IDENTIFICATION OF URBAN WATERSHED UNITS USING REMOTE MULTISPECTRAL SENSING

by

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ENVIRONMENTAL RESOURCES CENTER
Colorado State University
Fort Collins, Colorado

Norman A. Evans, Director

It is agayns the process of nature. CHAUCER

FRONTPIECE - EKTACHROME INFRARED AIRPHOTO OF THE RAPIDLY URBANIZING AREA SURROUNDING THE NORTHGLENN SHOPPING CENTER. Flown by Colorado State University on 28 April 1971. Scale approximately 1/20,000. The asphalted shopping center is the dark area in the center right. Green, healthy lawns are red. A trailer park shows as white in the lower left corner. The photo was taken in the spring and some agricultural fields are the reds and pinks of early crops, while others are the blues and greens of fallow or just-plowed fields.

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ABSTRACT

The rapid pace of development in the urban fringe has significant hydrologic effects. Changes due to urban development of natural watersheds are shown by an areal analysis of thirteen small watersheds from 40 to 600 acres located in the Denver suburbs. Airphotos for each of the watersheds were obtained at 5 to 10 year intervals for as far back as 1935. The surface composition of each watershed was determined from the airphotos, in terms of common urban surface materials such as rooftops, asphalt, and lawns. Examination of the results shows the developmental trends in changes in the impervious cover of each watershed and the effects on this imperviousness of different seasonal characteristics.

New urban hydrology analysis methods are necessary to keep pace with such rapid changes in surface cover. Recent progress in urban watershed modeling is a partial answer but further progress in relating changing surface cover to urban hydrology requires refined and timely measurements of the surface cover. This study illustrates the use of remote multispectral imagery to provide the more detailed analysis of surface characteristics which can, in turn, be related to hydrologic effects and input into watershed models.

A method is proposed for determining the optimum wavelength bands to be used for differentiating ten types of urban surface materials via automatic image processing based on measured spectral curves of the materials. The results can be used in the design or use of instruments to map urbanizing areas. Suggestions for further research are given, including the collection of multispectral imagery over the thirteen watersheds included in the study, and comparison of the automatic image processing results with areal analysis or "ground truth" obtained from low altitude color and color IR photography.

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INTRODUCTION

The rapid development of rural terrain into urban areas has created special problems which challenge city officials and hydrologists concerned with managing urban water resources. Hydrologic changes in rapidly urbanized watersheds are a complex phenomena and have been studied by increasingly complex mathematical methods to determine the effects of urban development on runoff. At present many computerized water yield simulation models have been and are being developed which predict the character of runoff from a given rainfall as a function of surface material, surface topography, antecedent moisture conditions, and overall area of the watershed, among others. A significant and somwhat difficult and time consuming parameter to measure is the type and distribution of the surface materials in these rapidly changing watersheds. In-the-field mapping of surface material is a time consuming process, and has largely been replaced by the interpretation of aerial photographs. However, it is now becoming possible to use automated techniques, both for the interpretation of aerial photographs and for interpretation of imagery from non-photographic remote sensing devices.

A technique for using computer-interpreted remotely sensed imagery has been proposed as an input into computerized watershed models. The purpose of this study is to document the need for frequent analysis of urbanizing watersheds, and to illustrate how the computer mapped surface materials can be interfaced for input into urban hydrological models.

THE URBANIZING WATERSHED

Alteration of natural watersheds by the process of urbanization causes significant hydrologic changes. Flooding and excessive erosion can result since peak discharge occurs sooner and is of greater volume, due to the extensive areas of impervious cover so characteristic of urban areas.

Urbanization of natural watersheds also effects significant changes in water quality. Erosion of large amounts of soil exposed by construction activities causes deleterious removal of topsoil and results in excessively turbid runoff. Once the watershed is fully developed, problems can still exist with residential, commercial and industrial wastes polluting surface runoff, such as pesticides, herbicides, and effluent chemicals discarded from commercial and industrial firms.

Lull and Sopper (1969) studied several small forested watersheds in southeastern Pennsylvania and found that urbanization caused a reduction in evapotranspiration in addition to increasing runoff and peak flows. During a period of 25 years as these watersheds were urbanized, annual ratios of stormflow to precipitation appeared to be the most sensitive indicator of urbanization.

The stormflow resulting from a given amount of precipitation depends on a large number of variables in the watershed such as area, character of surface materials, antecedent moisture, topography, etc. In past years the problem of predicting runoff from rainfall and these watershed characteristics was too complicated to treat rigorously, but with today's computerized techniques, it has become possible to simulate hydrologic processes mathematically.

URBAN WATERSHED MODELING

Both analog and digital models have been designed to predict runoff as a function of rainfall and the many hydrologic processes within an urbanized watershed. Narayana, et.al. (1970) have developed an analog model which analyzes a given watershed in terms of its subareas. The watershed is divided into a manageable number of subzones and the hydrologic parameters determined for each subzone. Losses from precipitation on the watershed due to interception, infiltration, and depression storage are chronologically deducted for each subzone and the remaining runoff is routed through surface subzones and channel storages. Outflow hydrographs are then routed through succeeding downstream subzones to the gaging point on the watershed. Such a model makes it possible to simulate runoff for subzones within the urban watershed, to account for spacial variation of storm and watershed characteristics, and to predict outflow hydrographs from subzones within the watershed for improved storm sewer design.

A study using a digital computer to estimate effects of urban development on flood peaks (James, 1965) used the Stanford Watershed Model (Crawford and Linsley, 1962), which uses mathematical algorithms to simulate the runoff cycle. The equations account for all moisture entering, stored within, and leaving the watershed via the various hydrologic processes. Runoff is routed from the point it enters tributary channels to the location downstream where a simulated hydrograph is desired. Input to the Stanford Watershed Model consists of hourly precipitation, average daily evaporation by ten-day periods, a translation histogram for channel routing, an array describing the interflow characteristics of the basin, an array describing infiltration characteristics, 28 constants describing physical characteristics of the watershed, and four constants describing initial moisture conditions. Values of the arrays and constants are determined by a trial and error process which matches a synthesized hydrograph to an actual recorded hydrograph. The computer output provides a continuous synthetic hydrograph for the entire period of analysis, from which interpretations can be made for flood control measures.

Gonzalez and Ducret (1971) are currently using a variant of the Stanford Watershed Model as an aid in defining the magnitude and frequency of floods in small urbanized watersheds in the Denver, Colorado metropolitan area. A total of 30 small watersheds in the Denver and Boulder area are being measured by dual digital stage rainfall gauges with a five-minute recording interval. Short-term rainfall runoff data is collected from each of these watersheds and is used to calibrate the coefficients in the watershed model which represent the physical watershed characteristics. Once a model is calibrated for each of the watersheds, long-term U. S. Weather Bureau rainfall records are input to obtain long-term synthetic hydrographs for each of the watersheds. Flood frequency is then determined from the long-term synthetic hydrographs, and by statistical methods the flood frequency and magnitude are defined over the entire Denver metropolitan area.

Computer simulation of hydrologic processes is continually becoming more sophisticated and increasing numbers of watershed models are appearing in the literature, both for urban and natural watersheds alike. The reader is referred to the two sections in the bibliography (Appendix A) dealing with watershed modeling for further references.

REMOTE SENSING RELATED TO URBAN STUDIES

The value and potential of using remote sensing methods in studying the urban environment is rapidly being realized. A study is currently under way in the Geologic Applications Division of the United States Geological Survey to test the feasibility of monitoring urban dynamics from earth orbiting satellites (Gerlach, 1971). Twenty-six cities are being photographed from altitudes in excess of 50,000 feet in color, color infrared, multiband, and black and white. The goals of the project are to develop techniques for detecting and identifying urban change and evaluating its significance from ERTS-A (Earth Resources Technology Satellite) imagery.

A method for interpreting housing quality data from multiband aerial photographs has been developed (Wellar, 1970) based on the unique characteristics of low quality housing, namely the presence of litter, garbage, junked cars, rubbish piles, the lack of landscaping in yards, presence of weeds in vacant lots, and the degree of crowding of houses on lots. Analysis of high resolution imagery for estimating urban residential housing quality (Marble, 1969), although not a replacement for ground surveys, was found to permit ground surveys to function more efficiently, and at lower cost.

High resolution remote sensor imagery can be used in a similar fashion for detecting surface characteristics of urban watersheds, which is a significant input into any watershed model. Colwell (1970) investigated the potential of using 18 channels of multispectral scanner imagery and its computer reduction to delineate different types of urban materials, namely bare soil, several vegetation types, concrete, asphalt, gravel, and a variety of roofing materials. This multispectral imagery obtained in the visible, photographic infrared and thermal infrared regions of the electromagnetic spectrum was originally recorded on analog tape and subsequently analyzed with an analog computer system using a spectrum matching technique.

A simple explanation of spectrum matching will assist the reader in understanding the results which follow. The computer is given a representative sample of known image points (data points) from the multispectral imagery tape for the surface material to be identified. It calculates and stores average spectral curves for these several hundred identified image points. This is the process of selecting and computing a training set. The computer then examines all the millions of unknown image points on the data tape attempting to match each unknown point's spectral curve with the stored, known training set's curve for the particular material. If a reasonable match is found, the unknown image point is identified as the material sought and a black and white film is exposed with a dot of light at that geographic position. If a match is not found, the film is not exposed. The resulting black and white, i.e., no gray, decision image (recognition map) is exposed in those portions representing the location of the surface material sought while the unexposed areas represent all other materials. This process can be repeated to obtain recognition maps of each material of interest. In practice, a more complex image processing approach is used. It checks the unknown image point simultaneously against all surface materials previously defined by training sets and identifies the point as 'most probably' being one of these materials or sufficiently different in spectra to be none of them. A black and white recognition map for each material is still output as noted above. Each of these transparencies can be reproduced in a different color and superimposed to produce a composite color-coded identification map of all the materials in the urban scene.

A simple spectrum matching analysis of multispectral imagery can be used to automatically subdivide the urban watershed into areas of vegetation, non-vegetation, and water (Fig. 1b). This simple breakdown very nearly represents a pervious versus impervious analysis of a watershed, obviously of great interest in urban hydrology. Unfortunately, bare soil and gravel which are pervious most of the year are classified with the other predominantly impervious non-vegetation areas such as concrete, asphalt, roofs, etc. A considerably more complex analysis shows the potential for an accurate automated analysis of urban surface materials (Fig. 1c). The same area is now automatically broken down into lawns, trees, water, rooftops, bare soil, gravel, and asphalt and the areal extent of each of these urban materials can also be calculated during the imagery processing. Colwell's study shows the feasibility for developing a computer analysis technique to accurately identify and map the areal extents of the surface materials in an urban scene. This technique will aid urban hydrologists by providing the important spatial input into urban watershed models. Currently most watershed simulation models use only a pervious-impervious classification of surface material. As these models become increasingly sophisticated, urban hydrologists are becoming more concerned with the degree of perviousness of surface materials from an input point of view. Rather than approximating this information by adjustment of physical parameters within the model, advanced process models will require a more detailed input of areal surface characteristics to reduce or eliminate the trial and error process. Computerized analysis of multispectral scanner imagery is capable of providing such an input, rapidly, over large areas, and repeatedly in a timely fashion and at short time intervals.

THE DYNAMIC NATURE OF URBAN WATERSHEDS

Thirteen of the small urbanized watersheds in the aforementioned USGS program by Gonzalez and Ducret were chosen for analysis in this study to show how the types of surface material in urbanizing watersheds change with time. These 13 watersheds are located in the residential suburbs surrounding Denver (Appendix B) and were chosen because of their well-delineated boundaries and because they are currently gaged for simultaneous measurement of rainfall and runoff. A historical sequence of aerial photographs was obtained for these watersheds, where available, since 1935 (Table 1). The most current set

TABLE 1. PERCENT PERVIOUS (P) AND IMPERVIOUS (I) COVER FOR 13 DENVER AREA WATERSHEDS, 1935-1970

WATERSHED \ PHOTO SOURCE AND DATE	1935[1]		1949[2]		1954[4]		1956[5]		1959[6]		1963[7]		1968[8]		1970[9]	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I	P	I
Arvada - N	np*	np	100	0	100	0	np	np	100	0	88	12	84	16	75	25
Arvada - S	np	np	100	0	99	1	np	np	99	1	87	13	np	np	62	38
Federal Heights	np	np	np	np	99	1	np	np	98	2	96	4	92	8	92	8
Northglenn 7204	np	np	np	np	100	0	np	np	100	0	100	0	48	52	45	55
Northglenn 7203	np	np	np	np	100	0	np	np	98	2	68	32	57	43	54	46
Northglenn 7201	np	np	np	np	100	0	np	np	100	0	86	14	53	47	50	50
Stapleton Airport	85	15	77	23	77	23	78	22	75	25	53	47	np	np	0	100
Stapleton - S	np	np	(1950)[3] 98	2	62	38	np	np	64	36	65	35	np	np	61	39
Aurora	np	np	np	np	100	0	np	np	99	1	94	6	np	np	63	37
Littleton	np	np	np	np	100	0	np	np	98	2	82	18	np	np	72	28
Fort Logan	np	np	100	0	100	0	np	np	100	0	84	16	np	np	51	49
Hyatt Lake - N	np	np	np	np	np	np	np	np	100	0	98	2	np	np	98	2
Hyatt Lake - S	np	np	np	np	np	np	np	np	98	2	98	2	np	np	96	4

1 - City planning Office, Denver, 1935

2 - Colorado Aerial, Denver, June, 1949

3 - American Soil Conservation Service, Salt Lake City, 1950

4 - Colorado Aerial, Denver, April, 1954

5 - American Soil Conservation Service, Salt Lake City, 1956

6 - Colorado Aerial, Denver, July, 1959

7 - American Soil Conservation Service, Salt Lake City, August, 1963

8 - Hotchkiss, Inc., Denver, August, 1968

9 - E. M. Clark and Associates, June, 1970

* - No photographs available

of photographs of these watersheds (1970) was analyzed to determine the types of materials present and a list of ten surface materials, hereafter called watershed units, resulted. These materials in aggregate constitute all the different surface materials whose areas are greater than .5 percent of the total area of the watershed. The ten units are

1. concrete, 2. natural and fallow fields, abandoned land, pasture,
3. asphalt, 4. gardens, agricultural crop areas,
5. rooftops, 6. forested areas,
7. gravel, 8. exposed soil,
9. lawns, and 10. water

and it is into these units that these watershed should be classified by multispectral sensing.

All the photographs obtained in each historical sequence for each watershed were analyzed to determine the areas of the surface units in terms of percent of total area. Appendix C contains an explanation of the interpretive technique used on the photographs for areal analysis. Appendix D contains the tabulation of the results of this analysis. The percentage obtained for the impervious materials (concrete, asphalt, and rooftops) can be summed for each watershed and year as well as the percentage of pervious materials (Table 1). The percent imperviousness or perviousness as a function of year provides a simple index of urbanization of each watershed. This simple summary classification into impervious versus pervious areas is the current areal input into the simulation models used by the USGS to synthesize the runoff from these basins.

The progress of the urbanization of each watershed is shown graphically by plotting percent impervious cover as a function of calendar year for each of the thirteen watersheds, hereafter called imperviousness development curves. Several imperviousness development curves are accompanied by a selected sequence of the available historical airphotos to pictorially illustrate the urban development. Note that the Fort Logan Watershed was virtually undeveloped in 1959, but by 1970 was completely developed with most of the construction occurring between 1963 and 1970 (Figs. 2 and 3d). The Stapleton Airport Watershed passed through two major developmental stages, the first reaching approximately 22 percent impervious cover by about 1945, and remaining essentially static (Figs. 4 and 5a). The advent of jet aircraft in the 1960s necessitated further development and by 1970 the watershed was completely covered by impervious material as airport runway aprons, hangar space, and terminal sizes increased. Three watersheds in Northglenn provide typical examples of the rapid growth of the Denver suburbs beginning in the 1960s (Figs. 6 and 7). Northglenn Shopping Center is partially in the Northglenn 7204 Watershed (Fig 6d). Extensive areas of impervious cover rapidly laid over large areas in this Center in parking lots and rooftops contributed significantly to the abnormally high rate of increase in imperviousness of this watershed (Fig. 7c).

The imperviousness development curve for each of the thirteen watersheds analysized in this study provide an index of urbanization rates in and about Denver over the past 30 years (Figs. 3, 5, 7, and 8). As expected, such curves are quite sensitive to the type of development taking place which in turn regulates the hydrologic surface characteristics of the basin. A comparison of several imperviousness development curves demonstrates that the conversion of a natural watershed to an urban watershed can proceed at greatly differing rates (Fig. 9). Similarly, the degree to which a watershed has developed is reflected in its impervious cover and differs greatly, depending upon its particular type of urban use (Fig. 10a). Imperviousness development curves approaching an asymptote imply a steady-state land use which may range from 100 percent for a metropolitan jet airfield to 30 or 40 percent for an urban subdivision and to less than 10 percent for a natural watershed (Fig. 10a). A curve asymptotically approaching an imperviousness of 25 to 50 percent indicates an urban dwelling land use with relatively complete occupancy of the land. It is important from a hydrologic viewpoint to note that the difference in amount of impervious cover can vary more between two different urban land uses than between natural and subdivided land. Thus the urban hydrologist is as concerned about the water yield effects of the conversion of suburban watersheds to commercial use as he is about the conversion from natural or agricultural to suburban land use. A review of all thirteen imperviousness development curves show that the conversion from natural to suburban land use proceeds most rapidly taking only two to three years while the conversion from suburban to commercial land use proceeds at much slower rates.

Finally, the point at which a natural watershed was converted to urban land use is clearly reflected in its imperviousness development curve (Fig. 10b). Again, the curves approach asymptotes commenserate with their new land use. The point in time at which the conversion takes place relates to the distance from the city core or local cores of commercial development. One consistent difference in impervious is apparent. The level approached is slightly higher for each successively new subdivision due to the trend toward larger dwellings, wider sidewalks, paved driveways, etc. (Fig. 10b).

The purpose of this historical analysis of imperviousness development of urban watershed surfaces was to clearly indicate the rapid and differing changes that occur and to highlight that a need exists for rapid and frequent analysis of the distribution of surface materials in urbanizing areas. This is not a need of the urban hydrologist alone but also of the city planner and other concerned municipal and county agencies. Annual or biannual analysis of the distribution of surface materials in urban areas can be based on small watersheds or other geographic cells. Remote sensing methods used together with the interpretation of historic airphotos of these units would produce well-defined development curves for all of a metropolitan area and its environs from which urban growth dynamics can be interpreted. Methods for collecting and interpreting remote multispectral imagery are becoming more sophisticated and the possibility of relatively low-cost yearly surveys and indexing of urban watersheds are imminent. Therefore, the question posed in this study is what kind of a remote multispectral mapping system would best map the ten key watershed units identified by the airphoto interpretation.

CLASSIFICATION OF URBAN WATERSHED UNITS BY REMOTE MULTISPECTRAL SENSING

The non-photographic multispectral mappers currently in operation are line scanning devices. They measure electromagnetic energy simultaneously from the air in a number of discrete wavelength bands at each instant of time for a small spot on the ground. This spot is swept or scanned perpendicular to the aircraft's forward motion to form a simultaneous image in each wavelength band. The level of energy (radiance*) received in each of these wavelength bands is dependent upon the reflectance** (or emissance) characteristics of the material under surveillance. All the simultaneous measurements made in the various wavelength bands taken together define a discrete spectral

*radiance is the electromagnetic energy coming from the surface by reflection or emission.

**reflectance is the ratio of the energy reflected from a surface to that incident upon it.

curve for the surface imaged at that particular instant, namely a curve of surface radiance as a function of wavelength, a spectroradiance curve. This curve is called the spectral signature of the ground point observed. Each type of surface material reflects electromagnetic energy with a reasonably consistent level in each wavelength band sensed giving a characteristic spectral signature for that surface. These levels vary, however, between different types of surface materials producing characteristic spectral signatures for each.

The output of a multispectral scanning device is recorded on parallel analog tape tracks (or digitally) as the ground is scanned and any slice across these parallel recording tracks represents the spectroradiance curve received from the scene at that instant of time. This method of recording multispectral images readily lends itself to rapid automatic analysis by computer to map the materials in the scene that are of particular interest.

The early identification by air photo interpretation of the ten surface units whose areas are each greater than .5 percent of the total area of the thirteen study watersheds had a dual purpose. These units must be sufficiently different in spectral signature so that they can be individually mapped by automatic computer processing of remote multispectral imagery. The same units must also contain as a subset the classification of the watersheds into their important hydrologic surface units. The object of the use of remote multispectral imagery is to map the surface materials in the watersheds automatically according to their spectral signature and determine their respective area and location. The resulting surface classifications in a remote sensing sense can then be logically combined according to the input requirements of the watershed model (Fig. 11). For example, asphalt and concrete are very different in spectral signature and must be mapped by remote multispectral sensing as two entirely different surface materials and yet they have identical surface hydrology. After their separate classification in automatic image reduction they can be combined into one area. This area is, in turn, refined by referring its location to a topographic model of the basin to account for depression storage. Rooftops are also separately mapped and entered into this same impervious hydrologic unit but require refinement to account for pitch slope (not to be confused with topographic slope). The final summation of all three surface materials yields the area and location of the impervious surfaces within the watershed for entry into the simulation model (Fig. 11).

Lawns, bare soil, and the other semipervious surface material units need individual refinement for interception rate, infiltration capacity, and antecedent soil moisture level (Fig. 11). The values of these hydrologic characteristics to be assigned to each surface material unit can be obtained by statistical field sampling in each surface unit, i.e., ground control measurements with reference to remote sensing. For example, interception rate, infiltration capacity, and antecedent soil moisture level can be measured from randomly selected lawns within the area mapped. The results can be combined to yield mean and variance levels for the soil hydrologic parameters needed for the lawn area at the time of water yield simulation. These hydrologic characteristics for each surface unit could also be simulated by 'process' subroutines in the simulation model. These subroutines would predict the needed hydrologic characteristics of the surface material unit, i.e., lawns, bare soil, etc., from limited field measurements, input precipitation, potential E-T, and topography, to be used with the areal classifications produced by the multispectral mapping.

The topographic data base used in the refinement of the surface units can be a topographic model (Oliver and Miller, 1971). This approach associates slope, aspect, and elevation values in a computer framework with each surface material cell classified by remote multispectral imaging. The topographic model can also be used in connection with the routing of surface flow in the main water yield simulation model.

The reader is cautioned that this explanation and associated diagram is generally conceptual. The specific input refinements needed for each surface unit mapped are the responsibility of the watershed simulation model and depend to a large extent on the type of modeling approach applied, i.e., process, emperical, static, dynamic, etc.

ANALYSIS OF URBAN WATERSHED SPECTRAL CHARACTERISTICS

Multispectral imaging hardware is constantly being improved and is sampling in a larger number of wavelength bands, in narrower bands, and over a wider range of the electromagnetic spectrum. Computerized analysis of multispectral imagery utilizing many selected wavelength bands simultaneously can distinguish the surface materials in the scene (Figs. 1b and 1c). It is possible to achieve satisfactory, even improved, classification with considerable economy in computer time by using a properly selected subset of the total available wavelength bands. The balance of this report is devoted to the procedure developed for optimizing the selection of the wavelength bands best suited to map the ten surface materials which define the Denver watersheds from an areal importance and multispectral imaging viewpoint.

The core of the optimization process used is the Euclidean distance algorithm which mathematically describes the distance between any two spectral curves in specified wavelength bands.

This Euclidean distance is

$$d = \left(\sum_{i=1}^{n} \frac{(B_i - A_i)^2}{S_p^2} \right)^{1/2}$$

where d = Euclidean distance,

A = average reflectance for material A in the i^{th} wavelength band,

B = average reflectance for material B in the i^{th} wavelength band,

n = number of optimum wavelength bands,

S_p^2 = pooled variance for N samples each for materials A and B in the i^{th} wavelength band where

$$S_p^2 = (S_{A_i}^2 + S_{B_i}^2)/2$$

and where N is the number of samples, i.e., the number of spectral curves used. N is constant for all materials, thus the simplified expression for pooled variance. The application of this technique can be outlined in five steps.

1) Determine the total number of wavelength bands over which the scene (watershed) can be simultaneously imaged by a particular multispectral scanner.*

2) The average reflectance (ρ) and its variance (S^2) are calculated in each of the wavelength bands determined above for each of the materials in the scene. Each value is assigned a position in a matrix in Table 2 where rows = curve numbers of surface materials and columns = wavelength bands. One matrix [AVE(i,j)] contains reflectance averages, and another [VAR(i,j)] contains the variance.

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* this could be either an existing device such as the University of Michigan 12 band scanner or the NASA-Bendix 24 band scanner or it might be a conceptual device yet to be constructed such as a special, simplified scanner optimized exclusively for urban mapping.

TABLE 2. MEAN REFLECTANCE (ρ) AND VARIANCE (S^2) MATRICES [AVE(i,j)] AND [VAR(i,j)] RESPECTIVELY. These matrices of mean reflectance and variance over each wavelength band are all the data used in the Euclidean distance (d) computations.

SURFACE MATERIAL \ SPECTRAL BAND	1	2	3	4
1 GRASS	ρ_{11} S^2_{11}	ρ_{12} S^2_{12}	ρ_{13} S^2_{13}	ρ_{14} S^2_{14}
2 BARE SOIL	ρ_{21} S^2_{21}	ρ_{22} S^2_{22}	ρ_{23} S^2_{23}	ρ_{24} S^2_{24}
3 CONCRETE	ρ_{31} S^2_{31}	ρ_{32} S^2_{32}	ρ_{33} S^2_{33}	ρ_{34} S^2_{34}
4 ASPHALT	ρ_{41} S^2_{41}	ρ_{42} S^2_{42}	ρ_{43} S^2_{43}	ρ_{44} S^2_{44}

3) In each wavelength band, all combinations of surface materials taken two at a time are determined. The difference in reflectance of the two average reflectance values for each combination is calculated, squared, and divided by the pooled variance of the average reflectance of the two materials. The results of this operation are stored in a matrix [U(IE,I)] in Table 3 where rows represent the two-curve combinations and columns represent wavelength bands. This step calculates and lays aside all the values within the summation sign in the Euclidean distance formula.

4) The rows of the [U(IE,I)] matrix are summed and raised to the 1/2 power giving d, the Euclidean distance, for all possible unique combinations of the number of wavelength bands chosen for optimization. The first value calculated is the Euclidean distance for the first two-material combination, e.g. concrete and asphalt. The operation is repeated for all two-material combinations, e.g. concrete and asphalt, concrete and lawns, etc., saving the highest and lowest Euclidean distances, and calculating the average Euclidean distance. These three values are printed out, for the first wavelength band combination, and the entire process is repeated for each subsequent wavelength band combination.

5) The average, minimum, and maximum Euclidean distances for each combination of wavelength bands are compared to select the best combination showing a high average, high minimum, and a high maximum, with the greatest emphasis given to the average Euclidean distance.

A further refinement of the Euclidean distance method, although not used in this study, would be to multiply each two-curve (material) combination value calculated in step 2 by a weighting factor indicating the importance, from a hydrologic viewpoint, of differentiating the two materials in question. For example, asphalt and concrete are easy to separate spectrally but should not heavily influence this spectral band optimization procedure as they are hydrologically identical in behavior and, therefore, their spectral separation is not important. On the other hand, concrete and bare soil are dissimilar in surface hydrology while their spectroreflectance might be similar, especially for old and dirty concrete. Thus, their spectral separation should be more heavily weighted in the optimization computation. The concrete-asphalt

TABLE 3. INTERMEDIATE MATRIX [U(IE,I)] USED IN CALCULATING THE EUCLIDEAN DISTANCE (d) FOR THE BEST 1, 2, 3, OR 4 OUT OF 4 WAVELENGTH BANDS. The matrix contains the squared differences in the mean reflectances and squared sums of the pooled variance from Table 2 for all possible combinations of four surface materials taken two at a time in each of the four spectral bands.

SURFACE MATERIAL COMBINATION \ SPECTRAL BAND	1	2	3	4
1 - 2	$\frac{(\rho_{11} - \rho_{21})^2}{(S^2_{11} + S^2_{21})/2}$	$\frac{(\rho_{12} - \rho_{22})^2}{(S^2_{12} + S^2_{22})/2}$	$\frac{(\rho_{13} - \rho_{23})^2}{(S^2_{13} + S^2_{23})/2}$	$\frac{(\rho_{14} - \rho_{24})^2}{(S^2_{14} + S^2_{24})/2}$
1 - 3	$\frac{(\rho_{11} - \rho_{31})^2}{(S^2_{11} + S^2_{31})/2}$	$\frac{(\rho_{12} - \rho_{32})^2}{(S^2_{12} + S^2_{32})/2}$	$\frac{(\rho_{13} - \rho_{33})^2}{(S^2_{13} + S^2_{33})/2}$	$\frac{(\rho_{14} - \rho_{34})^2}{(S^2_{14} + S^2_{34})/2}$
1 - 4	$\frac{(\rho_{11} - \rho_{41})^2}{(S^2_{11} + S^2_{41})/2}$	$\frac{(\rho_{12} - \rho_{42})^2}{(S^2_{12} + S^2_{42})/2}$	$\frac{(\rho_{13} - \rho_{43})^2}{(S^2_{13} + S^2_{43})/2}$	$\frac{(\rho_{14} - \rho_{44})^2}{(S^2_{14} + S^2_{44})/2}$
2 - 3	$\frac{(\rho_{21} - \rho_{31})^2}{(S^2_{21} + S^2_{31})/2}$	$\frac{(\rho_{22} - \rho_{32})^2}{(S^2_{22} + S^2_{32})/2}$	$\frac{(\rho_{23} - \rho_{33})^2}{(S^2_{23} + S^2_{33})/2}$	$\frac{(\rho_{24} - \rho_{34})^2}{(S^2_{24} + S^2_{34})/2}$
2 - 4	$\frac{(\rho_{21} - \rho_{41})^2}{(S^2_{21} + S^2_{41})/2}$	$\frac{(\rho_{22} - \rho_{42})^2}{(S^2_{22} + S^2_{42})/2}$	$\frac{(\rho_{23} - \rho_{43})^2}{(S^2_{23} + S^2_{43})/2}$	$\frac{(\rho_{24} - \rho_{44})^2}{(S^2_{24} + S^2_{44})/2}$
3 - 4	$\frac{(\rho_{31} - \rho_{41})^2}{(S^2_{31} + S^2_{41})/2}$	$\frac{(\rho_{32} - \rho_{42})^2}{(S^2_{32} + S^2_{42})/2}$	$\frac{(\rho_{33} - \rho_{43})^2}{(S^2_{33} + S^2_{43})/2}$	$\frac{(\rho_{34} - \rho_{44})^2}{(S^2_{34} + S^2_{44})/2}$

combination should have a low weighting factor, say 0.3, while the concrete-bare soil combination should be fully weighted to 1.0. This emphasizes the hydrologic behavior of each of the materials in the spectral optimization procedure and underscores the needed intercoupling of watershed modeling objectives and remote sensing methods. The subjective selection of the numeric weighting factors is the delicate, fine tuning of the optimization procedure done jointly by the hydrologist and the remote sensing specialist.

Another improvement in the optimization would be to account for the cross-overs or intersections in spectroreflectance curves of the surface materials. This requires the calculation of correlations for each two-material combination for comparison in each of the possible wavelength band combinations generated in the optimization process.* The presence of crossovers in the spectroreflectance curves of materials represents a greater dissimilarity of the materials and, therefore, leads to a more powerful optimization solution. However, the differentiation of asphalt from concrete from lawns, etc., is simpler due to their greatly differing spectroreflectances than the differentiation of materials in natural land areas such as the various prairie vegetation types whose classification has also been attempted using remote multispectral imaging. Thus, the simpler Euclidean distance method outlined is believed to be sufficiently accurate at present to select the wavelength bands to best map the surface materials in urban watersheds.

SPECTROREFLECTANCE MEASUREMENTS OF URBAN SURFACE MATERIALS

The input data for the optimization routine was obtained by field measurements of the ten significant surface materials present in the thirteen Denver watersheds. A field spectrometer was used to produce statistically significant spectroreflectance curves for each material. The principle components of this field spectrometer are a mini computer system (Fig. 12a) and associated FORTRAN data acquisition programs, a spectroradiometer (Fig. 12b), and a field trailer and ancillary equipment (Fig. 12c). Using this system, the *in situ* spectroreflectance of natural materials can be measured in the field at any view angle for all .005 μm wavelength intervals between .3 and 1.6 μm (Pearson and Miller, 1971). All spectroreflectance curves used in this study were measured by this device under natural sunlight in the field and normal to the surface of the material.

*this computational procedure has been designed but was not implemented in time to be used in the sample computations in this report.

The spectrometer system measures the total spectroreflectance curve in three segments, the ultraviolet, the visible, and the near infrared and punches these three segments on paper tape and simultaneously plots them (Fig. 13a) using a FORTRAN program called SAMPL (Pearson and Miller, 1971). A FORTRAN program called JOIN (Appendices E and F) re-reads the original punched tapes back into the mini computer and forms one composite spectroreflectance curve (Fig. 13b) and punched tape for each measurement of each material. Each of the ten surface materials were duplicated three times to represent the expected natural variability in them. Two spectroreflectance curves were measured at different positions on the three samples of each surface material giving six spectroreflectance curves for each of the ten materials defining the urban watershed (Fig. 14). The samples used were:

1) concrete (two curves of each of new, old but clean, and old and dirty (Fig. 14a),
2) asphalt (two curves of each of new, old but clean, and old and dirty),
3) rooftops (six curves of various colors and ages),
4) bare soil (two curves of each of three types differing in surface color),
5) gravel (two curves of each of three natural samples differing in particle size and type),
6) lawns (two curves on each of sparse, medium, and thick Kentucky Bluegrass (Fig. 14b),
7) trees (six curves on small Cottonwood trees),
8) pasture and fallow fields (two curves on each of three samples of natural grassland),
9) agricultural (six curves of wheat stubble and six of sugar beets used separately), and
10) water (two curves on shallow water in a blackened container with three types of bottom materials).

