIN RUNOFF MODEL COMPUTER PROGRAM FLOWCHARTS

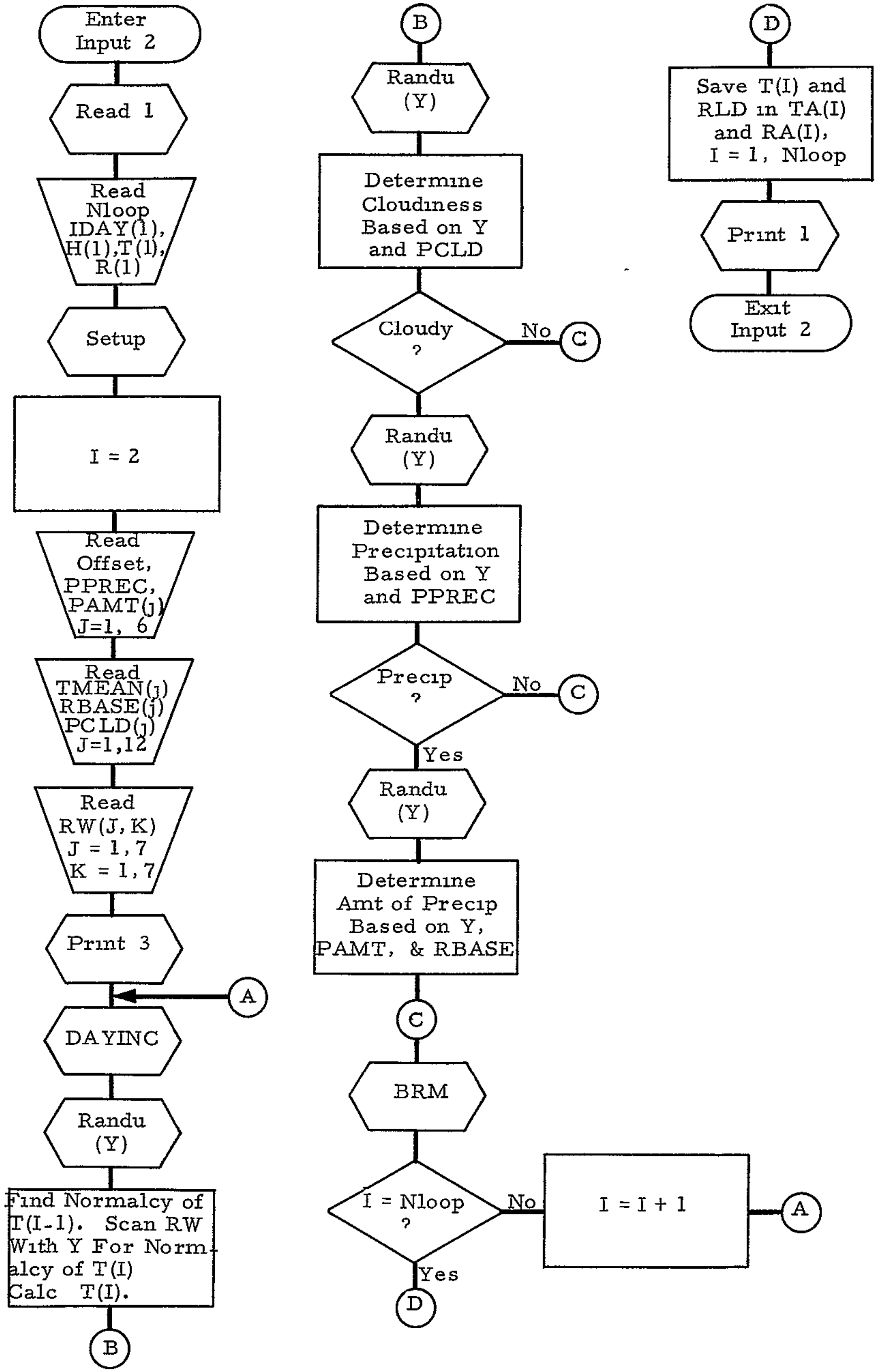


EXHIBIT B-28 (Continued)

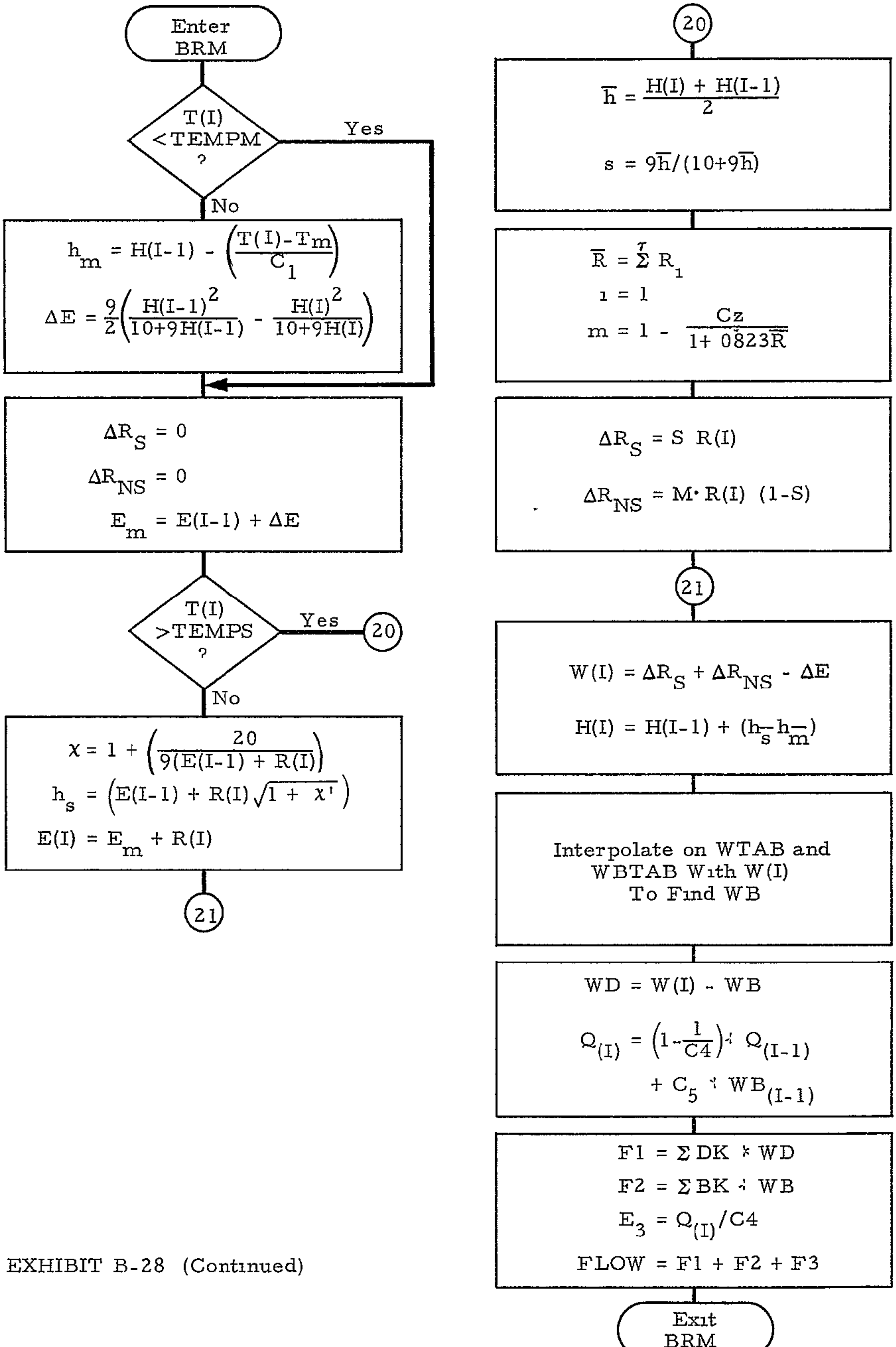


EXHIBIT B-28 (Continued)

EXHIBIT B-29 SAMPLE COMPUTER MODEL OUTPUT

DAY	T	C*	R	H	E	W	WB	WD	FLOW	SUM F
9	37.00	0	0.03	4.32	1.72	0.04	0.03	0.01	179.	38000.
10	35.00	0	0.01	4.34	1.73	0.01	0.00	0.00	216.	38216.
11	32.00	0	0.0	4.34	1.73	0.0	0.0	0.0	232.	38448.
12	34.00	0	0.01	4 36	1.74	0.00	0.00	0.00	237.	38685.
13	32.00	0	0.0	4.36	1 74	0.0	0.0	0.0	229.	38914.
14	34.00	0	0.03	4.42	1.76	0.00	0.00	0.00	222.	39136.
15	35.00	0	0.0	4.40	1.76	0.01	0.00	0.00	217.	39352.
16	41.00	0	0.0	4.34	1.73	0.03	0.02	0.01	217.	39569.
17	38.00	0	0.0	4.30	1.71	0.02	0.01	0.01	232.	39801.
18	34.00	0	0.0	4.29	1.70	0.00	0.00	0.00	248.	40049.
19	32.00	0	0.0	4.29	1.70	0.0	0.0	0.0	251.	40300.
20	28.00	0	0.0	4.29	1.70	0.0	0.0	0.0	238.	40538.
21	27.00	0	0.0	4.29	1.70	0.0	0.0	0.0	223.	40761.
22	25.00	0	0.0	4.29	1.70	0.0	0.0	0.0	206.	40966.
23	23.00	0	0.0	4.29	1.70	0.0	0.0	0.0	195.	41161.
24	23.00	0	0.0	4.29	1.70	0.0	0.0	0.0	180.	41341.
25	21.00	0	0.0	4.29	1.70	0.0	0.0	0.0	171.	41512.
26	21.00	0	0.0	4.29	1.70	0.0	0.0	0.0	161.	41673.
27	21.00	0	0.03	4.36	1.74	0.0	0.0	0.0	152.	41825.
28	22.00	0	0.15	4.66	1.89	0.0	0.0	0.0	144.	41969.
29	21.00	0	0.24	5.18	2.13	0.0	0.0	0.0	137.	42105.
30	23.00	0	0.0	5.18	2.13	0.0	0.0	0.0	130.	42235.
31	32.00	0	0.0	5.18	2.13	0.0	0.0	0.0	122.	42357.
32	33.00	0	0.01	5.20	2.14	0 0	0.0	0.0	117.	42474.
33	33.00	0	0.12	5.45	2.26	0.0	0.0	0.0	114.	42588.
34	36.00	0	0.0	5.43	2.25	0.01	0.01	0.00	113.	42701.
35	34.00	0	0.0	5.42	2.25	0.00	0.00	0.00	120.	42821.
36	34.00	0	0.18	5.78	2.42	0.00	0.00	0.00	126.	42947.
37	35.00	0	0.10	5.98	2.52	0.01	0.00	0.00	132.	43079.
38	37.00	0	0.05	5.95	2.51	0.06	0.04	0.02	142.	43220.
39	35.00	0	0.00	5.94	2.50	0.01	0.00	0.00	190.	43410.
40	33.00	0	0.04	6.02	2.54	0.0	0.0	0.0	223.	43633.
41	40.00	0	0.23	5.97	2.52	0.23	0.11	0.12	269.	43902.
42	40.00	0	0.26	5.91	2.49	0.25	0.11	0.14	515.	44417.
43	38.00	0	0.17	5.87	2.47	0.17	0.10	0.06	953.	45370.
Julian Date	Temperature	Clouds	Precipitation	Snow Water Equiv at Basin Divide	Snow Water Equiv over entire Basin	Total Water Release	Base Water Release	Direct Water Release	River Flow from Basin	Cumulative Daily River Flow from Basin

Note Clouds all zero because real input data were forced for T and R

V SCENARIO OF OBSERVATIONS AND WEATHER EVENTS, SOUTH FORK, FLATHEAD RIVER BASIN

Beginning on November 1, data was collected from the satellite-supported system for the management of the streamflow of the South Fork of Flathead River, Montana During the months of November and December, observations of the area showed the river was in its low flow stage Runoff was principally from ground water, because the precipitation, although heavy, fell mostly as snow. What rain did fall did not cause significant runoff because of the soil moisture deficit which had built up in previous months Runoff was further retarded by several days of below 20° F mean daily temperatures These low temperatures stored water as ice in shallow bodies of water and in stream margins Mean daily temperatures during the two months dropped from 40° F to 15° F During the two months, nineteen cloud-free days enabled the satellite system to observe that the deciduous trees had completed their change of color, and the snowpack had begun to accumulate

The satellite system compared the observations for November and December with all past records of the timing and extent of the phenomena which had been observed On January 1, using this comparison and incorporating the available climatic projections, short-term and extended weather forecasts, the satellite-supported system issued a prediction of total seasonal runoff to July 1

Streamflow remained low during January with only a minor increase in the middle of the month The system monitored large storms, from outside the basin, during the middle of the month which brought heavy snows, between 12 January and 25 January Especially during this period, the size and depth of the snowpack continued to increase Although there was a minor increase in runoff during the snow storm, severely low air temperatures restricted runoff principally to the ground water Eight cloud-free days during the month enabled the satellite system to confirm that deciduous trees were completely bare and assess the snowpack

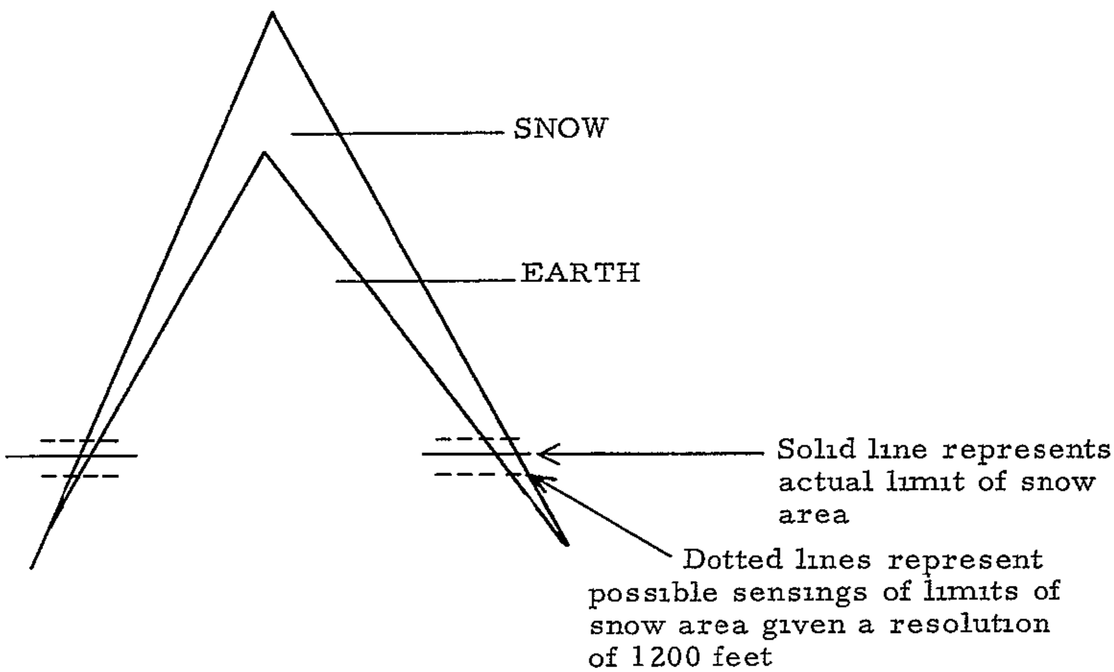
Mean daily temperatures during February averaged 10° F below freezing, virtually eliminating all surface runoff Very low temperatures caused a minor reduction in stream flow on 18 February Precipitation, which was only light snow, continued the snowpack buildup The bareness of the deciduous trees and the color loss of some of the coniferous trees were associated with an evapotranspiration of zero Similar conditions obtained through March, although temperatures averaged near the freezing point During February and March there were a total of 12 cloud-free days During March, the snowpack reached its maximum for the season Based upon its analysis of all the components of its forecast model, the system issued a prediction of total seasonal water runoff to July 1 and a 30 day forecast of daily stream flow through May 1

During the period between April 1 and April 23, light precipitation fell as a mixture of rain and snow, as mean daily temperatures were mostly above 40° F The rain fell on the snowpack rather than on bare ground, so much of the rain which fell ran off very rapidly The beginning of snow melt started to reduce the size of the snowpack, resulting in an additional runoff The satellite system observed during the 10 cloud-free days during the period that deciduous trees had begun to leaf and coniferous trees showed some new light green growth Evapotranspiration increased The result of the higher temperatures was an increase in streamflow to 5 times that of February

On 23 April the satellite-supported system began to monitor the beginning of a storm in the eastern Pacific The system continued to monitor the storm during its life over the ocean and over the land Between 23 April and 29 April, light rain continued over the Flathead Basin Together with temperatures with a daily mean over 50° F , this rain caused an increase in streamflow to double that of mid-April Evapotranspiration increased, but it did not affect runoff significantly There was one cloud-free day between April 23 and April 29 On April 29, with the forecast of heavy rain from the Pacific storm for the Flathead Basin for April 30, the system issued a prediction of the stream flow for May 1 This prediction made full use of the comparison of the situation on April 20 with actual events which occurred during April and confirmed earlier daily predictions

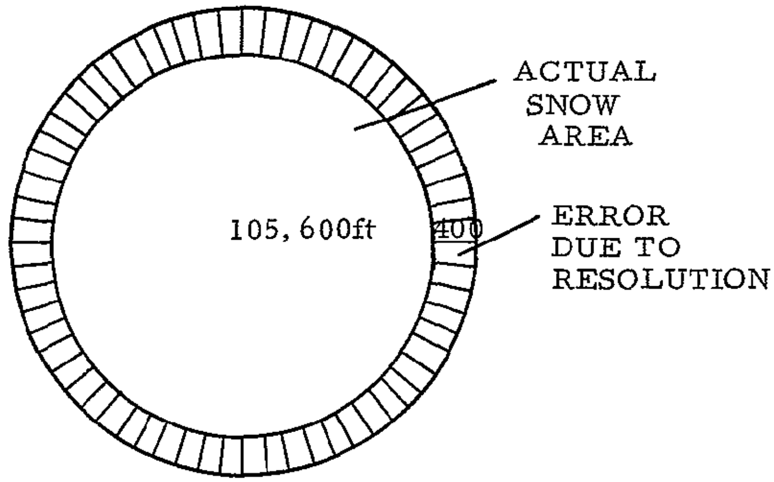
VI - DISCUSSION OF ERRORS DUE TO SENSOR RESOLUTION

The errors due to the current resolution of the sensors in the hydrology system can be computed in the following manner The buildup of snow on a mountain peak can be depicted approximately by the following diagram



Once the boundaries of the snow-covered area are defined, the amount of snow within those boundaries can be calculated The satellite system, of course, would view the snow cover from above This view can be approximated by a circle

With repeated sensings, the error due to resolution can be reduced by dividing it by the square root of the number of sensings Assuming that there are nine (9) sensings of a given peak, the resolution of 1200 feet is then reduced to $\frac{1200}{\sqrt{9}}$ or 400 feet Assuming that a single area of snow cover within a basin would be a circle with a radius of 20 miles, the area of snow cover plus the possible error of 400 feet can be depicted in the following way



The error due to resolution, then, is equal to the area of the shaded portion divided by the area of the entire surface

Area of the entire surface

$$A = \pi r^2$$

$$A = 3\ 17\ (105{,}600 + 400)^2$$

$$A = 3\ 17\ (106{,}000)^2$$

$$A = 35{,}618{,}120{,}000$$

Area of the actual snow area

$$A = \pi r^2$$

$$A = 3\ 17\ (105{,}600)^2$$

$$A = 35{,}349{,}811{,}200$$

Subtracting

$$\begin{array}{r} 35{,}618{,}120{,}000 \\ \underline{35{,}349{,}811{,}200} \\ 268{,}308{,}800 \end{array}$$ Area of the error due to resolution

Dividing

$$\frac{268,308,800}{35,618,120,000} = 0075$$

Therefore, the error due to resolution in this example is 0075

If the resolution is decreased to 1850 feet, the error for the same circular area (radius 20 miles) would be 012 after nine (9) sensings

Because the volume of snow is much greater at the elevations which are higher than the points at which the errors due to resolution would occur, the errors in estimation will not be as great as those calculated above

VII WEATHER FORECASTING

Considerable data on the accuracy of weather forecasting has been collected, the available material is presented in the exhibits in this section There is no single measure of forecasting accuracy, since the measure depends on the kind of information which is desired Much of the literature concerns itself with the degree of improvement that a forecaster can achieve beyond the simple application of climatology and near-term persistence It is quite possible to do worse than to rely on these two tools While the data in the exhibits may not seem very encouraging, there is a considerable expenditure under way to improve matters A new international observation system, the World Weather Watch, is being implemented The purpose is a more comprehensive system for observation, communication, processing, and analysis 1979 is planned as the operational date

Most of the material in the exhibits is self-explanatory Exhibit B-30 explains the nature and bases of forecasting methods and indicates the direction of expected improvements Exhibits B-31 to B-36 deal with various assessments of temperature and precipitation forecasting skill The rapid decline in capability from the first to the third 12-hour period in the future is evident

Exhibits B-37, B-38, and B-39 are conditional probability matrices All of the columns should add to 100 percent The entries are the percentage of the particular type of forecast associated with the indicated outcome Taking the 5-day temperature matrix in Exhibit B-37 as an example of the "much below" forecasts, 44 percent of the outcomes were actually much below normal, 39 percent were "below," etc

Exhibit B-40 interprets the numerical class limits and "normal" for a particular period and area For Spokane, the normal temperature in June and July is 66 8^{o} F , and the Above and Below class limits are 8^{o} to 2 8^{o} F away from normal for a 30-day period average The length of the period, as well as the season, covered by the outlook or forecast affects the class limit values A 5-day forecast will have wider class limits than one for 30 days essentially because there is less opportunity

EXHIBIT B-30 WEATHER PREDICTION - U S , 1970, 1979, 1989

Ambient Temperature and Precipitation at the Ground Level

RANGE	1970	1979	1989
SHORT RANGE Very Short Range Forecast 0 - 12 hours	Hourly weather conditions specific values of temperature precipitation & other weather elements (cloudiness ceiling visibility, etc) Issued every two hours For current forecast skill see Tables 2 7	Great advances can be expected in the very short range forecasts during this period	Great advances can be expected in the very short range forecasts during this period
Short Range Forecast 0 - 72 hours	Six-hourly weather conditions specific temperature values and ranges of values of precipitation and other weather elements Most reliable out to 48 hours rapid degradation beyond 48 hours Issued every six hours For current forecast skill see Tables 2-7	Increasing skill in forecasting specific values of weather conditions, particularly precipitation values Increased reliability out to 72 hours	Increasing skill in forecasting specific values of weather conditions particularly precipitation values Reliable out to 72 hours
EXTENDED RANGE 7-Day Outlook	Temperature average or mean conditions for the entire seven-day period Forecast — Class* Much Above — 125 Above — 25 Normal — 25 Below — 25 Much Below — 125 Precipitation - total amount which falls during the entire seven day period Forecast — Class* 1 Heavy — 333 Medium — 333 Light — 333 2 Heavy — 40 Moderate — 27 No Precip — 33 3 Precip — 34 No Precip — 66 Issued daily Most reliable for first five days For current skill of 5-Day outlook with respect to climatology see Table 8	Increased skill, particularly for sixth and seventh day Issued daily	

EXHIBIT B-30 (Continued)

RANGE	1970	1979	1989
14-Day Outlook		Temperature - day to day average or mean condition Forecast classes same as 7-Day Forecast Precipitation - total amount which falls each day Forecast classes same as 7-Day Forecast Most reliable out to 7 days rapid deterioration beyond 7 days Issued two times during week	Increasing skill particularly for later part of period Issued daily
LONG RANGE 30-Day Outlook	Temperature average or mean condition for the entire 30-day period plus some detail for first two weeks Forecast / Class* Much Above 125 Above 25 Normal 25 Below 25 Much Below 125 Precipitation - total amount which falls during the entire 30-day period, plus some detail for first two weeks Forecast / Class* Heavy 333 Moderate 333 Light 333 Issued two times during month For current skill of outlook with respect to climatology, see Table 9	Weekly timing of temperature and precipitation classes Increasing skill Monthly means forecast with more than double 1970 skill conditioned on degree of success attained by 14-day outlook (above) Issued two times during month	Increasing skill
Seasonal Outlook**	Temperature - average or mean condition for the entire three months period Forecast / Class* Above Normal 333 Normal 333 Below Normal 333 Precipitation total amount which falls during the entire three months period		Issued four times a year for the season one year ahead

EXHIBIT B-30 (Continued)

RANGE	1970	1979	1989
Seasonal Outlook** (Cont)	**Forecast** — **Class*** Heavy 333 Moderate 333 Light 333 Issued 23 November for Winter Season 21 February for Spring Season 24 May for Summer Season and 24 August for Autumn Season For current skill of outlook with respect to climatology, see Table 10		
90-Day Outlook		Temperature - average or mean condition for each month in the 90-day period **Forecast** — **Class*** Above 33 Normal 33 Below 33 Precipitation total amount which falls during the entire 90 day period **Forecast** — **Class*** Heavy 333 Moderate 333 Light 333 Issued the end of each month for the next three months	Increasing skill in temperature outlook less *or none in precipitation* Temperature same as 1979 Precipitation - total amount which falls during each month in the 90-day period **Forecast** — **Class*** Heavy 333 Moderate 333 Light 333 Issued the end of each month for the next three months
6-Month Outlook		*Temperature - average or mean condition for* the entire last three months of the period **Forecast** — **Class*** Above Normal 333 Normal 333 Below Normal 333 Precipitation - total amount which falls during the entire last three months of the period **Forecast** — **Class*** Heavy 333 Moderate 333 Light 333 Issued 3- November for the Spring Season 28 February for the Summer Season 31 May for *the Autumn Season and 30 August for the* Winter Season	*Same as 1979 except temperature and precipita-* tion values for each month Increased skill, especially in precipitation outlook

EXHIBIT B-30 (Continued)

RANGE	1970	1979	1989
VERY LONG RANGE			
5-Year Outlook			Evaluation of average climatic (primarily temperature and precipitation) deviation from normal for the entire period Issued 31 December each year

*Forecast classes - climatological or change probability of occurrence of the classes

5-Day Forecast Area to which 1 2 and 3 apply change each month depending on amount of precipitation

1 Wetter part of country
2 Drier part of country
3 Driest part of country - July and August includes U S part of Columbia River Basin
- September, includes the drier interior parts of Oregon and Washington

**Seasons

Winter December January, February
Spring - March, April May
Summer - June July August
Autumn - September, October November

EXHIBIT B-31 PRECIPITATION FORECASTS*, WESTERN REGION - UNITED STATES

Index of Forecast Accuracy	Fcst Issued by	April - September 1966			October 1966 - March 1967		
		Period (Hours)			Period (Hours)		
		0-12	12-24	24-36	0-12	12-24	24-36
Percent Correct (1)	LFO (5)	92 4	90 5	90 8	88 7	82 5	81 6
	AFC (6)	90 9	90 3	90.4	86 6	82 6	81 8
Post Agreement (2)	LFO (5)	58	42	43	73	59	58
	AFC (6)	47	40	36	68	59	59
Prefigurence (3)	LFO (5)	44	23	18	75	55	51
	AFC (6)	33	21	13	71	54	50
Threat Score (4)	LFO (5)	34	18	14	59	40	37
	AFC (6)	24	16	11	53	39	37

*Precipitation or no precipitation event - the accumulation of 0 01 inch of rainfall or water equivalent (melted snow) in the forecast period

(1) Percent Correct = $\frac{\text{Number of Correct Forecasts}}{\text{Total Number of Forecasts}} \times 100$

(2) Post Agreement = $\frac{\text{Number of Correct Precipitation Forecasts}}{\text{Number of Precipitation Forecasts}}$

(3) Prefigurence = $\frac{\text{Number of Correct Precipitation Forecasts}}{\text{Number of Precipitation Occurrences}}$

(4) Threat Score = $\frac{\text{Number of Correct Precipitation Forecasts}}{\text{Number of Precipitation Forecasts + Number of Precipitation Occurrences − Number of Correct Precipitation Forecasts}}$

(5) LFO = Local Forcast Offices include five stations in the Columbia River Basin, and a large number outside the Basin in the Western United States

(6) AFC = Area Forecast Centers in the Western United States (Figure 5)

EXHIBIT B-32 PRECIPITATION FORECASTS*, PERCENT IMPROVEMENT OVER CLIMATOLOGY, NORTHWESTERN UNITED STATES APRIL 1966 - MARCH 1967

Forecast Issued by	Period (hours)		
	0 - 12	12 - 24	24 - 36
Local Forecast Offices (1)	37 8	17 0	29 5
Area Forecast Centers (2)	27 9	16 3	9 4

* Precipitation or no precipitation event - the accumulation of 0 01 inch of rainfall or water equivalent (melted snow) in the forecast period

(1) Local Forecast Offices include five stations in the Columbia River Basin, Missoula, Spokane, Yakima, Boise, and Pocatello, and nine in neighboring areas outside the Basin

(2) Three Area Forecast Centers, Seattle, Great Falls and Salt Lake City, provide forecasts for adjacent parts of the U S portion of the Columbia River Basin (Figure 5)

EXHIBIT B-33 QUANTITATIVE PRECIPITATION FORECAST (QPF) VERIFICATION FOR THE UNITED STATES

A Post agreement Area correct divided by area forecast, $\frac{A_c}{A_f}$

B Prefigurence Area correct divided by area observed, $\frac{A_c}{A_o}$

In overforecasting, the prefigurence is larger than the post agreement In underforecasting, the post agreement is larger than the prefigurence

C Threat score Area correct divided by the area forecast plus area observed minus area correct, $\frac{A_c}{A_f + A_o - A_c}$

D Annual 1967 QPF Verification Statistics

FCST ISOHYET (inches)	FCST PERIOD (hours)	FCST Prepared Before Beginning of Verification Period (hours)	Post Agree-ment %	Pre-figurence %	Threat Score %	Bias A_f/A_o %
0 01	12	4	59	57	41	98
0 50	12	4	28	39	19	141
0 50	24	1	37	44	25	117
Mean 7 years - Approximate		Winter	42	55	31	130
		Summer	31	38	21	122
1 00	12	4	18	27	12	154
1 00	24	1	26	31	17	119
Mean 7 years - Approximate		Winter	32	46	23	142
		Summer	21	27	13	129
1 00	24	16	19	19	10	100
1 00	24	25	15	14	8	90

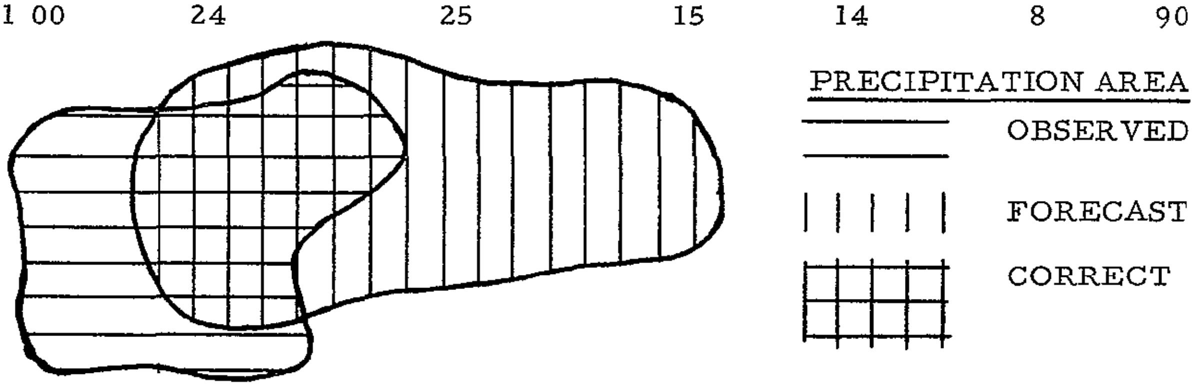


EXHIBIT B-34 HEAVY SNOW* WARNING VERIFICATION FOR THE UNITED STATES OF FORECASTS ISSUED BY REGIONAL FORECAST CENTERS

A Post Agreement Area correct divided by area forecast, A_c/A_f

B Prefigurence Area correct divided by area observed, A_c/A_o

In overforecasting, the prefigurence is larger than the post agreement In underforecasting, the post agreement is larger than the prefigurence

C Threat Score Area correct divided by the area forecast plus area observed minus area correct, $A_c/A_f + A_o - A_c$

D Bias, A_f/A_o

Verification	1966-67	1967-68
Total Area Forecast #	1075 6	803.2
Total Area Observed #	748 0	461 4
Total Area Correct #	277 7	148 8
Post Agreement	258	185
Prefigurence	371	322
Threat	180	133
Bias	1 44	1 74

*Heavy snow is defined as 4 inches of snow in the specified 12-hour periods of 0000Z to 1200Z or 1200Z to 0000Z Forecast is prepared 4 hours before the beginning of verification period

#Areas are expressed in arbitrary units Heavy snow forecasts for mountain areas only were not evaluated unless they were part of a more general area of heavy snow forecast Observations of heavy snow from these higher evaluations were not routinely available for the periods concerned

AREAS
- Observed
- Forecast
- Correct

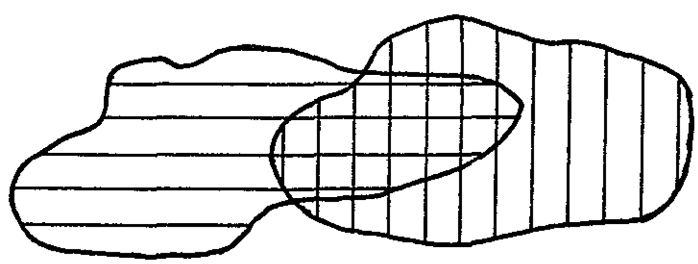


EXHIBIT B-35 TEMPERATURE FORECAST*, WESTERN UNITED STATES

Index of Forecast Accuracy	Fcst Issued by	April - September 1966 Period (Hours) 0-12	12-24	24-36	October 1966 - March 19 Period (Hours) 0-12	12-24	24-36
Mean Absolute Temperature Forecast Error (1)	LFO (5)	3 09	3 40	4 79	3 18	4 23	4 74
	AFC (6)	3 48	3 77	5 11	3 58	4 52	4 97
Mean Absolute 24 Hour Observed Temperature Change (2)	LFO (5)	4 90	4 11	4 88	5 21	5 47	5 16
	AFC (6)	4 90	4 11	4 88	5 21	5 47	5 16
Percent Improvement Over Observed Change (3)	LFO (5)	37 04	17 31	1 86	38 97	22 70	8 17
	AFC (6)	29 12	8 30	-4 68	31 35	17 41	3 69
Mean Absolute Abnormal Temperature Forecast Error (4)	LFO (5)	3 91	5 60	6 80	4 03	5 76	6 96
	AFC (6)	4 32	6 28	7 19	4 66	6 18	7 15

* Maximum and minimum temperature in the forecast period

(1) Mean Absolute Temperature Forecast Error $= \frac{1}{N} \sum (T_F - T_O)$

T_F = Temperature Forecast T_O = Temperature Observed

(2) Mean Absolute 24 Hour Observed Temperature Change $= \frac{1}{N} \sum (T_{Max} - T_{Min})$

(3) Percent Improvement Over Observed Change =

$$\frac{\text{Mean Absolute 24 Hour Observed Temperature Change} - \text{Mean Absolute Temperature Forecast Error}}{\text{Mean Absolute 24 Hour Observed Temperature Change}}$$

(4) Mean Absolute Abnormal Temperature Forecast Error = for the subset of forecasts in which the observed temperature was 8^{o}F less, or 8^{o}F greater than the mean maximum or mean minimum temperature for the month

(5) LFO = Local Forecast Offices include five stations in the Columbia River Basin, and a large number outside the Basin in the Western United States

(6) AFC = Area Forecast Centers in the Western United States (Figure 5)

EXHIBIT B-36 TEMPERATURE FORECAST*, PERCENT IMPROVEMENT OVER OBSERVED CHANGE, NORTHWESTERN UNITED STATES, APRIL 1966 - MARCH 1967

Forecast Issued by	Period (Hours)		
	0-12	12-24	24-36
Local Forecast Offices (1)	39 5	22 4	5 9
Area Forecast Centers (2)	33 2	17 4	5 0

* Maximum and minimum temperature in the forecast period

(1) Local Forecast Offices include five stations in the Columbia River Basin, Boise, Missoula, Spokane, Yakima, and Pocatello and nine in neighboring areas outside the Basin

(2) Three Area Forecast Centers, Seattle, Great Falls and Salt Lake City provide forecasts for adjacent parts of the U S portion of the Columbia River Basin

EXHIBIT B-37 ›-DAY OUTLOOK PROBABILITY OF ACHIEVING A FORECAST CLASS FOR THE UNITED STATES

5-Day Temperature 1962-68
% Prob of Obs.

Forecast

	MB	B	N	A	MA	Obs	Clim
MB	44	20	8	3	1	13	12.5
B	39	39	30	17	7	28	25
N	11	23	29	25	15	23	25
A	5	15	26	38	37	25	25
MA	1	3	7	17	40	11	12 5

5-Day Precipitation 1962-68
% Prob of Obs

Forecast

(1)

	L	M	H	Obs	Clim
L	45	35	24	33	33 3
M	31	35	34	34	33 3
H	24	30	42	33	33 3

% Prob of Obs

(2)

	NP	M	H	Obs	Clim
NP	52	38	30	41	40
M	24	29	29	27	27
H	24	33	41	32	33

% Prob of Obs

(3)

	NP	P	Obs	Clim
NP	73	49	66	66
P	27	51	34	34

*5-Day Precipitation Areas to which (1), (2), and (3) apply change each month depending on amount of total precipitation.

(1) Wetter part of country
(2) Drier part of country
(3) Driest part of country - July and August, includes U S part of Columbia River Basin September includes the interior parts of Oregon and Washington

NP = No Precipitation
P = Precipitation

EXHIBIT B-38 30-DAY OUTLOOK PROBABILITY OF ACHIEVING A FORECAST CLASS FOR THE UNITED STATES

30-Day Temperature 1954-67
% Prob. of Obs

Forecast

	MB	B	N	A	MA	Obs	Clim
MB	24	17	12	10	5	13	12 5
B	33	29	26	22	16	26	25
N	23	26	26	25	22	25	25
A	15	20	24	26	28	23	25
MA	5	8	12	17	29	13	12.5

30-Day Precipitation 1954-67
% Prob of Obs

Forecast

	L	M	H	Obs	Clim
L	39	35	31	35	33 3
M	34	36	36	35	33 3
H	27	29	33	30	33 3

EXHIBIT B-39 SEASONAL OUTLOOK PROBABILITY OF ACHIEVING A FORECAST CLASS FOR THE UNITED STATES

Seasonal Temperature 1959-68
% Prob. of Obs

Forecast

	B	N	A	Obs	Clim
B	49	42	29	41	33 3
N	29	30	31	30	33.3
A	22	28	40	29	33.3

Seasonal Precipitation 1959-68
% Prob of Obs

Forecast

	L	M	H	Obs	Clim.
L	36	32	30	33	33 3
M	32	35	36	34	33 3
H	32	33	34	33	33.3

EXHIBIT B-40 30-DAY WEATHER OUTLOOK
Normals and Class Limits for
June-July, Columbia River Basin

STATION*	TEMPERATURE (°F)			PRECIPITATION (Inches)	
	Norm	A B	MA MB	Hvy	Lgt
WASHINGTON					
Spokane	66 8	8	2 8	92	48
OREGON					
Portland	65 1	6	1 9	1 30	54
Pendleton	70 3	7	2 5	92	32
Burns	65 4	8	2 6	78	28
IDAHO					
Boise	71 3	8	2 7	54	20
Pocatello	68 5	9	3 0	1 12	43
MONTANA					
Missoula	63.5	8	2 7	1 90	90

*Stations in the Columbia River Basin for which temperature and precipitation predictions are verified for all weather outlooks

These class limits have been determined separately for every month and station from available uniform records in such a way that, on the average, one-eighth of the observed temperatures will fall in each of the much above (MA) and much below (MB) normal classes, and one-quarter in each of the above (A), below (B), and near (N) normal categories Temperature limits expressed in °F are distributed symmetrically about the normal values, so that the numerical value of the beginning of each class other than near normal can be determined by addition to, or subtraction from, the normal (NORM) of the values in the columns headed A, B or MA, MB Temperatures between the beginning of the above and below class are classified as near normal

The precipitation limits have been computed so that one-third of the observed amounts should occur in each of three classes Amounts (expressed in inches) are classified as heavy if equal to or greater than the value in the column headed HVY, and light if less than the value in the column headed LGT Precipitation amounts between these values are classified as moderate Exception must be made for a number of western stations during the dry season, the value 01 inches in the HVY column then indicates that any measurable precipitation must be classified as heavy, and that no distinction can be drawn between the moderate and light classes

ATTACHMENT

COMPUTER PROGRAM LISTING

```
0001         SUBROUTINE BRM(I)
0002         COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),KW(7,7),RBASE(12),
            1 PCLD(12)
0003         COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
            1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
0004         COMMON            CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
            1 BK(20),DK(20),TAU(12),INDXW,INDXK
0005         INTEGER*4 TAU
0006         INTEGER*4 C
0007         DELTAE=0
0008         H(I)=H(I-1)
0009         IF(T(I).LT.TEMPM) GO TO 30
0010         H(I)=H(I-1)-((T(I)-TEMPM)/CONST(1))
0011         IF(H(I).LT.0) H(I)=0
0012         TS=H(I)**2/(10+9*H(I))
0013         TS1=H(I-1)**2/(10+9*H(I-1))
0014         DELTAE=9/2*(TS-TS1)
0015      30 DELRS=0
0016         DELRNS=0
0017         IF(R(I).EQ.0) GO TO 21
0018         IF(T(I).GT.TEMPS) GO TO 20
0019         TS=1+(20/(9*(E(I-1)+R(I))))
0020         TS1=(E(I-1)+R(I))*(1+SQRT(TS))
0021         H(I)=TS1-H(I-1)+H(I)
0022         GO TO 21
0023      20 TS=(H(I)+H(I-1))/2
0024         S=9*TS/(10+9*TS)
0025         TS=0
0026         LIM=TAU(MONTH)+1
0027         IF(LIM.GT.I) LIM=I
0028         LIM=LIM-1
0029         DO 40 J=1,LIM
0030         IF(T(I-J).GT.TEMPS) TS=TS+R(I-J)
0031      40 CONTINUE
0032         A=1-(CONST(2)/(1+.0823*TS))
0033         DELRS=S*R(I)
0034         DELRNS=A*(1-S)*R(I)
0035      21 W(I)=DELRS+DELRNS-DELTAE
0036         E(I)=9*H(I)**2/(20+18*H(I))
0037         DO 50 J=2,INDXW
0038         IF(WTAB(J).LT.W(I)) GO TO 50
0039         TS=(W(I)-WTAB(J-1))/(WTAB(J)-WTAB(J-1))
0040         WB(I)=TS*(WBTAB(J)-WBTAB(J-1))+WBTAB(J-1)
0041         GO TO 60
0042      50 CONTINUE
0043         WRITE(6,102) W(I)
0044     102 FORMAT(8H W ERROR,F10.2)
0045         CALL EXIT
0046      60 WD(I)=W(I)-WB(I)
0047         Q(I)=(1-1/CONST(4))*Q(I-1)+CONST(5)*WB(I-1)
0048         F1=0
0049         F2=0
0050         LIM=I
0051         IF(I.GT.INDXK) LIM=INDXK
0052         J=I
0053         DO 1 K=1,LIM
```

```
C
C     BASIN REACTION MODEL
C
       COMMON /PROB/I1,OFFSET,PPREC,PATH(3),IHEAD(12),IW(7,7),KBASE(12),
      1  PCLD(12)
       COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
      1  WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
       COMMON           CONST(5),TEMPO,TEMPS,MONTH,WTAB(10),WDTAB(10),
      1  BK(20),DK(20),TAU(12),INDXW,INDXR
       INTEGER*4 TAU
       INTEGER*4 C
       DATA TYPE1,TYPE2,TYPE3,BLANK/1HI,1HA,1HF,1H /
       READ (5,103) I1
   103 FORMAT (I10)
     5 READ (5,105) TS
   105 FORMAT (A1)
       WRITE (6,104) I1
       IF(TS.EQ.TYPE1) GO TO 1
       IF(TS.EQ.TYPE2) GO TO 2
       IF(TS.EQ.TYPE3) GO TO 3
       IF(TS.EQ.BLANK) GO TO 4
       WRITE (6,106)
   106 FORMAT (19H1ERROR ON TYPE CARD)
       CALL EXIT
     1 CALL INPUT1
       GO TO 5
     2 CALL INPUT2
       GO TO 5
     3 CALL INPUT3
       GO TO 5
     4 WRITE(6,104) I1
   104 FORMAT(12H1RANDOM SEED,5X,I10)
       CALL EXIT
       END
```

```
      SUBROUTINE INPUT1
      COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),RW(7,7),RBASE(12),
     1  PCLD(12)
      COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
     1  WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
      COMMON            CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
     1  BK(20),DK(20),TAU(12),INDXW,INDXK
      INTEGER*4 TAU
      INTEGER*4 C
      CALL READ1
      READ(5,100) NLOOP,IDAY(1),H(1),Q(1)
  100 FORMAT(2I5,14F5.0)
      READ(5,101)(T(I),I=1,NLOOP)
      READ(5,101)(R(I),I=1,NLOOP)
  101 FORMAT(16F5.0)
      CALL SETUP
      I=2
      DO 20 M=2,NLOOP
      R(I)=R(I)*CONST(3)
      C(I)=0
      CALL DAYINC(I)
      CALL BRM(I)
   20 I=I+1
      WRITE (6,200)
  200 FORMAT (1H1,120X,5HINPUT)
      CALL PRINT1(NLOOP)
      RETURN
      END
```

```
                  SUBROUTINE INPUT2
      C   GENERATE ACTUAL
                  COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),RW(7,7),RBASE(12),
                1  PCLD(12)
                  COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
                1  WB(365),WD(365),Q(365),FLOW(365),SUMT(365)
                  COMMON           CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
                1  BR(20),DR(20),TAU(12),INDXW,INDXR
                  INTEGER*4 TAU
                  INTEGER*4 C
                  CALL READ1
                  READ (5,100) NLOOP,IDAY(1),H(1),T(1),R(1),Q(1)
              100 FORMAT (2I5,14F5.0)
                  CALL SETUP
                  I=2
                  READ (5,101) OFFSET,PPREC,(PAMT(J),J=1,6)
                  READ (5,101) (TMEAN(J),J=1,12)
                  READ (5,104) ((RW(J,K),J=1,7),K=1,7)
              104 FORMAT (7F5.0)
                  READ (5,101) (RBASE(J),J=1,12)
                  READ (5,101) (PCLD(J),J=1,12)
              101 FORMAT(16F5.0)
                  CALL PRINT3
                  DO 30 M=2,NLOOP
                  CALL DAYINC(I)
                  TS=T(I-1)-OFFSET-TMEAN(MONTH)
                  II=4-TS/5
                  CALL RANDU (I1,I2,Y)
                  I1=I2
                  DO 5 L=1,7
                  IF(Y.GT.RW(II,L)) GO TO 5
                  T(I)=TMEAN(MONTH)+OFFSET+(4-L)*5
                  GO TO 6
                5 CONTINUE
                  WRITE (6,200)
              200 FORMAT (27H1ERROR IN RANDOM WALK TABLE)
                  CALL EXIT
                6 CALL RANDU(I1,I2,Y)
                  I1=I2
                  R(I)=0
                  C(I)=0
                  IF(Y.GT.PCLD(MONTH)) GO TO 18
                  C(I)=1
                  CALL RANDU (I1,I2,Y)
                  I1=I2
                  IF(Y.GT.PPREC) GO TO 18
                  CALL RANDU (I1,I2,Y)
                  I1=I2
                  DO 7 L=1,3
                  IF(Y.GT.PAMT(L)) GO TO 7
                  R(I)=PAMT(L+3)*RBASE(MONTH)
                  R(I)=R(I)*CONST(3)
                  GO TO 18
                7 CONTINUE
                  WRITE (6,201)
              201 FORMAT (25H1ERROR IN PREC PROB TABLE)
```

```
          CALL EXIT
       18 CALL BRM(I)
       30 I=I+1
          WRITE (6,202)
      202 FORMAT (1H1,120X,6HACTUAL)
          CALL PRINT1(NLOOP)
          RETURN
          END
```

```
0001            SUBROUTINE INPUT3
0002            COMMON /PROB/I1,OFFSET,PPREC,PART(6),TMEAN(12),RW(7,7),RBASE(12),
               1 PCLD(12)
0003            COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
               1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
0004            COMMON          CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
               1 BK(20),DK(20),TAU(12),INDXW,INDXK
0005            INTEGER*4 TAU
0006            INTEGER*4 C
0007            RETURN
0008            END
```

```
      F1=F1+DK(K)*WD(J)
      F2=F2+BK(K)*WB(J)
    1 J=J-1
      F3=Q(I)/CONST(4)
      FLOW(I)=F1+F2+F3
      SUMF(I)=SUMF(I-1)+FLOW(I)
      RETURN
      END
```

```
0001          SUBROUTINE SETUP
0002          COMMON /PROB/I1,OFFSET,PPREC,PART(6),TMEAN(12),FW(7,7),RBASF(12),
             1 PCLD(12)
0003          COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
             1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
0004          COMMON        CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
             1 BK(20),DK(20),TAU(12),INDXW,INDXK
0005          INTEGER*4 TAU
0006          INTEGER*4 C
0007          TS=9*H(1)/(10+9*H(1))
0008          E(1)=H(1)*TS/2
0009          C(1)=0
0010          IF(R(1) NE.0) C(1)=1
0011          R(1)=R(1)*CONST(3)
0012          W(1)=0
0013          WB(1)=0
0014          WD(1)=0
0015          FLOW(1)=W(1)/CONST(4)
0016          SUMF(1)=FLOW(1)
0017          CALL DATE
0018          RETURN
0019          END
```

```
      SUBROUTINE DATE
      COMMON /PROD/I1,OFFSET,PPREC,PART(5),TMEAN(12),TW(7,7),RBASE(12),
     1 PCLD(12)
      COMMON /CAST/IDAY,FILL1(364),FILL2(365,11)
      COMMON           CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
     1 BK(20),DK(20),TAU(12),INDXW,INDXK
      INTEGER*4 TAU
      INTEGER*4 C
      DIMENSION MONTH(12)
      DATA MONTH/31,59,90,120,151,181,212,243,273,304,334,365/
   10 IF(IDAY.LE.365) GO TO 11
      IDAY=IDAY-365
      GO TO 10
   11 MONTH=0
      DO 12 I=1,12
      IF(IDAY.LE.MONTH(I)) GO TO 13
   12 MONTH=MONTH+1
   13 RETURN
      END
```

```
0001         SUBROUTINE DAYINC(I)
0002         COMMON /PROB/I1,OFFSET,PPREC,PATH(6),TMEAN(12),RW(7,7),RBASF(12),
            1  PCLD(12)
0003         COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
            1  WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
0004         COMMON             CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
            1  BK(20),DK(20),TAU(12),INDXW,INDXK
0005         INTEGER*4 TAU
0006         INTEGER*4 C
0007         DIMENSION MONTH(12)
0008         DATA MONTH/31,59,90,120,151,181,212,243,273,304,334,365/
0009         IDAY(I)=IDAY(I-1)+1
0010         IF(IDAY(I).GT.MONTH(MONTH)) MONTH=MONTH+1
0011         IF (MONTH.NE.13) GO TO 19
0012         MONTH=1
0013         IDAY(I)=1
0014      19 RETURN
0015         END
```

```
          SUBROUTINE READ1
          COMMON /PROB/II,OFFSET,PPREC,PART(6),PLAN(12),RW(7,7),RBASE(12),
         1 PCLD(12)
          COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
         1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
          COMMON          CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
         1 BK(20),DK(20),TAU(12),INDXW,INDXK
          INTEGER*4 TAU
          INTEGER*4 C
          DIMENSION MONTH(12)
          DATA MONTH/31,59,90,120,151,181,212,243,273,304,334,365/
          INTEGER*4 TAU
      100 FORMAT(2I5,14F5.0)
      101 FORMAT(16F5.0)
          READ(5,100) INDXW,INDXK,TEMPM,TEMPS
          READ(5,101) (WTAB(I),I=1,INDXW)
          READ(5,101)(WBTAB(I),I=1,INDXW)
          READ(5,102)(TAU(I),I=1,12)
      102 FORMAT(12I5)
          READ(5,101) (BK(I),I=1,INDXK)
          READ(5,101) (DK(I),I=1,INDXK)
          READ (5,103) (CONST(I),I=1,5)
      103 FORMAT (4F5.0,F10.0)
          CALL PRINT2
          RETURN
          END
```

```
      SUBROUTINE PRINT1(NLOOP)
      COMMON /PROB/I1,OFFSET,PPREC,PAMT(5),TMEAN(12),RW(7,7),RBASE(12),
     1 PCLD(12)
      COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
     1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
      COMMON            CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
     1 BK(20),DK(20),TAU(12),INDXW,INDXK
      INTEGER*4 TAU
      INTEGER*4 C
  200 FORMAT(80H
     1                           )
  201 FORMAT(85H0 DAY          T        C       R        H         E         W
     1 WB        WD       FLOW    SUM F)
  202 FORMAT(I5,3X,F8.2,I5,6F8.2,F8.2,F10.2)
  203 FORMAT (1H1)
      READ (5,200)
      WRITE (6,200)
      ICT=NLOOP
      L=1
      LIM=50
   60 IF(ICT.LT.50) LIM=ICT+L-1
      WRITE(6,201)
      DO 80 I=L,LIM
   80 WRITE(6,202)IDAY(I),T(I),C(I),R(I),H(I),E(I),W(I),WB(I),WD(I),
     1 FLOW(I),SUMF(I)
      L=L+50
      LIM=LIM+50
      ICT=ICT-50
   70 WRITE(6,203)
      IF(ICT.GT.0) GO TO 60
      RETURN
      END
```

```
      SUBROUTINE PRINT2
      COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),RW(7,7),RBASE(12),
     1 PCLD(12)
      COMMON/CAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
     1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
      COMMON          CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
     1 BK(20),DK(20),TAU(12),INDXW,INDXK
      INTEGER*4 TAU
      INTEGER*4 C
      WRITE (6,200) TEMPM,TEMPS
      WRITE (6,201) (WTAB(I),I=1,INDXW)
      WRITE (6,202) (WBTAB(I),I=1,INDXW)
      WRITE (6,203) TAU
      WRITE (6,204)(BK(I),I=1,INDXK)
      WRITE (6,205)(DK(I),I=1,INDXK)
      WRITE(6,206) (CONST(I),I=1,5)
      WRITE (6,207) Q(1)
  200 FORMAT (15H0TEMP OF MELT  ,F5.2,5X,14HTEMP OF SNOW  ,F5.2)
  201 FORMAT (9H W TABLE ,10F8.2)
  202 FORMAT (9H WB TABLE,10F8.2)
  203 FORMAT (9H TAU     ,12I8)
  204 FORMAT (9H KB      ,10F8.2)
  205 FORMAT (9H KD      ,10F8.2)
  206 FORMAT (10H CONSTANTS,4F8.2,F12.2)
  207 FORMAT(10H INITIAL Q,F13.0)
      RETURN
      END
```

```
0001          SUBROUTINE PRINT3
0002          COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),RW(7,7),RBASE(12),
             1  PCLD(12)
0003          COMMON/CAST/IDAY(365),T(365),C(365),F(365),H(365),E(365),W(365),
             1  WB(365),WU(365),Q(365),FLOW(365),SUMF(365)
0004          COMMON           CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
             1  BK(20),DK(20),TAU(12),INDXW,INDXK
0005          INTEGER*4 TAU
0006          INTEGER*4 C
0007          WRITE (6,200) OFFSET,PPREC
0008      200 FORMAT (23H0TEMP/SUBBASIN OFFSET  ,F5.2,5X,14HPROB OF PREC  ,F5.2)
0009          WRITE (6,201) (PAMT(J),J=1,6)
0010      201 FORMAT (17H PROB AMT OF RAIN,6F10.2)
0011          WRITE (6,202) (TMEAN(J),J=1,12)
0012      202 FORMAT (10H MEAN TEMP, 12F8.2)
0013          WRITE (6,203) ((RW(J,K),J=1,7),K=1,7)
0014      203 FORMAT (18H RANDOM WALK TABLE/(7F10.2))
0015          WRITE (6,204) (RBASE(J),J=1,12)
0016      204 FORMAT (15H AVE PRECIP/DAY,12F8.2)
0017          WRITE (6,205) (PCLD(J),J=1,12)
0018      205 FORMAT (15H PROB OF CLOUDS,12F8.2)
0019          RETURN
0020          END
```

```
            SUBROUTINE RANDU(IX,IY,YFL)
            COMMON /PROB/I1,OFFSET,PPREC,PAMT(6),TMEAN(12),RW(7,7),RBASE(12),
           1 PCLD(12)
            COMMON/LAST/IDAY(365),T(365),C(365),R(365),H(365),E(365),W(365),
           1 WB(365),WD(365),Q(365),FLOW(365),SUMF(365)
            COMMON          CONST(5),TEMPM,TEMPS,MONTH,WTAB(10),WBTAB(10),
           1 BK(20),DK(20),TAU(12),INDXW,INDXK
            INTEGER*4 TAU
            INTEGER*4 C
            IY=IX*899
            IF (IY)5,6,6
      5     IY=IY+2147483647+1
      6     YFL=IY
            YFL=YFL/2147483647.
            RETURN
            END
```

APPENDIX C

SYSTEM OPERATION AND BENEFITS

I INTRODUCTION

The following sections of Appendix C describe in detail the methods used to calculate hedge, drawdown and inter-dam coordination benefits which can be realized from satellite-based sensor system support to water management in the Pacific Northwest Consistent with the rest of the study, attention is focused on benefits to the Bonneville Power Administration (BPA) Calculations are presented, for benefits which will accrue in the near term and those which can be expected in the 1975-80 system The long term benefits for the 1975-80 period, and beyond, are based primarily on plans to add the Arrow, Mica, Libby and Dworshak dams to the BPA system in the late 1970's

Benefit calculation methods for the three water management areas described in this appendix assume that the satellite system will yield perfect information (i e , error-free observations of antecedent condtions and forecasts of coming hydrologic events) This premise of perfection is admittedly unrealistic, it is also unrealistic to assume that the three benefit areas discussed comprise the total benefits to accrue to the satellite-assisted water management system Other benefit areas such as head efficiency, non-BPA power utilities, power load forecasts, flood control and forecasts, and detection of overheating power transmission facilities, have not been included in the benefit calculations at this time because of their complexity Many benefits will certainly be gained from these related areas of water management when the satellite system evolves Thus the over-estimation of benefits due to assumption of perfect information is more than offset by omission of the additional areas in which benefits will be derived

Extrapolation of near term benefits to the Pacific Northwest and to other basins in the United States are included in the benefit summation chart, Exhibit II-54, in Volume II of this report

II REDUCTION IN HEDGE

The concept of hedge as a planning tool in water management is explained in paragraph II D 1, Volume II, this report Hedge is based on predicted runoff during the spring and summer months and is written in terms of the standard error of predicted inventory Thus, hedge in KSFD = 1 656, where KSFD is one thousand second foot days, a second foot day is 1 cubic foot per second per day, and 6 is one standard error of the predicted inventory Hedge benefits in terms of increased hydro-generating revenue can be expressed as follows

Benefits (in dollars) = Hedge (in KSFD) x conversion factor x \$2 39/megawatt hour x hours per day

where \$2 39/mwh is the present value of power when the power supply is forecastable It is assumed that the satellite-assisted system will provide this necessary forecast lead time The conversion factor is the amount of power produced at a given dam by each cubic foot per second of water outflow

Hedge estimates are made on January 1 each year and monthly thereafter until April 1 in connection with the requirement to revise the variable energy content curves Through this period, the hedge contains both forecast and modeling errors Any error remaining after August 1 is model error, since complete melt and runoff have occurred by that date The hedge used in the following calculations is for the month of June, by which time peak runoff has been reached, and rainfall runoff yet to come in, the water year is a small part of the total water year runoff

Since hedge benefits are applicable only to cyclic dams, benefits derived for the system in the near term are based on the two dams, Hungry Horse and Duncan, the only large cyclics in the Columbia River System The June hedges for Hungry Horse and Duncan were obtained from operational BPA data Hedge benefits for Hungry Horse and Duncan are calculated using the above benefit equation

Thus

Benefits (Hungry Horse) = (140)(175)($2 39)(24) = $1,405,320

Benefits (Duncan) = (103)(86)($2 39)(24) = $508,104

The total, rounded to $2 million represents the revenue which would accrue to BPA each year as a benefit from elimination of hedge in water management

In the late 1970's, it is expected that the Arrow, Mica, Libby and Dworshak dams will be added to the existing configuration The June hedges for the new dams that are anticipated additions to the BPA system in the 1970's were estimated by BPA from preliminary inflow forecasts to these dam sites Weighted hedges and conversion factors for all six dams are

	Hedge (KSFD)	Conversion (Kw/cfs)
Hungry Horse	140	175
Duncan	103	86
Arrow	593[1]	86
Mica	609	86
Libby	547	110
Dworshak	204	96

Using the formula stated above, benefits (rounded off) are calculated as follows

(140)	(175)	($2 39)	(24)	=	$1,400,000
(103)	(86)	($2 39)	(24)	=	$500,000
(593)	(86)	($2 39)	(24)	=	$2,900,000
(609)	(86)	($2 39)	(24)	=	$3,000,000
(547)	(110)	($2 39)	(24)	=	$3,600,000
(204)	(96)	($2 39)	(24)	=	$1,100,000
	TOTAL				$12,500,000

The total, rounded at $12 5 million, represents estimated benefits to BPA in the long term as a result of hedge reduction

[1] Does not include hedge for Mica, which is upstream, but is calculated separately for this table

The conversion factors used above represent the sum of the conversion factors for all dams in the Federal system downstream from the dam used for benefit calculations In order to derive realistic benefit estimates, the assumption was made that hedge spilled at the upstream dam is spilled at each successive dam downstream The value of the water lost then is the sum of all conversion factors below and including the originating dam The assumption also was made that the management system will be able properly to utilize the hedge

The benefits calculated are considered to be average--wetter years will provide greater revenue, dry years less Hedge is also a function of dam geometry and of installed capacity on the river system Since neither is expected to change after 1980, average annual benefits derived above for the long term will remain constant and will not be affected by future installation of nuclear thermal power generation

III OPTIMUM DRAWDOWN AND REFILL STRATEGY

The benefits calculated in this section result from a comparison of actual operations for three water years of record, with optimum drawdown and refill based on perfect inflow information, both short and long term Of most interest are the eight calendar months which represent the drawdown sequence, September through April

Refill for many dams is constrained by flood control requirements For this reason, interpretation of refill strategy from actual data is not meaningful. It is reasonable to assume, however, that the increase in efficiency gained from correct drawdown also would occur during the refill phase

To develop comparisons of power generated through use of actual data with projected power output based on perfect information, Grand Coulee was selected as the test dam It currently contains an estimated 5,232,000 acre feet of usable power storage capacity and, with an installed capacity of 1.944 million KW, annually generates 14 58 billion kilowatt hours Benefits were calculated by first estimating the improvement which could be expected by optimizing drawdown procedures The resulting difference was converted to a dollar-value and extrapolated to the entire Federal system Comparison of actual power output with projected rule curve operation is shown in Exhibit C-1

At Exhibit C-2, the calculated optimum power generation at Grand Coulee was averaged for years 1959-60-61 In computing optimal release figures, the following constraints were observed

- Minimum generation was considered to be in excess of 1,390 MW
- Maximum generation was set at 2,175 MW
- To prevent cavitation or pitting of turbine blades, the maximum allowable water volume through turbine cases was set at 109.5 KCFS.

From Exhibits C-1 and C-2, average generation for the three cases are

Actual Operations 12,890/8 = 1,611MW

EXHIBIT C-1 COMPARISON OF ACTUAL WITH PROJECTED RULE CURVE POWER OUTPUT AT GRAND COULEE DAM AVERAGED FOR WATER YEARS 1959-60-61

	Rule Curve						
	Inflow (KCFS)	Storage (KCFS)	Outflow (KCFS)	KW/CFS Factor	Rule Curve Average Generation(MW)	Actual Average Generation(MW)	Per Cent Dif.
Sept.	67 0	+ 2 66	= 69.66	x 25.2 =	1, 754	1, 710	- 2 5
Oct	60 8	+ 4 00	= 64 80	x 24 9 =	1, 614	1, 520	- 5 8
Nov	63 2	+ 6.00	= 67.20	x 24 7 =	1, 660	1, 580	- 4 8
Dec	43 8	+15 00	= 58 80	x 24 1 =	1, 417	1, 330	- 6 1
Jan	43.3	+33 60	= 76 90	x 22.8 =	1, 753	1, 390	-20.7
Feb.	74 4	+34 60	=109 00	x 19.8 =	2, 158	1, 900	-12 0
Mar	79 6	+25.30	=105 00	x 16 0 =	1, 680	1, 880	+11 9
Apr	103 3	+ 6 16	=109.50	x 12 7 =	1, 390	1, 580	+13 7
					13, 426	12, 890	

EXHIBIT C-2 CALCULATED OPTIMUM POWER GENERATION AT GRAND COULEE AVERAGED FOR WATER YEARS 1959-60-61

	Inflow KCFS	Storage KCFS	Outflow KCFS	KW/CFS Factor	Average Power Generated MW
Sept	67 0	+ 0	= 67 0	x25 37	=1,700
Oct	60 8	+ 0	= 60.8	x25 37	=1,542
Nov	63 2	+ 0	= 63.2	x25 37	=1,603
Dec.	43 8	+12.0	= 55.8	x25 10	=1,401
Jan	43 3	+44 26	= 87.5	x22.8	=1,995
Feb.	74 4	+35 1	=109.5	x19 8	=2,168
Marc	79 6	+29.9	=109 5	x16 3	=1,785
Apr	103.3	+ 6 16	=109 5	x12 7	=1,391
TOTAL					13,585

Projected Rule Curve	13,426/8 = 1,678 MW
Calculated Optimum	13,585/8 = 1,698 MW

Visual comparison in terms of dam elevation for actual, rule curve and optimum drawdown strategies is shown in Exhibit C-3.

To state power output in terms of revenue, the following formula was used

Dollar value of output = (Hours in year) x (Power in MW) x ($2.39/MWH[1])

or

Dollar value of output = (8760) x (MW) x (2.39)
= 20,936 x MW

Thus, calculated dollar values are

Actual Operations	20,936 x 1,611 = $33,727,896
Projected Rule Curve	20,936 x 1,678 = $35,130,608
Calculated Optimum	20,936 x 1,698 = $35,549,328

The increase in revenue from actual to calculated optimum operations is 5.1%

In gross terms, the assumption was made that the same percentage of improvement can be achieved by other hydro-generators in the system Therefore, the percent increase developed for Grand Coulee was applied to the entire Federal system, as currently installed From Exhibit C-4, the total output for the modelized system (comprising 80% of the Federal system) is 3,253[2] MW and

(0051) x (3,253) x (20,936) = $3,475,000

in additional revenue would be gained in the system as modeled. For the entire Federal system, the output is 3,903 MW, and

(0051) x(3,903) x (20,936) = $4,166,264

[1] BPA wholesale price for power, approximate.