The six curves taken for each of the ten materials were averaged at .005 μm intervals by a FORTRAN program, AVER (Appendices E and F) which reads in the paper tape versions of the JOINed data curves and calculates the average spectroreflectance and its variance at each wavelength. AVER plots these mean spectroreflectance curves for each material together with a curve envelope of $\pm$ 1 σ and simultaneously punches a new paper tape with the mean and variance values at .005 μm intervals (Fig. 15). In this fashion, mean spectroreflectance and variance curves were produced for each of the materials which can now be compared in terms of their statistically significant spectral differences (Fig. 16).

QUALITATIVE INTERPRETATION OF THE SPECTROREFLECTANCE CURVES WITH REFERENCE TO MULTIBAND PHOTOGRAPHY

Water was so different from the other nine surface classes that it was dropped from the further analysis as it is readily identifiable at virtually all wavelengths and combinations of wavelengths due to its unique spectroreflectance. The agricultural unit was divided into the two predominant crops present in larger areas in the early summer. These materials, wheat stubble and green sugar beet foliage, could not be lumped as one spectral unit. The natural breakdown of these ten materials into the two general classes of vegetation and non-vegetation is readily apparent (Fig. 17). All the mean curves for vegetation have a rise in spectroreflectance at .55 μm or green portion of the spectrum and an even greater rise at .7 μm or the beginning of the photo-infrared. However, the two drier vegetation surfaces of wheat stubble and fallow field do not have the high reflectance plateau in the photo infrared characteristic of healthy green vegetation nor the low reflectance at .68 μm resulting from chlorophyll absorbtion. All curves show a significantly steady decrease at wavelengths greater than .9 μm. Non-vegetation shows a higher reflectance in the red (.6 μm to 7 μm) than the vegetation and continues to increase rather than decrease above .9 μm. It should be clear that the best single band in which to differentiate these two material classes would be between 1.1 and 1.3 μm.

A more meaningful single breakdown for the urban hydrologist would be into pervious versus impervious surfaces (Fig. 18). Unfortunately, this is not the same situation as the natural and easy spectroreflectance separation of vegetation and non-vegetation (Figs. 1b and 17) as the non-vegetation surfaces of concrete, asphalt, and shingles are impervious while bare soil and gravel are not. While the five non-vegetation surfaces were spectrally similar to a first approximation, the collection of vegetative materials into one class of pervious land together with bare soil and gravel areas is clearly not spectrally similar (Fig. 18b). Thus, clearly the urban watershed cannot be separated directly into pervious and impervious surface areas based on spectral signature but must first be mapped into the ten different surface materials which can subsequently be recombined into two classes if desired (Figs. 1c and 11).

Eight of the thirteen small watersheds studied in Denver were photographed from the air during April, 1971, by a nine-inch format aerial camera using Ektachrome Aero IR film and a four-band multiband camera. The eight watersheds photographed were Northglenn (all three), Federal Heights, Arvada-N, Arvada-S, Hyatt Lake-N, and Hyatt Lake-S (Appendix B). The multiband camera yielded four separate photographs covering the same identical scene, in the blue, green, red, and photographic infrared portions of the spectrum (Fig. 19). These individual black and white film frames can be colored in any color and superimposed in varying intensities by a special color projection device yielding a color enhanced image. The important difference in spectral contrasts just noted between vegetation and non-vegetation versus impervious and pervious materials can be clearly shown in this fashion with the multiband imagery. Two of the frames, the red (.6 to .7 μm) and infrared images (.7 to .9 μm) are color coded red and blue respectively and superimposed to show the Northglenn 7201 watershed in false color (Fig. 20). The red colored image shows non-vegetative areas clearly as a red or pink color, while healthy green vegetation, having a high reflectance in the photographic infrared is color coded as blue. The red and blue areas, therefore, resemble an impervious-pervious classification of surface materials, with the exception of gravel and bare soil which, as predicted from the spectroreflectances, are incorrectly coded the color of impervious areas. Thus, these multiband photos show in specially enhanced pictures the degree to which nature provided a significant spectral difference between pervious and impervious materials.

The Ektachrome infrared air photos were obtained for the eight watersheds to provide detailed high resolution imagery (Frontpiece). The areas coded in red on these photos represent high reflectance in the photographic infrared and can be noted wherever healthy vegetation is present, especially in the lawns and open fields. This photography can be used for accurately preparing a map by conventional photo interpretation methods of the ten surface materials for comparison with the enhanced multiband imagery. More importantly, these accurate maps of surface materials can be compared with the results of automatic image processing of multispectral imagery of these basins when such imagery becomes available.*

OPTIMIZATION OF THE DEVICE AND/OR IMAGE PROCESSING FOR MULTISPECTRAL MAPPING OF URBAN WATERSHEDS

The curves output by AVER for each of the ten materials excluding water were input into a FORTRAN computer program, OPTIM (Appendices E and F), which performs all but the last step in the optimization procedure outlined in the earlier section. The mean curves and their variance are read by OPTIM and the average reflectance and variance is calculated for each wavelength band used in the multispectral scanner being analyzed. One analysis by OPTIM sought the best single band and best four bands of the 12 wavelength bands used on the 12 channel University of Michigan multispectral scanner, a device widely used for remote multispectral imaging. The 12 spectral bands used on this device occur in Table 4. Table 5 shows in abbreviated form how the data is stored in OPTIM. The mean reflectance values and the corresponding averaged variances in the 12 wavelength intervals are stored in separate matrices [AVE(i,j)] and [VAR(i,j)] respectively where i represents the number of the material, and j represents the wavelength interval number. For simplicity both the mean reflectance over each wavelength band (ρ) and the corresponding mean variance (S^2) are shown in Table 5. The matrix of squared differences of two-material combinations [U(IE,I)] in Table 6 gives the values within the summation sign of the Euclidean distance equation as outlined in step 3 of the optimization process. The operations on the proper ρ and S^2 values are in the appropriate locations of this matrix, where rows represent the two material combinations, consecutively numbered in the order they are generated, and columns again represent band numbers. Calculations of minimum, maximum, and average Euclidean distances were made for optimally selecting the best 1, 2, 3, ..., 12 wavelength bands in the manner outlined in step 4 of the optimization procedure using numerical data from the spectroreflectance measurements in the [U(IE,I)] matrix. The proper band combinations are generated and the corresponding proper elements of the [U(IE,I)] matrix are selected, summed, and raised to the 1/2 power for each of the two material combinations for each particular band combination. The minimum and maximum Euclidean distance between each two materials is listed under the band

*working computer programs for automatic multispectral image processing are available at Colorado State University (Smith, Miller, and Ells, 1972).

TABLE 4. TWELVE SPECTRAL BANDS OF TYPICAL SIMULTANEOUS MULTISPECTRAL SCANNER

Spectral Band (Channel No.)	Wavelength Interval	Spectral Band (Channel No.)	Wavelength Interval
1	.40-.44μm	7	.55-.58μm
2	.44-.46μm	8	.58-.62μm
3	.46-.48μm	9	.62-.66μm
4	.48-.50μm	10	.66-.72μm
5	.50-.52μm	11	.72-.80μm
6	.52-.55μm	12	.80-1.0μm

TABLE 5. MEAN REFLECTANCE (ρ) AND VARIANCE (S^2) MATRICES [AVE(i,j)] AND [VAR(i,j)], RESPECTIVELY. These matrices of mean reflectance and pooled variance over each of twelve wavelength bands are the data used in the Euclidean distance (d) computation.

SURFACE MATERIAL \ SPECTRAL BAND	1	2	3	--	--	11	12
1 GRASS	ρ_{11} S^2_{11}	ρ_{12} S^2_{12}	ρ_{13} S^2_{13}	--	--	ρ_{111} S^2_{111}	ρ_{112} S^2_{112}
2 CONCRETE	ρ_{21} S^2_{21}	ρ_{22} S^2_{22}	ρ_{23} S^2_{23}	--	--	ρ_{211} S^2_{211}	ρ_{212} S^2_{212}
3 BARE SOIL	ρ_{31} S^2_{31}	ρ_{32} S^2_{32}	ρ_{33} S^2_{33}	--	--	ρ_{311} S^2_{311}	ρ_{312} S^2_{312}
⋮	⋮	⋮	⋮			⋮	⋮
10 ASPHALT	ρ_{101} S^2_{101}	ρ_{102} S^2_{102}	ρ_{103} S^2_{103}	--	--	ρ_{1011} S^2_{1011}	ρ_{1012} S^2_{1012}

TABLE 6. INTERMEDIATE MATRIX [U(IE,I)] USED IN CALCULATING THE EUCLIDEAN DISTANCE (d) FOR THE BEST 1, 2, 3, ..., 12 OUT OF 12 WAVELENGTH BANDS. The matrix contains the squared differences in mean reflectances and squared sums of pooled variance from Table 4 for all possible combinations of ten surface materials taken two at a time in each of the twelve available spectral bands.

SPECTRAL BAND / SURFACE MATERIAL COMBINATION	1	2		12
1 - 2	$\frac{(\rho_{11} - \rho_{21})^2}{(S^2_{11} + S^2_{21})/2}$	$\frac{(\rho_{12} - \rho_{22})^2}{(S^2_{12} + S^2_{22})/2}$	-- --	$\frac{(\rho_{112} - \rho_{212})^2}{(S^2_{112} + S^2_{212})2}$
1 - 3	$\frac{(\rho_{11} - \rho_{31})^2}{(S^2_{11} + S^2_{31})/2}$	$\frac{(\rho_{12} - \rho_{32})^2}{(S^2_{12} + S^2_{32})/2}$	-- --	$\frac{(\rho_{112} - \rho_{312})^2}{(S^2_{11} - S^2_{112})/2}$
1 - 4	$\frac{(\rho_{11} - \rho_{41})^2}{(S^2_{11} + S^2_{41})/2}$	$\frac{(\rho_{12} - \rho_{42})^2}{(S^2_{12} + S^2_{42})/2}$	-- --	$\frac{(\rho_{112} - \rho_{412})^2}{(S^2_{112} + S^2_{412})/2}$
⋮	⋮	⋮		⋮
9 - 10	$\frac{(\rho_{91} - \rho_{101})^2}{(S^2_{91} + S^2_{101})/2}$	$\frac{(\rho_{92} - \rho_{102})^2}{(S^2_{92} + S^2_{102})/2}$	-- --	$\frac{(\rho_{912} - \rho_{1012})^2}{(S^2_{912} + S^2_{1012})/2}$

combination, and the average Euclidean distance for all two-material combinations is calculated, and also listed under the wavelength combination. This entire process is repeated for all wavelength interval combinations providing the data from which the best wavelength band combinations will be selected.

OPTIM computations were made for the Euclidean distances with which to select the best single wavelength interval for differentiating the urban materials from the 12 available on the University of Michigan multispectral scanner (Fig. 21). It can be deduced from this data that wavelength interval 2 or .44 to .46 μm is the best single band in which to simultaneously differentiate all ten surface materials because it shows the largest minimum (meaning that the closest 2 materials' spectroreflectance curves are further apart than in any other of the 12 wavelength bands), the largest maximum (greatest separation of curves farthest apart) and the largest average (greatest overall separation of all combinations of the ten curves). Visual inspection of the mean spectroreflectance curves for the materials (Fig. 21) indicates that the wavelength interval 2 is not the apparent position of maximum reflectance separation. This visual interpretation of only mean curves without regard to their statistical variance is misleading. The mean curves for these materials appear (Fig. 21) to be separated more greatly in wavelength interval 12 or 0.8 -1.0 μm, but the statistical variation is much greater in this band. The Euclidean distance calculations using the statistical variation therefore gives a more correct optimization result than would be determined by visual inspection of mean spectroreflectance curves, even for the simple selection of the single wavelength band in which to separate the ten materials.

The selection of the proper combination from the Euclidean distance calculations becomes more complex when optimizing for a choice of several best spectral bands taken simultaneously. For example, consider the selection of 4 spectral bands out of the 12. There are a total of 495 possible combinations of 12 items taken 4 at a time.* Examination of the 10 highest and 3 lowest combinations are listed from which the selection of the best 4 simultaneous wavelengths to map the urban scene may be made (Fig. 22). The 3 lowest values are listed solely for indicating the total range of Euclidean distance statistics calculated. From this data, it becomes apparent that the selection of the best one of the 4 band combinations is still a subjective value judgment. In selecting the one optimum combination the average should be weighted most

*the solution for the best 4 of the 12 bands for the 10 materials including all the numerical matrices involved occur in Appendix E on pages E-6 and E-7.

heavily, since it reflects the overall distribution of the curves. The best combination, therefore, would be intervals 1, 2, 3, and 4 from a purely numeric viewpoint. However, since curve crossovers are not accounted for by this technique, visual inspection of all of the mean curves suggests the selection of intervals 1, 2, 4, and 9 as the best combination since it occurs high up in both average and maximum Euclidean distances. To emphasize curve crossovers (intersections) at the expense of the Euclidean distance optimization calculations, the combination 1, 2, 4, and 12 is selected to utilize the vegetation-non-vegetation contrasts in the visible to the infrared regions. The selection of combination 1, 2, 4, and 9 does account for some mean curve crossovers in the green portion of the visible spectrum and is one of the optimal sets based solely on the Euclidean distance optimization calculations. This optimum combination for the ten materials defining the scene in the available 12 wavelength intervals could now be implemented in a simple 4 band multiband camera or processed from amongst the 12 available by the spectrum matching technique.

CONCLUSIONS

The choice of the optimum wavelength bands with which to map the urbanizing watershed is a complex process from a spectral point of view, still requiring subjective decisions. Equally important is the determination of the materials which are to define the scene together with the variation in these materials both spectrally and hydrologically, throughout the different seasons of the year. Ground measurements of the spectral properties of more of the important surface materials is recommended. This should include a thorough analysis of changes in the spectral and hydrological properties throughout the different seasons of the year. Seasonal data may be used to optimize the mapping operation spectrally and temporally. Spectral-time surfaces could be examined in 3 space with reflectance plotted as a function of both wavelength and time. Some curves will remain constant throughout the year, but others change, particularly vegetation, therefore providing another variable that can be used to distinguish and map urban materials. The measurements and results obtained in one urbanizing fringe such as that around Denver are generally applicable throughout the U. S. with the exception that spectroreflectance curves of some natural materials, especially vegetation, must be remeasured as a function of season for each metropolitan area.

The Euclidean distance method has been shown to effectively indicate the amount of minimum and maximum curve separation and overall curve distribution within any combination of wavelength bands while at the same time accounting for statistical variation within the spectral characteristics of the classes of materials to be imaged. The method has also been shown to be superior to inspection of mean curves by eye, but its most serious drawback is its failure to account for the information contained in curve crossovers or intersections. However, a more complicated optimization routine has been designed which will consider these crossovers by using correlation statistics. The most significant spectral difference in vegetation and non-vegetation is the contrast between the two surface classes in the red and infrared portions of the spectrum, resulting in a large number of curve crossovers (Figs. 16, 17, and 18). Therefore, future efforts for wavelength band optimization of vegetation and non-vegetation materials must utilize these techniques for recognizing curve crossovers such as the comparison of correlations from one band or band combinations to other bands.

Once the method for data collection has been optimized and multispectral imagery obtained over the urban fringe areas of interest, it is possible to analyze the data automatically using spectrum matching techniques to accurately calculate the area and distribution of each significant watershed surface material. The multispectral imagery can be analyzed for any combination of surface materials depending upon the requirements of the watershed model in question, and the results can be converted to hydrologic units and used as a <u>direct</u> input into the simulation model. This approach will bypass the subjective, laborious air photo interpretation of the surface cover types of the watershed. It should thus be possible to produce yearly maps of surface materials in urbanizing watersheds to keep simulation models current for flood prediction, etc. The computer mapping of surface materials could also produce the simple pervious-impervious classification, which many hydrologic models presently operating use as an input, or it could provide the more complicated breakdown of surface materials as input into the more complex research models. The detailed breakdown of surface cover required by these sophisticated process models rules out the practicability of human photo interpretation which could not keep pace with the yearly changes in the urbanizing areas. The use of remote multispectral sensing mapping methods by hydrologists involved in urban watershed modeling is therefore suggested to determine if "limiting factor" such as accurate, timely surface material maps are, in fact, limiting in process model design.

The next logical research step in this investigation is the expanded study of the eight Denver watersheds that have been analyzed and photographed. After more detailed ground study of spectral properties of the urban materials, including variation with seasons, actual multispectral scanner imagery should be flown over the watersheds at several times during the year. The multispectral imagery should be interpreted by computer and the accuracy of identifications of the watershed units and their calculated surface areas should be compared for accuracy with human identification and areal measurement of these same units. This could be accomplished by interpretation of blown up prints of color and color infrared photographs taken concurrently with each multispectral image collection mission.

After the degree of accuracy of the computer interpretation by spectrum matching is determined, experiments should be conducted for identifying three-dimensional spectroreflectance surfaces by including the time element for each curve to see if using three-dimensional spectral surfaces results in a greater mapping accuracy than the examination of the current spectroreflectance curves of the materials. In any further study, emphasis would be placed on additional collaboration with hydrologists involved in urban watershed modeling, especially those researching advanced models in order that both disciplines might effectively communicate and test their current requirements and objectives.

LITERATURE CITED

Colwell, J. E., 1970. Multispectral remote sensing of urban features. Willow Run Laboratories, University of Michigan, USGS 14-0001-11968, Ann Arbor, Michigan, 19 pp.

Crawford, N. H. and R. K. Linsley, 1962. The synthesis of continuous streamflow hydrographs on a digital computer. Technical Report 12, Stanford University, Department of Civil Engineering, Palo Alto, California, 121 pp.

Gerlach, A., 1971. Personal communication.

Gonzalez, D. D. and G. L. Ducret, 1971. Rainfall-runoff investigations in the Denver metropolitan area, Colorado. USGS, Water Resources Division, Open File Report 71003, Denver Federal Center, Denver, Colorado, 27 pp.

James, L. D., 1965. Using a digital computer to estimate the effects of urban development on flood peaks. Water Resources Research, 1:223-234.

Lull, H. W. and W. E. Sopper, 1969. Hydrologic effects from urbanization of forested watersheds in the northeast. USDA, N. E. Forest Experiment Station, Forest Service Research Paper NE-146, Upper Darby, Pa., 31 pp.

Marble, D. F. and F. E. Horton, 1969. Extraction of urban data from high and low resolution images. Proceedings of the 6th International Symposium on Remote Sensing of Environment, University of Michigan, Willow Run Laboratories, Ann Arbor, Michigan, pp. 807-818.

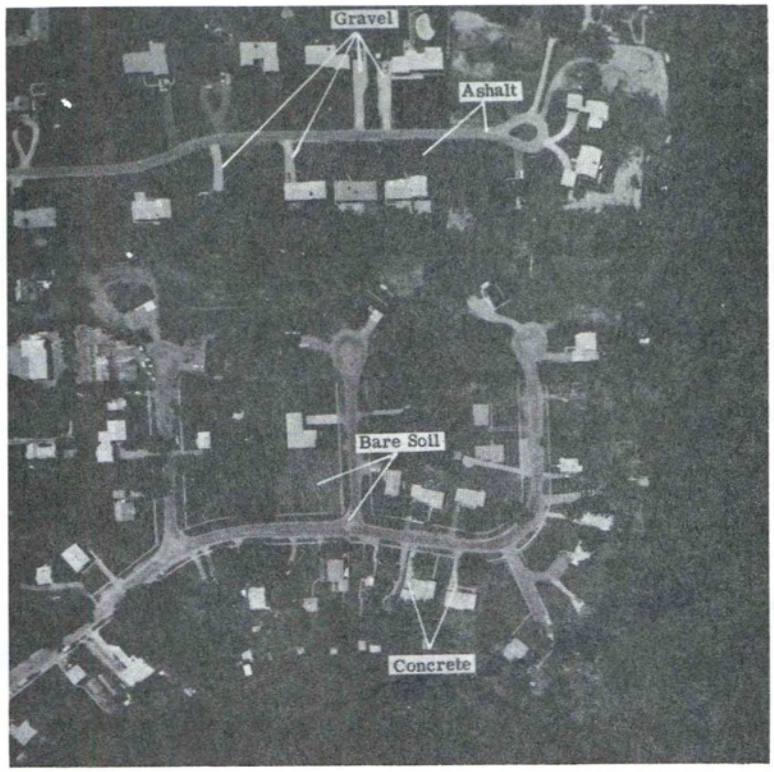
Narayana, V.V.D., J.B. Evelyn, and J.P. Riley, 1970. Simulation of runoff from urban watersheds. Utah State University, Utah Water Research Laboratory, Logan, Utah.

Oliver, R. E. and L. D. Miller, 1971. The design of a landscape model, Central Basin Watershed. International Biological Program, Grassland Biome, Technical Report 90, Colorado State University, Fort Collins, Colorado, 19 pp.

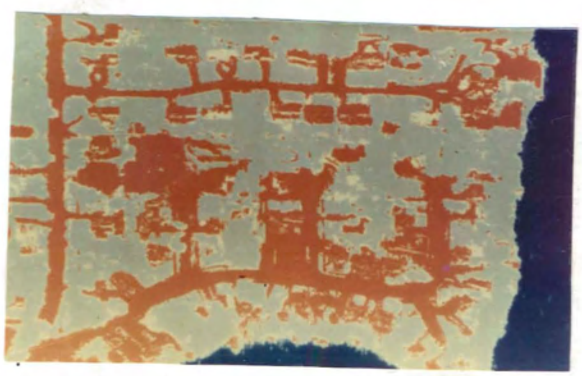
Pearson, R. L. and L. D. Miller, 1971. Design of a field spectrometer laboratory. Colorado State University, Department of Watershed Sciences, Science Series 2, Fort Collins, Colorado, 102 pp.

Smith, J. A., L. D. Miller, and T. Ells, 1972 (in publication). Pattern recognition routines for graduate training in the automatic analysis of remote sensing imagery. Colorado State University, Department of Watershed Sciences, Science Series 3, Fort Collins, Colorado, 125 pp.

Wellar, B., 1967. Generation of housing quality data from multiband aerial photographs. Geologic Applications Program, USGS Research Report 32, Department of Geography, Northwestern University, Evanston, Illinois.

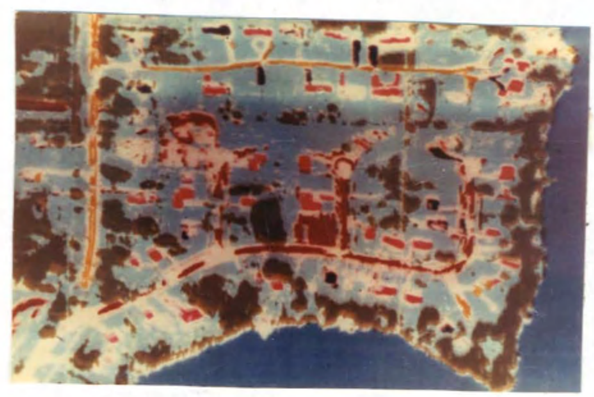


(a) reference airphoto - Belleville, Michigan area



(b) simple color-coded recognition map

blue = water
green = vegetation
brown = nonvegetation

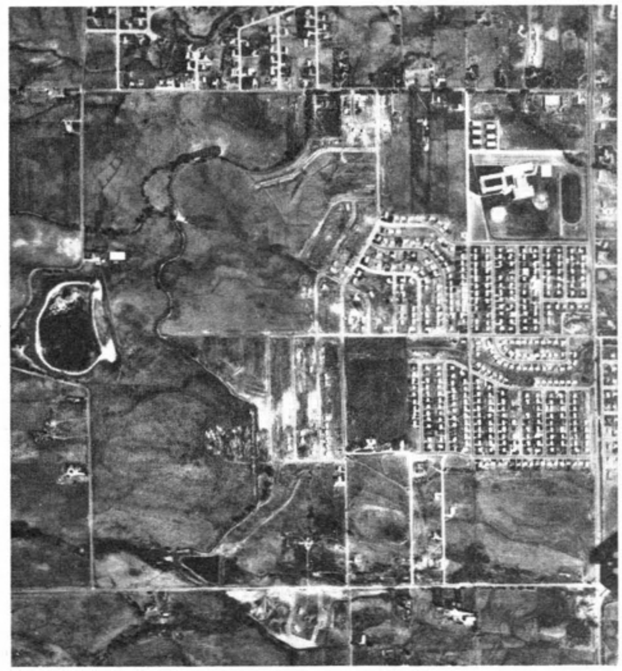


(c) complex color-coded recognition map

blue = water   red = roofs
cyan = lawns   green = trees
dark brown = bare soil
yellow brown = asphalt

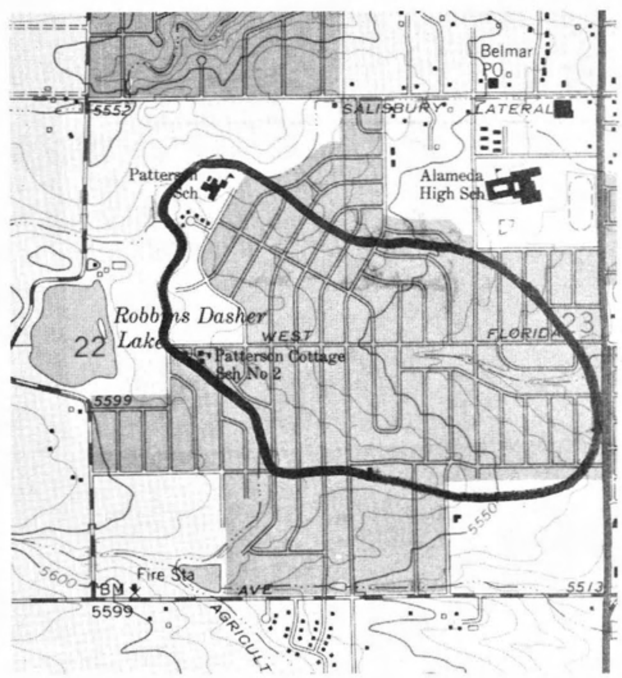
FIGURE 1. RECOGNITION MAPS OF A SUBURBAN SCENE AUTOMATICALLY PREPARED FROM REMOTE MULTISPECTRAL IMAGERY. The areal features were classified on an analog computer using techniques of automatic image interpretation by the University of Michigan. (b) Using ten spectral bands between .4 μm and 1.0 μm. (c) Using six spectral bands between .4 μm and 1.0 μm. (J. E. Colwell, 1970)

(a) 1959



(b) 1963

(c) 1970



(d) topographic map

FIGURE 2. URBANIZATION OF FORT LOGAN WATERSHED, DENVER, COLORADO. This historical aerial photography sequence illustrates the rapid development of the Fort Logan watershed from 1959 to 1970. Scale 1/24,000. See Figure 3d for imperviousness development curve.

(a) FEDERAL HEIGHTS
1954-1970

(b) AURORA
1954-1970

(c) LITTLETON
1954-1970

(d) FORT LOGAN
1949-1970

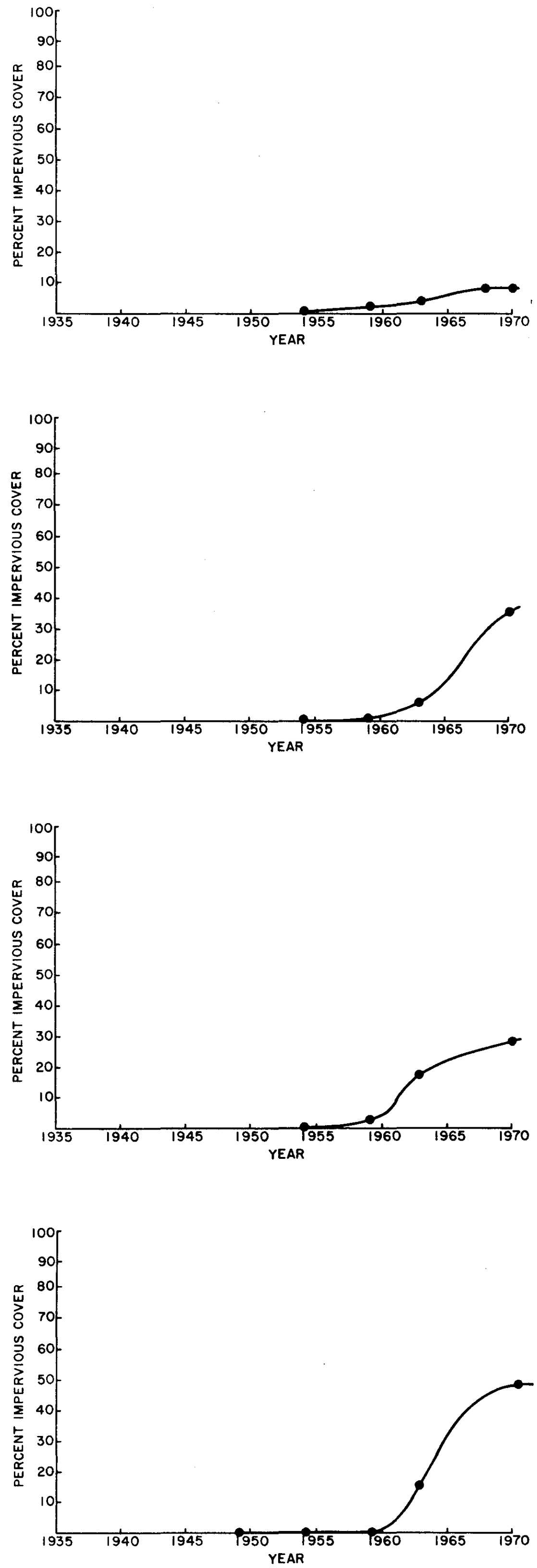
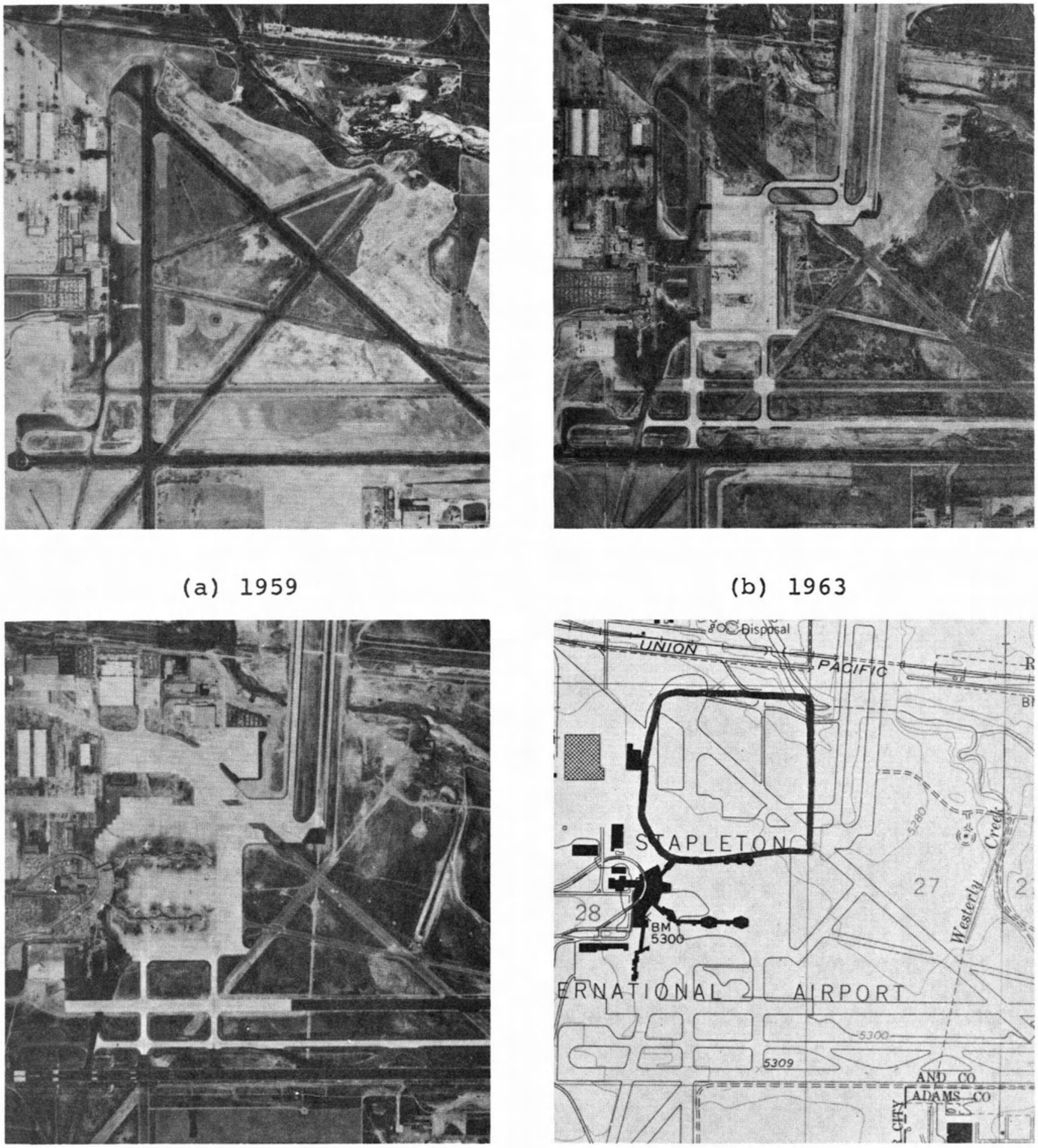


FIGURE 3. IMPERVIOUSNESS DEVELOPMENT CURVES FOR SEVERAL DENVER AREA WATERSHEDS. Percent of impervious material is plotted as a function of time in years. Figure 2 contains some of the historical photographs interpreted to form the curve for the Fort Logan watershed.



(a) 1959

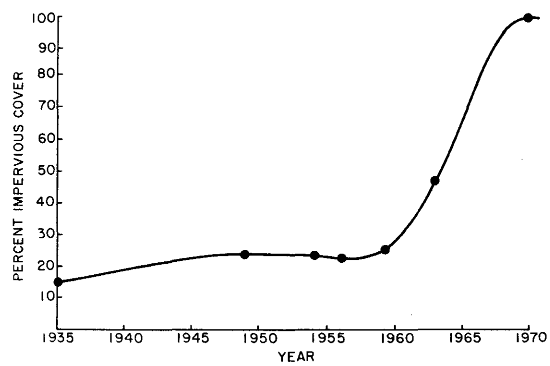
(b) 1963

(c) 1970

(d) topographic map

FIGURE 4. URBANIZATION OF STAPLETON AIRPORT WATERSHED, DENVER, COLORADO. This historical aerial photography sequence illustrates the rapid development of the Stapleton Airport watershed from 1959 to 1970. Scale 1/24,000. See Figure 5a for development curve.

(a) STAPLETON AIRPORT
1936-1970



(b) STAPLETON-S
1950-1970

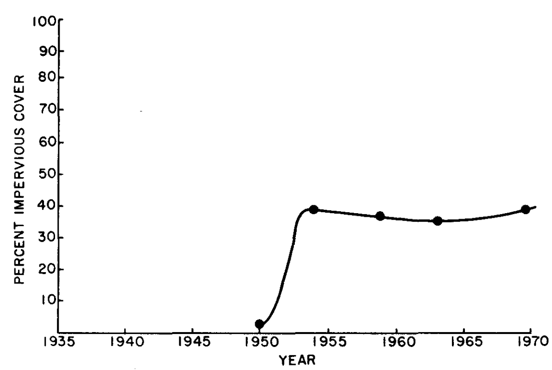
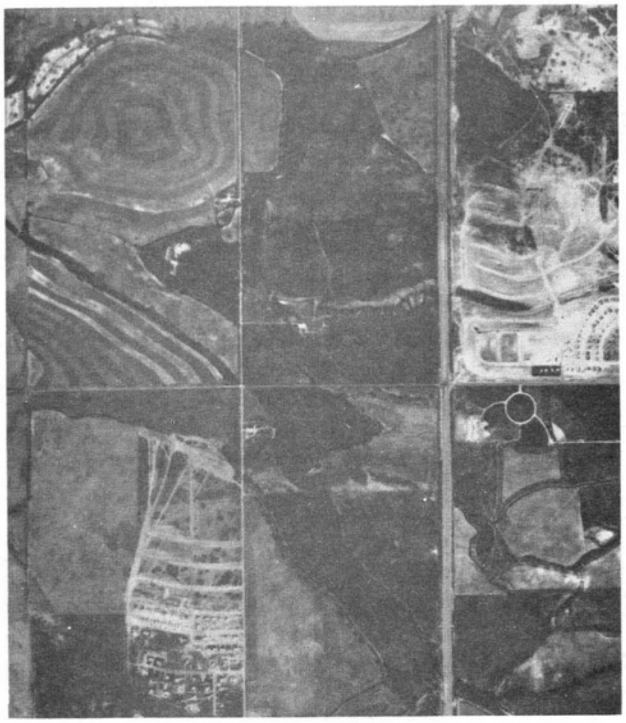


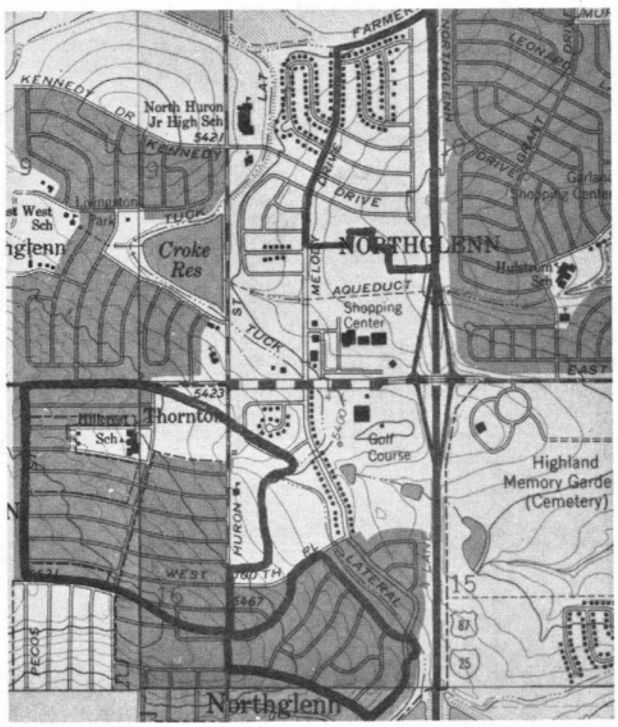
FIGURE 5. IMPERVIOUSNESS DEVELOPMENT CURVES FOR THE STAPLETON WATERSHEDS. Percent of impervious material is plotted as a function of time in years. Figure 4 contains some of the historical photographs interpreted to form the curve for the Stapleton Airport watershed.



(a) 1959

(b) 1963

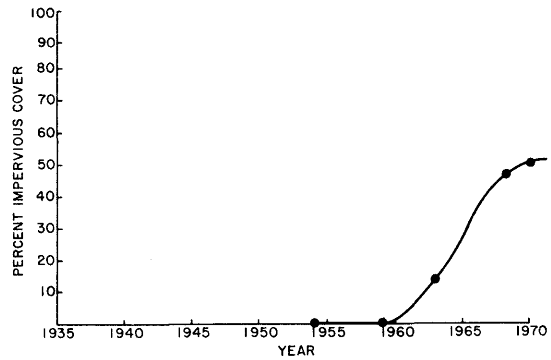
(c) 1968



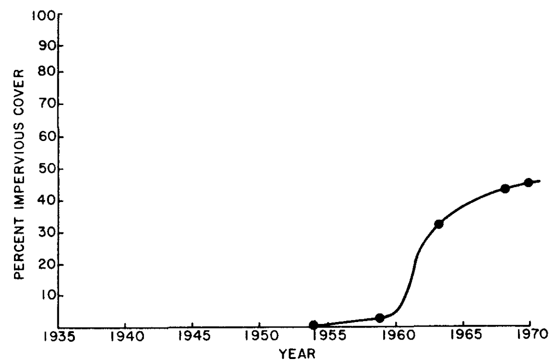
(d) topographic map

FIGURE 6. URBANIZATION OF THREE NORTHGLENN WATERSHEDS, NORTH OF DENVER, COLORADO. This historical aerial photography sequence illustrates the rapid development of three watersheds in the Northglenn area from 1959 to 1968. Scale 1/20,000. See Figure 7 for development curves.

(a) NORTHGLENN
1954-1970
Basin 7201



(b) NORTHGLENN
1954-1970
Basin 7203



(c) NORTHGLENN
1954-1970
Basin 7204

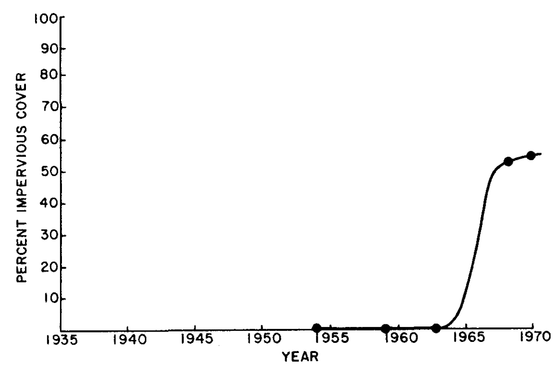


FIGURE 7. IMPERVIOUSNESS DEVELOPMENT CURVES FOR THE NORTHGLENN WATERSHEDS. Percent of impervious material is plotted as a function of time in years. Figure 6 contains some of the historical photographs interpreted to form these three curves.

(a) ARVADA-N
1949-1970

(b) ARVADA-S
1949-1970

(c) HYATT LAKE-N
1959-1970

(d) HYATT LAKE-S
1959-1970

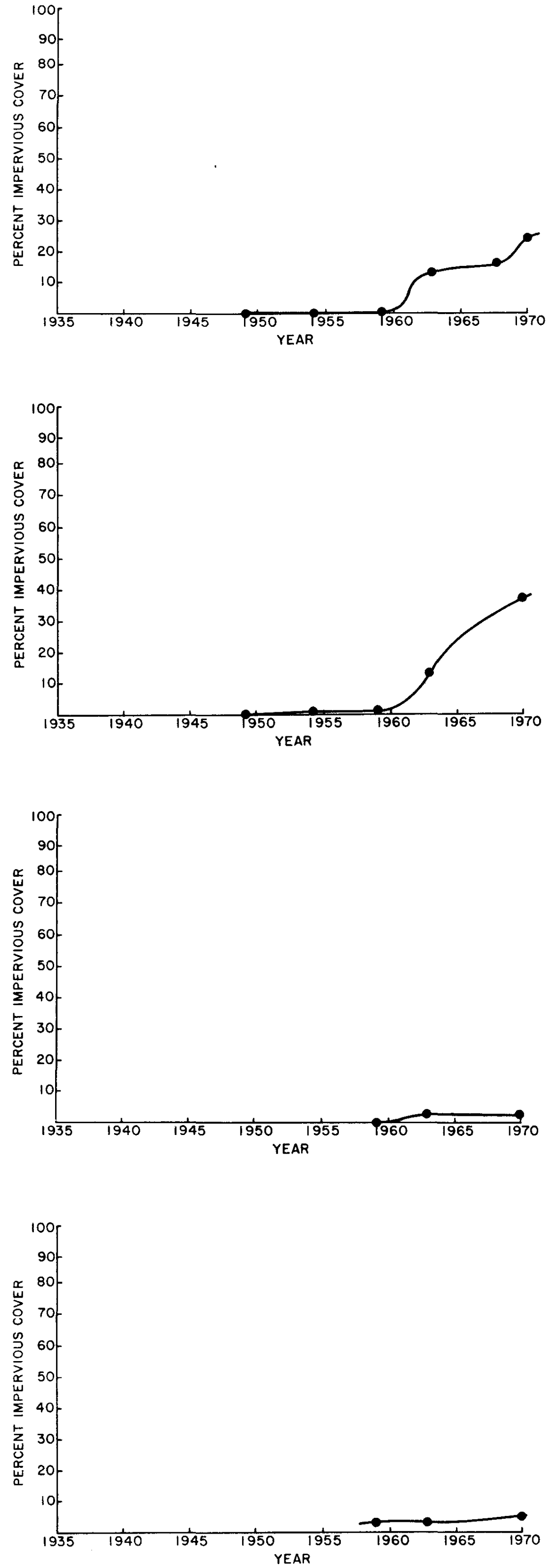
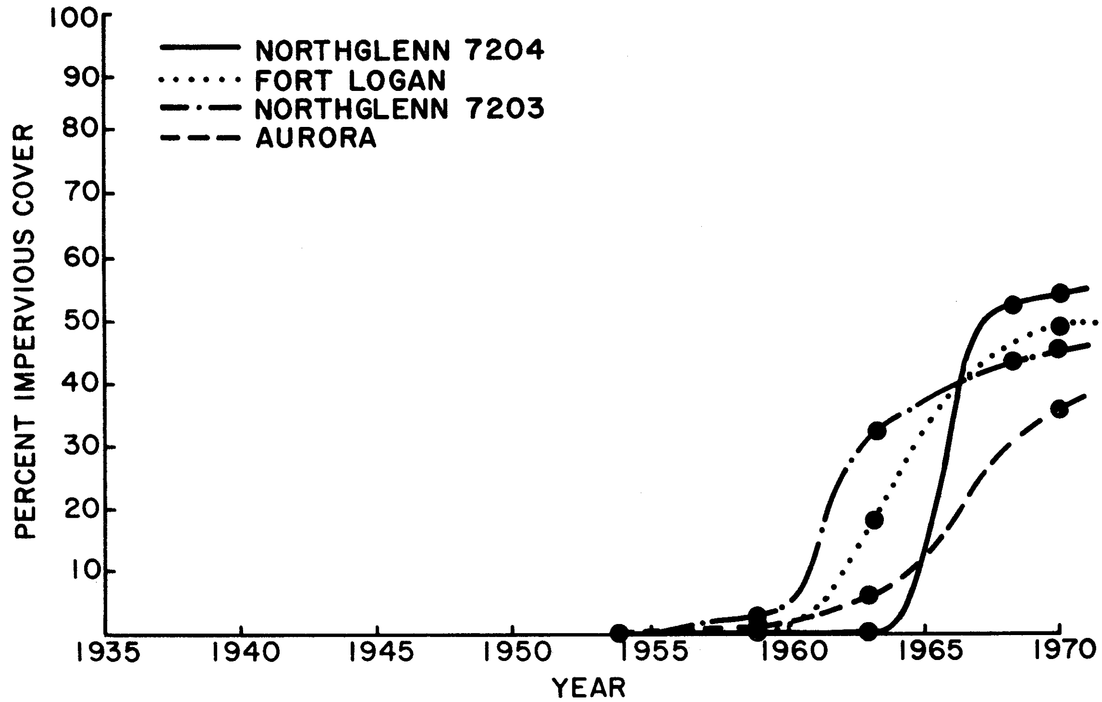
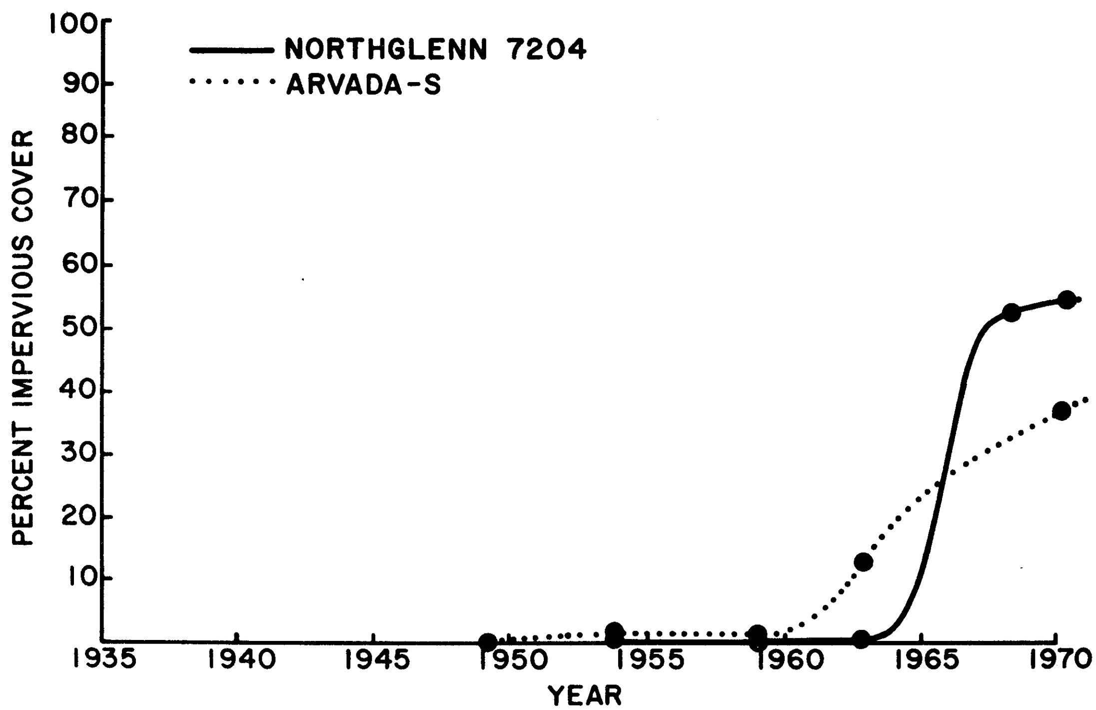


FIGURE 8. IMPERVIOUSNESS DEVELOPMENT CURVES FOR SEVERAL DENVER AREA WATERSHEDS. Percent of impervious material is plotted as a function of time in years.

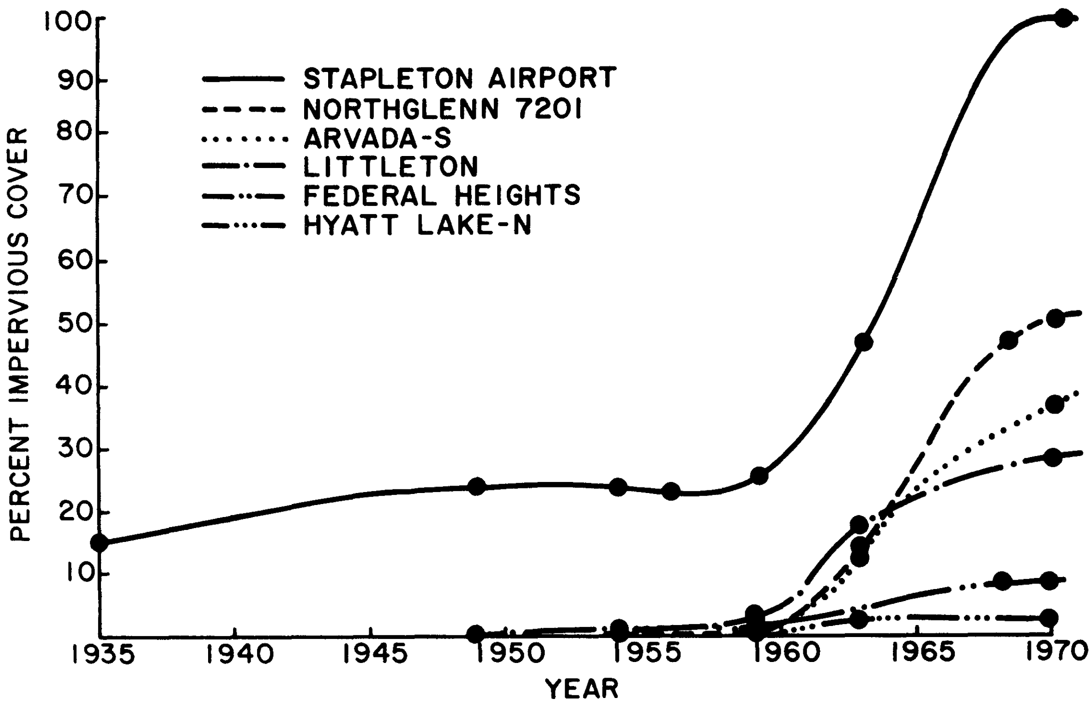


(a) different rates of urbanization

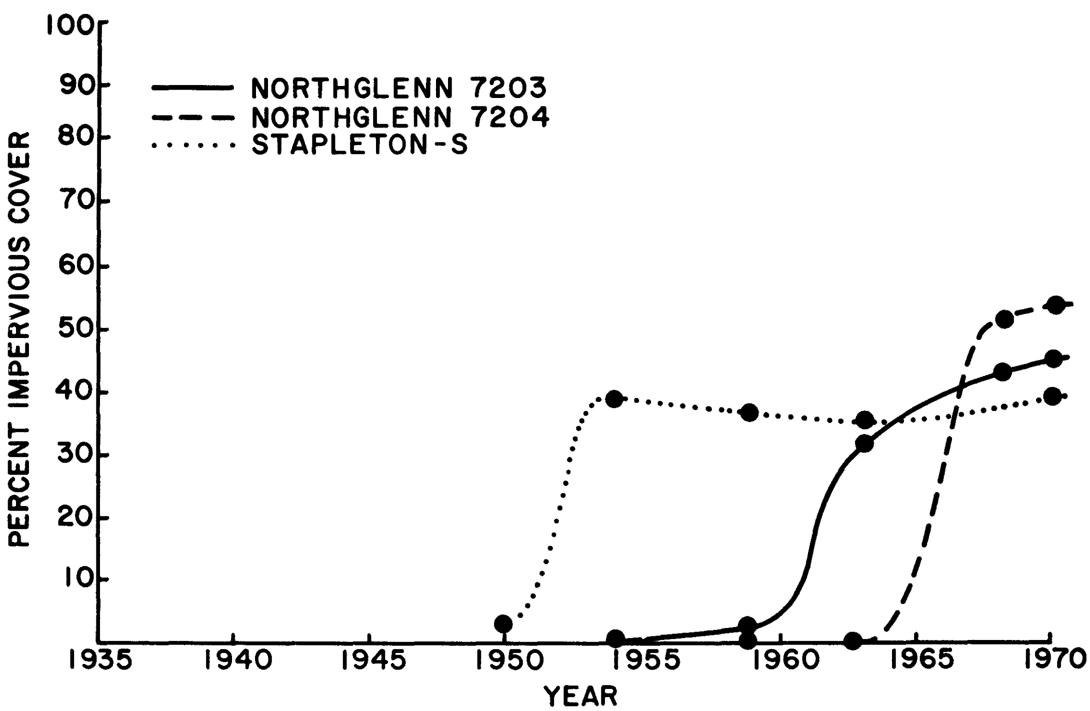


(b) rapid versus gradual urbanization

FIGURE 9. VARYING RATES OF DENVER URBANIZATION MEASURED BY PERCENT CHANGE IN IMPERVIOUS COVER. The individual imperviousness development curves used occur in Figures 3, 5, 7, and 8.



(a) different degrees of urbanization



(b) rapid urbanization beginning at different dates

FIGURE 10. VARYING DEGREES AND TIMES OF DENVER URBANIZATION MEASURED BY PERCENT CHANGE IN IMPERVIOUS COVER. The individual imperviousness development curves used occur in Figures 3, 5, 7, and 8.

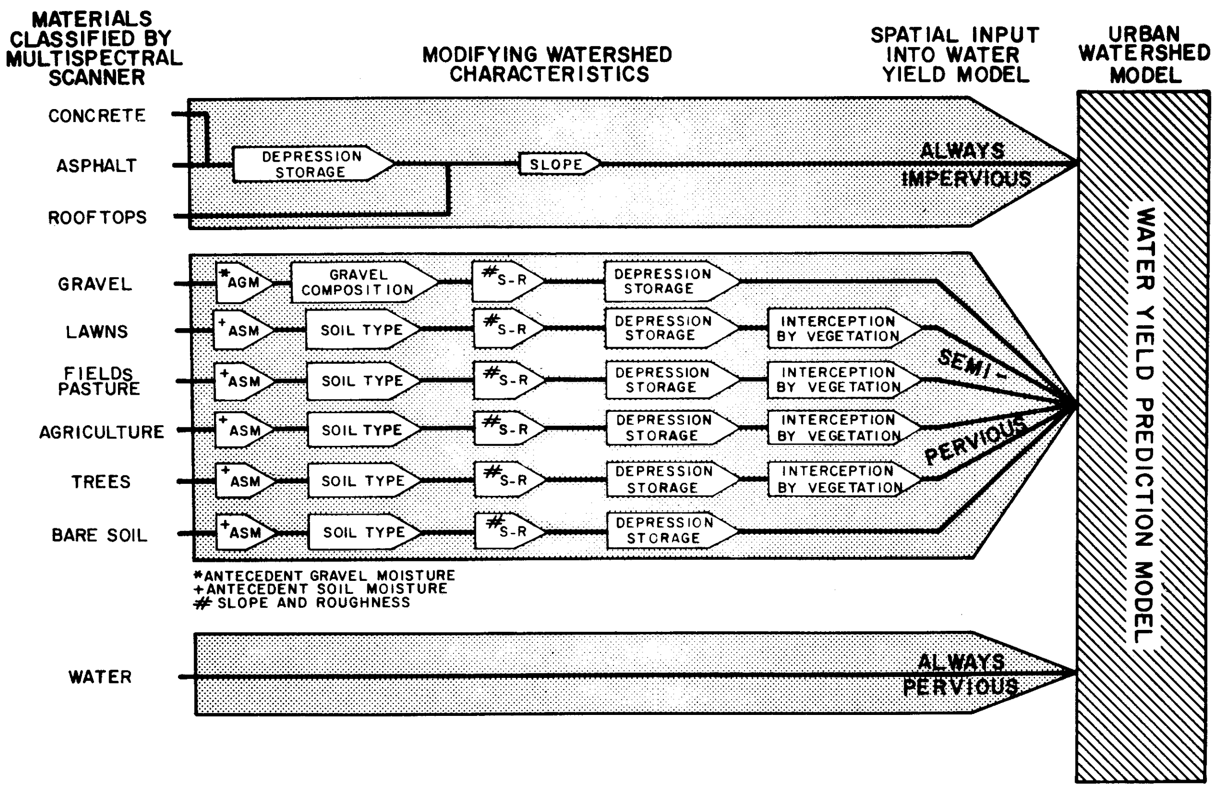
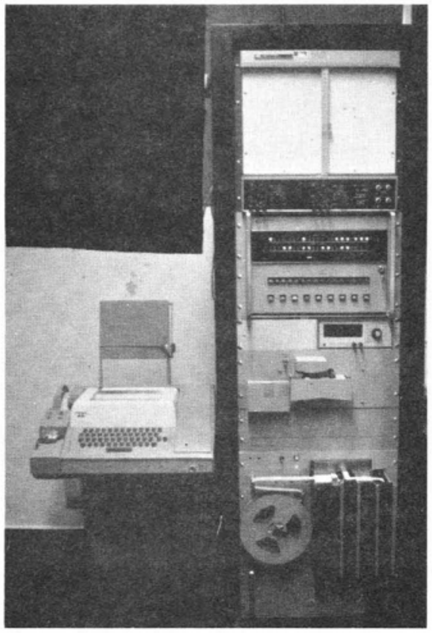
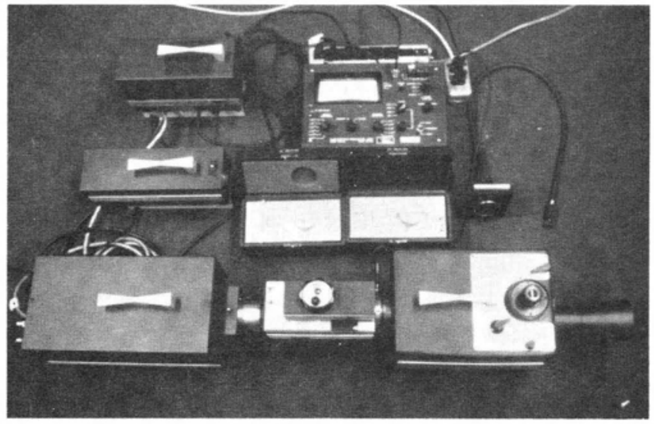


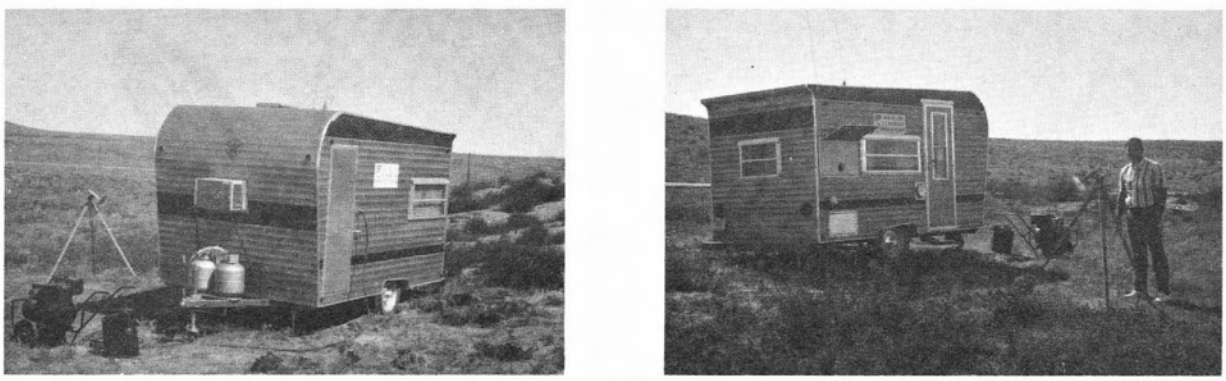
FIGURE 11. "MAPPING" THE CLASSIFICATION OF SURFACE MATERIALS INTO UNITS OF SURFACE HYDROLOGY BY REMOTE MULTISPECTRAL SENSING. Each hydrologic unit must be refined by the hydrologic characteristics of each of the contributing remote sensing units, such as antecedent soil moisture, soil type (e.g., porosity, permeability, etc.), depression storage, slope and roughness, and interception by vegetation, before being input into the watershed model.



(a) computer digital
data acquisition system



(b) spectroradiometer modules



(c) field trailer configuration

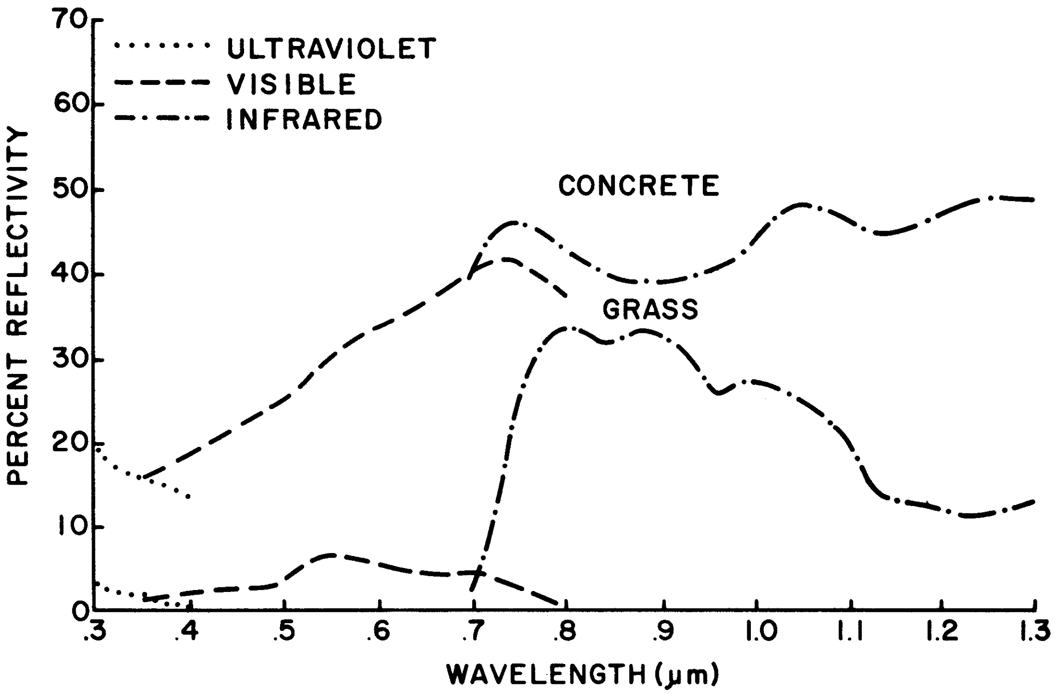
FIGURE 12. FIELD SPECTROMETER SYSTEM. This system was used in the field measurement of all spectroreflectance curves. (a) Computerized digital data acquisition system shown in the rack used for indoor laboratory operations during the winter months. (b) Composite view of the EG&G model 580-585 spectroradiometer showing all available hardware used in the laboratory. (c) Field trailer housing the spectroradiometer, computer system, and ancillary equipment as they are being used for 'in situ' collection of spectroradiance and spectroreflectance measurements. Note generator used for field power. Note also the small tripod mounted, first surfaced mirror used for folding the horizontal view of the spectroradiometer pointed out the side of the trailer down normal to the ground surface. Larger 75 by 100 cm mirrors are also used to measure quarter square meter ground patches. (Courtesy Pearson and Miller, 1971)

FIGURE 12a. DESCRIPTION EXPANDED. The Hewlett-Packard minicomputer data system consists of:

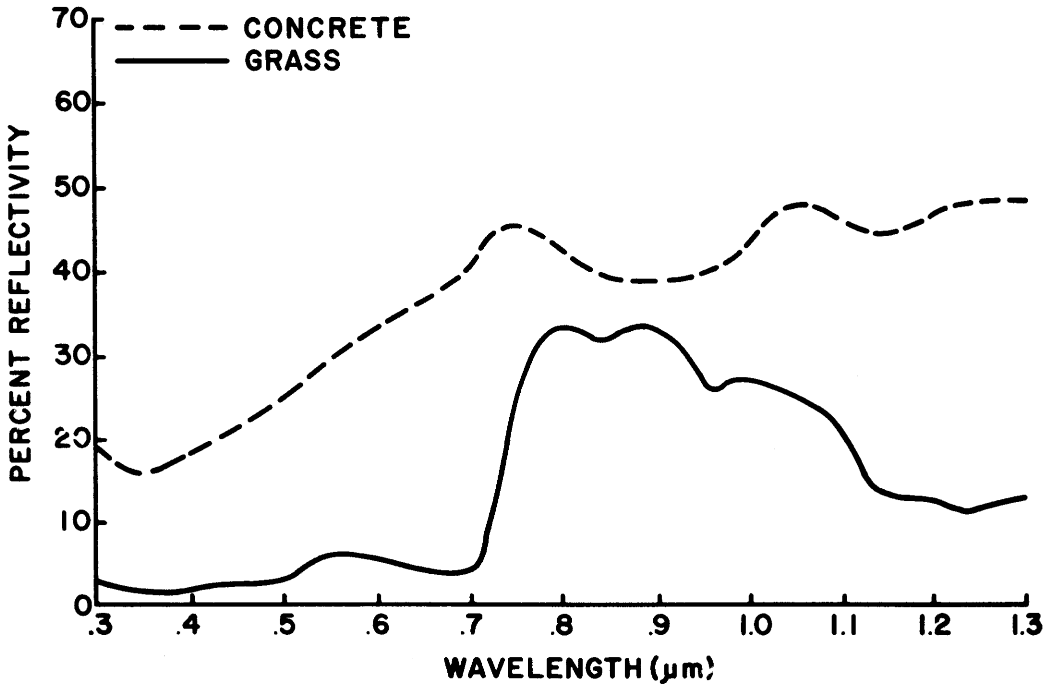
1. an analog x-y plotter, interfaced to the computer through a digital to analog converter card, and used to plot the spectral curves as they are reduced on line by the computer (top of rack);
2. a model 2114A digital computer (middle of rack);
3. a digital multimeter for system maintenance and testing (below computer);
4. a high speed (300 eight-bit characters per second) punched paper tape reader used primarily for program input to the computer (lower middle of rack);
5. a low level analog to digital converter for conversion of input analog signals from the spectroradiometer and other sensors (just below the paper tape reader);
6. a high speed (120 eight-bit characters per second) paper tape punch for data output (bottom of rack);
7. a multiplexer for selecting under program control the analog input channel to be digitized (below paper tape punch); and
8. a model ASR-33 teletype for keyboard input and printed output from the computer (left).