[2] Excludes ROR dams

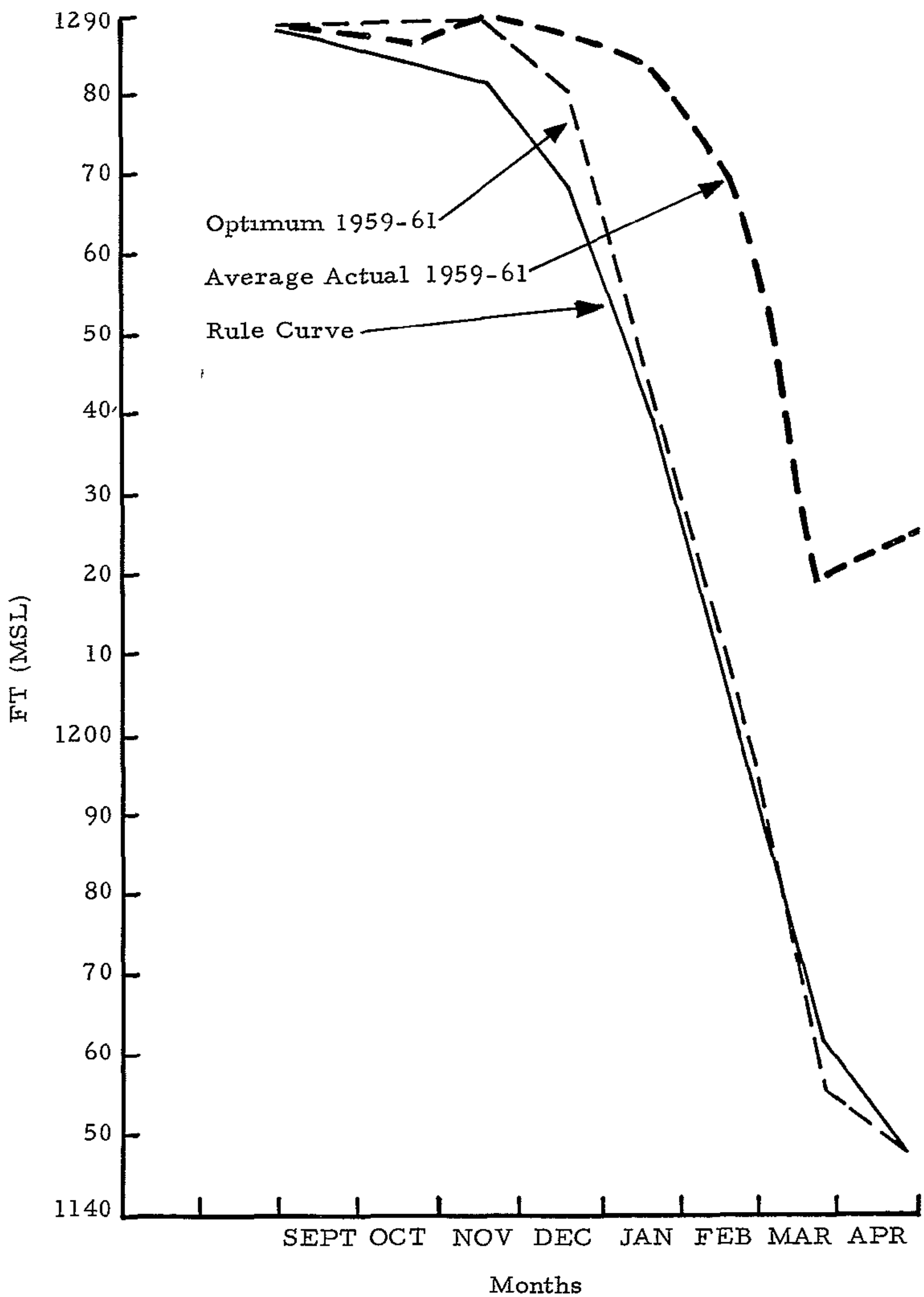


EXHIBIT C-3 RESERVOIR ELEVATION GRAND COULEE DAM

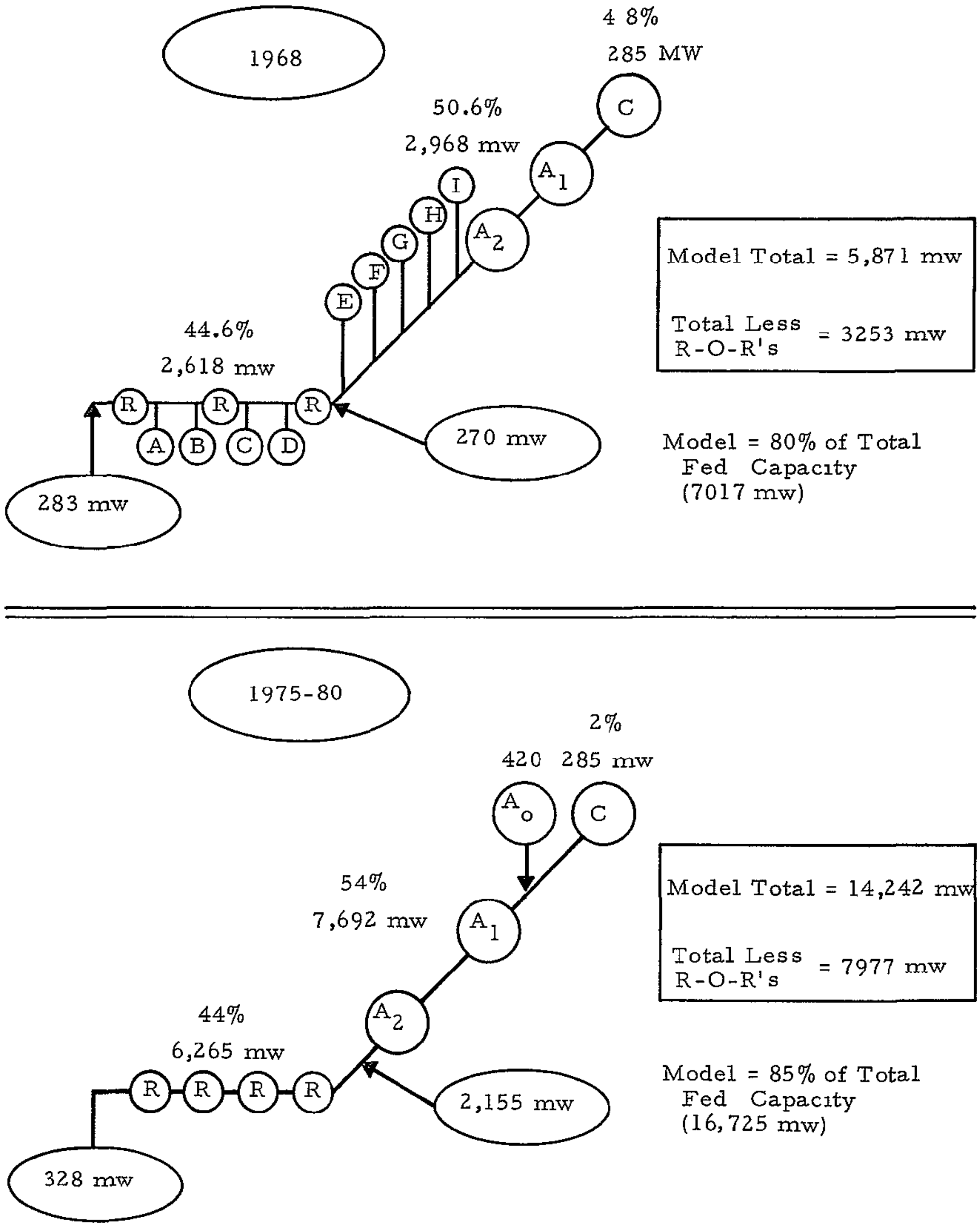


EXHIBIT C-4 SCHEMATIC REPRESENTATION OF THE COLUMBIA RIVER in additional revenue would accrue to the BPA by optimization of water releases

Exhibit C-4 also includes outputs, both modelized and total for the 1975-80 period To adjust for the learning process and improved operation which normally would occur between the two periods, under the present management system, the percent improvement was degraded judgmentally from 5 1 percent to 4 6 percent No further allowances were made after 1980, however.

Using the same formula, dollar benefits were then projected as

$$(0046) (7,977) (20,936) = \$7,683,512$$

in additional revenue from the system as modeled and

$$(0046) (9,572) (20,936) = \$9,211,890$$

in additional revenue which could be applied to the entire Federal system after 1975

In addition to these benefits derived from optimal drawdown strategy, an average volume of water equal to the contents of Grand Coulee reservoir between elevations 1218 feet and 1148 feet above mean sea level is also made available for downstream use during the three years after 1959-61 It is assumed under the current restriction of 1208 feet maximum drawdown elevation that a volume of water will be spilled in the peak flow season because storage space was not made available to the 1148 foot elevation level

From the Grand Coulee reservoir contents table, the volume of water between 1148 and 1218 foot elevations is about 1414 KSFD This volume of water can be used once a year If the drawdown from 1218 to 1148 is assumed to occur in one month, this rate of low from Grand Coulee is calculated as

$$\frac{1414 \text{ KSFD}}{30 \text{ Day}} = 47 \text{ KCFS } (1414 \text{ KSFD}) \left(\frac{\text{Month}}{30 \text{ Day}}\right) = 47\text{KCFS Month}$$

To calculate the value of this water flowing through the downstream run-of-the-river dams, the conversion factors in Section IV of this Appendix for these R-O-R's must be used

Conversion factor (Σ McNary, Dalles, Bonneville, and Chief Joseph) = 30 2 KW/CFS

Power Generated = (47 KCFS) x (30 2 KW/CFS)

Dollar value of power generated during the one month (730 hours) = (1420 MW) x (730 Hr) x (2 39/MWH) = \$2,477,464 per year under the current system

With the inclusion of John Day Dam in the 1975-80 system, the conversion factor would be increased by 7 2 KW/CFS and the total annual benefit would then be $\sim$\$3,000,000

In summary, with a management system capable of permitting optimum water release procedures, differences in dollar benefits as a result of improved operation can be computed for both the short and long term Benefits derived during the initial phase would average 6.7 million dollars per year For the 1975-80 system, expected improvement amounts to approximately 12 2 million dollars per year Since there are no current plans for additional installation of hydro-generation capacity on the Columbia River System after 1980, it is not expected that average improvement will increase significantly after that period

IV. INTER-DAM COORDINATION BENEFITS

This section describes the method used to calculate benefits derived from inter-dam coordination. Between Chief Joseph and Bonneville Dams on the Columbia River, two run-of-the-river (ROR) dams are located, McNary Dam and The Dalles. One additional ROR dam, John Day, will be built on this stretch of the river in the near future. This type of dam has no significant storage capacity and therefore must make immediate use of the water arriving from upstream.

Currently, total local inflow between dams cannot be predicted with much accuracy, hence spill and sluice may occur during power operations. The additional water, not predicted, may be used to generate more power. However, a market for this power cannot be planned and it will therefore be wasted or sold at low secondary rates. If the ROR dams are operating at near capacity, the effect of the additional water may be to partially swamp the dam, making its operation less efficient because the differential head is decreased. Utilization of water now being spilled and sluiced will provide increased benefits in an improved water management system

Numerous small tributaries and rivers feed the main stem of the Columbia between Chief Joseph and Bonneville. Of these, about 18 are gaged. From 1960-1961, the gaged inflow from the rivers and tributaries, added to the water known to be released from Chief Joseph, is compared with the amount of water received at Bonneville during each month on Exhibit C-5. The difference between anticipated and unanticipated water is first expressed on Exhibit C-5 as a percentage, then as unanticipated inflow to Bonneville. This unanticipated inflow is presumed to be the water which now is being spilled. Using the data in Exhibit C-5, the amount and value of the unanticipated inflow can be calculated by the following formula.

Flow in CFS x sum of conversion factors downstream x
730 hours per month x $2.39 per MWH.

Conversion factors for McNary, The Dalles and Bonneville are

EXHIBIT C-5 UNANTICIPATED INFLOW BETWEEN CHIEF JOSEPH AND BONNEVILLE DAMS

	Total Gaged Inflow KCFS	Total Rec'd at Bonneville KCFS	Unanticipated Inflow KCFS	Percent of Inflow Gaged
Oct 1960	98 3	100.0	1 7	98 3
Nov	112 0	115 0	3 0	97.3
Dec	97 3	101 0	3 7	96 3
Jan. 1961	108 6	112 0	3 4	97 0
Feb	179 7	189 0	9 3	95 0
Mar	163 3	177 0	8 7	95 0
Apr	187 0	180 0	0	105 0
May	358 0	300 0	0	119 0
Jun	584 0	587 0	3 0	99 5
Jul	225 4	236 0	10 6	95 5
Aug	123 0	127 0	4 0	96 9
Sept	96 0	96.0	0	100 0

McNary =	6.45 KW/CFS
The Dalles =	6.35 KW/CFS
Bonneville =	4.40 KW/CFS
Total	17.2 KW/CFS

Depending upon the distribution of the unanticipated water along the Chief Joseph-Bonneville reach of the river, the conversion factors may have to be weighted. The sum of the weighted conversion factors will be less than the total shown.

Power production in megawatts by month which could be produced from the unanticipated inflow is shown in Exhibit C-6. Dollar values of power production from unanticipated inflow can be computed as shown in Exhibit C-7.

If the assumption is made that the unanticipated inflow can be predicted and may be compensated for by reducing the release from Grand Coulee, i.e., water is conserved upstream for future power generation, then the future release of water thus conserved must also pass through Chief Joseph Dam. In this case, the conversion factor for Chief Joseph must be added to those of McNary, The Dalles and Bonneville. The new conversion factor is then:

McNary, Dalles, Bonneville =	17.2
Chief Joseph =	13.0
Total	30.2 KW/CFS

Using this new conversion factor in conjunction with the unanticipated inflows derived in Exhibit C-5, the total benefits to be derived from conserving the water are calculated below in Exhibit C-8. As shown in the exhibit, two additional steps are required to compute the total average benefit in dollars which will result from improved inter-reservoir coordination in the model designed for this study. First, the total loss resulting from the unanticipated inflows swamping the three ROR's is added to the benefit from conserving releases from Grand Coulee. The inefficiencies created by the swamping action of the unanticipated water are assumed to be equal to one-sixth of the power that could have been generated through their utilization. Second, since the water year 1960-1961 was wetter than normal, the above sum must

EXHIBIT C-6 POTENTIAL POWER PRODUCTION FROM UNANTICIPATED INFLOW

	Unanticipated inflow (KCFS)		Conversion Factor (KW/CFS)		Estimated Power Produced (MW)
Oct	1.7	x	17.2	=	29.2
Nov	3.0	x	17.2	=	51.6
Dec	3.7	x	17.2	=	63.6
Jan	3.4	x	17.2	=	58.5
Feb	9.3	x	17.2	=	160.0
Mar	8.7	x	17.2	=	150.0
Apr	0	x	17.2	=	0
May	0	x	17.2	=	0
Jun	3.0	x	17.2	=	51.6
July	10.6	x	17.2	=	182.3
Aug	4.0	x	17.2	=	68.8
Sep	0	x	17 2	=	0

EXHIBIT C-7 COMPUTATION OF DOLLAR VALUES FOR UNANTICIPATED INFLOW

	Esti-mated Power (MW)	Hours Per Month	Price Per MWH	Dollar Value
Oct	29.2	x 730	x 2 39	=$ 50,954
Nov.	51 6	x 730	x 2 39	= 90,042
Dec.	63 6	x 730	x 2 39	= 110,982
Jan.	58 5	x 730	x 2 39	= 102,083
Feb	160 0	x 730	x 2.39	= 279,200
Mar.	150.0	x 730	x 2.39	= 261,750
Apr	0	x 730	x 2 39	= 0
May	0	x 730	x 2 39	= 0
Jun	51 6	x 730	x 2 39	= 90,042
Jul	182 3	x 730	x 2 39	= 318,114
Aug.	68 8	x 730	x 2 39	= 120,056
Sept	0	x 730	x 2.39	= 0
		Total Dollar Value For Unanticipated Inflow		$1,423,223

	Unanticipated Inflow (KCFS)	New Conversion Factor (KW/CFS)	Estimated Power Produced (MW)		Hours Per Month	Price Per MWH	Dollar Value
OCT	1 7	x 30.2	= 51.3	x	730	x 2.39	= $ 89,519
NOV	3.0	x 30.2	= 90.6	x	730	x 2 39	= 158,097
DEC	3 7	x 30 2	= 111.7	x	730	x 2.39	= 194,917
JAN	3.4	x 30.2	= 102.7	x	730	x 2.39	= 179,212
FEB	9.3	x 30.2	= 280.9	x	730	x 2.39	= 490,171
MAR	8.7	x 30.2	= 262.7	x	730	x 2.39	= 458,412
APR	0	x 30.2	= 0	x	730	x 2 39	= 0
MAY	0	x 30.2	= 0	x	730	x 2.39	= 0
JUN	3.0	x 30.2	= 90.6	x	730	x 2.39	= 158,097
JUL	10.6	x 30.2	= 320 1	x	730	x 2 39	= 558,575
AUG	4.0	x 30.2	= 120 8	x	730	x 2 39	= 210,796
SEP	0	x 30.2	= 0	x	730	x 2 39	= 0
				Sub Total			$2,497,796

Estimated Benefit if generating inefficiencies are eliminated	
1/6 (1,393,206) =	237,204
	$2,735,000
Approximate Raw Total	$2,735,000
- 6% deduction, etc.	- 164,100
Total Avg, Value, etc	$2,570,900

EXHIBIT C-8 ADJUSTED COMPUTATION OF DOLLAR VALUES FOR UNANTICIPATED INFLOW be normalized by a 6 percent reduction. The remainder is an estimate of the total average benefit to be gained through improved coordination

A gross evaluation can also be made of the benefits which might be derived in the far term The calculation first involves the sum of water for the year and a change in the conversion factor because of the new dam configuration on the river.

Total current ROR's	=	17.2
John Day Dam	=	7.2
Total		24.4 KW/CFS

The formula from which dollar benefits might be derived is:

Total flow in CFS x Conversion factor x 1745 ÷ 1000

Total dollar benefits would then be $2,018,300. With compensatory releases of equal water volume from Grand Coulee, the new con version factor would require that the conversion factor for the Chief Joseph Dam be added, and would total 37 4 KW/CFS The total dollar benefit, using the formula above, would be $3,093,500 When added to the dollar benefits of reducing inefficiency (1/6 of $2,018,300), the total is $3,430,000

V IRRIGATION

A Potential Benefits from Power Generation Sales and Pumping Savings in the Pacific Northwest Through Improved Irrigation System

The overall hydrology study incorporates a detailed analysis of three sub-basins within the Columbia River Basin over a three-year period There is no irrigation in the area of the South Fork of the Flathead River Basin (near Hungry Horse Dam) Presently, the Klickitat River Basin area partially assists in the sprinkler irrigation of approximately 5000 acres of cherry trees in the Dalles area

The Colville River Basin drains into Lake Roosevelt behind Grand Coulee Dam, which is the source of irrigation water supply for the Columbia Basin Project, a Bureau of Reclamation irrigation project of approximately 500, 000 irrigated acres, located downstream from Grand Coulee Dam Irrigation water for the Columbia Basin Project is provided from an irrigation system which is unique primarily because of the method by which water passes from the Grand Coulee Reservoir to farms Water must be pumped from the reservoir up to Banks Lake, a storage reservoir for irrigation water to be used in the Columbia Basin Project The water is then released on demand from Banks Lake for irrigation in the Columbia Basin Project

The capacity of Banks Lake is over 700, 000 acre-feet, approximately one-fourth of the present annual diversion of irrigation water to the Columbia Basin Project

Historically, there has never been a water shortage for irrigation of the project, because the irrigation season essentially coincides with the water surplus season at Grand Coulee Dam, i e , the period during which the water supply at Grand Coulee Dam exceeds both the amount which can be used for power generation and the amount which can be stored in the reservoir Therefore, unless and until a water shortage condition exists, there can be no direct irrigation benefits in the Columbia Basin Project as a result of better runoff forecasts This water shortage could conceivably exist after the three large storage reservoirs located upstream from Grand Coulee Dam have been completed and the third power plant at Grand Coulee Dam is operational

Benefits could be realized, however, in power generation revenues as a result of better information which would permit the pumping of irrigation water into Banks Lake in only the amounts needed for efficient irrigation of the project Satellite-assist information which would aid in the improvement of irrigation efficiency includes an improved weather forecasting ability and information concerning soil moisture content Water not pumped into Banks Lake would then produce power revenues in two ways

1 the additional water would be used for power generation in lieu of being unnecessarily diverted for irrigation,

2 the power saved by not pumping the additional water into Banks Lake could then be used for normal power sales

Exhibit C-9 entitled, "Increased Hydro-electric Power Revenues Resulting from Increased Irrigation Efficiency--Grand Coulee Dam," shows in outline form the power dollar benefits resulting from more efficient irrigation

B <u>Potential Irrigation Benefits Through Forecast Error Reduction</u>

As indicated earlier, the value of a satellite-assisted information system to irrigation can probably be measured in terms of its contribution to the improvement of weather forecasting and its ability to measure soil moisture content as well as improvement in runoff forecasting accuracies

Most farmers presently make use of whatever information is available in planning for optimum water utilization during the growing season Information on soil moisture content and weather forecasting (primarily precipitation and temperature) has not been available to the degree of accuracy required to make a significant contribution to such planning Over the past forty-five years, runoff forecasting accuracy has covered the gamut from near-perfect, to seasonal errors for all

EXHIBIT C-9 INCREASED HYDRO-ELECTRIC POWER REVENUES RESULTING FROM INCREASED IRRIGATION EFFICIENCY-GRAND COULEE DAM

1	Water consumptive requirement for crops [Acreage irrigated in 1966 for Columbia Basin Project X Average consumptive use of water (2.3 acre-feet)]	-	870,111 acre-feet
2.	Less average rainfall of 8 inches	-	277,000 acre-feet
3.	Water necessary for consumptive requirements of crops		593,111 acre-feet
4	Irrigation supply requirement (this is double the consumptive requirement of crops)		1,200,000 acre-feet
5.	30% loss between reservoir (Banks Lake) and arrival at field	+	520,000 acre-feet
6.	Release requirement from reservoir in an average year necessary to irrigate 415,000 acres		1,720,000 acre-feet
7.	Amount of water actually released in 1966		2,720,000 acre-feet
8.	Difference - volume of water which need not be diverted for irrigation (Number 7 minus number 6)		1,000,000 acre-feet

9 Benefits

A. $\frac{\text{Annual Power Revenues}}{\text{1,000,000 acre-ft. x \$1 25 (value of one acre-ft. of water)}}$ = $1.250M

B. <u>Pumping Savings</u>

$\frac{\text{1,000,000 acre-ft}}{\text{2,720,000 acre-ft}}$ x $1,800 K (Total annual pumping cost) = $ 660M

Total $1 910M

of the Western states up to 40 percent off the observed flow The over-all mean forecast error has been in the order of 20 percent Even in the years when forecasts have been near-perfect, farmers have not had this knowledge at the beginning of the year and therefore could not operate with any degree of assurance that forecasts would turn out to be accurate.

Assuming a hypothetical forecast of 100,000 acre-feet total flow and a forecast error of 20 percent, we are in reality still dealing with a possible variance of flow from 80,000 to 120,000 acre-feet, since the forecast may be 20 percent above or below the observed Thus, the reduction of forecast error by 1% reduces the uncertainty of water supply by 2%

Potential irrigation benefits may be identified by taking the uncertainty out of the water supply and reducing the risk to the farmer Such a study was conducted by James Shelton, Economist of the Soil Conservation Service, Boise, Idaho, who developed two hypothetical farm models

Each of the two farms had 200 acres available for irrigation under normal water supply conditions, but water rights to irrigate only 150 acres This compares with the average size irrigated farm of 108 acres in the 1959 Census of Agriculture The comparison of the farm models measures the value of changing an uncertain situation to one of no risk for abnormal water supply years Having perfect information the number of acres planted was in relationship to the available water supply for the year. Under uncertain conditions of having no information, 150 acres was always planted irrespective of the available water supply for the year

From the cost and return estimates of Southern Idaho crops, the fixed cost for each farm model was calculated at $5,000 per year It was also concluded from the cost and return information and crop rotation used that the per acre weighted return over operating expenses would equal approximately $80 per acre for every acre fully irrigated on the farm This then gives a straight-line function for risk, since the number of acres planted equals the number that can be fully irrigated

When the year's available water supply is not known, the operator must plant his normal acreage and hope for adequate water If there is a normal water supply, both models will have the same income If the water supply is only 50% of normal for the year under the conditions of uncertainty, his more intensive crops will not be worth harvesting The less intensive crops might be worth harvesting, but may not be able to pay the total operational expenses

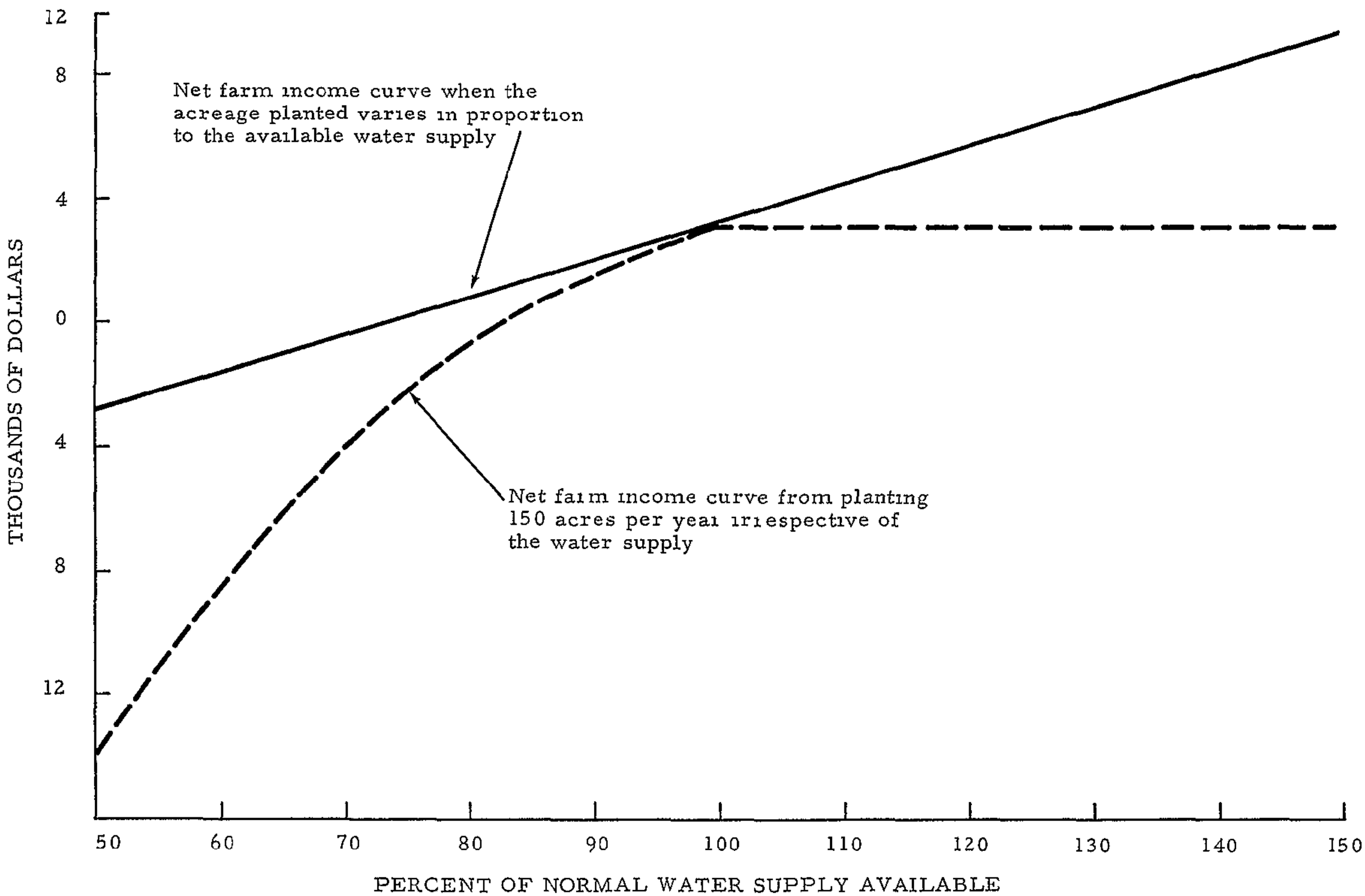
When the uncertainty is removed from the available water supply it is possible to calculate the various income levels because it is linear with respect to the available water Under conditions of having perfect information only two points were calculated--normal at 100% water supply, and 50% of normal Exhibit C-10 shows the range of benefits for varying water supplies for the 150 acre model farm As shown in this exhibit, if more acreage is available benefits can be derived in years having above normal water supply

In parts of southern Idaho, investigations have shown that under a water year 50% of normal, the loss per acre has varied from $10 to $50 an acre, depending upon the intensity of the cropping pattern. It is assumed in the investigations that the farmers took advantage of available runoff forecast information

These models have application to all streams in the west with limited storage facilities and great fluctuations in the water supply. The approach in the models, however, has been one in which benefits are shown by reducing the uncertainty of the water supply, comparing normal water supply years with years varying from the normal, assuming no forecast information in one case and assuming farmers operating with available forecast information in the other case This approach is consistant with the objective of the irrigation case study, namely, to determine how much the satellite-assist information system will reduce the uncertainty of the water supply to farmers for their crops

A normal water year in the models compares with a perfect forecast An 80% or 120% wateryear compares with a forecast error of 20% high or low, respectively A reduction of the forecast error from 20% to 15% would correspond in the models to a wateryear 15% off the

EXHIBIT C-10 ANALYSIS OF VALUE OF WATER SUPPLY INFORMATION



normal year. Assuming a 5% reduction in forecast error is analogous to improving the water supply by 5% toward the figure which farmers expect (in the models, they expect a normal year), the savings which would be realized in the Pacific Northwest are shown in Exhibit C-11. When the water supply falls to 70% of the normal water supply, it would be worth $135 million to farmers in this area to know this before spring work begins. Benefits are also derived in knowing when there will be more than the normal water supply available. For example, if this area were to have 20% more water than normal, the benefit to farmers would be over $75 million if this is known before spring work begins so that additional acreage or more intensive crops could be planted.

In Exhibit C-12, potential irrigation benefits for the Columbia Basin Project, the Pacific Northwest and the United States are shown. These are calculated for incremental periods of 5 years from 1959 to 1990, taking into account the projected number of irrigated acres over this period of time. It should be noted that the average value per acre of the crops grown on irrigated acreage in Idaho (Farm model study) is about 12 percent less than the average for the U.S. Therefore benefits calculated from the farm model study and projected to the U.S. are underestimated.

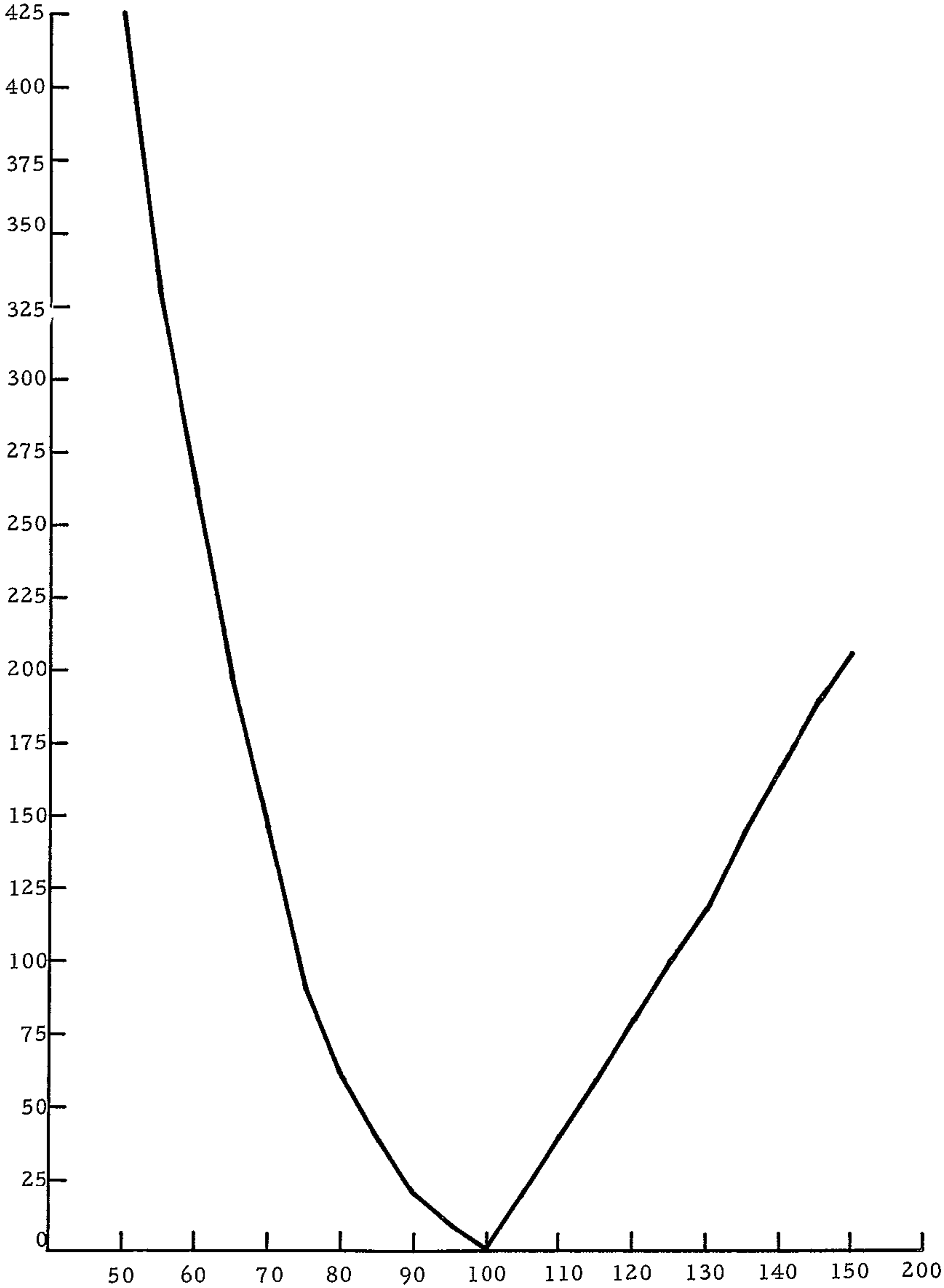


EXHIBIT C-11 VALUE TO FARMERS OF KNOWING YEARLY WATER SUPPLY—PACIFIC NORTHWEST, 1959

Observed Runoff as a Percent of Forecast	Benefits Per Acre (dollars)	1959 Columbia Basin Project (267 000 acres)	1959 Pacific Northwest (5 605 000 acres)	1959 United States (33 0 million acres)	1965 Columbia Basin Project (410 000 acres)	1965 Pacific Northwest (6 290 000 acres)	1965 United States (37 0 million acres)
50	76 00	20 3	426	2 500 0	31 1	478	2 810 0
55	59 00	15 7	331	1 950 0	24 2	371	2 180 0
60	47 00	12 5	263	1 550 0	19 3	296	1 740 0
65	35 00	9 5	196	1 150 0	14 4	220	1 300 0
70	24 00	6 4	135	790 0	9 8	151	890 0
75	16 00	4 3	90	530 0	6 6	101	590 0
80	10 70	2 9	60	353 0	4 4	67	395 0
85	7 10	1 9	40	235 0	2 9	45	263 0
90	3 33	9	19	120 0	1 4	21	123 0
95	1 67	4	9	55 0	7	11	62 0
100	0	0	0	0	0	0	0
105	3-4 00	8-1 1	17-22	99-132 0	1 2-1 6	19-25	111-148
110	6-8 00	1 6-2 1	34-45	198-264 0	2 5-3 3	38-50	222-296
115	9-12 0	2 4-3 2	50-67	297-396 0	3 7-4 9	57-75	333-444
120	12-16 0	3 2-4 3	67-90	396-528 0	4 9-6 5	75-100	444-592
125	16-20 0	4 3-5 3	90-112	528-660 0	6 5-8 2	100-126	592-740
130	18-24 0	4 8-6 4	100-134	594-792 0	7 4-9 8	113-151	666-888
135	22-29 3	5 9-7 8	123-164	726-966 9	9 0-12 0	138-184	814-1 084
140	25-33 3	6 7-8 9	140-187	825-1 100 0	10 2-13 6	157-209	925-1 232
145	28-37 4	7 5-10 0	157-210	924-1 234 0	11 5-15 3	176-235	1 036-1 383
150	31-41 4	8 3-11 0	174-232	1 023-1 366 2	12 7-17 0	195-260	1 147-1 531 8

Observed Runoff as a Percent of Forecast	1970 Columbia Basin Project (462 000 acres)	1970 Pacific Northwest (6 780 000 acres)	1970 United States (39 5 million acres)	1975 Columbia Basin Project (603 000 acres)	1975 Pacific Northwest (7 269 000 acres)	1975 United States (42 4 million acres)
50	35 1	515	3 000 0	45 9	552	3 230 0
55	27 3	400	2 330 0	35 6	429	2 500 0
60	21 7	319	1 860 0	28 3	341	1 990 0
65	16 2	237	1 380 0	21 1	254	1 480 0
70	11 1	163	950 0	14 5	174	1 020 0
75	7 4	108	633 0	9 7	116	680 0
80	4 9	73	425 0	6 4	78	454 0
85	3 3	48	280 0	4 3	52	300 0
90	1 5	23	132 0	2 0	24	141 0
95	8	11	66 0	1 0	12	71 0
100	0	0	0	0	0	0
105	1 4-1 8	20-27	118 5-158 0	1 8-2 4	22-29	172-169 6
110	2 8-3 7	41-54	237 0-316 0	3 6-4 8	44-58	254 4-339 2
115	4 1-5 5	61-81	355 5-474 0	5 4-7 2	65-87	381 6-508 8
120	5 5-7 4	81-108	474 0-632 0	7 2-9 6	87-116	508 8-678 4
125	7 4-9 2	108-136	632 0-790 0	9 6-12 1	116-145	678 4-843 0
130	8 3-11 1	122-162	711 0-948 0	10 8-14 5	131-174	763 2-1 012 6
135	10 2-13 5	149-199	869 0-1 157 3	13 3-17 7	160-213	932 8-1 292 3
140	11 5-15 4	170-226	987 5-1 315 3	15 1-20 1	182-242	1 060 0-1 412 0
145	12 9-17 3	190-254	1 106 0-1 477 3	16 9-22 5	203-272	1 187 2-1 585 8
150	14 3-19 1	210-281	1 224 5-1 635 3	18 7-24 9	225-301	1 314 4-1 755 4

Observed Runoff as a Percent of Forecast	1980 Columbia Basin Project (745 000 acres)	1980 Pacific Northwest (7 758 000 acres)	1980 United States (45 4 million acres)	1985 Columbia Basin Project (887 000 acres)	1985 Pacific Northwest (8 248 000 acres)	1985 United States (48 8 million acres)	1990 Columbia Basin Project (1 029 000 acres)	1990 Pacific Northwest (8 738 000 acres)	1990 Columbia Basin Project (52 2 million acres)
50	56 5	590	3 450 0	67 5	627	3 710 0	78 0	664	3 960 0
55	44 0	458	2 680 0	52 4	487	2 880 0	60 8	516	3 080 0
60	35 0	365	2 130 0	41 7	387	2 300 0	48 4	411	2 450 0
65	26 0	272	1 590 0	31 1	288	1 710 0	36 0	306	1 830 0
70	17 9	186	1 090 0	21 3	198	1 170 0	24 7	210	1 250 0
75	11 9	124	725 0	14 2	132	782 0	16 5	140	835 0
80	8 0	83	485 0	9 5	88	523 0	11 0	93	558 0
85	5 3	55	323 0	6 3	59	348 0	7 3	62	370 0
90	2 5	26	151 0	3 0	27	162 0	3 4	29	174 0
95	1 3	13	76 0	1 5	14	81 5	1 7	15	87 0
100	0	0	0	0	0	0	0	0	0
105	1 2-3 0	13-31	136 2-181 6	2 7-3 5	25-33	146 4-195 2	3 1-4 1	26-35	156 6-208 8
110	4 5-5 9	47-62	272 4-363 2	5 3-7 1	49-66	292 8-390 4	6 2-8 2	52-70	313 2-417 6
115	6 7-8 9	69-93	408 6-544 8	8 0-10 6	74 99	439 2-585 6	9 3-12 3	79-105	469 8-626 4
120	8 9-11 9	93-124	544 8-726 6	10 6-14 2	99-132	585 6-780 8	12 3-16 5	105-140	626 4-835 2
125	11 9-14 9	124-155	726 4-908 0	14 2-17 7	132-165	780 8-976 0	16 5-20 6	140-175	835 2-1 048
130	13 4-17 9	140-186	817 2-1 089 6	16 0-21 3	148-198	878 6-1 171 2	18 5-24 7	157-210	939 6-1 252
135	16 4-21 8	171-227	998 8-1 350 2	19 5-26 0	181-242	1 073 6-1 430 0	22 6-30 1	192-256	1 148 4-1 529
140	18 0-24 8	194-258	1 135 0-1 511 8	22 2-29 5	206-275	1 220 0-1 625 0	25 7-34 3	218-291	1 305 0-1 738
145	20 8-27 8	217-290	1 271 2-1 698 0	24 8-33 2	231-308	1 366 4-1 825 1	28 8-38 5	245-327	1 461 6-1 952
150	23 1-30 8	240-321	1 407 4-1 879 6	27 5-36 7	256-341	1 512 8-2 000 3	31 9-42 6	271-362	1 618 2-2 161

FOLDOUT FRAME

FOLDOUT FRAME 2

EXHIBIT C-12 POTENTIAL IRRIGATION BENEFITS THROUGH FORECAST ERROR REDUCTION IN HIGH AND LOW WATER SUPPLY YEARS (All Benefits in Millions of 1960 Dollars)

APPENDIX D

SATELLITE SYSTEM DESCRIPTION AND COSTS

PRECEDING PAGE BLANK NOT FILMED

FOREWORD

Appendix D provides details on methodology and techniques used to compute the satellite information system costs Details on costing alternative information systems and non-information alternatives are also provided in this Appendix.

Costs are one major factor in selecting a preferred system Beyond this factor, in order for the satellite information system to be preferred it should be superior to alternative means of gathering similar types of information, and also superior to at least marginal non-information alternatives being planned for activation over the coming 20-year period

I BASIC SYSTEM COSTING METHODOLOGY

The costs addressed in the study encompass total costs that would be incurred in undertaking the program, to include all associated research and development (R&D) costs needed to implement the system, all investment costs of an initial or recurring nature required to undertake and continue the system, and all operations and maintenance (O&M) costs associated with sustaining the system. Implied in the discussion is the fact that only total incremental system costs are relevant to the study. That is, existing facilities and systems are given, and their prior year costs are sunk and are not relevant to the study (e g , investment in existing ground receiving stations that may be used by the satellite system or the existing Department of Agriculture county agent system which may be used in the dissemination link).

To measure the resources utilized for the satellite information system and for competing information and non-information alternative systems on an equitable basis, a constant FY 1968 dollar unit of measurement has been used The choice of 1968 dollars reflects the costing guideline established early in the study, and a point of departure from which most cost information was available at that time. Costs of resources not in the 1968 time frame have been adjusted to this level

The constant dollar costs of the elements discussed previously are then time-phased over a 1970-1990 time horizon and discounted to present worth (FY 1970) values. Calculation of the present worth of cost streams (and benefit streams), through discounting, permits a comparison of alternative programs which gives consideration to the time periods of cost and benefit occurrence and the time value of money To avoid being presumptuous, cost streams are discounted over a range of rates (7 1/2, 10, and 12 1/2 percent) for decision-maker preference This allows the application of unique discount rates to satellite information systems, and to competing information and non-information alternatives in which differential elements of risk are involved

The specification of a 1970-1990 time horizon has introduced a problem insofar as assets developed for non-information alternatives have useful lifetimes, and hence value, well beyond the 1990 period. To adjust for this, estimates of asset values remaining in 1990, for competing systems, have been developed and added to the appropriate cost or benefit streams.

The specific cost analysis methodologies for the satellite system and competing systems are addressed in the following parts of this Appendix.

II SATELLITE INFORMATION SYSTEM COSTS

Satellite information system costs are divided into five basic system elements (1) program R&D (2) spacecraft and sensors, (3) launch vehicles, (4) data interpretation and analysis, and (5) communications and dissemination network Each element will be discussed in turn

Total system costs are summarized in Exhibit D-1 for two satellite programs involving the same numbers of spacecraft but with unique sensor packages. The preferred program incorporates a sensor package with color TV and synthetic aperture radar in addition to a multispectral scanner, for a total payload weight of about 2,800 lbs The alternative system incorporates only a seven channel multispectral scanner in the sensor package, for a total payload weight of about 1,400 lbs. Costs for the two programs differ most markedly in the launch vehicle and spacecraft cost elements. Although some unique costs would exist for the two programs in other cost elements, these are very minor in comparison, in both an absolute and relative sense, and are not addressed in this report.

Most cost detail in this Appendix is devoted to developing costs of the program with the MSS only, and these costs were factored upward to estimate the larger spacecraft costs where appropriate

A. Program R&D Costs

In the following discussion, an R&D program needed to develop an operational capability for the collection and analysis of satellite system data is described. Each of the tasks which make up the total program is discussed, indicating the objectives of the task and the specific activities needed to achieve these objectives for the various sensors and types of data to be collected Exhibit D-1 summarizes the tasks comprising the R&D program and schedule of costs as part of the overall Satellite Program System Costs, 1970-1990. Final confirmation of R&D results and further refinement of data collection and analysis techniques would be accomplished after the satellite information system becomes operational,

EXHIBIT D-1 SATELLITE PROGRAM 1970-1990 SYSTEM COSTS (IN MILLIONS OF DOLLARS)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
R&D																						
Earth Sciences	25 0	25 0	20 0	4 0	4 0																	78 0
Sensor Equipment	39 0	50 0	50 0	16 0																		155 0
Sensor Data Acquisition	10 0	10 0	15 0	15 0	10 0																	60 0
Sensor Data Processing & Rectification		5 0	6 0	10 0	5 0																	26 0
Automatic Data Interpretation			10 0	20 0	17 0	15 0	10 0															72 0
Historical Data Bank	2 0	2 0	1 5																			5 5
Decision Analysis		3 0	4 0	3 0	3 0																	13 0
Investment & Operations (With Radar & TV)																						
Launch Vehicles	0 0	7 1	14 2	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	28 4	532 5
Spacecraft	46 3	160 7	120 1	73 8	73 8	72 8	69 7	65 6	63 3	62 4	61 3	60 8	59 9	59 2	58 8	58 8	58 3	58 1	57 9	57 4	57 4	1 456 4
Analysis & Interpretation	0 0	2 6	2 4	2 5	2 6	2 6	2 5	2 5	2 4	2 4	2 4	2 3	2 3	2 3	2 2	2 2	2 1	2 1	2 1	2 1	2 1	46 7
Communications	2 0	3 9	3 8	3 6	3 5	3 3	3 2	3 1	3 0	2 8	4 7	2 6	2 6	2 4	2 4	2 3	2 2	2 1	2 0	2 0	1 9	59 4
Total (0 Percent Discount Rate)	124 3	269 3	247 0	176 3	147 3	122 1	113 8	99 6	97 1	96 0	96 8	94 1	93 2	92 3	91 8	91 7	91 0	90 7	90 4	89 9	89 8	2 504 5
(7-1/2 " " ")																						1 502 7
(10 " " ")																						1 338 4
(12-1/2 " " ")																						1 187 1
Investment & Operations (MSS Only)																						
Launch Vehicles	0 0	3 2	6 3	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	11 9	223 7
Spacecraft	25 9	89 9	67 2	41 3	41 3	40 7	39 0	36 7	35 4	34 9	34 3	34 0	33 5	33 1	32 9	32 9	32 6	32 5	32 4	32 1	32 1	814 7
Analysis & Interpretation	0 0	2 6	2 4	2 5	2 6	2 6	2 5	2 5	2 4	2 4	2 4	2 3	2 3	2 3	2 2	2 2	2 1	2 1	2 1	2 1	2 1	46 7
Communications	2 0	3 9	3 8	3 6	3 5	3 3	3 2	3 1	3 0	2 8	4 7	2 6	2 6	2 4	2 4	2 3	2 2	2 1	2 0	2 0	1 9	59 4
Total (0 Percent Discount Rate)	103 9	194 6	186 2	127 3	98 3	73 5	66 6	54 2	52 7	52 0	53 3	50 8	50 3	49 7	49 4	49 3	48 8	48 6	48 4	48 1	48 0	1 554 0
(7-1/2 " " ")																						1 010 0
(10 " " ")																						892 7
(12-1/2 " " ")																						798 8

but such activities may be considered as a part of the operational phase of system implementation.

I Earth Sciences

The research and development requirements of the system will require some fundamental changes in the ongoing water management and agriculture programs New research will not be required, however, some increased efforts in current projects with perhaps some re-examination in view of the satellite capabilities and limitations will be necessary The current research is oriented to ground-based data gathering with very different sampling problems and accuracy requirements While this work is necessary, and valuable to the satellite system, it is not sufficient and more work will be required to take full advantage of the system

Research in the agricultural areas of crop yield and rust control is undertaken jointly by Federal, State, and industrial interests It is anticipated that this cooperation will continue to the mutual interest of all The Agricultural Research Service (ARS), of the U S Department of Agriculture, is the primary coordinator of the efforts in plant industry and has close working relationships with the State Universities and interested chemical, fertilizer, and other industrial groups The Agricultural Weather Service of the Environmental Science Services Administration (ESSA) also conducts research in cooperation with ARS, and contributes work in the sciences of meteorology and hydrology to the plant sciences It is assumed that these organizations will carry their work forward to include the requirements of an operational satellite-assisted system, but it will be necessary for all groups concerned to be made cognizant of the new system requirements

Water management research will also require increased coordination The Soil Conservation Service currently does the snow survey but it is based entirely on surface observations and ground based instruments We would anticipate need for substantially more assistance from other interested groups in providing the basic research for the operational system The following lists of research organizations are representative of the interested groups.

- **Research in Water Management**
  - —Soil Conservation Service
  - —Weather Bureau
  - —Corps of Engineers
  - —State Departments of Water Resources
  - —State Universities
  - —U.S. Geological Survey
  - —U S Forest Service
- **Research in Agriculture**
  - —Agricultural Research Service
  - —State Experiment Stations
  - —Industry - chemical, petroleum, fertilizer, etc
  - —Agricultural Weather Service
  - —Cooperative Rust Laboratory

Research and development needs in the three areas of water management, wheat inventory/yield and rust control are listed separately in Exhibit D-2. It is necessary that coordination be emphasized to take advantage of mutual interests. For example, the accumulated soil moisture is an important input to all three cases.

Costs involved are calculated on the basis of $40,000 per man year for the effort, including required facilities

2 Sensor Equipment R&D

The objective of this phase of the work is to develop advanced sensor components and systems with increased resolution, sensitivity, accuracy and coverage, as needed to meet projected operational requirements. The development phase of the work extends throughout the R&D program, with airborne and satellite testing being used to check out and confirm sensor performance, including the reliability, stability, and other operational aspects

Mission sensors refer to all experiments and equipment whose primary purpose is to provide scientific information and consist of television systems, multispectral scanners and radar Design and development costs are those nonrecurring engineering, fabrication, and testing

EXHIBIT D-2 HYDROLOGY/WATER MANAGEMENT RESEARCH COSTS

	Estimated Costs for 5 Years (Millions)
Hydrology/Water Management	
Snow Area	5
Establish methodology for estimating snow area from samples.	
Establish methodology for estimating water equivalent from area.	
Depth of Snow	6
Establish methodology for estimating snow depth from samples.	
Establish relationship of area times depth to water equivalent	
Melt Volume	8
Develop precise measurements for heat budget studies, relate temperature, wind and radiation to melt	
Determine the effects of rain on snow and snowmelt.	
Rain	6
Calibrate size, duration and intensity of storms to precipitation.	
Relate precipitation distribution and intensity to basin runoff.	
Flow Volume	9
Calibration of marshes, lakes, and flood plains to volume of flow.	
Correlate ground water levels or water table to runoff.	
Relate evapotransportation to vegetation condition, weather, and soil types	
Relate water temperature to evaporation rate	

EXHIBIT D-2 (Continued)

	Estimated Costs for 5 Years (Millions)
<u>Hydrology/Water Management</u> (Con	
Travel Time	4
Establish a soil moisture index.	
Determine water holding and transporting characteristics of necessary soil types.	
Relate topography, geology, soil moisture and vegetative cover to travel time	
Determine effects of ice in stream flow	
	38
<u>Agriculture</u>	
Inventory/Yield	
Establish methodology for estimating total wheat areas from samples.	5
Develop a soil moisture model to forecast yield from the accumulated available moisture	15
Determine the cumulative weather, soil moisture and stress effects on yield	
	20
<u>Rust Control</u>	
Establish the relationships of degree of infection to yield and quality degradation	4
Establish correct applications and timing for reduction in infection rates and crop damage	3
Define the nature of the geographical spread of rust from south to north and from north to south.	5
Determine the relationship of soil moisture to free moisture	2
Establish pathological development of various races of rust with varying environment conditions	6
	20

costs associated with developing separate spacecraft subsystems These costs include design and development studies, reliability studies, ground testing, (excluding test equipment) as well as documentation.

The performance demanded of each type of sensor depends on its intended use in the operational system. For most applications, substantial improvements in sensor performance beyond the existing state of the art will be required to achieve desired operational objectives. The technical areas in which sensor improvement is particularly needed are listed in Exhibit D-3. In addition to improvement of sensor technology, increased performance will also be required for certain auxiliary types of equipment The most critical areas of improvement in performance are also listed in Exhibit D-3

3 Sensor Data Acquisition R&D

Extensive ground truth data must be collected on hydrologic, meteorological, and illumination conditions in connection with the collection of target signature data and also during airborne and satellite test programs This task must be performed with great care and thoroughness, since it provides information needed for accurate interpretation and evaluation of sensor outputs and for establishing suitable operational procedures for data analysis.

A major objective of this phase is to collect and organize comprehensive data on target and background signatures of various types and conditions of snow, ice, soil, vegetation, and other surface materials to provide a foundation for operational methods of interpreting remote sensor data. The signature data should cover the visible, IR, and microwave regions of the spectrum and should include polarization and other potentially useful effects. Signature data should be collected for various conditions of illumination, viewing angle, weather, time of day or season, and other factors having an influence on target conditions

Although quantities of laboratory or field data already exist, there are inconsistencies and inadequacies in the collection methods, expecially when attempts are made to use the data for research and development of satellite information systems Consequently, data collection

EXHIBIT D-3 REQUIRED EQUIPMENT R & D

Television

- Higher line densities and total number of lines per frame
- Accurate registration of images from different cameras (or ground-based automatic processing of imagery to obtain registration)
- Accurate representation of target radiance
- Greater sensitivity of photosensitive surfaces for low light level observations
- Extension of sensitivity to longer wavelengths
- Cycle time of vidicons approaching 5 seconds

Multispectral Scanner

- Large scanning-mirror systems with low distortion of optical surfaces.
- Large multiple-detector arrays.
- Higher detector sensitivities
- Reliable long-life cryogenic systems
- Accurate and consistent calibration methods

Coherent Radar

- Calibration methods for accurate measurement of signal strength
- Reduced power requirements
- Large antennas (up to 100 ft in length)
- Ruggedized high-power output amplifiers capable of coherent operation for frequencies above X-band

Auxiliary Systems or Special Components

Communications

- Wide bandwidth data links to handle multi-channel or high resolution imagery.

Altitude-Control Systems

- Adaptation of high-accuracy altitude measurement systems to provide accurate computation of ground position for imagery

Microwave Antennas

System techniques and mechanical design to provide best capabilities for large apertures, wide-scan angles and high beam efficiency, with minimum weight and volume during launch

Power Supply

Large power supply and thermal dissipation capability, particularly needed for coherent radar systems programs should be expressly planned to answer questions relating to the use of operational systems, and should provide for collection of all auxiliary data pertinent to the interpretation process.

a Preparing and Operating Ground Test Sites

For collecting the ground-based data mentioned above, ground test sites must be prepared and operated by installing field instrumentation and providing personnel and instrument maintenance and calibration facilities

The existing test site at South Cascade Glacier in Washington, and, possibly, hydrology test sites already established by NASA at other locations, could be used for laboratory and ground-based testing. It is also assumed that the existing network of snow observation stations in Canada and Alaska would be available for supplying ground truth data during aircraft flights and calibration data during satellite flights.

It would be desirable to have available, as test sites, typical areas in a large river basin which is part of a large hydroelectric development, such as areas in the Columbia River basin. These test sites could serve not only as locations for collecting ground truth, but would also be used in the later phases of the R&D program to develop and evaluate operational procedures for using remote sensing data Existing instrumentation and methods already in use for collecting operational data would provide ground truth. These would be supplemented by additional instrumentation to increase the number of quantities measured and the density of of measurement The test sites would also serve a function in determining how the forecasting accuracy of existing methods can be improved by the newer remote sensing methods.

b Collection of Target Signature Data

A large amount of pertinent target signature data has been collected by many workers. For example, there is a large amount of pertinent reflectance data for soils and vegetation There are some radar reflectance data and microwave and IR reflectance and emittance data for the objects of interest in hydrology.

Despite the amount of data that has been collected, there are not enough radiance data to permit the evaluation of most of the potential applications of satellites to hydrology More data on snow, ice, water, vegetation, soil, and crops are needed for the following reasons

Measured radiances are influenced by many factors See Exhibit D-4. For any given object of interest, only a few factors have been systematically studied. Many important factors are not reported and not measured.

Measurements by different workers have not been made in similar bands or with instruments having the same spectral resolutions Much of the data are reported in relative rather than absolute terms These and other shortcomings indicate the need for a systematic program of data collection specifically aimed at answering questions pertaining to the use of satellite-borne sensors for various hydrologic applications.

A systematic measurements program would include measurements made on snow, ice, water, soil, vegetation, and crops The conditions of measurement would include, where applicable

- Physical condition
- Viewing conditions
- Age or maturity
- Moisture content
- Geographic location

Objects would be measured by several sensors simultaneously - or virtually simultaneously That is, an attempt would be made to measure radiances for all samples in the visible, the IR, and the microwave regions, under the same conditions.

Every effort would be made to produce measured spectral radiances having generality and statistical significance Sensors would be calibrated to yield absolute radiances Measurements would be made with instruments of high spectral and geometric resolutions, in the visible and near IR (These high resolution data could be degraded to simulate the outputs of sensors having lower resolution)

Sensors would be mounted and made transportable to permit measurements in the laboratory and the field The experimental conditions would be carefully documented

EXHIBIT D-4 SNOW MEASUREMENT FACTORS

I. Conditions of Measurement Affecting Reported Reflectance Spectra of Snow

- Artificial or natural snow
- Illumination conditions
  - Source of illumination (point or extended).
  - Spectral content of illumination (e.g , sun, clear sky, overcast sky, glower, lamp)
  - Length and quality of air paths.
  - Angle of incidence.
- Viewing angles.
  - Angle of reflection
  - Azimuth (when incident ray, reflected ray, and zenith do not lie in the same plane).
- Instrumentation.
  - Reflectance standard.
  - Means of achieving dispersion (filters, prism, grating)
  - Spectral response of dispersing medium.
  - Detector (spectral response and sensitivity for, e.g , thermistor, photovoltaic material, photomultiplier tube, photographic plate).
  - Detector temperature (for thermal bands).
  - Amplifiers and recording media (e.g , linearity, bandwidth, dynamic range)
- Sampling methods
  - Number of replications.
  - Method of averaging measurements (over an area or a time interval).

II. Parameters Describing Physical Form of Snow

Density

Particle size

Wetness

Purity

Extent of sintering

Surface roughness

Surface ice and water

III. Factors Influencing the Physical Form of Snow

Temperature of snow

Temperature of air

Age

Winds

Sunlight

Dust and smoke in air

c. Airborne Test Program

The airborne test phase of the R&D program for implementing operational earth resources satellites has several distinct objectives

1. To check out and evaluate sensor equipment
2. To provide experience with data interpretation methods, and associated data processing techniques and equipment
3 To collect ground truth and target signature data useful for operational purposes

To a considerable extent, these same objectives can be achieved by the use of a pre-operational satellite test program, or during the initial use of the operational satellite system itself The exact distribution of R&D effort among the various phases of the program can be decided after a more detailed program is prepared, but it is believed that a substantial and balanced effort in the various phases of the program will be required for system implementation

d Sensor Check-out and Evaluation

In this task sensor performance will be checked out and evaluated in airborne and satellite tests to confirm anticipated performance. This evaluation will cover not only accuracy, sensitivity and resolution of the sensor outputs, but the reliability, stability, and other operational aspects of sensor performance

Airborne tests can provide much useful information concerning sensor performance, but final evaluation will come from the use of sensor equipment in satellite systems

e Collection of Ground Truth During Airborne Tests (U)

In the airborne testing program, data should be gathered by obtaining repeated coverage over the ground test sites for different seasons, time of day, surface temperatures, and target conditions Simultaneous coverage with more than one type of airborne sensor would further increase the value of the information Comprehensive efforts should be made to collect all necessary ground truth at the same time as the airborne coverage. Extending the same concept to preoperational or operational satellites, simultaneous coverage should be obtained with airborne systems and ground truth collection to facilitate the analysis and interpretation of the satellite data

4 Sensor Data Processing and Rectification

The objectives of this phase of the R&D program are to use data obtained from a pre-operational satellite to evaluate and confirm predicted satellite sensor performance Specific areas of investigation include the performance of the sensors and auxiliary satellite systems, performance of the ground data processing system, and effectiveness and accuracy of the data analysis and interpretation procedures for predicting river management conditions

Results of satellite testing will be used to confirm system performance predicted from system analytical and simulation studies and to modify and improve system operating procedures, where necessary.

The objectives of the satellite test program are basically similar to those of the airborne test program, and the use of a pre-operational satellite may obviate the need for some of the airborne tests In general, the results of the satellite test program provide experience under conditions which are most representative of operational conditions, even though the final operational equipment or procedures may not be fully employed.

The test program described under airborne testing is in large part applicable to satellite testing, but detailed procedures will be affected by the operational environment. Collection of data by satellite should be accompanied by simultaneous collection of airborne data and ground truth data.

In the early portion of the satellite test program, primary emphasis will be placed on analyzing sensor outputs to determine spectral, polarization, or other characteristics of the incoming radiation and their relationship to the various types of surface materials, and atmospheric and illumination conditions. This type of analysis will permit the improvement of interpretation techniques for operational application.

5. Automatic Data Interpretation

Relationships must be established between signature data and surface type and condition to allow reliable interpretation of sensor outputs identifying and measuring hydrologic variables Exhibit D-5 lists

Television

Interpret imagery of snow-covered areas to estimate snow thickness, measure snow-covered area or surface water, distinguish wet soil from dry soil, etc.

Determine ground resolution needed for various tasks.

Multispectral Scanner

Determine best spectral bands for differentiating snow covered areas from soil, rocks, or vegetation, wet soil from dry soil, etc

Develop precise measurement of snow albedo, for heat budget studies, identifying snow characteristics, etc.

Distinguish snow from cloud cover

Investigate effects of ground resolution on signature data

Develop correction methods for atmospheric effects on signatures and temperature measurements.

Establish relation of evaporation or transpiration to surface temperature for vegetation, water, or soil or other measured variables

Calculate heat absorbed and radiated by snow as a function of measured reflectances in bands containing solar energy

Provide accurate area measurement techniques.

a number of specific studies which should be carried out to develop the necessary interpretation methods.

Methods must also be developed for automatic processing of sensor outputs to alleviate the high cost and time requirements associated with human photo-interpretation Exhibit D-5 includes important interpretation problems which require automation.

6 Historical Data Bank

A bank of reference data and imagery will be collected and stored in photographic files or in computer memory banks for operational use. The required data include maps and photography of river basins and agricultural areas for various seasons Also, soil and vegetation types and characteristics, terrain slope and orientation, canopy density, distribution of rivers, lakes, and other bodies of water will be stored by geographic location for use in computer analysis and interpretation of operational data The stored information for each geographic area will include data on reflectances and emittances of surface materials in various spectral regions, as needed for data interpretation

The collection of data as described above will take place throughout the entire R&D program, but will be concentrated particularly in the airborne and satellite phases.

7 Decision Analysis

Using laboratory and field test data, outputs of airborne and preoperational satellite information systems can be analyzed

For purposes of comparison, the laboratory and ground-based data can be extrapolated to satellite altitudes by taking into account the effects of varying illumination and atmospheric absorption and scattering and the sensitivity and resolution characteristics of the operational sensor. Frequency of obscuration by cloud cover can also be taken into account analytically. These same general methods can also be used in the evaluation of airborne systems intended for later operational application.

In the latter stages, the emphasis will shift to demonstration and improvement of system performance. Data collected by satellite sensors will be used in a manner simulating operational procedures as closely as conditions permit. Data reduction and analysis procedures will be applied to the sensor output data and imagery, and the resulting estimates and forecasts of hydrologic variables compared with ground truth taken during the same test program The validity of extrapolations can be checked and improved by the actual satellite measurements.

The effectiveness of the remote sensor system can be expressed in terms of such factors as

(1) Probability of detection and probability of false alarm in identifying snow or other surface materials

(2) Accuracy of measuring area, albedo, or other physical variables

(3) Total rate of coverage, expressed in square miles per hour or day, or in frequency of looks at a specified area

Further analysis can be used to convert this type of information to estimates of the accuracy of predicting volume of snowpack, streamflow or other hydrologic conditions.

A research and development effort is anticipated for both hydrology and agriculture. (For hydrology, techniques of data analysis have been developed to the degree necessary to produce the initial outputs previously described.) Analysis of data from remote sensors has the potential to develop, for specified geographic areas, a historical data base for hydrologic variables such as snow cover and surface moisture From this base patterns can be detected from which analysts will be able to make reliable predictions A portion of the R&D effort will be expended on the task of determining such patterns, while the other portion will develop existing techniques for determining the parameters desired for this application, using aircraft data.

More research and development will be necessary in agriculture than in hydrology because wheat signatures will have to be improved in addition to the parameters that both systems require as outputs, such as surface moisture and temperature. Further, the geographic area to be studied is larger for agriculture than for hydrology As in the hydrology case, research will be directed toward the development of patterns to be used for predictive purposes, as well as toward developing automated data handling techniques Ultimately, research will be directed toward developing signatures for wheat, leading to automatic pattern recognition techniques for detecting wheat.

B Spacecraft System Costs

System costing is an iterative process since system requirements, specifications and costs are interrelated. The specifications are frequently a function of cost and accurate cost estimates are possible only after requirements for the system have been defined and system specifications determined to a reasonable degree of detail For the cases to be examined in this report, requirements for the spacecraft system include (1) area to be viewed, (2) frequency of observation, (3) response time, (4) data required, and (5) information output required. System specifications include (1) sensor types and swath widths, (2) spacecraft weight, (3) mission lifetime, (4) orbital altitude and inclination, and (5) spacecraft and launch vehicle reliability, and (6) numbers of spacecraft required

A number of models for estimating spacecraft program costs were examined for possible use, including models by PRC, RAND, and IITRI The PRC cost model[1] was chosen for the following reasons. (a) It most closely met NASA program needs (b) The model was detailed enough to permit modifications in the cost estimating relationships (CERs) as new information and/or accurate cost information became available. For example, estimates of sensor costs were made by Willow Run Laboratory and should be more accurate than CERs generalized for all experiments, as found in the model (c) It was possible to work closely with the men who had developed the model, facilitating understanding and modifications

Spacecraft costs are categorized both by subsystem, such as structure, power system, communications, etc , and by cost element Estimates of system costs are based on technical factors such as weight, thrust and kilowatts of power as well as cost factors such as the spacecraft total procurement cost.

[1] Development of Cost Estimating Techniques and Relationships for Unmanned Space Exploration Missions, by F. E. Hoffman, G W. S Johnson, L M Simonsen, PRC R-870, October 28, 1966

1 Spacecraft Subsystems

The structure subsystem supports and maintains the satellite configuration under design loads and comprises the main load carrying members, the outer skin, adapters, thermal control louvres and shields, solar panels and supporting structure for various instruments and mechanisms in the spacecraft

The propulsion subsystem provides thrust to eliminate orbital injection errors and station keeping, and consists of small rockets with their associated pumps, valves, plumbing and controls. The propulsion module structure consists primarily of the tanks or pressure vessels for the rocket propellants.

The navigation and guidance subsystem maintains a record of the trajectory, and takes course modification commands from memory or from Earth and relays them to the appropriate subsystems Costs would apply to inertial systems and radio command systems.

The stabilization and control subsystem senses the attitude of the spacecraft and provides the signals to the reaction control subsystem so that attitude changes can be made The subsystem consists largely of attitude control systems, e g , momentum storage, gravity gradient and cold jet storage, and includes items such as gas storage tanks, reaction jets, valves, gyroscopes, momentum wheels, associated electronics, and interconnecting cabling.

The communications subsystem provides for the transmission of information between the spacecraft and Earth. The subsystem consists of tracking, telemetry and command systems which include the beacons used to aid radar tracking, the transmission of all data from the mission sensors, the telemetry of engineering data, and the command receivers used to control the functions of the spacecraft

The data management subsystem provides for the orderly storage of data and comprises the data encoder, tape recorders and related cabling

The electrical power subsystem consists of equipment necessary to supply and condition power to the spacecraft subsystems and includes solar cells, fuel cells, batteries, RTG (isotope) systems, nuclear reactors, converters and inverters, regulators and transformers For our spacecraft program it is assumed that power would be provided by paddle-mounted solar cells.

Mission sensors refer to all experiments and equipment whose primary purpose is to provide scientific information, and consist of instruments such as television systems, optical mechanical scanner spectrographs, infrared radiometers and spectrometers.

2 Cost Elements

First unit cost includes production planning, material, manufacturing, and quality control (inspection) performed at the plant on test and flight spacecraft. In this study, spares and backup spacecraft are are treated as additional test spacecraft and flight spacecraft respectively. At least two test spacecraft must be built early in the program to qualify the spacecraft. And at least one spare and one backup spacecraft are required in case of damage due to testing or ground transportation or in case of failure of an operational spacecraft.

Costs for design and development and first unit costs both are derived from cost estimating relationships with inputs based on subsystem design parameters such as weight, power and thrust.

First unit cost is taken to be the cost per unit up to ten spacecraft. For programs with more than ten spacecraft, a learning curve of 95 percent has been applied (see Exhibit D-6) With such a learning curve, the 20th unit would cost approximately 84 percent of the first unit cost and the 30th unit would cost about 80 percent of the first unit cost. One can argue that no learning curve should be applied due to expected but unplanned engineering changes and other increased costs over a ten year program life. On the other hand, a production run of 20 or 30 spacecraft over a ten year period could certainly involve a continuous production run with an applicable learning curve. For this study, a small positive cost improvement was assumed

Aerospace ground equipment (AGE) includes the equipment at the launch site and contractor's plants that is used for spacecraft check-out and flight activities. Tooling and special test equipment include

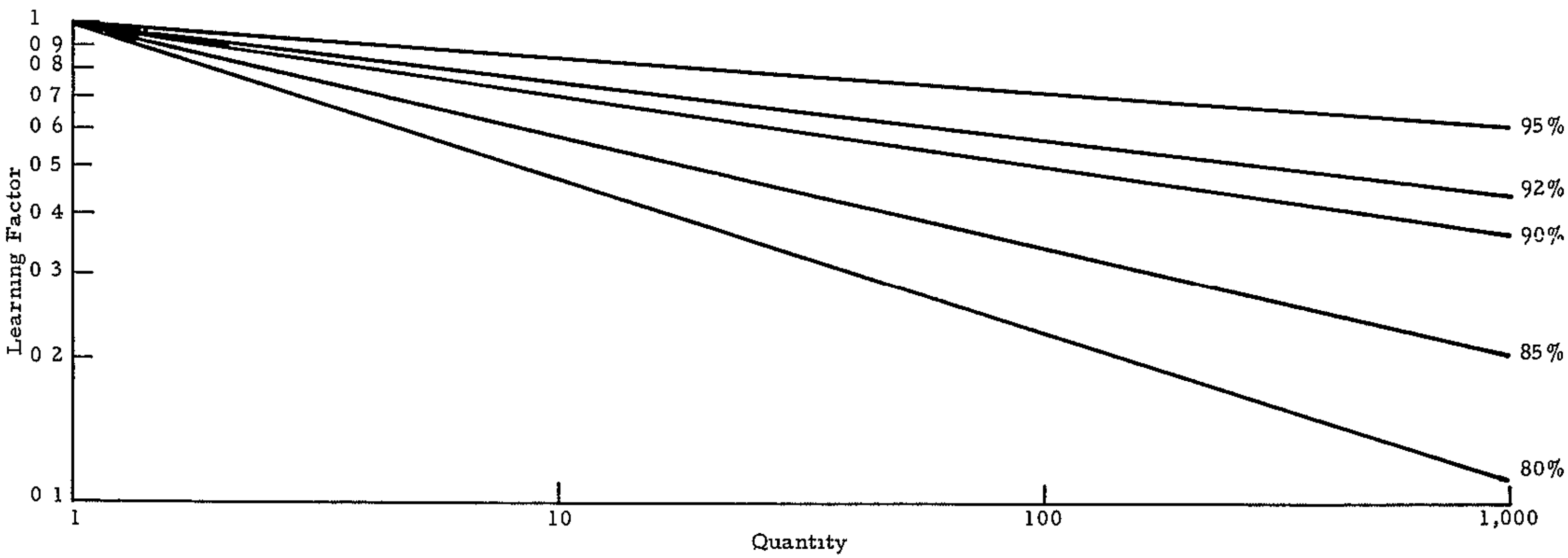


EXHIBIT D-6 UNIT LEARNING CURVE

tooling for production runs and equipment for ground testing. All of these cost elements are included in the design and development totals (nonrecurring) and are based on cost estimating relationships with total spacecraft weight as input parameter

Systems integration includes those costs involved in combining the separate subsystems into the composite satellite The cost of systems integration is based on a cost estimating relationship with design and development cost plus cost of test spacecraft as input parameter.

Costs for mission support include program management, systems engineering and technical direction (SETD), system procurement phases A, B, and C, and advance development The cost of program management is made up primarily of salaries and administrative support for the spacecraft program office The cost of SETD is made up of salaries, administrative support and studies to provide initial system engineering and technical advice to the spacecraft system program office. System procurement phases are identified as Phase A - Advanced studies, Phase B - Conceptual design, Phase C - Project definition, system design and critical hardware development. Advanced development costs refer to the development of long lead time items and the additional research and development required in new or unestablished technologies All these costs are based on a percentage of the spacecraft total procurement cost

Two other important aspects of spacecraft system costing are engineering change orders and reliability

Engineering changes ordered by the spacecraft program office over the lifetime of an extended program can add substantially to costs. These changes may be prompted by revised mission objectives, a technological breakthrough or just the gradual progress in research and development. An increase in program costs of 20 to 25 percent due to these changes would not be unexpected Although the possibility of these additional costs is recognized, their incidence is not inevitable so they were not explicitly added to the present cost estimate.

Reliability influences greatly a number of cost elements For this study, a reliability factor of 0 90 was taken for the spacecraft and

0.90 for the launch vehicle. These factors take into account aborts and infant failures due to design or manufacturing faults as well as malfunctions. The number of spacecraft and launch vehicles required for the programs have been increased proportionately to account for these failures Testing costs are affected as well, varying with the reliability required and can run from 10 percent to 40 percent of the total spacecraft cost.

While discussing reliability an interesting but extremely difficult question arises that relates to cost sensitivity - estimating the cost to increase the mean time between failures (MTBF). For example, what would be the cost to increase spacecraft lifetime from 12 to 24 months? Discussions with industry representatives indicated how difficult such a question is to answer. The MTBF can be a function of system degradation as well as design For example, the power system may be the limiting factor due to degradation over time of solar cells or batteries, or thrust rocket expendables for station-keeping operations may be the limiting factor On the other hand, tape recorders may be the limiting factor due to capacity limitations inherent in the design The MTBF can be increased to some extent by overdesigning a subsystem or by including redundant components, but very often, a marked improvement in the MTBF must await a technological breakthrough. Such breakthroughs, like an order of magnitude increase in capacity or reduction in weight, are very difficult to predict

3 Current System Costs

The current state-of-the-art system is made up of three flight spacecraft and one test spacecraft Since the current program is to be based on existing technology and may involve existing spacecraft types and some off-the-shelf subsystem components, a modest design and development effort was assumed - 25 percent of that of the advanced system Costs of test and flight spacecraft are based on parameter inputs shown in Exhibit D-7. Percentages of subsystem weights to conform with the cost model are based on discussions with NASA officials and a study of ten past NASA programs made by the Illinois Institute of

EXHIBIT D-7 SPACECRAFT COST

Case, Hydrology + Agriculture
Level of Technology: Advanced

Cost Categories	Description	Quantifying Parameter	Parameter Input	Design Development Cost	Parameter Output Dollars/____	First Unit Cost	No Test Spacecraft	Cost of Test Spacecraft	Number Flight Spacecraft
Structure		Weight (lbs)	350 lbs	$ 9 8 M	$ 2 550/lb	$ 892 500	3		
Propulsion Module Structure		Weight (lbs)	56 lbs	$10 2 M	$24, 000/lb	$1 344 000	3		
Propulsion	Liquid	Thrust (lbs)	112 lbs	$ 1 92 M	$ 250/lb	$ 28 000	3		
Navigation and Guidance		Weight (lbs)	42 lbs	$ 2 2 M	$ 5 000/lb	$ 210 000	3		
Stabilization and Control	Cold Gas	Weight (lbs)	112 lbs	$ 3 5 M	$ 4 000/lb	$ 448 000	3		
Communications		Weight (lbs)	168 lbs	$ 9 6 M	$ 5 200/lb	$ 873 600	3		
Data Management		Weight (lbs)	98 lbs	$ 4 6 M	$17 500/lb	$1 715, 000	3		
Electrical Power	Paddle Mtd Solar Cells	Kilowatts	700 watts	$ 7 4 M	$ 2 100/watt	$1 470 000	3		
Mission Sensors		Weight (lbs)	336 lbs	$20 0 M	$ 5 500/lb	$1 848 000	3		
AGE			1400 lbs	$11 5 M					
Tooling and Spec Test Equipment			1400 lbs	$ 4 9 M					
Totals				$85.62 M [1]		$8, 829 100	3	$26 49 M [(2)]	68
Systems Integration		1 + 2	112 11 M	$ 5 65 M					
Totals 1968 Constant Dollars				$93 56 M [1]		$9 647 600		$28 95 M [(2)]	

Technology Research Institute.[1] The subsystem weight percentages are displayed in Exhibit D-8. A summary of costs for the current program may be seen in Exhibit D-9

4 Advanced System Costs

The advanced level of technology system is made up of 68 flight spacecraft and three test spacecraft. Based on a spacecraft system constellation of four operational spacecraft at one time with an average mission lifetime of 16 months over the 18 year period from 1973 to 1990, one finds that 54 operational spacecraft are required With a reliability of 0 90 for the spacecraft and 0 90 for the launch vehicle, the number of flight spacecraft is increased by 54/0 81 to 67 plus one as backup for a total of 68 flight spacecraft. Two test spacecraft plus one spare make up the three test spacecraft

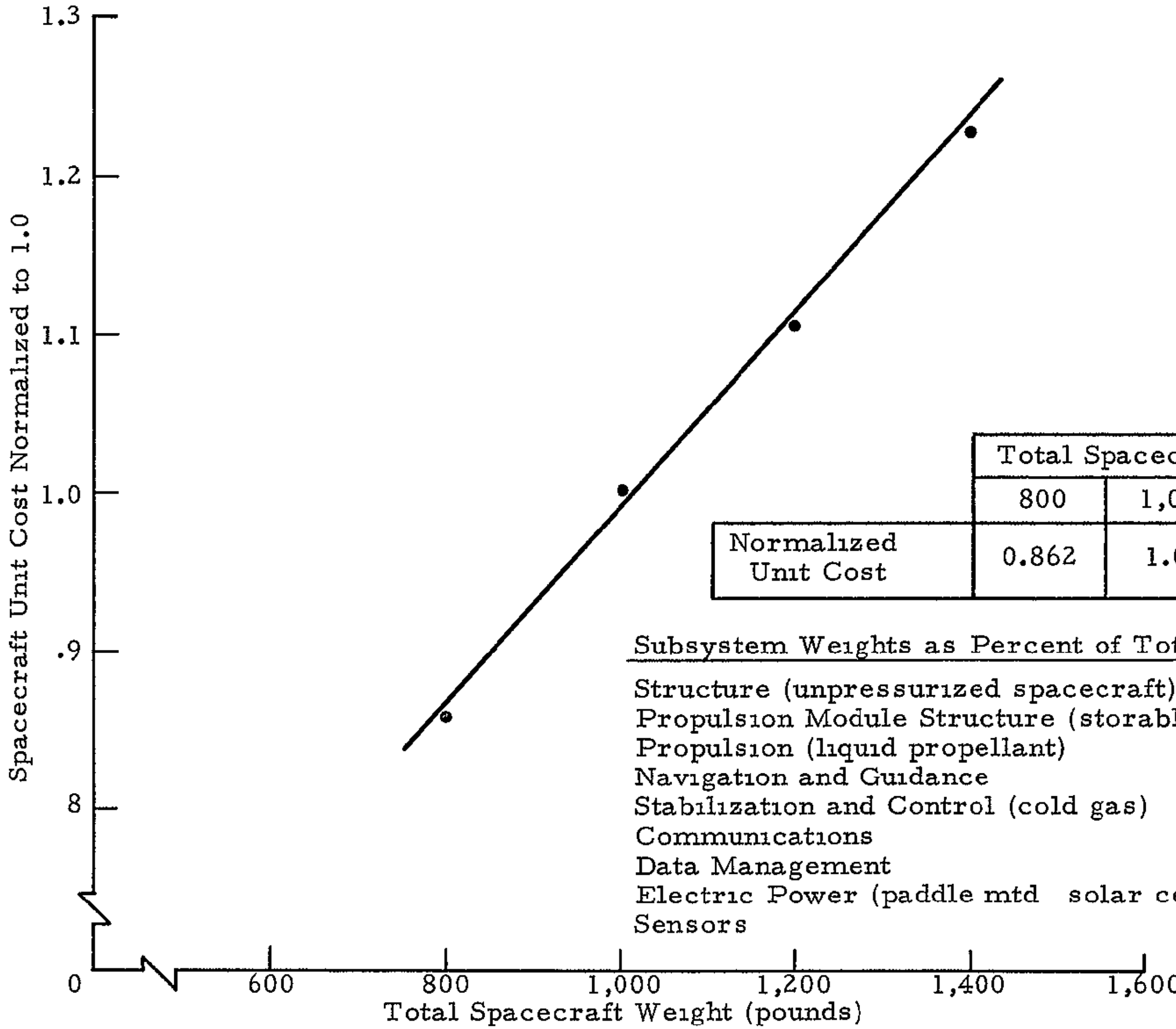
To determine the cost of flight spacecraft, a learning factor was selected from Exhibit D-6 for groups of three spacecraft beyond the first ten units. For example, the learning factor for the 17th through the 19th spacecraft was taken as 0 86, resulting in a unit cost of 0 86 x $9,647,600 = $8,296,900 for those three spacecraft The total cost of flight flight spacecraft for the advanced system, $545 09 million, is approximately 17 percent less than the cost would have been had no learning curve been applied

A summary of costs for the advanced system is shown in Exhibit D-10

5. Cost Schedule

The cost schedule for spacecraft program costs with only a MSS sensor package is shown in Exhibit D-11. Total program costs would increase by about 79 percent for a system with TV and radar in the sensor package The current level of technology system is treated

[1] Spacecraft Cost Estimation by W P Finnegan and C A Stone, Astro Sciences Center of IIT Research Institute, Report No C-6, May 1966



	Total Spacecraft Weight (pounds)			
	800	1,000	1,200	1,400
Normalized Unit Cost	0.862	1.00	1.104	1.225

Subsystem Weights as Percent of Total Spacecraft Weight	
Structure (unpressurized spacecraft)	25%
Propulsion Module Structure (storable propellant)	4%
Propulsion (liquid propellant)	5%
Navigation and Guidance	3%
Stabilization and Control (cold gas)	8%
Communications	12%
Data Management	7%
Electric Power (paddle mtd solar cells)	12%
Sensors	24%

EXHIBIT D-8 SENSITIVITY OF SPACECRAFT UNIT COST TO TOTAL SPACECRAFT WEIGHT

EXHIBIT D-9 , SPACECRAFT COST SUMMARY (Current)
1968 Dollars

ITEM	①	②	③	④	⑤	⑥
	Design/Development	Cost of Test Spacecraft	D/D Plus Test Spacecraft	System Integration	Cost of Flight Spacecraft	Total Cost
			① + ②			③ + ④ + ⑤
SPACECRAFT (Current)	23 39 M	9 65 M	33 04 M	1 68 M	28 95 M	63 67 M

MISSION SUPPORT	DESCRIPTION/INPUT	OPERATION	COST
Program Management		0 05 ⑥	3 18 M
SETD	Mgt Mode/Tech Manpower Ratio	0 10 ⑥	6 36 M
Phase A	Advanced Studies	0 01 ⑥	64 M
Phase B	Conceptual Design	0 01 ⑥	64 M
Phase C	Project Definition, System Design & Critical Hdw Dev	0 05 ⑥	3 18 M
Advance Development	N_r = O = Number of High Risk Sub Systems	0 05 ⑥ $(1 + \sqrt{N_R})$	3 18 M
		TOTAL 1968 Constant Dollars	$ 80 85 million

EXHIBIT D-10 SPACECRAFT COST SUMMARY (Advanced)
1968 Dollars

ITEM	①	②	③	④	⑤	⑥
	Design/Development	Cost of Test Spacecraft	D/D Plus Test Spacecraft	System Integration	Cost of Flight Spacecraft	Total Cost
			① + ②			③ + ④ + ⑤
SPACECRAFT (Advanced)	93 56 M	28 95 M	122 51 M	6 17 M	545 09 M	673 77 M

MISSION SUPPORT	DESCRIPTION/INPUT	OPERATION	COST
Program Management		0 05 ⑥	33 69
SET D	Mgt Mode/Tech Manpower Ratio	0,10 ⑥	67 38
Phase A	Advanced Studies	0 01 ⑥	6 74
Phase B	Conceptual Design	0 01 ⑥	6 74
Phase C	Project Definition System Design & Critical Hdw Dev	0 05 ⑥	33 69
Advance Development	N_R = 1 = Number of High Risk Sub-Systems	0 05 ⑥ $(1 + \sqrt{N_R})$	67 38

TOTAL 1968 Constant Dollars: $ 889 39 million

EXHIBIT D-11 SPACECRAFT PROGRAM COSTS (In Millions of Dollars)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Totals
Current System																						
Design & Development	16 37	7 02																				23 39
Test Spacecraft		9 65																				9 65
Flight Spacecraft		9 65	19 30																			28 95
System Integration		1 68																				1 68
Program Management	1 06	1 06	1 06																			3 18
Systems Engr & Technical Dir	2 12	2 12	2 12																			6 36
Procurement Phases A B & C	4 46																					4 46
Advance Development		3 18																				3 18
Totals	24 01	34 36	22 48																			80 85
Advanced System																						
Design & Development	22 36	33 68	21 43	16 09																		93 56
Test Spacecraft			28 95																			28 95
Flight Spacecraft				36 45	36 45	35 92	34 18	31 86	30 57	30 11	29 46	29 16	28 72	28 27	28 06	28 06	27 78	27 70	27 62	27 33	27 33	545 09
Flight Integration			6 17																			6 17
Program Management	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	33 69
Systems Engr & Technical Dir	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	67 38
Procurement Phases A B & C	13 48	33 69																				47 17
Advance Development		33 69	33 69																			67 38
Totals	40 65	105 87	95 05	57 35	41 26	40 73	38 99	36 67	35 38	34 92	34 27	33 97	33 53	33 08	32 87	32 87	32 59	32 51	32 43	32 14	32 14	889 39
Combined																						
Design & Development(1)	38 73	40 70	21 43	16 09																		116 95
Test Spacecraft(1)		9 65	28 95																			38 60
Flight Spacecraft		9 65	19 30	36 45	36 45	35 92	34 18	31 86	30 57	30 11	29 46	29 16	28 72	28 27	28 06	28 06	27 78	27 70	27 62	27 33	27 33	574 04
System Integration		1 68	6 17																			7 85
Program Management	2 66	2 66	2 66	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	1 60	36 87
Systems Engr & Technical Dir	5 33	5 33	5 33	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	3 21	73 74
Procurement Phases A B & C	17 94	33 69																				51 63
Advance Development		36 87	33 69																			70 56
Totals	64 66	140 23	117 53	57 35	41 26	40 73	38 99	36 67	35 38	34 92	34 27	33 97	33 53	33 08	32 87	32 87	32 59	32 51	32 43	32 14	32 14	970 24

Note (1) Included in Program R&D Costs

essentially as a large test program for the advanced system that becomes operational in 1973. In the current level system, procurement phases A, B, and C are programmed in 1970 as is 70 percent of the design and development The remaining 30 percent of the design and development is scheduled for 1971, along with advanced development, systems integration, testing and the first operational spacecraft The remaining two flights are made in 1972 Systems engineering and technical direction and program management are treated as levelized annual expenditures over the three year program

The advanced level spacecraft program is scheduled over a 21 year period Procurement phases A and B are programmed in 1970, with phase C in 1971 Design and development, including aerospace ground equipment and tooling and special test equipment, follow an S-shaped expenditure curve over a four year period, 1970 through 1973. Annual expenditures for design and development are at rates of 23 9 percent, 36.0 percent, 22.9 percent and 17 2 percent based on NASA experience Advance development is begun after one year of advanced studies and conceptual design (procurement phases A and B) and extends over a two year period, 1971 and 1972

Systems integration and spacecraft testing are scheduled during the year before the satellites are operational, 1972 Annual expenditures representing an equal number of flight spacecraft begin in 1973 and run for the next 18 years. Systems engineering and technical direction and program management are treated as levelized annual expenditures over 21 years.

6. Sensitivity Analysis

The sensitivity analysis of spacecraft systems cost is based on the number of spacecraft required for 100 percent mapping of the Columbia River Basin rather than the number of spacecraft required for the sampling coverage employed in the system chosen in this study Conclusions drawn from illustrative figures would not differ markedly for the system chosen.

Sensitivity of total spacecraft systems cost to swath width and frequency of observation is illustrated in Exhibit D-12 It can be seen

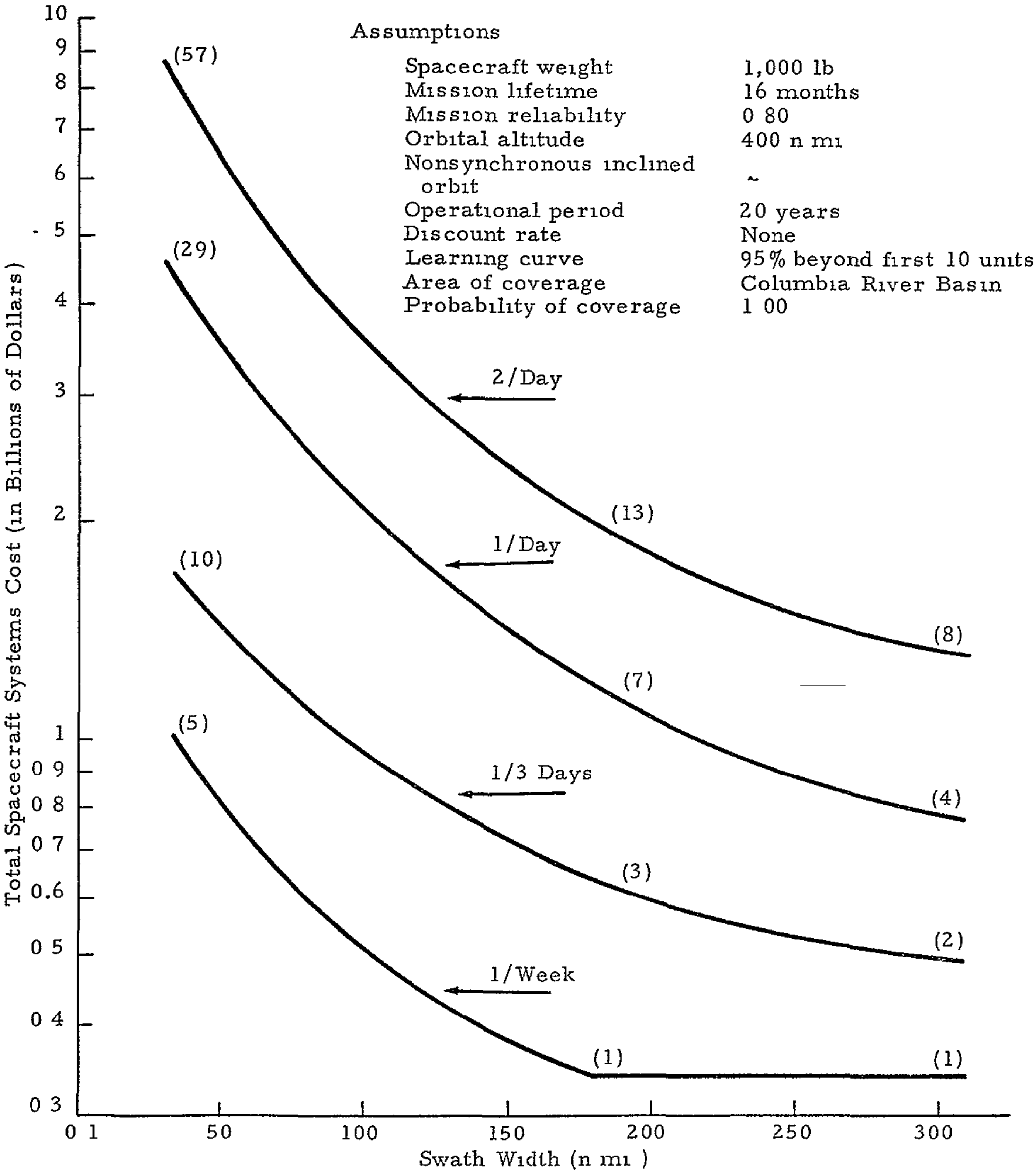


EXHIBIT D-12 SENSITIVITY OF TOTAL SPACECRAFT SYSTEM COST TO SWATH WIDTH AND FREQUENCY OF OBSERVATION that costs are more sensitive to swath width than to frequency of observation for the area of coverage encompassing the Columbia River Basin A reduction of the limiting sensor swath width from 200 n miles to 100 n miles at constant observation frequency of twice a day increases system costs by 95 percent, while a doubling of the observation frequency from once a day to twice a day at a constant swath width of 200 n miles results in an increase in systems costs of only 70 percent. One would expect that costs would be almost equally sensitive to swath width and frequency of observation since the number of spacecraft required at one time varies nearly linearly with both these parameters For this relatively small area of coverage (the Columbia River Basin), however, the linear relationship between the number of spacecraft and frequency of observation breaks down, since a minimum number of spacecraft are required. For example, at 300 n. miles swath width, two spacecraft at a time are required to see the basin area once every three days but only four spacecraft at a time are required to see it once every day.

The sensitivity of total spacecraft systems cost to mission lifetime is shown in Exhibit D-13 One can see that a 50 percent increase in mission lifetime from 16 to 24 months would result in a system cost reduction of about 20 percent, while a doubling of mission lifetime from 16 to 32 months would result in a cost reduction of about 30 percent.

The influence of discount rate on total spacecraft system costs can be seen in Exhibit D-14. For the discount rates of 7.5 percent, 10 percent, and 12 5 percent, the system costs are 58.7 percent, 50 7 percent, and 44 7 percent respectively of the undiscounted costs. Other rates and their discounted costs can be selected from the curve.

The sensitivity of spacecraft unit cost to total spacecraft weight has been shown in Exhibit D-8. Based on the subsystem weight percentages for a 1000 lb spacecraft, a ten percent change in spacecraft weight results in a change in unit cost of approximately 5 1/2 percent.

C Launch Vehicle Costs and Selection Criteria (U)

Section C describes the procedures and the data required to make a selection of the launch vehicle for a specific satellite program

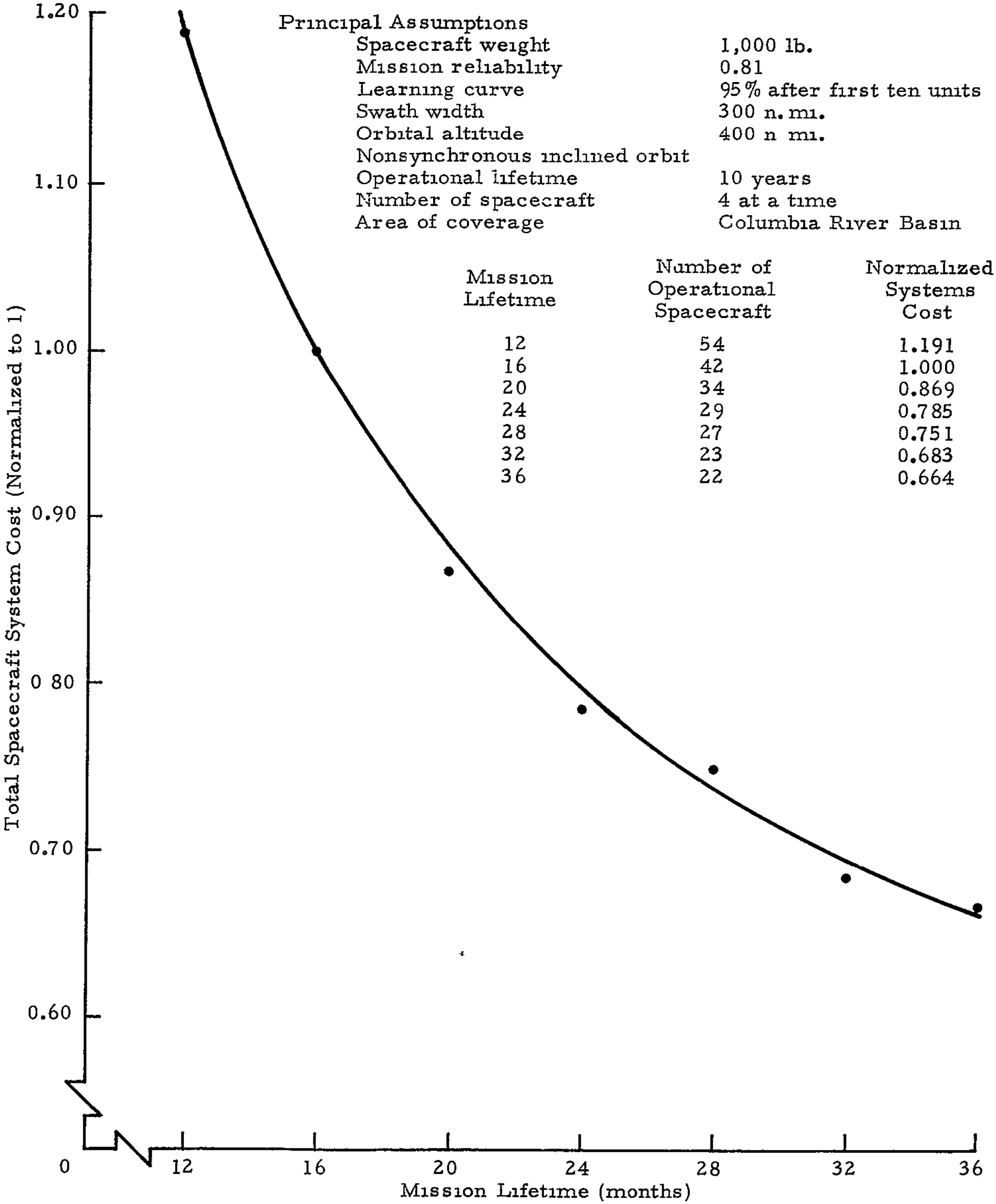


EXHIBIT D-13 SENSITIVITY OF TOTAL SPACECRAFT SYSTEM COST TO MISSION LIFETIME

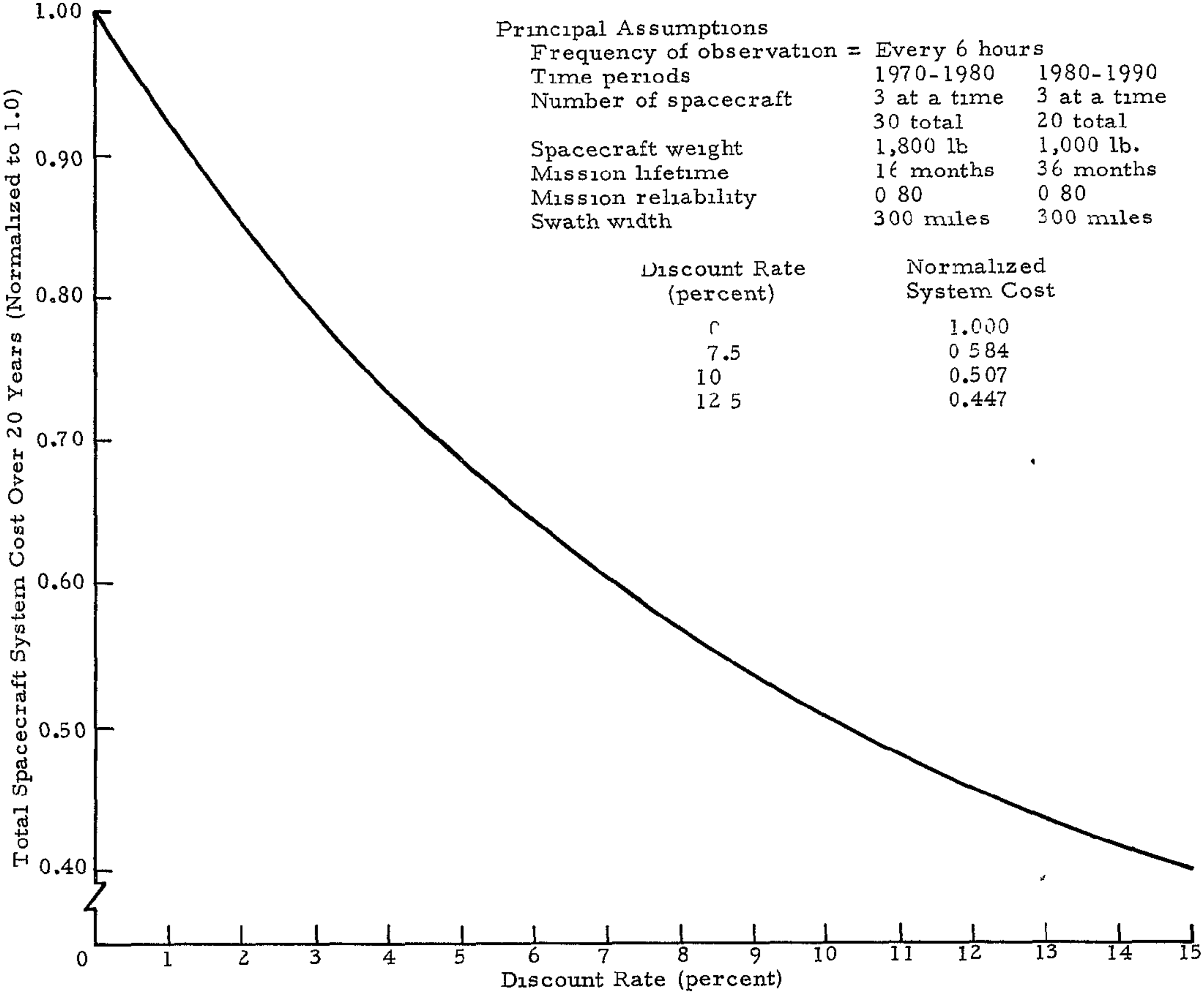


EXHIBIT D-14 SENSITIVITY OF TOTAL SPACECRAFT SYSTEM COSTS TO DISCOUNT RATE and the method to obtain its cost. Also included in this section is selection and costing of the launch vehicle for the proposed ERS program. All cost and vehicle performance data were obtained from the Battelle Memorial Institute and approved by the Launch Vehicle Requirements group at NASA Headquarters

1. Ground Rules and Assumptions

The basic ground rules and assumptions employed for launch vehicle selection are as follows

- There will be no RDT&E for candidate launch vehicles during the time frame under consideration per the OSSA Launch Vehicle Requirements Group at NASA Headquarters
- The costs and payload/velocity curves supplied by Battelle Memorial Institute (Exhibits D-15 and D-16 were approved by NASA and are the total launched cost of the vehicle with a 1400 pound payload.[1] Included in the costs are manufacture (assembly), factory checkout, shipping to launch site, erection and checkout at launch site, launch costs, and costs for sustaining launch crews
- The costs of the vehicles will not exhibit the standard learning effect usually associated with hardware programs per the Launch Vehicle Requirements Group at NASA Headquarters.
- The basic assumptions concerning velocity increments are contained in the launch vehicle selection criteria portion of the Procedure Section, 3b.

The following section presents the procedure for selecting an appropriate launch vehicle. It is in the form of a "cook book" with definitions and explanation, curves and graphs required to select a launch vehicle The section also contains an example of a launch vehicle selection for a proposed ERS program with a total payload weight of 1400 lbs The launch vehicle selection for a 2800 payload would follow similar procedures but lead to selection of a TITAN configuration rather than the THOR vehicle selected in the example.

[1] Payload/velocity curve for the Titan boosters, required to launch a 2800 pound payload is shown in Exhibit D-16-a

EXHIBIT D-15 LAUNCH VEHICLE UNIT COSTS

Launch Vehicle	Launch Rate ETR	Launch Rate WTR	First Year Operation	Cost (10^6)
THOR/FW-4	18 (6)	20 (5)	1968	1 247
THOR/BURNER II	18	20	1970	1 851
TAT (3 Castors)/BURNER II	18	20	1970	2 411
TAT (6 Castors)/BURNER II	18	20	1970	2 692
TAT (3 Castors)/DELTA	18	20	1968	2 743
TAT (6 Castors)/DELTA	18	20	1970	3 024
TAT (9 Castors)/DELTA	18 (3)	20 (2)	1970	3 280
TAT (3 Castors)/AGENA D	18	20	1967	4 439
TAT (3 Castors)/HOSS	18	20	1972	3 634
TAT (6 Castors)/HOSS	18	20	1972	3 915
TAT (9 Castors)/HOSS	18	20	1972	4 171
SLV3C (or X)/CENTAUR	16	40	1971	8 845
SLV3A/BURNER II	16	20	1970	4 257
TITAN III X/AGENA D		13	1968	8 032
TITAN III X/CENTAUR		13 (1)	1972	10 445
TITAN III X/HOSS		13 (1)	1972	7 100
TITAN III C (Transtage)	8 (4)	12 (1)	1968	15 640
TITAN III D/CENTAUR		12	1972	15 945
TITAN III D/HOSS		12 (1)	1972	12 600

EXHIBIT D-15 (Continued)

Launch Vehicle	Launch Rate ETR	Launch Rate WTR	First Year Operation	Cost (10^6)
TITAN III F/HOSS		12 [1]	1972	15 100
TITAN III F/CENTAUR		12 [1]	1972	18 445
Final Stages for the Above				
FW-4				0 073
TE-364				0 131
BURNER II				0 677

Notes
(1) Assumed same family as TITAN III C and has the same launch rate
(2) 20 total TAT combinations per year
(3) 18 total TAT combinations per year
(4) 8 assumed from analogy of SLV3 launch capability
(5) Assumed identical to TAT launch rate
(6) Assumed identical to TAT launch rate

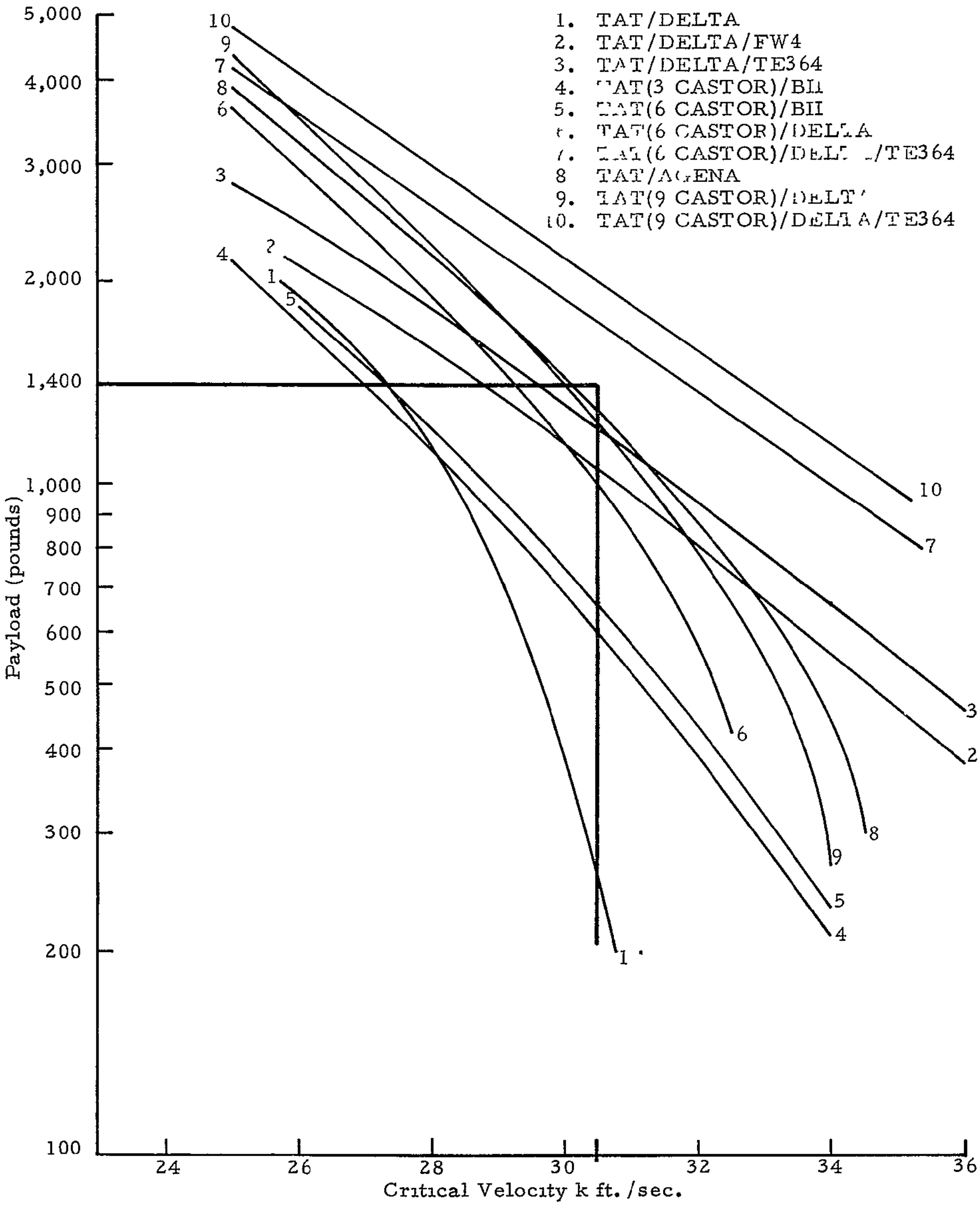


EXHIBIT D-16 LAUNCH VEHICLE VELOCITY--PAYLOAD LIMITS FOR SERIES OF TAT BOOSTERS

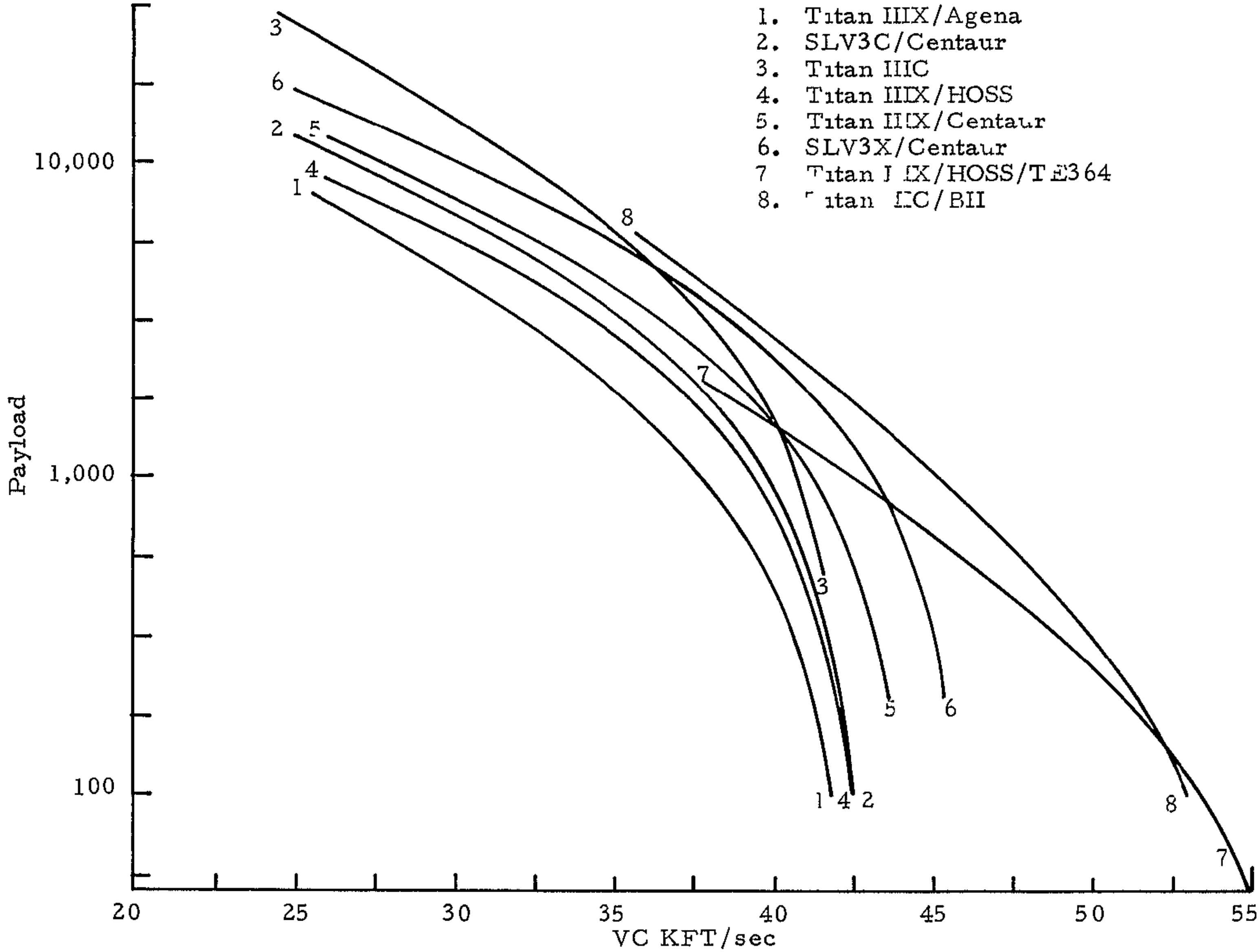


EXHIBIT D-16-a LAUNCH VEHICLE VELOCITY--PAYLOAD LIMITS FOR SERIES OF TITAN BOOSTERS

2 Launch Vehicle Selection Procedure

The basic procedure for selection of a launch vehicle is to (1) obtain complete mission information, launch azimuth, payload, orbit altitude and orbit inclination, (2) determine total velocity requirement for insertion into the final orbit, (3) from the performance curves determine the candidate vehicles which match or exceed the total velocity requirements and (4) obtain costs from the vehicle cost table and select the least cost system. The following presents the launch vehicle selection criteria and the associated assumptions

a. Selection Criteria

(1) It will be assumed that all launches will be minimum energy launches This means that all spacecraft will be put first into a 100 n mi circular parking orbit and then boosted or kicked into another orbit or combination orbit/plane change, using a Hohmann transfer and if required a "dog-leg" maneuver It is also assumed that the velocity losses attributable to gravity, atmospheric drag and thrust are 2000 fps total This number is hypothetical and is based solely on examples of sample calculations presented in "Handbook of Astronautics and Aeronautics" and the "Flight Performance Handbook for Orbital Operations."

(2) The following procedure is used in determining the appropriate or candidate launch vehicles The procedure is to determine total velocity requirements for each mission and relate it to the capabilities of the candidate launch vehicles. The general form of the equation is

$V_t = V_{100} + V_{1s} + V_{rot} + V_{trans}$ where

V_{100} = Velocity of the satellite in a 100 n.mi. circular parking orbit, and is a constant 25,281 fps

V_{1s} = Velocity penalty assessed for atmospheric drag, gravitational and thrust losses. For this study, these losses are assumed to be a constant 2,000 fps

V_{rot} = Velocity penalty assessed for specific launch sites and desired launch azimuths These losses are those due to the rotational effects of earth and the required ΔV's are found on Exhibits D-17 and D-18

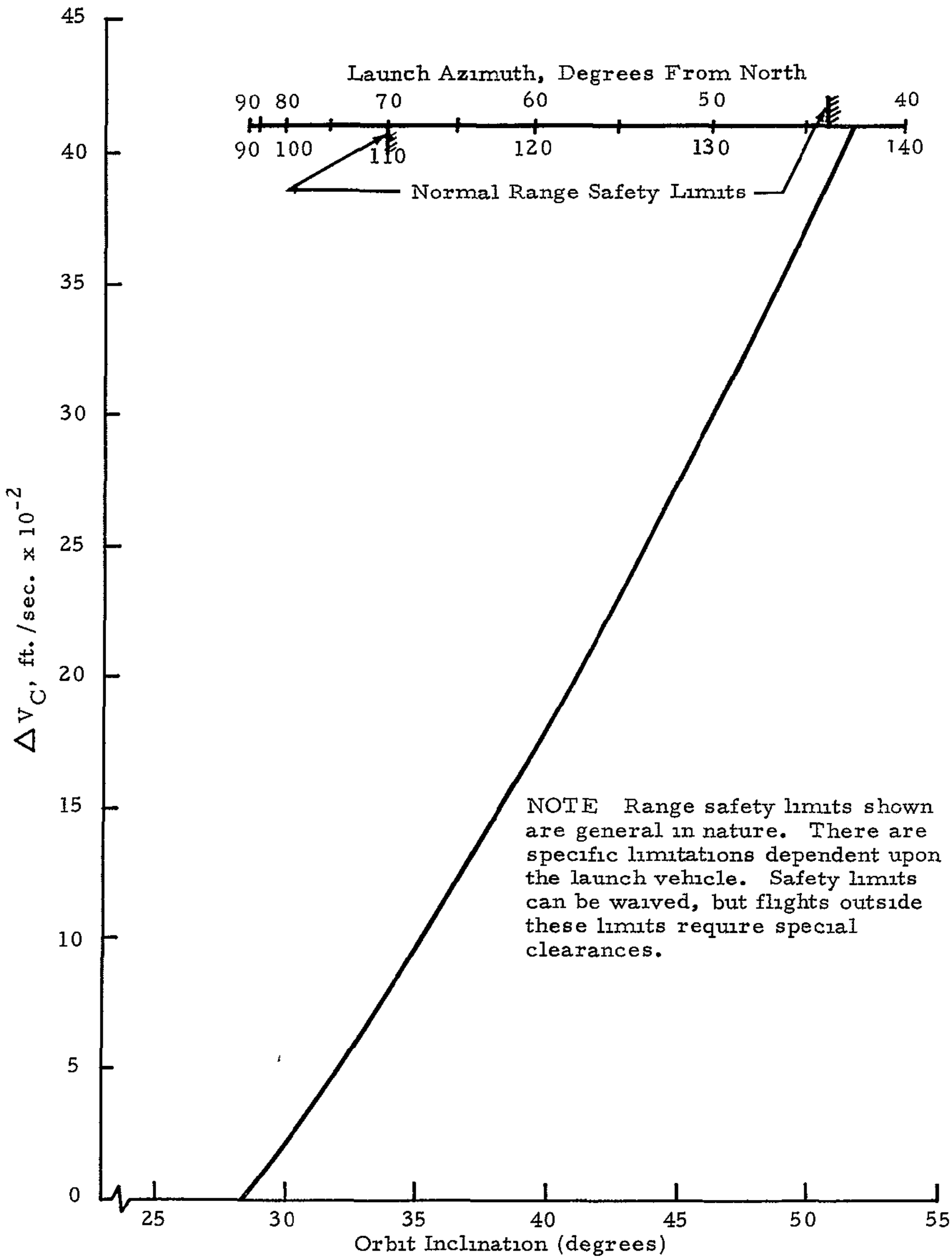


EXHIBIT D-17 VELOCITY PENALTY FOR LAUNCHES FROM EASTERN TEST RANGE (ETR)

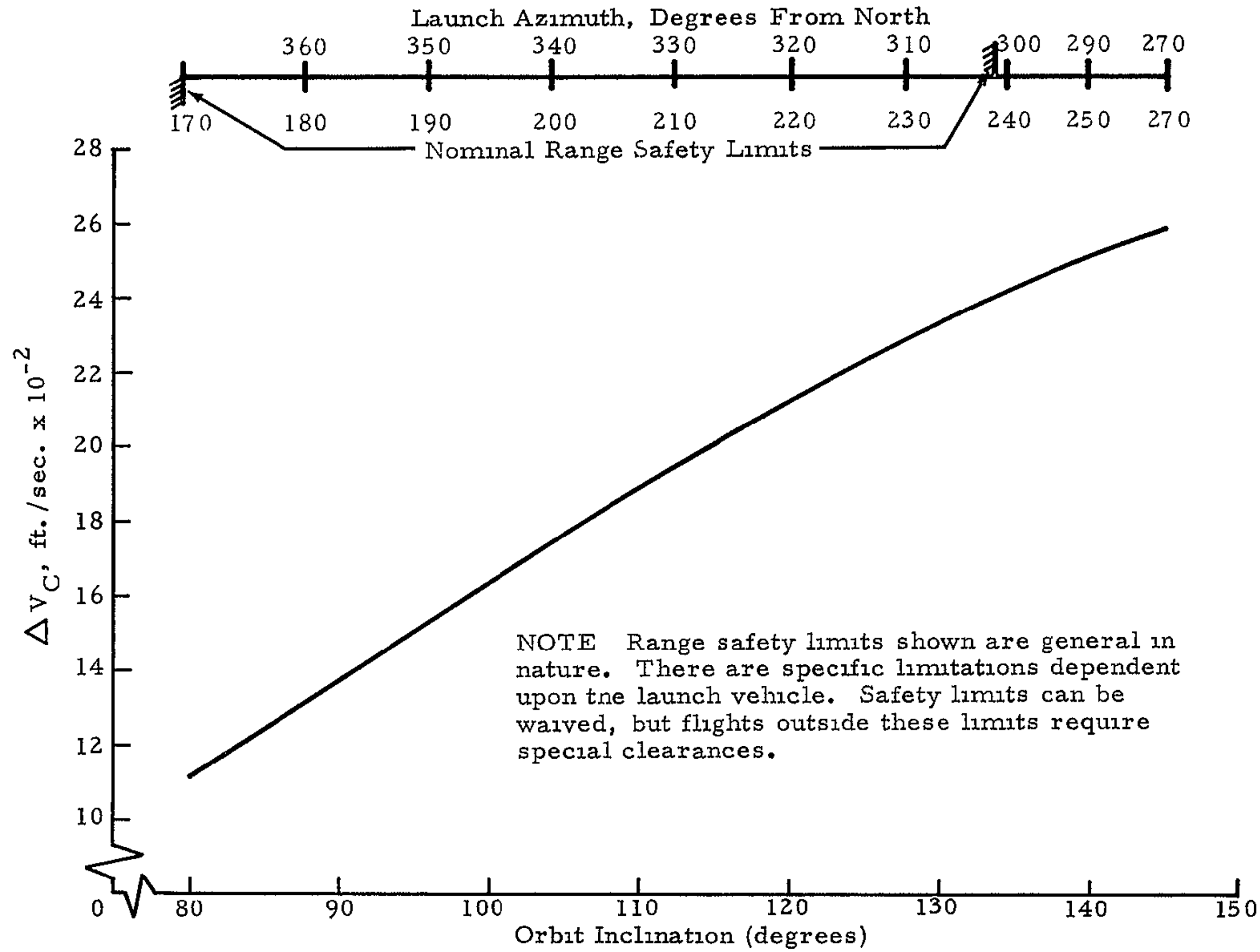


EXHIBIT D-18 VELOCITY PENALTY FOR LAUNCHES FROM WESTERN TEST RANGE

V_{trans} = Velocity required to perform a dog-leg and/or a Hohmann transfer from the original 100 n mi parking orbit to the desired final orbit. Exhibit D-19 gives total Δ V requirements for combination Hohmann transfer and dog-leg maneuvers

3. Once the total velocity is determined, the candidate launch vehicles are selected from the launch vehicles defined by the payload/critical velocity curves of Exhibit D-16 and associated costs shown in Exhibit D-15.

b. Launch Vehicle Selection Example

(1) Given

(a) Payload - 1,400 lbm,

(b) Orbit - Circular, 55° inclination, 300 n.mi altitude.

(2) Find

Least Cost Launch Vehicles

(3) Assumptions

(a) Minimum energy launch to inject payload into circular orbit with 50° inclination This results in an Eastern Test Range (ETR) launch site and a 44° launch azimuth.

(b) Gravitational, atmospheric drag, etc losses are 2,000 fps.

(c) Payload first injected into 100 n mi. orbit with a combination dog-leg and Hohmann transfer into the required orbit.

(4) Solution

(a) Critical Velocity to attain 100 n.mi parking orbit

$$V_c = V_{100} + V_{ls} + V_{rot}$$

from Exhibit D-17 $V_{rot} = 380$ fps

$$\therefore V_c = 25{,}581 + 2{,}000 + 380$$
$$= 27{,}961 \text{ fps}$$

(b) Velocity required to perform 5° dog-leg and Hohmann transfer to 300 n mi. from Exhibit D-19.

$$V_{tran} = 2{,}500 \text{ fps}$$

(c) Total Velocity requirements, V_{tot}

$$V_{tot} = V_c + V_{tran}$$
$$= 27{,}961 + 2{,}500 \text{ fps}$$
$$= 30{,}461 \text{ fps}$$

(d) Launch vehicle candidates From the Critical Velocity vs Payload curves supplied by Battelle Memorial Institute and shown here as Exhibit D-16, the two launch vehicles meeting the minimum requirements of this proposed mission are

1) TAT (6 Castor)/Delta/TE364
2) TAT (9 Castor)/Delta/TE364

(e) Results From Exhibit D-15 the FY 68 costs for the two candidate launch vehicles selected above are

1) \$3 155 Million
2) \$3.411 Million

Therefore, option 1) TAT (6 Castor/Delta/TE364) is the desired launch vehicle. This launch vehicle will be available beginning in FY 70 and can be launched from ETR at a rate of 18 per year. This launch rate is for all TAT combination launches.

Assuming the three satellite ERTS program, followed by a 68 satellite ERS program, the annual cost in FY 68 dollars for launch vehicles is simply the product of number of launches per year and launch vehicle unit cost. A TAT (6 Castor)/Delta with TE364 upper stage costing \$3.2 million would be used for a satellite program with 1,400 lb payload incorporating a MSS sensor package With TV and radar

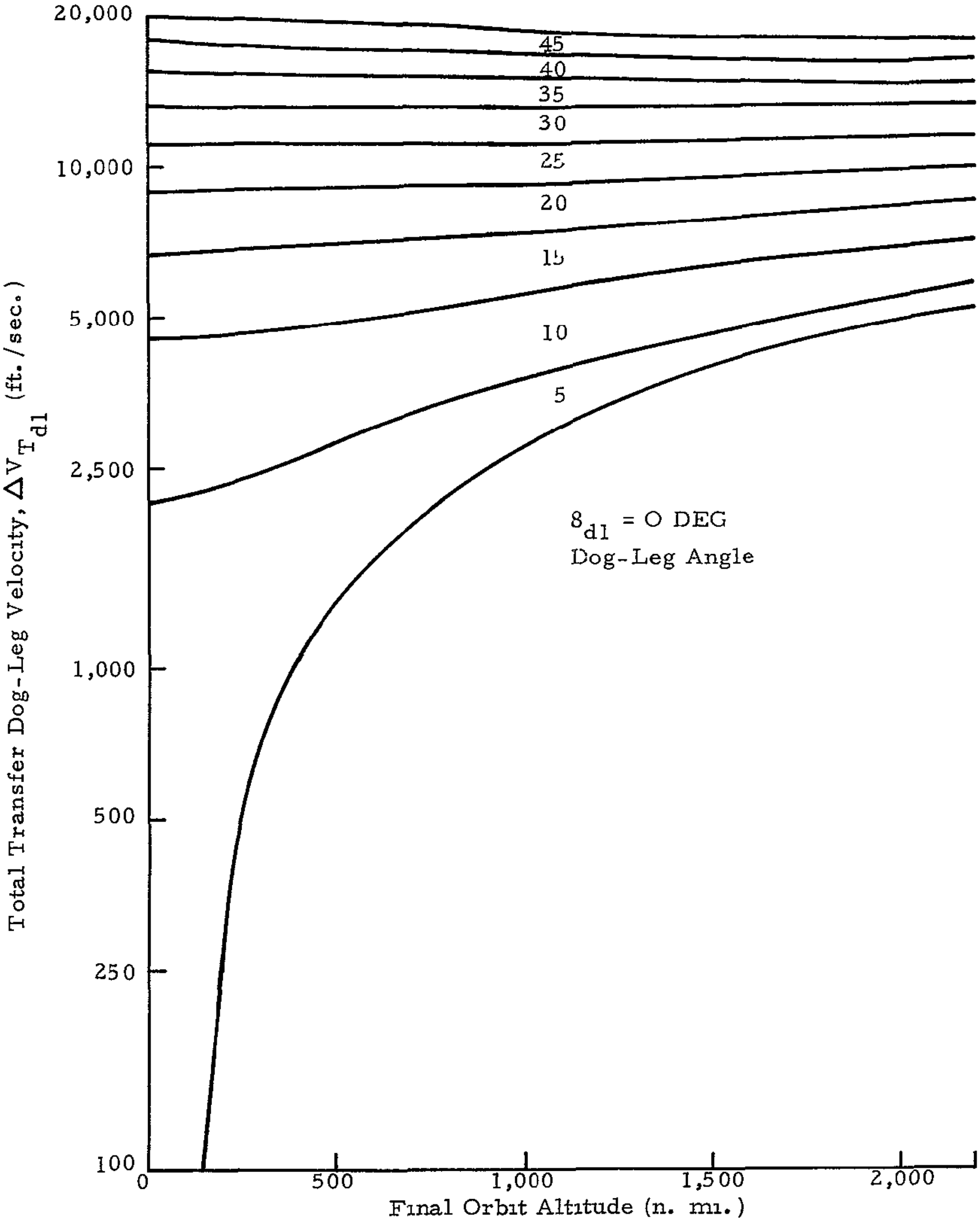


EXHIBIT D-19 TOTAL HOHMANN TRANSFER DOG-LEG INJECTION VELOCITY REQUIREMENTS (PARKING ORBIT ALTITUDE = 100 N. MI.)

incorporated in the package, a minimum cost TITAN IIIX/Hoss is required at $7.1 million per copy

3. Sensitivity Analysis

The launch vehicle selected in the example and the program costs are based on system parameters of an orbit inclination of 55°, an altitude of 300 n mi , and a spacecraft payload of 1,400 lbs. An increase in any of the three parameters requires greater critical velocity, which may necessitate a more costly launch vehicle configuration. Letting the number of operational spacecraft required for ERS program remain constant, the sensitivity of total launch vehicle costs to the above mentioned parameters was tested The results of the cost sensitivity analysis are displayed in Exhibit D-20. The approximate doubling of costs with payload increases to 2,200 lbs and/or a 60° orbit inclination reflects the discrete change in requirements from THOR series boosters to the TITAN series.

Thus a cost penalty of about 260 million is introduced when payload requirements are increased substantially beyond the multispectral scanner sensor package. For example, a radar sensor in addition to the MSS will incur this cost penalty Another interesting parameter is the orbit inclination For greater orbit inclination to 65°, or even 60°, which requires additional velocity for the dog-leg maneuver, the more costly TITAN configuration is required. At present, the 55° orbit inclination does not afford coverage of the Scandanavian countries and large portions of Northern Canada and north and central Russia (Leningrad is approximately 60°). Of course, whether coverage of south and central Scandanavia and larger slices of Canada and Russia are worth the 260 million must be balanced against the lower probability of coverage at more interesting latitudes, e.g., Columbia Basin.

D Data Analysis and Interpretation Costs

1 Introduction

The Interpretation and Analysis Center (IAC) designed for each of the satellite systems described in this report serves several

EXHIBIT D-20 SENSITIVITY OF TOTAL LAUNCH VEHICLE COSTS TO SYSTEM PARAMETERS
(Costs in Millions)

Orbit Inclination (degrees)	Altitude (nmi)	Critical Velocity (ft/sec)	Payload (lbs)		
			1,400	1,800	2,200
55°	300	30,461	224 0	242 1	504 1
	500	30,661	224 0	242 1	504 1
60°	300	32,661	242 1	504 1	504 1
	500	32,761	504 1	504 1	504 1
65°	300	34,761	504 1	504 1	504 1
	500	34,961	504 1	504 1	504 1

purposes. It is a command and control center to monitor the satellites around the clock, and to produce tapes to be used by the ground stations to interrogate the satellites and to command their sensors Secondly, it is a processing facility for the data from the satellites. Personnel and equipment are provided in the IAC to receive, reformat, edit, scan, display and otherwise analyze the data to reduce it to a form useful for decision-making. Once the data has been reduced to the desired form, the IAC will serve as a dissemination point from which information will be sent to users

In each case, the IAC has been designed to meet the analysis requirements of the sensors seen to be most promising for providing the user requirements as outputs from the raw data. Wherever possible, equipment types were selected such that if additional capability were desired, modular additions could be made to increase capacity without major disruptions to the basic configuration.

With the large volume of data provided by the sensors on the satellites, emphasis is placed on utilizing automatic processing techniques As repeated observations increase the analyst's familiarity with the sensor data, as well as with the earth areas to be covered, processing techniques will become increasingly automated. For this reason, the personnel strength at the center is seen to decrease toward the end of the program. Another reason for the decrease in personnel levels is the reduction in programming effort resulting from programs developed and experience gained in the first years of the operational system performance.

In selecting personnel for the IAC, provision should be made for representatives from the major interested user agencies A suggestion for this approach would be to assign, on a part time basis, a representative from each agency to work in conjunction with the specialized analysts at the Center and at the same time to serve as liaison between his agency and the IAC This would insure at all times that outputs from the IAC would be compatible with user requirements.

For either of the applications under consideration, processing requirements are based on the fact that it will not be necessary to cover

100 percent of the area of concern all of the time. Rather, a sampling technique will be used to selectively process data for only those areas known from ground observations and predictions to be of interest because of significant changes in measurable parameters such as extreme rainfall in the Columbia River Basin or drought in major wheat growing areas.

In the case of wheat rust, several measurable parameters must change such that an exact combination of them must occur for wheat rust to form and spread If the parameters are not seen to be moving toward the rust-forming combination, using historical data stored from previous passes of the satellite and ground truth data collected before and during the operational years of the satellite, it will not be necessary to process the data from that area. If, however, it is predicted that conditions might be favorable for rust formation, the satellite data for that area would be collected and processed.

2. General Information Flow

Exhibit D-21 illustrates the major steps in the processing of data at a IAC Data will be received from the satellite via a ground receiving station in the form of an FM signal containing several channels of sensor and housekeeping data. The signal will be recorded on a master tape for "back-up" and will simultaneously be decommutated or separated into discrete signals for each channel of each spacecraft sensor Each signal must also be converted into digital form by a series to parallel converter.