FIGURE 12b. DESCRIPTION EXPANDED. The spectroradiometer system is composed of the following modular subsystems:

1. a reflective telescope for viewing the sample (lower right);
2. a monochromator housing which accepts one of three gratings used to select the wavelength being sampled (lower center and middle);
3. a high sensitivity, near infrared detector head (lower left) and a separate power supply and cooling controller (upper left);
4. a high sensitivity, ultraviolet-visible detector head (middle left);
5. an indicator unit through which the radiant intensity signal is amplified (upper middle); and
6. a one-meter fiber optics probe which replaces the telescope (upper left).

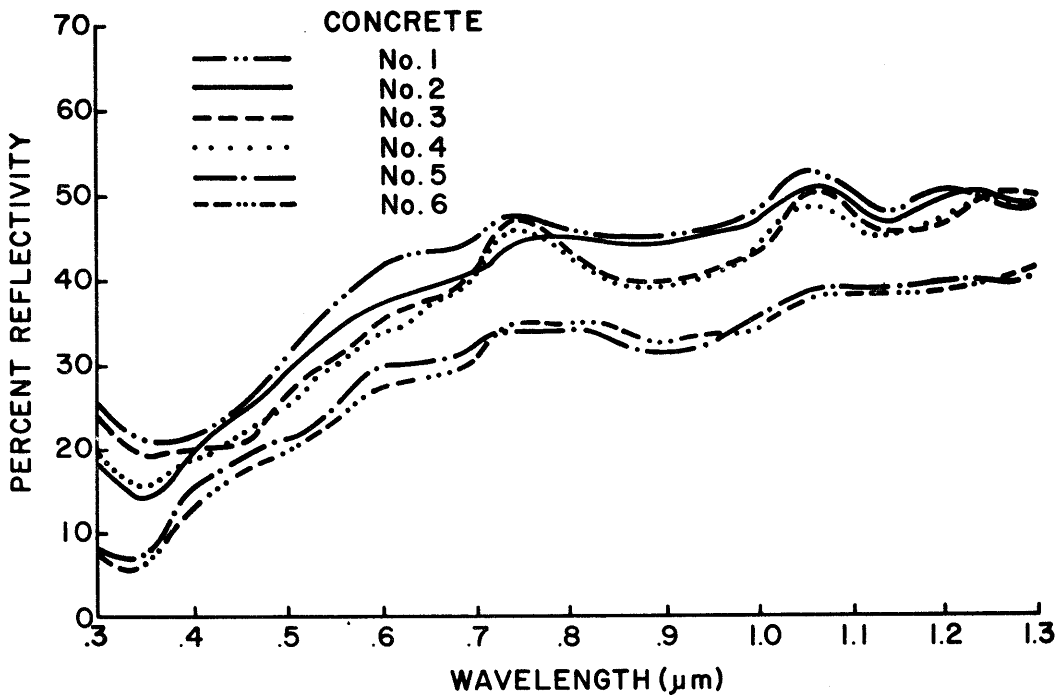


(a) "raw" spectroreflectance curves

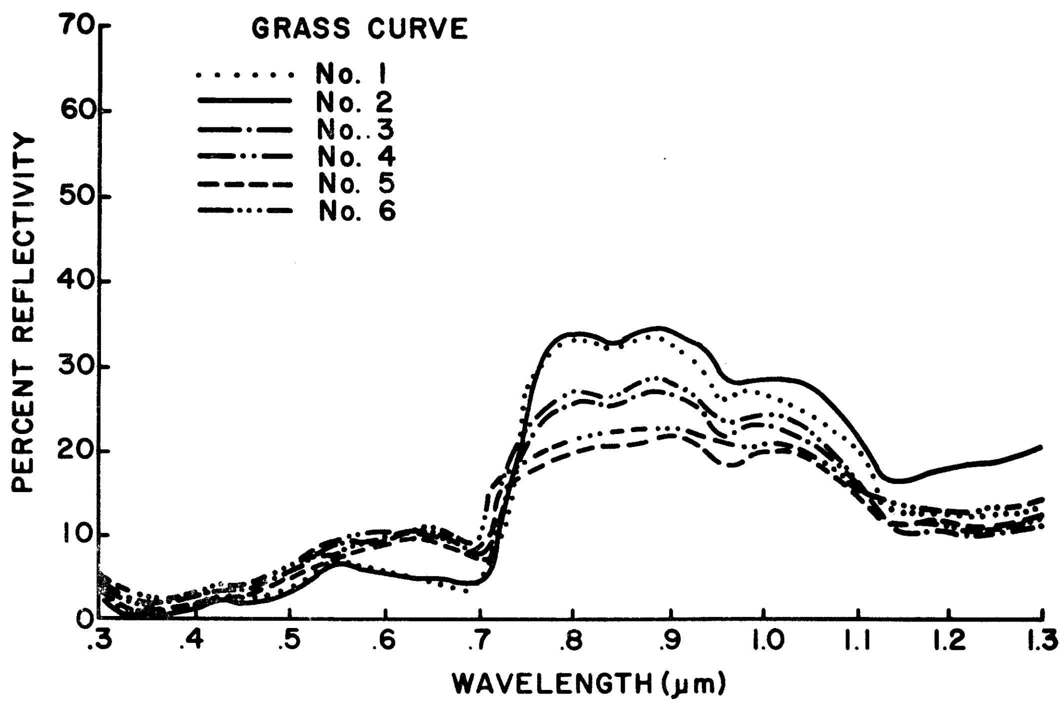


(b) "JOINed" spectroreflectance curves

FIGURE 13. SAMPLE SPECTROREFLECTANCE CURVES OF GRASS AND CONCRETE. (a) The spectroreflectance is measured normal to the plane of the material in three segments - ultraviolet, visible, and photo infrared by various detector-grating combinations. (b) The three segments of the raw data curves are formed into a contiguous curve and replotted using a FORTRAN program JOIN (Appendices E and F).



(a) 1&2 = fresh concrete, 3&4 = intermediate, 5&6 = dirty concrete



(b) 1&2 = lush green lawn, 3&4 = intermediate, 5&6 = dried lawn

FIGURE 14. REPLICATED SPECTROREFLECTANCE CURVES FOR GRASS AND CONCRETE. Six curves are shown for each material representing two measurements on each of three samples. The three samples represent the natural variability in each material and the two replicate runs measured at different positions on each sample represent its variability.

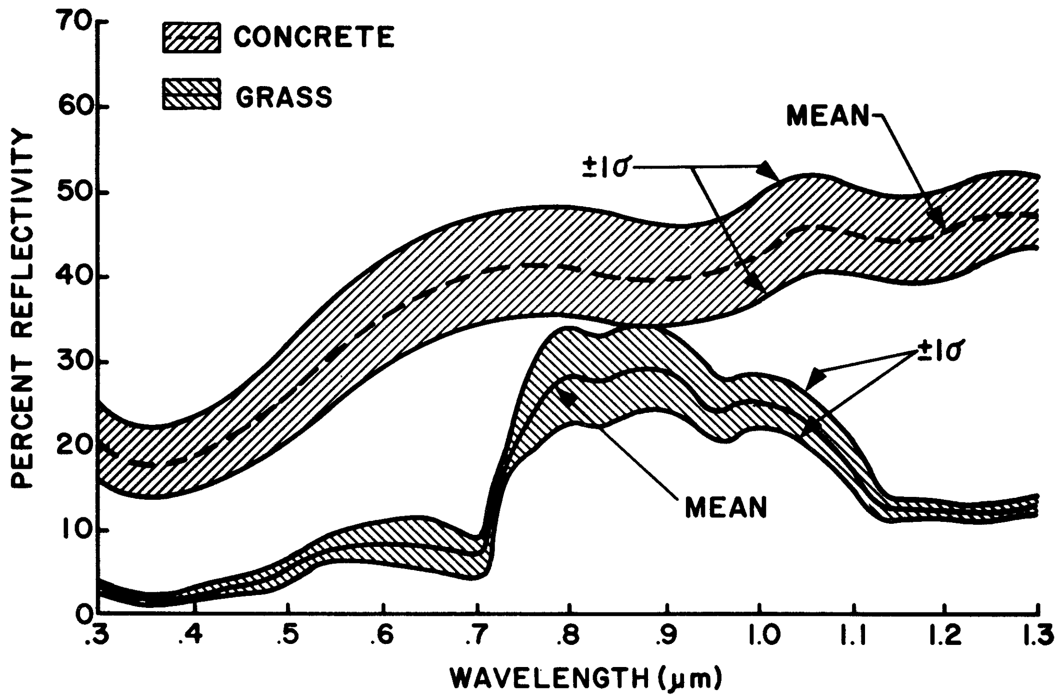


FIGURE 15. MEAN SPECTROREFLECTANCE AND STANDARD DEVIATION FOR GRASS AND CONCRETE. The six curves for each material shown in Figures 14a and b are combined and plotted in the field trailer by the FORTRAN program AVER (Appendices E and F).

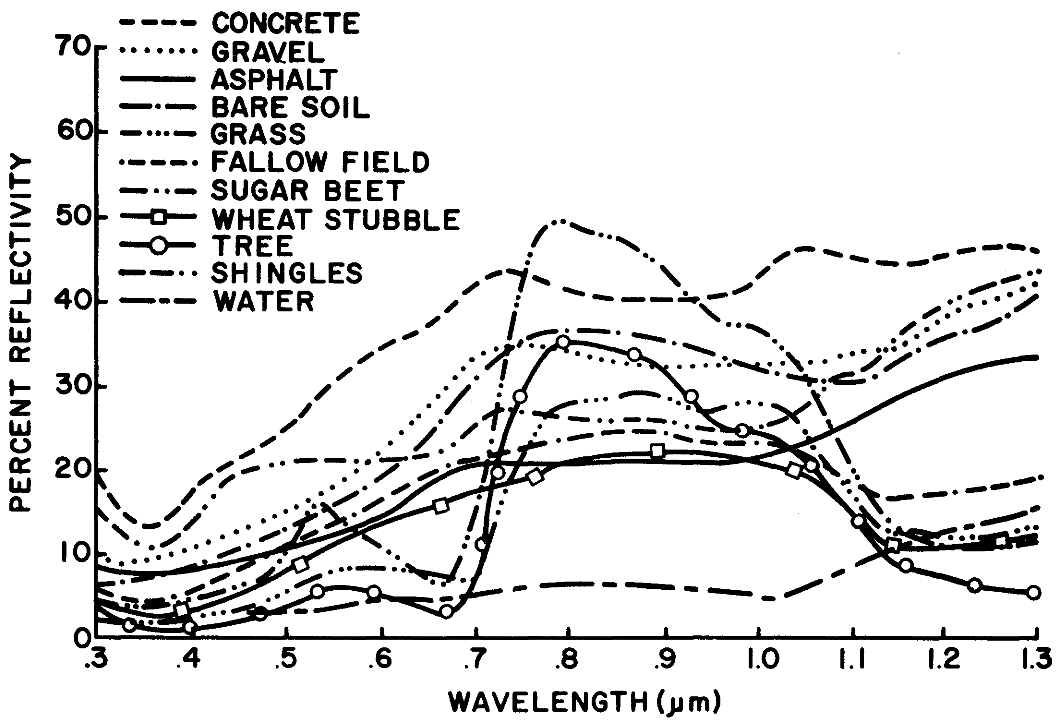
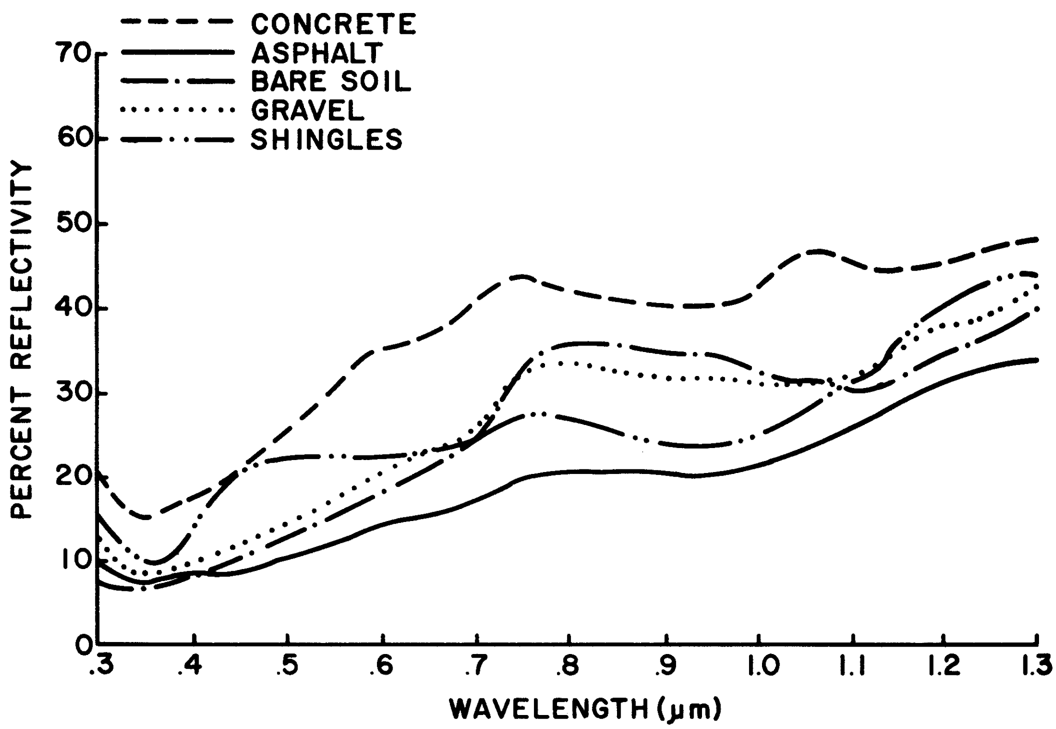
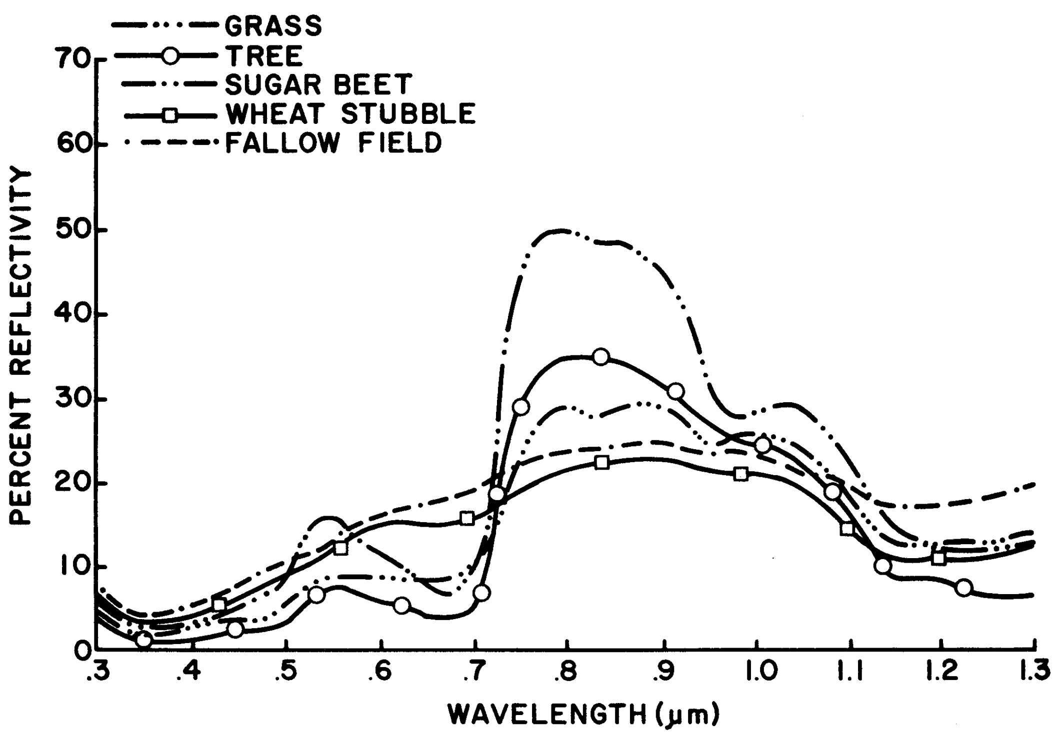


FIGURE 16. MEAN SPECTROREFLECTANCE CURVES FOR ELEVEN SURFACE MATERIAL CATEGORIES IN AN URBANIZING WATERSHED. These mean curves were formed from six complete spectroreflectance curves for each of the materials in the same fashion as illustrated in Figures 13 to 15. The surface material "agriculture" is here represented by green sugar beets and wheat stubble, which constitute the primary agricultural land use around Denver at this time of year. Each of the eleven units constituted an area of greater than .5% in a typical Denver watershed in midsummer.

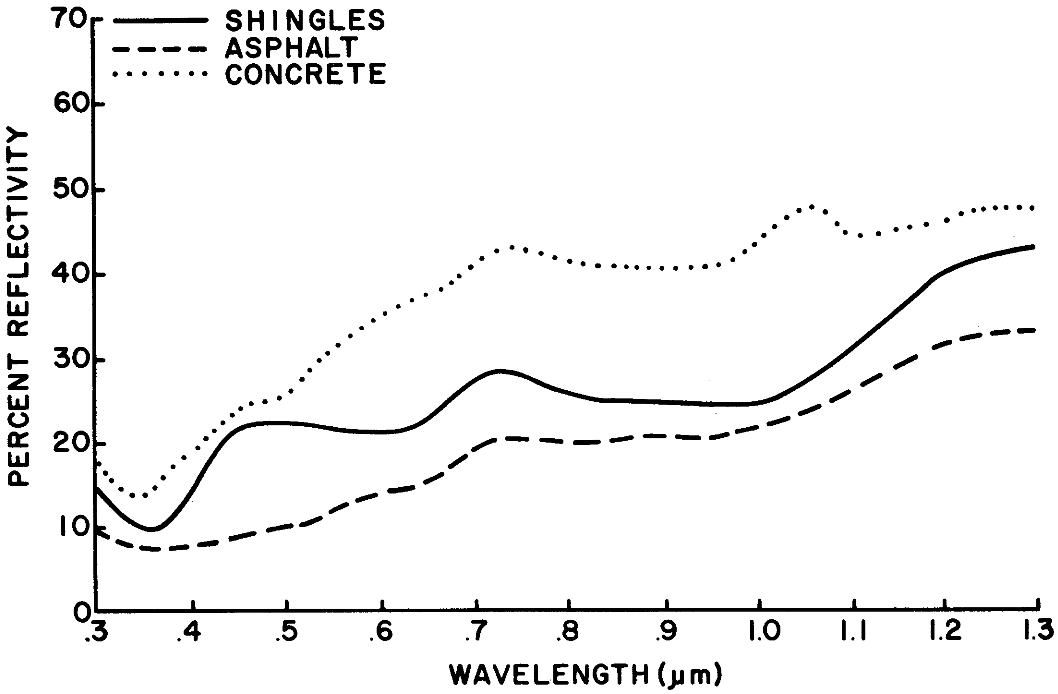


(a) nonvegetated land areas

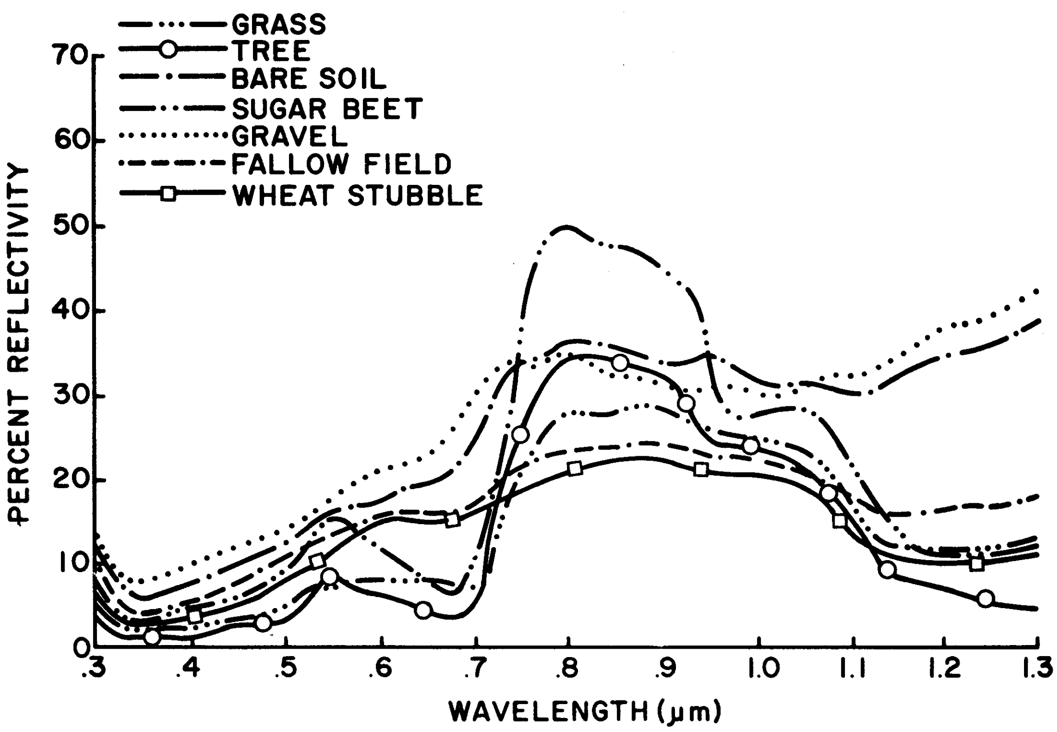


(b) vegetated land areas

FIGURE 17. COMPARISON OF MEAN SPECTROREFLECTANCE CURVES FOR NON-VEGETATED AND VEGETATED URBAN UNITS. This division of the curves is similar to that shown by the University of Michigan in Figure 1. Note that a division of the urban watershed into these two classes could easily be made at 1.2 μm.



(a) impervious land areas



(b) pervious land areas

FIGURE 18. COMPARISON OF MEAN SPECTROREFLECTANCE CURVES FOR IMPERVIOUS AND PERVIOUS URBAN UNITS. This division of the curves illustrates the basic hydrologic classification of an urban watershed. Note that bare soil and gravel which could be properly classified as nonvegetation in Figure 17 at 1.2 μm would be confused with impervious materials in this example.

(a) blue band (.4-.5μm)

(b) green band (.5-.6μm)

(c) red band (.6-.7μm)

(d) photo infrared band (.7-.9μm)

FIGURE 19. MULTIBAND AERIAL PHOTOGRAPHS OF THE NORTHGLENN-7201 WATERSHED. Flown by Civil Engineering Department, Colorado State University on 28 April 1971 with an I^2S multiband camera. Scale approximately 1/30,000. Figure 20 contains a selective color combination of these photographs.

(a) blue band (.4-.5μm)

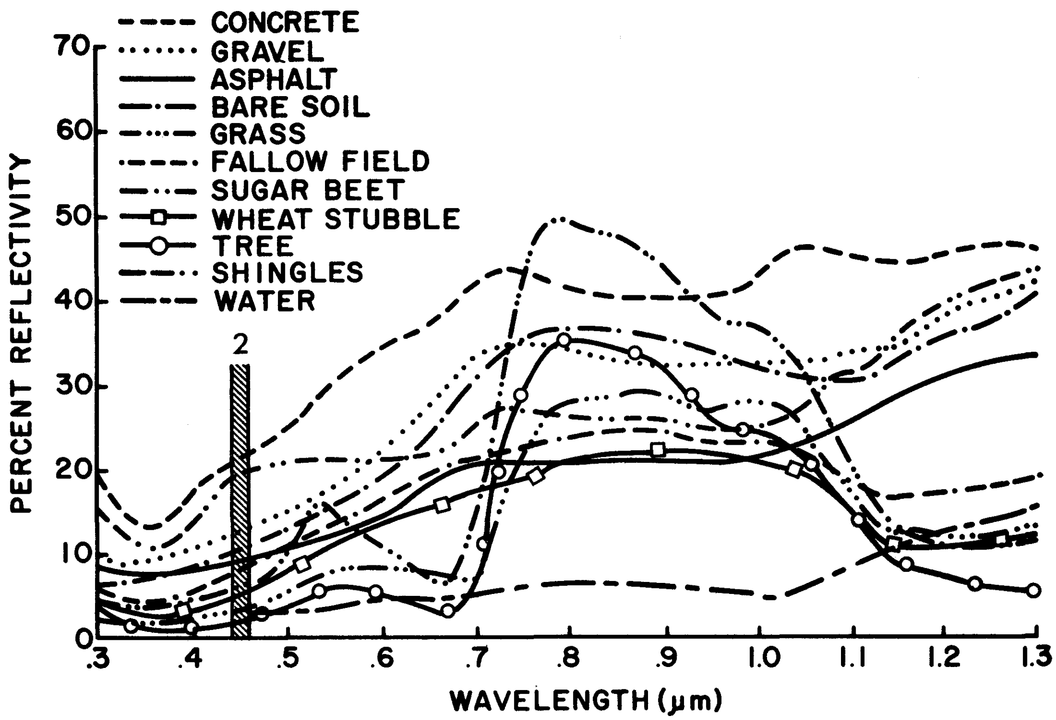
(b) green band (.5-.6μm)

(c) red band (.6-.7μm)

(d) photo infrared band (.7-.9μm)

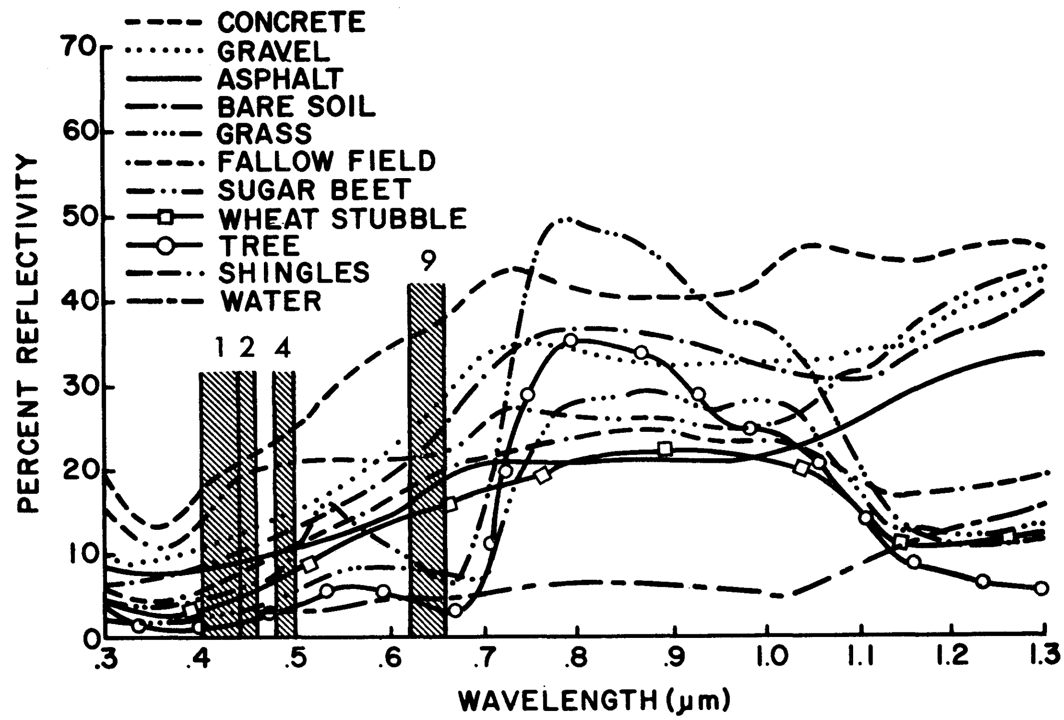
FIGURE 19. MULTIBAND AERIAL PHOTOGRAPHS OF THE NORTHGLENN-7201 WATERSHED. Flown by Civil Engineering Department, Colorado State University on 28 April 1971 with an I^2S multiband camera. Scale approximately 1/30,000. Figure 20 contains a selective color combination of these photographs.

FIGURE 20. COLOR COMBINED BLACK AND WHITE MULTIBAND PHOTOGRAPHS (Fig. 19). Flown in the spring on 28 April 1971 at a scale of approximately 1/14,000. Impervious materials appear pink with the exception of some fallow fields, while pervious areas are blue. A check of this classification can be made with the frontpiece which contains this same area. The individual photographs used occur in Figure 19. In superimposing in color the red image (Fig. 19c) was coded red while the photo infrared (Fig. 19d) was coded blue.



Band Combination	Maximum Euclidean Distance	Band Combination	Minimum Euclidean Distance	Band Combination	Average Euclidean Distance
2	14.812	2	.245	2	3.511
3	14.324	10	.124	1	3.202
9	14.038	11	.107	3	3.081
4	12.982	7	.081	4	2.948
1	12.915	1	.052	9	2.627
8	10.475	2	.039	5	2.602
5	9.477	9	.036	10	2.548
7	8.345	12	.032	8	2.393
10	7.231	3	.030	7	2.381
6	6.876	6	.016	6	2.314
11	6.159	5	.006	12	1.793
12	4.778	8	.002	11	1.482

FIGURE 21. OTPIMIZED SINGLE SPECTRAL BAND FOR URBAN MAPPING. The .44-.46μm spectral band (no. 2) is highest in all three qualifying statistics denoting the separation of the eleven materials shown with their mean curves. The spectral interval of each of the twelve bands tested can be found in Table 4.



Band Combination	Maximum Euclidean Distance	Band Combination	Minimum Euclidean Distance	Band Combination	Average Euclidean Distance
2,3,4,9	28.110	1,6,7,12	.957	1,2,3,4	6.430
1,2,3,9	28.079	1,5,11,12	.957	1,2,3,9	6.390
1,2,3,4	27.566	1,7,8,12	.948	1,2,3,10	6.367
1,2,4,9	27.419	1,6,8,12	.946	1,2,3,5	6.324
1,3,4,9	27.158	1,4,6.12	.945	1,2,4,9	6.331
2,3,8,9	27.044	1,5,6,12	.937	1,2,4,10	6.304
2,3,5,9	26.673	1,4,8,12	.936	1,2,4,5	6.257
2,3,4,8	26.511	1,4,7,12	.932	1,2,3,8	6.256
1,2,3,8	26.478	1,5,8,12	.928	1,2,3,6	6.240
2,4,8,9	26.358	1,5,7,12	.924	1,2,3,7	6.231
⋮	⋮	⋮	⋮	⋮	⋮
6,7,11,12	11.191	1,2,3,4	.300	7,8,11,12	4.412
7,10,11,12	11.159	7,8,9,11	.291	6,8,11,12	4.378
6,10,11,12	10.901	7,9,11,12	.280	6,7,11,12	4.351

FIGURE 22. OTPIMIZED FOUR SPECTRAL BANDS FOR URBAN MAPPING. The .40-.44μm, .44-.46μm, .48-.50μm, and .62-.68μm spectral bands (nos. 1, 2, 4, and 9) are consistently high in the three qualifying statistics denoting the separation of the eleven materials shown with their mean curves. This solution neglects curve crossovers and the redundancy of adjacent bands. The spectral interval of each of the twelve bands tested can be found in Table 4.

APPENDIX A: ABRIDGED BIBLIOGRAPHY ON THE IMPACT OF REMOTE SENSING ON URBAN WATERSHED ANALYSIS

The articles in the bibliography have been selected from 7000 in the RESEÑA (REmote SEnsing of NAture) library, Department of Watershed Sciences, Colorado State University. This list of references relates selected articles and reports dealing with urban hydrology and watershed modeling to those dealing with the capabilities of remote sensing of urban areas. The bibliography is divided into six sections.

I. GENERAL HYDROLOGY covering a wide variety of topics in hydrology of possible use in urban watershed studies.

II. URBAN HYDROLOGY dealing specifically with hydrology studies related to urban areas.

III. GENERAL WATERSHED MODELING including varying types of watershed models over a variety of types of watersheds.

IV. URBAN WATERSHED MODELING specifically dealing with modeling of urban watersheds.

V. REMOTE SENSING: GENERAL SOURCES dealing with potentialities and problems of remote sensors and imagery analysis.

VI. REMOTE SENSING: URBAN ENVIRONMENT specifically describes the use of remote sensors for evaluating the surface characteristics of urban areas.

ALLISON, S.V. 1967. REVIEW OF SMALL BASIN RUNOFF PREDICTION METHODS. J. IRRIG. AND DRAINAGE, 93(IR1)/1-6.

AMORCCHO, J. AND HART, W.E. 1965. THE USE OF LABORATORY CATCHMENTS IN THE STUDY OF HYDROLOGIC SYSTEMS. J. OF HYD., 3/106-123.

ANDERSON, H.W. AND YERKE, T.B. 1968. COMPUTER DOCUMENTATION AND RETRIEVAL OF HYDROLOGIC INFORMATION FOR SMALL RESEARCH GROUPS OR INDIVIDUALS. IASH, 81(2)/555-560.