Video data or data from one or more channels of the multispectral scanner will be converted into analog form and fed directly into a display device that exposes film which will be developed in the photo lab. A polaroid camera may also be attached to this device so that "instant" pictures are available for making spot checks The display device can also add pre-determined latitude-longitude grids to the photographs. The resulting photographs will be utilized by photo interpreters

In addition, it may be necessary to utilize the video data to determine the area viewed by the sensors. Current techniques, which use satellite ephemeric data, timing, and sensor orientation, are

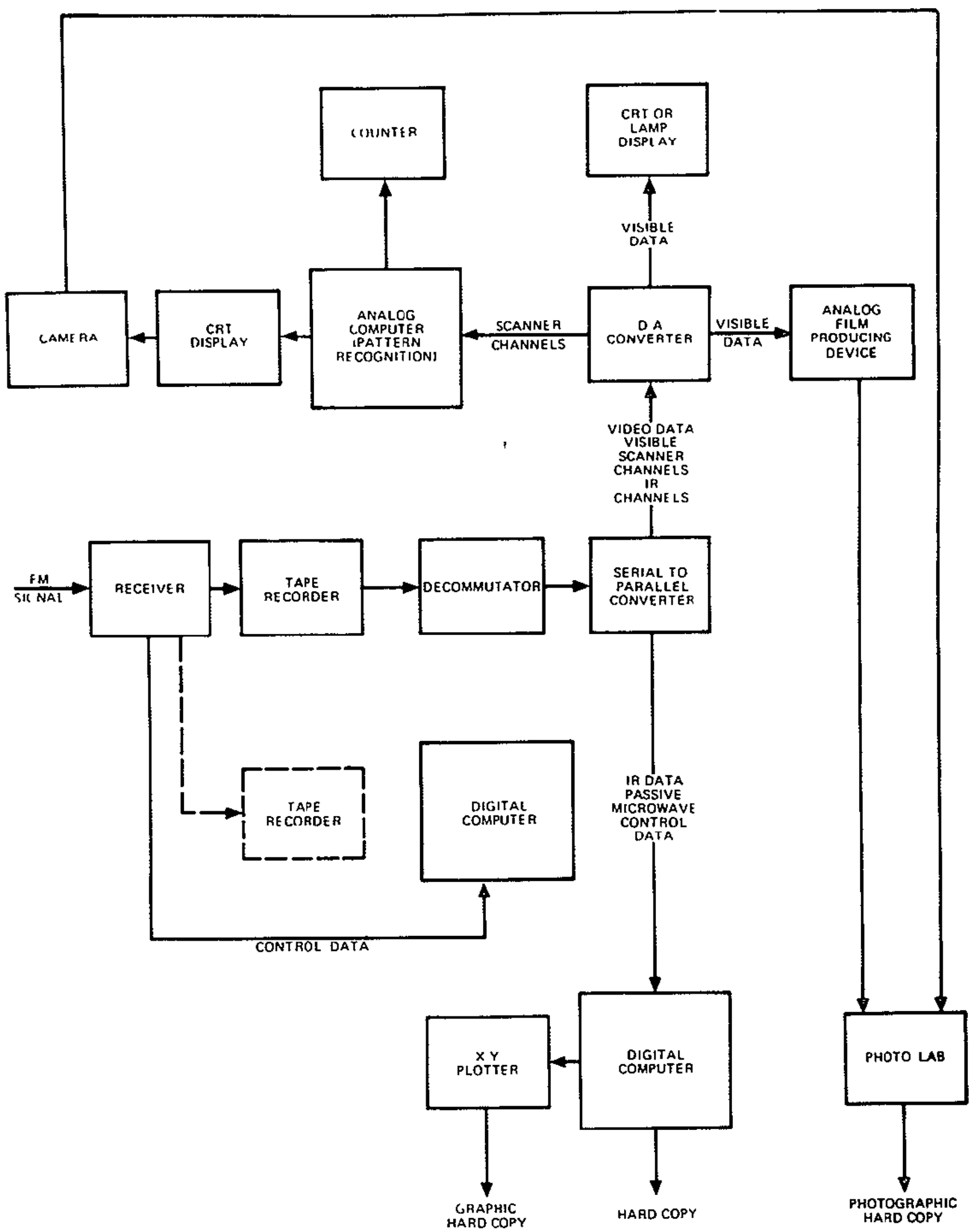


EXHIBIT D-21 GENERAL INFORMATION/DATA FLOW accurate to within one or two miles. The desired accuracy would be less than or equal to the resolution of the spacecraft sensors (less than one-fourth of a mile). Photographs could be calibrated against a map to determine location to nearest resolution element of the sensor

It may also be desirable to feed the digital video signal into the digital computer for processing The digital computer can be programmed to "mosaic" and grid several frames whereas the analog method is limited to producing photographs of single frames In addition, the digital computer has at least three other advantages First, it may be programmed to enhance the discrimination available from the input signal Second, it can produce photographs in various projections (e.g Mercator) and correct for variations in sensor viewing angles. This method is expecially desirable if a sensor has an extreme viewing angle And third, it can be used to eliminate duplicated or unusable areas from further processing. Duplicated areas may be eliminated by "remembering" areas covered by successive frames or passes Unusable areas may be determined by detecting the presence of clouds, fog and other conditions which would make the signals from the other sensors inaccurate or meaningless Currently, it is not known if this technique would allow automatic discrimination between clouds and snow. Additional investigation will be required before this technique can be applied.

Digital processing of multispectral scanner data will primarily consist of computing temperature and surface moisture percentage by resolution element. Automatic corrections for atmospheric and surface conditions and differing instrument calibrations may also be possible Outputs will be one or more of the following types Alphanumeric listings which display parameters by resolution element or summation of parameters by specified geographic areas, digital tapes containing information to be fed into the x-y plotter, digital tapes to be used by automated analysis models, and magnetic tapes to be used in photo processing.

Multispectral scanner data will also be processed by the analog computer at the Agriculture IAC The main purpose of this processing is to detect the existence of wheat, determine its stage of growth, and determine if wheat rust is present. The computer can also accumulate these parameters by specified areas The results can be used to estimate wheat yield and assist in controlling the spread of wheat rust. This type of processing, called "pattern recognition," can be accomplished approximately 1000 times faster by an analog computer than a digital computer State-of-the-art for this particular requirement for pattern recognition, however, is such that a long R&D program might be necessary before processing can become fully operational An alternative or supplemental method would be to produce either black and white or color photographs with signals from one or more of the scanner's infrared channels. The disadvantage of this method is that it requires a substantial manual effort for photo interpretation

Additional functions which are needed include computation of various orbital parameters required by the monitoring center and processing of housekeeping data to determine the condition of the spacecraft and sensors

3 Hydrology Interpretation and Analysis Center (HIAC)

a Output Requirements

The Interpretation and Analysis Center (IAC) for the hydrology application has been specifically designed to produce the following initial and potential outputs.

(1) Initial Outputs

(a) Isothermal maps and/or temperature listings by resolution element.

(b) Snow area in square miles or in map form by specified geographic areas

(c) Area of new snow.

(d) Surface moisture by resolution element.

(e) Aerial distribution and intensity of precipitation

(2) Potential Outputs:

(a) Stream widths for desired areas.

(b) Location and identification of potential precipitation clouds.

(c) Soil moisture by resolution element.

Isothermal maps can be made of any desired geographic area within the Columbia River Basin utilizing a digital plotter and data obtained from the thermal channel on the IR scanner or a passive microwave sensor Such a map would be desired for each complete coverage by the satellite. Temperature differences noticed from one coverage to the next impact on rate of melt of snow, and can be used to forecast precipitation.

Snow area in square miles can be accumulated for specified geographic areas from the television data, or from data from the visible channels of the multispectral scanner. Either automatic analog or digital processing can be used, or areas can be calculated manually from photographs developed from analog or digital film producing equipment. The advantage to utilizing automatic analog techniques is the rapid processing speed, a rate of one hundred thousand resolution elements per second It is very likely that in the early years of the program, both automatic and manual techniques will be utilized to compute the desired hydrologic variables until the analyst's familiarity and experience with the data dictate the most efficient processing techniques to be used.

Area of new snow, inferred from the snow albedo, can also be calculated automatically or manually desired geographic area from TV or visible scanner data. Again it is evident that both methods will be utilized early in the program using the TV photographs as a check particularly if cloud formations are present at the time of the data collection, affecting the reflectance recorded by the scanner. In such a case, the area of imagery obscured by extensive cloud cover would be located using the photograph and deleted from the channels of the other sensors, where appropriate, utilizing programming techniques on the digital computer.

Surface moisture can be calculated by element for any desired geographic area from data from the passive microwave sensor. The results can be in either map form with superimposed percentages or accumulated and listed for any desired subbasin.

Surface water area, such as lakes and large rivers, can be accumulated from TV imagery for any desired subbasin or area. It is also possible to present the information as outlined areas superimposed on a map

The final results of all data processing will be presented to an operator for review and adjustment When finally passed by the operator, they are ready for input to a river basin model, or for distribution to hydrologists or other trained personnel for further interpretation and for use in decision-making

b. Processing Requirements

Certain ground rules and assumptions were made in order to estimate the Hydrology TAC costs for a "base case." However, how these costs would vary with changes to ground rules and assumptions which may be highly variable or which are especially critical to cost is shown in the part of this section concerning sensitivity analysis.

The Columbia River Basin has an area of approximately 312,000 square miles, and it is assumed here that data will be collected by the sensors every 6 hours when desired. However, data representing less than 20 percent of the total area will be processed in any 6-hour period Specific areas to be processed will be selected by the hydrology analysts at the IAC and the computer will screen and process the appropriate data It is also assumed that the data must be processed within 1 hour These two assumptions will allow 100 percent coverage, when desired, if equipment is operated at absolute capacity (assuming 4 hours of processing not related to sensor data are required) In this case response times would increase by approximately 4 hours

It is further assumed that the principal sensor will have a ground resolution of 1,200 feet and each character to be processed by the digital computer will require an internal processing time equivalent to 100 addition times. These assumptions and ground rules for the "base case" HIAC are summarized in Exhibit D-22.

EXHIBIT D-22 HYDROLOGY IAC GROUND RULES AND ASSUMPTIONS

Total Area	312,000 square miles
Frequency of Coverage	4 times per day
Percent Area To Be Processed	20 percent maximum
Processing Time	1 hour every 6 hours
Ground Resolution of Sensor	1,200 feet
Internal Processing Time (Digital Computer)	100 additions per character

c Equipment Requirements

Exhibit D-23 lists the equipment, excluding the digital computer system, required for the HIAC and the other IAC's to be described below. Procurement costs are shown in the first column and number required for the HIAC in column three. These costs are based on the costs of equipment now in use at ESSA, NASA Houston, or the University of Michigan for similar purposes All are believed to have sufficient but not excessively high capacity to meet the processing requirements at the HIAC.

A high-speed digital computer system will be required to process the data within the time requirement. The internal processing time, assuming 100 additions per character, becomes the limiting type of processing even for the fastest available general purpose computer. This assumes that inputs from the separate multiple spectral scanner channels will be read in on separate tape drives at the same time and that outputs will be highly aggregated with respect to input data. It also assumes that any large amount of printing can be accomplished off-line.

The cost of a computer is related to its processing speed and the processing speed required for this application is related to area to be covered, the number and resolution of the sensors, and the amount of time allowed for processing. Since sensor resolution is one of the parameters which is subject to change, a plot of resolution versus annual rental cost of a sample of general purpose digital computers was derived (See Exhibit D-31) This plot shows that the annual rental, including maintenance, of the required digital computer would be approximately $400,000

d Personnel Requirements

Exhibit D-24 lists the personnel requirements by function and year for the operational phases of this hydrology application. In the operation of the HIAC, two positions will be manned around the clock at the control center. The manning requirement per position is approximately four based on three shifts of eight hours each, seven days a week The level of eight men is retained throughout the operation of .

EXHIBIT D-23 INITIAL FACILITY EQUIPMENT

	Unit Cost $000's	Number Required Per Facility		
		HIAC	AIAC	H/A IAC
Receiver	0 5	1	2	3
Tape Recorder (1)	40 0	2	3	5
D/A Converter	5 0	1	1	2
CRT/Lamp Display	5 0	1	2	3
Analog Computer (2)	40 0	1	1	0
Analog Computer (3)	100 0	1	0	1
Analog Computer (4)	200 0	0	1	1
DeGausser, Loop Adaptor	4 5	1	1	1
Photo Processor (5)	20 0	1	2	2
Film Display Device (6)	30 0	1	1	2
X-Y Plotter (7)	48 0	1	1	1
Counter	1 6	1	1	2
Series to Parallel Converter	2 0	1	1	2
Tape Recorder	20 0	1	1	2

Notes
(1) 10-12 track record-playback 1"
(2) For producing photographs in the analog mode, ESSA
(3) For accumulating snow areas, simple pattern recognition, Willow Run Laboratories
(4) For signature analysis to include wheat signatures, temperature, etc
(5) 30 ft/min, 35 or 70 mm film (Hooston Fearless)
(6) Any film size accepted, MSC, Houston, Texas
(7) 31" x 34", 8 vector Plotter $17K, Tape Drive $21K, Contouring package $10K, CALCOMP

EXHIBIT D-24 HYDROLOGY IAC PERSONNEL REQUIREMENTS

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Operational																				
Control Center	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Administration	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Analyst/Programmers	10	15	20	20	20	20	20	15	15	15	15	15	15	15	12	12	12	12	12	12
Photo Lab	8	8	8	8	8	8	8	6	6	6	6	6	6	3	3	3	3	3	3	3
Computer Operators	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Hydrology/Analysts	13	14	14	16	18	18	18	18	15	15	15	15	15	10	10	10	10	10	10	10
Total	69	75	80	82	84	84	84	77	74	74	74	74	74	66	63	63	63	63	63	63

the satellite system. The administration requirement is based on approximately seven positions (eight hours per day) to include personnel, supervisory and secretarial positions with an excess of three to report for a different shift An average of approximately fifteen programmer/analysts, with twenty during the first operational years of the program, is compatible with programming efforts currently in use for satellites returning data to earth As programming techniques develop for this satellite system general programs will be produced allowing a reduction in the manning levels of this position The number of technicians in the photo laboratory also decreases as techniques of analysis become automated requiring less manual photointerpretation For this reason, the number of hydrologist/analysts is seen to peak in the early years of the program, and diminish as automatic techniques develop.

An estimate of five positions for computer operators for each eight hour shift around the clock is maintained at a requirement of twenty per day throughout the program. Their time will be divided between the analog and digital computers.

4 Agriculture Interpretation and Analysis Center (AIAC)

a. Output Requirements Agriculture Inventory and Yield

The facility designed to process data for the agricultural applications of the satellite system will produce the following outputs for the inventory and yield case

(1) Acreage of plowed and harrowed land by specified geographic area.

(2) Identification of wheat fields and stages of growth by resolution element

(3) Ambient temperature by resolution element

(4) Snow area, when applicable by resolution element

(5) Plant reflectance by resolution element.

(6) Surface moisture by resolution element

(7) Aerial distribution and intensity of precipitation

The visible channels of the multispectral scanner will yield acreage of plowed and harrowed land by resolution element for any desired geographic area. The information may be presented as a listing by resolution element, an aggregate listing by specified geographic area, as a photograph, or in map form as desired.

Identification of wheat fields will be accomplished through the use of automatic pattern recognition techniques utilizing data from the infrared channels of the multispectral scanner The analog computer will be used to process the data. Stages of growth in seven steps from emergence to ripeness can also be determined using the infrared channels of the multispectral scanner. The analog computer will be used to process the data. Stages of growth in seven steps from emergence to ripeness can also be determined using the infrared channels of the scanner. This information can be presented as a listing by resolution element, aggregated by specified geographic area, or in map form if desired.

Snow area, when applicable, will be determined from the visible channels of the scanner, and can be presented by resolution element or, more likely, aggregated for a specified geographic area.

Plant reflectance and surface moisture can be determined from the infrared channels of the scanner, and printed out in alphanumeric form or aggregated for any specified area

b Output Requirements Wheat Rust

The IAC for this agriculture application has been designed to meet the following output requirements for use in detecting and forecasting wheat rust.

(1) Crop identification and stages of growth by resolution element

(2) Area and intensity of rust by resolution element.

(3) Ambient temperature by resolution element for any specified geographic area.

(4) Soil moisture by resolution element.

(5) Existence of free moisture (dew) by resolution element.

(6) Aerial distribution and intensity of precipitation.

With the use of ground truth data collected prior to, as well as during the operational years of the satellite program, the analog computer utilizing automatic techniques of pattern recognition, will identify wheat fields by resolution element for any desired geographic area, and can, if desired, accumulate these areas utilizing an on-line counter

The infrared channels of the multispectral scanner will produce data on the maturity of the crop under consideration and classify the level of maturity as one of seven stages from emergence to ripeness or full maturity This can be done by resolution element and aggregated by maturity level for any desired geographic area. Crop identifications and maturity levels can be presented in map form also, if desired.

Area and intensity of wheat rust will be inferred from the ambient temperature readings produced from the multispectral scanner If, within given wheat fields, significant temperature differences are seen between resolution elements, the geographic coordinates of the differing elements can be determined and areas of wheat rust thus located

Soil moisture data taken from the multispectral scanner readings can be presented as a listing by resolution element or in map form if desired Further, the multispectral scanner readings will be used to detect the presence of free moisture (dew) by resolution element This information can be presented as a listing or in map form

Cloud speed and direction to be used for predictive purposes can be obtained from the visible channels of the sensors Photographs can be produced from which a trained photointerpreter can determine the speed and direction of clouds, as well as any cloud anomalies indicating rainfall.

Between August 1 and March 1, a thirty day rust forecast will be produced every fifteen days, and between February 1 and August 1 a daily rust forecast will be produced for specified areas throughout North America

c Processing Requirements

The Agriculture IAC (AIAC) will have two basic applications--prediction of wheat rust and of wheat yield The rust application is concerned with predicting where wheat rust exists, its intensity, and where and when additional rust is likely to occur Approximately 330,000 square miles of North America will be observed for this purpose Frequency of coverage will be twice per day, but data representing only 20 percent or less of this area will be processed per coverage

For the wheat yield application, data will be collected from all major wheat growing areas of the world This area is approximately 2 7 million square miles (including North America) and a selected data sample of 20 percent or less of this area will be processed each day

These ground rules and assumptions, along with those which are identical with the HIAC are summarized in Exhibit D-25.

d. Equipment Requirements

The third column of Exhibit D-19 lists the equipment, along with estimated procurement costs, required for the AIAC The digital computer is excluded since it is assumed to be rented. The list is similar to that for the HIAC, but the costs of some were changed because of differences in processing requirements.

The type of processing by the digital computer should be very similar to that for the HIAC (e g , determination of temperature and moisture) Thus, assumptions made for estimating the annual rental are the same with the exception of the amount of data and time allowed for processing. The total area to be covered for wheat rust application will be approximately 330,000 square miles in North America, and coverage will be made every twelve hours Total area for the yield application is 2,400,000 square miles, including the rust area in North America, coverage is once per day If 100 percent coverage were required, total area to be observed each day would be (2,400,000 - 330,000) + 2 x (330,000) or 2,730,000 square miles It is assumed, however, that no more than 20 percent of this area will be processed on any given day This reduces the maximum area to be processed to 546,000 square miles Allowances must then be made for possibly greater coverage and for checking out new programs In addition, the computer would be idle some part of the day when tapes are being loaded and because the sensor

EXHIBIT D-25 AGRICULTURE IAC GROUND RULES AND ASSUMPTIONS

Total Area -	
Rust Application	330,000 square miles
Yield Application	2,700,000 square miles
Percent Area To Be Processed	20 percent maximum
Frequency of Coverage -	
Rust Application	2 times per day
Yield Application	1 time per day
Ground Resolution of Sensor	1,200 feet
Internal Processing Time (Digital Computer)	100 additions per character
Total Data Processing Time Per Day (Digital Computer)	10 hours

data would not be received at regular intervals. It was estimated that the computer should be capable of processing about twice the data representing 20 percent coverage. Thus, the AIAC should have a capacity equivalent to processing data collected from about 1,100,000 square miles per day as compared to the HIAC computer capacity of 1,248,000 square miles per day Since these capacities are approximately equal, it was assumed that the two IAC's should use identical computers which have an annual rental of $400,000 This computer would process data for the rust application in slightly more than an hour (twice per day) and yield data could be processed in about seven hours, assuming 20 percent coverage for each. Orbital calculations and other types of operational processing would require two to four hours per day The remaining time could be utilized for testing and debugging programs in R&D stages.

e Personnel Requirements

Exhibit D-26 lists the personnel requirements by function and year for the operational phases of this agriculture application In the operation of the AIAC, two positions will be manned around the clock in the control center. The manning requirement per position is approximately four This is based on three shifts of eight hours each, seven days per week The level of eight men is maintained throughout the program. The administration requirement is based on approximately seven eight-hour per day positions including those of personnel director, group leaders and supervisor and secretarial assistance. As in the hydrology case, several administrative personnel will work during an off-shift

The number of programmer/analysts peaks at a level of 25 which is compatible with present programming and analysis requirements for operational satellite systems such as those existing at the ESSA facility in Suitland, Maryland

The number of required positions for computer operators is slightly larger for this IAC than for that of hydrology This is explained by the additional requirements in this case for signature analysis, necessitating increased computer use, particularly on the analog computer

EXHIBIT D-26 AGRICULTURE IAC PERSONNEL REQUIREMENTS

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Operational																				
Control Center	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Administration	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Analyst/Programmers	15	20	25	25	25	25	25	18	18	18	18	18	18	18	15	15	15	15	15	15
Photo Lab	12	12	12	12	12	12	12	9	9	8	8	8	8	8	8	6	6	6	6	6
Computer Operators	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Agriculture Analysts	15	20	20	20	20	20	20	20	18	18	18	18	18	15	15	15	15	12	12	12
Total	81	91	96	96	96	96	96	86	84	83	83	83	83	80	77	75	75	72	72	72

The number of agricultural analysts is slightly larger for this case than for hydrology because the geographic area to be covered is larger and more varied, and because of the requirement for signature analysis of wheat However, as techniques of data handling improve and automatic data analysis develops, the required number of analysts is seen to decrease. A further explanation for this is the expected development away from manual photointerpretation and analysis toward automatic processing by computers

5 Combined Interpretation and Analysis Center

This section describes the personnel and equipment requirements and related costs for a facility which would perform the combined functions of the Hydrology and Agriculture IAC's. Costs are shown to be considerably less than the combined cost of the separate facilities since duplication of personnel and equipment which perform identical functions in both facilities could, in some cases, be eliminated Since the daily operational schedule was not known, the center could not be designed to handle the "peak" hour processing load However, it was designed to have the capability to perform all the known tasks required during a "peak" day and so that photo processing and pattern recognition for both applications could be accomplished simultaneously

The fourth column of Exhibit D-23 shows the equipment, excluding the digital computer, required for the combined center Since it is probable that data would be received from as many as three satellites at the same time, three units of each equipment which are on-line to the receiver are shown. The analog computers are special purpose for each of the two applications and therefore both are required Each equipment in the analog processing chain also requires two units so that both computers may process data at the same time.

The annual rental for the Combined IAC digital computer was calculated using the "base case" assumptions for each The HIAC assumption that data must be processed in one hour for each coverage can be met, of course, by the HIAC or AIAC computer if the additional assumption is made that the computer will be available when required for this purpose. The combined processing requirements were obtained by adding the requirements for each application assuming 20 percent coverage. This value was increased by 100 percent so that the computer would be available for other purposes as discussed in previous sections. This analysis showed that the capacity should be approximately 30 percent greater than that of the HIAC, that is, the processing speed should be about 30 percent faster The annual rental of such a computer system should be approximately $435,000. This computer should be capable of processing the hydrology data in less than one hour (four times a day), the wheat rust data in about an hour (twice a day), and the wheat yield data in about six hours

Exhibit D-27 shows the personnel requirements for the combined IAC by function and year. For the operational personnel the same number of positions in the control center is maintained in the combined facility since the number of satellites is a system constant regardless of the application. Several additional administrative positions are required for the additional personnel The number of analyst programmers increases slightly because certain general programs such as those to automatically print temperature readings, to command the satellites, and to be used in area computations apply to both applications The same is true in the case of the specialist analysts Their efforts, in part, will be spent on developing techniques and skill in recognizing patterns of temperature for each application and relating these to either wheat growth, rust formation or snow melt.

With only a few exceptions, it is readily seen that efficient use is made of manpower at the combined IAC saving duplication of effort expenditures in all areas of the operational effort.

6 Analysis and Interpretation System Costs

The system costs for the Hydrology, Agriculture, and Combined IAC's are presented in Exhibits D-28, D-29, and D-30, respectively. Cost categories are shown in rows and expenditures by year are shown in columns. Initial investment includes procurement of only that equipment which is to be acquired after launch. Costs shown

EXHIBIT D-27 COMBINED IAC PERSONNEL REQUIREMENTS

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Operational																				
Control Center	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Admin	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Analyst/Programmers	20	25	30	30	30	30	25	25	25	25	20	20	20	20	18	18	18	18	18	18
Photo Lab	15	18	18	18	18	18	18	15	15	15	15	15	15	12	12	12	12	12	12	12
Computer Operators	20	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Hydrology/Agriculture Analysts	20	25	30	30	30	30	30	30	30	30	25	25	20	20	20	16	16	16	12	12
Totals	98	116	126	126	126	126	121	118	118	118	108	108	103	100	98	94	94	94	90	90

EXHIBIT D-28 HYDROLOGY IAC SYSTEM COSTS ($000's)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Initial Investment		200	100		10	10																
Recurring																						
Digital Computer		400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
Personnel		828	900	960	984	1 008	1 008	1 008	1,008	924	888	888	888	888	792	756	756	756	756	756	756	
Other Recurring		297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	297	
Total Costs	0	1 725	1 597	1 657	1 681	1 805	1 705	1 765	1 705	1 621	1 585	1 585	1 585	1 585	1 489	1 453	1 453	1 453	1 453	1 453	1 453	31 808

EXHIBIT D-29 AGRICULTURE IAC SYSTEM COSTS $000's

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Initial Investment		254	200		10	10																
Recurring																						
Digital Computer		400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	
Personnel		972	1 092	1 152	1 152	1 152	1 152	1 152	1 032	1 008	996	996	996	960	924	900	900	864	864	864	864	
Other Recurring		365	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	365	
Total Costs	0	2 001	2 057	1 917	1 927	1 927	1 917	1 917	1 797	1 773	1 761	1 761	1 761	1 725	1 689	1 665	1 665	1,629	1 629	1 629	1 629	35 776

EXHIBIT D-30 COMBINED IAC HYDROL/AG SYSTEM COSTS $000's

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Initial Investment		382	200		20	20																
Recurring																						
Digital Computer		435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	435	
Personnel		1 176	1,392	1 512	1 512	1 512	1 512	1 452	1 416	1 416	1 416	1 296	1 296	1,236	1 200	1 176	1 128	1 128	1 128	1,080	1,080	
Other Recurring		585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	585	
Total Costs	0	2 578	2 412	2 532	2 552	2 552	2 502	2 472	2 436	2 436	2 430	2 316	2 316	2 256	2 220	2,196	2 148	2,148	2 148	2 100	2 100	46 750

for Recurring, Digital Computer and Personnel have been discussed in detail in the separate sections above for each IAC

Other recurring consists of the following costs, rental of facilities, photographic supplies, and equipment operation and maintenance and other consumables Floor space requirements of 5700, 6800, and 8600 square feet are based on the number of personnel and the area required for the computer room The annual rental was then assumed to be $5 per square foot Photographic supply cost estimates were based on costs obtained from ESSA and are $5K, $19K, and $15K, respectively, per year Annual costs for maintenance and operation of equipment are estimated at 5 percent of the procurement cost of equipment, excluding the photographic equipment and digital computer Other recurring were estimated to be $250K, $300K, and $500K per year on the average Spares and miscellaneous parts were calculated to be 10 percent of the initial investment

7 Sensitivity Analysis

a Digital Computer Cost Sensitivity

Exhibit D-31 illustrates how the annual rental cost of the digital computer for the Hydrology IAC would change with respect to both sensor ground resolution and amount of time allocated for processing (with other "base case" assumptions remaining constant) The curves were derived by computing sensor resolution as a function, processing speeds of various general purpose computers, and plotting these values against the annual computer rental costs Resolution was computed by the equation

$$r = \sqrt{\frac{\frac{(A)\ (P)\ (NC)\ (f)}{(T)}}{(h)\ (a)}}$$

where r = sensor resolution

A = total area to be covered in square feet = 312,000 x $(5,280)^2$

P = maximum percent of data to be processed per coverage = 20 percent

NC = Number of sensor channels = 7

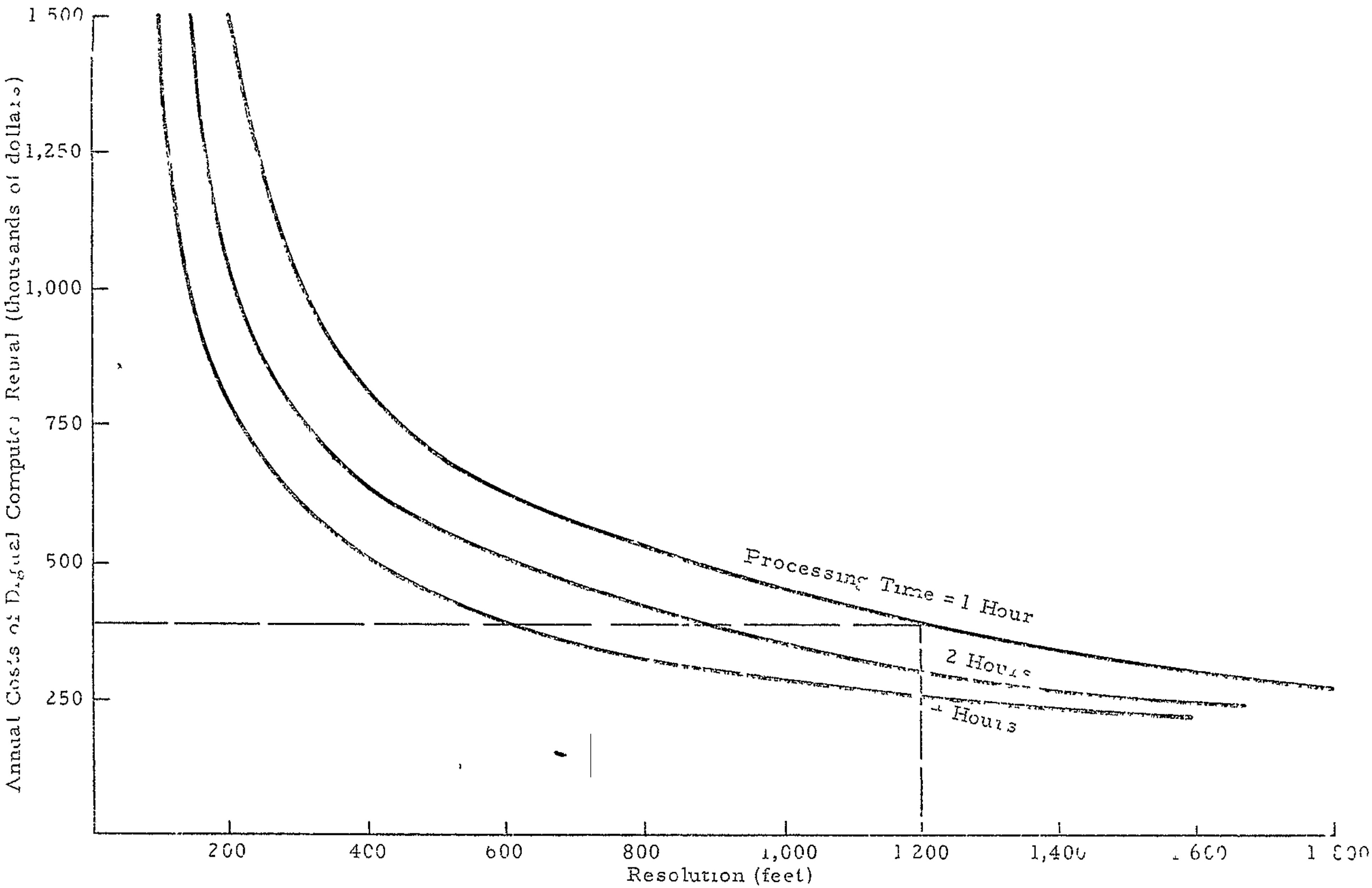


EXHIBIT D-31 DIGITAL COMPUTER COSTS FOR HYDROLOGY IAC VS SENSOR RESOLUTION AND PROCESSING TIME f = factor to account for telemetry data = 1 2

T = time allowed for processing per day in seconds = 1, 2, or 4 times 3600

n = number of additions per character required for processing = 100

a = add time of the computer in seconds per add

The dotted lines on the exhibit show the computer rental cost ($400,000) for the "base case" assumptions for processing time (one hour) and for sensor resolution (1 200 feet) If sensor resolution were reduced to, for example 600 feet (and processing time held to one hour), computer rental would increase to approximately $625,000 However, if the time allocated for processing were increased to two hours, the computer rental would be about $500,000

Exhibit D-32 shows how the annual rental of the digital computer required for the combined IAC would change if the percent of area coverage were changed The equation used for deriving this curve was the same as given above

b System Cost Sensitivity

Exhibit D-33 shows the total system cost for the combined IAC plotted against sensor ground resolution The variation shown is due entirely to the change in digital computer rental since no other quantifiable differences were known for a change in this single parameter Communications costs, which are derived separately from IAC costs, would also change

Exhibit D-34 shows how the system costs would change if another assumption concerning the digital computer, the number of addition cycles per input character required for internal processing, were changed

Exhibit D-35 summarizes the effect of the more critical cost categories on total system costs Operational personnel contribute more to the total cost than any other cost category As shown in the exhibit, a change in the estimated number of personnel of, for example, 20 percent would cause a change of 11 percent in the total cost A like percentage change in the estimated digital computer cost would result in changes of 4 5 percent to total cost

E Communications Costs

Costs will be treated in two main categories, investment, and operations and maintenance. The only investment costs considered explicitly in the following are those of the ground receiving station Other necessary equipment will be leased and will therefore be considered as operations costs Operations and maintenance costs fall into two categories ground station operations and maintenance costs and the cost of leasing equipment and circuits from common communications carriers

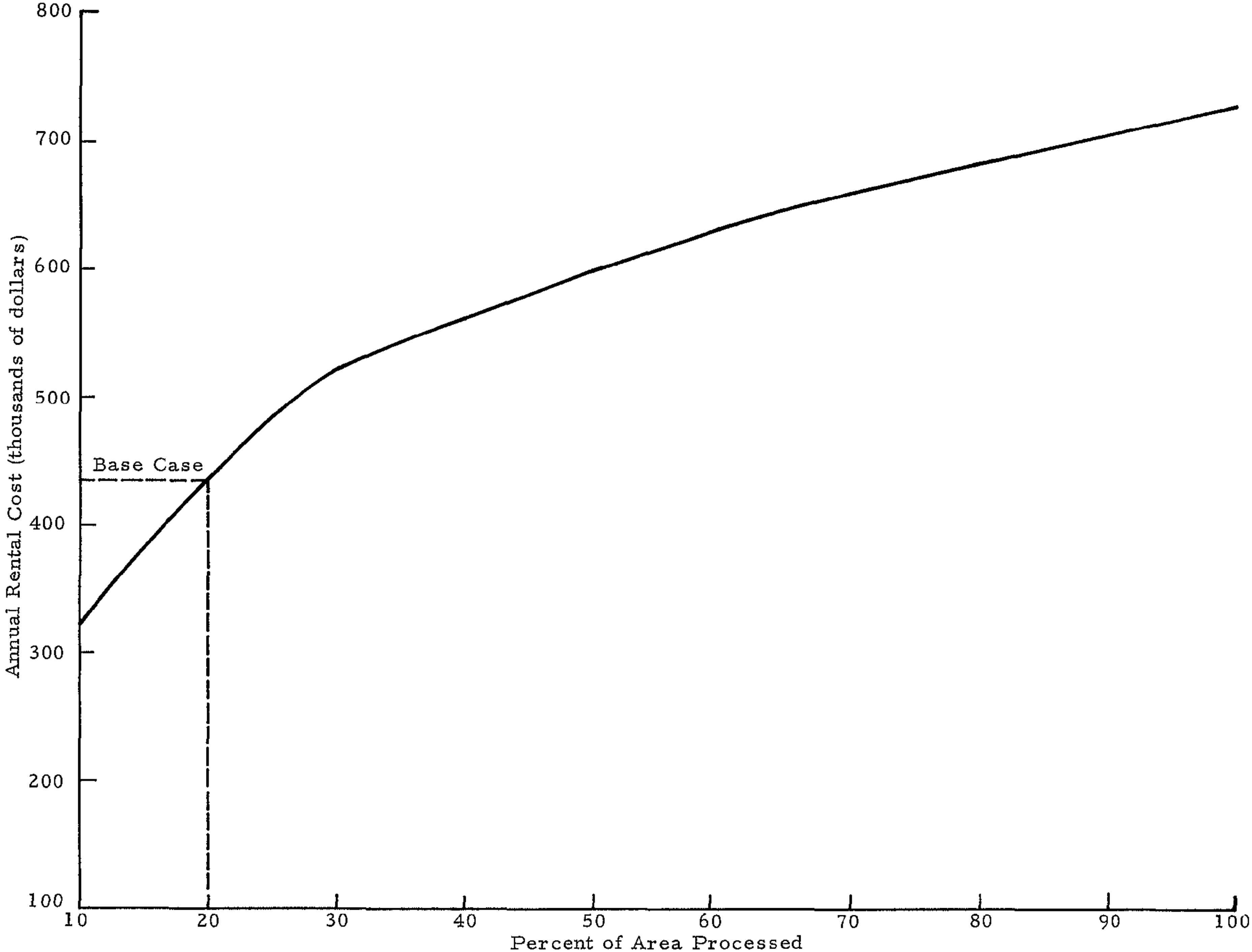


EXHIBIT D-32 DIGITAL COMPUTER COST FOR COMBINED IAC VS. PERCENT COVERAGE

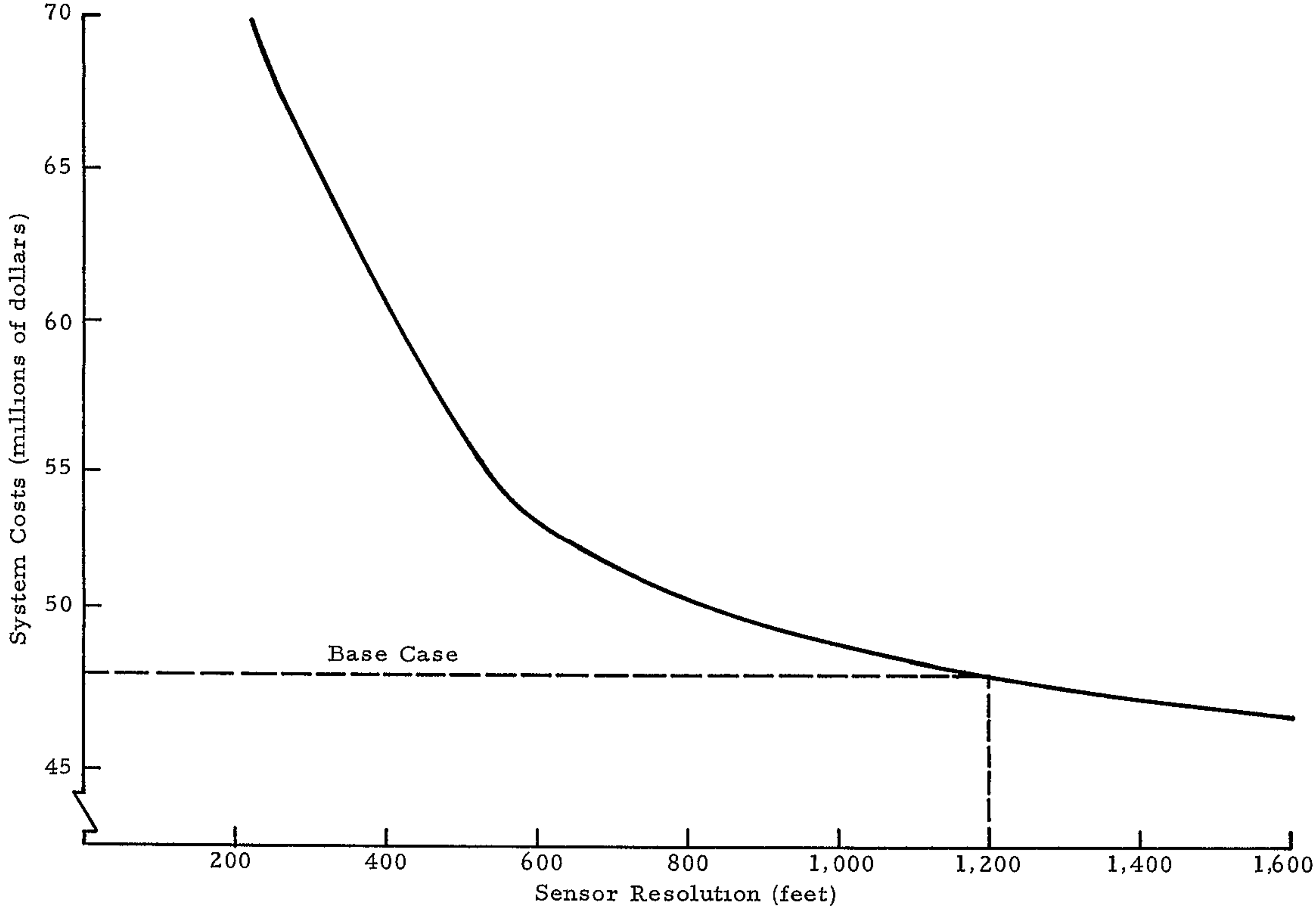


EXHIBIT D-33 COMBINED IAC SYSTEM COST VS. SENSOR RESOLUTION

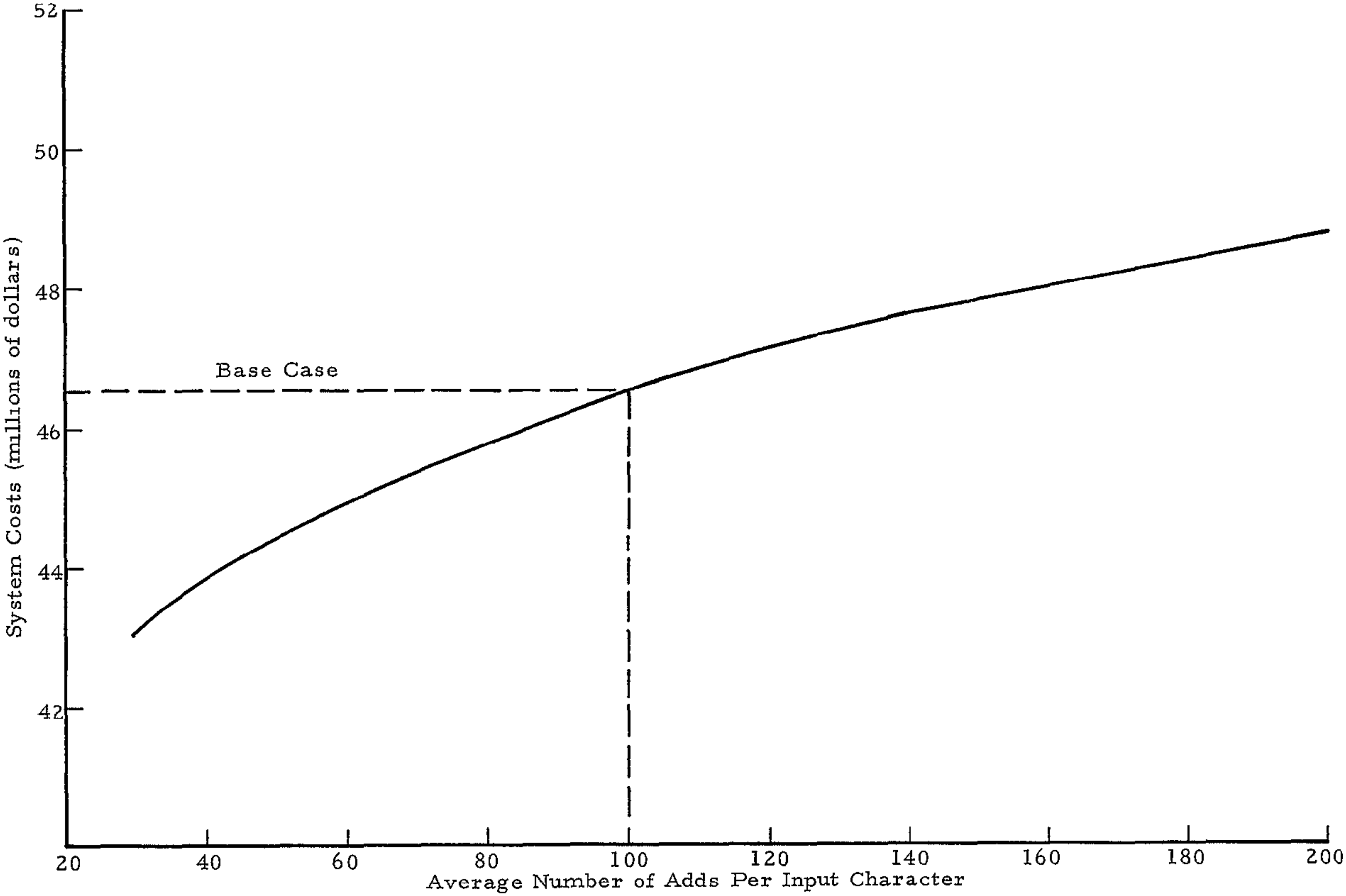


EXHIBIT D-34 COMBINED IAC SYSTEM COSTS VS AVERAGE NUMBER OF ADDITION CYCLES PER INPUT CHARACTER

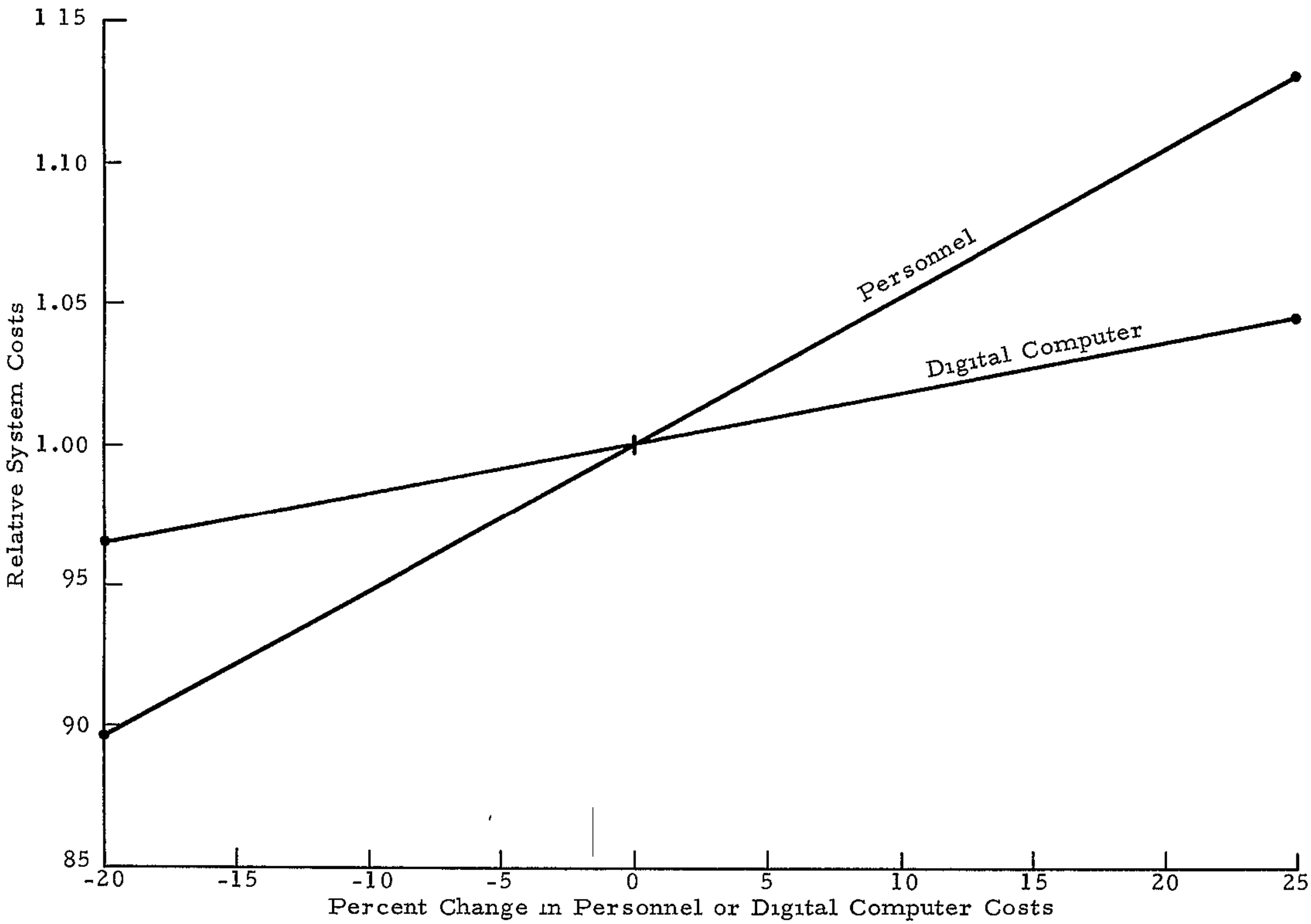


EXHIBIT D-35 COMBINED IAC, RELATIVE SYSTEM COST VS PERCENT CHANGE IN PERSONNEL AND DIGITAL COMPUTER COSTS

1 Ground Receiving Stations

a Antenna System

The antenna system consists of the following components

- dish
- pedestal and mount
- tracking system

The dish includes the cost of the surface and the frame of the antenna itself and the associated waveguides The pedestal and mount cost includes these costs plus the foundation The tracking system includes the tracking antenna, the associated radio and computer equipment, and the mechanical means of rotating and tilting the dish (The ground station tracking system investment costs include only the costs of equipment for aiming the antenna Additional tracking equipment will be necessary in order to precisely locate the satellite for purposes connected with the analysis of data It is assumed that the mini-track network which is already in existence can perform these functions)

The cost curves associated with the sizes of the dish are given in Exhibit D-36 These costs are turnkey (i e installed and tested) costs based on data from commercial manufacturers Curve "T" represents the cost of an antenna system with full X, Y tracking capability, curve "S" represents the cost of a non-tracking antenna

b Electronic Equipment

Electronics equipment consists of

- Parametric amplifier and other wideband receiver components
- Wideband tape recorder
- VHF equipment
- Command and encoding device

The first category, in addition to the parametric amplifier, consists of demultiplexing equipment (filters), line drives and demodulators Dual video tape recorders are included in the ground station complement

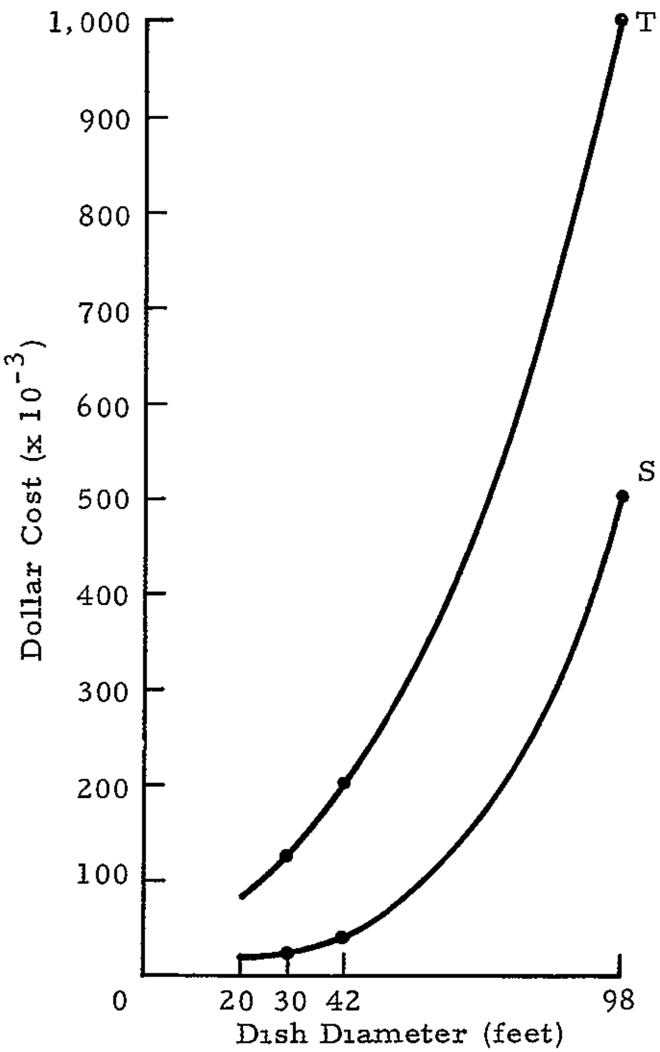


EXHIBIT D-36 ANTENNA DISH COST RELATIONSHIP

Other equipment includes the VHF receivers and transmitters and the computer equipment associated with command and encoding functions

An allowance for maintenance float and initial spare parts is computed at 20 percent of the ground station electronic equipment The cost of facilities includes the cost of the building, auxiliary power generators, and miscellaneous equipment such as furniture and office equipment

The costs associated with a ground station with a 42 foot X, Y track antenna are given in Exhibit D-37 The costs were developed from information provided by manufacturers and Willow Run Laboratories

2 Ground Station Operations and Maintenance

Two technicians can perform the communications functions at the ground receiving station at any one time Because the station will be in operation for 24 hours a day, however, 8 technicians will be required at a salary of $10,000 per year apiece A ground station manager with extensive electronics engineering background would be required at a salary of $18,000 per year

The station electronics equipment and the antenna are estimated to consume spare parts and maintenance materiel at an annual rate of 10 percent of their investment cost The cost of operating consumables consisting of such things as electricity, station environment control, and office supplies is estimated at $5,000 yearly

If the signal received from the satellite is not compatible with the communication lines between the ground receiving station and the central analysis facility, it will be necessary to rent from the common carrier providing those lines the necessary equipment to provide the proper interface Such equipment can be secured on a leased basis at an approximate cost of $500 per month

The annual costs of operating and maintaining the ground station are summarized in Exhibit D-38

3 Data Communications Cost

As the data is received from the satellite at the ground receiving station, it must be communicated to the central analysis facility

EXHIBIT D-37 GROUND EQUIPMENT INVESTMENT COSTS (IN THOUSANDS OF DOLLARS)

Ground Receiving Station			
42' antenna (including tracking)			200
Parametric amplifier	15		
Other receiving	50		
Tape recorder (22/unit)	44		
VHF equipment	10		
Command and encoding	5		
Total - Electronics		124	
Maintenance Float/Spares		25	
Facility			
Building	30		
Auxiliary Power	5		
Miscellaneous Equipment	10		
Total - Facility		45	
Total - Ground Station			394

EXHIBIT D-38 GROUND STATION OPERATIONS AND MAINTENANCE COSTS (ANNUAL, IN THOUSANDS OF DOLLARS)

Salary		
Technicians	80	
Manager	16	
Total Salary		96
Spare Parts and Maintenance Materiel (10)		12 4
Operating Consumables		5
Interface Equipment (leased)		5
Total		118 4

This will be accomplished through the leasing of wideband communications circuits from common carriers such as A T & T and others Both ground networks and communications satellites will be used

Circuits of $4MH_z$ bandwidth are to be offered at a tentative cost of $60 per mile per month. (A final determination of this tariff by the FCC is underway presently.) This cost is based on 24 hours a day, 7 days a week usage.

Exhibit D-39 illustrates the estimated cost per mile per month for the leasing of circuits necessary to transmit satellite outputs of 520 KH_z, 815 KH_z, 2 05 MH_z, and 8 MH_z information bandwidth

Exhibit D-39 also depicts estimates of monthly cost per mile as a function of the communications lag The principle behind this rationale is that short periods of wideband data can be drawn out, transmitted over a longer period of time on circuits which are of smaller bandwidth and which are therefore less expensive The Communications Response Factor (CRF) is therefore the maximum allowable factor by which the satellite readout time can be multiplied without attenuating the responsiveness of the whole system For example, if the satellite transmits two minutes of data, and if it is determined that a 20-minute lag is the maximum possible, then the CRF can be as much as 10

If the sensors of the satellite produced an information bandwidth of 815 KH_z, we could find in Exhibit D-39 the cost of the necessary circuits by locating the CRF of 10 on the abcissa, and using the 815 KH_z curve to find the per-mile monthly cost on the ordinate $35

It was assumed that 75 percent of any unused capacity in a 4 MH_z line would be absorbed by other applications or could be sublet at cost

Certain applications may require the location of a ground receiving station outside of the continental United States Various common carriers provide service to these areas through the facilities of Comsat Corporation and its international affiliates It is envisioned that if such stations are needed, they will be located on Ascension Island and somewhere in northeastern South America The ground station could be located contiguous to a Comsat Earth Terminal In the case of world-wide

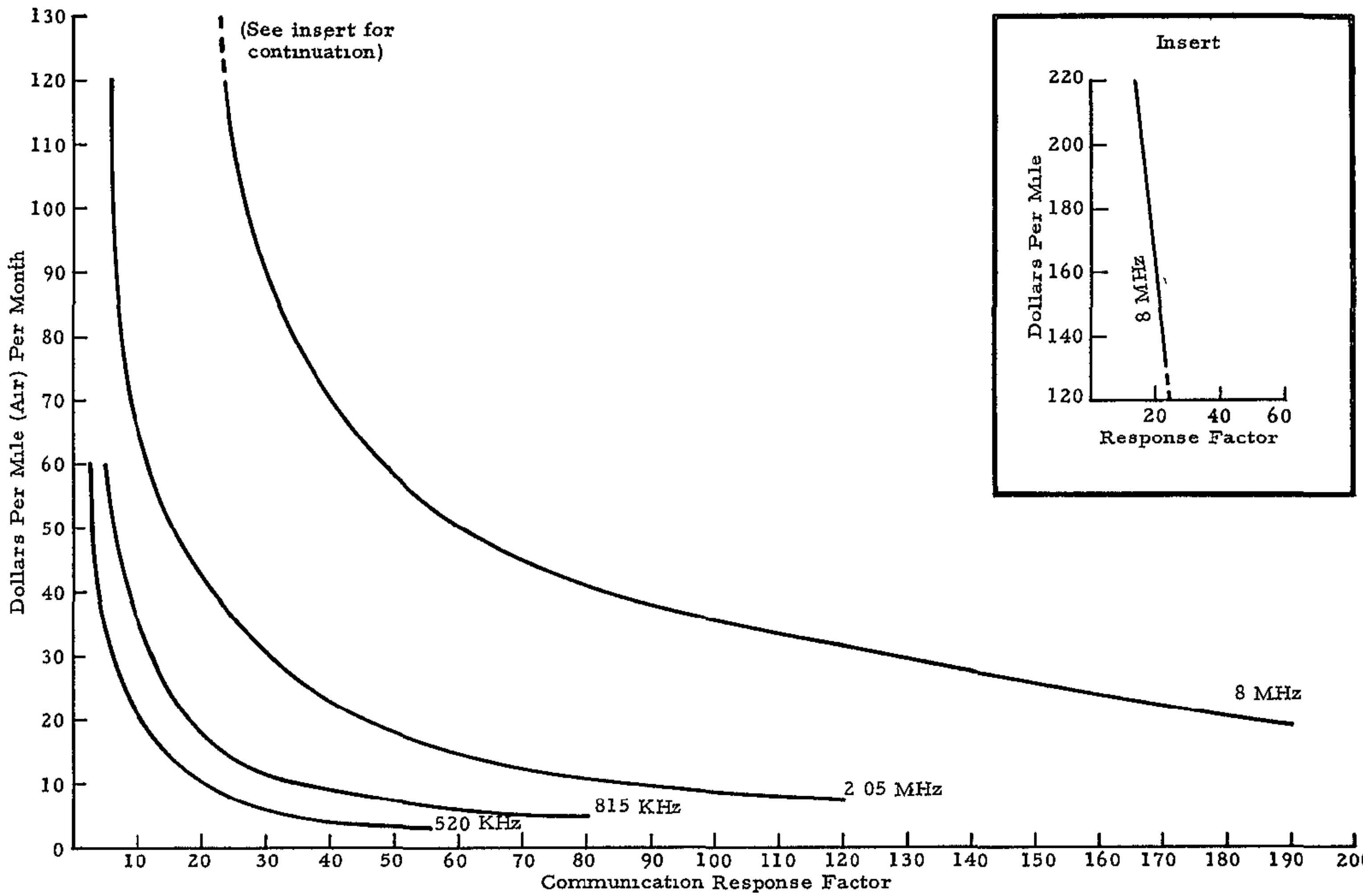


EXHIBIT D-39 CIRCUIT LEASING COST SENSITIVITY agricultural yield, data can be collected over remote areas of the world and stored on tape for transmission to the ground A satellite in an orbit of approximately 50° will, after it has observed one of the world's major agricultural areas, necessarily pass over the readout area of one of the ground receiving stations if they are placed on a line between the northwestern United States and Ascension Island in the South Atlantic A tape recorder capable of on-board recording of data of up to 4 MH_z bandwidth is currently in the final stages of development by several manufacturers Such a recorder is capable of recording up to 30 minutes of 4 MH_z data and will cost approximately $ 3 million per single unit

The cost of one fully dedicated voicegrade circuit between Etam, West Virginia, and the Comsat Earth Terminal in the Atlantic area is approximately $9,800 per month A wideband circuit of 48 KH_z consists of 12 voicegrade circuits, and the set of 12 is provided with a 20 percent discount The cost of this 48 KH_z circuit is $94,000 per month The costs will vary slightly among different earth station locations

4 Future Communications Costs

Communications costs have been greatly affected by the advent of communications satellites The cost of international circuits has already decreased and will continue to do so in the future Domestic satellite service will quite likely be available within a short time and the cost of domestic service will decrease as well Because communication tariffs are set by the FCC so as to meet criteria which reflect the long-range communications needs of the United States, the impact of communications satellites on charges made under the tariff structure may not be directly felt for some time As the carriers begin to amortize more and more of their investments in relatively obsolete cable and microwave equipment, rates will reflect to a greater extent the less expensive costs of the satellites

It is assumed for the purpose of this study that the changes will decrease at a rate of 5 percent per year. Exhibit D-40 compares

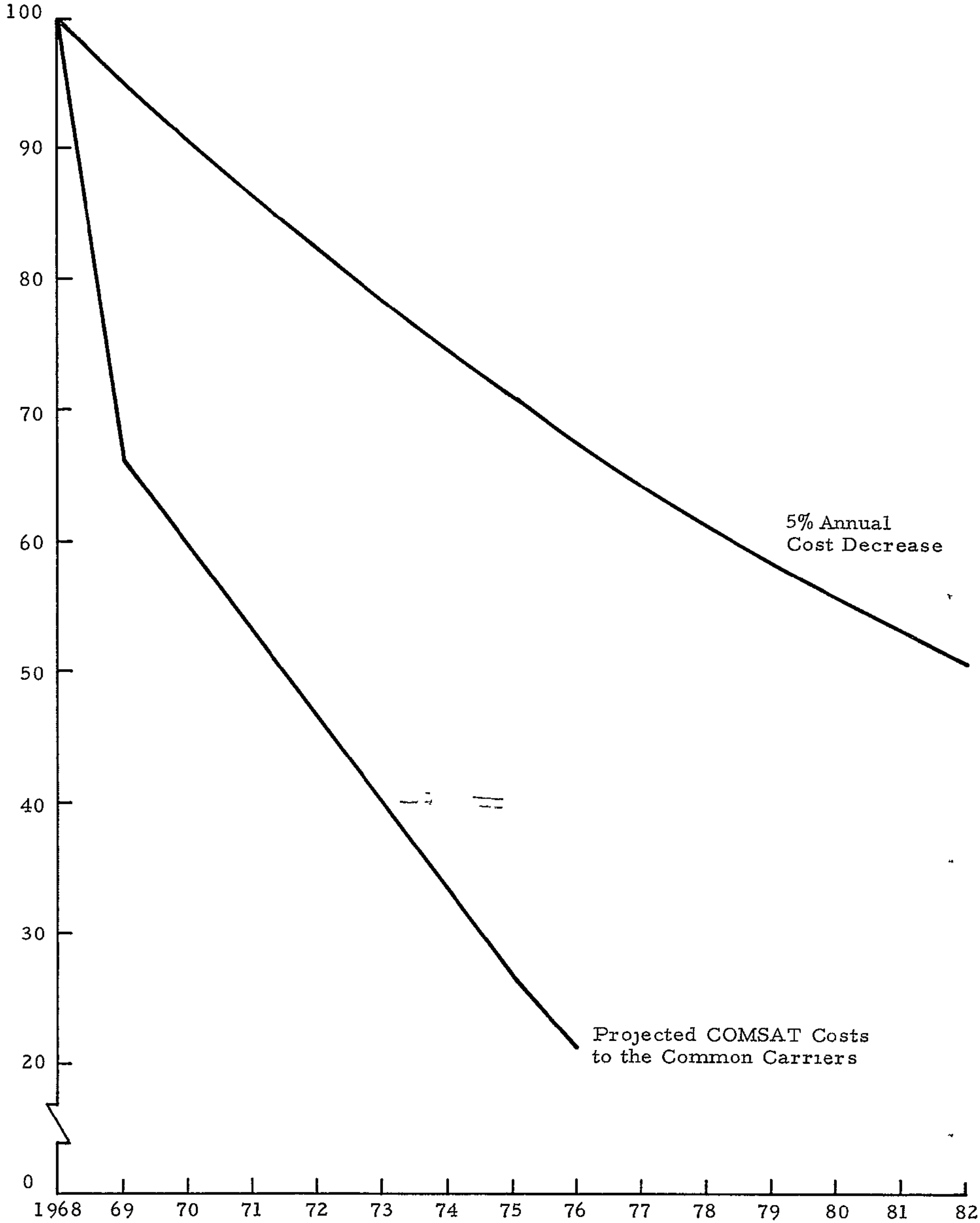


EXHIBIT D-40 RELATIVE COMMUNICATION COSTS PROJECTION the 5 percent cost decrease to the projected[1] decrease in charges for a Comsat circuit

5 Communications System Costs

The following assumptions form the basis for the systems costs of the communications system

(1) All systems are within current state of the art capabilities--no R&D funds are obligated or spent

(2) Investment costs are obligated and spent in the year before the system becomes operational

(3) The life expectancy of ground station equipment is 10 years Funds for replacement are obligated in the 10th year for equipment constructed in that year and operational in the 11th

(4) Five ground receiving stations will be constructed, one each in the following areas

- Northwest
- North Central
- Middle Atlantic
- Northeast South America
- Ascension Island

the latter three stations being located contiguous to Comsat-Intelsat earth terminals A factor of 1 2 is applied to investment outside of the continental United States

(5) Only agriculture yield data will be collected at the South American and Ascension Island stations Because of relatively low frequency of observations and relaxed response requirements for this case (leading to a high communications response factor), it is assumed that only one 48 KH_z wideband data link will be required to handle the data

[1] See Comsat Corp , ICSC-26E-T/5/67, Projected Profile of Intelsat Utilization Charge
and
Comsat Corp , ICSC/F-16-5 W/1/69 (Rev 1), Intelsat Utilization Charge Profile

(6) Approximately 3,000 miles of wideband (4 MH_z) circuit will be required within the United States This assumption requires that the analysis facility is located in close proximity to one of the ground stations (If more than one facility is needed, each could be so located.)

(7) The maximum output of the sensors on the satellite in the base case is 5 27 MH_z Assuming a CRF of 60 which would communicate any one-minute readout within an hour, the cost per mile is about $30 per month The cost of domestic wideband circuits is derived from Exhibit D-39

Exhibit D-41 details the investment, and annual operations and maintenance costs for the communications systems in the base case Exhibit D-42 shows the system cost

EXHIBIT D-41 COMMUNICATIONS COST ELEMENTS

Investment (in 1000 dollars)	
Ground Stations (5 at 394 K)	1,970
Operations and Maintenance (annual in 1000 dollars)	
Ground Stations (5 at 118 4)	592
Domestic Data Circuits (3000 miles at 30 dollars/mile x 12 months)	1,080
Comsat - Intelsat Circuits (2 48 KH_z at $94,000/month each x 12 months)	2,260
Total	3,932

EXHIBIT D-42 COMMUNICATIONS SYSTEM COSTS (COSTS IN THOUSANDS)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Investment	1970										1970										
O & M																					
Ground Stations		592	592	592	592	592	592	592	592	592	592	592	592	592	592	592	592	592	592	592	592
Circuits		3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340	3340
Circuits at 5% Decrease		3340	3181	3029	2885	2748	2617	2492	2374	2261	2153	2050	1953	1860	1771	1687	1607	1530	1457	1388	1332
Total	1970	3932	3773	3621	3477	3340	3209	3084	2966	2853	4715	2642	2545	2452	2363	2279	2199	2122	2049	1980	1914

APPENDIX E

ALTERNATIVE INFORMATION SYSTEMS

I AIRCRAFT INFORMATION SYSTEM

A Introduction

An obvious alternative to information gathering by satellite is the use of aircraft equipped with proper sensing equipment Almost any aircraft large enough to accommodate a few hundred pounds of sensor equipment could be a candidate for the information gathering mission Rather than to evaluate each of the many potential aircraft candidates on a cost/benefit basis, it was decided to select three typical candidates, each of which would be representative of a general class or type of aircraft The three aircraft chosen represent a wide range of possible alternatives By evaluating each of the three aircraft on a cost/performance basis, it is possible (especially if the results differ widely) to get a good indication of the type of aircraft best suited for this particular mission

The aircraft chosen as an example of a comparatively low cost alternative is the Cessna U-3 It is a light twin-engine propeller driven aircraft used by the U S Air Force for administrative liaison and light cargo It attains analtitude of about 20,000 feet and a speed of approximately 200 mph On the high end of the cost scale is the Air Force's SR-71 high-altitude strategic reconnaissance aircraft Not too much data is available on this aircraft but Jane's publication, All the World's Aircraft, states that it has been tested in sustained flight at speeds of more than 2,000 mph and at heights in excess of 70,000 feet. From another source, information[1] indicates that the SR-71A has an operational ceiling of approximately 100,000 feet. Cost data on the SR-71A is quite closely held Since the SR-71 more closely approximates a satellite's characteristics (great speed and height) than any other known aircraft and therefore could be considered the "closest" competitor, it was arbitrarily decided to use the "best estimates" of its performance characteristics, i e , 100,000 ft altitude and 2,000 mph speed, and the most conservative estimates of its cost, so that it would be compared

[1] Aviation Week and Space Technology, March 18, 1968

on its most favorable aspects If under these conditions it does not prove to be the optimum aircraft for the information gathering mission, then clearly it is not the best candidate The U-3 and SR-71 represent the opposing parameters - the former low, slow, and inexpensive - the latter high, fast, and costly The aircraft selected to be somewhere in the middle of the range is the North American T-39, a swept wing twin turbojet, used by both the Air Force and Navy as a trainer and used commercially as an executive transport aircraft The T-39's cruising speed is approximately 500 mph with a service ceiling of about 40,000 feet These, then, are the three candidates which were selected for the cost-performance comparison

B Aircraft System Cost Analysis

In general, costs for the U-3 and T-39 are based on U S Navy and U S Air Force cost factors It is assumed that, since the military usage of the U-3 and the T-39 is not too drastically different from the data gathering mission, the operating and maintenance costs for the NASA mission should approximate military costs, with the exception of pay and allowances cost which has been escalated to civilian rates In the investment cost area, procurement cost of the aircraft, initial spares, special support equipment (SSE), attrition, and pipeline factors were based on Air Force and Navy experience The cost of the sensor packages was estimated by the Willow Run Laboratories A gross approximation of airport facilities cost was derived by assuming that such facilities as operations buildings, aircraft maintenance buildings, parking aprons and taxiways would be added to existing airport facilities The basis for construction cost estimates was a factoring of cost developed for Navy patrol aircraft (P-3 Orion) facilities used in the "Crisis at Sea II" land-based vs sea-based patrol aircraft study The original costs were derived by applying military construction cost factors to the size of the appropriate facility, i e , operations building, parking apron, taxiway, maintenance hangar For the T-39 and U-3, it was assumed that the operations building would be about the same cost as for the P-3 and the cost of the other facilities would be proportional to the size (area) of the aircraft as compared to the size of the P-3 The costs developed herein for facilities are considered fair approximations even if facilities are leased rather than built, since the costs of leasing the facilities would probably be based on the costs of constructing them, amortized over a number of years See Exhibit E-1

Since specific cost data for the SR-71 is not available, order of magnitude estimates were made by a "gross" and arbitrary extrapolation from cost data based on other less sophisticated military reconnaissance aircraft. $20 million was used for total investment cost and $2 million for annual operating and maintenance costs These estimates are considered conservative Exhibit E-2 summarizes the 20 year systems costs of the three alternatives, for operating in North America All costs presented are in terms of 1968 constant dollars

Costs are developed in Exhibit E-3 for operating the "optimum" aircraft (the T-39) at overseas locations Overseas costs reflect a pay and allowances differential of 25% additional and an escalation of facilities cost and other annual operating and maintenance costs The escalation factor is based on an average country price index used by DOD agencies to estimate the construction cost of various facilities throughout the world The price index is indicative of the costs of labor and material in foreign countries For the agriculture cases, a price index of 1 20 was used This represents the gross average of Northern Hemisphere countries For hydrology an index of 1 40 was used representing the average costs of Northern Europe

C Aircraft Performance Characteristics

Exhibit E-4 presents the cruise speed, service ceiling and range of each of the aircraft alternatives The viewing angles for the sensors were provided by the Willow Run Laboratory A 120° angle is used for the U-3 and T-39 and 90° for the SR-71 Swath widths were calculated simply as a function of viewing angle and service ceiling as illustrated below

EXHIBIT E-1 ESTIMATE OF BASE FACILITIES COST

Facilities Package Per Navy P-3 Squadron (9 A/C)

Parking Apron	45,000 sq yards	750 K
Taxiway	60,000 sq feet	100 K
Aircraft Maintenance Hangars	90,000 sq feet	2,250 K
Operations Bldg		156 K
		3,256 K

Variable Portion (3,100) – 9 =344 per A/C

Operations Bldg (156) - 9= 17 per A/C

Area of Candidate Aircraft

	Wing Span	Length	Area	% of P-3	Cost/A/C*
U-3	37'6"	29'7"	1,140 SF	10%	51 K
T-39	44'5"	43'9"	1, 936 SF	17%	76 K
P-3	99'8"	116'10"	11,700 SF		

* Including 17 K for Operations Bldg

EXHIBIT E-2 COSTS OF CANDIDATE AIRCRAFT

(North America)

($ In Millions)

	U-3	T-39	SR-71
Investment Cost			
Flyaway	05	92	
Sensor Package	20	30	
Modification for Sensor[1]	05	08	
Spares and SSE[2]	05	24	
Attrition & Pipeline	10	29	
Sub-Total	45	1 83	
Base Facilities[3]	51	76	
Total Investment	96	2 59	20 00
Annual Operating & Maintenance Cost			
Operating Hours/Month	60	60	45
Flight & Maintenance Crew Costs[4]	243	305	
Flight Operations	045	091	
Sensor Spares[5]	030	045	
Airframe Overhaul	050	015	
Total Annual O&M	368	456	2 00
20 year Systems Cost[6]	9 28	14 30	80 00

[1] Assumed 25% of sensor cost

[2] Includes sensor spares at 30%

[3] See Exhibit E-1

[4] Estimated at commercial rates - pilot and officers $25,000/year crew $12,000/yr

[5] Estimated at 15% of procurement cost per year

[6] Assumes procurement of 2 aircraft and 10 year life per aircraft

EXHIBIT E-3 T-39 COSTS

(For Use in Other Countries)

($ In Millions)

Agriculture Case (Average of Northern Hemisphere)

Investment Cost

North America (Exhibit 1)	2 59
Additional Facility Cost + 20% (20 x 76)	15
Total Investment	2 74

Annual O&M Cost

North America (Exhibit 1)	456
Additional Flight and Maintenance Crew Costs + 25% (25 x 305)	076
Additional Other O&M Costs[1] + 20% (20 x .151)	030
Total Annual O&M	562
20 Year Systems Cost	16 72

Hydrology Case (Northern Europe)

Investment Cost

North America (Exhibit 1)	2 59
Additional Facility Cost + 40% (40 x 76)	30
Total Investment	2 89

[1] Flt Opns + Sensor Spares + Airframe Overhaul

EXHIBIT E-3 (Continued)

Annual O&M Cost

North America (Exhibit 1)	456
Additional Flt & Maintenance Crew Costs + 25% (.25 x .305)	076
Additional Other O&M Costs[1] + 40% (.40 x 151)	060
Total Annual O&M	.592
20 Year Systems Cost	17.62

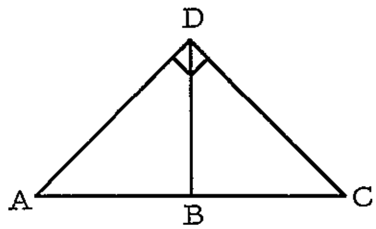
EXHIBIT E-4 CHARACTERISTICS OF CANDIDATE AIRCRAFT

	U-3	T-39	SR-71
Economical Cruise Speed (mph)	200	500	2,000
Service Ceiling (feet)	20,000	42,000	100,000
Range at Economical Cruise Speed (miles)	1,200	2,000	2,300
Sensor Viewing Angle	120°	120°	90°
Swath Width - At Sea Level (miles)	13 1	27 8	37 9
- Hydrology Case[1] (miles)	9 2	23 6	35 6
- Wheat Case[2] (miles)	11 5	25 9	37 0
Flying Hour Program[3] (hours/month)	60	60	45

[1] Assumes terrain averages 6,000 feet above sea level

[2] Assumes terrain averages 2,500 feet above sea level

[3] Constrained by aircraft availability due to aircraft maintenance for the SR-71 and due to sensor maintenance for the U-3 and T-39



$\angle ADC$ = viewing angle = 90°

BD = ceiling (at sea level) = 100,000 feet

ABC = base (swath width) = 200,000 feet

The base of the triangle in the illustration above represents the swath width of an aircraft flying at 100,000 feet with a sensor package having a 90° viewing angle No correction is made for the curvature of the earth, since the effect would only be slight at 100,000 feet or lower

To account for the fact that the terrain being covered is not always at sea-level, it was arbitrarily decided that for the agriculture case the average level would be 2,500 feet above sea level and, since the hydrology case covered more mountainous terrain, the average height was assumed to be 6,000 feet above sea level As can be seen from the exhibit the swath width ranges from 9 2 (11 5) miles for the U-3 to 35 6 (37 0) miles for the SR-71 The T-39's swath width is 23 6 (25 9) miles

D Aircraft Cost/Performance Evaluation

The performance of each alternative aircraft is evaluated in terms of area coverage per month It is assumed that the quality of the data gathered by each aircraft does not vary with the speed or altitude of the aircraft and the effectiveness of the mission is only limited by the area each candidate can cover in a given period of time The monthly area coverage is determined for each candidate by the following

$$A_c = S \times FH_m \times SW$$

where A_c = Area Coverage per month

S = Economic Cruise Speed

FH_m = Monthly Flying Hour Program

SW = Swath Width

Solvıng for the above equatıon produces the followıng results ın the hydrology case

A_c (U-3) = 200 x 60 x 9 2 = 110,400 square mıles

A_c (T-39) = 500 x 60 x 23 6 = 708,000 square mıles

A_c (SR-71) = 2,000 x 45 x 35.6 = 3,204,000 square mıles

The agrıculture case results ın

A_c (U-3) = 200 x 60 x 11 5 = 138,000 square mıles

A_c (T-39) = 500 x 60 x 25 9 = 777,000 square mıles

A_c (SR-71) = 2000 x 45 x 37 0 = 3,330,000 square mıles

Exhıbıt E-5 portrays the cost/performance relatıonshıp for each of the candıdates As can be seen from the chart, the mıddle range class of aırcraft represented by the T-39 ıs the "optımum" class for the data gatherıng mıssıon Due to ıts relatıvely narrow swath wıdth and slow speed, the U-3 has lımıted coverage and, despıte ıts lower cost, requıres many aırcraft to match the coverage of the two other alternatıves, therefore ıt costs more per more per area covered On the other hand, the SR-71, although ıt has a very large swath wıdth and tremendous speed, ıs handıcapped by a shorter flyıng hour program (45 hours per month versus 60) due to maıntenance requırements and also ıncurs very hıgh ınvestment and operatıng costs

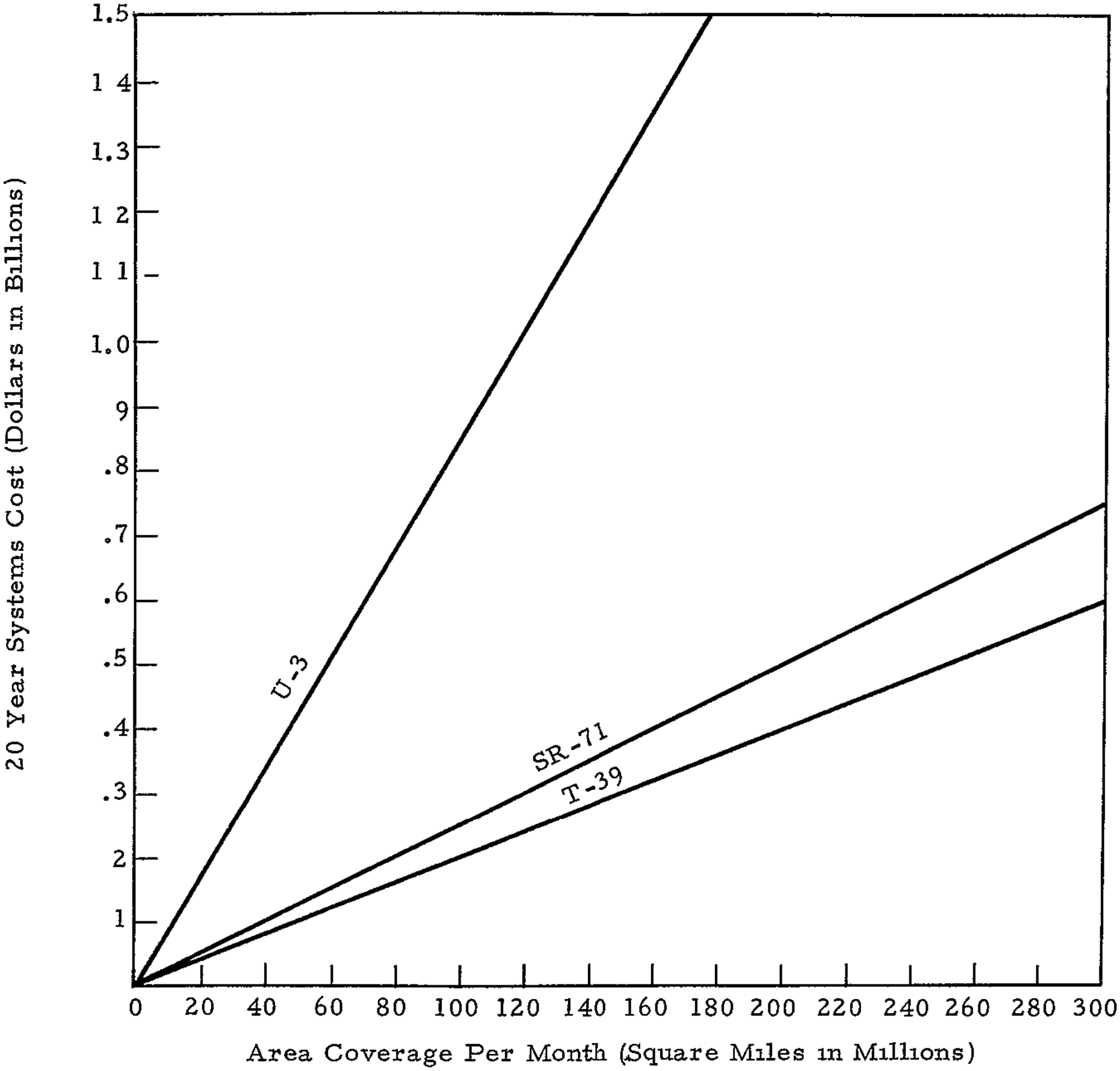


EXHIBIT E-5 COST/PERFORMANCE COMPARISON CANDIDATE AIRCRAFT (HYDROLOGY MISSION)

II GROUND INFORMATION SYSTEM

Automated measuring devices have been developed for use in determining the water content of snow and measuring several other environmental conditions which can have an effect on water runoff and stream flow The data are collected at remote measuring sites, the information is encoded in binary form and transmitted by radio to a base station via a repeater which receives the signal from the collection site, re-amplifies it and re-transmits it to the base station [1] It is possible for each base station to have up to 99 data collection stations associated with it, and up to 10 variables can be measured and transmitted to the base station In practice, only 20 collection stations have been associated with each base station due to transmission problems arising from the mountainous terrain in the area

Exhibit E-6 shows the investment costs associated with the data collection sites, the repeaters, and the base stations Each collection site consists of a "snow pillow" which measures the snow water content by weight, and other devices which are capable of measuring the temperature, the amount of precipitation, and the humidity Operations and maintenance costs are assumed to be 10 percent of the investment cost annually and the life expectancy of equipment is assumed to be 10 years for base stations and 5 years for outside equipment (data collection stations and repeaters)

There are approximately 1500 snow courses in the area examined by this study and it is estimated that four times that number of river gauge stations would be needed to provide sufficient information with regard to the depth, rate of flow, and temperature of the water in major rivers and tributaries It is assumed that river gauge data collection and base station costs are approximately the same as the snow course system

---

[1] See documentation of the Hydromet Study for a detailed description Preliminary Development Plan for Operational Hydromet Data Management Study, C8-1441/030, 1 July 1968

EXHIBIT E-6 GROUND INFORMATION SYSTEM INVESTMENT COSTS

Data Collection Sites		
Snow Pillow/transducer	$650	
Thermocouple	250	
Precipitation Meter	400	
Humidity Measure	500	
Batteries	300	
Solar Panels	200	
Antenna	1000	
Installation	1000	
Total per site		$4,300
Repeater		$2,000
Base Station		$10,000

The estimated systems costs are shown in Exhibit E-7 for 1500 snow courses and 6000 river gauge stations Estimates for data analysis and interpretation costs were made using twenty five percent of the costs that were associated with the hydrology Interpretation and Analysis Center since the processing of data from the snow pillows and river gauges is relatively simple For year 4 through 20, 25 percent of the average recurring costs of the HIAC were assumed to be the recurring costs for this information alternative

EXHIBIT E-7 GROUND INFORMATION SYSTEM COSTS

(Costs in Millions)

Snow Information

Investment Costs		
1500 data sites at $4,300	6 45	
255 repeaters at $2000	45	
Total 5 year life		6 90
75 base stations at $10,000	75	
Total 10 year life		75
Total		7.65
Operation and Maintenance Costs (at 10% of investment annually		.765

River Information

River Gauges (6000)		
Investment Costs		
5 year life	27 60	
10 year life	3 00	
Total		30 60
Operation and Maintenance Costs (at 10% of investment annually)		3 06
Data Analysis and Interpretation Costs		8 98
Total Ground Information System Costs		234 41

APPENDIX F

NON-INFORMATION ALTERNATIVES

I HYDROLOGY NON-INFORMATION ALTERNATIVES

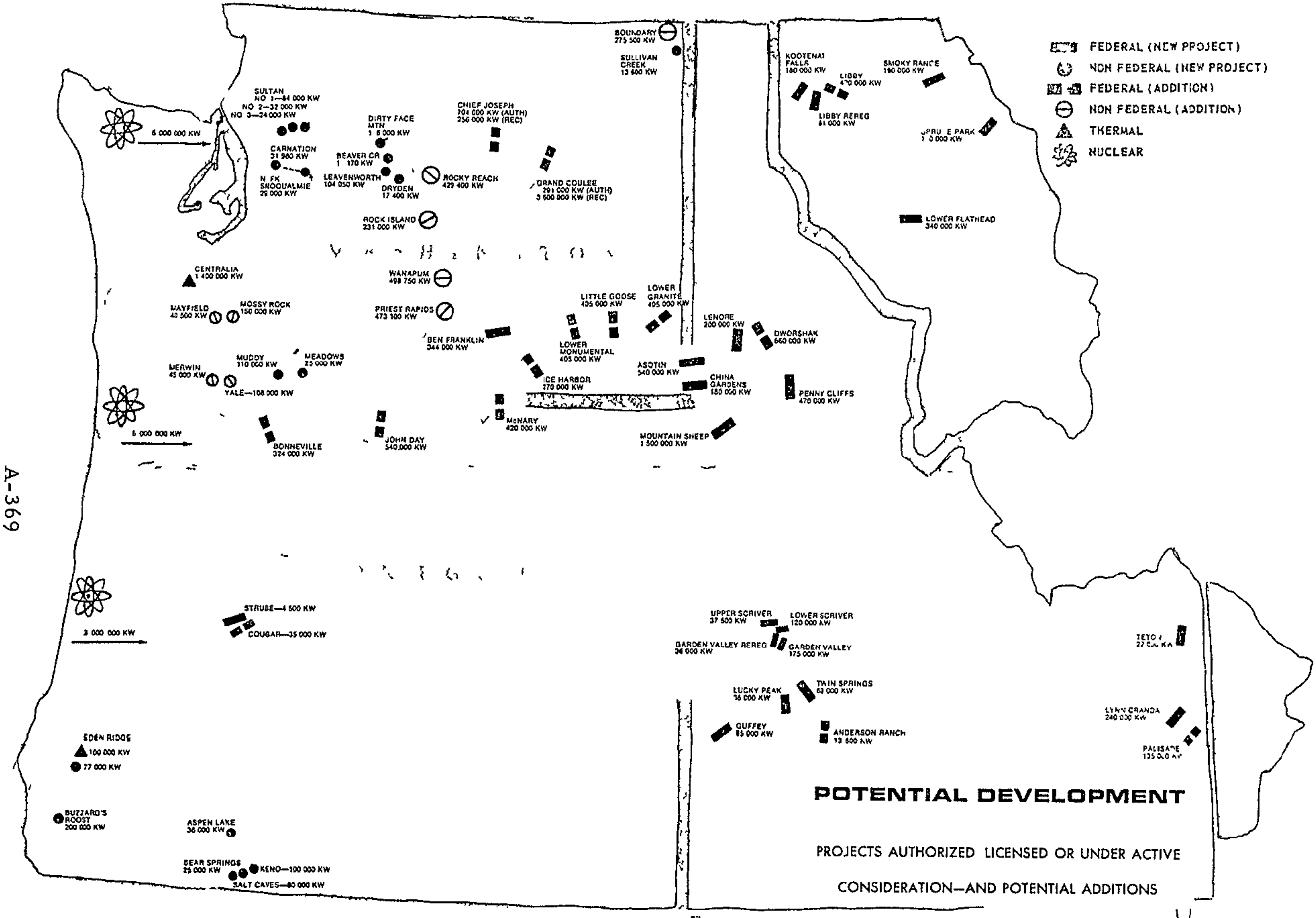
A plethora of potential projects in the Columbia Basin area are under active consideration An overview of potential hydroelectric projects is provided in Exhibit F-1, which indicates locations of potential new projects and additions to existing projects For this analysis, several potential hydroelectric projects have been grouped on a logical area development basis and combined with potential irrigation projects in the same areas to provide a range of non-information alternatives, from more marginal new project alternatives in remote areas to less marginal incremental-project alternatives at existing sites Clearly, the satellite information system should be superior to the marginal new-project alternatives and, at least, comparable to incremental-project alternatives

Five area development alternatives comprised of several Federal projects were selected to provide a range of alternatives for comparative analysis They are·

1 Flathead River Development
2 Snake River Power Development
3 Upper Snake River Development
4 Southwest Idaho Water Development
5 Columbia Basin Power Additions

Generally speaking, each alternative is comprised of varying elements of potential and/or authorized (but not yet under construction) Federal power and irrigation projects and, hence, is in the current decision-making phase Benefits from other project features such as navigation, flood control and recreation are relatively minor for the range of alternatives considered in this analysis and are not included, nor are the specific costs and allocations of joint costs for these features included in cost-benefit calculations

The Flathead River Development (alternative No 1) consists primarily of new power projects, and also includes some new irrigation development in western Montana The Snake River Power Development



*BPA Advance Program 1967-1987 EXHIBIT F-1

This page intentionally left blank

(alternative No 2) consists entirely of new power projects along the mid-Snake River area, of which the often discussed Appaloosa (or High Mountain Sheep) project is the principal element Alternatives No 1 and No 2, consisting of entirely new projects, are expected, a priori, to be representative of more marginal non-information alternatives being planned for activation in the next 20-year period Alternatives No 3 and No 4 represent continuing Federal irrigation and power development of the Snake River in southern Idaho and adjoining areas of Wyoming and Oregon respectively These two alternatives consist of many new, relatively small, power and irrigation projects with some additions to existing projects Hence, they are representative of somewhat less marginal non-information alternatives than Developments in alternatives No 1 and No 2 The Columbia Basin Power Additions of alternative No 5 consist solely of power additions to several existing multi-purpose projects in the Columbia Basin and this is expected to be the least marginal non-information alternative from the range of alternatives offered

In the subsequent section, non-information alternative costs and benefits are summarized (using several cost summarization methodologies) and compared with the costs and benefits of the satellite information system Each non-information alternative is described in terms of power and irrigation development, time phasing, and estimates of costs and benefits, and associated assumptions, in following sections

A Cost and Benefit Summaries

As discussed above, the non-information alternatives considered for this analysis are comprised of potential Federal projects in the Pacific Northwest which are currently in the decision-making phase Typically, these projects (depending on the size and type of the project) experience about a ten year cycle, from initial surveys, investigations, and planning to final installation of the last unit Thus, a non-information alternative considered during a 1970-1990 time period would be penalized for comparative purposes in the sense that full investigations and planning costs (roughly comparable to satellite R&D costs), and investment costs, would be attributed to the alternative and measured against a benefit stream of only about 5 to 10 years. The typical project assets involve high initial investment costs and low operating costs with useful lifetimes of 50 years or more The satellite system, however, involves a relatively low, but continuing, investment in spacecraft with about 2 to 3 year lifetimes in order to realize continuing benefits Thus, the arbitrary 1990 cutoff time gives a zero value to the remaining useful lifetimes of non-information alternative assets (e g , the capability to generate power for several more decades) while assuming that costs and benefits cease for the satellite system with little or no penalty. In other words, a benefit-cost ratio for the satellite system would show relatively little improvement if the cutoff data were extended to the year 2000 and beyond as compared to the non-information alternatives whose benefit-cost ratios would show significant improvement if the cutoff date were extended This general argument holds true irrespective of the discount rate employed in the analysis

Several cost/benefit summarization techniques are available to make the comparison between non-information and satellite alternatives more equitable

(1) The satellite system costs and benefits could be extended to cover the same time period as the useful lifetimes of non-information alternative assets The costs and benefits of alternatives would then be discounted to present worth over this longer time period This implies forecasting satellite technology to at least the year 2030 (equivalent to about a 50 year lifetime of multi-purpose projects) in order to estimate costs and benefits beyond the 1990 cutoff time.

(2) Similar to the above summarization methodology, costs and benefits of non-information and satellite alternatives could be computed on an equivalent annual cost basis In this method, capital outlays are ammortized over useful lifetimes of the assets and added to annual operations and maintenance costs to derive equivalent annual costs which are compared with annual benefits This, too, implies forecasting satellite technology improvements in the future to determine an equivalent annual cost for the satellite system on the basis of a 20 year period

(Satellite system costs are extremely sensitive to satellite mission lifetimes Computation of equivalent annual costs on the basis of mission lifetimes from current technology would be inequitable, and prediction of future mission lifetimes for 1990 and beyond approaches pure guessing)

(3) A third summarization methodology would be to use the 1990 cutoff period, but estimate the market value of assets at the cutoff period, in current dollars, and add these values to the benefit streams of both satellite and non-information alternatives, and then discount costs and benefits for the 1970-1990 period to present worth This method eliminates the need for projecting beyond 1990 but introduces the problem of estimating asset market values in 1990, either by some arbitrary depreciation method or from some predictive method based on historical data Nevertheless, this methodology is deemed preferable to those requiring technology projections beyond the 1990 cutoff period

(4) Another summarization methodology would be to sum all non-recurring costs through 1990, add this total to an arbitrary multiple (about 20 years might be a reasonable multiple) of level annual recurring costs, and compare with an equivalent multiple of level annual benefits In this case, the summarization technique would be known as the 20 year systems cost/benefit technique The principal advantage of this method is its simplicity However, no weight is assigned to differences in asset lifetimes nor is the time value of money recognized For these reasons alone, this technique is not preferable to any of the above

Non-information alternative costs and benefits are summarized in Exhibit F-2 The overall scope of each alternative in terms of power development (thousands of KW's of installed capacity) and irrigation development (thousands of irrigable acres for full and supplemental service) is included in Exhibit F-2 Also given are total alternative costs and benefits (excluding remaining asset values in 1990), at a zero percent discount rate and at discount rates of 7-1/2, 10, and 12-1/2 percent The undiscounted remaining asset values for each alternative in 1990, using an approximative useful asset lifetime of 50 years, subject to straight line depreciation, are also indicated

EXHIBIT F-2 NON-INFORMATION ALTERNATIVES CHARACTERISTICS AND COSTS TO 1990 (Costs in Millions)

		Alt No 1 Flathead River Development	Alt No 2 Snake River Power Development	Alt No 3 Upper Snake River Development	Alt No 4 Southwest Idaho Water Development	Alt No 5 Columbia Basin Power Additions
Power (Thousands of KW's Installed Capacity)		822.0	3,790.0	427.0	571.0	3,116.0
Irrigable Acreage for Service (Full 000's)		150.0	-	197.5	489 0	-
(Supplemental 000's)		-	-	228 6	61.9	-
Total Costs Undiscounted		633 4	946.0	517 6	865 5	663.1
Investigations & Planning		(35 2)	(48 9)	(27 4)	(47 0)	(31 5)
Investment		(541 8)	(753.0)	(422.3)	(722 6)	(484 1)
Operations & Maint		(40 8)	(128.9)	(55 7)	(75 0)	133.4
General Expenses & Administration		(15 6)	(15 2)	(12 2)	(20 9)	(14 1)
Total Costs Discounted	7-1/2%	351 3	530.5	335 0	514 0	407 0
	10%	294.7	450.0	295 4	441 8	356 5
	12-1/2%	249.5	386.1	262.6	383 4	316.0
Total Benefits Undiscounted		166.8	544 0	695.6	969 0	618 5
Power		(73 8)	(544 0)	(58 3)	(63 1)	(618.5)
Irrigation		(93.0)	-	(637 3)	(905 9)	-
Total Benefits Discounted	7-1/2%	61.9	186.5	276 6	383 0	246 3
	10%	46 1	134 5	210 8	291 4	188 3
	12-1/2%	34 8	98.3	163 3	225 3	146 5
Remaining Asset Values 1990 (straight line depreciation - 50 year lifetime)		422 8	572 3	304 2	549 1	338 9
Undiscounted B/C Ratio						
(No Remaining Values)		0 26	0 58	1 34	1 12	0.93
(With Remaining Values)		0 93	1.18	1 93	1 75	1.44

EXHIBIT F-2 (Continued)

	Flathead River Development Alt No. 1	Snake River Power Development Alt No 2	Upper Snake River Development Alt No 3	Southwest Idaho Water Development Alt. No 4	Columbia Basin Power Additions Alt. No 5
Annual Level Recurring					
Costs	3 8	13.9	4 1	6 0	10 4
Benefits	14 1	55 3	51 5	72 8	48.7
20-Year System B/C Ratio	0.42	1 01	1.89	1 60	1.32

The importance of considering remaining asset values is highlighted in the undiscounted benefit/cost ratios with, and without, remaining values attributed to each alternative in 1990 Without remaining asset values considered, only alternatives No 1 and No 2 would be judged better than marginal (i e , benefit/cost ratio > 1 0) at a zero percent discount rate With remaining asset values considered, all alternatives, except the Flathead River Development alternative, are better than marginal at a zero percent discount rate

Discounted costs and benefits, with and without remaining asset values for each alternative, are shown in Exhibits F-3, F-4, and F-5. The order of preference for each alternative does not change with discounting, however, each alternative becomes less favorable with increasing discount rates as more weight is attributed to time differences in cost and benefit streams. Thus, given the assumptions and factors used to develop cost and benefit streams, only the Snake River alternatives are judged better than marginal at a minimum attractive rate of return of 7-1/2 percent, even when remaining asset values are included

The 20 year system cost/benefit summarization technique gives similar ranking of alternatives, as shown in Exhibit F-2 The benefit/cost ratios derived from using this simplified method are about equivalent to a 3 percent discount rate No change in ranking of alternatives is expected from using the first two equivalent cost/benefit summarization techniques discussed above, and these techniques were not utilized in the analysis

The Snake River irrigation development alternatives (No. 3 and 4) are judged to be about equal in preference and superior to the power development alternatives (Nos 1, 2, and 5) However, among the power development alternatives, the ranking of alternatives is quite clear Alternative No 5 which consists entirely of power additions to existing projects is preferred over new power projects (alternatives No 1 and No 2) Between the new-project power development alternatives, the larger and, hence, more efficient Snake River Power Development alternative is preferred over the smaller and more remote Flathead River Development alternative

EXHIBIT F-3 NON-INFORMATION ALTERNATIVES TOTAL COSTS AND BENEFITS TO 1990 DISCOUNTED AT 7-1/2 PERCENT (Millions)

Alternative Description	No Remaining Values			With Remaining Values		
	Costs	Benefits	B/C Ratio	Costs	Benefits	B/C Ratio
No 1 Flathead River Development	351 4	61 9	0 18	350 4	161 4	0 46
No 2 Snake River Power Development	530 5	186 5	0 35	530 5	321 2	0 61
No 3 Upper Snake River Development	335 0	276 6	0 83	335 0	348 2	1 04
No 4 Southwest Idaho Water Development	514 0	383 0	0 75	514 0	512 3	1 00
No 5 Columbia Basin Power Additions	407 0	246 3	0 61	407 0	326 1	0 80

EXHIBIT F-4 NON-INFORMATION ALTERNATIVES TOTAL COSTS AND BENEFITS TO 1990 DISCOUNTED AT 10 PERCENT (Millions)

Alternative Description	No Remaining Values			With Remaining Values		
	Costs	Benefits	B/C Ratio	Costs	Benefits	B/C Ratio
No 1 Flathead River Development	294 7	46 1	0.16	294 7	108 9	0 37
No 2 Snake River Power Development	450 0	134 5	0 30	450 0	219 5	0 49
No 3 Upper Snake River Development	295 4	210 8	0 71	295 4	256 0	0 87
No 4 Southwest Idaho Water Development	441 8	291 4	0 66	441 8	373 0	0 84
No 5 Columbia Basin Power Additions	356 5	188 3	0 53	356 5	238 7	0 67

EXHIBIT F-5 NON-INFORMATION ALTERNATIVES TOTAL COSTS AND BENEFITS TO 1990 DISCOUNTED AT 12-1/2 PERCENT (Millions)

Alternative Description	No Remaining Values			With Remaining Values		
	Costs	Benefits	B/C Ratio	Costs	Benefits	B/C Ratio
No 1 Flathead River Development	249 5	34 8	0 14	249 5	74 9	0 30
No 2 Snake River Power Development	386 1	98 3	0 25	386 1	152 6	0 40
No 3 Upper Snake River Development	262 6	163 3	0 62	262 6	192 1	0 73
No 4 Southwest Idaho Water Development	383 4	225 3	0 59	383 4	277 4	0 72
No 5 Columbia Basin Power Additions	316 0	146 5	0 46	316 0	178 6	0 57

B Cost and Benefit Methodology

The cost and benefit summaries of the five area development alternatives presented earlier were prepared from time-phased streams of costs and benefits through the 1970-1990 period The general cost and benefit methodology, factors, and time-phasing assumptions used to derive approximate estimates of each of the cost and benefit elements are discussed in this section In the next section, the time-phased costs and benefits and project elements for each alternative will be addressed It is important to note that the basic factors and time-phasing assumptions used to generate streams of costs and benefits are of a gross nature, and in no way should they prejudice a more detailed project-by-project analysis encountered in typical Corps of Engineer or Bureau of Reclamation studies The gross factors and assumptions employed on a consistent basis in this analysis are used only to indicate preferences among alternatives and to compare alternatives with the satellite assisted information system

a Cost Elements

Costs of each alternative are divided into four distinct elements, (1) investigations and planning, (2) investment, (3) operations and maintenance, and (4) general expenses and administration Each cost element will be discussed in turn

Investigations and planning costs are derived on an overall percent of investment cost basis and time-phased over the initial five years of each alternative. Thus, the underlying assumption is that investigations and planning costs will vary with the magnitude of the investment For Bureau of Reclamation projects, the sum of cumulative appropriations through FY 1967 for Investigations and Secondary and Advance Planning activities amounted to 6 5 percent of cumulative construction project appropriations For Corps of Engineer projects, the sum of General Investigations and Advance Engineering and Design activities amounted to 4 8, 6 6, and 6 8 percent of General Construction program costs (less Advance Engineering and Design costs) for FY's 1967, 1968, and 1969, respectively A similar estimate of 6 5 percent was utilized here for calculating investigations and planning costs

Investment costs are divided into two categories, (1) power and associated transmission facility investment costs, and (2) irrigation investment costs Power investment costs were computed by applying cost per KW factors to the nameplate rating capacity of each power project of each alternative For new power projects, in cases where project cost estimates were provided in power planning documents, the estimates were used directly in the analysis after estimating power allocations and adjusting to 1968 levels In cases where new power project cost estimates were not readily available, the power investment costs per KW were estimated from the relationship shown in Exhibit F-6 The relationship approximates power investment costs per KW from data on recently completed projects, projects under construction, and some authorized and recommended projects The cost basis and sources of data are provided in Exhibit F-7 Power investment costs were spread over a period of from three to seven years depending on the size of the project The years of power installation by project were derived from tentative installation schedules given in BPA's Advance Program 1967-1987 document Investment in transmission facilities was assumed to approximately coincide with investment in power facilities An overall factor of 26 2 percent, which represents the ratio of cumulative BPA transmission facility investment to cumulative power investment through FY 1967, was derived from BPA's Annual Report, 1968 and was applied to annual power investment costs to estimate time-phased transmission facility investment costs For power projects involving additions to existing facilities, a similar methodology was used with the following exceptions for those projects where cost estimates were not readily available, a $100 investment cost per KW was employed, and costs were spread over a somewhat shorter period of from two to five years Exhibit F-8 provides investment cost data for some projects involving additions to existing power projects, from which an average figure of about $100 per KW was derived

Irrigation investment costs were developed by applying cost per acre factors to irrigable acres of potential reclamation projects in each alternative An average cost of $562 per acre was derived from

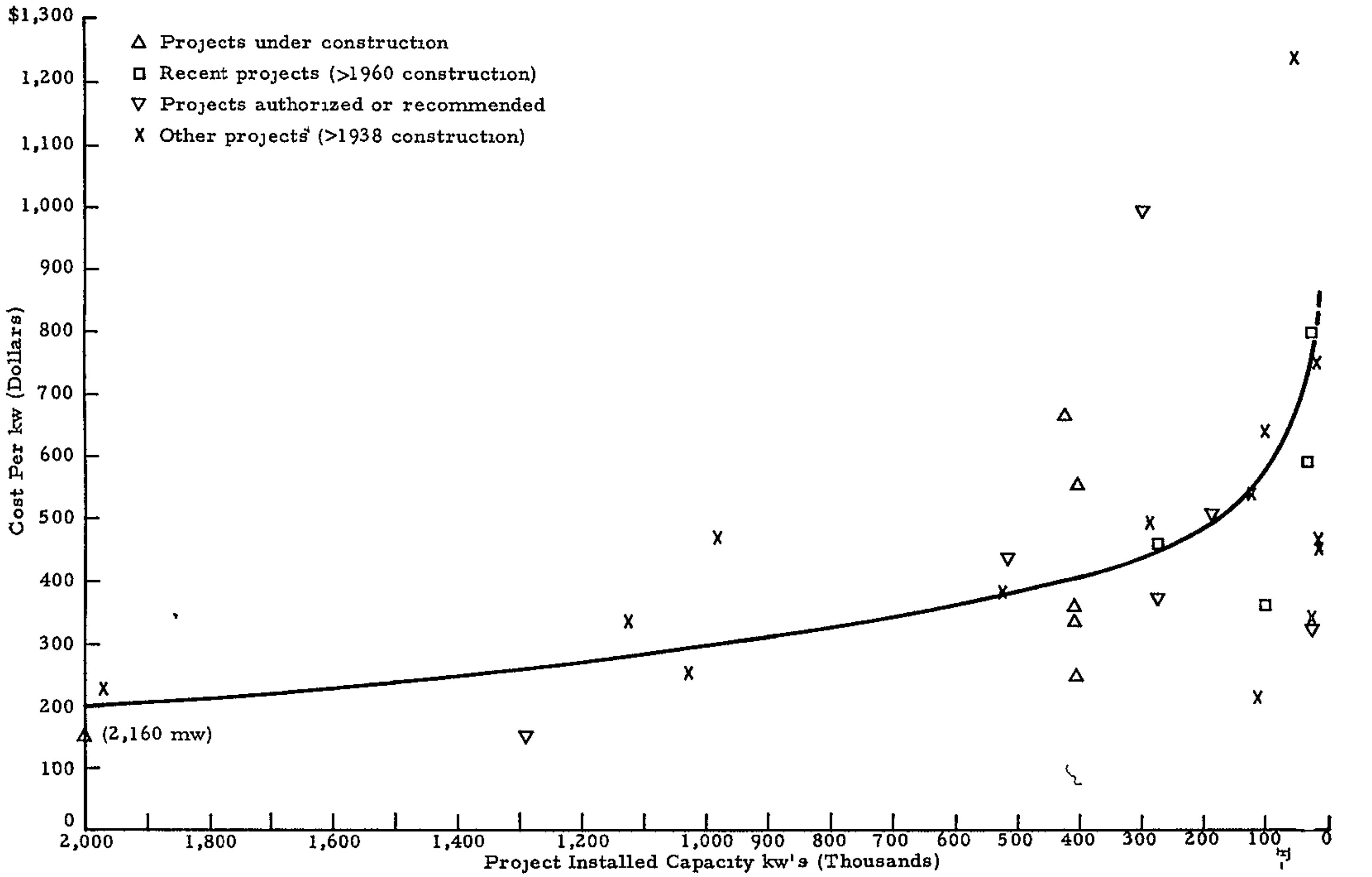


EXHIBIT F-6 1968 POWER INVESTMENT COST PER KW

EXHIBIT F-7 POWER INVESTMENT AND ANNUAL OPERATING COSTS

Projects Authorized or Recommended[1]	Agency[5]	Project Cost (Millions)	Estimated Power Cost (Millions)	Capacity[6] (Thousands of KW's)	Investment Cost per KW of Capacity	Estimated 1968 Cost per KW of Capacity[7]	Annual Operating Cost per KW[8]	Estimated 1968 Annual Operating Cost per KW[9]
Teton	BR	52 0	7 0	22 0	$ 316	$ 329	-	-
Asotin	CE	102 0	96 9	270 0	359	373	-	
Penny Cliffs	CE	246 0	221 4	292 0	758	997		
China Gardens	CE	73 0	69 4	180 0	385	507	-	-
Knowles	BR	235 0	176 3	512 0	344	435	-	-
High Mountain Sheep	PNPC	205 6	195 3	1 290 0	151	151	-	-
Projects Under Construction[2]								
Dworshak	CE	248 0	220 7	400 0	$ 552	$ 552		-
John Day	CE	448 0	324 8	2 160 0	150	150	-	-
Libby	CE	360 0	280 4	420 0	668	668	-	-
Little Goose	CE	148 0	100 8	405 0	249	249	-	-
Lower Granite	CE	190 0	146 5	405 0	362	362		-
Lower Monumental	CE	181 0	136 3	405 0	337	337	-	-
Recent Projects (1960 s)[3]								
Ice Harbor	CE	-	94 0	270 0	$ 348	$ 458	$ 1 52	$ 1 66
Hills Creek	CE	-	14 0	30 0	467	591	1 90	2 08
Cougar	CE	-	17 0	25 0	681	797	3 08	3 37
Green Peter-Foster	CE		34 1	100 0	341	354	-	-
Other Projects (1938 1960)[4]								
Albeni Falls	CE	-		42 6	$ 747	$ 1 244	$ 8 05	$ 8 80
Dalles	CE	-	-	1,125 0	218	336	0 98	1 07
Detroit	CE	-	-	100 0	355	639	3 16	3 45
Lookout Point	CE		-	120 0	310	537	2 25	2 46
Bonneville	CE	-	-	522 4	118	383	1 75	1 91
McNary	CE	-	-	986 0	262	472	1 02	1 11
Chief Joseph	CE	-	-	1 028 8	152	253	0 85	0 93

EXHIBIT F-7 (Continued)

Other Projects (1938-1960)	Agency(5)	Project Cost (Millions)	Estimated Power Cost (Millions)	Capacity(6) (Thousands of KW's)	Investment Cost per KW of Capacity	Estimated 1968 Cost per KW of Capacity(7)	Annual Operating Cost per KW(8)	Estimated 1968 Annual Operating Cost per KW(9)
Anderson Ranch	BR	-	-	27 0	$ 173	$ 337	$ 2 74	$ 2 99
Palisades	BR	-	-	114 0	132	211	1 31	1 43
Hungry Horse	BR		-	285 0	264	494	0 88	0 96
Chandler	BR	-	-	12 0	282	451	4 00	4 37
Grand Coulee	BR	-	-	1 974 0	80	230	0 78	0 85
Greensprings	BR	-	-	16 0	549	751	1 94	2 12
Roza	BR	-	-	11 3	312	462	3 54	3 87

Notes (1) Project costs derived from Review of Power Planning in the Pacific Northwest Calendar Year 1967 Power Planning Committee Pacific Northwest River Basins Commission April 1968 Power Cost Allocations estimated (except for Teton project)--95 percent for Snake River projects 90 percent for Clearwater River projects and 75 percent for Flathead River projects

(2) Project costs derived from FY 1969 Budget data Power cost allocations derived from BPA Annual Report 1968

(3) Power cost derived from BPA Annual Report 1967

(4) Power cost per KW derived from Hydroelectric Plant Construction Cost and Annual Production Expenses 1965 FPC

(5) BR = Bureau of Reclamation CE = Corps of Engineers PNPC = Pacific Northwest Power Company

(6) Capacities relate to project costs and not potential project capacity Nameplate rating capacities derived from Advance Program 1967-1987 BPA and Review of Power Planning in The Pacific Northwest CY 1967

(7) Investment costs escalated to 1968 at 4 percent per annum.

(8) Annual operating costs derived from Hydroelectric Plant Construction Cost and Annual Production Expenses 1965

(9) Annual operating costs escalated to 1968 at 3 percent per annum.

EXHIBIT F-8 POWER ADDITIONS INVESTMENT COSTS

Project	Project Cost (Millions)	Capacity Added[1] (Thousands of KW's)	Investment Cost Per KW of Capacity Added	1968 Investment Cost Per KW of Capacity Added[4]
Ice Harbor	22 0[1]	333 0	$ 66	$ 69
Bonneville	116 0[1]	324 0	358	372
Chief Joseph	62 2[1]	704 0	88	92
The Dalles	57 2[2]	688 0	83	83
Grand Coulee	388 7[3]	3,600 0	108	112

Notes

(1) Capacity added and project costs derived from Review of Power Planning in the Pacific Northwest, CY 1967, PPC, PNRBC, April 1968

(2) Project cost derived from FY 1969 Budget data

(3) Project cost derived from Summary Report of the Commissioner, BR, 1967, Statistical Appendix .

(4) Investment costs escalated to 1968 at 4 percent per annum

data pertaining to recent irrigation projects undertaken in the southern Idaho area, and applied to potential acreage of the Upper Snake River and Southwest Idaho Water Development alternatives Exhibit F-9 provides these data For the relatively minor irrigation acreage of the Flathead River Development alternative, a cost of $400 per acre was estimated Irrigation acreage was assumed to come into service over a ten year period in equal annual increments, with a four year development period over which investment costs were phased equally

Operations and maintenance (O&M) costs are divided into two categories, (1) power plant and associated transmission facility operations, and (2) irrigation operations Annual power plant operating cost data are given in Exhibit F-7 and a relationship fitted to these data as shown in Exhibit F-10 This relationship between O&M costs and project power capacity was used to estimate power plant O&M costs for new power projects in each alternative For add-on power projects, O&M costs of the existing project were used Transmission facility annual O&M costs are also estimated on the basis of power capacity An estimate of $2 15 per KW capacity was derived from BPA Operations and Maintenance costs contained in FY 1969 Budget data Annual irrigation O&M costs were computed on a per acre irrigated basis using existing representative irrigation project data as cost analogs Annual 1968 O&M costs per irrigated acre, to include Bureau of Reclamation and water user costs, of $6 34 per irrigated acre for the Boise project, $5 51 irrigated acre for the Minidoka project, and $4 38 per irrigated acre for the Bitter Root project were applied in the Southwest Idaho Water Development, Upper Snake River Development, and Flathead River Development alternatives respectively Before application of O&M costs per irrigated acre, the acreages developed in each alternative were adjusted to account for the ratio of irrigated acres to available irrigable acres An Idaho-wide average ratio of 0 93 was employed for the two Idaho alternatives and a ratio of 0 97 (using the Bitter Root project as an analog) was used for the Montana alternative.

EXHIBIT F-9 IRRIGATION INVESTMENT COSTS

Recent Idaho Projects	Irrigation Investment(1) Cost (Thousands)	Estimated 1968 Investment(2) Cost (Thousands)	Irrigation Development(1) (Thousands of Acres)			Investment Cost Per Acre
			Full	Suppl	Total	
Little Wood River	1,474	2,098	-	9,549	9,549	$220
Michaud Flats	4,848	7,463	9,720	-	9,720	768
Mann Creek	3,828	4,140	650	4,460	5,110	810
Totals		13,704			24,379	$562

Notes

(1) Project costs and irrigation acreage derived from Summary Report of the Commissioner, BR, 1967, Statistical Appendix

(2) Investment costs escalated to 1968 at 4 percent per annum

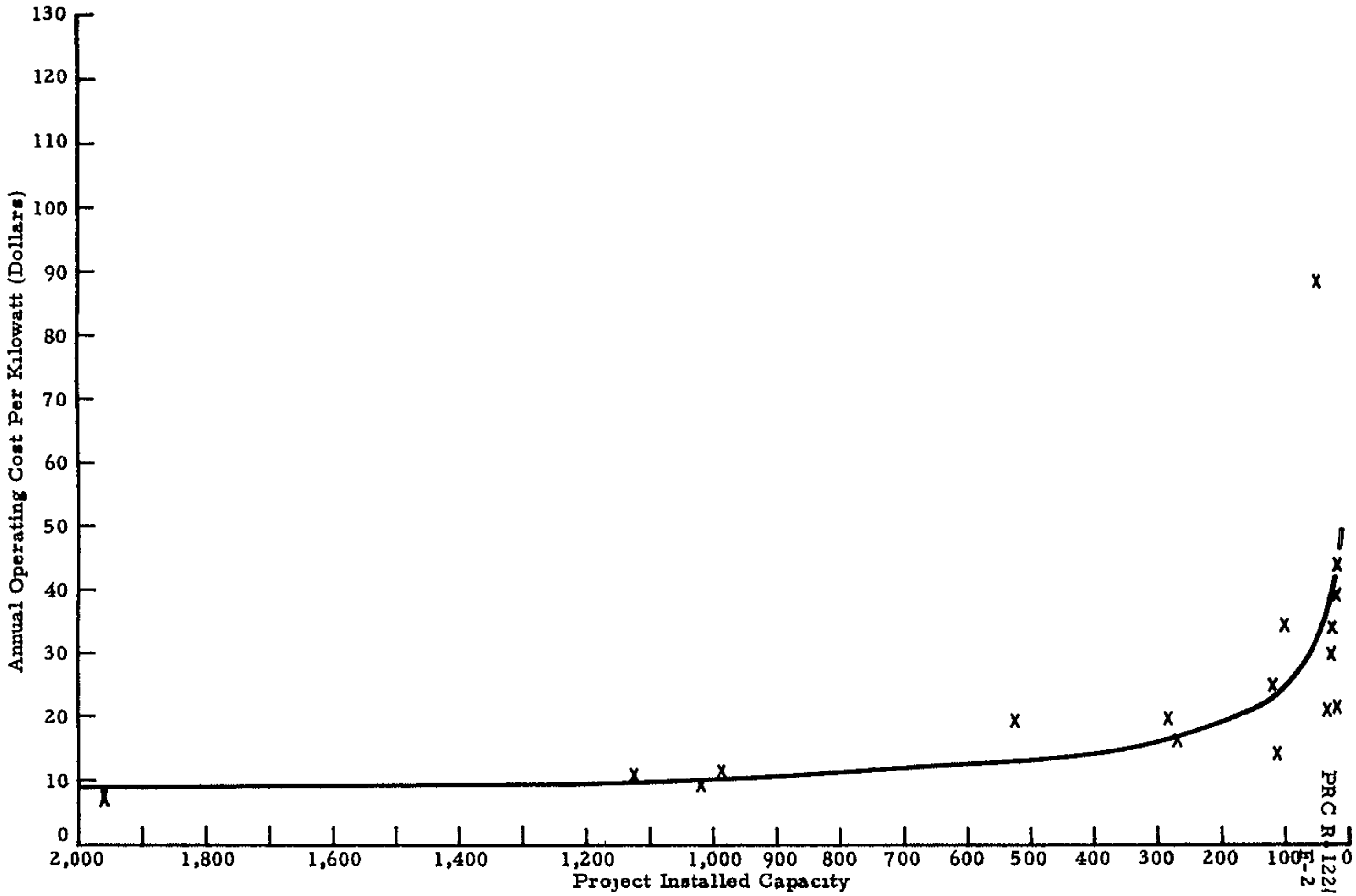


EXHIBIT F-10 1968 ANNUAL POWER OPERATING COST PER KILOWATT

General expenses and administration costs essentially account for agency overhead expenses Overall estimated from FY1969 Budget data of 2 9 and 2 0 percent of total construction program costs were derived for the Bureau of Reclamation and Corps of Engineers respectively These costs are assumed to vary most closely with investment costs and were time-phased accordingly

b Benefit Elements

Benefits of each alternative are divided into three categories, (1) power benefits, (2) irrigation benefits, and (3) remaining asset values The benefit analysis has been treated at a relatively gross level for purposes of comparative analysis and no attempt has been made to identify and measure unique benefits accruing to individual power and irrigation projects within each large scale alternative

Power benefits were taken as the product of rated power capacity in kilowatts, available hours, plant factor (i e utilization of power plant), and power price per kilowatt-hour Irrigation benefits were taken as the product of irrigable acres developed, irrigable-to-available-acres factor (i e , utilization of developed acreage), and gross crop value per irrigated acre Where possible, analogies to existing projects were drawn, and experience data from these projects were used The specific factors and assumptions used in the analysis are listed in Exhibit F-11

Similarly, estimation of remaining asset values in 1990 for each alternative was treated on a gross level The revenue producing assets developed in each alternative will undoubtedly have value in 1990 and, theoretically, one would use actual market values to estimate the remaining value of the assets In lieu of 1990 market information, a gross straight line depreciation technique was used to estimate remaining values A fifty year useful asset lifetime was assumed in the analysis, which may be conservative The beginning lifetime of each alternative's assets was assumed to occur in the year in which cumulative investment costs reached fifty percent of the total The remaining values calculated in this manner are given in Exhibit F-11

EXHIBIT F-11 BENEFIT FACTORS

	Flathead River Development Alt No 1	Snake River Power Development Alt No 2	Upper Snake River Development Alt No 3	Southwest Idaho Water Development Alt No 4	Columbia Basin Power Additions Alt No 5
Power Benefit Factors					
Power Sales Price (Mils per KW-hr)	2 38(1)	2 38(1)	2 26(2)	2 26(2)	2 38(1)
Estimated Plant Factor(3)	0 42	0 70	0 50	0 50	0 75
Irrigation Benefit Factors					
Gross Crop Value Per Irrigated Acre (Full)	$47 17(4)	-	$124 65(5)	$135 44(6)	-
Gross Crop Value Per Irrigated Acre (Supp'l)	-	-	$114 62(5)	$155 59(6)	-
Irrigated/Available Service Acres	0 97(4)	-	0 93(5)	0 89(6)	-
Remaining Asset Values (Millions)					
Total Investment	541 8	753 0	422 3	722 6	484 1
Remaining Years at 1990	39	38	36	38	35
Assets Present Worth Value (0 percent)	422 8	572 3	304 2	549 1	338 9
(7-1/2 percent)	99 5	134 7	71 6	129 3	79 8
(10 percent)	62 8	85 0	45 2	81 6	50 4
(12-1/2 percent)	40 1	54 3	28 8	52 1	32 1

Notes

(1) Average BPA Power Price, BPA 1967 Annual Report

(2) Palisades-Boise-Minidoka Power Pool Price, Summary Report of the Commissioner, BR, 1967, Statistical Appendix

(3) Plant factors for BR and CE projects in Columbia Basin range from 0 41 to 0 88 (Hydroelectric Plant Construction Cost and Annual Production Expenses, 1965, FPC) Analog projects used where appropriate for estimating plant factor (e g Hungry Horse plant factor used for Flathead River projects)

(4) Bitter Root project analog

(5) Minidoka project analog

(6) Boise project analog

C Project Elements and Time-Phased Costs and Benefits

In this section, project elements of each alternative, in terms of power and irrigation development, are made explicit The time phasing and magnitude of each alternative's power and irrigation development, and associated cost and benefit streams, are also presented, using the methodology previously described Exhibit F-12 presents the project elements of each alternative Exhibits F-13 through F-17 present the time-phased power and irrigation development, and cost and benefit streams, of each alternative

EXHIBIT F-12 NON-INFORMATION ALTERNATIVE PROJECT ELEMENTS

Alternative No 1

Flathead River Project Elements	Irrigable Acres[1] Full	Irrigable Acres[1] Supp'l	Power Development (KW's)
Montana			
Flathead River Project	150,000	-	-
Knowles (Lower Flathead)	-	-	512,000[2]
Spruce Park	-	-	120,000[3]
Smoky Range	-	-	190,000[3]
Total	150,000	-	822,000

Alternative No 2

Snake River Power Project Elements	Irrigable Acres Full	Irrigable Acres Supp'l	Power Development (KW's)
Idaho-Wash -Oregon			
Asotin Dam	-	-	270,000[3]
Asotin Dam Additions	-	-	270,000[3]
High Mountain Sheep (Appaloosa)	-	-	1,290,000[2]
High Mountain Sheep Additions	-	-	1,720,000[2]
China Gardens	-	-	180,000[3]
China Gardens Additions	-	-	60,000[3]
Total	0	0	3,790,000

Alternative No 5

Columbia Basin Power Additions - Project Elements	Irrigable Acres Full	Irrigable Acres Supp'l	Power Development (KW's)
Washington			
Ice Harbor	-	-	333,000[2]
Chief Joseph (Units No 17-27)	-	-	704,000[3]
Lower Monumental	-	-	405,000[3]
Little Goose	-	-	405,000[3]
Lower Granite	-	-	405,000[3]
			2,252,000
Washington - Oregon			
Bonneville	-	-	324,000
John Day	-	-	540,000
Total	0	0	3,116,000

Alternative No 3

Upper Snake River Project Elements	Irrigable Acres[1] Full	Irrigable Acres[1] Supp'l	Power Development(KW's)
Idaho			
Alta Division	-	3,700	-
American Falls Dam Replacement	-	-	30,000[2]
Big Lost River Division	9,000	-	-
Big Wood River Division	-	-	-
Birch Creek Division	6,500	15,000	-
Lake Channel Division	1,500	-	-
Little Lost River Division	15,000	13,500	-
Lynn Crandall Division	-	-	240,000[3]
North Side Unit B Extension	12,000	-	-
Oakley Fan Division	35,000	62,000	-
Raft River Division	85,000	27,000	-
Rockland Division	3,100	600	-
Salmon Falls Division	14,700	49,400	-
Snake Plain Recharge Division	-	-	-
Upper Teton Division	13,600	26,600	22,000[2]
Palisades Additions	-	-	135,000[3]
	195,400	200,000	427,000
Wyoming			
Alta Division	-	2,800	-
Jackson Hale Division	2,100	4,300	-
Upper Star Valley Division	-	21,500	-
Total	197,500	228,600	427,000

Alternative No 4

Southwest Idaho Water Development Project Elements	Irrigable Acres[1] Full	Irrigable Acres[1] Supp'l	Power Development(KW's)
Idaho			
Mountain Home Division	105,100	25,700	85,000[2]
Garden Valley Division	137,000	28,000	368,500[2]
Bruneau Division	238,000	2,000	-
Weiser River Division	9,900	6,200	-
Anderson Ranch Dam Additions	-	-	13,500[3]
Lucky Peak Dam	-	-	35,000[3]
Twin Springs Dam	-	-	69,000[3]
Total	489,000	61,900	571,000

(1) Summary Report of the Commissioner, BR, 1967, Statistical Appendix
(2) Review of Power Planning in the Pacific Northwest, 1967, PNWRBC
(3) Advance Program 1967-1987, U S Dept of the Interior, BPA

EXHIBIT F-13 FLATHEAD RIVER DEVELOPMENT (BR)

	Y	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11	Y+12	Y+13	Y+14	Y+15	Y+16	Y+17	Y+18	Y+19	Y+20	Sub-totals	Totals
Costs (Millions)	8 7	10 1	11 6	13 3	13 3	35 8	58 4	58 4	75 5	106 0	106 2	52 9	52 8	3 8	3 8	3 8	3 8	3 8	3 8	3 8	3 8		633 4
Investigations and Planning	7 2	7 0	7 0	7 0	7 0																	35 2	
Investment																						541 8	
Irrigation	1 5	3 0	4 5	6 0	6.0	6 0	6 0	6 0	6 0	6 0	4 5	3 0	1 5									(60 0)	
Power																						481 8 (481 8)	
Knowles						22 7	40 0	40 0	40 0	40 0	40 0											(227 7)	
Spruce Park										16 5	16 5	16 5	16 5									(66 0)	
Smoky Range									13 1	20 0	20 0	20 0	20 0									(93 1)	
Transmission Facilities						5 9	10 5	10 5	13 9	20 0	20 0	9 6	9 6									(100 0)	
Operations and Maintenance																						40 8	
Irrigation				0 1	0 1	0 2	0 3	0 3	0 4	0 5	0 5	0 6	0 7	0 7	0 7	0 7	0 7	0 7	0 7	0 7	0 7	(9 3)	
Power											1 8	1 8	3 1	3 1	3 1	3 1	3 1	3 1	3 1	3 1	3 1	(31 5)	
General Expenses and Administration		0.1	0 1	0 2	0 2	1 0	1 6	1 6	2 1	3 0	2 9	1 4	1 4									15 6	
Benefits (Millions)				0 7	1 4	2 1	2 7	3 4	4 1	4 8	10 0	10 7	14 1	14 1	14 1	14 1	14 1	14 1	14 1	14 1	436 9		589 6
Irrigation				0 7	1 4	2 1	2 7	3 4	4 1	4 8	5 5	6 2	6 9	6 9	6 9	6 9	6 9	6 9	6 9	6 9	6 9	93 0	
Power											4 5	4 5	7 2	7 2	7 2	7 2	7 2	7 2	7 2	7 2	7 2	73 8	
Remaining Asset Values																					422 8	422 8	
Project Development																							
Irrigation (Thousands of Acres)																							
Annual																							
Full				15 0	15 0	15 0	15 0	15 0	15 0	15 0	15 0	15 0	15.0										
Supplement																							
Cumulative				15 0	30 0	45 0	60 0	75 0	90 0	105 0	120 0	135 0	150 0	150 0	150 0	150 0	150 0	150 0	150 0	150 0	150 0		
Power (Thousands of Kilowatts)																							
Annual											512 0		310 0										
Cumulative											512 0	512 0	822 0	822 0	822 0	822 0	822 0	822 0	822 0	822 0	822 0		

EXHIBIT F-14   SNAKE RIVER POWER DEVELOPMENT (CE)

	Y	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11	Y+12	Y+13	Y+14	Y+15	Y+16	Y+17	Y+18	Y+19	Y+20	Sub-totals	Totals
Costs (Millions)	8 9	10 0	23 8	54 8	80 8	85 4	91 2	65 5	65 5	113 8	49 5	49 5	57 7	63 1	22 7	22 7	25 5	13 9	13 9	13 9	13 9		946 0
Investigations and Planning	8 9	10 0	10 0	10 0	10 0																	48 9	
Investment																						753 0	
Asotin			10 7	20 0	25 0	25 0	20 0															(100 7)	
Asotin Additions															9 0	9 0	9 0					(27 0)	
High Mountain Sheep				14 8	30 0	30 0	30 0	30 0	30 0	30 0												(194 8)	
High Mountain Sheep Additions										34 0	34 0	34 0	35 0	35 0								(172 0)	
China Garden						11 3	20 0	20 0	20 0	20 0												(91 3)	
China Garden Additions													3 0	3 0								(6 0)	
Transmission Facilities			2 8	9 1	14 4	17 4	18 3	13 1	13 1	22 0	8 9	8 9	10 0	10 0	2 4	2 4	2 4					(161 2)	
Operations and Maintenance							1 1	1 1	1 1	5 7	5 7	5 7	5 7	11 1	11 1	11 1	13 9	13 9	13 9	13 9	13 9	128 9	
General Expenses and Administration			0 3	0 9	1 4	1 7	1 8	1 3	1 3	2 1	0 9	0 9	1 0	1 0	0 2	0 2	0 2					15 2	
Benefits (Millions)	0 0	0 0	0 0	0 0	0 0	0 0	3 9	3 9	3 9	25 4	25 4	25 4	25 4	51 4	51 4	51 4	55 3	55 3	55 3	55 3	627 6		1,116 3
Power							3 9	3 9	3 9	25 4	25 4	25 4	25 4	51 4	51 4	51 4	55 3	55 3	55 3	55 3	55 3	544 0	
Remaining Asset Values																					572 3	572 3	
Project Development																							
Power (Thousands of Kilowatts)																							
Annual							270 0			1,470 0				1,780 0			270 0						
Cumulative							270 0	270 0	270 0	1,740 0	1,740 0	1,740 0	1,740 0	3,520 0	3,520 0	3,520 0	3,790 0	3,790 0	3,790 0	3,790 0	3,790 0		

FOLDOUT FRAME

PRECEDING PAGE BLANK NOT FILMED

FOLDOUT FRAME 2

EXHIBIT F-15 UPPER SNAKE RIVER DEVELOPMENT (BR)