ASMUSSEN, L.E. AND THOMAS, A.W. 1969. NUMERICAL WATERSHED DESCRIPTION FOR A WATER BALANCE. ASCE NAT. MEETING ON WATER RES. ENG., PREPRINT 811, 23P.

BUIL, J.A. 1968. UNIT GRAPHS FOR NONUNIFORM RAINFALL DISTRIBUTION. J. HYDRAULICS DIV., 94(HY1)/235-257.

COOPER, C.F. 1968. WATERSHEDS AS ECOSYSTEMS. AM. SOC. RANGE MGT., ANNU. MEETING, ALBUQUERQUE, N.M., FEB. 14.

EMMETT, W.W. 1965. THE VIGIL NETWORK/ METHODS OF MEASUREMENT AND A SAMPLING OF DATA COLLECTED. IASH, PUB. NO. 66, PP. 89-106.

GRAY, D.M. 1961. SYNTHETIC UNIT HYDROGRAPH FOR SMALL WATERSHEDS. J. HYDRAULICS DIV., 87(HY4)/33-53.

HAUPT, H.F. 1967. INFILTRATION, OVERLAND FLOW, AND SOIL MOVEMENT ON FROZEN AND SNOW-COVERED PLOTS. WATER RES. RES., 3/145-161.

HORTON, R.E. 1933. THE ROLE OF INFILTRATION IN THE HYDROLOGIC CYCLE. TRANS., AGU, 14/446-460.

HORTON, R.E. 1935. SURFACE RUNOFF PHENOMENA, PART 1, ANALYSIS OF THE HYDROGRAPH. EDWARDS BROTHERS, INC., ANN ARBOR, MICH.

HORTON, R.E. 1940. AN APPROACH TOWARDS A PHYSICAL INTERPRETATION OF INFILTRATION CAPACITY. SOIL SCI. SOC. AM., PROC., 5/399-417.

HUDSON, G.D. 1936. THE UNIT AREA METHOD OF LAND CLASSIFICATION. ANN. ASSOC. AM. GEOGR., 26(2)/99-112.

ISHIHARA, Y. 1964. HYDRAULIC MECHANISM OF RUNOFF. HYDRAULICS AND FLUID MECHANICS, N.Y., MACMILLIAN CO., 503P.

KALININ, G.P. AND KUCHMENT, L.S. 1964. THE USE OF INFLUENCE FUNCTIONS FOR COMPUTING A DISCHARGE HYDROGRAPH. IASH, PUB. NO. 63, PP. 77-80.

BIBLIOGRAPHY

KEIFER, C.J. 1961. ANALYSIS OF THE RUNOFF HYDROGRAPH. ASCE HYDRAULICS DIV., CONFERENCE, AUG. 16-18, URBANA, ILL.

KERBY, W.S. 1959. TIME OF CONCENTRATION FOR OVERLAND FLOW. CIVIL ENG., 29/60.

KNISEL, W.G., BAIRD, R.W. AND HARTMAN, M.A. 1969. RUNOFF VOLUME PREDICTION FROM DAILY CLIMATIC DATA. WATER RES. RES., 5(1)/84-94.

LINSLEY, R.K., KOHLER, M.A. AND PAULHUS, J.L.H. 1949. APPLIED HYDROLOGY. MCGRAW-HILL BOOK CO., INC., N.Y., 699P.

MERVA, G.E., BRAZEE, R.D., SCHWAB, G.O. AND CURRY, R.B. 1969. A PROPOSED MECHANICS FOR THE INVESTIGATION OF SURFACE RUNOFF FROM SMALL WATERSHEDS. 1, DEVELOPMENT. WATER RES. RES., 5(1)/76-83.

MORGALI, J.R. 1963. HYDRAULIC BEHAVIOR OF SMALL DRAINAGE BASINS. STANFORD UNIV., DEPT. OF CIVIL ENG., TECH REPORT NO. 30, 115P.

MYERS, L.E., FRASIER, G.W. AND GRIGGS, J.R. 1967. SPRAYED ASPHALT PAVEMENTS FOR WATER HARVESTING. J. IRRIG. AND DRAINAGE, 93(IR3)/79-97.

NASH, J.E. 1958. DETERMINING RUNOFF FROM RAINFALL. INST. OF CIVIL ENG., 10/163-184.

OSBORN, H.B. AND LANE, L. 1969. PRECIPITATION-RUNOFF RELATIONS FOR VERY SMALL SEMIARID RANGELAND WATERSHEDS. WATER RES. RES., 5(2)/419-425.

OVERTON, D.E. 1967. ANALYTICAL SIMULATION OF WATERSHED HYDROGRAPH FROM RAINFALL. INT. HYDROLOGY SYMP., PAPER NO. 2, VOL. 1, PP. 9-17.

POPOV, E.G. 1962. NON-UNIFORMITY OF SURFACE RETENTION AS A FACTOR OF RUNOFF. IASH, 7/21-26.

REICH, B.M. 1962. DESIGN HYDROGRAPHS FOR SMALL WATERSHEDS FROM RAINFALL. COLO. STATE UNIV., CIVIL ENG. SECT., FT. COLLINS, 57P.

SCHAAKE, J.C. 1965. SYNTHESIS OF THE INLET HYDROGRAPH. JOHNS HOPKINS UNIV., STORM DRAINAGE RES. PROJECT, TECH. REPORT NO. 3, 105P.

SOLOMON, S.I., DENOEWELLIEY, J.P. AND CHART, E.J. 1968. THE USE OF A SQUARE GRID SYSTEM FOR COMPUTER ESTIMATION OF PRECIPITATION, TEMPERATURE AND RUNOFF. WATER RES. RES., VOL. 4(5)/919-929.

BIBLIOGRAPHY

SWANSON, R.W. 1969. WATERSHEDS AND INFORMATION FLOW. USAF, OFF. OF SCI. RES., ARLINGTON, VA., 27P.

BIBLIOGRAPHY

ANDERSON, J.J. 1970. REAL-TIME COMPUTER CONTROL OF URBAN RUNOFF. J. HYD., 96(HY1)/153-164.

BIBELLO, M.A. 1967. SURVEY OF FROZEN PRECIPITATION IN URBAN AREAS AS RELATED TO CLIMATIC CONDITIONS. U.S. ARMY CRREL, HANOVER, N.H., 29P.

BRATER, E.F. 1968. STEPS TOWARD A BETTER UNDERSTANDING OF URBAN RUNOFF PROCESSES. WATER RES. RES., 4(2)/335-347.

CARTER, R.W. 1964. MAGNITUDE AND FREQUENCY OF FLOODS IN SUBURBAN AREAS. USGS, PROF. PAPER 424-B, WASH., D.C., 42P.

CHOW, V.T. 1952. HYDROLOGIC STUDIES OF URBAN WATERSHEDS-RAINFALL AND RUNOFF OF BONEYARD CREEK CHAMPAIGN-URBANA, ILLINOIS. UNIV. ILL., DEPT. CIVIL ENG., HYDRAULIC ENG. SER. NO. 2, URBANA, ILLINOIS, 66P.

CRIPPEN, J.R. 1965. CHANGES IN CHARACTER OF UNIT HYROGRAPHS, SHARON CREEK, CALIFORNIA AFTER SUBURBAN DEVELOPMENT. USGS, PROF. PAPER 525-D, PP. 196-198.

DAWDY, D.R. 1967. KNOWLEDGE OF SEDIMENTATION IN URBAN ENVIRONMENTS. J. HYDRAULICS DIV., 93(HY6)/235-245.

EAGLESON, P.S. 1962. UNIT HYDROGRAPH CHARACTERISTICS FOR SEWERED AREAS. J. HYDRAULICS DIV., 88(HY2)/1-25.

ESPEY, W.H., MORGAN, C.W. AND MASCH, F.D. 1965. A STUDY OF SOME EFFECTS OF URBANIZATION ON STORM RUNOFF FROM A SMALL WATERSHED. UNIV. TEXAS, DEPT. CIVIL ENG.

ESPEY, W.H. AND WINSLOW, D.E. 1968. THE EFFECTS OF URBANIZATION ON UNIT HYDROGRAPHS FOR SMALL WATERSHEDS, HOUSTON, TEXAS, 1964-1967. REP. BY TRACOR, DOC. NO. 68-975U, 1/70.

GUY, H.P. AND FERGUSON, G.E. 1962. SEDIMENT IN SMALL RESERVOIRS DUE TO URBANIZATION. J. HYDRAULICS DIV., 88(HY2)27-37.

HACKETT, J.E. 1969. WATER RESOURCES AND THE URBAN ENVIRNOMENT. GROUND WATER, 7(2)/11-15.

HICKS, W.I. 1944. A METHOD FOR COMPUTING URBAN RUNOFF. ASCE PROC., 109/1217.

HORNER, W.W. AND FLYNT, F.L. 1936. RELATION BETWEEN RAINFALL AND RUNOFF FROM SMALL URBAN AREAS. ASCE TRANS., 101/140-183.

JENS, S.W. AND MCPHERSON, M.B. 1964. HYDOLOGY OF URBAN AREAS. MCGRAW HILL BOOK CO., N.Y.

BIBLIOGRAPHY

JONES D.E. 1967. URBAN HYDROLOGY/A REDIRECTION. J. CIVIL ENG., 37/58-62.

KEIFER, C.J. AND CHU, H.R. 1957. SYNTHETIC STORM PATTERN FOR DRAINAGE DESIGN. J. HYDRAULICS DIV., 33(HY4)/1-25.

KING, M.V. 1967. STORM RUN-OFF FROM URBAN AREAS. ASCE PROC., VOL. 109, P. 1217.

LEOPOLD, L.B. 1968. HYDROLOGY FOR URBAN LAND PLANNING-A GUIDEBOOK ON THE HYDROLOGIC EFFECTS OF URBAN LAND USE. USGS, CIRC. 554, WASH., D.C., 18P.

LULL, H.W. AND SOPPER, W.E. 1969. HYDROLOGIC EFFECTS FROM URBANIZATION OF FORESTED WATERSHEDS IN THE NORTHEAST. NE FOR. EXP. STA., RES. PAP. NE-146, UPPER DARBY, PA., 31P.

MCPHERSON, M.B. 1968. URBAN WATER RESOURCES RESEARCH. ASCE, ANNU. PROC. REP., 43P.

NEWHALL, G.N. AND SMITH, J.L. 1965. WATERSHED MANAGEMENT/ EFFECTS ON BASIN DEVELOPMENT. PROC. ASCE BILLINGS CONF., IRRIG. AND DRAINAGE, 47-86.

NO AUTHOR. 1969. EFFECT OF URBAN DEVELOPMENT ON FLOOD DISCHARGES. J. HYDRAULICS DIV., 95(HY1)/287-309.

NO AUTHOR. 1969. SELECTED URBAN STORM WATER RUNOFF ABSTRACTS. FRANKLIN INST. RES. LABS, PHIL., PA.

PLUHOWSKI, E.J. 1968. URBANIZATION AND ITS EFFECT ON THE TEMPERATURE OF LONG ISLAND STREAMS. USGS, OPEN FILE REP., DENVER, COLO., 278P.

PLUHOWSKI, E.J. 1968. EFFECTS OF URBAN DEVELEPEMENT ON THE HYDROLOGY. NASA, EARTH RESOURCES AIRCRAFT PROGRAM - STATUS REVIEW, 9P.

RANTZ, S.E. 1970. URBAN SPRAWL AND FLOODING IN SOUTHERN CALIFORNIA. USGS, GEOL. SURV. CIRC. 601-B, WASH., D.C., 11P.

SAVINI, J. AND KAMMERER, J.C. 1961. URBAN GROWTH AND THE WATER REGIMEN. USGS, PAPER 1591-A, WASH., D.C.

SAWYER, R.M. 1963. EFFECT OF URBANIZATION ON STORM DISCHARGE AND GROUNDWATER RECHARGE IN NASSAU COUNTY, N.Y. USGS, PROF. PAPER 475-C, ART. 106, PP. 185-187.

SCHAAKE, J.C. 1968. RESPONSE CHARACTERISTICS OF URBAN WATER RESOURCE DATA SYSTEMS. ASCE URBAN WATER RESOURCES RES. PROGRAM, 57P.

SMITH, H.F., ED. 1969. EFFECTS OF URBAN DEVELOPMENT ON FLOOD DISCHARGES. A PROGRESS REPORT BY THE TASK FORCE ON EFFECT OF URBAN DEVELOPMENT ON FLOOD DISCHARGES. J. HYDRAULICS DIV. 95(HY1)/287-309.

SPIEKER, A.M. 1970. WATER IN URBAN PLANNING, SALT CREEK BASIN, ILLINOIS. USGS, WATER-SUPPLY PAPER 2002, WASHINGTON, D.C., 147P.

TERSTRIEP, M.L. AND STALL, J.B. 1969. URBAN RUNOFF BY ROAD RESEARCH LABORATORY METHOD. J. HYDRAULICS DIV., 95(HY6)/1809-1834.

THOLIN, A.L. AND KEIFER, C.J. 1960. THE HYDROLOGY OF URBAN RUNOFF. ASCE TRANS., PART 1, 125/1308-1379.

THOMAS, D.M. 1970. STATUS OF FINDINGS ON EFFECTS DUE TO URBANIZATION. USGS, WATER RES. DIV., WASH., D.C.

TUCKER, L.S. 1969. AVAILABILITY OF RAINFALL-RUNOFF DATA FOR SEWERED DRAINAGE CATCHMENTS. ASCE URBAN WATER RESOURCES RES. PROGRAM, 43P.

TWITCHELL, T. 1966. BASIC DATA FOR URBAN HYDROLOGY STUDY DALLAS, TEXAS, 1966. USGS, AUSTIN, TEXAS, 203P.

VELDKAMP, F.B. 1963. PROBLEMS OF WATER DISCHARGE IN URBAN AREAS. VERSLAG VAN DE TECHNISCHE BLUEENKOMST, NO. 18 PP. 73-94.

VIESSMAN, W. JR. 1966. HYDROLOGY OF SMALL IMPERVIOUS AREAS. WATER RES. RES., 2(3)/405-412.

VIESSMAN, W., KEATING, W.R. AND SRINIVASA, K.N. 1970. URBAN STORM RUNOFF RELATIONS. WATER RES. RES., 6(1)/275-279.

WAANANEN, A.O. 1961. HYDROLOGIC EFFECTS OF URBAN GROWTH - SOME CHARACTERISTICS OF URBAN RUN-OFF. USGS, PROF. PAPER 424-C, C. 353-C. 356.

WATKINS, L.H. 1962. THE DESIGN OF URBAN SEWER SYSTEMS. ROAD RES. LAB. DEPT. SCIENTIFIC AND INDUSTRIAL RES., TECH. PAPER NO. 55, LONDON, 16P.

WILLEKE, G.E. 1962. THE PREDICTION OF RUNOFF HYDROGRAPHS FOR URBAN WATERSHEDS FROM PRECIPITATION DATA AND WATERSHED CHARACTERISTICS. J. GEOPHY. RES., 67(9)/3610.

WILLEKE, G.E. 1966. TIME IN URBAN HYDROLOGY. J. HYDRAULICS DIV., VOL. 92(HY1)/29-31.

BIBLIOGRAPHY

WOOD, D.F. 1967. URBAN AND BASIN PLANNING. WATER RES. RES., 3(1)/279.

BIBLIOGRAPHY

ANDERSON, H.W. 1966. WATERSHED MODELING APPROACH TO EVALUATION OF THE HYDROLOGY POTENTIAL OF UNIT AREAS. PA. STATE UNIV., PP. 735-746.

AYERS, H.D. AND BALEK, J. 1967. AN HOURLY WATER BALANCE MODEL AS A BASIS FOR CONTINUOUS WATER RESOURCES ASSESSMENT ON A WATERSHED. IASH, PUB. NO. 76, PP. 227-234.

BAGLEY, J.M., HICKOK, R.B., CHADWICK, D.G., ROSA, M.J. AND BRAKENSIEK, D.L. 1963. REPORT ON THE FEASIBILITY OF AN ELECTRONIC ANALOG APPROACH TO SEVIER RIVER BASIN INVESTIGATIONS FOR WATER RESOURCES DEVELOPMENT AND CONSERVATION PLANNING. UTAH STATE UNIV., ENG. EXPERIMENT STATION, REPORT NO. EC-51-G-1, 47P.

BETSON, R.P., TUCKER, R.L. AND HALLER, F.M. 1969. USING ANALYTICAL METHODS TO DEVELOP A SURFACE-RUNOFF MODEL. WATER RES. RES., 5(1)/103-111.

CHAPMAN, T.G. 1968. CATCHMENT PARAMETERS FOR A DETERMINISTIC RAINFALL RUNOFF MODEL. MACMILLAN CO. OF AUST., 107 MORAY ST., S. MELBORNE, VICTORIA.

CHERY, D.L. 1966. DESIGN AND TESTS OF A PHYSICAL WATERSHED MODEL. J. HYD., 4/224-235.

CHERY, D.L., JR. 1967. A REVIEW OF RAINFALL-RUNOFF, PHYSICAL MODELS AS DEVELOPED BY DIMENSIONAL ANALYSIS AND OTHER METHODS. WATER RES. RES., 3(3)/881-889.

CRAWFORD, N.H. AND LINSLEY, R.K. 1962. THE SYNTHESIS OF CONTINUOUS STREAMFLOW HYDROGRAPHS ON A DIGITAL COMPUTER. STANFORD UNIV., DEPT. OF CIVIL ENG., TECH. REPORT NO. 12, 121P.

CRAWFORD, N.H. AND LINSLEY, R.K. 1966. DIGITAL SIMULATION IN HYDROLOGY. STANFORD UNIV., DEPT. CIVIL ENG., TECH. REP. NO. 39, 210P.

CRAWFORD, N.H. 1969. DIGITAL SIMULATION METHODS FOR HYDROLOGICAL FORECASTING. WORLD METEOROL. ORGAN., IHD TECH. NOTE NO. 92, PP. 162-171.

DAWDY, D.R. AND O-DONNELL, T. 1965. MATHEMATICAL MODELS OF CATCHMENT BEHAVIOR. J. HYDRAULICS DIV., PART 1, 91(HY4)/123-137.

DAWDY, D.R. AND TERRY, H. 1968. DIGITAL COMPUTER SIMULATION IN HYDROLOGY. AM. WATER WORKS ASSOC. J., 59(6)/685-688.

BIBLIOGRAPHY

DENISOV, J.M. 1969. MATHEMATICAL MODELING OF THE RUN-OFF PROCESS OF RIVERS WITH COMPOUND ALIMENTATION. WORLD METEOROL. ORGAN., GENEVA, SWITZ., PP. 172-180.

FIERING, M.B. 1967. STREAM FLOW SYNTHESIS. HARVARD UNIV. PRESS, CAMBRIDGE, MASS.

HALL, J.M. AND WOLF, O.P. 1967. DESIGN CRITERIA FOR LABORATORY CATCHMENT EXPERIMENTS, WITH PARTICULAR REFERENCE TO RAINFALL SIMULATION. IASH, PUB. NO. 76, PP. 395-406.

HUDLOW, M.D. AND CLARK, R.A. 1969. HYDROGRAPH SYNTHESIS BY DIGITAL COMPUTER. J. HYDRAULICS DIV., 95(HY3)/839-860.

HUGGINS, L.F. AND MONKE, E.J. 1968. A MATHEMATICAL MODEL FOR SIMULATING THE HYDROLOGIC RESPONSE OF A WATERSHED. WATER RES. RES., 4(3)/529-539.

LAURENSON, E.M. 1964. A CATCHMENT STORAGE MODEL FOR RUNOFF ROUTING. J. HYD., 2/151-163.

LIGON, J.T., LAW, A.G. AND HIGGINS, D.H. 1969. EVALUATION AND APPLICATION OF A DIGITAL HYDROLOGIC SIMULATION MODEL. CLEMSON UNIV., WATER RES. RES. INST., REP. NO. 12, CLEMSON, S. CAROLINA, 120P.

MACHMEIER, R.E. AND LARSON, C.L. 1968. RUNOFF HYDROGRAPHS FOR MATHEMATICAL WATERSHED MODEL. J. HYDRAULICS DIV., 94(HY6)/1453-1474.

MORE, R.J. 1967. HYDROLOGICAL MODELS AND GEOGRAPHY. METHUEN AND CO., LONDON, PP. 145-185.

NARAYANA, D.V.V. AND BAGLEY, J.M. 1967. MATHEMATICAL SIMULATION OF SMALL WATERSHED HYROLOGIC PHENOMENA. UTAH WATER RES. LAB., UTAH STATE UNIV., DEPT. OF ENG., PRWG 46-2.

NO AUTHOR. 1963. A WATER YIELD MODEL FOR ANALYSIS OF MONTHLY RUNOFF DATA. TENNESEE VALLEY AUTHORITY, OFFICE OF TRIBUTARY AREA DEVELOPMENT, RES. PAPER NO. 2.

PRASAD, R. 1967. A NONLINEAR HYDROLOGIC SYSTEM RESPONSE MODEL. J. HYDRAULICS DIV. 93(HY4)/201-221.

RAGAN, R.M. 1966. LABORATORY EVALUATION OF A NUMERICAL FLOOD ROUTING TECHNIQUE FOR CHANNELS SUBJECT TO LATERAL FLOW. WATER RES. RES., 2(1)/111-122.

RILEY, J.P., CHADWICK, D.G. AND ISRAELSEN, E.K. 1967. APPLICATION OF AN ELECTRONIC ANALOG COMPUTER FOR THE SIMULATION OF HYDROLOGIC EVENTS ON A SOUTHWEST WATERSHED. UTAH WATER RES. LAB., DEPT. OF ENG., REPORT PRWG-38-1, 53P.

RILEY, P.J., CHADWICK, D.G. AND BAGLEY, J.M. 1966. APPLICATION OF ELECTRONIC ANALOG COMPUTER TO SOLUTION OF HYDROLOGIC AND RIVER BASIN PLANNING PROBLEMS. UTAH WATER RES. LAB., REP. WG 32-1.

SHANHOLTZ, V.O. AND BURFORD, J.B. 1969. NUMERICAL EXPERIMENTS WITH THE STANFORD WATERSHED MODEL ON SMALL AGRICULTURAL WATERSHEDS IN VIRGINIA. VA. WATER RES. RES. CNT. REP., 37P.

SHEN, J. 1965. USE OF ANALOG MODELS IN THE ANALYSIS OF FLOOD RUNOFF. USGS, PROF. PAPER 506-A, 24P.

SINHA, L.K. 1970. AN OPERATIONAL WATERSHED MODEL/ STEP 1-B/ REGULATION OF WATER LEVELS IN THE KISSIMMEE RIVER BASIN. WATER RES. BULL., 6/209.

BIBLIOGRAPHY

BIBLIOGRAPHY

BIBLIOGRAPHY

DAWDY, D.R. 1969. CONSIDERATIONS INVOLVED IN EVALUATING MATHEMATICAL MODELING OF URBAN HYDROLOGIC SYSTEMS. USGS, WATER SUPPLY PAPER 1591-D, WASH., D.C.

DOUGLAS, J.L. 1965. USING A DIGITAL COMPUTER TO ESTIMATE THE EFFECTS OF URBAN DEVELOPMENT ON FLOOD PEAKS. WATER RES. RES., 1(2)/223-234.

GRACE, R.A. AND EAGLESON, P.S. 1967. SCALE MODEL OF URBAN RUNOFF FROM STORM RAINFALL. J. HYDRAULICS DIV., 1
93(HY3)/161-176.

ROBERTSON, A.F., TURNER, A.K., CROW, F.R. AND REE, W.O. 1966. RUNOFF FROM IMPERVIOUS SURFACES UNDER CONDITIONS OF SIMULATED RAINFALL. AM. SOC. AGR. ENG., 9(3)/343-351.

BIBLIOGRAPHY

BARRINGER, A.R. 1966. THE USE OF MULTI-PARAMETER REMOTE SENSORS AS AN IMPORTANT NEW TOOL FOR MINERAL AND WATER RESOURCE EVALUATION. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 313-325.

BELCHER, D.J. AND MAJTENYI, S.I. 1970. DISCHARGE PROPERTIES OF DRAINAGE BASINS OBSERVABLE FROM AERIAL PHOTOGRAPHS (70-145). ASP, FALLS CHURCH, VA., PP. 583-595.

BLANCHARD, B.J. AND WIEGAND, C.L. 1970. MEASURING HYDROLOGIC CHARACTERISTICS OF WATERSHEDS REMOTELY. USDA, 1970 ANN. REP., WESLACO, TEXAS, 6P.

COLLETT, L.S. 1969. REMOTE SENSING GEOPHYSICAL APPLICATIONS TO HYDROLOGY. NRC OF CAN., HYD. SYMP. PROC. NO. 7, VICTORIA, B.C. PP. 237-260.

COULSON, K.L. 1966. EFFECTS OF REFLECTION PROPERTIES OF NATURAL SURFACES IN AERIAL RECONNAISSANCE. APPL. OPT., 5(6)/905-918.

DALKE, G.W. 1967. AUTOMATIC PROCESSING OF MULTI-SPECTRAL IMAGES. UNIV. KANSAS, CNT. FOR RES., INC., ENG. SCI. DIV., 67P.

FERGUSON, H.L., CORK, H.F. AND O-NEILL, A.D.J. 1970. APPLICATIONS OF SATELLITE PHOTOGRAPHY TO HYDROLOGY IN CANADA. NRC OF CAN., HYD. SYMP. PROC. NO. 7, VICTORIA, B.C., PP. 311-343.

HULBURT, E.O. 1928. THE ULTRAVIOLET, VISIBLE AND INFRARED REFLECTIVITIES OF SNOW, SAND AND OTHER SUBSTANCES. J. OPT. SOC. AM., 17/23-25.

KENNEDY, J.M. 1968. MICROWAVE SENSORS FOR WATER MANAGEMENT AND HYDROLOGY FROM SPACE. UNPUBLISHED.

KONECNY, G. AND DERENYI, E.E. 1966. GEOMETRICAL CONSIDERATIONS FOR MAPPING FROM SCAN IMAGERY. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 327-338.

MILLER, V.C. 1968. CURRENT TRENDS IN PHOTOGEOLOGY AND IN THE USE OF OTHER REMOTE SENSING METHODS IN GEOLOGIC INTERPRETATION. EARTH SCI. REV., 4(2)/135-152.

NO AUTHOR. 1969. USEFUL APPLICATION OF EARTH-ORIENTED SATELLITES/HYDROLOGY. NAS-NRC, 73P.

ROBINOVE, C.J. 1965. INFRARED PHOTOGRAPHY AND IMAGERY IN WATER RESOURCES RESEARCH. AM. WATER WORKS ASSOC., 57/834-840.

BIBLIOGRAPHY

ROBINOVE, C.J. 1966. REMOTE-SENSOR APPLICATIONS IN HYDROLOGY. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 25-32.

ROBINOVE, C.J. AND ANDERSON, D.G. 1969. SOME GUIDELINES FOR REMOTE SENSING IN HYDROLOGY. WATER RES. BULL, 5(2)/10-19.

SILVESTRO, F.B. 1969. MULTISPECTRAL PHOTOGRAPHIC DETERMINATION OF REFLECTANCE. PHOTO. ENG., 35(3)/258-262.

TAYLOR, J.I. AND STINGELIN, R.W. 1969. INFRARED IMAGING FOR WATER RESOURCES STUDIES. J. HYDRAULICS DIV., 65(HY1)/175-189.

WELCH, R.I. 1969. THE USE OF REMOTE SENSING IN WATER RESOURCE MANAGEMENT. UNIV. CALIF., BERKELEY, CALIF., 15P.

BIBLIOGRAPHY

BOWDEN, L.W. 1968. MULTI-SENSOR SIGNATURES OF URBAN MORPHOLOGY, FUNCTION, AND EVOLUTION. UNIV. CALIF., REP. 2, RIVERSIDE, CALIF.

BOWDEN, L.W. 1970. REMOTE SENSING OF URBAN ENVIRONMENTS IN SOUTHERN CALIFORNIA (70-124). ASP, FALLS CHURCH, VA., PP. 363-373.

COLWELL, J.E. 1970. MULTISPECTRAL REMOTE SENSING OF URBAN FEATURES. UNIV. MICH., WRL, REP. 2772-6-F ANN ARBOR, MICH., 19P.

DILL, H.W. 1970. REMOTE SENSING IN LAND RESOURCE INVENTORY IN THE URBAN FRINGE AREA (70-120). ASP, FALLS CHURCH, VA., PP. 338-342.

GARRISON, W.L. 1966. FIVE PAPERS ON REMOTE SENSING AND URBAN INFORMATION SYSTEMS. NO SOURCE, APRIL.

HOLZ, R.K., HUFF, D.L. AND MAYFIELD, R.C. 1969. URBAN SPATIAL STRUCTURE BASED ON REMOTE SENSING IMAGERY. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 819-830.

MANJI, A.S. 1968. USES OF CONVENTIONAL AERIAL PHOTOGRAPHY IN URBAN AREAS/ REVIEW AND BIBLIOGRAPHY. NO SOURCE, JULY.

MARBLE, D.F. AND THOMAS, E.N. 1966. SOME OBSERVATIONS ON THE UTILITY OF MULTISPECTRAL PHOTOGRAPHY FOR URBAN RESEARCH. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 135-144.

MARBLE, D.F. AND HORTON, F.E. 1968. REMOTE SENSING AND THE STUDY AND PLANNING OF URBAN AREAS. NASA, EARTH RES. AIRCRAFT PROGRAM - STATUS REV., 9P.

MARBLE, D.F. AND HORTON, F.E. 1969. EXTRACTION OF URBAN DATA FROM HIGH AND LOW RESOLUTION IMAGES. UNIV. MICH., CNT. FOR REMOTE SENSING INFO. AND ANALYSIS, ANN ARBOR, MICH., PP. 807-818.

MOORE, E.G. 1968. REMOTE SENSOR IMAGERY IN URBAN RESEARCH/ SOME POTENTIALITIES AND PROBLEMS. USGS, WASH., D.C. 32P.

MOORE, E.G. 1968. SIDE-LOOKING RADAR IN URBAN RESEARCH/ A CASE STUDY. NO SOURCE, JUNE.

MOORE, E.G. 1968. EXPERIMENTAL APPLICATIONS OF MULTIBAND PHOTOGRAPHY IN URBAN RESEARCH. NO SOURCE, FEBRUARY.

BIBLIOGRAPHY

MOORE, E.G. 1970. APPLICATION OF REMOTE SENSORS TO THE CLASSIFICATION OF AREAL DATA AT DIFFERENT SCALES/ A CASE STUDY IN HOUSING QUALITY. REMOTE SENSING OF ENVIRONMENT, 1/109.

PALUDAN, T.N. 1969. POTENTIAL CONTRIBUTIONS OF ORBITAL EARTH RESOURCES DATA TO URBAN PLANNING. AM. ASTR. SOC., NAT. MEETING, JUNE 17-20, DENVER, COLO.,.

SCHNEIDER, C.H.P. 1967. MATERIAL IDENTIFICATION IN URBAN AREAS FROM GRAY TONE VARIATIONS IN MULTISPECTRAL PHOTOGRAPHY. NO SOURCE, JUNE.

THOMAS, E.N. AND MARBLE, D.F. 1965. THE USE OF REMOTE SENSORS IN URBAN INFORMATION SYSTEMS. OFF. OF NAVAL RES., GEOGR. BRANCH, TECH. REP. 1, WASH., D.C.

THOMAS, E.N. 1968. THERMAL INFRARED IMAGERY IN URBAN STUDIES. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB., EVANSTON, ILL.

THOMAS, E.N. AND WELLAR, B.S. 1968. EXPERIMENTAL APPLICATIONS OF MULTIBAND PHOTOGRAPHY IN URBAN RESEARCH. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB, EVANSTON, ILL.

VISSER, J. 1969. CADASTRAL AND URBAN MAPPING. IIAS, DELFT, NETH., PP. 166-177.

WARREN, C. AND CHANG, S. 1970. COASTAL AND URBAN SURVEYS WITH IR. PHOTO. ENG., 36(2)/173-180.

WELLAR, B. AND MARBLE, D.F. 1968. HYPERALTITUDE PHOTOGRAPHY AS A DATA SOURCE FOR URBAN AND TRANSPORTATION RESEARCH. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB, EVANSTON, ILL.

WELLAR, B.S. 1968. UTILIZATION OF THERMAL IMAGERY IN URBAN AREAS/ AN EMPIRICAL STUDY. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB, EVANSTON, ILL.

WELLAR, B.S. 1968. UTILIZATION OF MULTI-BAND AERIAL PHOTOGRAPHY IN URBAN HOUSING QUALITY STUDIES. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB, EVANSTON, ILL.

WELLAR, B.S. 1969. THERMAL IMAGERY IN URBAN STUDIES. NORTHWESTERN UNIV., DEPT. GEOGR., REMOTE SENSING LAB, EVANSTON, ILL.

WELLS, R.F. 1969. APPLICATION OF AIR PHOTO INTERPRETATION TECHNIQUES TO PROBLEMS IN URBAN AND REGIONAL PLANNING. OKLAHOMA STATE UNIV., MASTER OF SCI. THESIS, 207P.

APPENDIX B: 13 STUDY WATERSHEDS, DENVER, COLORADO

The 13 watersheds analyzed in this study are located in and about the suburbs of Denver, Colorado (Fig. B-1). These watersheds were chosen for study from those being modeled by the USGS, Water Resources Division because of their varying degrees of urbanization, from undeveloped to completely developed. For a more detailed look at the watersheds, a USGS topographic map at 1/24,000 and an airphoto at 1/27,500 (May, 1970) are provided (Figs. B-2 to B-9) showing the detailed distribution of topography and surface features of the watersheds and for the areas immediately surrounding them. Watershed boundaries are marked as heavy black lines on both the maps and aerial photos. Inspection of these maps and photographs reveals the range of urbanization of the 13 study watersheds in the variation of impervious cover in the form of rooftops, streets, and parking lots.