	Y	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11	Y+12	Y+13	Y+14	Y+15	Y+16	Y+17	Y+18	Y+19	Y+20	Sub-totals	Totals
COSTS (Millions)	12 6	20 9	29 4	40 2	48 5	69 8	63 6	63 0	60 4	28 1	22 2	16 3	10 2	4 0	4 0	4 0	4 0	4 1	4 1	4 1	4 1		517 6
Investigations and Planning	6 4	7 0	7 0	7 0																		27 4	
Investment																						422 3	
Irrigation	6 0	12 0	18 0	24 0	24 0	24 0	24 0	24 0	24 0	24 0	18 0	12 0	6 0									(240 0)	
Power																						182 3 (182 3)	
American Falls				3 3	5 0	5 0																(13 3)	
Teton		1 2	3 0	3 0																		(7 2)	
Lynn Crandall					10 4	25 0	25 0	25 0	25 0													(110 4)	
Palisades Additions					2 5	4 0	4 0	3 0														(13 5)	
Transmission Facilities		0 3	0 8	1 7	4 7	8 9	7 6	7 3	6 6													(37 9)	
Operations & Maintenance																						55 7	
Irrigation				0 2	0 5	0 7	0 9	1 2	1 4	1 6	1 9	2 1	2 2	2 2	2 2	2 2	2 2	2 3	2 3	2 3	2 3	(30 7)	
Power				0 1	0 1	0 3	0 3	0 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	1 8	(25 0)	
General Expenses and Administration	0 2	0 4	0 6	0 9	1 3	1 9	1 8	1 7	1 6	0 7	0 5	0 4	0 2									12 2	
BENEFITS (Millions)	0 0	0 0	0 0	4 9	9 6	14 7	19 4	25 5	32 5	37 3	42 0	46 7	51 4	51 4	51 4	51 4	51 4	51 5	51 5	51 5	355 7		999 8
Irrigation				4 7	9 4	14 2	18 9	23 6	28 3	33 1	37 8	42 5	47 2	47 2	47 2	47 2	47 2	47 2	47 2	47 2	47 2	637 3	
Power				0 2	0 2	0 5	0 5	1 9	4 2	4 2	4 2	4 2	4 2	4 2	4 2	4 2	4 2	4 3	4 3	4 3	4 3	58 3	
Remaining Asset Values																					304 2	304 2	
PROJECT DEVELOPMENT																							
Irrigation (Thousand of Acres)																							
Annual Full				19 75	19 75	19 75	19 75	19 75	19 75	19 75	19 75	19 75	19 75										
Supp'l				22 86	22 86	22 86	22 86	22 86	22 86	22 86	22 86	22 86	22 86										
Cumulative				42 61	85 22	127 83	170 44	213 05	255 66	298 27	340 88	383 49	426 10	426 1	426 1	426 1	426 1	426 1	426 1	426 1	426 1		
Power (Thousands of Kilowatts)																							
Annual				22 0		30 0		135 0	240 0														
Cumulative				22 0	22 0	52 0	52 0	187 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0	427 0		

FOLDOUT FRAME

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED

EXHIBIT F-16 SOUTHWEST IDAHO WATER DEVELOPMENT PROJECT (BR)

	Y	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11	Y+12	Y+13	Y+14	Y+15	Y+16	Y+17	Y+18	Y+19	Y+20	Sub-totals	Totals
COSTS (Millions)	16 9	25 4	33 4	42 2	58 4	50 6	71 9	113 8	102 6	89 6	98 8	70 3	26 6	23 0	6 0	6 0	6 0	6 0	6 0	6 0	6 0		865 5
Investigations and Planning	9 0	9 5	9 5	9 5	9 5																	47 0	
Investment																						722 6	
Irrigation	7 7	15 5	23 2	31 0	31 0	31 0	31 0	31 0	31 0	31 0	23 2	15 5	7 7									(309 8)	
Power																						412 8 (412 8)	
Anderson Ranch Additions				0 4	0 5	0 5																(1 4)	
Mountain Home Div (Guffey)					12 0	13 0	13 0	13 0														(51 0)	
Lucky Peak							8 0	8 0	9 2													(25 2)	
Garden Valley Div							8 6	40 5	43 0	42 0	44 6	27 7										(206 4)	
Twin Springs											10 0	10 0	10 0	13 1								(43 1)	
Transmission Facilities				0 1	3 3	3 5	7 8	16 1	13 7	11 0	14 3	9 9	2 6	3 4								(85 7)	
Operations and Maintenance																						75 0	
Irrigation				0 3	0 7	1 0	1 3	1 6	2 0	2 3	2 6	3 0	3 3	3 3	3 3	3 3	3 3	3 3	3 3	3 3	3 3	44 5	
Power						0 2	0 2	0 5	0 9	0 9	1 4	2 4	2 4	2 7	2 7	2 7	2 7	2 7	2 7	2 7	2 7	30 5	
General Expenses and Administration	0 2	0 4	0 7	0 9	1 4	1 4	2 0	3 1	2 8	2 4	2 7	1 8	0 6	0 5								20 9	
BENEFITS (Millions)				6 7	13 4	20 2	26 9	34 6	42 0	48 7	56 6	65 4	72 1	72 8	72 8	72 8	72 8	72 8	72 8	72 8	621 9		1518 1
Irrigation				6 7	13 4	20 1	26 8	33 6	40 3	47 0	53 7	60 4	67 1	67 1	67 1	67 1	67 1	67 1	67 1	67 1	67 1	905 9	
Power						0 1	0 1	1 0	1 7	1 7	2 9	5 0	5 0	5 7	5 7	5 7	5 7	5 7	5 7	5 7	5 7	63 1	
Remaining Asset Values																					549 1	549 1	
PROJECT DEVELOPMENT																							
Irrigation (Thousands of Acres)																							
Annual Full				48 90	48 90	48 90	48 90	48 90	48 90	48 90	48 90	48 90	48 90										
Supp'l				6 19	6 19	6 19	6 19	6 19	6 19	6 19	6 19	6 19	6 19										
Cumulative				55 09	110 18	165 27	220 36	275 45	330.54	385 63	440 72	495 81	550 90	550 9	550 9	550 9	550 9	550 9	550 9	550 9	550 9		
Power (Thousands of Kilowatts)																							
Annual						13 5		85 0	72 5		120 0	211 0		69 0									
Cumulative						13 5	13 5	98 5	171 0	171 0	291 0	502 0	502 0	571 0	571 0	571 0	571 0	571 0	571 0	571 0	571 0		

EXHIBIT F-17 COLUMBIA BASIN POWER ADDITIONS (CE)

	Y	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11	Y+12	Y+13	Y+14	Y+15	Y+16	Y+17	Y+18	Y+19	Y+20	Sub-Totals	Totals
COSTS (Millions)	6 0	36 6	68 1	70 0	62 8	47 5	49 7	17 7	32 8	32 0	32 0	51 5	39 9	26 2	27 9	10 4	10 4	10 4	10 4	10 4	10 4		663 1
Investigations and Planning	6 0	6 0	6 5	6 5	6 5																	31 5	
Investment																						484 1	
Ice Harbor		7 5	7 5	7.9																		22 9	
Chief Joseph (#17-27)		16 0	16 0	16 0	16 7																	64 7	
Bonneville			24 0	24 0	24.0	24 0	24 6															120 6	
Lower Monumental						10 0	10 0	10 0	10 5													40 5	
Little Goose									10 0	10 0	10 0	10 5										40 5	
Lower Granite										10 0	10 0	10 0	10 5									40 5	
John Day												13 5	13 5	13 5	13 5							54 0	
Transmission Facilities		6 2	12 4	12 5	10 7	8 9	9 1	2 6	5 4	5 2	5 2	8 9	6 3	3 5	3 5							100 4	
Operations and Maintenance				1 3	3 4	3 4	4 7	4 7	6 1	6 1	6 1	7 4	8 7	8 7	10 4	10 4	10 4	10 4	10 4	10 4	10 4	133 4	
General Expenses and Administration		0 9	1 7	1 8	1 5	1 2	1 3	0 4	0 8	0 7	0 7	1 2	0.9	0 5	0 5							14 1	
BENEFITS (Millions)				5 2	16 2	16 2	21 3	21 3	27 6	27 6	27 6	34 0	40 3	40 3	48 7	48 7	48 7	48 7	48 7	48 7	387 6		957 4
Power				5 2	16 2	16 2	21 3	21 3	27 6	27 6	27 6	34 0	40 3	40 3	48 7	48 7	48 7	48 7	48 7	48 7	48 7	618 5	
Remaining Asset Values																					338 9	338 9	
PROJECT DEVELOPMENT																							
Power (Thousands of Kilowatts) Annual				333 0	704 0		324 0		405 0			405 0	405 0		540 0								
Cumulative				333 0	1037 0	1037 0	1361 0	1361 0	1766 0	1766 0	1766 0	2171 0	2576 0	2576 0	3116 0	3116 0	3116 0	3116 0	3116 0	3116 0	3116 0		

II WHEAT YIELD NON-INFORMATION ALTERNATIVE COSTS

The non-information alternative considered here on worldwide wheat yields is that alternative which has been the policy of the U S for the past several years This policy calls for considerable wheat storage resulting from both a high minimum desirable annual carry-over reserve of wheat--about 400 million bushels--and recurring over-production which results in both the procurement and storage of excess stocks

The goal of the U S wheat production and storage programs is to provide a supply of wheat each year sufficient to provide for domestic and foreign demand and to maintain a minimum adequate carryover for pipeline (commercial) stocks and for yield variations due to weather While there is no official determination of an adequate minimum carry-over level, a comprehensive study of desirable stock levels was prepared by the Bureau of Agricultural Economics for the Senate Committee on Agriculture and Forestry in 1952, and printed as Senate Document No 130, 82nd Congress, 2nd Session, Reserve Levels for Storable Farm Products This report (page 5) recommended a desirable carryover of about 500 million bushels--approximately 100 million bushels for working or pipeline stocks, and 400 million bushels in storage to take care of reduced yields which would result from one very low yield year followed by one moderately low yield year (This would have taken care of all contingencies since 1900 except for the drought years 1933-36) With the increased level of wheat exports in recent years, however, pipeline stocks now require about 150 million bushels rather than 100 million so that total carryover stocks today should approximate 550 million bushels Domestic consumption of wheat has remained quite level

Historical experience in stored inventories of U S wheat from 1953 to 1968 shows a range of about 100 to 1,300 million bushels It is quite unlikely, though, that the current program would allow stocks to get to the high extreme of that range in the future The program has been modified to give more flexibility on downward acreage adjustments

In the past, bad situations were allowed to get successively worse, but under the current information system there is only a two year lag in the adjustment process to an undesirable carryover level Acreage allotments established in the summer of year (X) affect production in year (X+1) and carryover levels July 1 (X+2) At the time of allotment decision, although U S supplies and consumption are known, there is little accurate information on foreign crop conditions and potential foreign requirements for U S wheat With this weak link in the supply-distribution balance (exports account for more than half of total disappearance), the carryover July 1 (X+1) cannot be determined accurately and the error carries forward into the following year The successive build-up in inventories by a surplus 300 million bushels in 1954, and by an additional 200 million bushels in 1955, is a case in point Similarly, in the process of reducing stocks from 1965 to 1967, the two year inflexibility lowered the level of stocks to about 250 million bushels below desirable levels Thus, with a two year lag, and two successive years of bad or good weather and other variables, the range in stock levels could be from 0 to 900 million bushels, with around 400 million bushels as the desirable stock level but with a constant bias towards stocks in excess of those desired This bias is due to the constantly improving yields in wheat as well as a constant conservative attitude--better to store some extra wheat than to run the risk of famine

For purposes of this analysis an average stored inventory, exclusive of pipeline supplies, of 700 million bushels will be assumed for the next 20 years This amount is less than the actual inventories experienced in eleven of the last fifteen years The total annual cost of the current wheat storage program is composed of two major components, annual operating costs and opportunity costs During FY 68 the average cost for storage and handling of a bushel of wheat in the government reserves was 12 6 cents, the average cost for transporting that bushel was 8 8 cents and the average investment cost of that bushel of wheat was $1 52 Thus, assuming constant FY 68 rates, the annual operating cost of a 700 million bushel storage program is ($12 6 + $8 8) x 700,000,000 or $149 8 million If an opportunity cost rate of 7 5% is used the opportunity cost of the 700 million bushel storage program is $1 52 x 700,000,000 x 075 or $79 8 million The sum of the two major elements results in a total annual cost for storing 700 million bushels of $229 6 million in constant FY 68 dollars

III WHEAT RUST NON-INFORMATION ALTERNATIVE COSTS

Current U S policy for control of wheat rust is centered on the development of varieties of wheat which are resistant to identified strains of infectious wheat rust Generally, there is a time lag of from 8 to 15 years between the initial identification of a potentially dangerous wheat rust strain and the availability of commercial quantities of a new wheat variety which is resistant to that strain Thus, it is expremely important that new dangerous wheat rust strains be identified as early as possible so that new varieties of wheat can be made commercially available before any individual strain of rust can become widespread

Currently, the Cereal Crops Research Branch, Agricultural Research Service, of the U S Department of Agriculture conducts a continuous survey of wheat rust which annually identifies as many as 300 new strains of rust The Research Branch annually publishes pathogenicity reports describing each of these new strains, and of the hundreds considered, usually five to ten are deemed potentially very dangerous These strains are usually identified early enough so that the lead time before they become widespread is at least equal to the new variety development cycle After identification and selection, a breeding program is then initiated to develop a variety of wheat resistant to each of the selected strains of dangerous rust The breeding program is a joint venture among the Cereal Crops Research Branch, various State agricultural research stations and commercial seed companies, and the cost of research is borne approximately equally by the three groups It is estimated that each spends about $1 5 million, so that the current wheat research program in the United States costs about $5 million in current FY 68 dollars

There are many cases where a developed variety of wheat never is used on a commercial basis because the strain of rust for which it was developed never spreads or becomes a problem Conversely, there are some instances where particular rust strains deemed not dangerous do spread and become important, or selected strains spread faster than resistant varieties of wheat become available In these instances, if losses are projected at a level of at least two bushels an acre, the wheat farmer should spray his fields with a chemical spray An alternative to this, however, is to increase the level of wheat research and to breed more new varieties of resistant wheat It is felt that for twice the total effort, or about $10 million annually, wheat losses due to rust could be diminished by about 50 percent

In every case where a new, resistant variety of wheat is made commercially available the yield and quality are at least as good as the old variety it is to replace New varieties are, in fact, constantly improving in yield due to this stipulation and often a new variety is useful over a wider geographic region Thus, a new resistant variety developed for North Dakota might later be planted widely in Washington because of either resistance or some other characteristic

It is estimated that of the total worldwide wheat research about 25 percent currently is conducted in the United States In addition to that actually done in the U S , a substantial amount of the other Free World research is paid for by U S funds Much of the wheat research conducted in Latin American countries, for instance, is supported by Rockefeller and Ford Foundation grants The U S Department of Agriculture, Foreign Agricultural Service, also supports research in many countries Many varieties of wheat developed in the U S prove to be valuable to agriculture in foreign countries

In addition to developing varieties of wheat resistant to wheat rust, some research work is being done on seed treatment to the end that any wheat seed can be made resistant to all, or at least many, strains of wheat rust This technique offers the next potential breakthrough in wheat rust resistance if it can be developed so that treatment of all seed becomes commercially feasible This research is being accomplished within the programs described earlier

APPENDIX G

USER SENSOR MODEL--AGRICULTURE

I SUMMARY OF TECHNIQUES FOR DATA COLLECTION (WHEAT YIELD AND WHEAT RUST)

Exhibit G-1 is a summary of techniques for data collection in the wheat yield and wheat rust cases Information requirements are listed, together with the observed and inferred measurements necessary to produce individual informational factors

EXHIBIT G-1 SUMMARY OF TECHNIQUES FOR DATA COLLECTION (WHEAT YIELD AND WHEAT RUST)

Required Information	Inferred Quantities	Observed Quantities	Sensor Problems	Interpretation Problems
Daily temperature	Foliage temperature	See "Plant temperature"	---	---
	Ground temperature	Thermal IR scanner imagery, microwave brightness temp	Resolution	Separation of individual effects
Rainfall	Surface water	Water surfaces in visible, IR, or radar imagery	Resolution	---
	Soil moisture	See "Free moisture"	---	---
	Intensity & distribution of rainfall	Non-coherent radar signal strength and range	Resolution, ground clutter, calibration	Intermittent coverage
	Distribution of rainfall	Microwave brightness temp	Resolution	Temp discrimination of rain from underlying terrain
Free moisture (soil moisture)	Surface water	Water surfaces in vivible, IR, or radar imagery	Resolution	---
	Vegetation lushness	TV or MS imagery	---	Limited correlation, delay in color effect
	Soil reflectivity	TV or MS imagery	---	Soil variability, vegetation cover
	Diurnal temp variations	Thermal IR scanner imagery	---	Emissivity variations, solar heating, vegetation cover
	Water content	Microwave brightness temp	Resolution	Separation of individual effects
Plant temperature	Foliage temperature	Thermal IR scanner imagery,	Calibration	Emissivity variations, solar heating, atmospheric effects
		microwave brightness temp	Resolution, calibration	Solar heating
Respiration	---	---	---	---
Evapotranspiration	Air temperature	See "Plant temperature"		
	Ground temperature Soil moisture	See quantities listed		
	Cloud cover	Visible, near IR and thermal IR		Distinguishing clouds from snow
Acres of wheat (or host distribution	Crop identification	See "Crop identification or vigor"		
	Acreage measurement		Resolution, scanning, precision	
Crop identification or vigor	Same	Spectral response in visible and IR,	Lack of automatic processing (for TV)	Spectral variability
		Radar cross-section of vegetation	Limited area coverage, size, weight, power requirements	Weak relationship of crop type to requirements
Wind (direction and velocity)		Cross-beam correlation from two locations		

NOTE Problems underlined are considered most limiting ones Other problems listed may require substantial R&D for satisfactory solution

FOLDOUT FRAME

FOLDOUT FRAME 2

II INTERPRETATION OF AGRICULTURAL DATA

The problem is to determine the feasibility of detecting and identifying wheat fields from aircraft and/or spacecraft using a multispectral scanner To establish feasibility, seven stages in the growth of winter wheat, in Northern Indiana were examined Pattern recognition techniques and the associated computer software, previously developed, were used These computer programs require that particular wavelengths or spectral bands be chosen and specified a priori A choice was made to conform to an existing twelve channel, multispectral scanner The advantage of this choice is that it permits comparison of calculated results with those actually measured Another constraint introduced by the analysis techniques is the requirement that all spectral reflectance data for a particular sample must be available over all channels considered Unfortunately, the bulk of available data on wheat only covered the region 0 48μm to 1 00μm Therefore not all the available channels could be used Presented in Exhibit G-2 are those nine channels, and their spectral boundaries, which could be used Numbering of the channels was based on their spectral location and no other reason

Because the only data available were in the form of directional reflectance, it was necessary to assume that all materials were perfectly diffuse reflectors Another assumption was that either the same irradiance is incident on both the target and background or the irradiance on each is known Two sets of calculations were made For one set it was assumed that either the transmission from reflector to detection system is the same for both target and background or the transmission is known for each With the second set it was assumed that the transmission is a statistically variable quantity for which the means and covariances among the different channels is known

EXHIBIT G-2 SPECTRAL CHANNELS CONSIDERED IN ANALYSIS

Channel Number	Spectral Limits of Channel Bands (μm)
1	0 48-0 50
2	0 50-0 52
3	0 52-0 55
4	0 55-0 58
5	0 58-0 62
6	0 62-0 66
7	0 66-0 72
8	0 72-0 80
9	0 80-1 00

A Choice of Optimum Channels - Wheat Yield

When the transmission is not treated statistically, the radiance statistics are determined solely by the reflectance statistics Therefore the choice of optimum channels and their probabilities of error are independent of the sky condition (irradiance) and atmospheric conditions (transmission) Exhibit G-3 gives the results of such calculations for seven growth stages of wheat field For each stage, probabilities of detection and false alarms resulting from using the indicated best channel, three best channels, and all nine channels are shown Here the "wheat field" is assumed to occupy one resolution element When a wheat field is larger than one resolution element, one must decide how many resolution elements need be identified as part of a wheat field and whether all, or some, must be contiguous before it can be said that the field has been detected On the other hand, if the interest is in detecting wheat-field acreage, then the results in Exhibit G-3 accurately represent the probabilities of detecting wheat-field acreage in units of a resolution element

Exhibit G-3 clearly indicates that in every case significant improvements are obtainable by using multispectral techniques, and the greatest improvement is obtained in going from one to three channels as compared with going from three to nine channels However, since different channels are optimum for the different stages, all the channels may need to be flown in order that the three or more optimum channels will be available for each stage

Some discussion concerning the results for stages one and two is needed to prevent misinterpretation The first stage was specified to be a freshly plowed field Since no data were available on such a field, wet soil was chosen as a substitute for freshly turned earth It was to be detected against a Northern Indiana background in early September, with the restriction that (except for the plowed fields) the soil was not wet As a substitute for a planted field (the second stage) we used dry soil The background was the same geographical region as previously, but in October Implicitly, then, it was assumed that any

EXHIBIT G-3 DISCRIMINATION BASED ONLY ON REFLECTANCE STATISTICS

Growth Stage	Target	Best Channels	Prob of Detection Percent	Prob of False Alarms Percent
1 (Sept)	Plowed	9	96 86	8 34
	(wet soil)	7, 8, 9	99 66	0 88
		All	99 96	0 10
2 (Oct)	Planted	9	81 45	25 69
	(dry soil)	5, 7, 8	98 10	4 75
		All	99 18	1 12
3. (Oct /Nov)	Seedling	8	79 33	55 19
	(wheat= 35)	6, 7, 8	99 33	1 26
	(dry soil= 65)	All	99 59	0 77
4 (March/April)	Seedling	9	89 36	37 96
	(wheat= 35)	6, 7, 8	98 48	4 71
	(dry soil= 65)	All	99.50	1 13
5 (May)	Mature	9	93 65	20 58
	(wheat= 80)	6, 7, 8	99 94	0.13
	(dry soil= 20)	All	99 98	0 05
6 (June/July)	Ripe	1	65 84	9 80
	(wheat= 80)	1, 2, 3	93 25	1.66
	(dry soil= 20)	All	97 34	1 24
7 (July)	Stubble	1	62 54	10 89
	(wheat= 40)	1, 2, 9	91 05	3 16
	(dry soil= 60)	All	97 05	1.87

fields composed entirely of soil (wet in September, and dry in October) are "wheat fields" in one of two stages of growth

1 Effect of Altitutde on Channel Choice

To determine how altitude may affect the choice of spectral channels and the probabilities of error, it is necessary to have information about (1) the average value of the transmission at a given altitude and how it can vary from point to point along the flight path at that altitude, and (2) how these transmission statistics change with altitude

a Relationship of Atmosphere to Transmission

The sky model was used to determine the transmission statistics While this model takes account of both scattering and molecular absorption by water vapor, only the absorption is treated statistically It uses as inputs the measured values (at ground level) of relative humidity and temperature corresponding to the chosen sky conditions Such data, obtained daily and hourly, are available from the Weather Bureau It was hypothesized that these hourly and daily values will give the same statistics as if the values were taken along the flight path and at different altitudes Exhibit G-4 gives the relative humidity and temperature (at ground level) at Fort Wayne, Indiana for the beginning of May (stage 5), and for the end of June and the beginning of July (stage 6), under less than one-tenth cloud cover

Exhibit G-5 presents the probabilities of detection and false alarms at altitudes of zero, one, and three kilometers, and of space (greater than ten kilometers), using the statistical data in Exhibit G-4 These calculations were done for two stages of wheat-field growth using the best channel, the three best channels, and all nine channels The previous arguments concerning the size of a wheat field and wheat acreage apply here also Examination of the results clearly indicates that altitude is not important in detecting the fifth and sixth stages of a wheat field

In Stage 5, it may seen surprising that at zero altitude channel number nine is the best, and one of the three best channels for discrimination, while at the other altitudes it is replaced by channel number eight

EXHIBIT G-4 MEASURED VALUES OF RELATIVE HUMIDITY AND TEMPERATURE AT FORT WAYNE, INDIANA

(Cloud Cover 0 10 and Time 1100-1300)

Date	Relative Humidity %	Temperature °C	Date	Relative Humidity %	Temperature °C
May 1966			May 1959		
3	45	11 1	2	51	26 66
4	38	10 55		42	29 99
6	28	18 3	May 1958		
11	44	7 2	7	29	14 99
May 1964				28	15 55
2	68	18 3		27	16 66
	63	20.55	May 1957		
	59	21 66	5	22	13 88
3	63	19 99		18	15 55
	59	21 66		20	16 1
	54	23 3	6	25	18 3
May 1963				28	19 4
2	.34	14.4		24	19 99
	56	18 88	7	34	22 77
May 1961				28	22.77
4	47	13 88		24	23 3
10	51	12 2			
	55	12 77			
	55	13 3			
May 1960					
2	43	16 1			
	.40	16 66			
	37	18 3			

EXHIBIT G-4 (Continued)

Date	Relative Humidity %	Temperature °C	Date	Relative Humidity %	Temperature °C
July 1966			June 1962		
1	30	29 4	26	60	25 55
3	36	33 3		54	26 66
June 1964			27	41	26 1
26	57	28 3		37	27 2
	53	29 4		33	28 3
	50	29 99	28	49	28 88
27	57	29 99	June 1961		
	57	30 55	28	44	28 3
	55	31 66		39	29 4
28	44	28 3	July 1961		
	41	29 4	3	32	24 4
	42	30 55	June 1960		
29	40	30 55	26	39	24 99
	41	31 66		34	25 55
	39	32 2		30	26 66
July 1964			July 1957		
2	65	27 77	2	48	25 55
4	46	22 2		45	26 1
	43	23 3		43	27 2
June 1963					
30	60	29 4			
	59	30 55			
July 1963					
1	53	31 66			
2	55	32 2			

EXHIBIT G-5 A DISCRIMINATION USING STATISTICS FOR RELATIVE HUMIDITY AND TEMPERATURE

(Cloud Cover = 0)

Altitude Stage 5	Best Channels Mature Wheat	Probability of Detection %	Probability of False Alarm %
0 km	9	93 65	20 58
1 km	8	93.14	22 05
3 km	8	93 08	22 13
space	8	92 94	22 3
0 km	6, 7, 9	99 94	0 13
1 km	6, 7, 8	99 92	0 14
3 km	6, 7, 8	99 92	0 14
space	6, 7, 8	99 91	0 15
0 km	All	99 98	0 05
1 km	All	99 97	0 06
3 km	All	99 97	0 07
space	All	99 97	0 07

EXHIBIT G-5 (Continued)

Altitude Stage 6	Best Channels Ripe Wheat	Probability of Detection %	Probability of False Alarm %
0 km	1	65 84	9 80
1 km	1	65 82	9 80
3 km	1	65 80	9 81
space	1	65 72	9 84
0 km	1, 2, 3	93 25	1 66
1 km	1, 2, 3	93 24	1 67
3 km	1, 2, 3	93 23	1 67
space	1, 2, 3	93 20	1 68
0 km	All	97 34	1 24
1 km	All	97 08	1 29
3 km	All	97 97	1 31
space	All	97 82	1 32

There is a plausible explanation Discrimination for this stage is based on a strong correlation among the channels of longer wavelength But the channel of longest wavelength (number nine) contains the edge of an absorption band of atmospheric water vapor Therefore the statistical variations of the relative humidity reduce the correlation between this channel and the others Channel number eight is far enough from the absorption band not to be affected, thus it replaces number nine This conclusion, as well as some of the other previous ones, depends upon the particular choice of spectral banks Different conclusions might be reached using the results obtained from other bands Most importantly, the degrading effect of noise in the detection and false alarms has not been considered in the calcualtions of the probabilities of errors The effect can be accounted for if the value of the noise is known

b Radiance Values Versus Altitude

But probabilities are not the whole story in designing a system The radiance incident on the detector must exceed its threshold value By having available the value of the radiances expected at the detection system, the effectiveness of the system can be evaluated The results of this evaluation are shown in Exhibit G-6 The average radiance in each band reflected from the target and background for stages five and six is presented in Exhibit G-6 under the heading of altitude, h, equal zero Also shown are the average radiances at altitudes of 1, 3 and 10 kilometers These latter values show the effect of transmission, where the data in Exhibit G-4 were used to calculate the average transmission

B Choice of Optimum Channels - Wheat Rust Detection

Calculations were also performed to find the best channels, and their corresponding probabilities of errors, for the discrimination between rusty wheat and healthy, ripe wheat These results are given in Exhibit G-7 Here, also, only the reflectance statistics were used The target was rusty wheat and the background, healthy wheat Note that, in both cases, the field (i e , including soil) was not used, only the plants themselves

EXHIBIT G-6 AVERAGE RADIANCES FROM TARGET AND BACKGROUND

(Zero Cloud Cover - 12 Noon - Observed at Various Altitudes)

Stage 5

Channel Number	Altitude = 0 Target Radiance (W/M^2/-sterad)	Altitude = 0 Background Radiance (W/M^2/-sterad)	Altitude = 1 kilometer Target Radiance (W/M^2/-sterad)	Altitude = 1 kilometer Background Radiance (W/M^2/-sterad)
1	1 388	8428	1 100	6681
2	1 529	9205	1 228	7395
3	2 871	1 675	2 339	1 365
4	2 878	1 773	2 379	1 465
5	3 359	2 359	2 814	1 976
6	3 014	2 342	2 547	1 979
7	4 141	3 983	3 535	3 400
8	12 992	7 776	11 347	6 792
9	25 713	15 788	18 336	11 259

Channel Number	Altitude = 3 kilometers Target Radiance	Altitude = 3 kilometers Background Radiance	Altitude = 10 kilometers Target Radiance	Altitude = 10 kilometers Background Radiance
1	9335	5667	8070	4900
2	1 054	6343	9236	5596
3	2 030	1 185	1 804	1 053
4	2 088	1 286	1 882	1 159
5	2 497	1 753	2 278	1 600
6	2 276	1 768	2 090	1 624
7	3 183	3 062	2 945	2 833
8	10 389	6 218	9 805	5 869
9	14 407	8 846	10 748	6 599

EXHIBIT G-6 (Continued)

Stage 6

Channel Number	Altitude = 0: Target Radiance (W/M²/-sterad)	Altitude = 0: Background Radiance (W/M²/-sterad)	Altitude = 1 kilometer: Target Radiance (W/M²-sterad)	Altitude = 1 kilometer: Background Radiance (W/M²/-sterad)
1	2 193	9572	1 668	7281
2	2 290	1 042	1 771	8057
3	3 513	1 876	2 766	1 477
4	3 483	1 959	2 792	1 571
5	4 606	2 633	3 754	2 146
6	4 573	2 638	3 764	2 171
7	6 993	4 527	5 823	3 769
8	8 725	8 039	7 488	6 899
9	18 063	16 469	11 489	10 590

Channel Number	Altitude = 3 kilometers: Target Radiance	Altitude = 3 kilometers: Background Radiance	Altitude = 10 kilometers: Target Radiance	Altitude = 10 kilometers: Background Radiance
1	1 373	5991	1 133	4946
2	1 478	.6722	1 243	5652
3	2 342	1.251	2 007	1 072
4	2 398	1 349	2 093	1 178
5	3 267	1 868	2 898	1 657
6	3 301	1 904	2 951	1 702
7	5.154	3 336	4 651	3 011
8	6 773	6 240	6 285	5 791
9	8 164	7 525	5 146	4 744

EXHIBIT G-7 DETECTION OF RUST WHEAT AGAINST A RIPE WHEAT BACKGROUND

Best Channels	Probability of Detection (%)	Probability of False Alarms (%)
2	77 40	57 51
1, 2, 5	85 24	11 88
All	93 85	5 66

1 Comparison of Analysis Data and Observed Data

As a check on our modeling techniques, a comparison was made between the radiance values calculated from the models and some calibrated data taken from an aircraft The comparison is illustrated in Exhibit G-8, where the radiance in each channel is presented for the analysis and aircraft data The important point is the similarity in "spectral shape," i e , the relationship among the radiances in each channel Apparently the same relationship applies to both sets of data There is a marked difference between analysis and aircraft data in that the aircraft data has consistently smaller radiances A reasonable explanation for this difference may be found in the fact that although the aircraft data were collected under conditions of little cloud cover, there was a condition of hazy skies Haze would tend to decrease not only the irradiance from the sun but also the radiance reflected upwards from the ground The modeling techniques, therefore, appear to be satisfactory for this problem

Observational Conditions	
Sun angle (from zenith)	40°
Detector's view angle (from zenith)	0°
Altitude of detector	0 3 km
Time of year	June/July
Cloud cover	0
Target	Ripe wheat

Channel Number	Bandwidth (pm)
1	0.48 - 50
2	0 50 - 52
3	0 52 - 55
4	0 55 - .58
5	0 58 - 62
6	0 62 - 66
7	0 66 - 72
8	0 72 - 80
9	0.80 - 1 0

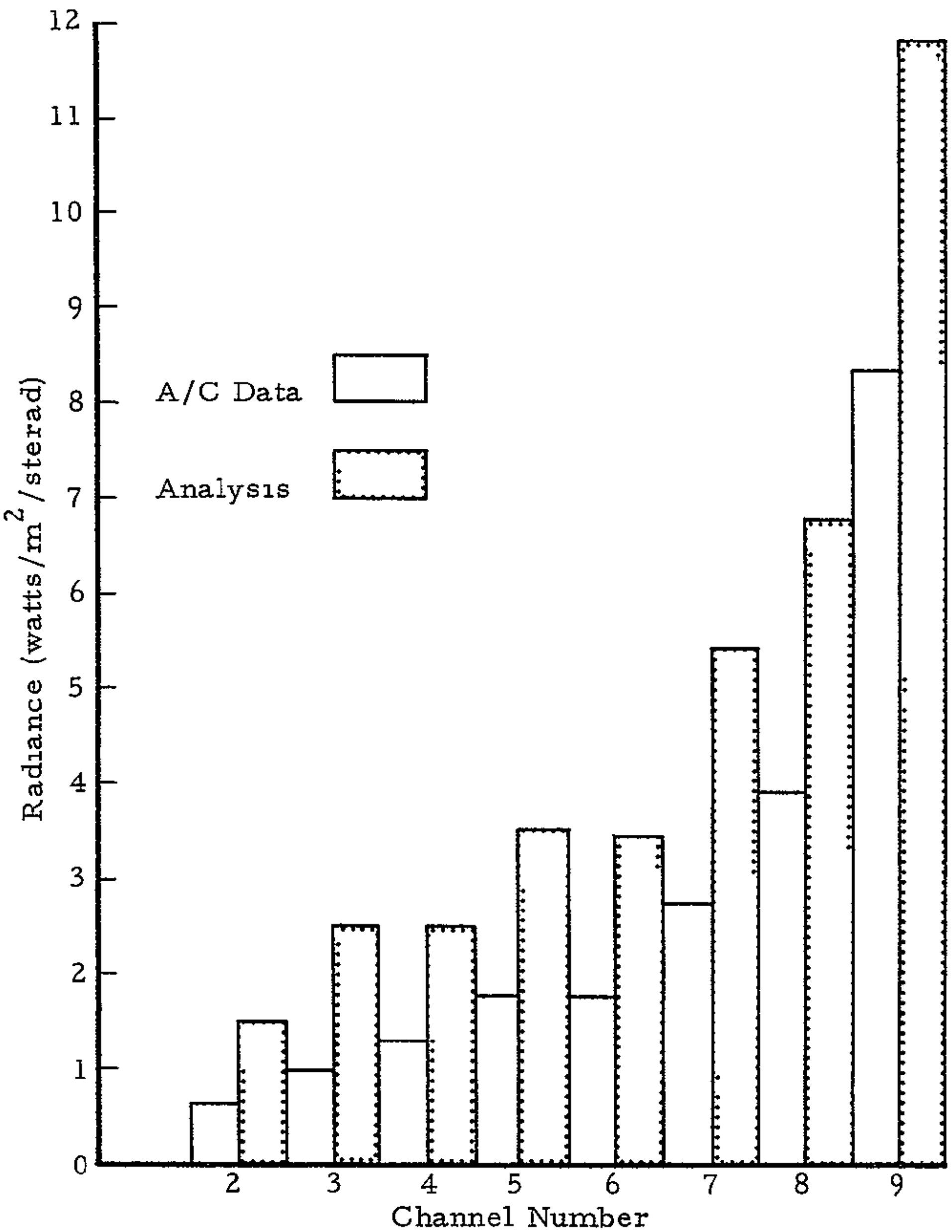


EXHIBIT G-8 COMPARISON OF LABORATORY AND AIRCRAFT DATA

APPENDIX H

WHEAT PRODUCTION MANAGEMENT

I USER DECISION MODEL

The user decision model is based on the development of a satellite-assisted information system which will improve the accuracy of world wheat production estimates

The accuracy of world wheat harvest estimates presented in Appendix Exhibit H-1 and domestic harvest estimates presented in Appendix Exhibit H-2 are based on harvest statistics published by USDA and analytical assumption concerning the variation of established accuracies with time

World production statistics indicate an annual world wheat production trend line which increases approximately two percent per year [1] This trend line represents the mean annual production rate which experiences an average fluctuation of ± 8 percent per year Based on these statistics, it was assumed that, on the average, the maximum forecast error was 16% (i e , a high production year 8 percent above trend projection followed by a low production year 8 percent below trend projection), and would represent the accuracy of the harvest forecast at planting before actual growth environment for that year is experienced by the planted wheat crops

Similarly, USDA Agricultural Statistics[2] published 16 months after harvest are designated as "preliminary" and are approximately within 4 percent of subsequently established production levels

It was assumed that one-fourth of the improvement in forecast accuracy (from ± 16 percent at 14 months before harvest to 4 ± percent at 16 months after harvest) occurs during the growing season based on observed and reported environmental conditions, and three-fourths occurs as actual foreign production reports of data are received after harvest This assumption establishes the current ± 13 percent accuracy as of September 1 as shown in Exhibit H-1

---

[1] United Nations, Food and Agriculture Organization, World Crop Statistics 1968, (and preceding issues)

[2] U S., Department of Agriculture, Agricultural Statistics 1968, (and preceding issues)

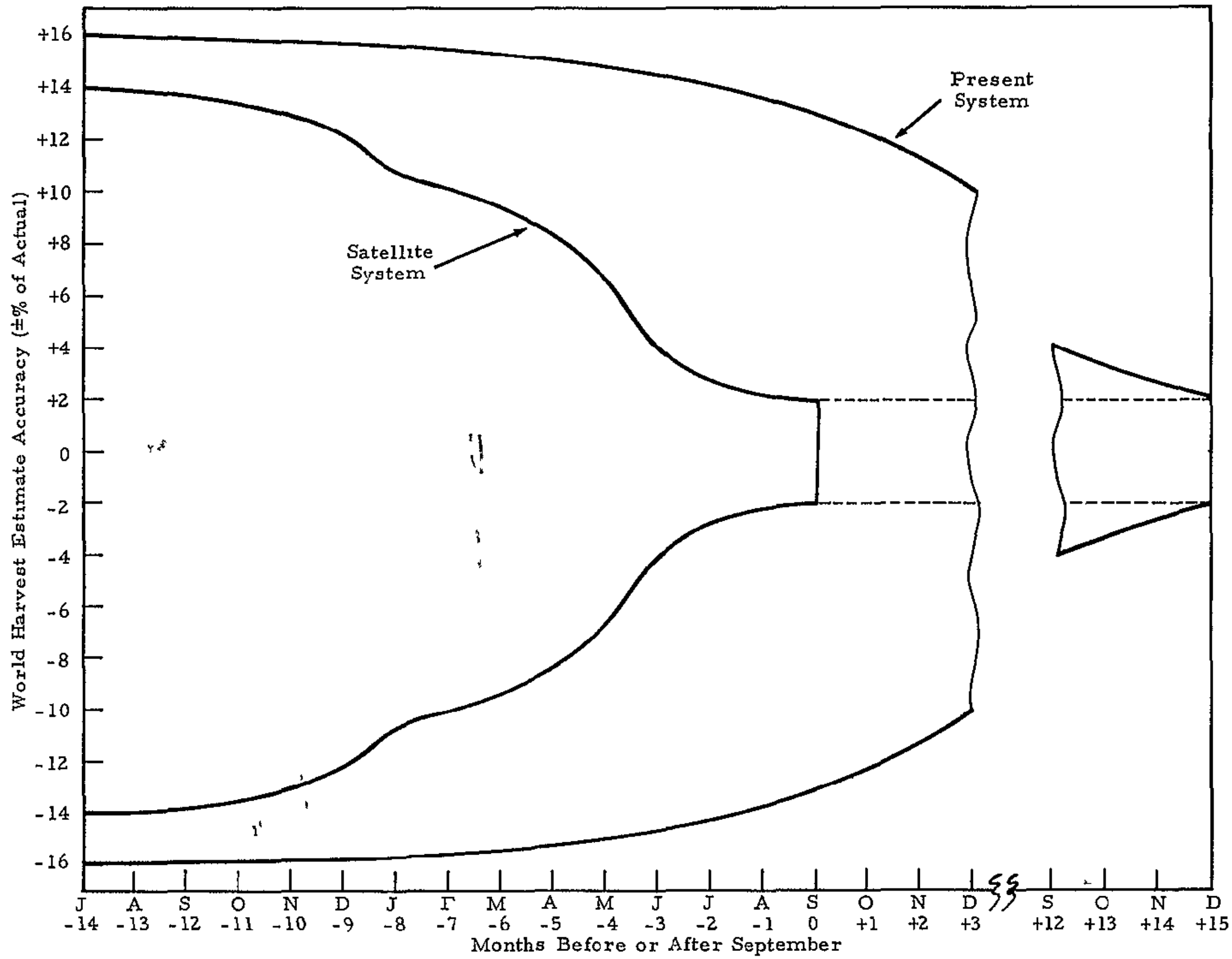


EXHIBIT H-1 POTENTIAL IMPROVEMENT IN WORLD WHEAT HARVEST ESTIMATES

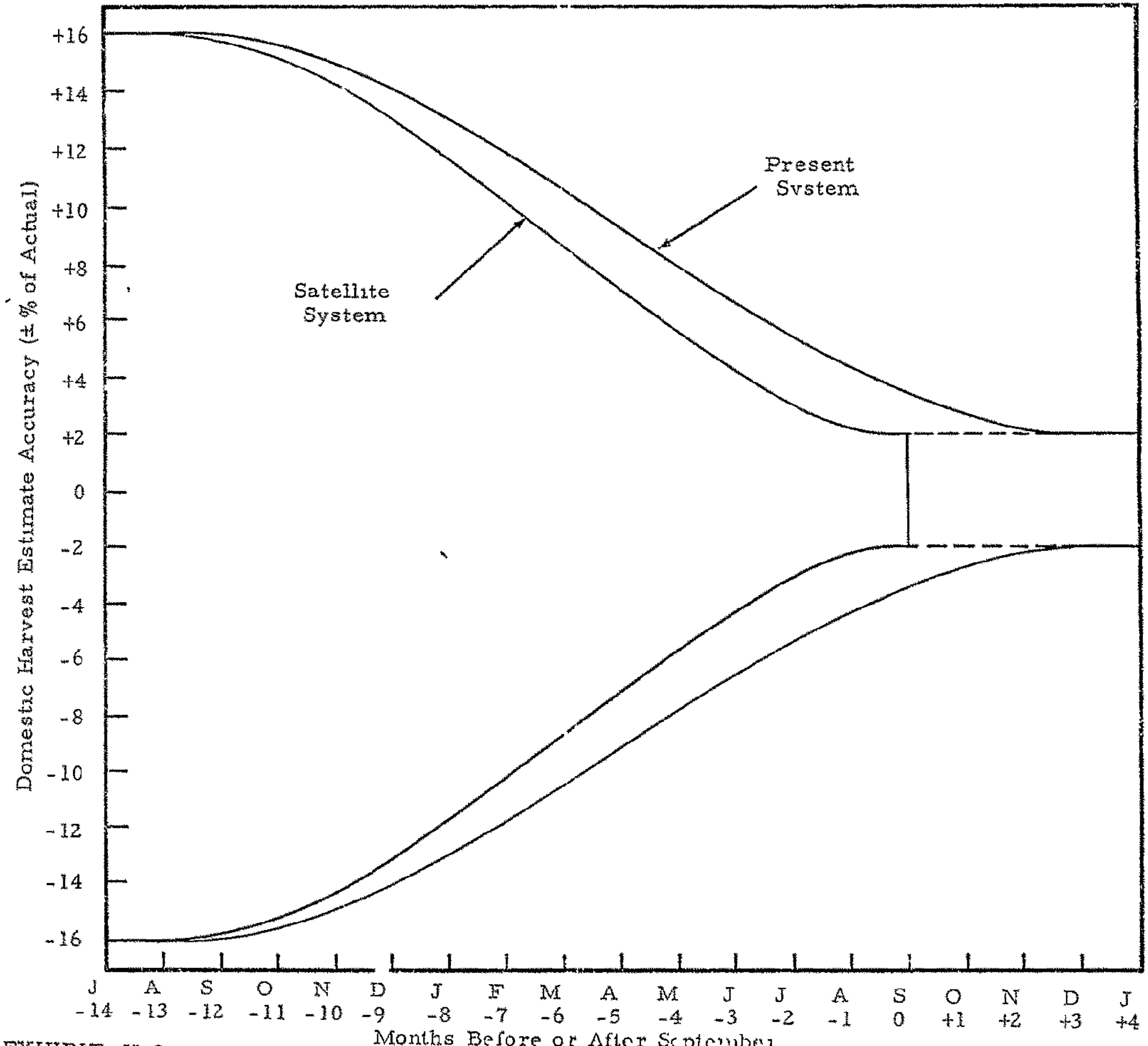


EXHIBIT H-2 POTENTIAL IMPROVEMENT IN DOMESTIC WHEAT HARVEST ESTIMATES

The accuracy of the present system in providing estimates of anticipated domestic harvests is based on a study conducted by the Kansas Agricultural Experiment Station[1] on the historical accuracy of winter wheat production estimates issued by the Crop Reporting Board Data covered the period from 1920 to 1957 and included for each year the estimates issued on the 1st of the month from April through August The earliest estimates in this data were those issued April 1 which had an average indicated accuracy of ± 15 percent An attempt to extrapolate backwards to earlier months indicated inaccuracies greatly exceeding ± 15 percent It seemed unrealistic for domestic harvest estimates to be more inaccurate than those for foreign crops and thus the cone presented in Exhibit H-2 flattens out at the ± 16 percent level

Harvest forecast accuracies anticipated with the satellite system are derived from the responsiveness of this system compared to present information networks providing quantitative measures of foreign wheat crop conditions and harvest results The satellite system will virtually eliminate the current disparity between domestic and foreign wheat production estimates by providing timely information concerning the quality and quantity of wheat being produced throughout the world at a level of accuracy comparable to the current USDA crop monitoring capabilities

Thus, for estimates of world harvests with the satellite system, it is expected that an accuracy of ± 2 percent at harvest (i e , September 1) can be achieved equal to the present accuracy of domestic harvest estimates at that date Similarly, it is expected that the accuracy of world harvest estimates at winter wheat planting will be reduced from ± 16 percent to ± 14 percent primarily from observation of soil moisture at planting and the actual number of acres planted The dip in the world cone (Exhibit H-1) in the November to January period represents the effects of verified estimates of Southern hemisphere harvests The

---

[1] Leonard W Schruben, "Changes in Winter Wheat Crop Prospects in the United States During a Growing Season as Measured by Official Production Estimates " Agricultural Experiment Station, Kansas State College, Manhattan Technical Bulletin 95, July 1958.

remainder of the accuracy improvement results from actual monitoring of climatic and crop conditions with the largest improvement achieved in late spring in the April 1 to June 1 period

The domestic harvest estimates with the satellite system are essentially at the same accuracy levels as those for foreign crops except in the immediate pre-harvest months when the domestic harvest estimates are slightly more accurate than world harvest estimates The rationale behind this difference is that in the United States ground truth data for correlating satellite data will be more readily available than similar foreign ground truth data

II A NOTE ON SUBSTITUTION IN WHEAT PRODUCTION AND CONSUMPTION

In estimating some benefits of gathering wheat inventory data via satellite, it is necessary to make reliable assumptions about the substitution of other commodities, both in production and consumption, for shifts in wheat production The purpose of this note is not to make the assumptions but to report the results of extensive literature searching and computations made in order to estimate the magnitude of these substitutions

A Kinds of Substitution Effects

There are basically two kinds of substitution effects that are important production and consumption The production effects estimate the changes in acreage of other crops that occur with shifts (up or down) in wheat acreage The consumption effects reflect two things (1) the impact of income changes on demand for wheat, and (2) the relationship of domestic wheat production (yield x area) and imports of wheat and other food grains

B Countries Analyzed

Visual observation of charted data on log paper did not reveal meaningful changes, particularly in traditional aggregations such as continents Therefore, it was necessary to select a representative group of countries for more thorough numerical analysis The following group of countries was selected because they account for most of the world trade in wheat The six exporters are the principal ones historically appearing in the export columns The 17 importing countries account for nearly 70 percent of the world wheat imports

Exporters	Developed Country Importers	UDC Importers (Traditionally Wheat Consumers)	UDC Importers (Traditionally Rice Consumers)
United States	Belgium - Lux	Algeria	Brazil
Canada	Japan	Morocco	China (Mainland)
Australia	Netherlands	Spain	India
Argentina	Poland	Turkey	Pakistan
France	Soviet Union	U A R	
Italy	United Kingdom		
	W Germany		
	Yugoslavia		

Among the importing countries, in most years, the 10 largest importers accounted for about 60 percent of the world wheat trade Doubling the number of countries would only increase the percent of world wheat trade explained by about 10 percent Therefore, it is reasonable to assume that using this group of countries in a detailed analysis would produce information from which generalizations could be drawn that would reflect the majority of the wheat trade

C Production Response

If farmers make major shifts to other commodities to substitute for wheat in their production cycle, the shift may be reflected in the number of acres seeded to selected commodities. This relationship may be tested by the use of regression analysis

1 Hypothesis If farmers increase area planted to other crops and reduce the area planted to wheat, other crops can be said to substitute for wheat This would be indicated by a negatively sloping regression line A close correlation would indicate a high association

2 Methodology Data on production area were taken from the FAO publications Production Yearbook[1] for the years 1952-1966, the time period for which most complete data were available Production data are reported on a calendar year basis, and the comparisons of wheat area with other crop areas were made on this basis In several

[1] United Nations, Food and Agriculture Organization, World Crop Statistics Area, Production and Yield 1948-64, (Rome, 1966) and Ibid , Production Yearbook, (Rome, annual).

countries where there were inadequate data on certain commodities, the crop was dropped from analysis for that country The regressions were completed using a MULREG program of the GE Time Sharing service

3 <u>Results</u> The results of a series of correlations testing this hypothesis are shown in Exhibit H-3 The Y values were the area seeded to wheat in each country The X_1 values were area seeded to rice, X_2 values were area seeded to corn (maize), X_3 values were area seeded to sorghum and millet, and X_4 values were area seeded to all other grains The b values shown in each of the columns are the coefficients which reflect the amount of change in that variable which is simultaneous with a 1 unit change in wheat area The percentages shown in parenthesis after each b value are the percent of time that the b value can be interpreted as being significantly different from zero The t test was used in making the analysis The R^2 value (Index of Determination) reflects the amount of variation in wheat area explained by the X variables The R^2 values found to be significant using the F test were indicated with an asterisk A significant value indicates that the null hypothesis is rejected and that there is in fact a correlation other than zero

Two caveats on interpretation of the data should be sounded First, the data, particularly from underdeveloped countries may or may not be reliable Most data were obtained from FAO publications, principally from one, but supplementing from other sources in order to fill gaps Secondly, the degree of cause-effect relationship can not be inferred from correlation data That is, there may not be a direct substitution effect even though the direction of the regression line may indicate it

The relationships are expressed in the table and will not be repeated here To illustrate use of the table, however, the data for the United States will be explained A one percent increase in wheat area is correlated with a three percent decrease in rice area This relationship may be questionable because the predominant wheat areas and rice areas do not overlap, making it unlikely that there would be much shifting from one commodity to another The corn area variable of + 0 9 is

EXHIBIT H-3 REGRESSION COEFFICIENTS RELATING DOMESTIC WHEAT AREA TO AREA PLANTED TO OTHER SELECTED COMMODITIES

Country	X_1 Rice Area b value	X_2 Corn Area b value	X_3 Sorghum and Millet Area b value	X_4 Other Grain Area b value	R^2
Principal Exporters					
United States	-3 1963 (50%) *	+0 9611 (100%)	-1 5358 (100%)	-0 0884 (30%)	86**
Canada	——	-6 1781 (70%)	——	-0 6276 (95%)	29
Australia	+41 8139 (30%)	+144 1320 (100%)	+0 2916 (20%)	-0 3532 (30%)	74
Argentina	-7 9597 (20%)	+0 4464 (60%)	-0 4761 (50%)	+0 8795 (98%)	43
France	+5 9194 (50%)	+0 1367 (30%)	-48 9457 (100%)	-1 3861 (100%)	95
Italy	-0 1656 (50%)	+2 9785 (99%)	——	-0 9420 (70%)	59
Principal Developed Country Wheat Importers					
Belg - Lux	——	——	——	-0 9857 ——	77
Japan	+0 1507 (40%)	-3 5322 (70%)	+2 4950 (95%)	-0 0033 (50%)	83**
Netherlands	——	——	——	-0 5751 ——	59
Poland	——	——	——	-0 1281 ——	33
United Kingdom	——	——	——	-0 0519 ——	007
Soviet Union	-9 2021 (60%)	-0 1959 (20%)	+1 5584 (80%)	-3 0946 (100%)	86**
W Germany	——	+15 1431 (80%)	——	+0 7918 (98%)	35
Yugoslavia	-3 8560 (10%)	+0 6545 (10%)	-17 2511 (95%)	-0 5736 (70%)	58**

EXHIBIT H-3 (Continued)

Country	X_1 Rice Area b value	X_2 Corn Area b value	X_3 Sorghum and Millet Area b value	X_4 Other Grain Area b value	R^2
Principal UDC Wheat Importers (Traditionally Wheat Consumers)					
Algeria	——	-122 9770 (90%)	+11 3384 (50%)	+0 9159 (90%)	34
Morocco	——	-2 5889 (80%)	-1 1580 (70%)	+0 3617 (90%)	34
Spain	+34 4781 (100%)	-3 0140 (80%)	+7 1765 (70%)	-0 4808 (60%)	58**
Turkey	-1 5373 (30%)	-2 6629 (70%)	-10 4065 (90%)	+2 5454 (100%)	98**
U A R	-0 2377 (70%)	+0 3973 (95%)	+1 3913 (95%)	-0 2672 (10%)	52
Principal UDC Wheat Importers (Traditionally Rice Consumers)					
Brazil	+0 3462 (80%)	-0 3925 (95%)	——	+24 8504 (100%)	85**
China (Mainland)	+0 6603 ——	——	——	——	69
India	+0 1235 (60%)	+3 2182 (100%)	-0 1621 (70%)	+2 4202 (95%)	86**
Pakistan	+0 0479 (20%)	+6 7956 (98%)	-0 7627 (90%)	-0 4957 (10%)	76**

*Number in parentheses is the percent of the time that the b value is significantly different from zero (t test)

**F ratio is significant, null hypothesis is rejected, i e , there is a correlation other than zero

——Insufficient data available for computation reasonable since it is also unlikely that there would be significant shifting from one commodity to another The sorghums and millets and other grains are competitive with wheat in the sense that they could be substituted for wheat in the production cycle Their b values of - 1 5 and - 0 9 are therefore reasonable The R^2 value of 86 is high and significant indicating that these four variables explain much of the variation in wheat area

D Consumption Response

(S) Consumers respond to wheat availability in relation to their income levels and the price of wheat The Food and Agriculture Organization of the United Nations has done pioneering work on income elasticity studies for the developing countries. Price elasticity data are notably absent, however. Therefore, it was also necessary to analyze the demand for wheat in terms of quantities and the disappearance of the other food grains in relationship to wheat by means of regression analysis

1 Income Elasticities The income elasticity coefficients are shown in Exhibit H-4 In general, most coefficients for wheat in the developed countries are negative and relatively inelastic This can be interpreted to mean that wheat is an inferior good in these countries and the consumption of wheat declines as income rises All under-developed countries, on the other hand, have positive income elasticities for wheat except for Spain, which is negative Generally, these countries have had sub-standard nutritional levels, and as the income levels rise, people tend both to purchase more food and improve their diets by switching to wheat.

Income elasticities for rice are positive in all countries except Japan, where there is evidence in the literature of a shift from rice to wheat products as a result of rising incomes In general, the coefficients tend to be quite inelastic in the developed countries and more elastic in the developing countries, reflecting again the dietary improvement associated with rising incomes

The income elasticities for coarse grains form a similar pattern to wheat with negative income elasticities for developed countries and

EXHIBIT H-4 INCOME ELASTICITY COEFFICIENTS, SELECTED COMMODITIES AND COUNTRIES, 1960-63 BASE PERIOD

Country	Wheat	Rice	Coarse Grains
Principal Wheat Exporters			
United States	-0 2	0.2	-0.3
Canada	-0.5	0.1	-0 3
Australia	-0.2	0 0	-0 3
Argentina	0.2	0.0	---
France	-0 3	0 2	0 0
Italy	-0.2	0.1	-0.9
Principal Developed Country Wheat Importers			
Belg - Lux.	-0.4	0.2	0.0
Japan	0 3	-0 1	-0 5
Netherlands	-0.3	0.2	-0 5
Poland	0.0	0 2	-0 4
United Kingdon	-0.5	0 4	-0.5
Soviet Union	-0 2	0 3	-0 3
W. Germany	-0.5	0 2	-0.6
Yugoslavia	-0.2	0.3	-0.3

Country	Wheat	Rice	Coarse Grains
Principal UDC Wheat Importers (Traditional Wheat Consumers)			
Algeria	0 2	0 4	0 2
Morocco	0 4	0 4	0.2
Spain	-0 2	0.0	0 0
Turkey	0 2	0 3	-0 1
U. A. R.	0 3	0.3	0 2
Principal UDC Wheat Importers (Traditional Rice Consumers)			
Brazil	0.4	0.3	0.2
China (Mainland)	0 5	0.4	0.2
India	0.6	0.5	0.2
Pakistan	0.5	0.4	0 2

Source Food and Agricultural Organization of the United Nations Agricultural Commodities--Projections for 1975 and 1985, Volume II, Methodological Notes, Statistical Appendix. Rome, Italy 1967 and positive elasticities for developing countries. The values are higher in the developed countries, reaching as high as - 0 9 in the United Kingdom, indicating a low preference for the commodities made with coarse grains Similarly, the developing countries indicate a low preference for coarse grains because, although the sign is positive, the value is low, ranging from 0 to + 0 2

2 Demand Elasticity The most authoritative means of measuring consumers' response to changes in wheat availability would be via price elasticity That would test consumer reaction to cereal food price changes resulting from crop failures or bumper crops The major weakness, however, is that price elasticity data do not exist for most wheat importing countries The alternative is to analyze the impact of domestic production on the imports of wheat and other commodities

a Hypothesis In a correlation analysis, if the imports of wheat and other commodities are inversely related to domestic wheat production fluctuations, they can be said to substitute for wheat

b Methodology Data for wheat production were obtained from the FAO, Production Yearbook[1] series and the data on wheat and other crop imports were taken from FAO, World Grain Trade Statistics[2] series. The production data are reported on a calendar year basis, but the import data are on a fiscal year (July 1-June 30) basis. In making the analysis, the production data for a calendar year (1955, for example) were related to the imports beginning on July 1 of the same year (1955/56) This measured a direct relationship between domestic production of a given year and imports until the subsequent harvest A constant to indicate stocks was not used because there are no sufficient data on a country basis to make accurate judgments on size of stocks, furthermore, most underdeveloped countries, in particular, do not have significant storage capacity to make such computations necessary The time period covered was 1952-1966 except in unusual cases where there were insufficient data to provide a time series that long for particular crops

[1] Ibid

[2] United Nations, Food and Agriculture Organization, World Grain Trade Statistics, (Rome, Annual)

and countries Some crops were omitted completely because there were either no data available or the amount of information was insufficient to establish a time series

c Results The results of these regressions are shown in Exhibit H-5 The responses are mixed with little overall generalization possible. Among the developed countries, there are negative b values for most countries for wheat and wheat flour imports, indicating that an increase in domestic wheat production is associated with a decrease in wheat and wheat flour imports The results range from very inelastic (Netherlands) to very elastic (Soviet Union)

Among the underdeveloped countries, this pattern of substitution is much less pronounced Among the wheat consuming underdeveloped nations, three countries showed negative relationships and two showed positive relationships for wheat and wheat flour imports. So few data for imports of other commodities were available, that it is equally impossible to say that other crops are substituted for wheat None of the R^2 values were significant in this group

Among the rice consuming underdeveloped countries, there is a more interesting pattern India and Pakistan, particularly known to be wheat importers on a major scale because of rapidly growing population and other conditions, both had positive b values for wheat imports but negative b values for rice imports It is possible to hypothesize that while there is a growing market for wheat in these countries, the domestic price relationships are such that they substitute wheat for rice rather frequently, and in major proportions

A similar multiple regression analysis was conducted for the two groups of underdeveloped countries using rice production as the Y variable and relating it to the imports of wheat, rice, corn, sorghum and millet, and other grains The wheat and wheat flour imports have positive relationships to rice production, which would indicate that imports do not substitute for domestic production Rice imports had negative signs, indicating that there is a substitution effect of imports for domestic production The b values were highly elastic, almost to the point of being

EXHIBIT H-5 REGRESSION COEFFICIENTS RELATING WHEAT PRODUCTION TO GRAIN IMPORTS

Y = wheat production (area x yield)

Country	X_1 Wheat and Wheat Flour Imports b value	X_2 Rice Imports b value	X_3 Corn Imports b value	X_4 Sorghum and Millet Imports b value	Other Grain Imports b value	R^2
Principal Developed Country Wheat Importers						
Belg - Lux	+0 0085(40%)*	-5 0715(40%)	-0 0696(40%)	+1 8240(70%)	+1 2504(60%)	23
Japan	-0 3534(95%)	+0 1847(70%)	+0 1768(60%)	-0 1900(50%)	-0 3399(80%)	70**
Netherlands	-0 1259(20%)	+0 8535(50%)	+0 1176(70%)	+0.1622(50%)	-0 1388(90%)	90**
Poland	+0 4583(95%)	+0 8684(20%)	+1 0248(95%)	—	-1 1788(90%)	77
Soviet Union	-1 9822(90%)	-4.2401(20%)	—	—	—	31
United Kingdom	-0 3470(60%)	+12 7210(70%)	-0 0210(60%)	-0 1936(10%)	-0 3147(50%)	62
W Germany	-0 4057(70%)	+18 3546(98%)	+0 2368(60%)	-4 3166(95%)	-0 0490(80%)	80**
Yugoslavia	-0 7460(60%)	+4 5748(20%)	-3 4341(50%)	—	+14 2773(60%)	23
Principal UDC Wheat Importers (Traditionally Wheat Consumers)						
Algeria	-0 7548(95%)	-2 5292(40%)	+62 4226(20%)	—	—	45
Morocco	-0 4356	—	—	—	—	08
Spain	-0 7810(50%)	—	+0 2781(40%)	—	-0 5099(30%)	30
Turkey	+0 1546	—	—	—	—	001
U A R	+0 0570(60%)	—	-0 1532(40%)	+1 9075(50%)	—	15

EXHIBIT H-5 (Continued)

Country	X_1 Wheat and Wheat Flour Imports b value	X_2 Rice Imports b value	X_3 Corn Imports b value	X_4 Sorghum and Millet Imports b value	X_5 Other Grain Imports b value	R^2
Principal UDC Wheat Importers (Traditionally Rice Consumers)						
Brazil	+0 1149(50%)	——	——	-0 3413(20%)	-10 3849(98%)	57**
China (Mainland)	-0 3851(50%)	-16 8061(30%)	——	——	——	08
India	+0 6857(100%)	-2,5130(80%)	——	——	——	55**
Pakistan	+0 1049(40%)	-2 3136(100%)	——	——	——	82**

*Number in parenthesis is percent of time, b value is significantly different from zero (t test)

**F ratio is significant, null hypothesis is rejected, i e , there is a correlation other than zero

——Insufficient data available for computation questionable in the cases of Mainland China, India, and Pakistan The b values and R^2 values are summarized in Exhibit H-6

E Summary

1 Production

a Only for the category "other grains" is there a possible clearcut generalization that other crops substitute for wheat in the production cycle

b All other commodities have to be examined on a commodity-by-commodity, country-by-country basis

2 Consumption·

a It seems fairly clear that when domestic wheat production declines, most countries tend to import wheat and wheat flour This relationship is not absolute, but 10 countries show the relationship while 7 countries do not

b There is also some evidence that imports of other grains are inversely related to domestic production of wheat

c Most developed countries have negative income elasticities for wheat, meaning that as incomes rise, wheat consumption declines

d Most underdeveloped countries have positive income elasticities for wheat, meaning that as incomes rise, wheat consumption rises also

EXHIBIT H-6 REGRESSION COEFFICIENTS RELATING RICE PRODUCTION TO IMPORTS OF SELECTED COMMODITIES

Y = rice production (area x yield)

Country	X_1 Wheat and Wheat Flour Imports b values	X_2 Rice Imports b values	X_3 Corn Imports b values	X_4 Sorghum And Millet Imports b values	X_5 Other Grain Imports b values	R^2
Principal UDC Wheat Importers (Traditionally Wheat Consumers)						
Algeria	+0 0023 (60%)	-0 1818 (40%)	-5 1215 (95%)	-	-	48
Morocco	+6 3908	-	-	-	-	16
Spain	+0 0060 (20%)		-0 0353 (90%)	-	+0 1048 (90%)	29
Turkey	+0 5543	-	-	-	-	005
U A R	+0 5968 (90%)	-	-0 9455 (50%)	+21 2293 (80%)	-	47
Principal UDC Wheat Importers (Traditionally Rice Consumers)						
Brazil	+1 1151 (80%)	-	-	+10 8231 (90%)	-33 2473 (90%)	72
China (Mainland)	-2.4741 (40%)	-146 6210 (30%)	-	-	-	08
India	+2 6729 (100%)	-15 9267 (90%)	-	-	-	53 *
Pakistan	+2 3300 (80%)	- 9 0366 (90%)	-	-	-	71 *

! Number in parentheses is percent of time b value is significantly different from zero (t test).
* F ratio is significant, null hypothesis is rejected, i e , there is a correlation other than zero
\- Insufficient data available for computation

III. OBSERVATIONAL REQUIREMENTS NECESSARY FOR DETECTING SEASONAL FACTORS WHICH AFFECT THE WHEAT INVENTORY AND WHEAT YIELD

The factors such as plowed land, plant density, temperature, plant color, and other items that must be observed in order to accurately estimate wheat inventory and wheat yield are summarized in Exhibit H-7

EXHIBIT H-7 OBSERVATIONAL REQUIREMENTS NECESSARY FOR DETECTING SEASONAL FACTORS WHICH AFFECT THE WHEAT INVENTORY AND WHEAT YIELD

Seasonal Factors	Months S O N D J F M A M J J A	Source: Direct Observation	Source: From Analysis	Plowed Land	Harrowed Land	Emergence: Location	Emergence: Area	Wheat Recognition	Plant Density	Snow Cover	Air Temp	Plant Temp	Plant Color	Freq Quantity	Soil Moisture	Wheat Harvested	Basis for Analysis
Fall																	
Plowing	X X	X		X										X			
Harrowing	X X	X			X									X			
Emergence	X	X				X	X				X	X	X		X		
Growth Stages	X X X X X X X	X						X	X		X	X	X	X	X		
Storm Damage	X X X X X X X	X							X		X	X	X	X			
Vigor & Vitality [1]	X X X X X X X	X	X						X		X	X	X		X	X	
Severe Cold [2]	X X X X	X	X								X						
Snow Protection	X X X X	X								X							
Winds (Damage) [3]	X X X		X						X			X	X				
Heaving (Freezing and Thawing) [4]	X X X X		X								X			X			
Spring																	
Replowing	X X	X		X										X			
Plowing	X X	X		X										X			
Harrowing	X X	X			X									X			
Emergence	X X	X				X	X				X	X	X		X		
Growth Stages	X X X X X	X						X	X		X	X	X	X	X		
Vigor & Vitality [5]	X X X	X	X						X		X	X	X		X	X	
Relative Soil Moisture [6]	X X X X X	X	X								X			X	X	X	
High Temperatures	X X	X									X						
Storm Damages	X X X X	X							X		X	X	X	X			
Total Acres in Cultivation	X X X X X X X X X X X	X				X	X	X								X	
Total Acres Harvested	X X X	X							X		X	X	X	X	X	X	

[1] Historic stage of growth for same time period cumulative temps + observational reqs

[2] Historic cumulative temps + air temp

[3] Historic wind velocity readings & present readings

[4] Air temp variation within 36 hours

[5] Historic stage of growth for same time period cumulative temps + observational requirements as shown

[6] Historic information ground observations + observational requirements as shown

IV WHEAT PRODUCTION ANALYSIS SYSTEM SCENARIO

A Introduction

Concepts and operational procedures for the wheat production analysis system are discussed in Section III of the Technical Report The following scenario has been developed to illustrate a set of hypothetical, seasonal events which affect the quantity and quality of the eventual wheat harvest

The scenario is limited to one illustrative geographical area--the Great Plains--for simplicity The events that occur and the selections that develop in the Great Plains between North Dakota and Texas are representative of most wheat production regions of the world

As the events occur, starting in September, the satellite is providing continuous monitoring of factors affecting inventory (area) and yield In addition, although not described in all cases, it is implicit that associated system analysis will similarly be providing forecasts of these factors for the time remaining until harvest

B Scenario

1 Date

It is now September 1

2 Background

Both the winter and spring wheat regions of the USA experienced cool and relatively moist conditions during the previous March, April, and early May In this period, temperatures and precipitation were below and above normal, respectively, causing good growth during the wheat tillering and jointing stages

By late May, however, the weather returned to normal and mid-June marked a somewhat late beginning of what proved to be an unusually hot summer Overall summer environmental conditions, however, were favorable to the wheat stem extension stages Although temperatures, particularly those in July and August, were considerably above normal, they did not adversely affect the heading and ripening stages of the wheat Furthermore, precipitation was received during the ripening stage and had a marked beneficial effect on the subsequent yields achieved at harvest

Essentially all harvesting was completed by the end of August and large stocks of wheat were stored Earlier in June, taking into consideration the slightly above average quantity of wheat in storage at that time and the anticipated bountiful harvest, the U S acreage allotment for the coming year was announced as 59 0 million acres, representing a 15 percent decrease from the 69 3 million acres in the year just completed

3 Autumn

As a result of above normal temperatures during June, July, and August, the soil moisture content at the beginning of September was verified by satellite observation to be below normal The satellite also detected that wheat growers in response had plowed their fields earlier than usual to increase the infiltration capabilities of their fields and thus gain maximum benefit from any rainfall that might be received in September

When plowing had been completed, wheat growers delayed their planting operation as long as possible because of the soil moisture content which was low and a critical factor at planting Although wheat seed will germinate with a minimum amount of moisture, without adequate moisture in the soil the plants may die in the period after the germination state Furthermore, in certain areas seed is not planted in dry soil if wind erosion can occur

Although observed mid-September rainfall was slightly above normal, it was verified to be insufficient to raise the soil moisture content up to average levels In addition, long-range weather forecasts indicated less than normal rainfall through November Because of these conditions, harrowing and planting of Nebraska winter wheat was not started until approximately September 15, two weeks later than usual Similarly, the satellite observed that Kansas, Oklahoma, and Texas wheat growers started their winter wheat planting 12 to 18 days later than their customary dates The amount of plowed land not being harrowed indicated that many growers were planning to fallow an above-normal number of acres the coming summer In the marginal areas of Montana and the Dakotas where winter wheat can be produced, many growers chose not to risk the hazards of winter because of the low soil moisture and elected to wait until spring before planting their wheat This was also verified by the number of plowed acres not being harrowed Those winter wheat growers who did plant however, sowed fewer pounds of seed per acre and at greater depths than usual These are customary practices when the soil moisture content is low

It was observed that winter wheat began in emerge in Nebraska during the last week in September and in subsequent weeks in areas further south confirming the late planting dates The absense of emerging wheat verified earlier indications of fallowing and spring wheat substitution decisions Late fall temperatures were normal from Nebraska to Texas, and the winter wheat growth pattern was normal when adjusted for the delay in planting dates Plant vitality and color indicated that the wheat satisfactorily advanced to the tillering stage because of the conducive fall weather However, grazing in those areas where it is practiced was held to a minimum to avoid damaging the less developed plants caused by the approximate 2-week slippage in the production cycle and lower sowing rate at planting

By November preliminary forecasts of the subsequent harvest were prepared These forecasts incorporated early observation of the actual current crop to adjust downward the earlier preseason forecasts which were based primarily on only allotted acres, current trends in average yield, and historical ratios of harvested to seeded acres

Wheat inventory forecasts were based first on evaluation of the number of acres of land historically used for growing winter wheat that had been observed to be plowed and harrowed (thereby deleting the unharrowed acres which are assumed at this time to be used primarily for spring crops or fallowed the following summer) Second, the number low temperatures In late January, however, abnormally heavy snowstorms blanketed the United States east of the Rockies Wheat growers were encouraged since this snow represented potential replenishment of moisture to the soil and provided protection to the plants from any subsequent winter winds

In February southern Oklahoma and Texas experienced a sudden warm spell with temperatures averaging 10° F above normal, which melted the snow cover through this area and caused thawing and subsequent heaving of the soil through southern Texas Soil moisture in this areas was observed to be now close to normal From northern Oklahoma through Nebraska temperatures were slightly above normal with some diminishing in the snow cover

Throughout the winter, forecasts were adjusted based on observed and forecasted conditions Preliminary estimates of acreage losses were prepared for Texas wheat because of the sever cold in early January and the thawing and heaving during February It was estimated that 250,000 acres of Texas wheat would be damaged beyond economical recovery For Nebraska, Kansas, Oklahoma, and remaining Texas wheat yield estimates were lowered due to the effects of below normal December precipitation and the exposure without snow cover to the early January cold and drying effects of the Canadian winds Compensation was allowed, however, for the heavy snowfall in late January

5 Spring

March brought the advent of steadily rising temperatures, particularly in the wheat areas north of central Oklahoma In southern Oklahoma and Texas the rise was not as pronounced because the February warm spell did not appreciably abate and temperatures there remained above normal for the entire month March precipitation from Texas to North Dakota was observed to be below normal and diminished the beneficial effect of the previous abnormally heavy January snowfall

In early March the effects of the severe winter on the Texas and Oklahoma winter wheat crop were verified by the observed number of of harrowed acres was then adjusted by the number of acres where growing wheat was actually observed (thereby deleting any other fall planted grain crops)

Lower wheat yield forecasts at this time were based on the anticipated effects of the observed soil moisture content which was lower than normal seasonal values in each observed area, the actual cumulative temperatures since planting compared to normal values, and any independent effects caused by the delay in the schedule itself These yield estimates also incorporated the anticipated effects of the lower sowing rates which were confirmed by observations that showed greater background reflectance in the post-emergence stages than would normally be expected for crops experiencing the actual cumulative rainfall and temperature

4 Winter

It was detected in early December that winter wheat crops were less developed (i e , slightly stunted with less vigor) than what would normally be expected or desirable This was anticipated, however, because cumulative temperatures through November had proved to be above normal as forecasted, and the October-November below normal precipitation materialized, also as forecasted, causing soil moisture to fall further below normal by December

Although December temperatures were considerably lower relative to those in November and sufficient to halt the growth of the winter wheat, they were still higher than normal levels and delayed the penetration of frost deep into the soil and the arrival of the first snowfall Weather forecasts indicated that heavy snows could not be expected until late January or early February

In early January the exposed dormant winter wheat suffered an extended period of severe cold without the insulating effects of snow cover Several below zero mornings were recorded in Nebraska and Kansas and below freezing temperatures were not unusual even in southern Texas The effect of these severe conditions on the winter wheat was further aggravated by unusually strong Canadian winds which accompanied the previously planted acres that were replowed in the spring in preparation for alternate summer crops In Texas this amounted to 300,000 acres and another 350,000 in Oklahoma In late March the same effects were observed in Kansas and Nebraska where 450,000 and 100,000 acres respectively were replowed

Although the detected spring soil moisture content in the winter wheat areas was still below normal, it was observed that the generally warmer early spring temperatures caused the winter wheat to leave the dormant stage earlier than usual and thus partially compensated for the delays in the production cycle caused by the late fall planting Kansas, Oklahoma, and Texas winter wheat was observed to be jointing 5 to 10 days later than usual and Nebraska winter wheat only 3 to 5 days behind schedule

The below normal precipitation and above normal temperatures in the early spring permitted the northern Great Plains spring wheat growers to harrow their land at the normal dates Harrowing of fall plowed lands was observed in South Dakota in early April and in Montana and North Dakota in late April

In April and May temperatures continued to range up to 8° F above normal and cumulative rainfall was on the average 4 inches below normal by mid-May through the entire wheat growing areas In Texas and Oklahoma winter wheat reached the heading stage in middle-to-late May, about a week later than usual Although the adverse weather had no appreciable slowing effect on the northern spring wheat, it was observed, however, that the wheat at jointing on or about May 20 had less vitality than desired and appeared more stunted than usual

Inventory forecasts were adjusted downward in March for the wintering losses to winter wheat which were verified to be greater than forecasted earlier Similarly, the below normal temperatures and cumulative moisture through April allowed early forecasts for anticipated further acreage losses from the forthcoming hotter months which were expected to average up to 5° above normal

Yield forecasts were updated periodically during March, April, and May, and showed continuing lower anticipated values because of the above normal temperatures and below normal precipitation which overcame the benefits of the above average late January snowfall The effects of the weather had caused earlier than normal spring growth with little moisture reserves for the summer season

6 Summer

It was confirmed by June 1 that an average of only 85 percent of the winter wheat acreage planted the previous fall could be harvested As determined earlier, over 1 2 million acres had been lost due to the effects of winter in the states of Texas, Oklahoma, Kansas, and Nebraska In addition, the higher than normal spring and early summer temperatures and lower than normal precipitation caused an anticipated loss of another 2 3 million acres in these four states

Texas and Oklahoma winter wheat headed a week later than usual and harvesting did not start in these states until late June and early July respectively Similar delays in harvesting were noted in Kansas and Oklahoma

Although June and July weather was somewhat unfavorable to wheat, it had relatively little effect on the anticipated yield of winter wheat at harvest It was observed, however, that in general winter wheat at harvest was unusually stunted and showed considerably less vitality than usual

While planting, emergence, and jointing of spring wheat was on schedule, the below normal spring precipitation adversely affected the anticipated yield of wheat in South Dakota, North Dakota, and Montana. By late June it was noted that much of the spring wheat was greatly stunted at the boot and heading stages. Growers did not apply fertilizer at the approach of the heading stage to increase the size of the wheat grains and their nitrogen content Since moisture conditions were less than desirable, they feared that an application of fertilizer would have an adverse effect

Although the earlier weather forecasts correctly predicted that May temperatures would be 5° F above normal, the average temperatures during June and July were 7° F above normal   Precipitation was sporadic and light during June and July with no sustained rains to raise the moisture content of the soil   It was confirmed by early July, when the spring planted wheat began to flower, that the spring wheat yield would also be poor   It was also forecast that 0 9 to 1 2 million acres would be lost from the inventory of seeded spring wheat acres

While the conditions in late July and early August were normal for the area and usually favorable for the ripening, the spring wheat plants showed a definite weakening effect from the earlier growth stages which had been stunted   The wheat kernels were unusually small and lightweight   The earlier inventory forecast was confirmed when nearly one million acres of wheat were lost in South Dakota, North Dakota, and Montana

Continuing harvest forecasts during the summer months served the primary purpose of refining the previous estimates of inventory and yield   Inventory forecasts were finalized by actual observation of the results of the actual harvest   Yield forecasts received their final modification taking into account preharvest cumulative temperatures and precipitation

V BENEFITS FROM STABILIZING COMMODITY CREDIT CORPORATION OPERATIONS

The annual rate of benefits depends on three principal factors (1) the ability of the satellites to provide the information, (2) the rate at which the U.S Department of Agriculture agency personnel can incorporate the satellite information into their operations, and (3) the rate at which farmers can adjust their operations to shift spring wheat acreages to substitute for winter wheat when winter wheat yields appear to be hurt by fall and winter weather conditions These three rates were averaged and applied to the maximum annual benefit of $184 million calculated in section III C 2 a of Volume II, the technical report The annual benefits were discounted at the rates of 7-1/2 percent, 10 percent, and 12-1/2 percent The resulting annual benefits and 20 year totals are shown in Exhibit H-8.

EXHIBIT H-8 RATE AND AMOUNT OF BENEFITS FROM STABILIZING COMMODITY CREDIT CORPORATION OPERATIONS, UNITED STATES DISCOUNTED 7-1/2%, 10%, AND 12-1/2%, 20 YEARS

YEAR

Rate and Amount of Benefits	Unit	0 1971	1 1972	2 1973	3 1974	4 1975	5 1976	6 1977	7 1978	8 1979	9 1980	10 1981
Rate												
Satellite Capability	Percent			100	100	100	100	100	100	100	100	100
Agency Participation	Percent		-	30	60	80	95	95	95	95	95	95
Farmer Participation	Percent	-	-	30	50	70	90	90	90	90	90	90
Mean Rate	Percent	-	--	53	70	83	95	95	95	95	95	95
Annual Benefits												
Undiscounted	Million Dollars	-	-	45	60	71	81	81	81	81	81	81
Discounted 7-1/2%	Million Dollars	-	--	39	48	53	57	53	49	45	42	40
Discounted 10%	Million Dollars	--	-	37	45	48	50	45	41	37	34	32
Discounted 12-1/2%	Million Dollars	-	--	36	42	44	45	40	36	32	28	25

Rate and Amount of Benefits	Unit	11 1982	12 1983	13 1984	14 1985	15 1986	16 1987	17 1988	18 1989	19 1990	20-Year Total
Rate											
Satellite Capability	Percent	100	100	100	100	100	100	100	100	100	
Agency Participation	Percent	95	95	95	95	95	95	95	95	95	
Farmer Participation	Percent	90	90	90	90	90	90	90	90	90	
Mean Rate	Percent	95	95	95	95	95	95	95	95	95	
Annual Benefits											
Undiscounted	Million Dollars	81	81	81	81	81	81	81	81	81	1 391
Discounted 7-1/2%	Million Dollars	36	34	28	29	28	25	24	22	20	672
Discounted 10%	Million Dollars	28	26	24	21	19	18	16	15	13	549
Discounted 12-1/2%	Million Dollars	22	19	18	15	14	12	11	10	9	458

VI EFFECT OF STABILIZING WHEAT ACREAGE ON UNIT COSTS OF PRODUCTION AND FARM PRODUCTION EXPENSES

Wheat acreage allotments and wheat acres harvested have shown wide variation during the past decade It is hypothesized that because of this variation, average unit costs of production have been higher than necessary, resulting in inefficient use of resources The purpose of this section is to illustrate the possible saving of resources that might occur with the aid of a satellite-assisted information system

A Wheat Acreage Allotment Levels

Wheat acreage allotments in the 1954-67 period ranged from 47 8 million acres per year to 68 2 million acres per year, a 41 percent variation Wheat acreage harvested during the same time period, ranged from 43 7 million acres per year to 59 million acres per year, a 35 percent variation Carryover of wheat accumulated to a peak in 1961 and then declined to about U S D A optimum levels at the end of the period, indicating that while the total production during the period was of a desirable magnitude, the year to year fluctuations were not

The changes in wheat acres per individual farm were generally greater than for the total U S , reflecting in part the declining numbers of farms as well as fluctuations in wheat allotments Typical wheat farms showed ranges in wheat acres harvested as set forth in Exhibit H-9

B Indices of Unit Costs

1 Historical Costs

Unit cost curves were derived for wheat-fallow farms in the Northern Plains (see Exhibit H-10) Because unit costs are affected by variations in yields, the curves are normalized for yield The curve representing yields of 20 bushels per acre reflects the average yield situation during 1954-67

It was not possible to derive statistically significant unit cost curves for representative wheat farms in other areas The unit cost curve derived

EXHIBIT H-9 RANGE IN WHEAT ACRES HARVESTED PER FARM BY ENTERPRISE - 1954-1967

Enterprise	Average Annual Wheat Acres Harvested per Farm		Percent Fluctuation
	Low Acres	High Acres	
Wheat-fallow, Northern Plains	144	237	65
Winter Wheat, Southern Plains	198[1]	265	34
Wheat-grain Sorghum, Southern Plains	133[1]	257	93
Wheat-pea, Washington-Idaho	150	231	54
Wheat-fallow, Washington-Oregon	270	511	89

[1] Extremes of low acreage harvested due to drought eliminated

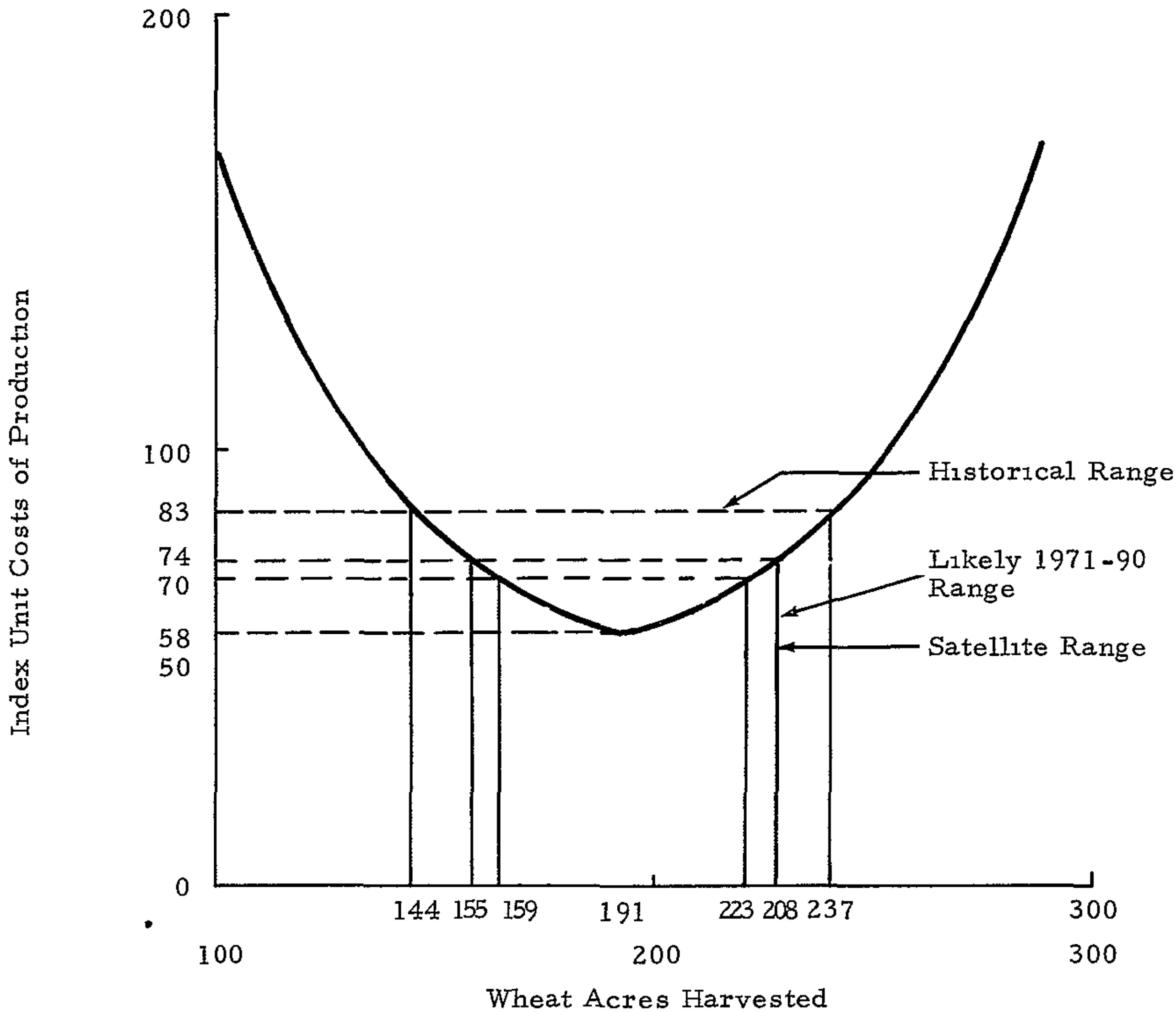


EXHIBIT H-10 UNIT COST CURVE FOR WHEAT-FALLOW ENTERPRISE IN THE NORTHERN PLAINS, UNITED STATES for the wheat-fallow, Northern Plains case is a classic curve and is of the kind that might well be considered generally indicative of wheat farms in other areas

Unit costs in constant prices were calculated by deflating the index of cost per unit of production by an index of prices paid by farmers for producing goods and services [1]

The range in acreage for this type of farm was from 144 to 237 acres The chart indicates that index of unit costs for yields of 20 bushels per acre would range from a high of about 83 at 144 acres to a low of 58 at 191 acres and increase again to a high of about 83 at 237 acres The average index of unit costs was 70 5 That range of acres produced peak CCC stocks of 1,300 million bushels

2 Non-Information Alternative Costs

The non-information alternative, it has been shown elsewhere in this report, would likely result in CCC stocks of about 400 million bushels per year in the next 20 years Under these assumptions, the future range for wheat acreage under a non-satellite system would likely run about 80 percent of the historical peak In the wheat-fallow, Northern Plains example, acreage in the future under a non-satellite system would range from 155 to 228 acres The unit cost curve would yield an index of 74 at the high point and a low of 58, with the average point at 66

3 Satellite-Assisted System Costs

The satellite-assisted information system would allow an even further reduction in the range of acres by eliminating errors in estimation and hence the acreage that would be required to achieve optimum production levels The satellite system has the capability of reducing estimation errors by ± 13 percent over current systems This

[1] Farm Costs and Returns, Economic Research Service, U S Department of Agriculture, Washington, D C Ag Information Bulletin 230 and preceding issues

could conceivably reduce the range of acres below the likely 1971-1990 level by 13 percent The range of acres needed could run from a low of 159 acres to a high of 223 acres The index of unit costs under this situation would be from 70 at 159 acres to the low of 58 at 191 acres, and return to a high of about 70 at 233 acres The index of unit costs would average about 64 for the satellite information system, a reduction of 9 percent from the average index of 70 5 for the historical highs and 3 percent from the average index for the non-information alternative

C Production Costs

There is no data series from which costs of producing wheat can be calculated directly An estimate of $1,375 million annual cost of production was derived based on unpublished data from a 1955 U S D A input-output study PRC estimates of production expenses per acre for the years of 1966-1967 resulted in an average expenditure of $1,589 million dollars per year for producing wheat, as follows

Average Costs Per Acres of Producing Wheat, 1966-1967

Acres	Cost of Production per Acre	Total Cost
Acres seeded but not harvested - 6,769	$10 02	$ 67,825
Acres harvested - 54,436	$27 94	1, 520, 942
TOTAL		$1, 588, 767

D Benefits

The monetary benefits accrue from reducing the average unit costs of producing wheat Both the non-information alternative and the satellite-assisted system appear to result in lower unit costs of production than the historical system has shown For purposes of this study, it is most reasonable that the benefits accruing to the satellite-assisted system result from reducing costs below the non-information alternative The maximum annual saving from this would be $29 million per year These calculations are summarized as follows

Summary of Calculations for Reducing Unit Costs of Producing Wheat

	Range in Acres	Percent Change in Index from Previous System	Average Index of Unit Costs	Average Annual Total Costs of Producing Wheat (millions)
Historical System 1954-1967	144-237	---	70.5	$ 1,589
Non-Information Alt 1971-1990	155-228	9	62	1,446
Satellite 1971-1990	159-223	2	60	1,417

The rate and amount of United States benefits for the 20-year period, 1971-1990, are summarized in Exhibit H-11 Benefits do not occur at the same rate throughout the 20-year period because of changes in the capability of the satellite system, and the ability of farmers to adjust their enterprises based on improved information The satellite capability rate is that developed in Volume II, Chapter IV, Technological Phasing The farmer participation rate is based on conversations with University researchers engaged in diffusion research [1] These rates were averaged and multiplied by the maximum annual rate computed above in this appendix This resulted in the annual undiscounted benefits which were then discounted by 7-1/2 percent, 10 percent, and 12-1/2 percent

While there is inadequate information to develop unit cost curves for other countries, the assumption was made that the other free world, developed countries experience cost curve relationships similar, if not identical, to those of the United States Therefore, a simple extrapolation

[1] Based on telephone conversations with George Beale, University of Iowa, Marion Brown and Len Maurer, University of Wisconsin, and Milton Morris, University of Minnesota

EXHIBIT H-11 RATE AND AMOUNT OF BENEFITS THAT RESULT FROM STABILIZING UNIT COSTS OF PRODUCING WHEAT, UNITED STATES AND WORLD, DISCOUNTED 7-1/2%, 10%, AND 12-1/2%, 20 YEARS

Rate and Amount of Benefits	Unit	Year 1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	20-Year Total
United States			1	2	3	4	5	6	7	8	0	10	11	12	13	14	15	16	17	18	19	
Rate																						
Satellite Capability	Percent	-	-	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	Percent	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Farmer Participation	Percent		-	30	50	70	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Mean Rate	Percent		-	65	75	85	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	
Annual Benefits																						
Undiscounted	Million Dollars	--	--	19	22	25	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	486
Discounted 7-1/2%	Million Dollars	--		17	18	19	20	18	17	16	15	14	13	12	11	10	10	9	8	8	7	242
Discounted 10%	Million Dollars		-	16	17	17	17	16	14	13	12	11	10	9	8	7	7	6	6	5	4	195
Discounted 12-1/2%	Million Dollars		--	15	15	16	15	14	12	11	10	9	8	7	6	5	5	4	4	3	3	162
Other Free World Developed Countries																						
Rate																						
Satellite Capability	Percent	-		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	Percent	-		--	--	--	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	
Farmer Participation	Percent		-	30	50	55	60	65	70	74	78	80	82	84	85	86	88	90	90	90	90	
Mean Rate	Percent			65	75	78	80	83	85	87	89	90	91	92	93	93	94	95	95	95	95	
Annual Benefits																						
Undiscounted	Million Dollars	-	--	30	35	36	37	38	39	40	41	41	42	42	43	43	44	44	44	44	44	727
Discounted 7-1/2%	Million Dollars	-	-	26	28	27	26	25	23	22	21	20	19	18	17	15	15	14	13	12	11	352
Discounted 10%	Million Dollars	--	-	25	26	24	23	21	20	19	17	16	15	13	12	11	10	10	9	8	7	286
Discounted 12-1/2%	Million Dollars	-	-	24	25	22	20	19	17	16	14	13	11	10	10	8	7	7	6	5	5	239

of the benefits from improving the operating position on the unit cost curve was made for the rest of the relevant free world

The countries which would benefit from this information principally those that have production controls and are wheat exporters Since they produce for other than their domestic market, they would be subject to fluctuating market pressures for acreage changes The extrapolation relationship should be based upon acres, which are the principal unit in computing the benefits The principal free world, developed country wheat exporters and their average annual acreage are

Country	Average Annual Acres
	1,000 acres
Argentina	13,491
Australia	19,506
Canada	29,445
France	10,399
West Germany	3,498
Italy	10,490
Total	85,829
U S A	52,047

Based upon this relationship of $\frac{85,829}{52,047} = 1\ 6$, the extrapolation of U S benefits to world benefits was estimated at \$45 million x 1 6 = \$76 million per year The annual rates based on satellite capability and farmer participation were calculated in the same procedure as those for the United States These annual and 20-year benefits are also summarized in Exhibit H-11

VII PRODUCER OPTION BENEFITS

United States farmer may derive economic benefits from increases in the quality and timeliness of information on wheat production. The basis for these benefits comes mainly from the improved weather and climatological forecasts and knowledge of soil conditions expected from the satellite system This section has been divided into three major parts Production costs of the farmer, options available throughout the production cycle, and calculation of the expected benefits to the farmer

A Production Costs

Wheat is produced in most areas of the United States, but major production occurs in the Pacific Northwest and Great Plains states These states accounted for an average of 81 percent of the total wheat acres planted and harvested during the 1961-65 period In these regions, wheat is a major crop and at times the only significant cash crop that can be planted The additional 19 percent of wheat acreage is located in California and the Eastern United States where wheat production is a poor economic alternative and at best is a minor competitor to row crops For these reasons, the analysis was limited to the Pacific Northwest and Great Plains states

The production costs of the three major wheat producing areas, Northwest and Upper and Lower Plains, weighted to represent the proportion of total acres planted and harvested for each of the three regions, were used to develop a cost of production table. The resulting weighted costs of production are assumed to be representative of a 400-600 acre farm The calculations and weighted costs are shown in Exhibit H-12

Within each region a representative state was picked and its cost structure was used to determine cost of production that would be typical of that region The state of Washington was used for the Northwest, Colorado/Kansas for the winter production on the Lower Plains and North Dakota for spring production on the Upper Plains

EXHIBIT H-12 BASIC COSTS OF WHEAT PRODUCTION

Region	Northwest[2]				Upper Plains[2]				Lower Plains[2]				Weighted Cost/Acre for Domestic Wheat Production[3]			
Regional Weights	12%				34%			36%	54%			52%				
Cost Per Acre[1]	(1) Planning/ Preparation	(2) Planting	(3) Intermediate Activities	(4) Harvest	(1) Planning/ Preparation	(2) Planting	(3) Intermediate Activities	(4) Harvest	(1) Planning/ Preparation	(2) Planting	(3) Intermediate Activities	(4) Harvest	(1) Planning/ Preparation	(2) Planting	(3) Intermediate Activities	(4) Harvest
Variable Costs	Dollars Per Acre				Dollars Per Acre				Dollars Per Acre				Dollars Per Acre			
Seed		2 02	14			2 20				1 58				1 84	02	
Chemicals	1 39	7 16	2 35			1 30	25			09	32		17	1 35	54	
Financial	24	76	10	40	09	1 89	03	11	21	1 59	06	21	17	1 59	05	20
Mach Oper[4]	1 87	3 27	70	8 47	84	1 15	1 04	2 12	2 72	4 19	86	3 98	1 98	3 04	90	3 85
Misc[5]	94	1 65	36	1 52	N B O[6]	N B O[6]	N B O[6]	N B O[6]	33	50	10	33	29	47	09	35
Total Variable Costs	4 44	14 86	3 65	10 37	93	6 54	1 32	2 23	3 26	7 95	1 34	4 52	2 61	8 29	1 60	4 40
% Variable Costs of TVC (Each Stage)	13%	45%	11%	31%	8%	60%	12%	20%	19%	47%	8%	26%	15%	49%	9%	26%
Fixed Costs																
Taxes	9 95				2 80				38				2 35			
Mach	7 91				7 56				4 94				6 19			
Land Charge	20 41				10 79				15 95				14 73			
Total Fixed Costs	38 27				21 15				21 27				23 27			
Total Costs (Cumulative)	42 71	57 57	61 22	71 59	22 08	28 62	29 94	32 17	24 53	32 48	33 82	38 34	25 88	34 17	35 77	40 17
% of Total Costs at Each Stage - Cumulative	60%	80%	86%	100%	69%	89%	93%	100%	64%	85%	88%	100%	64%	85%	89%	100%
% of Variable Costs at Each Stage to TVC-- Cumulative	13%	58%	69%	100%	8%	68%	80%	100%	19%	66%	74%	100%	15%	65%	74%	100%

[1] Does NOT include returns to management which ranged between $3 $9/acre

[2] Average dates used for each stage of production cycle

	Winter Wheat (lower plains and part of NW)	Spring Wheat (mainly upper plains)
Planning/Preparation	Major planning/preparation prior to August of current growing period	Oct/April
Planting	Sept/Oct	April/May
Intermediate Activities	Nov to beginning of June	June to beginning of August
Harvest	June to mid-July	August to Sept

[3] Representative cost/acre weighted based on region's proportionate share of total acres planted for stages 1 2 and 3 and total acres harvested for stage 4 (see % values for each region)

[4] Includes hired and farmer labor

[5] Storage, electricity phone calls bookkeeping, etc

[6] N B O --Not broken out

Sources

Northwest: Norman K Whittlesey and R E Oehlschlaeger Cost of Production Budgets for Dryland Crops in Eastern Washington (Review Draft)

Upper Plains: Rodney Paul and Dale Anderson Small Grain Production Costs on North Dakota Farms Department of Agricultural Economics, North Dakota State (Agricultural Economics Statistical Series Issue No 2 Sept 1968)

Lower Plains: Glen J Vollmar and others Wheat Production Costs in the Nebraska Panhandle (Summary of Report) Nebraska Agricultural Experiment Station 1966

Frank Orazery and others Implications of Projected Changes in Farming Opportunities in Western Kansas Agricultural Experiment Station Kansas State University Bulletin 452 December 1962

Harry G Sitler Crop Enterprise Costs for Northeastern Colorado Colorado State University Cooperative Service Fort Collins Colo in Cooperation with U S D A , June 1966

Jay L Treat, Comparing Crop Profits in Southeast Kansas Extension Service, Kansas State University Manhattan Kansas MF-197 May 1968

In the Northwest, costs were determined for each major subregion and weighted to reflect their portion of the total production for the region Winter wheat accounted for 89% of Washington's production and was grown in 10 subregions, with 70% of this production occuring in 3 subregions The remaining 11% was spring wheat production grown in 7 of the subregions Costs were rather high, but the yield in the three principal districts ranged up to two times as high as any other part of the state and, incidentally, the nation

In the Lower Plains, farms were on the average rather large (800-1100 acres) Winter wheat is normally planted and alternated with a fallow period which requires more extensive farming in order to make up for one-crop farming Cattle grazing in the Western part of Kansas, Oklahoma, and Texas Panhandle is used as an income supplement In good wheat years 1-2 million cattle may be grazed for 30-120 days of the production period

In the Upper Plains, the North Dakota area represents a somewhat more varied cropping system The region is mainly a spring wheat producing area but other small grain alternatives are available to rotate or complement wheat production

Exhibit H-13 shows the individual costs that were aggregated under selected cost components

In his day-to-day short-run decisionmaking, the farmer considers only variable costs because his fixed costs are not changeable and must be taken as given A significant amount of the farmer's variable costs occur at two major points -- planting and harvesting -- as shown in Exhibit H-14 The same exhibit also shows the variable cost function for the production cycle. Approximately 65 percent of the farmer's immediate expenses occur between his initial planning and final planting of the wheat seed In the case of winter wheat this occurs within a 2-3 month period but he receives no return for another 8-9 months The satellite system, with improved forecast capability, would reduce the degree of uncertainty under which the farmer now works For example, the farmer would be better able to determine whether or not there will

EXHIBIT H-13 SELECTED MAJOR COST COMPONENTS

	Variable Costs				Fixed Costs		
Seed	Chemicals	Financial	Machine Operation	Misc	Taxes	Mach	Land Charge
Normal seeding Spring reseed	Fertilizer Herbicide Diuron	Crop Ins Interest on Operating Capital	Hired and Operator's Own Labor Repairs Fuel & Lubricants Hauling Handling	Phone Electricity Travel Licenses Accounting Fees Etc			

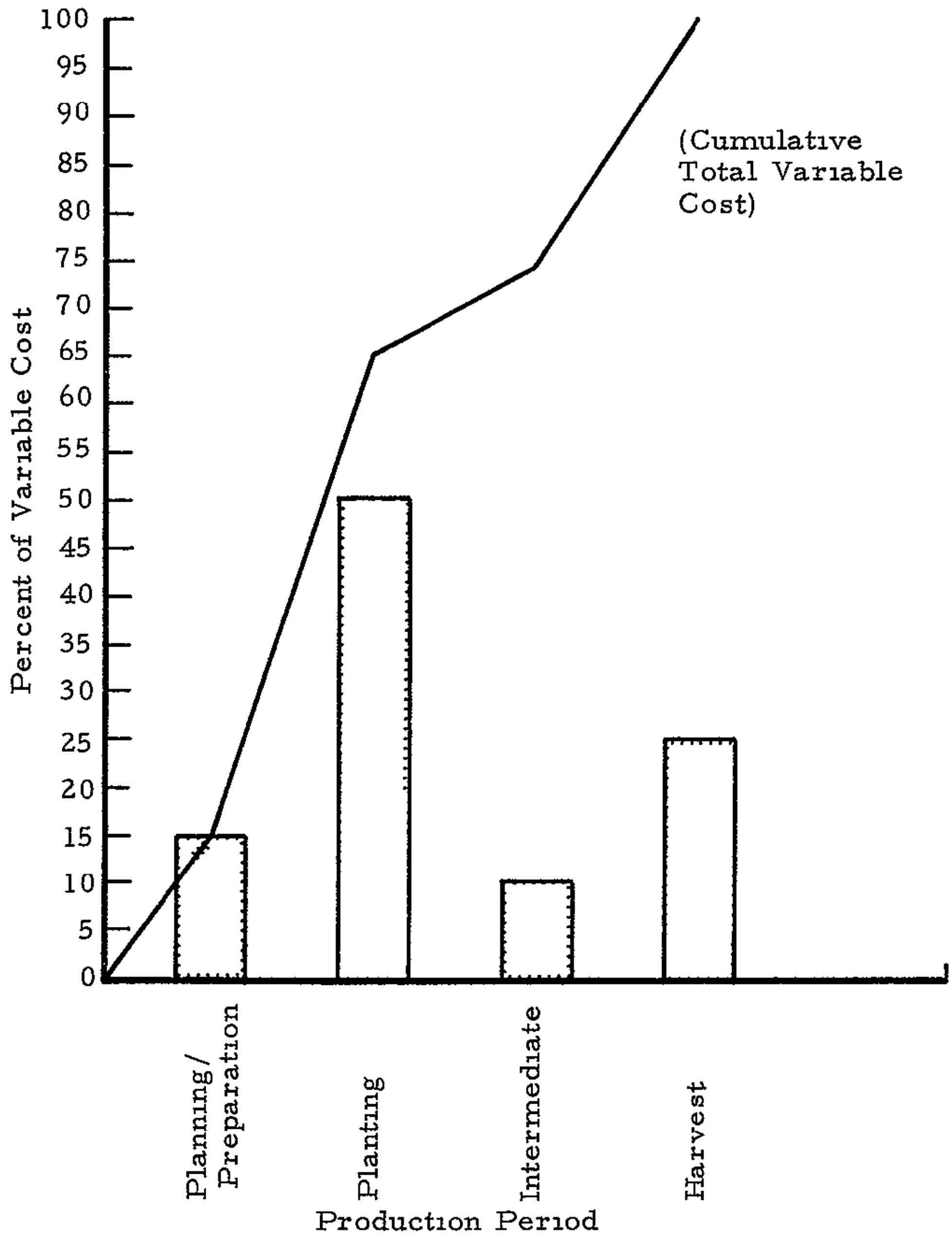


EXHIBIT H-14 DISTRIBUTION OF VARIABLE COSTS BY PRODUCTION PERIOD be sufficient moisture to make planting a cash crop in the fall profitable instead of going fallow and/or waiting until the spring months to decide to plant a cash crop or continue to remain in a fallow condition

B Options Available to Farmers (U)

Wheat farmers in the United States as well as in the developed countries of the world have several production options available to them at various points in their decision process Exhibit H-15 presents the maximum options possible for the U S wheat farmer Not all of these options will be influenced by the proposed satellite information system However, farmers may benefit from the availability and timing of data not currently available at all in some cases, or not to the same degree as would be provided by the satellite system

The options may be broken down into four major groups based on the planting periods of winter and spring wheat These periods are pre-seed bed preparation (planning/preparation), final seed bed preparation and planting of the seed (planting), growing of wheat plant (intermediate), and the last period maturation and harvesting of the crop (harvest) The farmer may influence at these various points what his crop and gross return will be for the upcoming year While both winter and spring wheat producers have similar production functions, the winter wheat producer (about 80% of the total acres harvested) has a longer growing period in which to vary his plans The winter farmer, unlike the spring producer, plants his crop in the fall, allowing the plant to establish its basic root and stem structure before winter interrupts its growth The plant then is able to take full advantage of the early spring cool weather and avoid the hot, dry, late summer weather Therefore, the winter wheat producers have the opportunity to consider a complete change in their production plans, i e , fall planting vs plowing up the prior fall-planted growth and putting in a spring crop if the fall-planted crop is below acceptable vigor

EXHIBIT H-15 OPTIONS AVAILABLE TO FARMERS FOR CHANGING PRODUCTION FUNCTION[1]

	Stage of Production Cycle			
	Planning/Preparation	Planting	Intermediate	Harvest
Options Available	Plant/Fallow Plowing technique Custom-hired work Cattle grazing	Change fertilizer Change seed amount and variety Change labor Change Crop Custom-hired work Cattle grazing	Fertilize All-purpose fungicide, herbicide Revise crop cycle (winter wheat) Cattle grazing	Delay Harvest Plow after harvest Storage facilities Custom-hired work Cattle grazing

[1] Limits to Options Operating capital availability

Investment capital

Labor inputs Farm originating or custom-hired

Material inputs certified seed, fertilizer

Meteorological condition

1 Major Options

Major changes can occur in the following areas of production options determination of the crop cycle, custom work, cattle grazing, fertilizer application, and storage of crop

a Determination of Crop Cycle

Farmers make certain basic decisions, subject to change, early in the fall growing period and again in the spring One of these is whether or not to go fallow or plant a continuous cash crop In those areas where fallowing is not automatically used because of moisture and conservation requirements the farmer could expect up to an increase in his net return if fallowing is not practiced

In the Plains States summer fallowing is required about four years out of five due to present meteorological forecast capability Farmers in this case are able to increase the per acre yield in the year following the fallow period by up to 50% over continuous cropping. Farmers must weight the choice of going fallow or putting in a cash crop which may not mature

The satellite system would allow farmers to develop a plan more closely following the meteorological conditions for the upcoming year. This option, along with farmers' option to vary fertilizer inputs, is probably the most important decision in estimating his basic farm income

b Plowing Technique

Farmers may postpone plowing when inadequate moisture is present Yields may decrease some 5 bushels an acre but this outweighs reseeding in the spring due to planting too late

Farmers may also option to change plowing techniques where there is a temporary lack of adequate moisture This practice is called listing and mainly occurs in the Lower Plains States in July The practice may increase the yield as much as 50% over later plowing in September

c. Custom Work

Outside help normally is needed during the harvest period. The availability of outside assistance during the seed-bed preparation period is not as great as during the harvesting operation. Custom rates for plowing and planting where available normally run about the same or slightly less than the average farmer's costs for the same operation.

d. Cattle Grazing

Winter wheat land is used for cattle grazing in the fall after the wheat plant has established its basic root system. Farmers may keep the cattle on wheat land through April if the winter has been dry. In a normal year, farmers would sell cattle after a 60-day grazing period. An average farm might have one animal for every four acres, increasing in weight about 1 lb. per day. This would provide a net return of $0.10 per pound or $1.50 an acre for a 600-acre farm. If the moisture level were above normal, a greater amount of fertilizer could be applied in the early fall, increasing the available pasturage. Farmers could then add more cattle for the same period, and if weather conditions appeared to be favorable for the winter months, farmers could extend their grazing an additional 60-90 days. It is expected that there would be no problem in borrowing additional operating capital for these cattle as the loan would be backed by the income from the wheat crop.

e. Fertilizer

Farmers planting winter wheat have two major points at which they may directly affect yield through the application of chemicals like nitrogen (liquid, solid, gas), phosphorous and potassium derivatives. The amounts applied vary based on soil characteristics. In the Upper Plains States, spring wheat is fertilized at planting while in the Lower Plains States and the Northwest fertilizer is applied both before and after seeding.

Nitrogen compounds are the basic determinants of the increase in yield when additional amounts are applied. The amount of nitrogen is dependent on the amount of moisture available irrespective of the form in which it is applied Exhibit H-16 shows the yield changes based on changing the amounts of nitrogen, etc , at planting time The satellite forecast capability would allow farmers to benefit from increased knowledge of the expected weather/moisture conditions at planting Nitrogen may also be applied during the growing season as an intermediate activity

C Benefit Calculations

Dollar benefits were calculated based on the improved capability of satellite-assisted weather forecasts As previously noted, potential dollar benefits would occur in the following areas crop rotation, cattle grazing, fertilizing and custom work The level of benefits would be dependent on the degree to which the satellite system is capable of coming up with the improved weather measurements as a part of the water management case

One basic assumption involved in all of the following calculations is that the satellite system will provide improved capability for forecasting precipitation levels for the major wheat growing regions of the country This assumption allows the analyst to postulate what would be the farmer's range of reactions based on improved knowledge Thirty-seven years of historical data (1931-1967) were summarized (see Exhibit H-17) and extrapolated for the twenty years under study Exhibit H-18 presents the expected distribution of precipitation for 1970-1989 Normal, above, and below normal periods of precipitation have been developed The years of above and below normal precipitation are based on 1 inch above or 1 inch below the mean value which is defined as the normal level of precipitation It has been assumed that there is sufficient residual soil moisture in the ground to complement the assumed level of precipitation Periods of low rainfall occur which result in low soil moisture Periods of above normal rainfall occur which result in a normal soil moisture base This assumption, therefore, excludes counteracting existing soil moisture conditions which limits the effectiveness of this analysis

In addition, the benefits developed in the following section do not reflect the effect that increasing or decreasing wheat and cattle production have on the prices of wheat and cattle The question of cross

EXHIBIT H-16 RETURNS FROM INCREASED FERTILIZER APPLICATION AT PLANTING TIME

Region	Representative Yields per Acre 1960-64 Average	Estimated Rates and Yields with Additional Fertilizer per Acre	
		Fertilizer Rates	Yields
	Bushels	Pounds	Bushels
Northwest	36	44	+ 7
		30	+ 1
		30	+ 0
Upper Plains	29	24	+ 2
		24	+ 2
		24	+ 2
Lower Plains	34	80	+ 10
		46	+ 5
		35	+ 3

Sources U S D A Economic Research Service, Crop Yield Response to Fertilizer in the United States, Statistical Bulletin No 431 (August 1968) and U S D A Statistical Reporting Service, Crop Production, 1966 Annual Summary

EXHIBIT H-17 NUMBER OF YEARS RAINFALL EXCEEDED THE MONTHLY MEAN RAINFALL BY ONE INCH OR MORE, 1931-1967

	Northwest Spokane Washington			Upper Plains Bismark N Dakota			Lower Plains Dodge City Kansas		
	Mean	Mean + 1"	No Years	Mean	Mean + 1"	No Years	Mean	Mean + 1"	No Years
Jan.	2 08	3 08	14	0 46	1 46	0	0 44	1 44	1
Feb.	1 61	2 61	6	0 46	1 46	0	0 70	1 70	2
Mar	1 35	2 35	7	0 87	1 87	2	0 97	1 97	4
Apr	1 07	2 07	3	1 48	2 48	7	1 84	2 84	9
May	1 33	2 33	7	2 26	3 26	6	3 00	4 00	11
June	1 29	2 29	7	3 38	4 37	10	3 21	4 21	12
July	0 50	1 50	1	2 23	3 33	9	2.94	3 94	9
Aug	0 59	1 59	3	1 80	2 80	9	2 54	3 54	8
Sept	0 84	1 84	3	1 30	2 30	7	1 79	2 79	5
Oct	1 24	2 26	9	0 91	1 91	4	1 37	2 37	7
Nov	2 04	3 04	8	0 56	1 56	1	0 73	1.73	4
Dec	2 20	3 20	8	0 51	1 51	0	0 58	1 58	2
Annual	16.16			16 21			20 11		

EXHIBIT H-17 (Continued)

NUMBER OF YEARS MONTHLY RAINFALL WAS ONE INCH OR MORE BELOW THE MONTHLY MEAN, 1931-1967

	Northwest Spokane Washington			Upper Plains Bismark N Dakota			Lower Plains Dodge City Kansas		
	Mean	Mean - 1"	No Years	Mean	Mean - 1"	No Years	Mean	Mean - 1"	No Years
Jan	2 08	1 08	5	0 46	0	0	0 44	0	0
Feb	1 61	0 61	6	0 46	0	0	0 70	0	0
Mar	1 35	0 35	1	0 87	0	0	0 97	0	0
Apr	1 07	0 07	1	1 48	0 48	7	1 84	0 84	15
May	1.33	0 33	5	2.26	1 26	13	3 00	2 00	13
June	1.29	0.29	4	3 37	2.36	12	3 21	2 21	16
July	0 50	0	0	2 23	1.23	8	2 94	1 94	17
Aug	0 59	0	0	1 80	0 80	9	2 54	1 54	10
Sept	0 84	0	0	1 30	0 30	4	1 79	0 79	10
Oct	1.26	0 26	3	0 91	0	0	1 39	0 39	10
Nov	2.04	1 04	10	0.56	0	0	0.73	0	0
Dec	2 20	1 20	3	0 51	0	0	0 58	0	0
Annual	16 16			16 21			20 11		

EXHIBIT H-18 FREQUENCY OF ABOVE NORMAL, NORMAL, AND BELOW NORMAL PRECIPITATION, SELECTED MAJOR WHEAT PRODUCTION AREAS, UNITED STATES, 20 YEARS

	Northwest						Upper Plains						Lower Plains					
	Above Normal Precipitation		Normal Precipitation		Below Normal Precipitation		Above Normal Precipitation		Normal Precipitation		Below Normal Precipitation		Above Normal Precipitation		Normal Precipitation		Below Normal Precipitation	
	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent	Number of Years	Percent
Fall Planting (September October November)	4	18	9	47	7	35	2	11	17	85	1	4	3	14	13	68	4	18
Spring Planting and/or Intermediate Fertilizing (March April)	3	14	16	83	1	3	2	12	16	79	2	9	4	18	12	62	4	20

[1] Based on monthly records of precipitation at Spokane Washington Bismark North Dakota and Dodge City Kansas

elasticities and substitution effects has in the main not been investigated in this study

1 Crop Rotation

Benefits from revising the crop rotation plan occur from the savings of preplanting and planting costs in the fall winter wheat areas when precipitation is below normal, and there is a long-range forecast of above normal precipitation levels during the spring planting months of March and April The available data (Exhibit H-18) did not directly link the frequency of below normal fall precipitation with normal and/or above precipitation in the spring Therefore, the frequency of this direct relationship was estimated for the Lower Plains area by the following formula

$$\text{Frequency} = \begin{pmatrix}\text{Percent} \\ \text{years below} \\ \text{normal fall} \\ \text{precipitation}\end{pmatrix} \times \begin{pmatrix}\text{Percent years} \\ \text{normal and} \\ \text{above spring} \\ \text{precipitation}\end{pmatrix} \times \begin{pmatrix}\text{Study} \\ \text{Period}\end{pmatrix}$$

$$= \ (\ 18) \times (\ 80) \times 20$$

$$= \ 2\ 8 \text{ years}$$

Under these conditions, it would be possible to save preplanting and planting costs that Lower Plains states farmers might incur in the fall These farmers would otherwise plant winter wheat and in the spring replant sorghum or the new varieties of spring wheat after they had experienced an unfavorable fall and winter precipitation Using the costs calculated in the previous section, the farmers in this region as a whole would save the cost up through planting ($32 48) times the total acres of winter wheat production in Colorado, Kansas, Oklahoma and Texas that could be involved (18 58 million acres) Savings would equal $603 5 million a year Over the next twenty years, potential conditions would occur 3 times equal to a savings of $1811 million in fall planting costs

2 Cattle Grazing[1]

The grazing of cattle on wheat pasturage for various periods of the winter wheat growing cycle occurs in Western Kansas, parts of Oklahoma and the Texas Panhandle Weather conditions are very important in that the amount of precipitation available, *ceteris paribus,* not only determines the number of cattle that can be supported on the wheat shoots but also how long a time period cattle can be left on the land without damaging the wheat due to overly wet ground The satellite system, with improved forecast capability, is well suited to give the farmer possibilities due to the need to contract for the cattle two to three months ahead of time

On the average, an estimated 1 4 million head of cattle are grazed on wheat pasture for two months in a normal year In a very good year with an increase in moisture at the proper time, an additional 1 3 million head of cattle could be grazed All of the 2 7 million head could be grazed an additional 2 7 months throughout the crop year up to April Assuming an average weight increase of one pound per day over a total period of 4 7 months (141 days), the potential benefits due to grazing on wheat land would amount to $44 5 million Based on the expected occurrence of above normal precipitation two years out of twenty, benefits would equal $89 million

Wheat farmers could invest their capital in other areas in those years which the satellite system predicts below normal moisture It has been assumed that farmers could place their $125 per calf investment in other endeavors and receive a 4-1/2% return equal to $9 38 per animal In a year of below normal moisture the maximum reduction would be 1 3 million cattle Assuming no other significant costs assignable to cattle grazing, the benefits for the twenty-year period would equal $24 4 million (1 3 million cattle x $9 38 = $12 2 million x 2 = $24 4 million)

[1] Quantitative data in this section was developed from conversations with Mr R J Reierson, Colorado State Extension Service, Western Livestock Marketing Association, Denver, Colorado, and Mr Wilton Thomas at Kansas State University, Agronomy Department, Manhattan, Kansas

The total benefits for both above and below normal moisture conditions would equal $113 million in 20 years

3 Intermediate Fertilizing

The winter wheat farmers in the Northwest and Lower Plains may marginally affect output by intermediate fertilizing in the spring Normally, farmers will apply fertilizer at a rate that will be commensurate with moisture conditions and prevent fertilizer burn However, if it can be predicted that moisture will be above normal, more fertilizer can be applied with an increase in output that will be beneficial to the farmers

The Northwest wheat area was assumed to have above normal spring precipitation three years out of twenty and the Lower Plains four years out of twenty, based on Exhibit H-18

The increase in net returns per acre would be about $3 54 due to increased fertilizer application at planting time or in the spring based on an expected return of 7 bushels of wheat per 56 pounds of fertilizer applied in conjunction with an expected one inch of rain The net returns were computed as follows

Returns		
Marginal yield (7 bushesl at $1 52)	=	$10 64
Costs		
Fertilizer (56 lbs at 10)	=	5 60
Airplane application	=	1 50
Net Returns		$ 3.54

The gross benefits were estimated at $75 million in a given year The benefits were based on Northwest acres in winter wheat (2 5 million) plus the Lower Plains acres (18 6 million) for a total of 21 1 million acres at $3 54 equal to $74 7 million The frequency of this occurrence in the next 20 years would be three times in the Northwest and four times in the Lower Plains which would yield 20-year gross benefits of about $290 million

4 Custom Work

No dollar benefits were calculated due to the expected existence of a sensor-borne satellite system capable of improved weather forecasting Farmers could greatly benefit from real-time information as to the possibility of a potential local hailstorm or other natural event at harvest which requires speeding up harvesting It is possible to visualize increased use of present combine teams in potential storm damage areas where farmers would be willing to pay more to attract the combine teams into their area Afterwards, the combine teams could return to their regular seasonal harvesting, moving up through the Plains States

5 Total Dollar Benefits

The total potential undiscounted dollar benefits that would accrue to United States wheat producers in the 1971-1990 period are summarized in Exhibit H-19 The undiscounted benefits total $2,214 million in the 20 years including crop rotation $1811 million, cattle grazing $113 million, and intermediate fertilizing $290 million The average annual maximum benefit is $111 million

The potential annual benefits have been modified by the rates at which the satellite-assisted system has the capability to provide data and the rate at which farmers adopt the new technology and management practices The satellite capability rates are somewhat less in this area than in other benefit areas because the information generated depends heavily on the ability to predict weather Definite improvements will be made in the ability to correlate cumulative meteorological, snow pack, and soil moisture conditions through direct observations and inferences However, in the immediate future, the ability to advise farmers in the fall about the potential spring weather condtions is limited The farmer participation rate was developed following conversations with university researchers about the rate at which farmers adopt new technology such as new crop varieties, fertilizers, farm chemicals, etc.

The United States benefits were extrapolated to the rest of the free world, developed winter wheat producing countries Most of the

EXHIBIT H-19 SUMMARY OF POTENTIAL ANNUAL UNDISCOUNTED BENEFITS

Benefit Area	Basis for Benefits	Relevant Geographical Regions	Gross Benefits (1971-1990) Millions $
Crop Rotation	Save production costs of crop that would be lost	Lower Plains	1811
Graze Cattle	Increase in cattle in fall, winter and spring months	Western Kansas Texas Panhandle Parts of Oklahoma	113
Fertilizer	Intermediate fertilizing	Northwest Lower Plains	290
Custom Work	Reduce harvest loss due to inclement weather	Northwest Lower Plains Upper Plains	Not Investigated
		TOTAL GROSS BENEFITS	2214

United States benefits were calculated on the basis of acres, therefore, in the absence of a thorough study of winter wheat culture in other countries, a simple extrapolation based on the number of winter wheat acres was made The countries most likely to benefit include the West European countries (48,160 million acres), Argentina (12,884 million acres) and Oceania (20,510 million acres) for a total of 81,554 million acres of winter wheat in proportion to the United States winter wheat acreage (42,974 million acres) [1] The ratio of 81,554 million to 42,974 million is 1 9 Therefore the extrapolation of United States benefits to the free world developed winter wheat producing countries was on the basis of $111 million x 1 9 = $211 million The phasing of the satellite capability and farmer participation was done in much the same way as for the United States The world farmer participation rates increase at a slightly slower rate than for United States farmer participation This is in accordance with discussions on diffusion rates and also takes into account somewhat the problems of organizing a dissemination system It also accounts for the fact that not all winter wheat farmers elsewhere have the full range of alternatives open to United States farmers because they do not graze cattle or do not have the full range of crop options

The discounted benefits for both the United States and the other free world, developed wheat producing countries are summarized in Exhibit H-20

[1] Calculated for the year 1966/67 from International Wheat Council, World Wheat Statistics, (London, 1968) and U S Department of Agriculture, Economic Research Service, Food Grain Statistics Through 1967, Statistical Bulletin No 423, (Washington, April 1968)

EXHIBIT H-20 RATE AND AMOUNT OF BENEFITS THAT RESULT FROM FARMER OPTIONS, UNITED STATES AND WORLD

Rate and Amount of Benefits		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	20-Year Total
United States																						
Rate																						
Satellite Capability	Percent	5	7	10	15	20	25	30	35	40	45	50	50	50	50	50	50	50	50	50	50	
Agency Participation	Percent																					
Farmer Participation	Percent	10	20	30	50	70	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Mean Rate	Percent	8	14	20	33	45	58	60	63	65	68	70	70	70	70	70	70	70	70	70	70	
Annual Benefits																						
Undiscounted	Million dollars	9	16	22	37	50	64	67	70	61	75	78	78	78	78	78	78	78	78	78	78	1242
Discounted 7-1/2%	Million dollars	9	15	19	30	37	45	43	42	34	39	38	35	33	30	28	26	25	23	21	20	592
Discounted 10%	Million dollars	9	15	18	28	34	40	38	36	28	32	30	27	25	23	21	19	17	15	14	13	482
Discounted 12-1/2%	Million dollars	9	14	17	26	31	36	33	31	24	26	24	21	19	17	15	13	12	11	9	8	396
Other Free World, Developed Countries																						
Rate																						
Satellite Capability	Percent	5	7	10	15	20	25	30	35	40	45	50	50	50	50	50	50	50	50	50	50	
Agency Participation	Percent																					
Farmer Participation	Percent	10	20	30	50	55	60	65	70	74	78	80	82	84	85	86	88	90	90	90	90	
Mean Rate	Percent	8	14	20	33	38	47	47	53	57	61	65	66	67	68	68	69	70	70	70	70	
Annual Benefit																						
Undiscounted	Million dollars	17	30	12	70	80	99	99	112	120	129	137	139	141	143	143	146	148	148	148	148	2239
Discounted 7-1/2%	Million dollars	17	28	36	56	60	69	64	68	67	67	66	63	59	56	52	49	47	43	40	37	1044
Discounted 10%	Million dollars	17	27	35	53	55	61	56	57	56	55	53	49	45	41	38	35	32	29	27	24	845
Discounted 12-1/2%	Million dollars	17	27	33	49	50	55	49	49	47	45	42	38	34	31	27	25	22	20	18	16	694

VIII BENEFITS TO LDC'S AND U S FOREIGN ECONOMIC ASSISTANCE FROM STABILIZING FOODGRAIN PRODUCTION

A Role of Production Data in Economics Development

The direction of efforts of Less Developed Countries (LDC's) is to maximize agricultural production, particularly foodgrain production Agriculture is generally the largest sector of the economy, averaging about 40 percent for the important LDC's In recent years, the food-population deficit problem has shifted national plans to give more emphasis to agricultural development as compared with industrial development

Lack of accurate and timely data is a serious flaw in carrying out national development plans A Waterston of the World Bank in his comparative study of development ranks this as a prime factor P Streeter and M Lipton in their recent work, The Crisis in Indian Planning, evaluate this lack as the most important factor in the failure of Indian planning [1]

The benefits of a satellite information system accrue from providing quick and accurate estimates of foodgrain crop conditions as contrasted with the present system wherein the estimates are of poor quality (with no known statistical error) and with timing of first estimates lagging several months after the harvest The satellite information system can yield a faster rate of agricultural growth and gross domestic product for the LDC's and thus more efficient returns for U S economic assitance

The capability for adjusting cropping decisions using the satellite-assisted information system come from three main sources

[1] Albert Waterston, Development Planning Lessons of Experience, Johns Hopkins Press (Baltimore, 1965) and Paul Streeter and Michael Lipton (editor) The Crises of Indian Planning Economic Planning in the 1960's, Oxford University Press (New York, 1968)

1 Rice-wheat-corn-sorghum and millet substitution Most LDC's lie in the tropical or sub-tropical zone which allows almost continuous cropping In India, for example, the main rice crop harvested in October-November is followed closely by planting the main wheat crop (November-December) If the condition of the fall harvest (rice and other grains) can be determined in October, there is opportunity to adjust the spring crop (wheat and other grains) to offset declines in fall output It is probably not feasible to make a total offset since the fall crop accounts for two-thirds of annual foodgrain output and the spring crop the remainder Thus, it would take twice as much adjustment to equalize changes in the fall crop But since India is centrally planned, the national direction would be concerned with expanding wheat varieties for higher yields and importing and allocating more fertilizer

2 Adjustments, at national direction, for action by individual cultivators in response to weather factors such as the selection of crops in relation to soil-moisture conditions, the timing of fertilizer applications and other field and harvesting operations

3 Quick identification of stress and hail threats and action to prevent them

A satellite system for LDC's would need to cover other foodgrains in addition to wheat In East and South Asia, rice is the most important foodgrain, corn in Latin America, and sorghum and millets in Middle Africa Food deficits in these countries are largely determined by the outcome of these other foodgrains although deficits, if they are met, are usually with U S P.L 480 wheat

Foodgrain production in the LDC's is a major part of total agricultural production causing trends in agricultural and foodgrain production to be much the same Therefore, the benefits calculated from stabilizing foodgrain output can be subsumed to total agricultural production

Growth Rates, LDC's, 1953-1963[1]

Sector	Rate of Growth
Total agricultural production	3 1%
Total food production	3 0%
Total foodgrain production	3 0%
Wheat production	3 0%
Coarse grain production	3 1%
Rice production	2 9%

[1]Source Food and Agricultural Organization of the United Nations, Agricultural Commodities--Projections for 1975 and 1985, Volume I (Rome, 1967)

B. Effect on Economic Growth (U)

A group of 14 LDC's was used for calculating the benefits from damping declines in production These were the three most important countries in agricultural production in South America, The Near East and The Far East and the five most important in Africa where there is more fragmentation The countries represented from one-half to three-fourths of total agricultural output in each region (excluding developed countries such as Japan and the Republic of South Africa) Countries selected were

South America - Brazil, Argentina and Colombia
Near East - Turkey, Iran and UAR
Far East - India, Pakistan and Indonesia
Africa - Nigeria, Ethiopia, Ghana, Algeria and Morocco

In the LDC's the average annual fluctuations in wheat production are somewhat less than developed country fluctuations, i e , about 7 percent The satellite-assisted information system has the potential capability to measure all but about 2 percent of the total fluctuation at harvest time This makes it possible to mobilize national plans for dealing with about 5 percent of the fluctuation This 5 percent adjustment must further be modified by the rate at which farmers comply with government programs to adjust production plans both between cropping seasons and during early portions of the growing season The maximum potential rate of farmer compliance was estimated at 90 percent for this study

This rate was used on the basis of the following assumptions

1 Farmer response to production improvement practices is increasing as a result of experience, and improving education in agrarian development

2 Nearly all LDC's have national agricultural plans and intent to improve and refine them

3 The satellite-assisted system will provide the national planners better information and more information than previously available which will make possible the development of better programs that will result in high farmer response

4 The cumulative effect of the program over a period of years will result in high level response

This means that instead of being able to adjust the full 5 percent of annual fluctuation, adjustment ot 4 5 percent allowing for 90% farmer compliance, would be more reasonable In other terms, we are able to adjust, at most, 4 5 percent (or 65 percent) of the total 7 percent average fluctuation in annual wheat production

Foodgrain production indexes for the selected countries were calculated and then adjusted to reduce declines in production by 65 percent The change was computed as a ratio which was applied to food grain value in order to convert the index to growth in dollar terms These calculations are shown in Exhibit H-21

The regional gains in terms of percent and dollar terms as a result of damping declines by 65 percent are shown in the following table

EXHIBIT H-21 EFFECT OF FOOD GRAIN ADJUSTMENTS ON AGRICULTURAL GROWTH

Far East	Index [1/]	Food Grain Production Indexes (1957-59=100)[3] 1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	Average Index --	Increase Effected by Adjusted Index [2/]	Food Grain Value 1957-1959 (millions of dollars) [3/]	Average Annual Gain 1957-1959 (millions of dollars) [4/]	Average Increase for Area [5/]
India	Actual	103	105	112	115	110	118	123	104	104	132	112 6				
	Adjusted	103	105	112	115	113	118	123	116	112	132	114 9	1 0204	6892	140 6	
Pakistan	Actual	93	109	118	118	113	129	130	132	121	137	120 0				
	Adjusted	93	109	118	118	116	129	130	132	128	137	121 0	1 0083	975	8 1	
Indonesia	Actual	102	103	110	104	115	109	114	110	117	118	110 2				
	Adjusted	102	103	110	108	115	113	114	113	117	118	111 3	1 0100	602	6 0	1 8
Near East																
Turkey	Actual	102	94	107	96	142	120	99	106	119	129	107 4				
	Adjusted	102	99	107	103	102	120	113	106	119	129	110 0	1 0242	596	14 4	
Iran	Actual	96	105	100	103	105	119	109	116	124	141	111 8				
	Adjusted	96	105	103	103	105	119	115	116	124	141	112 7	1 0081	303	2 5	
U A R	Actual	96	102	106	97	124	123	122	119	126	132	114 7				
	Adjusted	96	102	106	103	124	123	122	121	126	132	115 5	1 0070	284	2 0	1 6
Latin America																
Brazil	Actual	95	100	113	120	126	132	135	165	133	154	127 3				
	Adjusted	95	100	113	120	126	132	135	165	154	154	129 4	1 0165	912	15 0	
Argentina	Actual	109	106	80	95	92	124	151	100	118	166	114 1				
	Adjusted	109	108	97	95	94	124	151	133	118	166	119 5	1 0413	436	20 5	
Colombia	Actual	105	104	115	110	126	115	125	136	132	128	119 6				
	Adjusted	105	104	115	113	126	122	125	136	135	131	121 2	1 0134	109	1 5	2 5
Africa																
Nigeria	Actual	98	102	106	99	115	114	122	101	123	106	108 6				
	Adjusted	98	102	106	104	115	115	122	115	123	117	111 6	1 0276	311	8 6	
Ethiopia	Actual	97	107	106	114	116	118	122	102	114	132	112 8				
	Adjusted	97	107	107	114	116	118	122	115	114	132	114 2	1 0124	268	3 3	

EXHIBIT H-21 (Continued)

Food Grain Production Indexes (1957-59=100)[3]

Africa (Cont)	Index[1/]	1958	1959	1960	1969	1962	1963	1964	1965	1966	1967	Average Index[3]	Increase Effected by Adjusted Index[2/]	Food Grain Value 1957-1959 (millions of dollars)[3/]	Average Annual Gain 1957-1959 (millions of dollars)[4]	Average Increase for Area[5/]
Ghana	Actual	100	100	94	100	101	102	100	100	101	114	101 2				
	Adjusted	100	100	108	100	101	102	101	100	101	114	102 7	1 0148	31 7	0 47	
Algeria	Actual	100	92	124	53	116	123	85	94	49	100	93 6				
	Adjusted	100	97	124	99	116	123	110	94	78	100	104 1	1 1122	117	13 1	
Morocco	Actual	131	99	107	55	116	121	111	118	67	103	102 8				
	Adjusted	131	120	107	89	116	121	117	118	100	103	112 2	1 0914	124	11 3	4 3