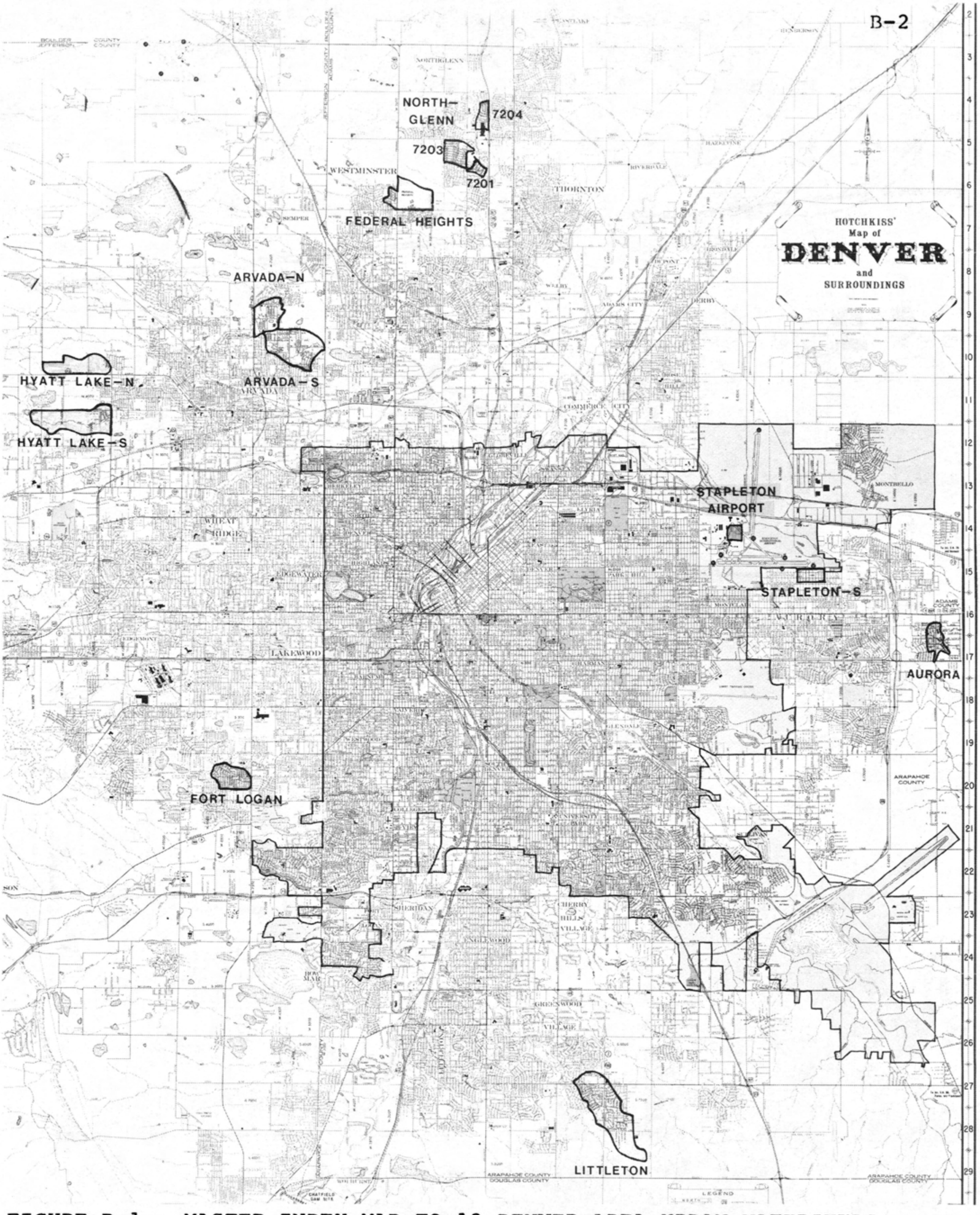
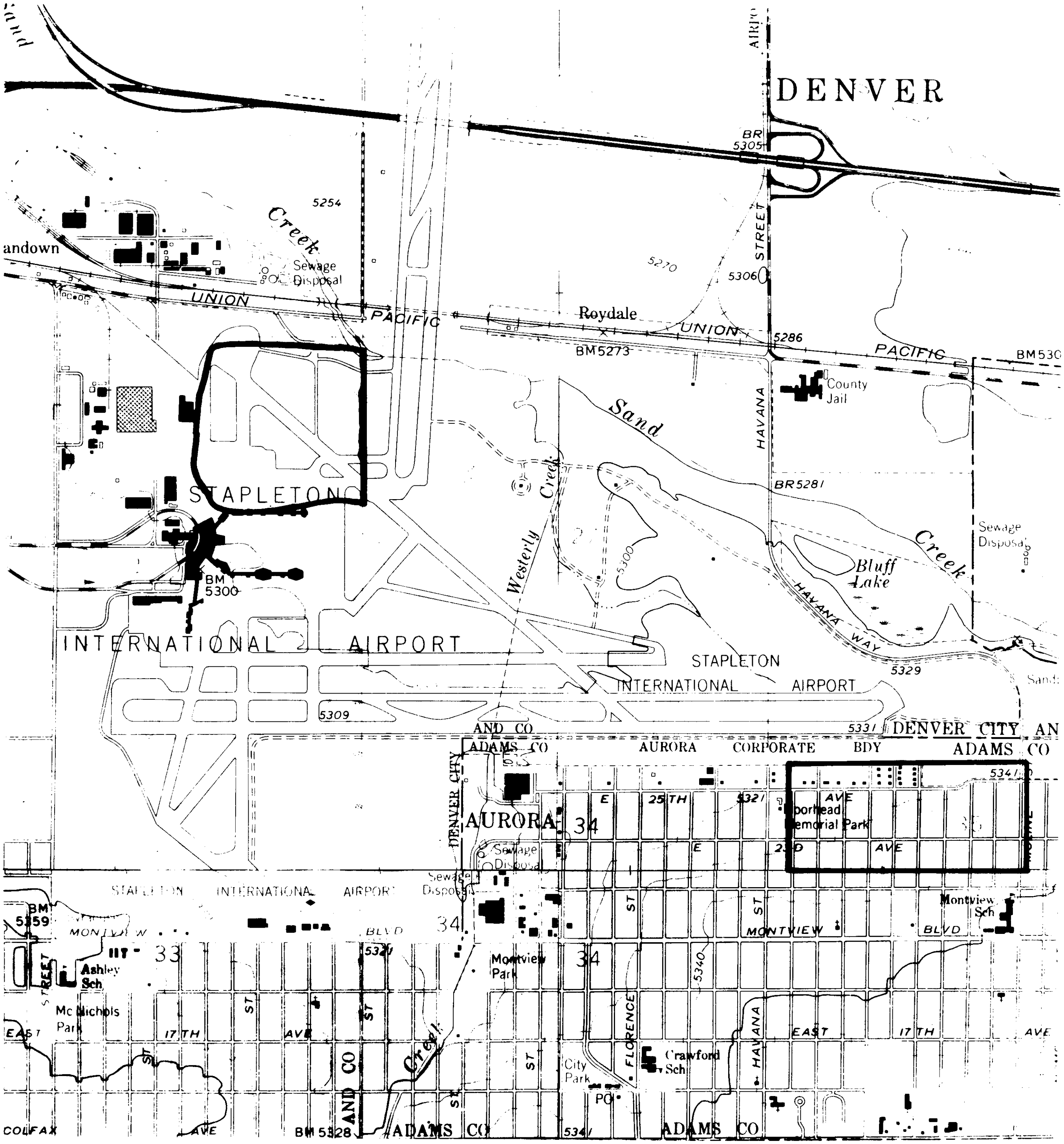


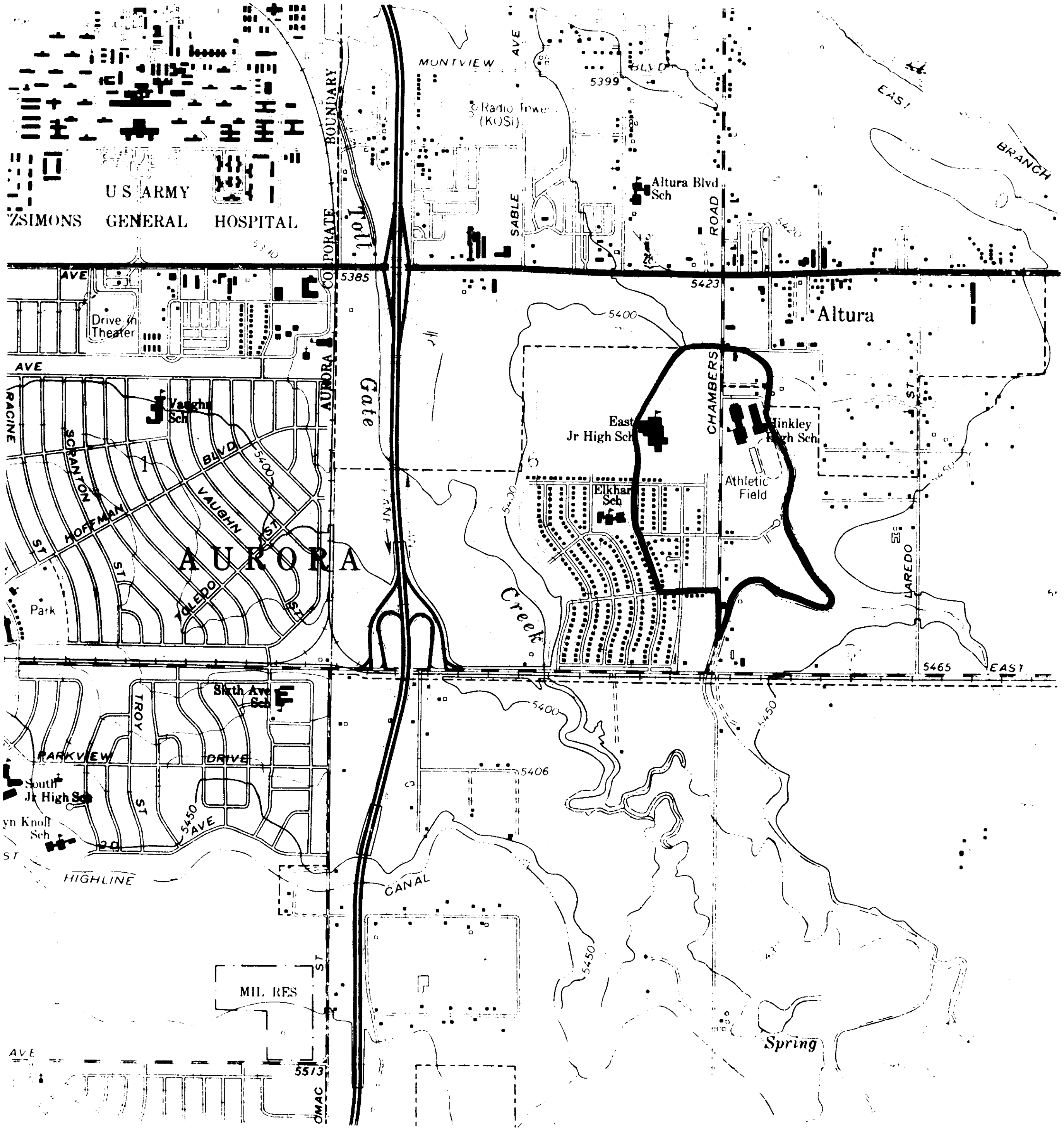
FIGURE B-1. MASTER INDEX MAP TO 13 DENVER AREA URBAN WATERSHEDS. This map shows the location of 13 watersheds used in this study. These watersheds were selected from 30 under study by the USGS - Water Resources Division for the effects of urbanization on water yield.



(a) topographic map - 1/24,000

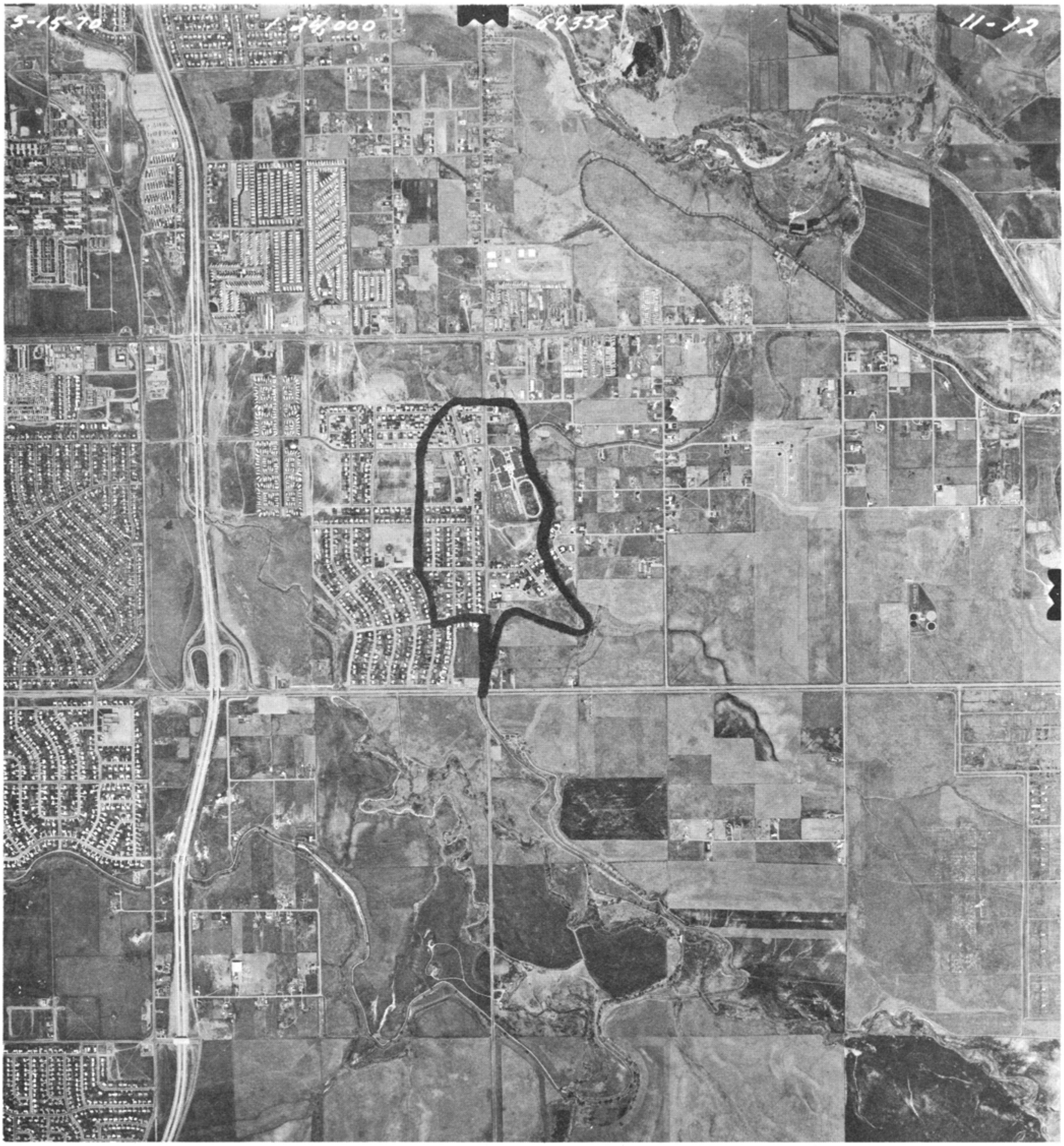
FIGURE B-2. STAPLETON WATERSHEDS. The upper basin is the Stapleton Airport basin and contains 70 acres. The lower right basin is Stapleton-S and contains 130 acres.

(b) airphoto - 1/27,500

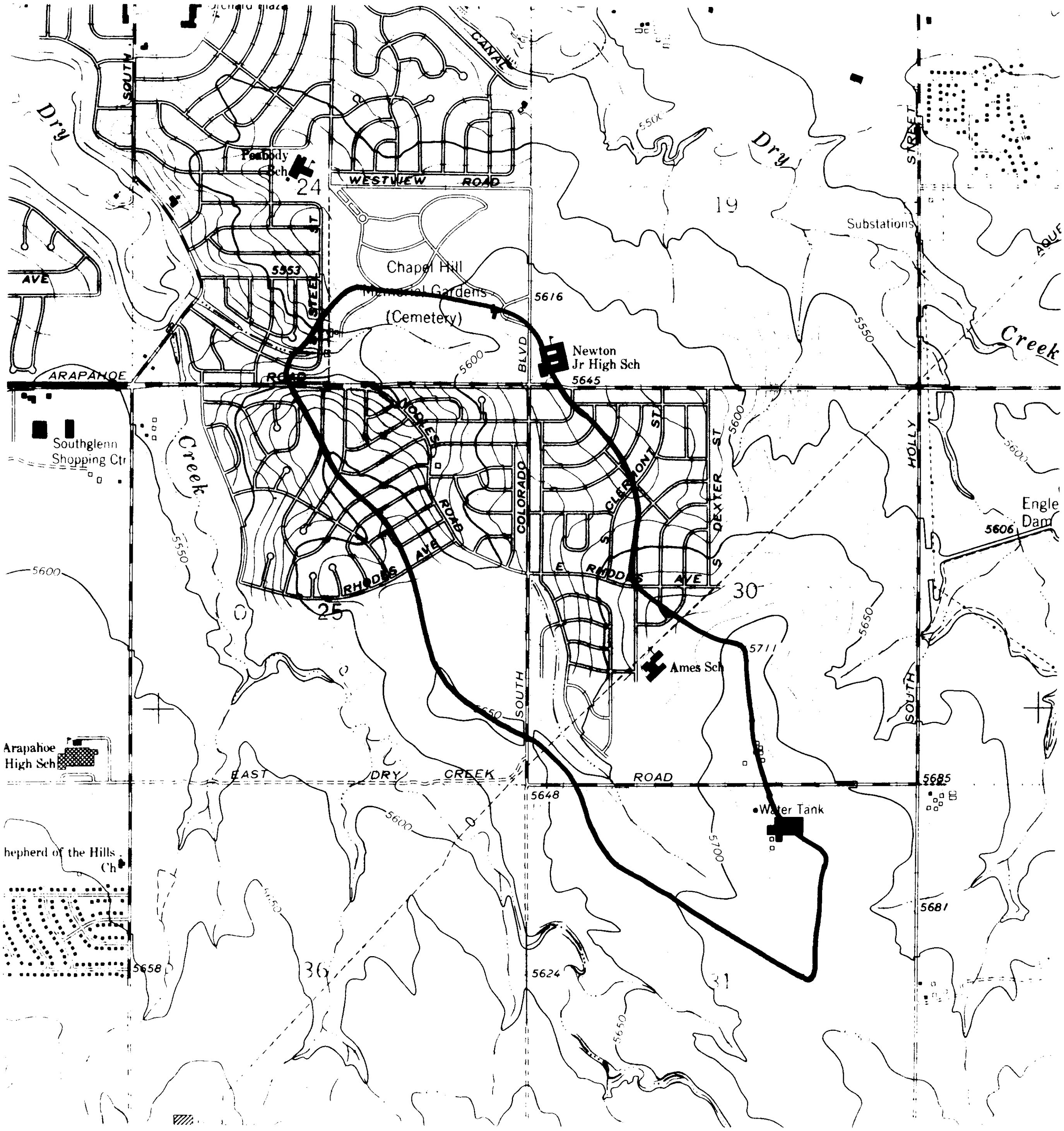


(a) topographic map - 1/24,000

FIGURE B-3. AURORA WATERSHED. The basin contains 180 acres.

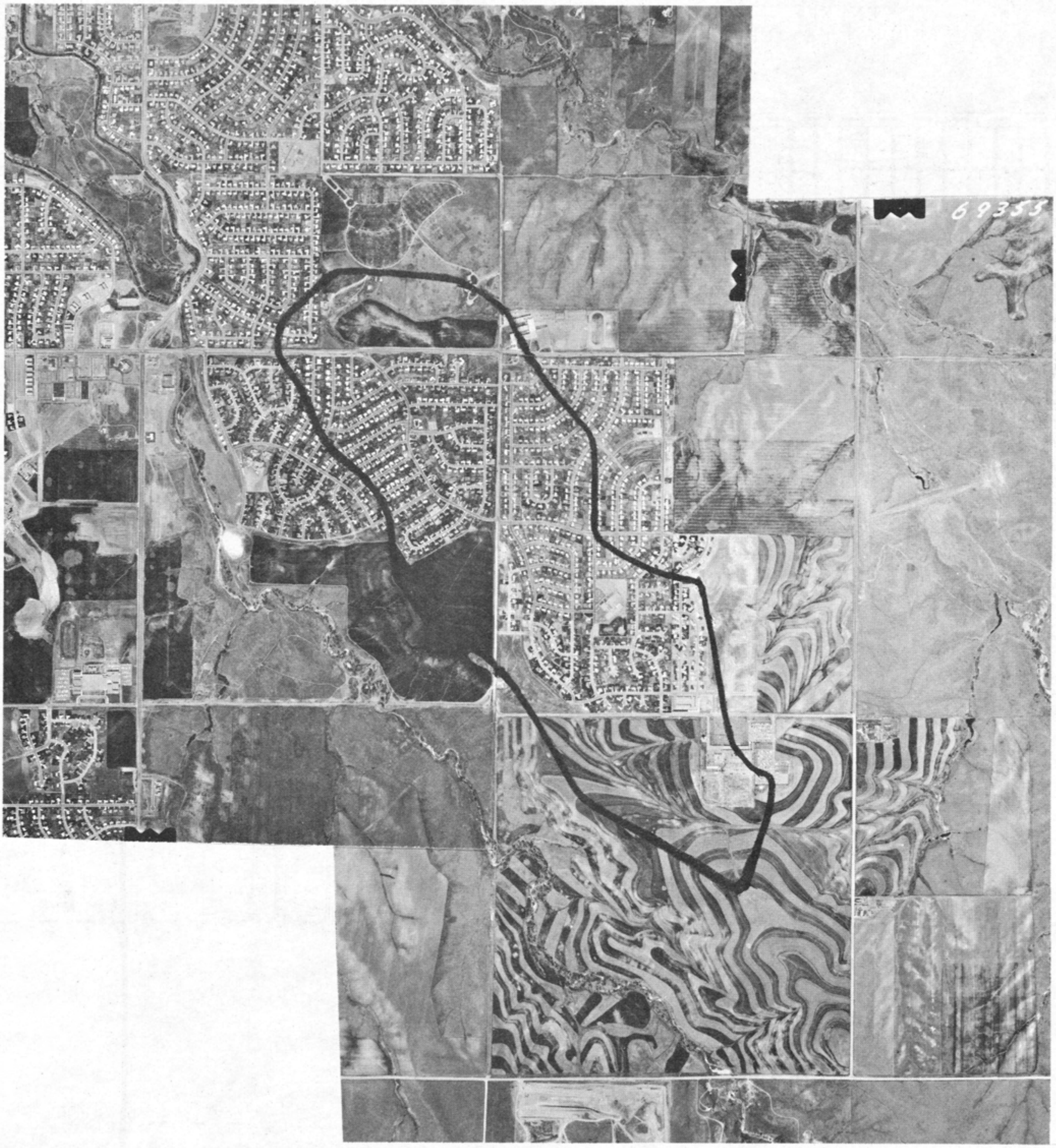


(b) airphoto - 1/27,500

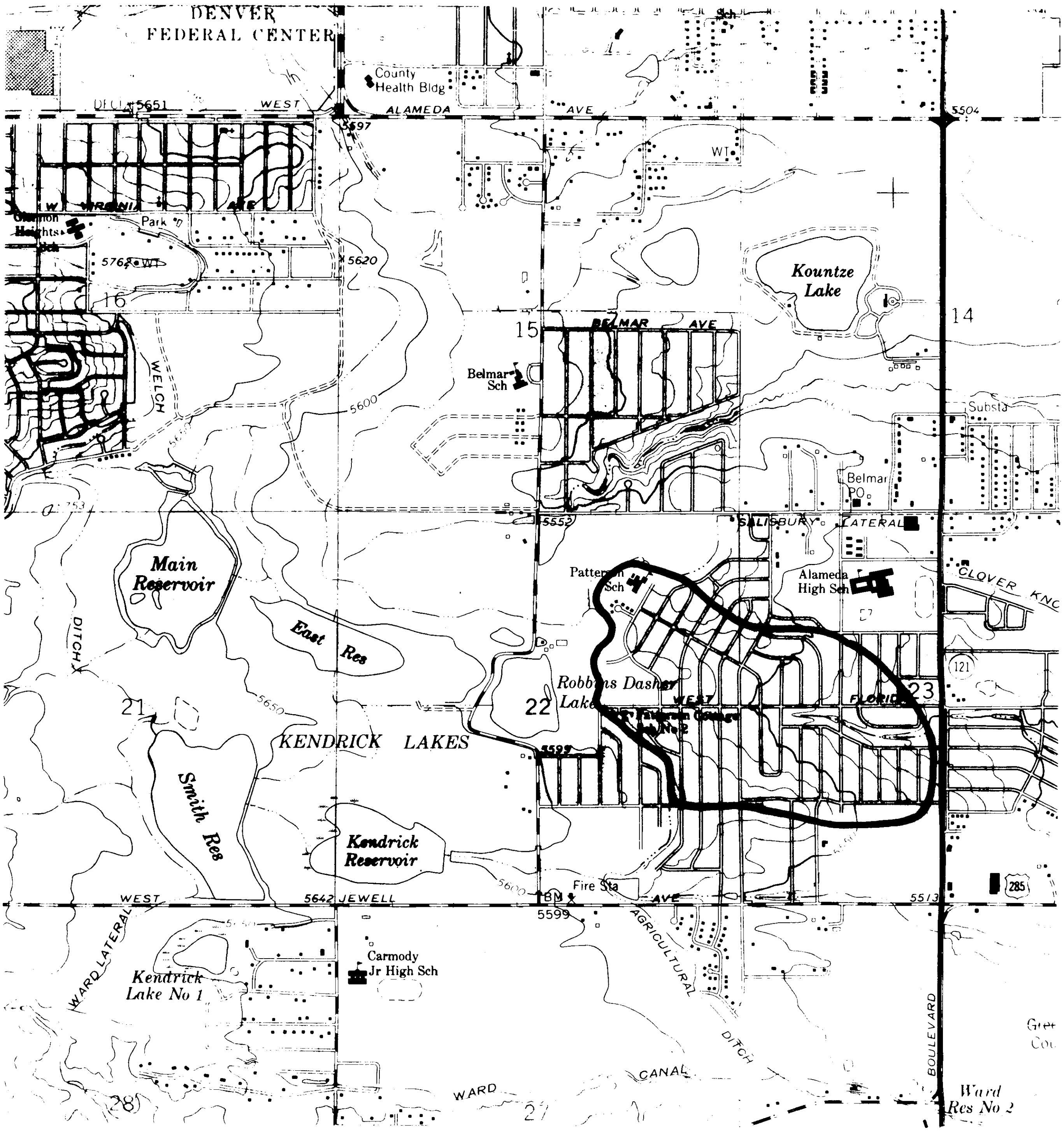


(a) topographic map - 1/24,000

FIGURE B-4. LITTLETON WATERSHED. The basin contains 600 acres.



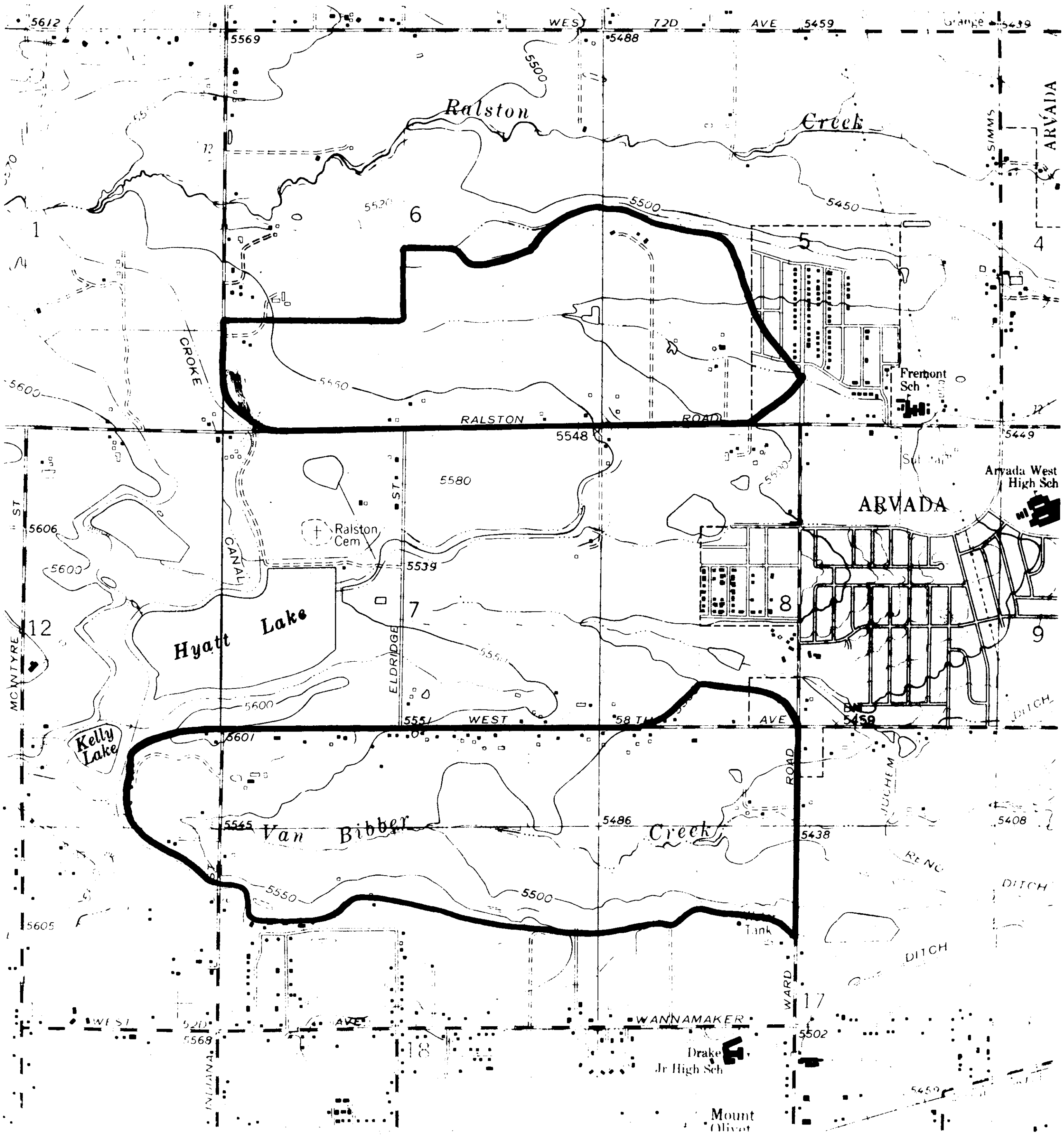
(b) airphoto - 1/27,500



(a) topographic map - 1/24,000

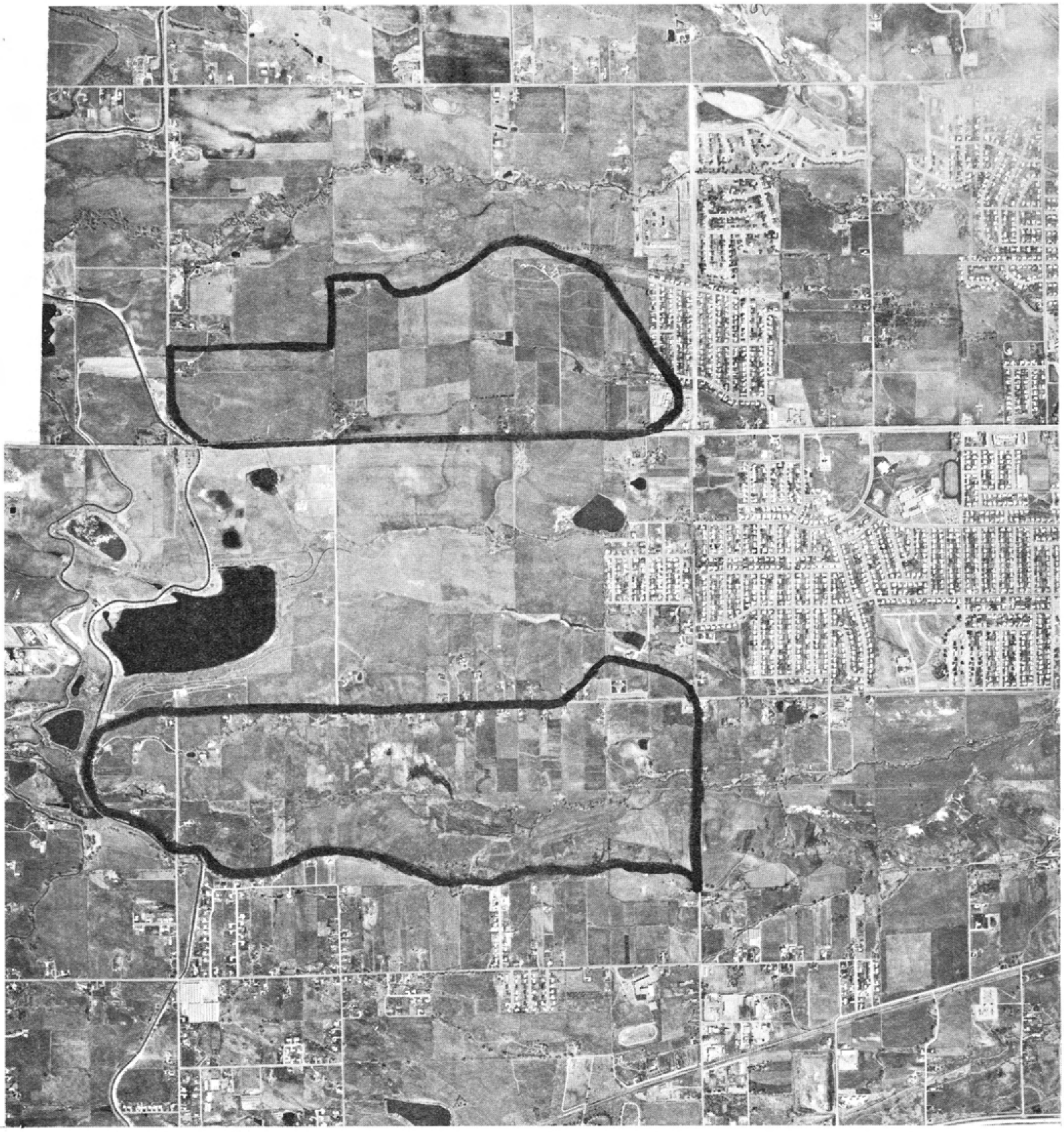
FIGURE B-5. FORT LOGAN WATERSHED. The basin contains 275 acres.