Notes (1) Adjusted' Figures are the actual figures adjusted to reduce declines by 65%
(2) Ratio of average adjusted index to average actual index
(3) Indices of Agricultural Production for the Near East (Unnumbered) Africa Indices of Agricultural Production (Unnumbered) Indices of Agricultural Production for the 20 Lation American Countries (ERS-Foreign 44) and The Far East and Oceania, Agricultural Data Book (ERS Foreign 189), U S Department of Agriculture, Economic Research Service
(4) Growth rate of effected increase applied to total Food Grain Value
(5) Total average annual gain as percent of total Food Grain Value for the area

Effect of Increased Growth Rate on Value of Agricultural Production

Region	Average Annual Gain in Agricult Prod Percent	Average Annual Gain in Value of Agric Prod 1957-1959 (Millions)
Far East	1 8	$294
Near East	1 6	73
Latin America	2 5	275
Africa	4 3	298
Total LDC's	2 6	$940

For the LDC's, this would mean a 2 6 percent improvement in average annual agricultural production, or an increase in value of agricultural production of $940 million a year (in constant 1957-1959 dollars)

During the period 1958-1967, total U S economic assistance averaged $3,485 million a year, $1,367 million for P L 480 grain shipments and economic assistance $2,118 In the fiscal year 1967, the total was $3,787 million, $1,538 million for P L 480 and $2,249 million for economic assistance. These expenditures are summarized in Exhibit H-22

A 2 6 percent improvement in agricultural performance of LDC's would be the equivalent of 1 0 percent in the total economy (40% in the agricultural sector) Thus, the maximum annual direct saving from total U S assistance would have been about $35 million per year in the past 10-year period

C Total Benefits

The benefits in this section, as in other portions of this appendix, have been calculated as maximum annual benefits These maximum benefits were then scaled according to the capability of the satellite and the participation rates of government agencies and farmers These rates were averaged and applied to the maximum annual benefit to derive a more realistic estimate of increasing annual benefits over the 1971-1990 period The annual benefits and 20-year totals are shown in Exhibit H-23 for both the LDC's and the United States

EXHIBIT H-22 U S FOREIGN ECONOMIC AID EXPENDITURES TO ALL COUNTRIES, 1958-1967

Year	P L 480[1] (Millions)	US/AID Economic Assistance[2] (Millions)
1958	$ 982	$ 1,620
1959	1,017	1,916
1960	1,116	1,866
1961	1,317	2,012
1962	1,496	2,508
1963	1,466	2,297
1964	1,494	2,136
1965	1,671	2,026
1966	1,574	2,545
1967	1,538	2,249
Total	$13,671	$21,175
Average	1,367	$ 2,118

Sources U S Department of Agriculture, Economic Research Service, Foreign Agricultural Trade of the United States, (Washington, November, 1968) and U S Department of State, Agency for International Development U S Economic Assistance Programs Administered by the Agency for International Development and Predecessor Agencies, April 3, 1948-June 30, 1967 (Washington, February 1968)

EXHIBIT H-23 RATE AND AMOUNT OF BENEFITS THAT RESULT FROM IMPROVED ECONOMIC GROWTH RATE IN LESS DEVELOPED COUNTRIES, SELECTED LDC's AND UNITED STATES, DISCOUNTED 7-1/2%, 10%, and 12-1/2%, 20 YEARS

Rate and Amount of Benefits	Unit	Year																				20-Year Total
		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	
Selected Less Developed Countries																						
Rate																						
Satellite Capability	Percent	25	63	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	Percent	1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	31	32	33	36	
Farmer Participation	Percent	10	20	30	50	55	60	65	70	74	78	80	82	84	85	86	88	90	90	90	90	
Mean Rate	Percent	12	28	44	52	54	57	59	61	63	65	66	68	69	70	71	72	73	74	74	75	
Annual Benefits																						
Undiscounted	Million dollars	113	263	414	489	507	534	554	573	592	611	620	639	649	658	667	677	686	696	696	705	11 343
Discounted 7-1/2%	Million dollars	113	245	358	394	380	372	359	345	332	319	301	288	272	257	242	229	216	204	189	178	5,593
Discounted 10%	Million dollars	113	239	342	367	346	332	313	294	276	259	239	224	207	191	176	162	149	138	125	115	4 607
Discounted 12 1/2%	*Million Dollars*	113	234	327	343	317	296	273	251	231	212	191	175	158	142	128	116	104	94	84	75	3 864
United States																						
Rate																						
Satellite Capability	Percent	(1)																				
Agency Participation	Percent	(1)																				
Farmer Participation	Percent	(1)																				
Mean Rate	Percent	12	28	44	52	54	57	59	61	63	65	66	68	69	70	71	72	73	74	74	75	
Annual Benefits																						
Undiscounted	Million dollars	4	10	16	19	19	21	21	22	23	23	24	24	25	25	26	26	26	27	27	27	435
Discounted 7-1/2%	Million dollars	4	9	14	15	14	15	14	13	13	12	12	11	10	10	9	9	8	8	7	7	214
Discounted 10%	Million dollars	4	9	13	14	13	13	12	11	11	10	9	8	8	7	7	6	6	5	5	4	175
Discounted 12-1/2%	Million dollars	4	9	13	13	12	12	10	10	9	8	7	7	6	5	5	4	4	4	3	3	148

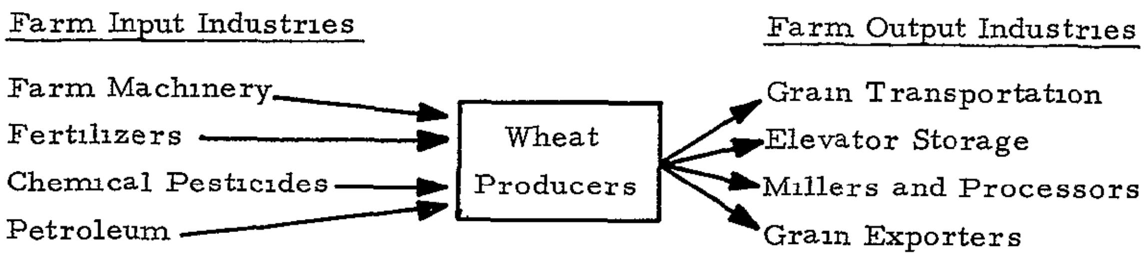
Note (1) Satellite rates were not calculated for the United States benefits because the United States benefits are returns to aid investment in the LDC's Therefore the United States benefits are a direct function of LDC benefits and the mean rates are identical

IX BENEFITS IN THE AGRIBUSINESS SECTOR

The objective of this analysis was to quantify the benefits accruing to the agribusiness sector in the form of (1) reduced storage costs of inventories through better estimation of demand, and (2) reduced costs of production by shifting operations to a more optimum point on the total average unit cost curve This approach proved to be feasible for three farm input industries--farm machinery manufacturing, fertilizer manufacturing, and pesticides manufacturing However, it was not used for the other agribusiness, principally, the farm output industries, because they do not have clearly quantifiable benefits within the current system

The identifiable industries in the wheat sector of the agricultural economy and the benefits and methodology used in the calculations or the reasons for excluding them from the benefit calculations are described below

Structure of the Agriculture Input and Output Industries



This diagrammatic scheme of farm input and farm output industries greatly oversimplifies the true situation because the actual structure of the industries is very complex Many industries are diversified, and others are vertically integrated, therefore, they are not neatly separated entities But they have been assumed to be separated for simplification of the benefit calculations

A Farm Machinery

Farm machinery and equipment sales are generally increasing due to the adoption of new technology by farmers, enlarged size of farms, and substitution of capital and machinery for labor Therefore, the longrun growth outlook for the industry is good The major problem faced by the industry is annual estimates of farm machinery sales so that optimal production decisions can be made to maximize income and minimize inventories One key factor in the sales of farm machinery is farm income in the year preceding the one in which sales are actually made Cromarty found that a 10 percent change in net farm income in t_o was followed by a 5 percent change (in the same direction) in farm machinery sales in t_1 [1] Therefore, it follows logically that if erroneous, high estimates of farm production, hence income, are made, that unexpected inventories will occur The satellite-assisted information system would enable better projections of farm production to be made and allow farm machinery and equipment manufacturers to more accurately gear production to expected farmer demand in the following year

The month of April was selected as the point for this analysis, on the assumption that this would allow lead time for making production plans for eventual sales to follow the harvest of the current crop and precede the fall planting of winter wheat The error in estimating wheat production for the month of April, as illustrated in Exhibit H-2, is about 15 percent Assuming that the farm equipment industry uses this projection for estimating demand for farm machinery, unnecessary capital investments and storage costs would be incurred

Income from wheat sales is about 5 6 percent of gross farm income [2] The assumption was made that this same relationship exists

---

[1] William A Cromarty, The Demand for Farm Machinery and Tractors, Agricultural Experiment Station, Michigan State University, East Lansing. Technical Bulletin 272 November, 1959

[2] Calculated from farm income data in Agricultural Statistics 1967.

for net farm income, also A 15 percent error in overestimating wheat production would result in an overestimation of total farm income of 0 84 percent With the Cromarty elasticity of 0 5, this would result in overestimation of machinery sales by 0 42 percent Applying this percentage to the average annual machinery inventory[1] of $592,646,000, an excess inventory of $2,489,000 would result

The satellite-assisted system, according to Exhibit H-2 would reduce the April estimate error to about 9 percent Using the same method of calculating inventory, the excess inventory under the improved system would be about $1,482,000 Excess inventory under the satellite-assisted system would be reduced by about $1,000,000 from the current system

The actual benefits are in the reduced storage costs and the opportunity cost of the capital invested in the inventory Industry economists estimate these costs as being equal to about 20 to 24 percent of the value of the inventory Using the midpoint of 22 percent, the storage costs and opportunity costs of holding excess inventory of $1 million would be 220,000 per year The total potential benefits over a 20-year period would be $880,000, based upon a frequency of one year in five [2]

The second major area of potential benefits in the farm machinery industry, that of shifting to a more optimum position on the cost curve as a result of increased demand from the wheat sector for farm machinery did not warrant in-depth study First, many farmers are overinvested in machinery and possess excess capacity which gives them the flexibility to meet short run changes in production Therefore, production changes as reflected back to manufacturers are damped Second, the general long run outlook for the industry is one of continued growth as farm size increases bringing about a demand for larger, more powerful machinery and farmers continue to substitute mechanization for labor. Third, the

---

[1] Calculated from 1958 and 1963 Census of Manufacturers

[2] Estimated from Leonard W. Schruben, Changes in Winter Wheat Crop Prospects In The United States During a Growing Season as Measured by Official Production Estimates, Agricultural Experiement Station, Kansas State College, Manhattan Technical Bulletin 95 July, 1958

cost position of the industry would be most affected if, in the short run, suddenly increased demand from the farm sector would necessitate additional production under the cyclic, or batch process For the reasons explained above, this is unlikely From the industry side, it is unlikely that significant opportunities for shifting occur Tractors and other self-propelled machinery account for over half of the value of domestic shipments Tractors are produced on a nearly continual basis, much like automobiles, with major manufacturers running more than one tractor assembly line Complicated assembly lines for other major machinery are left standing and never disassembled The manufacturers have found the labor cost too high and have substituted plant space for the start-up labor costs They find it possible to minimize these costs and inventories by starting and stopping the production line merely by shifting work crews from one location to another

B Fertilizer Manufacturing

Fertilizer manufacturing is a rapidly growing industry in the United States Production and consumption of the primary nutrients--nitrogen (N), phosphorus (P), and potassium (K)--have about doubled in the past ten years Farmer use of commercial fertilizer is increasing as a part of the general, widespread technological revolution in American agriculture Use of fertilizers on wheat is not as widespread, however, as on other crops, particularly corn and soybeans A 1964 survey by the Department of Agriculture reported that about 54 percent of wheat acres harvested were fertilized [1] The long run outlook for increased use of fertilizers is favorable

The principal contribution of the satellite information system is in early projections of acres planted which would allow manufacturers to better anticipate demand and avoid surplus stocks in short run situations

[1] D B Ibach and J R Adams, Fertilizer Use in the United States By Crops and Areas, Economic Research Service and Statistical Reporting Service, U S Department of Agriculture, Washington, D C Statistical Bulletin No 408 August, 1967

In calculating benefits, the effect of changes in fertilizer use in relation to changes in wheat acreages was computed as follows: The U S average rate of application of primary nutrients (N, P, K) on wheat is about 71 pounds per acre About 54 percent of the wheat acres harvested are fertilized. The rate of application is thus 3,834 pounds (1 9 tons) per 100 acres of wheat harvested During the 10 year period 1959-1968, wheat acres harvested decreased 5 times with a mean decrease of 5 million acres The amount of wheat that would have been consumed on those 5 million acres is 95,000 tons Decreases in wheat acres harvested occurred simultaneously with increases in fertilizer stock levels 2 times in a 9 year period

Experts on inventory control and warehousing suggest that storage costs of approximately 10 percent of the value of the product would be reasonable estimates Manufacturers' prices for the three principal nutrients averaged $64 per short ton in the 1963 Census of Manufacturers This would be a storage charge of about $6.40 per ton for a period of one year Storage costs for the 95,000 tons are about $608,000 However, since fertilizer is applied in two peak periods (March, April, May) and (September, October), a 6 month period for storage would be more realistic That reduces the storage cost to about $304,000 Again, that estimate is somewhat inflated because it includes handling costs and other variables which are incurred regardless of the amount of time in storage

Based on historical evidence, this storage cost would have occured 2 times in a 9 year period, or 4 4 times in 20 years The total benefit over a 20 year period would be $1,338,000

In addition to the storage cost, there is interest foregone on the investment in stock The 95,000 tons at $64 per ton = $6,080,000 The interest rate on $6,080,000 at 7 5 percent = $456,000 per year, or $228,000 for the 6 month period Occuring 4.4 times in 20 years, that would be a potential total of about $1 million

In summary, the potential benefits from reducing excess stocks in the fertilizer manufacturing industry for the 20 year period would be $1,338,000 for storage and $1 million opportunity costs

The second objective of quantifying benefits from shifting operations to a more optimum point on the total average unit cost curve was not realized The best information available on the unit costs of producing fertilizers indicates that the industry as a whole is operating at the rate of about 1,000 tons per day which puts it at a low, flat portion of the curve [1] Exhibit H-24 is a composite of production curves for producing anhydrous ammonia (nitrogen) and granular superphosphate (phosphorous) The assumption was made that the costs for granular superphosphate were not unlike those of potassium for which no cost curves were available

Thus shifts in the cost functions of the firms did not seem to be a particularly fruitful source of benefits

C Chemical Pesticide Manufacturing

Herbicides are the principal chemical pesticides used on wheat While the use of chemicals is growing as general farm practice, the extent of use on wheat as a general weed control practice is not great Of the 54 3 million acres of wheat planted in 1966, only 28 percent of 15 2 million acres were treated with herbicides Wheat farmers spent 9 5 million for materials and an additional $7.8 million for custom application of the sprays The principal herbicide in use is 2,4-D for which the stocks have been dropping because of heavy demands by the Defense Department for use in Vietnam

[1] Data obtained from John F Gale, "Fertilizers" in Structure of Six Farm Input Industries, Economic Research Service, U S Department of Agriculture, Washington, D C ERS-357, January, 1968, and David W Bixby, Delbert L Rucker, and Samuel L Tisdale, Phosphatic Fertilizers, Properties and Processes, The Sulphur Institute, Washington, D C Technical Bulletin No 8, October, 1966

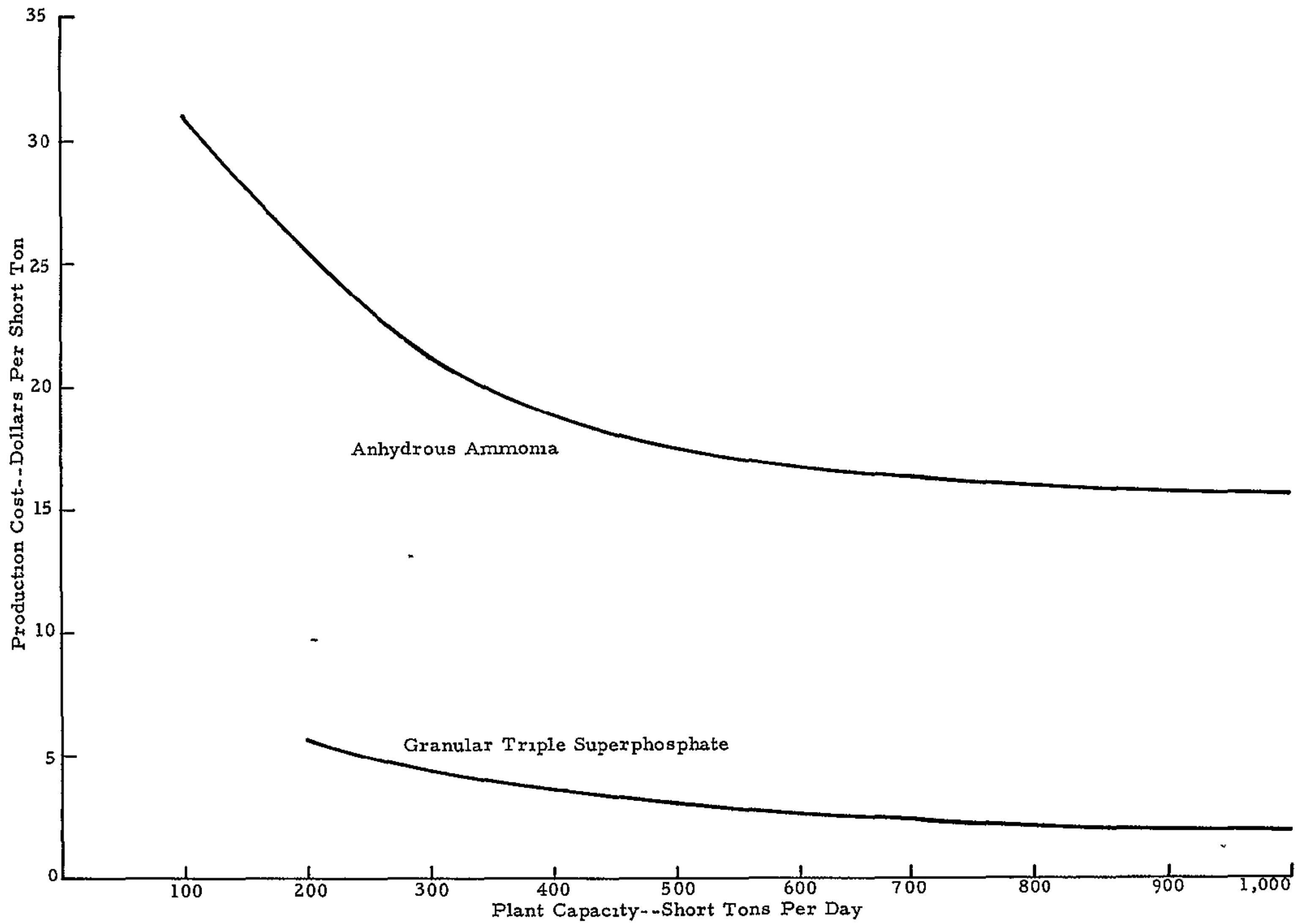


EXHIBIT H-24 COST OF PRODUCING (RAW MATERIALS EXCLUDED) NITROGEN AND PHOSPHORUS

Again, the principal area of benefit is in reduced costs of stocks which may appear in the short run as the result of imprecise estimates of farm demands The application rates for pesticides are on a per acre basis, and the manufacturers would benefit from accurate early season estimates of the number of acres planted Since there is a variation in wheat acres, there is also likely to be a variation in demand in relation to the acres.

Only 28 percent of wheat acres harvested are treated with herbicides The average rate of herbicide application on wheat is about 0 5 pounds per acre The rate of herbicide consumption is about 14 pounds per 100 acres The mean downward shift in wheat acres in the 1960's was 5 million acres about 5 times in 10 years The amount of herbicide consumption foregone on the 5 million acres which was carried as stock was 700,000 pounds at about $504,000

Again, specific storage costs were unavailable Estimates of 10 percent of the stock value were used at the rate of 7 cents per pound The storage costs for 700,000 pounds would be $49,000 per year Declines in wheat acres harvested were associated with increases in pesticide stocks two of 5 years in the 1960's. This would be at the rate of 8 in 20 years At that rate, costs of $49,000 would occur 8 times in 20 years for a potential total of $392,000

The interest rate opportunity cost on the $504,000 investment at 7 5 percent would be $37,8000 8 times in 20 years for a potential total of $302,400 during the 20 year period

In summary the potential benefits to be gained from a better information system that would eliminate unnecessary pesticide stocks are $392,000 in storage costs saved and $302,400, in the form of opportunity cost of the capital invested in the stocks

The second objective of quantifying benefits that would result from shifting operations to a more optimum point on the total average unit cost curve was not explored in great detail The representative costs were not available Indications from the literature are that the increased demand for herbicides, and other chemical pesticides, has increased to the point where plants are now operating on a year-around basis This would eliminate the major savings of reduced start-up costs should plants be operating on a batch basis and have to produce more than one batch a year because of underestimated demand

D Total Benefits

The total potential benefits for the 1971-1990 period are

Farm Machinery	
Storage and opportunity costs	$ 880,000
Fertilizer Manufacturing	
Storage costs	1,338,000
Opportunity costs	1,000,000
Chemical Pesticide Manufacturing	
Storage costs	392,000
Opportunity costs	302,400
	$3,912,000

For the 20-year period, the maximum annual benefit would be $196,000 This figure was modified by the satellite capability rate and the rate at which manufacturers might adopt the new information in their managerial processes The results of these rates as applied to the maximum annual rate are shown in Exhibit H-25 as undiscounted and discounted data

EXHIBIT H-25 RATE AND AMOUNT OF BENEFITS ACCRUING TO AGRIBUSINESS, UNITED STATES, DISCOUNTED 7-1/2%, 10%, AND 12-1/2%, 20 YEARS

Rate and Amount of Benefits	Unit	Year																				
		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	20-Year Total
Rate																						
Satellite Capability	Percent	90	95	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	Percent	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Farmer Participation	Percent	10	20	30	50	70	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Mean Rate	Percent	50	57	65	75	85	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	
Annual Benefits																						
Undiscounted	Thousand dollars	98 000	117,720	127 400	147 000	167,000	186 000	186,000	186 000	186 000	186 000	186 000	186 000	186 000	186,000	186 000	186,000	186 000	186 000	186 000	186 000	3 447 120
Discounted 7-1/2%	Thousand dollars	98 000	103 922	110 239	118 335	125,050	129 568	120 528	112,121	104 290	97,018	90,247	83 942	78,083	72 633	67 574	62,849	58 460	54 386	50 592	47 058	1784,895
Discounted 10%	Thousand dollars	98,000	101 564	105,283	110 441	114,061	115 487	104,997	95,455	86,769	78,882	71,703	65 193	59,260	53,884	48 974	44,528	40 474	36,791	33 461	30 411	1 495 618
Discounted 12-1/2%	Thousand dollars	98,000	99 308	100,659	103 238	104,258	103 211	91 754	81,561	72 484	64,430	57 267	50 908	45 254	40,232	35 749	31 787	28 253	25 110	22 320	19 846	1 275 629

APPENDIX I

WHEAT RUST CONTROL

PRECEDING PAGE BLANK NOT FILMED

I HYPOTHETICAL TECHNIQUE FOR PREDICTING RUST SEVERITY AT HARVEST

A possible technique for predicting the severity of rust at harvest is described below With further research it may be possible to better estimate the variables upon which this technique depends

1. the time required for each generation of pustules to develop, which would be based upon the variety of wheat, the race of rust, and the moisture and temperature conditions after inoculation,
2. the spore germination rate or the number of spores from pustules produced locally which would re-infect the local wheat field, this could also be estimated from predictions of moisture and temperature conditions,
3. the intensity of the initial dosage of spores delivered to each uninfected plant, this could be estimated from the intensity of spore concentrations in the air

An essential requirement of research is the establishment of a clear correlation between severity at harvest and damage to the crop This subject is discussed in detail by Van der Plank, [1] but no general functional relationship between severity and loss of yield could be specified with the limited data available Severities of 75% or higher were considered to be equivalent to 100% damage At lower severities, however, the degree of loss of yield could not be stated in genetic terms

A. Factors Influencing Severity of Rust at Harvest

1. Time before harvest for rust to develop
2. Time required for each generation of pustules to develop (i.e , days from contamination to appearance of pustules)

[1] J.E Van der Plank, Plant Diseases, Epidemics and Control, Academic Press (New York, 1963)

3 Spore germination rate

4 Intensity of initial dosage of uninfected plant

1 Example 1

It is forecast that spore-laden rain will contaminate farmer Brown's wheat tomorrow, 95 days before his planned harvest date Because of the historical climate in his area (modified by long range weather forecast) it is assumed that rust pustules will appear 16 days hence Again, historical climate (or long range weather) allows an assumption that each subsequent generation of spores will germinate at a rate which doubles the number of pustules of each generation If the initial innoculum, by spores delivered by the forecasted rain, will be light and cause only ten pustules per plant (after 16 days), farmer Brown's wheat will have 30% rust severity at harvest if he does not spray after the rain

If he sprays after the rain he will limit his severity at harvest (from that particular contamination) to 1% if, as predicted, ten pustules per plant appear The following sequence of events, for Example 1 should be followed in Exhibit I-1

A = 95 days before harvest

B = 16 days per rust generation

C = 2 (pustules double)

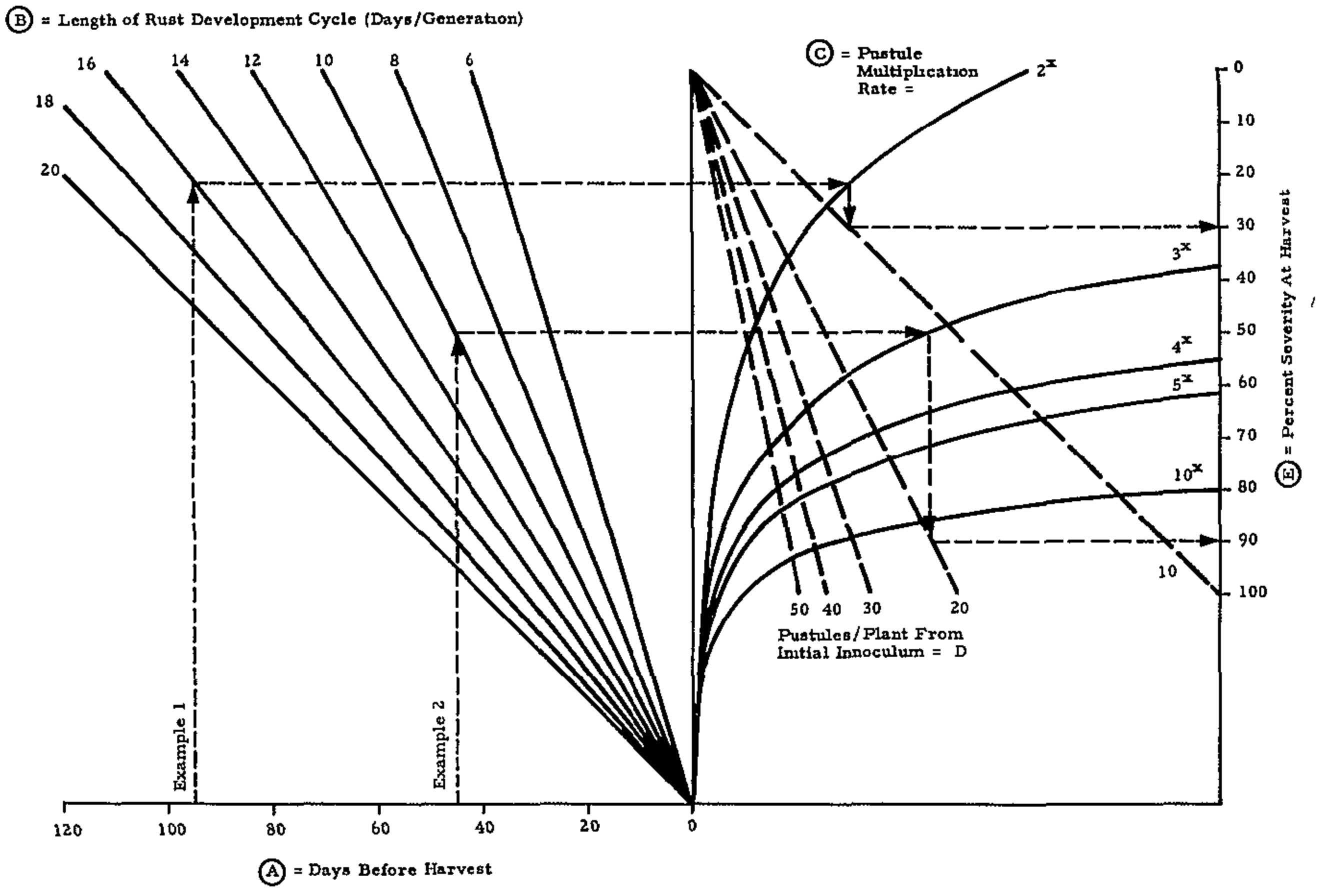
D = 10 pustules/plant appear

E = 30% severity

2 Example 2

Farmer Jones is 45 days before harvest and lives in a region where B is apt to be only 10 days and C is such to triple pustules from generation to generation If Farmer Jones receives an innoculum of 20 pustules from the 1st generation he will have 90% severity at harvest if he does not spray, and only 2% if he does The following sequence of events for Example 2 should be followed in Exhibit I-1

EXHIBIT I-1 TECHNIQUE FOR DETERMINING RUST SEVERITY AT HARVEST



A = 45 days before harvest

B = 10 days per rust generation

C = 3 (pustules triple)

D = 20 pustules/plant appear

E = 90% severity

3 Application of Technique

(1) Calculate from detected stage of growth as verified by observed cumulative weather

(2) Derive historical values for individual areas based on local climate and update based on long range weather forecast

(3) Derive localized values from research or assume nominal 2^x for threshhold damage estimates or assume historical value and update based on long range weather forecast

(4) Derive from sensed spore cloud density, or derive from characteristics of spore blow away pattern downwind of detected hot spot, or assume 10 for threshhold estimates

(5) Convert percent severity at harvest into equivalent effects on anticipated yield

II STRATEGY FOR CONTROL OF WHEAT RUST

The most extensive attempt at control of wheat stem and leaf rust has been in the breeding of resistant varieties This strategy, however, has not been completely successful although it has helped to control the disease The incomplete success in breeding immune plants rests on the following conditions.

1. The resistance bred into the plant is associated with single genes Thus, for a plant to be resistant to a given race of rust, the resistance is bred in through a single gene When a different race of rust appears, the plant is likely not to be resistant to the new race,
2. Even plants with resistance bred against given rust races will have different degrees of resistance depending upon the cultural practices and the weather conditions which prevail at the time of infection,
3. The rust fungi has the ability to produce mutants, i e , new races of rust, which defy the immunity which has previously been bred into the wheat plants

Thus, although the breeding of resistant varieties has managed to control many races of rust and the losses accruing from them, serious crop losses still occur when a new race of rust occurs As late as 1965, 45% of the North Dakota spring wheat crop was destroyed by rust Until broad spectrum resistance to rust can be accomplished rather than resistance by individual gene type, rust epidemics will continue to threaten wheat crops

A second strategy is biological control whereby pathogens, which are not injurious to the wheat crop, are introduced to destroy the rust pathogen in the infected plant USDA plant pathologists indicate that such pathogens exist but, as yet, no successful application has been undertaken

A Stem Rust

The seriousness of a wheat rust infection is dependent on light, temperature, and moisture conditions The approximate ranges of these conditions at various stages in spore development are summarized in Exhibit I-2

A strategy which has been employed quite successfully in controlling the wintering over of stem rust in the northern areas has been the destruction of the alternate host of the rust pathogen, barberry Prior to the destruction of the barberry, the rust pathogen would overwinter in these bushes as an alternate host and then appear in the spring. The rust would then spread to wheat crops and infect them Recently, however, a program of barberry eradication has been almost 100% effective Thus, rust which, at one point would winter in the producing states, now must go through a geographical cycle of wintering in the south and summering in the north This movement is completed by spore dispersion by the southerly winds in the spring and northerly winds in the late summer and fall Severe drought condtions, extremely hot summers and severe winter weather tends to break this geographic cycle and diminish the infestation of rust in the following season Rust spores seldom survive extremely hot summers, do not germinate in droughts and seldom winter at latitutdes above 35^{o} Leaf rust however, will winter above this latitude if it infects winter wheat plants in the fall since its tolerance tends to be approximately that of the host plant

It may be possible at some point in the future to help break this geographic cycle by controlling the pathogen in its winter habitat The use of herbicides on alternate wintering hosts, mostly other grasses, and perhaps on infected winter wheat plants themselves in the wintering areas, may decrease the amount of inoculum originating in the southern states

A desirable method of chemical control of the pathogen would be the use of a systemic spray which would prevent the pathogen from penetrating or surviving in a host plant This would completely disrupt the life cycle of the pathogen and would eventually provide almost complete control of the disease There are systemic sprays which are effective at the present time A single treatment with the chemical will penetrate the plant and give long-term protection against the invading pathogen However, to date, the systemics have not been approved by the Food and Drug Administration because traces of undesired substances have appeared in the kernels of wheat which was sprayed with the systemics Thus, crops which are sprayed with the systemic are not marketable

Protectant fungicides, i e , chemicals which are sprayed on the plant to kill the rust spores upon contact, offer the best control strategy at the present time If applied at the appropriate times protectant fungicides give high levels of control of the pathogen and prevent wheat rust epidemics from developing The drawbacks of protectant fungicides are that they control only the pathogen which is outside of the plant, they have a relatively short residual period, and they can be washed off the plant by heavy rains Thus, a single application of a protectant fungicide, probably will not protect the plant throughout the growing season However, if the protectant is applied at the proper time in terms of the stage of the plant growth and the development of the disease, it will provide sufficient protection to prevent widespread damage to the wheat fields Protectant fungicides are most effective if applied before the spore arrival However, if they are applied so as to arrest the development of the disease prior to the heading stage in the growth of the plant, or to arrest the development of rust epidemics past this stage, they will give favorable results

With the satellite system, the effectiveness of protectant fungicide control will be greatly improved. Starting our strategy in the wintering phase of the rust cycle, the satellite will sense changes in plant vigor which are due to rust infections The location and intensity of these infected areas can be monitored and ground truth checking can identify the rust races Identification of the rust races prevalent in the wintering areas will enable producers in the spring wheat areas to select the appropriate resistant wheat varieties for maximum initial protection, if sufficient seed of resistant varieties is available. Wintering conditions

EXHIBIT I-2 ENVIRONMENTAL FACTORS IN WHEAT STEM RUST INFECTION

CONDITIONS	SPORE SURVIVAL	PRE-PENETRATION (GERMINATION & APPRESSORIUM)	PENETRATION	DEVELOPMENT	SPREAD/BLOW-AWAY
OPTIMUM	Light Minimal Temperature 40°F Moisture <40% Rel Hum Host NA Spore may live 2 weeks under these conditions	Light Minimal Temperature 60°-70°F Moisture Free 8 hrs Host NA Spore may germinate in 2-4 hours Appressori forms in 4-8 hours	Light >500 <5000 F C Temperature 85° F Moisture Free - slow dry Host Any host 2-4 hours drying time with high humidity	Light Sunlight Temperature 70° F Moisture From host Host Non-resistant 10 days to develop spores	High wind speed Unstable dry air with convective currents carrying spores aloft Rain showers downwind to deposit spores
ADEQUATE	Light <400 Foot Candles Temperature <90°, >32° Moisture NA Host NA Spore will survive and germinate but will lose viability sooner	Light <300 F C Temperature 50°-80° Moisture Free > 4 hrs Host NA Germination in 5 to 7 hrs	Light >500 <5000 F C Temperature <95° >60° Moisture Rel Hum >60% Host Any host	Light Overcast Temperature <90°, >40° Moisture From living host Host Partial resistance 10 to 30 days to develop spores	Light wind Delivery Gravity Air Subsidence Light Rain
INADEQUATE	Light Direct sun Temperature <32°F, >90° Moisture NA Host NA	Light 1000 F C Temperature <40°F, >80° Moisture Dry Host None needed	Light 500 F C Temperature <60°, >95° Moisture Dry Host No condition relevant Rapid drying after appressori form will prevent penetration	Light NA Temperature <90°, >32° Moisture None from host Host Immune or dead	Wind -- Dead calm Heavy rains will wash away spores at point of infection

FOLDOUT FRAME

FOLDOUT FRAME

2

will then be monitored to determine the degree to which they are favorable to the rust pathogen In those areas where conditions are particularly favorable, ground truth will watch the development of the pathogen and determine the timing of their change from the mycelium or wintering stage to the urideal stage When the urideospores begin to be produced, conditions will be monitored to determine the probable development of spore clouds in the infected areas Spore dissemination is very limited when the humidity in the infected areas is high, but when extended periods of dry weather with high winds or surface turbulence prevail, spore clouds are likely to enter the troposphere and move with the prevailing winds The satellite will monitor the direction and speed of the prevailing winds Producers in areas in the path of the spore cloud where precipitation is likely to occur will be given advance warning of the probability of rust infection Treatment with fungicides will then protect the crops from initial inoculation, or control the speed of the disease development if initial inoculation has taken place before treatment

The interactions become complex since the development of rust epidemics depends upon the so-called "disease square", i e , the stage of growth and susceptibility of the host, the presence, type, race and virulity of the pathogen, the existing environmental conditions, and the type and timing of fungicide application However, with improved information from the satellite system, the probabilities of controlling the disease or preventing epidemics by protectant spraying is much improved

B Leaf Rust

For rust that infects the newly planted winter wheat crops in the fall of the year and carries through the winter, the strategy will be slightly different Again, the satellite will sense the location and intensity of infection in the winter wheat crop Ground truths will identify the race which is present and give the lead time to producers in the spring wheat areas Simultaneously, the farmers in the infected areas will be kept informed as to the seriousness of the infection so that they can make decisions regarding whether to (1) graze their crop "into the ground" and not raise a crop of grain in the spring, (2) plow the crop in the fall and plant a spring crop in its place, or, simply (3) monitor the wintering condition of the wheat and the pathogen with the possibility of controlling the epidemic in the spring until the stage of plant growth is such that yield will not be seriously affected Since the conditions necessary for the fall establishment of rust in winter wheat are also the conditions which result in a good volunteer crop of wheat, the farmer should be advised to plow under the infected volunteer crops in the fall, or at least, prior to the pathogen's emergence from its wintering mycelium stage

Since the location and race of the pathogen will be known, ground truth should monitor the rust carefully and determine when the mycelium stage turns into the urideal stage At this time the satellite will be monitoring the environmental conditions and advising farmers in the northward production areas as to the probabilities of serious rust infections. This again will provide a lead time to the farmers to make arrangements for necessary chemical protectant fungicide treatment

Another strategy, which may be useful in given years in local areas where the infection is particularly serious, is the treatment of the crop with a herbicide which will kill the host plants and thus kill the rust Such a program is rational in that, by destroying the centers of infection, the amount of inoculum which will move into uninfected areas will be decreased Government support payments for such a program might eventually be feasible.

Providing forecasts to the producer prior to the planting season will enable him to make improved decisions on the type or variety of wheat to plant, or whether to plant wheat at all or go to some alternative crop not affected by rust Once the wheat is in the ground, forecasting will allow him to make improved decisions on whether to treat with the protectant fungicide If infection does not occur before the critical stages in the growth of the plant, the forecast may prevent him from making unnecessary chemical fungicide treatments

The critical period in the central winter wheat areas for leaf rust normally ends around May 20 after heading has occurred The critical period for stem rust extends perhaps ten days beyond this date In the northern winter wheat areas, these same periods would likely end June 15 for leaf rust and perhaps ten days later for stem rust In the northern spring wheat areas the critical date for leaf rust is approximately June 20, for stem rust it is July 1 If serious infection of rust has not occurred before these critical periods, then the necessity for chemical control of the disease is greatly diminished

The important factors in determining whether a farmer will sustain loss from rust in a given year are weather conditions, mass air movements, the time and amount of the original infection, rust races present, and wheat varieties grown In the next section, III, a rust spread scenario is presented, showing the influence of these factors on the spread of the disease In the following section, IV, a second scenario depicting rust observation, analysis and control is presented The strategy outlined in this second scenario, based on the satellite system, will provide information on the critical factors to the producer and allow him to make decisions on chemical fungicide control A summary of the significant events in the National Rust Spread Scenario and the Rust Observation, Analysis and Control Scenario is outlined in Exhibit I-3

EXHIBIT I-3 SUMMARY OF EVENTS IN RUST SPREAD AND RUST CONTROL SCENARIOS

Phase Relative to Shawnee and Ford Counties	Time	Event From Scenario	Component of Model Affected by This Event
Post-Harvest	Aug 1 - Aug 15	Heavy wheat rust infection in northern U S and in Canada and on volunteer grasses in Central and southern U S and in Mexico Most prevalent rust is identified as stem rust 15-B	Location of rust Type of rust Race of rust Intensity and size of potential spore clouds Probable damage to wheat Confirmation, assessment and prediction
Post-Harvest	Aug 10 - Aug 15	Dry weather in northern U S and Canada	Soil moisture Spore cloud development
Post-Harvest	Aug 10 - Aug 15	Local convection carries spores into the air over parts of U S and Canada	Spore cloud development
Post-Harvest	Aug 16 - Aug 17	Canadian air mass with northerly winds and rain crosses U S Rain delivers spores to volunteer grasses	Soil moisture Winds to move spores Location of rains in forecast Delivery of spores
Post-Harvest	Aug 18 - Aug 25	Temperature of volunteer grasses in some areas increases Weather is warm and moist	Location of rust Assess growth of rust
Post-Harvest	Sep 10 - Sep 20	Dry weather over Great Plains Temperatures of plants in large areas of Great Plains have increased Local convection carries spores into the air	Soil moisture Size and intensity of spore concentration Spore cloud development
Post-Harvest	Sep 20 - Sep 22	Air mass with northerly winds and rain carries spores into Texas and Mexico Rains deliver spores to grasses	Winds to move spore cloud Location of rains within wind trajectory Delivery of spores
Planting	Sep 1 - Nov 1	Winter wheat is planted and grows until vernalization Varieties in Shawnee and Ford are X, Y, and I	Wheat areas Variety of wheat Stage of growth Probable date of harvest
Post-Planting to Growing Season	Oct 1 - April 10	Fall and winter weather includes above normal precipitation and higher than normal temperatures in Mexico and Texas	Probable damage Soil moisture

EXHIBIT I-3 (Continued)

Phase Relative to Shawnee and Ford Counties	Time	Event From Scenario	Component of Model Affected by This Event
Post-Planting to Growing Season	Feb 1 - April 10	Heavy rust infection in Mexico and Texas over large areas	Location of rust Intensity and size of probable spore concentration
Post-Planting to Growing Season	Feb 1 - April 10	Most prevalent form of rust is stem rust 15-B to which varieties X, Y, and I are susceptible	Type and race of rust
Post-Planting to Growing Season	Oct 1 - March 10	Fall and winter in central and northern Great Plains include above normal precipitation	Soil moisture
Growing Season	March 1	Winter wheat emerges in Shawnee and Ford	Wheat areas Stage of growth of wheat Probable date of harvest Probable damage from rust
Growing Season	Feb 10 - April 10	Wheat areas of Kansas and northern Great Plains experience below normal temperatures Harvest is predicted for June 17	Stage of growth of wheat Probable date of harvest Probable damage from rust
Growing Season	March 27 - March 29	Heavy snowfall occurs in the spring wheat area causing late spring wheat planting	Stage of growth of wheat
Growing Season	April 2 - April 10	Dry weather over Mexico and Texas Local convection carries rust into the air	Soil moisture Spore Cloud Development
Growing Season	April 6 - April 12	Air mass from Mexico moves north across the Great Plains Rains are predicted to deliver spores to growing winter wheat in Oklahoma and Kansas	Winds to move spores Location of rains within wind trajectory Delivery of spores

III NATIONAL RUST SPREAD SCENARIO

By 15 August, wheat stem rust 15-B had reached a severity of 100 percent over large areas of Alberta, Manitoba and Saskatchewan and had infected parts of Alaska This widespread epidemic of rust in these northern areas was attributed to (a) severe infections in the United States, (b) an above normal number of warm nights and rains, and (c) to the planting of most wheat fields to hard red varieties which were susceptible to 15-B

On 16 August a frontal system began to move southward from Canada accompanied by high winds and rain over much of the Great Plains The rust spores from the infected wheat in Canada, and from rust which had infected volunteer grasses in the United States, were carried southward where they infected volunteer grasses, barley, and early-sown wheat in the Great Plains This infection of early-sown wheat did not significantly damage the crop, but served as a source for spores which were blown southward across the Great Plains into Texas and Mexico A general freeze in late November eliminated most of the remaining host plants north of Fort Worth

During the winter, which had above normal temperatures and rains in Mexico and Texas, stem rust infected large areas Infection was especially heavy in those areas which were irrigated, probably because these fields provided more moisture for the rust than did the dry land farms The farmers in Mexico and Texas had anticipated a heavy rust infection by race 15-B, but there was little they could do to protect their crops Sufficient seed of varieties resistant to 15-B was not yet available, and the farmers chose not to spray their plants with protectants The available protectant sprays lose their efficacy within two weeks and rain washes them from the leaves of wheat plants Not knowing where and when the rust spores would arrive, farmers were unwilling to invest in spraying operations Also, much of the Texas wheat was intended for grazing Rust does not significantly damage the grazing value of wheat, and the farmers who grew wheat for this purpose could only raise their costs by spraying

In early April, southerly winds transported rust spores northward from Mexico and Texas The volume of spores in the air increased very rapidly because dry weather conditions facilitated blowing of spores into the air These spores were carried over Oklahoma and Kansas where they were deposited in large quantities by rains during early morning of April 12 Following the rain, a body of warm air moved in, bringing persistent nighttime temperature as high as 65° in Kansas, which is above normal Daytime temperatures as high as 85° were noted on April 13 The unseasonably high night and day temperatures, combined with plentiful moisture remaining from the early morning rain on April 12, provided an environment uniquely favorable for the pre-penetration and penetration stages of rust development By April 14 large areas of Oklahoma and Kansas were infected with rust

The rust which infected wheat in Kansas and Oklahoma during the period April 12-14 developed rapidly Pathologists attributed this rapid development not only to the 70-75° weather which persisted after April 15, but also to the large amount of moisture which had collected in the soil because of fall and winter precipitation Because of the unique combination of weather conditions at the time when the spores were infecting the wheat and afterward, the rust spores delivered on April 12 yielded pustules on April 27

The early pustules caused reinfection of wheat plants and local spread of stem rust in Kansas Night temperatures continued higher than normal, with lows averaging 60° during May, and daytime highs averaging 80°, thus providing a greater than normal number of hours with temperatures higher than 70° Under these conditions rust development continued rapidly The third generation of pustules appeared on 12 May These pustules served as the source for an irregular spore cloud which developed as a result of local turbulence in northern Kansas on 13 May The spore cloud moved northward and crossed a rain shower pattern in the Red River Valley north of Fargo, North Dakota on 15 May

This delivery of spores to Fargo on May 15 was unusually early in absolute terms, and also relative to the growth of the wheat Because of a heavy snowfall in late March, spring wheat farmers in the northern great plains had been forced to postpone planting until April 10 By May 15, when the stem rust spores arrived, the wheat plants had not yet reached even the tillering stage, and farmers estimated that the crop would require 75-85 days before harvest With this much time available for the development of rust, the danger of heavy rust damage to spring wheat in the Red River Valley was very great

By 15 May there was a general rust epidemic in the central winter wheat area In Texas, where wheat had passed the heading stage, severities were higher than 10 percent in some areas As far north as Topeka, severities of 1 percent were common Farmers attributed this severe epidemic to the unusually warm and wet weather conditions and the virulence of 15-B relative to the varieties of wheat which they had planted.

Widespread inoculation of the spring wheat area did not occur until after June 1 when local infection and reinfection in the winter wheat area had reached high levels During June, however, as winter wheat farmers began harvesting operations, and ground temperatures rose, large numbers of spores were carried high into the air by convection These spores comprised a spore cloud which moved across the Great Plains and into Canada Local rains delivered spores from this cloud over large areas Farms which were still 40-50 days from harvest were threatened by this June inoculation in those areas which had daytime temperatures in the $70-85^{\circ}$ range, and nights with 60° temperatures, with 4 hours of free moisture The northern areas were also threatened by local infection from the Red River Valley, which had produced enough pustules by June 15 to be considered a source area

By June 15 there was a severe epidemic of rust as far north as the Canadian border, in all areas where moisture was sufficient Especially hard-hit was the Red River Valley area where the free moisture level was exceptionally high

By June 15, Oklahoma and Kansas reported losses of up to 100 percent on some fields, with the Statewide total amounting to 11 percent The harvest in Nebraska was completed by 1 July, and the total losses amounted to 13 percent North Dakota, South Dakota, and Minnesota were not able to complete harvesting until 10 August because of the late planting time By this time, a large area of the Red River Valley had rust losses of 100 percent, with the total loss for the state comprising 18 percent of the crop

Conditions favorable to rust obtained in Manitoba and Saskatchewan, and by 15 August severity also had reached 100 percent over large areas in those Provinces

IV RUST OBSERVATION, ANALYSIS AND CONTROL SCENARIO

In early April, the satellite-supported Rust Observation Analysis, and Control Headquarters (ROACH) and its ground surveillance extensions monitored conditions indicating probable development of a spore cloud in Mexico and Texas in wheat areas which were infected with stem-rust 15-B. The rust satellite system had predicted that the spore cloud would form as the result of ground winds and late afternoon convective air turbulence in the infected areas. Because these areas were dry, following 10 days without precipitation, ROACH predicted that local ground turbulence would be sufficient to carry the spores aloft where they could be carried northward by southerly winds. Ground stations confirmed the generation of the spore cloud and transmitted this verification to ROACH.

The satellite system had monitored heavy infections of rust in Texas and Mexico. From these sensings, ROACH estimated the intensity of the spore cloud as heavy. Using information from the meteorological community, ROACH calculated the direction and speed of the winds at 5,000 feet, where there was a significant concentration of spores. ROACH plotted the limits which these winds would reach within the life span (48 hours) of the spores in the air, and within these limits ROACH constructed a trajectory for the spores. This trajectory extended across Oklahoma and Kansas, with fringes in southern Nebraska and eastern Colorado. ROACH then entered this trajectory into the integrated long-range forecast program which performed further analysis of the new data.

The computer immediately issued a full analysis of areas in and around two Kansas counties, Ford and Shawnee, for which USWB had predicted rain during the next 48 hours. Both of these counties were within the probable fallout pattern of the rust spores, which could be delivered in large numbers by the predicted rain. From historical data, ROACH had previously determined that these counties represented two different cultivation, geography and climate types within the state of Kansas. If the predicted rust trajectory were to hit these counties, the probability of rust in other Kansas counties and in counties in other states would increase.

Ford and Shawnee counties have similar soils Most farmers in Ford County plant variety X winter wheat because it is especially suited to a very dry growing season, which is characteristic of western Kansas Some farmers, however, plant variety I on irrigated land Some planting in Ford is done on September 1, because farmers are attempting to maximize the length of their growing season Other farmers, afraid of the presence of the Hessian fly which can damage early-sown crops, wait until October 1 to plant, especially if they must wait for rain to increase soil moisture to a level which is suitable for planting Farmers in Shawnee, which is relatively moist, plant winter wheat variety Y Within Shawnee County as in Ford, planting dates vary from September 1 to October 1

These planting dates and wheat varieties had been entered into the historical data bank, and they were verified by ROACH satellites ROACH satellites had also monitored fall and winter weather in Ford and Shawnee, and ROACH analyzed these data for their significance to rust and to plant growth, and stored the analyses These cumulative wheat/soil/rust/weather analyses were continually updated This information indicated the probable progress of the winter wheat, and the amount of soil moisture that would be available, both for later growth of the wheat and for use by the rust as free moisture The ROACH program also continually updated the stage of growth of the plant after reemergence in the spring, both by updating the wheat/weather/rust/soil analyses and by directly sensing the growing wheat from the satellite

By comparing the current trend in the growth of the wheat with historical growth curves, ROACH made a weekly prediction of probable dates of harvest Before these predictions were set and stored, they were refined by the cumulative wheat/weather/rust/soil analyses and by long-range weather forecasts

As of April 8, two days before the development of the spore cloud in Mexico and Texas, ROACH had rated Ford and Shawnee Counties as high potential damage areas, even though rust had not yet been detected in these counties The computer analysis stated that county agents in both counties had been informed of this condition The computer analysis showed that these counties were areas in which rust damage was potentially high if infection occurred within the next 15-25 days Varieties X, Y and I were susceptible to race 15-B The previous fall and winter had been wet, which made moisture for potential rust development plentiful. The spring in both counties had been colder than normal, and this condition retarded the growth of the wheat, which was now 52-62 days before harvest. Short- and long-range weather forecasts and climatic trends indicated that the remaining 52-62 days would probably be favorable for the development of rust.

ROACH then received a satellite sensing which was used to estimate that the spore cloud was now passing over Oklahoma, where cloudiness was developing ROACH estimated from the satellite sensing that some spores would fall in rain in Ford and Shawnee counties within the next 24 hours. ROACH checked with USWB which set the probability of rain for Kansas at .9 ROACH notified Shawnee and Ford that the probability of rust inoculation was 9 for those areas

The growers, spray-aircraft operators and the county agents in Ford and Shawnee were prepared for these predictions Each day since reemergence of the winter wheat, the county agents had asked ROACH for its estimate of this year's rust damage in their counties Because of the high severity and broad extension of rust in Mexico and Texas, ROACH had advised Ford and Shawnee to arrange for a quick response capability to be available by April 1 The county agents informed the farmers of this situation

The farmers and the county agents arranged with spraying firms to have a 12-hour spray response capability These preparations were completed by March 31 On April 8, when ROACH first classified Ford and Shawnee as potential high damage areas, the users in those counties went on alert for the arrival of spores

ROACH updated its integrated long-range forecast programs with a tentative delivery of spores to Shawnee and Ford counties ROACH noted that this information had special significance for the other counties of Kansas, and for Buffalo County, Nebraska, and Brookings County, South Dakota, which had similar wheat/weather/rust/soil antecedent conditions as Ford and Shawnee In 11 of the 13 years in which both Shawnee and Ford counties had significant rust, Buffalo and Brookings had it also

Based on the probable arrival and development of rust in Ford and Shawnee counties, ROACH predicted that the other counties of Kansas and other areas to the north would be threatened by rust developing in Ford and Shawnee within 25 days Because of analyses of historical data, antecedent conditions and weather forecasts, the confidence level of these predictions was high, and it might improve in time As more data confirmed the inoculation of Ford and Shawnee or monitored the development of rust there, ROACH could increase the accuracy of its predictions for other areas The satellite system might contribute to this flow of information by sensing a decrease in crop vigor This might occur before the rust had reached a severity at which it was visible, ground detection of spore arrival or rust development would also improve predictions made on early tentative statements

Ground sources, for example, might have been able to confirm the arrival of spores on April 12, and the development of pustules on April 22. Given these data, ROACH could now make more accurate predictions of the rust threat to other areas The satellite could contribute by monitoring the condition of the wheat, soil and weather in Shawnee and Ford These data would improve ROACH's predictions for other areas A ground report of spraying and subsequent low infection in Ford and Shawnee would enable ROACH to decrease the probability estimate

After ROACH had issued the prediction of the arrival of rust to Shawnee and Ford counties, the monitoring of those counties and the rest of the southern Great Plains continued Using data obtained from this surveillance, ROACH continued to update its forecasts in order to assist farmers for the rest of the growing season

V BENEFITS FROM PREVENTING WHEAT RUST AND OTHER FUNGUS DISEASES

The direct benefit from controlling crop fungus diseases would result from saving those portions of the small grain crops which are currently lost through fungus infections

A Wheat Rust Prevention Benefits - U S A

The amount of loss due to wheat rust infection in the United States has been estimated by the United States Department of Agriculture to average about 6 5 percent of the total annual wheat crop Stem rust contributes an estimated 4 percent and leaf rust accounts for 2 5 percent of the total 6 5 percent loss[1] During the 1957-1966 period, this percentage amounted to an average loss of 80 5 million bushels of wheat per year, valued at approximately $154 million

The incidence and severity of rust damage varies tremendously from year to year, from merely "trace damage," to damage valued at hundreds of millions of dollars In 1953 and 1954, stem rust alone caused damage in the original thirteen barberry-control states, which produce just over 40 percent of the total wheat crop The losses in those years exceeded $200 million for all cereal crops At the other extreme, in 1958, there was only trace damage from stem rust in the same area

Loss estimates are likely to be low since losses tend to be estimated and reported in years of epidemic or near epidemic proportions Rusts, particularly leaf rust, seldom cause a 100 percent loss, but rather, they lower the weight of the wheat kernels and the yield. Heavy infections occurring early in the season may cause very appreciable losses in yield However, light infections may not cause obvious damage and thus be overlooked by the producer, even though losses did occur Some areas in the Mississippi Valley tend to have light infections almost every year and

[1] U.S. Department of Agriculture, Agricultural Research Service, Losses in Agriculture, Agricultural Handbook No 291, Government Printing Office (Washington, August 1965)

producers probably do not realize that yields are perennially lowered Thus, it is likely that rust damages are underestimated

Estimated benefits from reducing wheat stem and leaf rust losses during the 1971-1990 period are shown in Exhibit I-4 The annual loss values computed above were adjusted by factors that allow for (1) the cost of spraying, (2) the satellite capability to provided the needed information, and (3) the rate at which farmers may be expected to adopt the new technology for spraying rust The resulting annual benefit figures were discounted 7-1/2 percent, 10 percent, and 12-1/2 percent and summed for the 20-year period

B Wheat Rust Prevention Benefits - Selected Foreign Countries

Fifteen countries were selected as major wheat producing countries which might participate and benefit from the use of the satellite-assisted information system In order to estimate the value of annual wheat rust losses, average production in these countries from 1960 to 1966 was multiplied by the 6 5 percent loss factor, the U S Department of Agriculture estimate for the United States This quantity of wheat estimated to be lost to rust was then multiplied by the average 1960-1966 domestic price of wheat in each country to arrive at an estimated value of the losses These calculations are shown in Exhibit I-5

To calculate the potential benefits from the wheat rust prevention in the selected countries, the estimated annual loss data were adjusted to reflect satellite capability and farmer participation rates in much the same way as other non-United States benefits were calculated for the wheat production management case. The annual data then were discounted and summed for the 20-year period The estimated benefits for these countries are shown in Exhibit I-4

C Losses From Other Fungus Diseases

Chemical treatment of wheat with fungicides will control not only wheat rusts, but other fungus diseases, e g , septoria and powdery mildew, as well These two diseases cause estimated annual crop losses of 1 0 percent and 0 4 percent, respectively

Similarly, fungicides applied to other small grain crops could control septoria, stem rust and crown rust in oats, septoria and powdery mildew in barley, and stem rust in rye Altogether, these diseases cause estimated average annual losses in the United States of $50 8 million of oats, $4 9 million of barley and $300,000 of rye

The estimated value potential of small grains saved, through control of the fungus diseases other than wheat rust, in the United States, is shown in Exhibit I-6 The data have not been adjusted to subtract the cost of spraying because of the difficulty in estimating the spray cost over such a wide geographic area Also, they have not been calculated on an annual basis to reflect the satellite capability and farmer participation rates, instead, several alternative levels of control were assumed to illustrate the possible savings, totaled for a 20-year period

Calculation of benefits for the selected foreign countries, followed the same procedure as for wheat rust benefits The 20-year benefits by commodity for several fungus diseases are summarized in Exhibit I-7 The costs of spraying for control were not subtracted from the gross benefits

EXHIBIT I-4 RATE AND AMOUNT OF ANNUAL BENEFITS FROM REDUCTION OF LEAD AND STEM RUSTS IN WHEAT - UNITED STATES AND 15 COUNTRIES - DISCOUNTED 7-1/2 PERCENT, 10 PERCENT, AND 12-1/2 PERCENT, OVER A 20-YEAR SPAN

Rate and Amount of Benefits	Unit	Year 1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	20-Year Total
United States																						
Rate																						
Satellite Capability	%	15	15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	%	-	-				-	-	-		-	-	-	-	-	-	-		-	-	-	
Farmer Participation	%	10	20	30	50	70	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	
Mean Rate	%	12 5	17 5	65	75	85	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	
Annual Benefits																						
Undiscounted	M $[1]	17 5	24 5	91 1	105 1	119 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	133 1	2353 8
Discounted 7-1/2%	M $	17 5	22 7	78 8	84 6	89 2	92 7	86 2	80 2	74 9	69 4	64 6	60 1	55 9	51 9	48 4	45 0	41 8	38 9	36 2	33 7	1172 7
Discounted 10%	M $	17 5	22 3	75 3	79 0	81 3	82 6	75 1	68 3	62 1	56 4	51 3	46 7	42 4	38 6	35 0	31 9	29 0	26 3	23 9	21 8	966 8
Discounted 12-1/2%	M $	17 5	21 8	72 1	73 8	74 4	73 9	65 6	58 4	51 9	46 1	41 0	36 4	32 4	28 8	25 6	22 7	20 2	17 7	15 9	14 2	810 6
15 Selected Countries																						
Rate																						
Satellite Capability	%	15	15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
Agency Participation	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Farmer Participation	%	10	20	30	50	55	60	65	70	74	78	80	82	84	85	86	88	90	90	90	90	
Mean Rate	%	12 5	17 5	65	75	77 5	80	82 5	85	87 5	89	90	91	92	92 5	93	94	95	95	95	95	
Annual Benefit																						
Undiscounted	M $	90 7	126 9	471 6	544 1	562 2	580 4	598 5	616 7	634 8	645 7	652 9	660 2	667 5	671 1	674 7	682 0	689 2	689 2	689 2	689 2	11636 8
Discounted 7-1/2 %	M $	90 7	118 0	408 1	438 0	421 0	404 3	387 8	371 7	355 9	336 8	316 8	297 9	280 2	262 1	245 1	230 4	216 6	201 5	187 5	174 4	5744 8
Discounted 10%	M $	90 7	115 4	389 7	408 8	384 0	363 8	337 9	316 5	296 1	273 8	251 7	232 1	212 7	194 4	177 6	163 3	150 0	131 3	124 0	112 7	4731 5
Discounted 12-1/2%	M $	90 7	112 8	372 6	382 1	351 0	322 1	295 2	270 4	247 4	223 7	201 0	180 7	162 4	145 1	129 7	116 6	104 7	93 0	82 7	73 5	3957 4

Note (1) Denotes Million dollars

EXHIBIT I-5 WHEAT PRODUCTION, VALUE, AND ESTIMATED RUST LOSS IN SELECTED COUNTRIES - 1960-1966 AVERAGE

Country	Production[a] Thousand Bushels	Price[b]	Total Value Thousands	Est Rust Loss[e] Thousand
Canada	598,392	$ 1.84[b]	$ 1,101,041	$ 71,568
Argentina	255,989	1.39[b]	355,825	23,129
France	455,353	2 60[b]	1,157,918	75,265
Germany (West)	170,946	2.85[c]	487,196	31,568
Italy	317,829	2 89[b]	918,526	59,704
Spain	158,298	2 71[b]	428,988	27,884
United Kingdom	127,097	1 94[c]	246,568	17,027
Romania	158,957	1 85[d]	294,071	19,115
Yugoslavia	137,505	2 07[c]	284,625	18,501
U.S S.R.	1,951,807	1 59[b]	3,103,373	201,719
Turkey	265,495	2 37[c]	629,223	40,900
India	404,874	2 18[c]	882,625	57,371
Pakistan	151,959	2 20[c]	334,310	21,730
China (Mainland)	765,025	1 85[d]	1,415,530	92,010
Oceania	328,900	1.86[c]	611,554	39,751
Total				$ 797,242

[a] 1960-1966 average

[b] 1960-1966 average domestic price

[c] 1964-1968 average basic producer prices

[d] Estimated from World Wheat export-import prices

[e] Estimated as 6.5% of wheat crop Based on 1951-1960 U S average loss.

EXHIBIT I-6 ESTIMATED VALUE OF SMALL GRAIN CROPS SAVED WITH SELECTED LEVELS OF FUNGUS DISEASE CONTROL IN THE UNITED STATES - 20 YEAR PERIOD

Crops	Control				
	10%	40%	70%	95%	100%
	Million	Million	Million	Million	Million
Wheat[1]					
Undiscounted	$ 68	$ 266	$ 468	$ 635	$ 668
Discounted 7-1/2%	37	146	256	348	366
Discounted 10%	32	125	219	297	313
Discounted 12-1/2%	28	108	191	258	272
Oats[2]					
Undiscounted	102	406	712	965	1,016
Discounted 7-1/2%	56	222	390	529	557
Discounted 10%	48	190	333	452	476
Discounted 12-1/2%	42	165	290	393	414
Barley[3]					
Undiscounted	10	40	68	93	98
Discounted 7-1/2%	5	22	37	51	54
Discounted 10%	5	19	32	44	46
Discounted 12-1/2%	4	16	38	38	40
Rye[4]					
Undiscounted	-	2	4	6	6
Discounted 7-1/2%	-	1	2	3	3
Discounted 10%	-	1	2	3	3
Discounted 12-1/2%	-	1	2	2	2
Total, All Crops					
Undiscounted	$ 180	$ 714	$1,252	$1,699	$ 1,788
Discounted 7-1/2%	98	391	685	931	980
Discounted 10%	85	335	586	796	838
Discounted 12-1/2%	74	290	521	691	728

[1] Includes only Septoria and powdery mildew
[2] Includes Septoria, stem rust, and crown rust
[3] Includes Septoria and powdery mildew
[4] Includes only stem rust

EXHIBIT I-7 ESTIMATED VALUE OF SMALL GRAIN CROPS SAVED WITH SELECTED LEVELS OF FUNGUS DISEASE CONTROL IN 15 SELECTED COUNTRIES - 20 YEAR PERIOD

Crops	Control				
	10%	40%	70%	95%	100%
	Million	Million	Million	Million	Million
Wheat[1]					
Undiscounted	$343	$1,372	$2,401	$3,259	$3,430
Discounted 7-1/2%	188	752	1,316	1,786	1,880
Discounted 10%	161	643	1,124	1,526	1,606
Discounted 12-1/2%	140	559	978	1,327	1,397
Oats[2]					
Undiscounted	314	1,258	2,201	2,987	3,144
Discounted 7-1/2%	172	689	1,206	1,637	1,723
Discounted 10%	147	589	1,030	1,399	1,472
Discounted 12-1/2%	128	512	896	1,217	1,281
Barley[3]					
Undiscounted	100	401	701	951	1,001
Discounted 7-1/2%	55	219	384	521	549
Discounted 10%	47	188	328	445	469
Discounted 12-1/2%	41	163	286	387	408
Rye[4]					
Undiscounted	20	78	137	186	198
Discounted 7-1/2%	11	43	75	102	107
Discounted 10%	9	37	64	87	92
Discounted 12-1/2%	8	32	56	76	80
Total, All Crops					
Undiscounted	$777	$3,109	$5,440	$7,383	$7,773
Discounted 7-1/2%	426	1,701	2,981	4,046	4,259
Discounted 10%	364	1,457	2,546	3,457	3,639
Discounted 12-1/2%	317	1,266	2,216	3,007	3,166

[1] Includes only Septoria and powdery mildew

[2] Includes Septoria, stem rust, and crown rust. Data not available for Mainland China, India, Pakistan, and Australia

[3] Includes Septoria and powdery mildew Data not available for Mainland China, India, and Pakistan

[4] Includes only stem rust Data not available for Mainland China, India, Pakistan, and Australia