(b) airphoto - 1/27,500

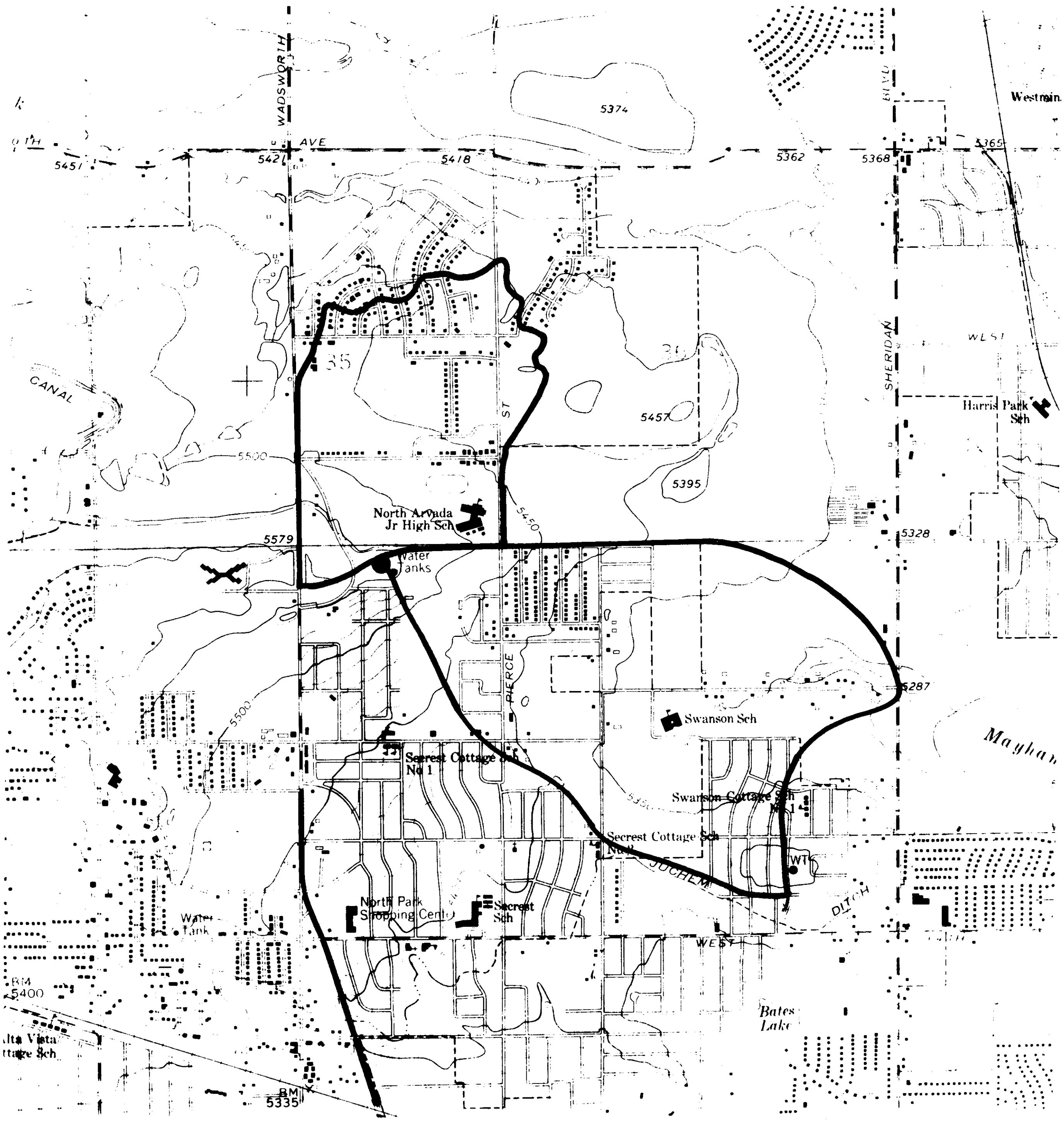


(a) topographic map - 1/24,000

FIGURE B-6. HYATT LAKE WATERSHEDS. The upper basin is Hyatt Lake-N and contains 380 acres, while the lower basin is Hyatt Lake-S and contains 600 acres.



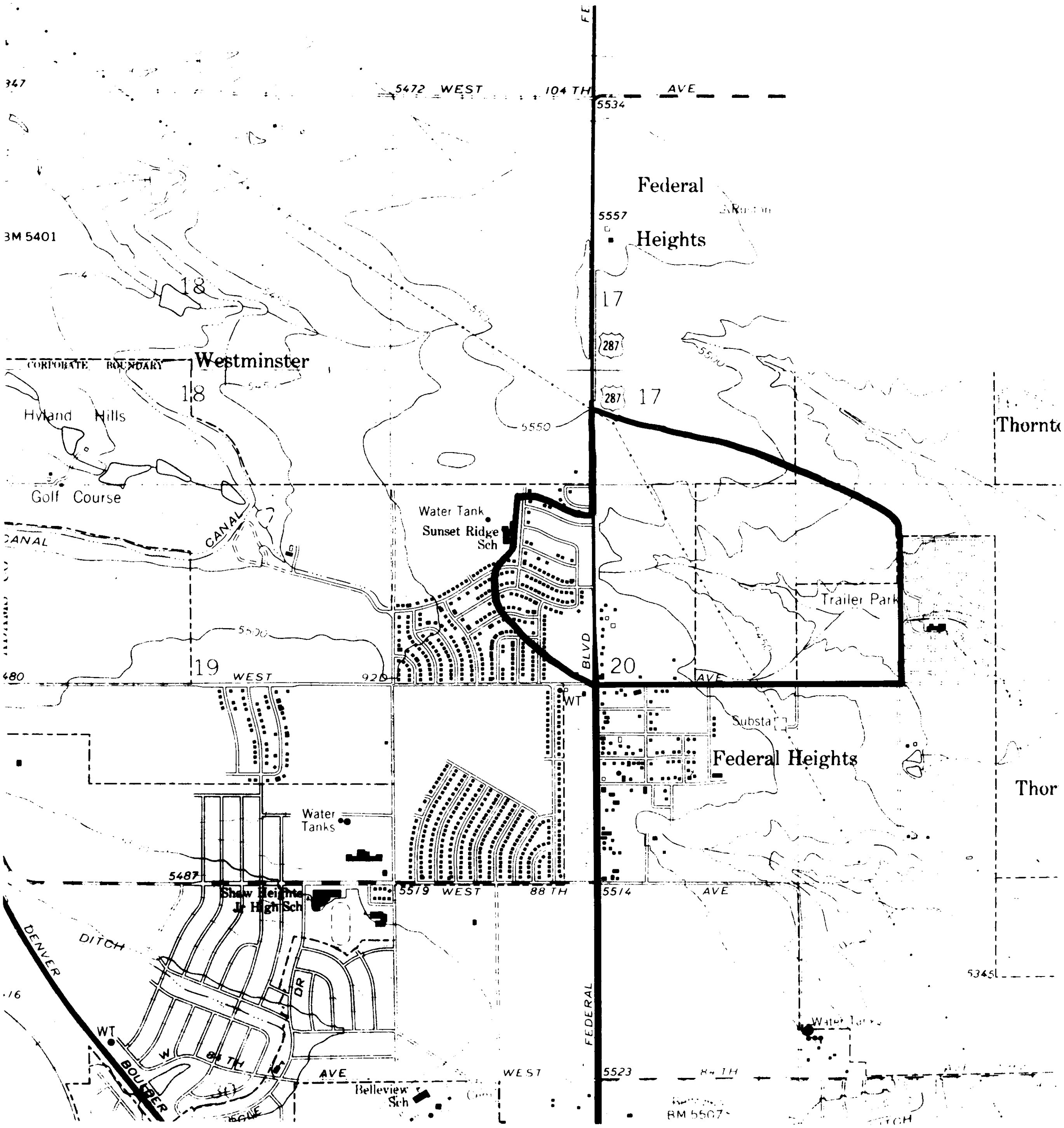
(b) airphoto - 1/27,500



(a) topographic map - 1/24,000

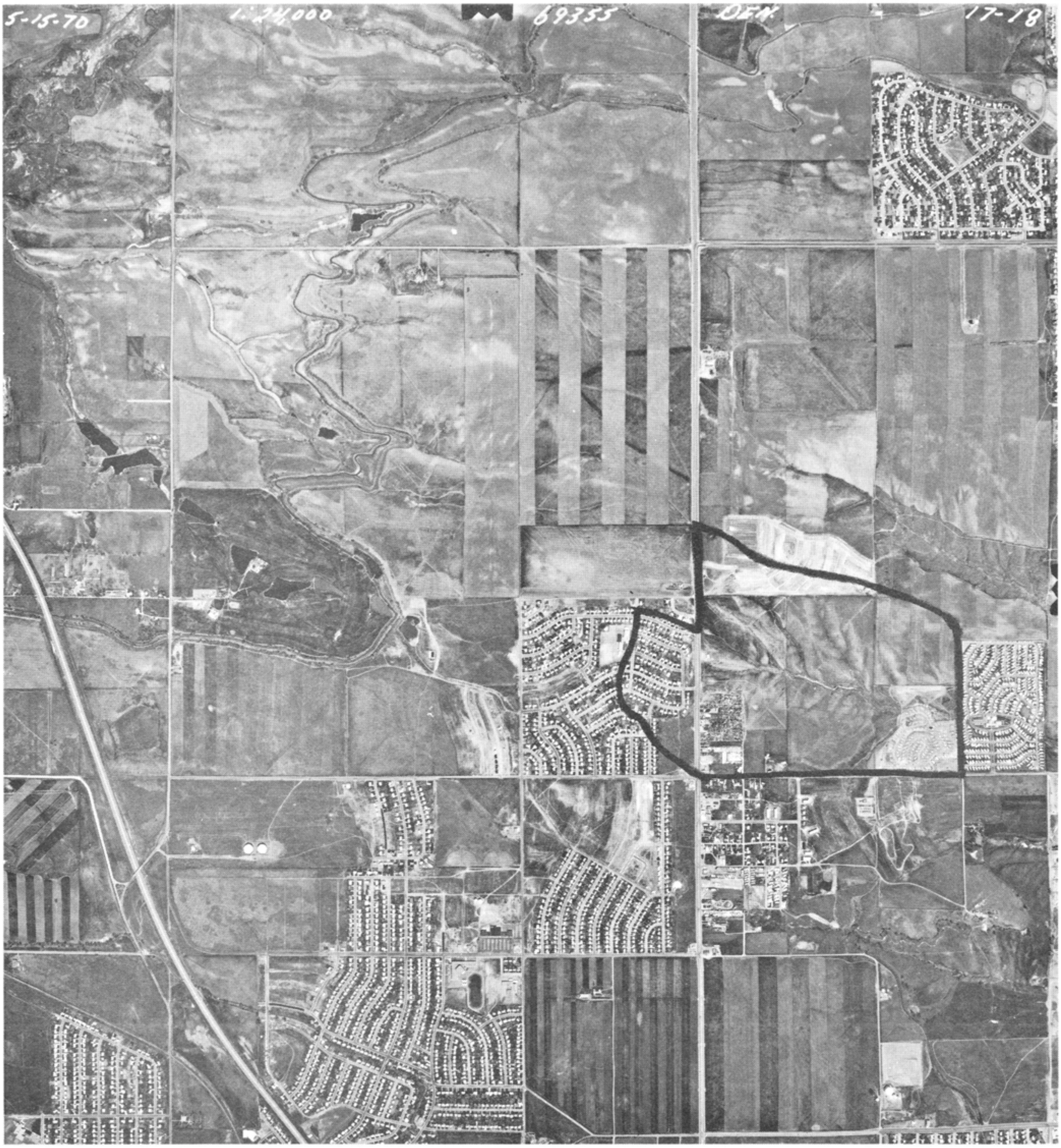
FIGURE B-7. ARVADA WATERSHEDS. The upper basin is Arvada-N and contains 200 acres, while the lower basin is Arvada-S and contains 450 acres.

(b) airphoto - 1/27,500

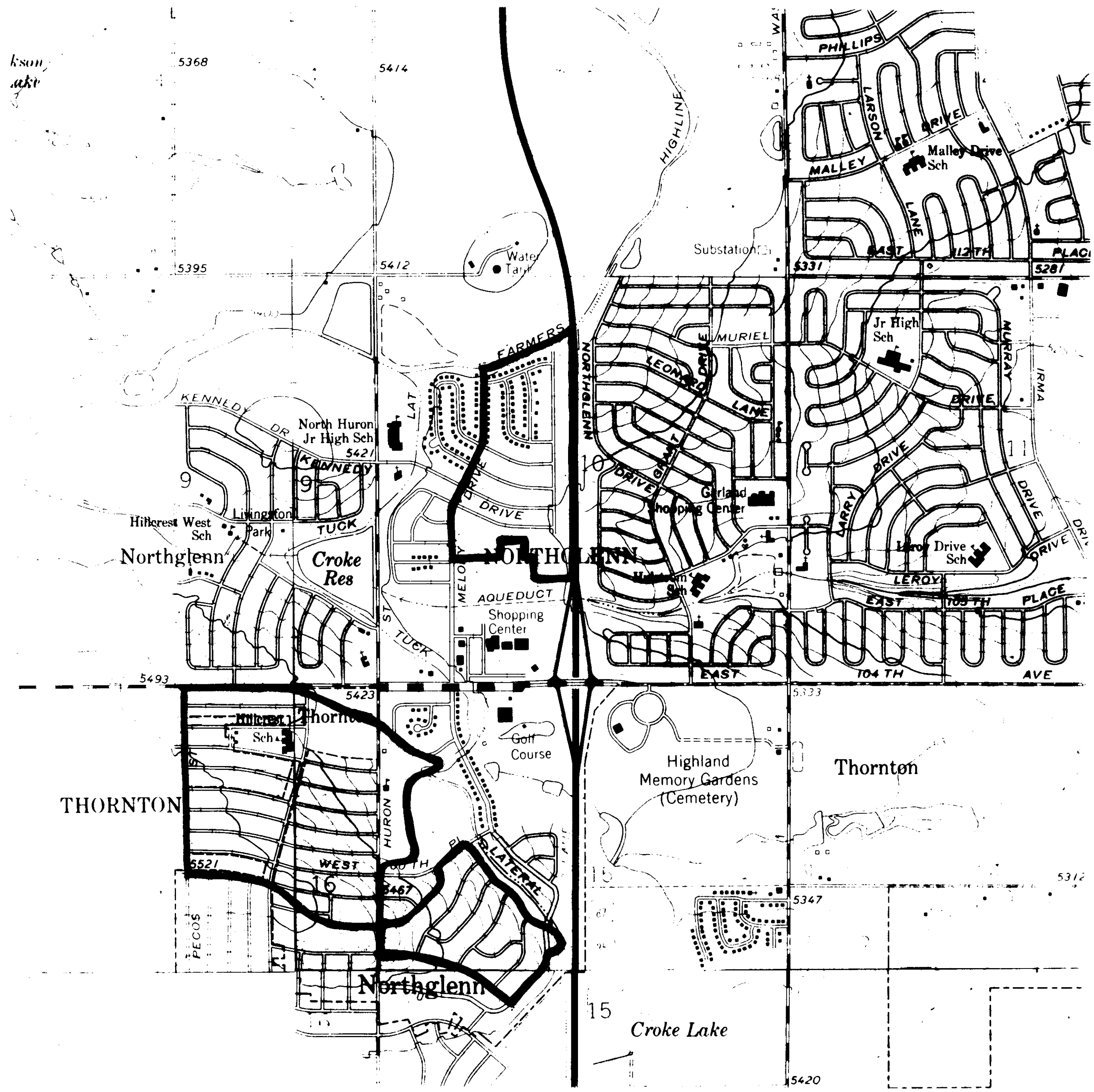


(a) topographic map - 1/24,000

FIGURE B-8. FEDERAL HEIGHTS WATERSHED. The basin contains 300 acres.



(b) airphoto - 1/27,500



(a) topographic map - 1/24,000

FIGURE B-9. NORTHGLENN WATERSHEDS. Upper basin is Northglenn #7204 and contains 70 acres. Middle left basin #7203 contains 180 acres. Lower basin #7201 contains 40 acres.

(b) airphoto - 1/27,500

APPENDIX C: DESCRIPTION OF THE EQUIVALENT-SQUARE INTERPRETIVE TECHNIQUE

The total area of each watershed is initially determined by fitting a square of equal area to the irregular boundary of the basin being analyzed such that parts of the watershed lying outside the square are equal to areas within the square not contained in the watershed (Fig. C-1). One side of the square is scaled into ten equal parts which are marked off on a note card as a scale and each resulting interval is the side of a square which comprises one percent of the watershed area. The note card is then used essentially as a scale to measure the areas of each of the watershed units within the watershed, referenced to a one percent estimation area. For example, the number of rooftops necessary to fill a one percent square (N) is determined, the total number of houses in the watershed counted (H), and the percent area of rooftops calculated as H/N. Larger roofs are treated separately and added to the total figure. Street areas are determined by measuring total street length on one percent units and multiplying by the street width, also in one percent units. Grass, fields, and cultivated areas are measured by counting the number of one percent squares that occupy the area.

The final tally of all areas for a watershed does not generally exactly equal one hundred percent and all measured areas are adjusted in proportion to their size to compensate for the difference. Measurements normally need to be slightly adjusted one way or the other by increments of one to five percent, depending on the area initially measured. After initial development and practice, the equivalent-square technique reproduces percent area measurements on the same basin to within one to two percent. Possible sources of measurement error are:

1. Incorrect determination of the initial equivalent square.
2. Difficulty in delineating object boundaries on poorer quality photos.
3. Incorrect determination of the number of rooftops contained in the one percent square.
4. Difficulty in measuring areas much smaller than the one percent square, such as driveways, small grass plots, small areas of bare soil, etc.

Considering the time involved to measure the areal percentage of surface units in each watershed (45 minutes to one hour) and the overall purpose of the resulting data, this method is sufficiently accurate. Changes in impervious cover with time, due to urban development, can be detected from this data to within five percent.

A tabulation form showing the areal extent of each watershed unit in terms of pervious or impervious cover is used during the interpretation of each basin (Fig. C-2). A second tabulation form is constructed from these airphoto interpretations which indicates short term and seasonal changes of the hydrological character of each of the watershed units (Fig. C-3). All impervious materials show little or no change with changing conditions, but the pervious materials will behave differently under different rainfall, snowfall, and seasonal conditions. The approximate ratio between pervious and impervious surface materials can be logically estimated for each season condition, e.g., the soil area is one hundred percent impervious in frozen winter conditions. These estimated ratios (Fig. C-3) for each surface material and season can be applied to the percentage of the surface material in a given watershed to arrive at a seasonal estimation of the variation in impervious and pervious surface area in that watershed.

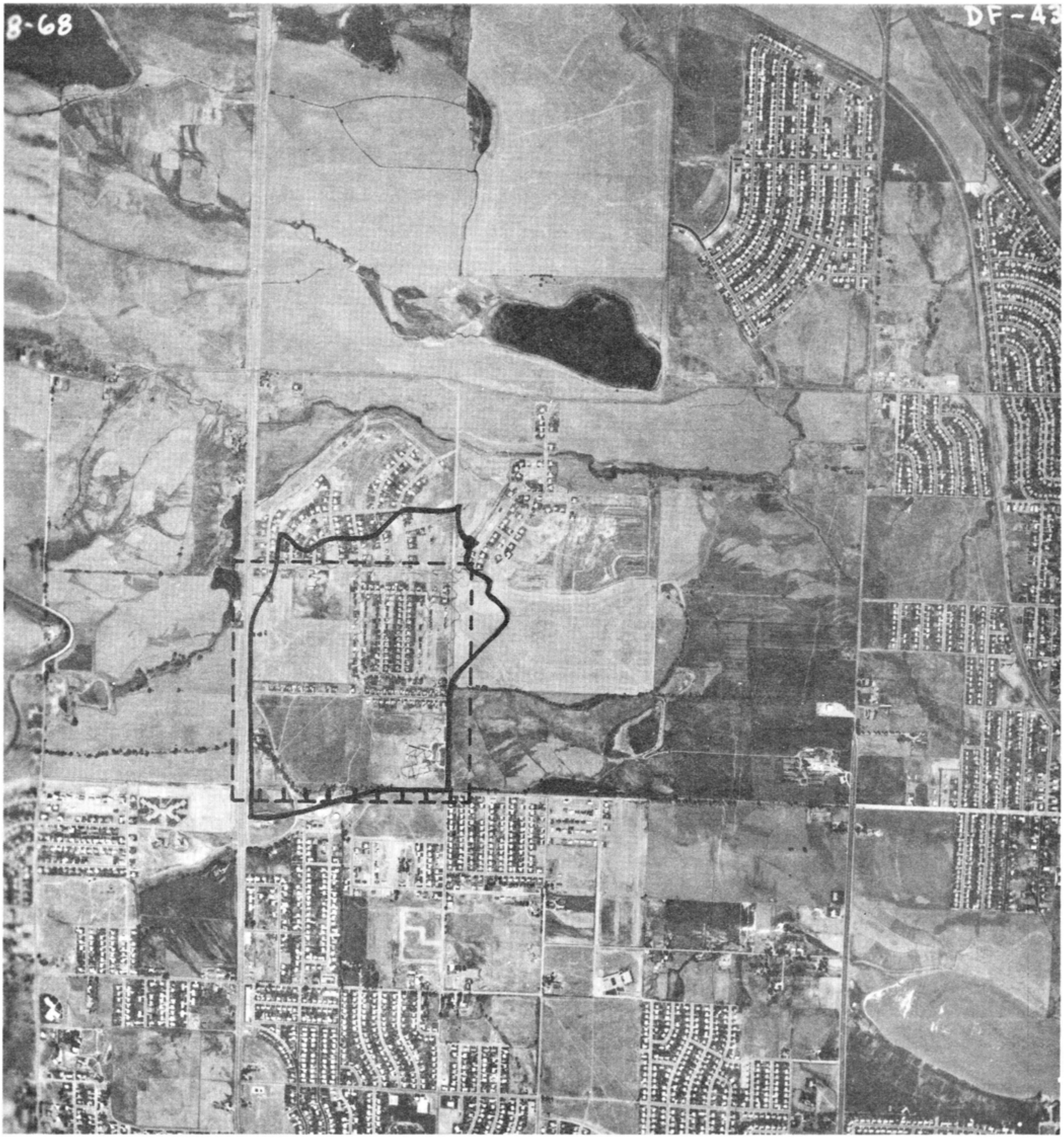


FIGURE C-1. FITTING AN EQUIVALENT-SQUARE TO THE ARVADA-N WATERSHED. The area inside the dashed square is approximately equal to the area inside the solid irregular watershed boundary. The tick marks on the edge of the square represent the sizes of measurement cells whose areas are one percent of the watershed boundary.

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE	8													
AGRICULTURE	90													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

FIGURE C-2. SAMPLE EQUIVALENT-SQUARE TABULATION. Pervious (P) and impervious (I) areas as a percent of the total watershed area for the Arvada-N watershed using a 1949 airphoto. See Figure C-1 for an airphoto of this watershed.

P = PERVIOUS
I = IMPERVIOUS
na = not applicable

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0
ASPHALT	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0
ROOFTOPS	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	1.0
GRAVEL	.10	.90	.15	.85	.20	.80	.25	.75	.25	.75	0	1.0	.10	.90
LAWNS	.25	.75	.17	.83	.30	.70	.25	.75	.35	.65	0	1.0	.10	.90
FIELDS/PASTURE	.20	.80	.15	.85	.25	.75	.60	.40	.30	.70	0	1.0	.10	.90
AGRICULTURE	.25	.75	.17	.83	.35	.65	.30	.70	.40	.60	0	1.0	.10	.90
TREES	.30	.70	.20	.80	.35	.65	.30	.70	.40	.60	0	1.0	.10	.90
EXPOSED SOIL	.20	.80	.15	.85	.30	.70	.65	.35	.40	.60	0	1.0	.10	.90
WATER	1.0	0	1.0	0	1.0	0	1.0	0	1.0	0	0	1.0	0	1.0
TOTAL AREA P	na	na	na	na	na	na	na	na	na	na	na	na	na	na
TOTAL AREA I	na	na	na	na	na	na	na	na	na	na	na	na	na	na

FIGURE C-3. FACTORS USED FOR PRORATING MEASURED VALUES TO ACCOUNT FOR SEASONAL VARIATIONS. These factors applied to the surface area estimates in Figure C-2 reapportion the surfaces into impervious and pervious areas according to season. These are only logical estimates and the user may substitute his own factors.

APPENDIX D: SURFACE MATERIAL CLASSIFICATION OF THIRTEEN WATERSHEDS, DENVER, COLORADO

The watershed surface material classifications which follow are in horizontal, adjacent, twin tables. The left table represents percent areas of the surface materials found in the watershed and the right table the projected seasonal variation in the perviousness and imperviousness of the materials.

The percent area of each of the surface materials in the watershed is determined by the equivalent-square technique (Appendix C). The resulting data is tabulated according to perviousness or imperviousness under the appropriate land use category in the left half of each twin table. These surface material classifications characterize the watershed as it would appear to a remote sensing device and during subsequent image processing.

The surface material classification is further refined to account for seasonal effects which may cause the relative perviousness of many surface materials to vary considerably. Estimates of degrees of perviousness of the pervious materials were calculated based upon the proportions shown in Figure C-3 of Appendix C. The percent area of pervious materials is multiplied by the proportions for the appropriate seasonal conditions and occurs in the right half of each of the twin tables. Totals at the bottom of the table show the total relative perviousness versus imperviousness of the watershed under the different seasonal conditions. In this analysis the impervious surface materials were treated as impervious under all conditions. For the pervious materials the relative degree of perviousness or imperviousness takes into account such factors as lawn sprinkling, irrigation, soil compaction in pasture, imperviousness of frozen surfaces, etc. This portion of the analysis represents possible interpretations of the surface material classifications that may be of interest to the hydrologist in a water yield prediction model and further illustrates how remote multispectral classification of surfaces might be refined for use in an urban watershed model.

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE	8													
AGRICULTURE	90													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE	2	6	1	7	2	6	5	3	2	6	0	8	1	7
AGRICULTURE	22	68	15	75	31	59	27	63	36	54	0	90	9	81
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		16		33		32		38		0		10	
TOTAL AREA I		76		84		67		68		62		100		90

Watershed analysis data for Arvada - N, 1949

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE	10													
AGRICULTURE	89													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE	2	8	2	8	3	7	6	4	3	7	0	10	1	9
AGRICULTURE	22	67	15	74	31	58	27	62	36	53	0	89	9	80
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		17		34		33		39		0		10	
TOTAL AREA I		76		83		66		67		61		100		90

Watershed analysis data for Arvada - N, 1954

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural P	Undeveloped Rural I	Semideveloped Suburban P	Semideveloped Suburban I	Completely Developed Suburban (<5 Years Old) P	Completely Developed Suburban (<5 Years Old) I	Completely Developed Suburban (>5 Years Old) P	Completely Developed Suburban (>5 Years Old) I	Business P	Business I	Light Industry (Offices, Light Manufacturing) P	Light Industry (Offices, Light Manufacturing) I	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) P	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE	8													
AGRICULTURE	90													
TREES														
EXPOSED SOIL	1													
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen P	Winter or Spring Ground Bare and Partly Frozen I	Spring Ground Almost Saturated with Water P	Spring Ground Almost Saturated with Water I	Summer One Hr After a 0.5 Inch Rainfall P	Summer One Hr After a 0.5 Inch Rainfall I	Summer One Week After Rainfall P	Summer One Week After Rainfall I	Autumn 2-3 Weeks Without Rain P	Autumn 2-3 Weeks Without Rain I	Winter Ground Bare and Completely Frozen P	Winter Ground Bare and Completely Frozen I	Winter Ground Covered with Snow P	Winter Ground Covered with Snow I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE	2	6	1	7	2	6	5	3	2	6	0	8	1	7
AGRICULTURE	22	68	15	75	32	58	27	63	54	36	0	90	9	81
TREES														
EXPOSED SOIL	0	1	0	1	0	1	1	0	0	1	0	1	0	1
WATER														
TOTAL AREA P	24		16		34		33		56		0		10	
TOTAL AREA I		76		84		66		67		44		100		90

Watershed analysis data for Arvada - N, 1959

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural P	Undeveloped Rural I	Semideveloped Suburban P	Semideveloped Suburban I	Completely Developed Suburban (<5 Years Old) P	Completely Developed Suburban (<5 Years Old) I	Completely Developed Suburban (>5 Years Old) P	Completely Developed Suburban (>5 Years Old) I	Business P	Business I	Light Industry (Offices, Light Manufacturing) P	Light Industry (Offices, Light Manufacturing) I	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) P	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) I
CONCRETE														
ASPHALT				7										
ROOFTOPS				5										
GRAVEL			2											
LAWNS			6											
FIELDS/PASTURE			65											
AGRICULTURE			2											
TREES			1											
EXPOSED SOIL			12											
WATER														
TOTAL AREA P			88											
TOTAL AREA I				12										

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen P	Winter or Spring Ground Bare and Partly Frozen I	Spring Ground Almost Saturated with Water P	Spring Ground Almost Saturated with Water I	Summer One Hr After a 0.5 Inch Rainfall P	Summer One Hr After a 0.5 Inch Rainfall I	Summer One Week After Rainfall P	Summer One Week After Rainfall I	Autumn 2-3 Weeks Without Rain P	Autumn 2-3 Weeks Without Rain I	Winter Ground Bare and Completely Frozen P	Winter Ground Bare and Completely Frozen I	Winter Ground Covered with Snow P	Winter Ground Covered with Snow I
CONCRETE														
ASPHALT		7		7		7		7		7		7		7
ROOFTOPS		5		5		5		5		5		5		5
GRAVEL	0	2	0	2	0	2	0	2	0	2	0	2	0	2
LAWNS	2	4	1	5	2	4	2	4	2	4	0	6	1	5
FIELDS/PASTURE	13	52	10	55	16	49	39	26	19	46	0	65	6	59
AGRICULTURE	0	2	1	1	1	1	1	1	1	1	0	2	0	2
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	2	10	2	10	4	8	4	8	5	7	0	12	1	11
WATER														
TOTAL AREA P	17		14		23		46		27		0		8	
TOTAL AREA I		83		86		77		54		73		100		92

Watershed analysis data for Arvada - N, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				9										
ROOFTOPS				7										
GRAVEL														
LAWNS			19											
FIELDS/PASTURE			35											
AGRICULTURE			18											
TREES			1											
EXPOSED SOIL			11											
WATER														
TOTAL AREA P			84											
TOTAL AREA I				16										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	9	0	9	0	9	0	9	0	9	0	9	0	9
ROOFTOPS	0	7	0	7	0	7	0	7	0	7	0	7	0	7
GRAVEL														
LAWNS	5	14	4	15	9	10	10	9	11	8	0	19	1	18
FIELDS/PASTURE	9	26	6	29	9	26	23	12	12	23	0	35	3	32
AGRICULTURE	5	13	3	15	5	13	11	7	9	9	0	18	1	17
TREES	0	1	0	1	0	1	1	0	0	1	0	1	0	1
EXPOSED SOIL	2	9	2	9	3	8	4	7	1	10	0	11	1	10
WATER														
TOTAL AREA P	21		15		26		49		34		0		6	
TOTAL AREA I		79		85		74		51		66		100		94

Watershed analysis data for Arvada - N, 1968

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				10										
ROOFTOPS				14										
GRAVEL														
LAWNS			21											
FIELDS/PASTURE			29											
AGRICULTURE														
TREES			1											
EXPOSED SOIL			24											
WATER														
TOTAL AREA P			75											
TOTAL AREA I				25										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	10	0	10	0	10	0	10	0	10	0	10	0	10
ROOFTOPS	0	14	0	14	0	14	0	14	0	14	0	14	0	14
GRAVEL														
LAWNS	5	16	4	17	10	11	11	10	12	9	0	21	2	19
FIELDS/PASTURE	7	22	5	24	6	23	19	10	10	19	0	29	3	26
AGRICULTURE														
TREES	0	1	0	1	0	1	1	0	1	0	0	1	0	1
EXPOSED SOIL	6	18	4	20	7	17	16	8	9	15	0	24	2	22
WATER														
TOTAL AREA P	18		13		23		47		32		0		7	
TOTAL AREA I		82		87		77		53		68		100		93

Watershed analysis data for Arvada - N, 1970

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	3													
LAWNS														
FIELDS/PASTURE	28													
AGRICULTURE	67													
TREES	2													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	3	0	3	1	2	1	2	1	2	0	3	0	3
LAWNS														
FIELDS/PASTURE	6	22	4	24	7	21	17	11	8	20	0	28	3	25
AGRICULTURE	17	50	11	56	23	44	20	47	27	40	0	67	7	60
TREES	1	1	0	2	1	1	1	1	1	1	0	2	0	2
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		15		32		39		37		0		10	
TOTAL AREA I		76		85		68		61		63		100		90

Watershed analysis data for Arvada - S, 1949

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS		1												
GRAVEL	3													
LAWNS														
FIELDS/PASTURE	27													
AGRICULTURE	68													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	99													
TOTAL AREA I		1												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	3	0	3	0	3	1	2	1	2	0	3	0	3
LAWNS														
FIELDS/PASTURE	5	22	4	23	6	21	16	11	8	19	0	27	3	24
AGRICULTURE	17	51	11	57	24	44	20	48	27	41	0	68	7	61
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	22		15		30		37		36		0		10	
TOTAL AREA I		78		85		70		63		64		100		90

Watershed analysis data for Arvada - S, 1954

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) I
CONCRETE														
ASPHALT														
ROOFTOPS		1												
GRAVEL	3													
LAWNS														
FIELDS/PASTURE	25													
AGRICULTURE	70													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	99													
TOTAL AREA I		1												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE														
ASPHALT														
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	3	0	3	0	3	1	2	1	2	0	3	0	3
LAWNS														
FIELDS/PASTURE	5	20	4	21	6	19	15	10	8	17	0	25	3	22
AGRICULTURE	18	52	12	58	25	45	21	49	28	42	0	70	7	63
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	23		16		31		37		37		0		10	
TOTAL AREA I		77		84		69		63		63		100		90

Watershed analysis data for Arvada - S, 1959

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) I
CONCRETE				1										
ASPHALT				7										
ROOFTOPS				5										
GRAVEL			1											
LAWNS			9											
FIELDS/PASTURE			50											
AGRICULTURE			18											
TREES			1											
EXPOSED SOIL			8											
WATER														
TOTAL AREA P			87											
TOTAL AREA I				13										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	7	0	7	0	7	0	7	0	7	0	7	0	7
ROOFTOPS	0	5	0	5	0	5	0	5	0	5	0	5	0	5
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS	2	7	2	7	3	6	3	6	3	6	0	9	1	8
FIELDS/PASTURE	10	40	7	43	12	38	30	20	15	35	0	50	5	45
AGRICULTURE	4	14	3	15	6	12	5	13	7	11	0	18	2	16
TREES	0	1	0	1	0	1	0	1	1	0	0	1	0	1
EXPOSED SOIL	2	6	1	7	2	6	5	3	3	5	0	8	1	7
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	18		13		23		43		29		0		9	
TOTAL AREA I		82		87		77		57		71		100		91

Watershed analysis data for Arvada - S, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				2										
ASPHALT				15										
ROOFTOPS				20										
GRAVEL				1										
LAWNS			25											
FIELDS/PASTURE			32											
AGRICULTURE														
TREES			1											
EXPOSED SOIL			4											
WATER														
TOTAL AREA P			62											
TOTAL AREA I				38										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	15	0	15	0	15	0	15	0	15	0	15	0	15
ROOFTOPS	0	20	0	20	0	20	0	20	0	20	0	20	0	20
GRAVEL	0	1	0	1	0	1	0	1	1	0	0	1	0	1
LAWNS	7	18	4	21	6	19	9	16	10	15	0	25	2	23
FIELDS/PASTURE	8	24	4	28	18	14	20	12	8	24	0	32	3	29
AGRICULTURE														
TREES	1	0	0	1	1	0	1	0	1	0	0	1	1	0
EXPOSED SOIL	2	2	0	4	2	2	4	0	4	0	0	4	2	2
WATER														
TOTAL AREA P	18		8		27		34		24		0		8	
TOTAL AREA I		82		92		73		66		76		100		92

Watershed analysis data for Arvada - S, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	8													
AGRICULTURE	91													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	99													
TOTAL AREA I		1												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	2	6	1	7	2	6	5	3	2	6	0	8	1	7
AGRICULTURE	23	68	15	76	32	59	27	64	36	55	0	91	9	82
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		16		34		32		38		0		10	
TOTAL AREA I		75		84		66		68		62		100		90

Watershed analysis data for Federal Heights, 1954

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural P	Undeveloped Rural I	Semideveloped Suburban P	Semideveloped Suburban I	Completely Developed Suburban (<5 Years Old) P	Completely Developed Suburban (<5 Years Old) I	Completely Developed Suburban (>5 Years Old) P	Completely Developed Suburban (>5 Years Old) I	Business P	Business I	Light Industry (Offices, Light Manufacturing) P	Light Industry (Offices, Light Manufacturing) I	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) P	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) I
CONCRETE														
ASPHALT		1												
ROOFTOPS		1												
GRAVEL														
LAWNS														
FIELDS/PASTURE	22													
AGRICULTURE	74													
TREES														
EXPOSED SOIL	2													
WATER														
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen P	Winter or Spring Ground Bare and Partly Frozen I	Spring Ground Almost Saturated with Water P	Spring Ground Almost Saturated with Water I	Summer One Hr After a 0.5 Inch Rainfall P	Summer One Hr After a 0.5 Inch Rainfall I	Summer One Week After Rainfall P	Summer One Week After Rainfall I	Autumn 2-3 Weeks Without Rain P	Autumn 2-3 Weeks Without Rain I	Winter Ground Bare and Completely Frozen P	Winter Ground Bare and Completely Frozen I	Winter Ground Covered with Snow P	Winter Ground Covered with Snow I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL														
LAWNS														
FIELDS/PASTURE	4	18	3	19	5	17	13	9	7	15	0	22	2	20
AGRICULTURE	18	56	13	61	26	48	22	52	30	44	0	74	7	67
TREES	0	2	0	2	1	1	1	1	1	1	0	2	0	2
EXPOSED SOIL														
WATER														
TOTAL AREA P	22		16		32		36		38		0		9	
TOTAL AREA I		78		84		68		64		62		100		91

Watershed analysis data for Federal Heights, 1959

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural P	Undeveloped Rural I	Semideveloped Suburban P	Semideveloped Suburban I	Completely Developed Suburban (<5 Years Old) P	Completely Developed Suburban (<5 Years Old) I	Completely Developed Suburban (>5 Years Old) P	Completely Developed Suburban (>5 Years Old) I	Business P	Business I	Light Industry (Offices, Light Manufacturing) P	Light Industry (Offices, Light Manufacturing) I	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) P	Heavy Industry (Steel Mills, Refineries, Heavy Manufac.) I
CONCRETE														
ASPHALT				3										
ROOFTOPS				1										
GRAVEL														
LAWNS			1											
FIELDS/PASTURE			26											
AGRICULTURE			65											
TREES														
EXPOSED SOIL			4											
WATER														
TOTAL AREA P			96											
TOTAL AREA I				4										

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen P	Winter or Spring Ground Bare and Partly Frozen I	Spring Ground Almost Saturated with Water P	Spring Ground Almost Saturated with Water I	Summer One Hr. After a 0.5 Inch Rainfall P	Summer One Hr. After a 0.5 Inch Rainfall I	Summer One Week After Rainfall P	Summer One Week After Rainfall I	Autumn 2-3 Weeks Without Rain P	Autumn 2-3 Weeks Without Rain I	Winter Ground Bare and Completely Frozen P	Winter Ground Bare and Completely Frozen I	Winter Ground Covered with Snow P	Winter Ground Covered with Snow I
CONCRETE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASPHALT	0	3	0	3	0	3	0	3	0	3	0	3	0	3
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
FIELDS/PASTURE	5	21	4	22	7	19	16	10	8	18	0	26	3	23
AGRICULTURE	16	49	11	54	23	42	19	46	26	39	0	65	7	58
TREES	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPOSED SOIL	1	3	1	3	1	3	3	1	2	2	0	4	0	4
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	22		16		31		38		36		0		10	
TOTAL AREA I		78		84		69		62		64		100		90

Watershed analysis data for Federal Heights, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				4										
ROOFTOPS				4										
GRAVEL														
LAWNS			7											
FIELDS/PASTURE			21											
AGRICULTURE			64											
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P			92											
TOTAL AREA I				8										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	4	0	4	0	4	0	4	0	4	0	4	0	4
ROOFTOPS	0	4	0	4	0	4	0	4	0	4	0	4	0	4
GRAVEL														
LAWNS	2	5	1	6	3	4	4	3	4	3	0	7	0	7
FIELDS/PASTURE	5	16	4	17	5	16	14	7	7	14	0	21	2	19
AGRICULTURE	16	48	11	53	16	48	40	24	34	30	0	64	4	60
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	23		16		24		58		45		0		6	
TOTAL AREA I		77		84		76		42		55		100		94

Watershed analysis data for Federal Heights, 1968

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				5										
ROOFTOPS				3										
GRAVEL														
LAWNS			6											
FIELDS/PASTURE			15											
AGRICULTURE			57											
TREES														
EXPOSED SOIL			14											
WATER														
TOTAL AREA P			92											
TOTAL AREA I				8										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	5	0	5	0	5	0	5	0	5	0	5	0	5
ROOFTOPS	0	3	0	3	0	3	0	3	0	3	0	3	0	3
GRAVEL														
LAWNS	2	4	1	5	3	3	3	3	3	3	0	6	0	6
FIELDS/PASTURE	5	10	2	13	8	7	13	2	5	10	0	15	2	13
AGRICULTURE	22	35	8	49	28	29	23	34	22	35	0	57	5	52
TREES														
EXPOSED SOIL	5	9	2	12	8	6	10	4	12	2	0	14	2	12
WATER														
TOTAL AREA P	34		13		47		49		42		0		10	
TOTAL AREA I		66		87		53		51		58		100		90

Watershed analysis data for Federal Heights, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	100													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	25	75	17	83	35	65	30	70	40	60	0	100	10	90
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		17		35		30		40		0		10	
TOTAL AREA I		75		83		65		70		60		100		90

Watershed analysis data for Northglenn 7204, 1954

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	100													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	25	75	17	83	35	65	30	70	40	60	0	100	10	90
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		17		35		30		40		0		10	
TOTAL AREA I		75		83		65		70		60		100		90

Watershed analysis data for Northglenn 7204, 1959

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	100													
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	20	80	15	85	25	75	60	40	30	70	0	100	10	90
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	20		15		25		60		30		0		10	
TOTAL AREA I		80		85		75		40		70		100		90

Watershed analysis data for Northglenn 7204, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				38										
ROOFTOPS				13										
GRAVEL														
LAWNS			30											
FIELDS/PASTURE			18											
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P			48											
TOTAL AREA I				52										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	38	0	38	0	38	0	38	0	38	0	38	0	38
ROOFTOPS	0	13	0	13	0	13	0	13	0	13	0	13	0	13
GRAVEL														
LAWNS	8	22	5	25	15	15	16	14	17	13	0	30	2	28
FIELDS/PASTURE	5	13	3	15	4	14	12	6	6	12	0	18	2	16
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	13		8		19		28		23		0		4	
TOTAL AREA I		87		92		71		72		73		100		96

Watershed analysis data for Northglenn 7204, 1968

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						3								
ASPHALT						38								
ROOFTOPS						14								
GRAVEL														
LAWNS					24									
FIELDS/PASTURE					21									
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P					45									
TOTAL AREA I						55								

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	3	0	3	0	3	0	3	0	3	0	3	0	3
ASPHALT	0	38	0	38	0	38	0	38	0	38	0	38	0	38
ROOFTOPS	0	14	0	14	0	14	0	14	0	14	0	14	0	14
GRAVEL														
LAWNS	6	18	4	20	7	17	8	16	9	15	0	24	2	22
FIELDS/PASTURE	5	16	3	18	5	16	13	8	17	4	0	21	2	19
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	11		7		12		21		26		0		4	
TOTAL AREA I		89		93		88		79		74		100		96

Watershed analysis data for Northglenn 7204, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	98													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	25	73	17	81	34	64	29	69	39	59	0	98	9	89
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		17		34		29		39		0		9	
TOTAL AREA I		75		83		66		71		61		100		91

Watershed analysis data for Northglenn 7203, 1954

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS				2										
GRAVEL			3											
LAWNS														
FIELDS/PASTURE			85											
AGRICULTURE														
TREES			1											
EXPOSED SOIL			9											
WATER														
TOTAL AREA P			98											
TOTAL AREA I				2										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS	0	2	0	2	0	2	0	2	0	2	0	2	0	2
GRAVEL	0	3	0	3	1	2	1	2	1	2	0	3	0	3
LAWNS														
FIELDS/PASTURE	17	68	13	72	21	64	51	34	24	60	0	85	9	76
AGRICULTURE														
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	2	7	1	8	3	6	6	3	4	5	0	9	1	8
WATER														
TOTAL AREA P	19		14		25		58		30		0		10	
TOTAL AREA I		81		86		75		42		70		100		90

Watershed analysis data for Northglenn 7203, 1959

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				17										
ROOFTOPS				14										
GRAVEL														
LAWNS			13											
FIELDS/PASTURE			39											
AGRICULTURE														
TREES														
EXPOSED SOIL			16											
WATER														
TOTAL AREA P			68											
TOTAL AREA I				32										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	17	0	17	0	17	0	17	0	17	0	17	0	17
ROOFTOPS	0	14	0	14	0	14	0	14	0	14	0	14	0	14
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	3	10	2	11	4	9	3	10	5	8	0	13	1	12
FIELDS/PASTURE	8	31	6	33	10	29	23	16	12	27	0	39	4	35
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPOSED SOIL	3	13	2	14	5	11	10	6	6	10	0	16	2	14
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	14		10		19		36		23		0		7	
TOTAL AREA I		86		90		81		64		77		100		93

Watershed analysis data for Northglenn 7203, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						1								
ASPHALT						22								
ROOFTOPS						20								
GRAVEL														
LAWNS					28									
FIELDS/PASTURE					23									
AGRICULTURE														
TREES														
EXPOSED SOIL					6									
WATER														
TOTAL AREA P					57									
TOTAL AREA I						43								

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	22	0	22	0	22	0	22	0	22	0	22	0	22
ROOFTOPS	0	20	0	20	0	20	0	20	0	20	0	20	0	20
GRAVEL														
LAWNS	7	21	5	23	14	14	14	14	16	12	0	28	2	26
FIELDS/PASTURE	6	17	4	19	6	17	15	8	8	15	0	23	2	21
AGRICULTURE														
TREES														
EXPOSED SOIL	2	4	1	5	2	4	4	2	2	4	0	6	0	6
WATER														
TOTAL AREA P	15		10		22		33		26		0		4	
TOTAL AREA I		85		90		78		67		74		100		96

Watershed analysis data for Northglenn 7203, 1968

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						2								
ASPHALT						26								
ROOFTOPS						18								
GRAVEL														
LAWNS					30									
FIELDS/PASTURE					23									
AGRICULTURE														
TREES														
EXPOSED SOIL					1									
WATER														
TOTAL AREA P					54									
TOTAL AREA I						46								

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	26	0	26	0	26	0	26	0	26	0	26	0	26
ROOFTOPS	0	18	0	18	0	18	0	18	0	18	0	18	0	18
GRAVEL														
LAWNS	18	22	4	26	10	20	13	17	15	15	0	30	3	27
FIELDS/PASTURE	6	17	3	20	8	15	9	14	7	16	0	23	2	21
AGRICULTURE														
TREES														
EXPOSED SOIL	0	1	0	1	0	1	1	0	1	0	0	1	0	1
WATER														
TOTAL AREA P	14		7		18		23		23		0		5	
TOTAL AREA I		86		93		82		77		77		100		95

Watershed analysis data for Northglenn 7203, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	97													
TREES	2													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	73	16	81	34	63	29	68	39	58	0	97	9	88
TREES	1	1	0	2	1	1	1	1	1	1	0	2	0	2
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		16		35		30		40		0		9	
TOTAL AREA I		75		84		65		70		60		100		91

Watershed analysis data for Northglenn 7201, 1954

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	97													
TREES	2													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	73	16	81	34	63	29	68	39	58	0	97	9	88
TREES	1	1	0	2	1	1	1	1	1	1	0	2	0	2
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		16		35		30		40		0		9	
TOTAL AREA I		75		84		65		70		60		100		91

Watershed analysis data for Northglenn 7201, 1959

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				6										
ROOFTOPS				7										
GRAVEL														
LAWNS			3											
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL			83											
WATER														
TOTAL AREA P			86											
TOTAL AREA I				14										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	6	0	6	0	6	0	6	0	6	0	6	0	6
ROOFTOPS	0	7	0	7	0	7	0	7	0	7	0	7	0	7
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	1	2	1	2	1	2	1	2	1	2	0	3	0	3
FIELDS/PASTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPOSED SOIL	17	66	12	71	25	58	54	29	33	50	0	83	8	75
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	18		13		26		55		34		0		8	
TOTAL AREA I		82		87		74		45		66		100		92

Watershed analysis data for Northglenn 7201, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						2								
ASPHALT						23								
ROOFTOPS						22								
GRAVEL														
LAWNS					53									
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P					53									
TOTAL AREA I						47								

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	23	0	23	0	23	0	23	0	23	0	23	0	23
ROOFTOPS	0	22	0	22	0	22	0	22	0	22	0	22	0	22
GRAVEL														
LAWNS	14	39	9	44	26	27	27	26	28	25	0	53	4	49
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	14		9		26		27		28		0		4	
TOTAL AREA I		86		91		74		73		72		100		96

Watershed analysis data for Northglenn 7201, 1968

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (<5 Years Old)		Completely Developed Suburban (>5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						2								
ASPHALT						22								
ROOFTOPS						26								
GRAVEL														
LAWNS					50									
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P					50									
TOTAL AREA I						50								

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	22	0	22	0	22	0	22	0	22	0	22	0	22
ROOFTOPS	0	26	0	26	0	26	0	26	0	26	0	26	0	26
GRAVEL														
LAWNS	12	38	8	42	25	25	26	24	27	23	0	50	4	46
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	12		8		25		26		27		0		4	
TOTAL AREA I		88		92		75		74		73		100		96

Watershed analysis data for Northglenn 7201, 1970

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (<5 Years Old)		Completely Developed Suburban (>5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL			25											
LAWNS														
FIELDS/PASTURE				15										
AGRICULTURE														
TREES														
EXPOSED SOIL			60											
WATER														
TOTAL AREA P			85											
TOTAL AREA I				15										

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	3	22	4	21	5	20	6	19	6	19	0	100	3	22
LAWNS														
FIELDS/PASTURE	3	12	2	13	4	11	9	6	5	10	0	15	2	13
AGRICULTURE														
TREES														
EXPOSED SOIL	12	48	9	51	18	42	21	39	24	36	0	60	6	54
WATER														
TOTAL AREA P	18		15		27		36		35		0		11	
TOTAL AREA I		72		86		73		64		65		100		89

Watershed analysis data for Stapleton Airport, 1935

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				23										
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE			75											
AGRICULTURE														
TREES														
EXPOSED SOIL			2											
WATER														
TOTAL AREA P			77											
TOTAL AREA I				23										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	23	0	23	0	23	0	23	0	23	0	23	0	23
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	15	60	11	64	19	56	45	30	22	53	0	75	8	67
AGRICULTURE														
TREES														
EXPOSED SOIL	0	2	0	2	1	1	1	1	1	1	0	2	0	2
WATER														
TOTAL AREA P	15		11		20		46		23		0		8	
TOTAL AREA I		85		89		80		54		77		100		92

Watershed analysis data for Stapleton Airport, 1949

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				23										
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE			76											
AGRICULTURE														
TREES														
EXPOSED SOIL			1											
WATER														
TOTAL AREA P			77											
TOTAL AREA I				23										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	23	0	23	0	23	0	23	0	23	0	23	0	23
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	15	61	11	65	19	57	46	30	23	53	0	76	8	68
AGRICULTURE														
TREES														
EXPOSED SOIL	0	1	0	1	0	1	1	0	0	1	0	1	0	1
WATER														
TOTAL AREA P	15		11		19		47		23		0		8	
TOTAL AREA I		85		89		81		53		77		100		92

Watershed analysis data for Stapleton Airport, 1954

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				22										
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE			78											
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P			78											
TOTAL AREA I				22										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	22	0	22	0	22	0	22	0	22	0	22	0	22
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	16	62	12	66	20	58	47	31	23	55	0	78	8	70
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	16		12		20		47		23		0		8	
TOTAL AREA I		84		88		80		53		77		100		92

Watershed analysis data for Stapleton Airport, 1956

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				24										
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE			55											
AGRICULTURE														
TREES														
EXPOSED SOIL			20											
WATER														
TOTAL AREA P			75											
TOTAL AREA I				25										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	24	0	24	0	24	0	24	0	24	0	24	0	24
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	11	44	8	47	14	41	33	22	17	38	0	55	6	49
AGRICULTURE														
TREES														
EXPOSED SOIL	4	16	3	17	6	14	13	7	8	12	0	20	2	18
WATER														
TOTAL AREA P	15		11		20		46		25		0		8	
TOTAL AREA I		85		89		80		54		75		100		92

Watershed analysis data for Stapleton Airport, 1959

P = PERVIOUS, I = IMPERVIOUS	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC) I
CONCRETE				15										
ASPHALT				32										
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE			35											
AGRICULTURE														
TREES														
EXPOSED SOIL			18											
WATER														
TOTAL AREA P			53											
TOTAL AREA I				47										

P = PERVIOUS, I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE	0	15	0	15	0	15	0	15	0	15	0	15	0	15
ASPHALT	0	32	0	32	0	32	0	32	0	32	0	32	0	32
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	7	28	5	30	9	26	21	14	10	25	0	35	3	32
AGRICULTURE														
TREES														
EXPOSED SOIL	4	14	3	15	5	13	12	6	7	11	0	18	2	16
WATER														
TOTAL AREA P	11		8		14		33		17		0		5	
TOTAL AREA I		89		92		86		67		83		100		95

Watershed analysis data for Stapleton Airport, 1963

P = PERVIOUS, I = IMPERVIOUS	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC) I
CONCRETE										60				
ASPHALT										30				
ROOFTOPS										10				
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P									0					
TOTAL AREA I										100				

P = PERVIOUS, I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE	0	60	0	60	0	60	0	60	0	60	0	60	0	60
ASPHALT	0	30	0	30	0	30	0	30	0	30	0	30	0	30
ROOFTOPS	0	10	0	10	0	10	0	10	0	10	0	10	0	10
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	0		0		0		0		0		0		0	
TOTAL AREA I		100		100		100		100		100		100		100

Watershed analysis data for Stapleton Airport, 1970

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS														
GRAVEL		1												
LAWNS														
FIELDS/PASTURE	10													
AGRICULTURE	88													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE	2	8	2	8	3	7	6	4	3	7	0	10	1	9
AGRICULTURE	22	66	15	73	31	57	26	62	35	53	0	88	9	79
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		17		34		32		38		0		10	
TOTAL AREA I		76		83		66		68		62		100		90

Watershed analysis data for Stapleton - S, 1950

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				20										
ROOFTOPS				14										
GRAVEL				3										
LAWNS			15											
FIELDS/PASTURE			44											
AGRICULTURE														
TREES														
EXPOSED SOIL			3											
WATER														
TOTAL AREA P			62											
TOTAL AREA I				38										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	20	0	20	0	20	0	20	0	20	0	20	0	20
ROOFTOPS	0	14	0	14	0	14	0	14	0	14	0	14	0	14
GRAVEL	0	3	0	3	1	2	1	2	1	2	0	3	0	3
LAWNS	4	11	3	12	5	10	4	11	5	10	0	15	2	13
FIELDS/PASTURE	9	35	7	37	11	33	26	18	13	31	0	44	4	40
AGRICULTURE														
TREES														
EXPOSED SOIL	1	2	0	3	1	2	2	1	1	2	0	3	0	3
WATER														
TOTAL AREA P	14		10		18		33		20		0		6	
TOTAL AREA I		86		90		82		67		80		100		94

Watershed analysis data for Stapleton - S, 1954

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) I
CONCRETE				1										
ASPHALT				19										
ROOFTOPS				15										
GRAVEL				1										
LAWNS			42											
FIELDS/PASTURE			22											
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P			64											
TOTAL AREA I				36										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	19	0	19	0	19	0	19	0	19	0	19	0	19
ROOFTOPS	0	15	0	15	0	15	0	15	0	15	0	15	0	15
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS	10	32	7	35	12	30	10	32	15	27	0	42	4	38
FIELDS/PASTURE	4	18	3	19	6	16	13	9	7	15	0	22	2	20
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	14		10		18		13		22		0		6	
TOTAL AREA I		86		90		82		77		78		100		94

Watershed analysis data for Stapleton - S, 1959

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL P	UNDEVELOPED RURAL I	SEMIDEVELOPED SUBURBAN P	SEMIDEVELOPED SUBURBAN I	COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD) I	COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD) P	COMPLETELY DEVELOPED SUBURBAN (≥5 YEARS OLD) I	BUSINESS P	BUSINESS I	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) P	LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING) I	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) P	HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.) I
CONCRETE								1						
ASPHALT								19						
ROOFTOPS								15						
GRAVEL														
LAWNS							43							
FIELDS/PASTURE							20							
AGRICULTURE														
TREES							1							
EXPOSED SOIL							1							
WATER														
TOTAL AREA P							65							
TOTAL AREA I								35						

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN P	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN I	SPRING GROUND ALMOST SATURATED WITH WATER P	SPRING GROUND ALMOST SATURATED WITH WATER I	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL P	SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL I	SUMMER ONE WEEK AFTER RAINFALL P	SUMMER ONE WEEK AFTER RAINFALL I	AUTUMN 2-3 WEEKS WITHOUT RAIN P	AUTUMN 2-3 WEEKS WITHOUT RAIN I	WINTER GROUND BARE AND COMPLETELY FROZEN P	WINTER GROUND BARE AND COMPLETELY FROZEN I	WINTER GROUND COVERED WITH SNOW P	WINTER GROUND COVERED WITH SNOW I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	19	0	19	0	19	0	19	0	19	0	19	0	19
ROOFTOPS	0	15	0	15	0	15	0	15	0	15	0	15	0	15
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	11	32	9	34	13	30	11	32	15	28	0	43	4	39
FIELDS/PASTURE	4	16	3	17	5	15	12	8	6	14	0	20	2	18
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	15		12		18		23		21		0		6	
TOTAL AREA I		85		88		82		77		79		100		94

Watershed analysis data for Stapleton - S, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (< 5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (> 5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE								1						
ASPHALT								22						
ROOFTOPS								16						
GRAVEL														
LAWNS							46							
FIELDS/PASTURE							12							
AGRICULTURE														
TREES							2							
EXPOSED SOIL							1							
WATER														
TOTAL AREA P							61							
TOTAL AREA I								39						

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	22	0	22	0	22	0	22	0	22	0	22	0	22
ROOFTOPS	0	16	0	16	0	16	0	16	0	16	0	16	0	16
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	11	35	8	38	14	32	11	35	16	30	0	46	5	41
FIELDS/PASTURE	2	10	2	10	3	9	7	5	4	8	0	12	1	11
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	1	1	0	2	1	1	1	1	1	1	0	2	0	2
EXPOSED SOIL	0	1	0	1	0	1	1	0	1	0	0	1	0	1
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	14		10		18		20		22		0		6	
TOTAL AREA I		86		90		82		80		78		100		94

Watershed analysis data for Stapleton - S, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (< 5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (> 5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	2													
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	97													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	2	0	2	0	2	1	1	1	1	0	2	0	2
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	73	16	81	34	63	29	68	39	58	0	97	9	88
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		16		34		30		40		0		9	
TOTAL AREA I		76		84		66		70		60		100		91

Watershed analysis data for Aurora, 1954

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS		1												
GRAVEL	2													
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	96													
TREES	1													
EXPOSED SOIL														
WATER														
TOTAL AREA P	99													
TOTAL AREA I		1												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	2	0	2	0	2	1	1	1	1	0	2		2
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	72	16	80	34	62	29	67	38	58	0	96	9	87
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		16		34		30		39		0		9	
TOTAL AREA I		76		84		66		70		61		100		91

Watershed analysis data for Aurora, 1959

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				2										
ROOFTOPS				4										
GRAVEL														
LAWNS			1											
FIELDS/PASTURE			60											
AGRICULTURE														
TREES														
EXPOSED SOIL			33											
WATER														
TOTAL AREA P			94											
TOTAL AREA I				6										

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASPHALT	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ROOFTOPS	0	4	0	4	0	4	0	4	0	4	0	4	0	4
GRAVEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAWNS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
FIELDS/PASTURE	12	48	9	51	15	45	36	24	18	42	0	60	6	54
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPOSED SOIL	7	26	5	28	10	23	21	12	13	20	0	33	3	30
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	19		14		25		57		31		0		9	
TOTAL AREA I		81		86		75		43		69		100		91

Watershed analysis data for Aurora, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				2										
ASPHALT				15										
ROOFTOPS				18										
GRAVEL				2										
LAWNS			24											
FIELDS/PASTURE			36											
AGRICULTURE														
TREES			1											
EXPOSED SOIL			2											
WATER														
TOTAL AREA P			63											
TOTAL AREA I				37										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	15	0	15	0	15	0	15	0	15	0	15	0	15
ROOFTOPS	0	18	0	18	0	18	0	18	0	18	0	18	0	18
GRAVEL	0	2	0	2	0	2	0	2	0	2	0	2	0	2
LAWNS	6	18	4	20	7	17	6	18	8	16	0	24	2	22
FIELDS/PASTURE	7	29	5	31	9	27	22	14	11	25	0	36	4	32
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	0	2	0	2	1	1	1	1	1	1	0	2	0	2
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	13		9		17		29		20		0		6	
TOTAL AREA I		87		91		83		71		80		100		94

Watershed analysis data for Aurora, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS														
FIELDS/PASTURE	12													
AGRICULTURE	87													
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS														
FIELDS/PASTURE	2	10	2	10	3	9	7	5	4	8	0	12	1	11
AGRICULTURE	22	65	15	72	30	57	26	61	35	52	0	87	9	78
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	24		17		33		33		39		0		10	
TOTAL AREA I		76		83		67		67		61		100		90

Watershed analysis data for Littleton, 1954

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT				1										
ROOFTOPS				1										
GRAVEL			3											
LAWNS														
FIELDS/PASTURE			22											
AGRICULTURE			67											
TREES														
EXPOSED SOIL			6											
WATER														
TOTAL AREA P			98											
TOTAL AREA I				2										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	3	0	3	1	2	1	2	1	2	0	3	0	3
LAWNS														
FIELDS/PASTURE	4	18	3	19	6	16	13	9	7	15	0	22	2	20
AGRICULTURE	17	50	11	56	23	44	20	47	27	40	0	67	7	60
TREES														
EXPOSED SOIL	2	4	1	5	2	4	2	4	4	2	0	6	1	5
WATER														
TOTAL AREA P	23		15		32		36		39		0		10	
TOTAL AREA I		77		85		68		64		61		100		90

Watershed analysis data for Littleton, 1959

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				8										
ROOFTOPS				9										
GRAVEL														
LAWNS			18											
FIELDS/PASTURE			22											
AGRICULTURE			26											
TREES														
EXPOSED SOIL			16											
WATER														
TOTAL AREA P			82											
TOTAL AREA I				18										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	8	0	8	0	8	0	8	0	8	0	8	0	8
ROOFTOPS	0	9	0	9	0	9	0	9	0	9	0	9	0	9
GRAVEL														
LAWNS	5	13	3	15	5	13	5	13	6	12	0	18	2	16
FIELDS/PASTURE	4	18	3	19	5	17	13	9	7	15	0	22	2	20
AGRICULTURE	6	20	4	22	9	17	8	18	10	16	0	26	3	23
TREES														
EXPOSED SOIL	3	13	2	14	5	11	10	6	6	10	0	16	2	14
WATER														
TOTAL AREA P	18		12		24		36		29		0		9	
TOTAL AREA I		82		88		76		64		71		100		91

Watershed analysis data for Littleton, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				12										
ROOFTOPS				15										
GRAVEL														
LAWNS			33											
FIELDS/PASTURE			12											
AGRICULTURE			25											
TREES			1											
EXPOSED SOIL			1											
WATER														
TOTAL AREA P			72											
TOTAL AREA I				28										

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	12	0	12	0	12	0	12	0	12	0	12	0	12
ROOFTOPS	0	15	0	15	0	15	0	15	0	15	0	15	0	15
GRAVEL														
LAWNS	8	25	4	29	11	22	12	21	14	19	0	33	3	30
FIELDS/PASTURE	3	9	2	10	3	9	8	4	4	8	0	12	1	11
AGRICULTURE	6	19	5	20	6	19	16	9	14	11	0	25	2	23
TREES	0	1	0	1	0	1	1	0	1	0	0	1	0	1
EXPOSED SOIL	0	1	0	1	1	0	1	0	1	0	0	1	0	1
WATER														
TOTAL AREA P	17		11		21		38		34		0		6	
TOTAL AREA I		83		89		79		62		66		100		94

Watershed analysis data for Littleton, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	97													
TREES	1													
EXPOSED SOIL	1													
WATER	1													
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	73	17	80	34	63	29	68	39	58	0	97	10	87
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
WATER	1	0	1	0	1	0	1	0	1	0	0	1	0	1
TOTAL AREA P	25		18		35		30		40		0		10	
TOTAL AREA I		75		82		65		70		60		100		90

Watershed analysis data for Fort Logan, 1949

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (≤5 Years Old)		Completely Developed Suburban (≥5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	97													
TREES	1													
EXPOSED SOIL	1													
WATER	1													
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE														
AGRICULTURE	24	73	17	80	34	63	29	68	39	58	0	97	10	87
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
WATER	1	0	1	0	1	0	1	0	1	0	0	1	0	1
TOTAL AREA P	25		18		35		30		40		0		10	
TOTAL AREA I		75		82		65		70		60		100		90

Watershed analysis data for Fort Logan, 1954

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (≤5 Years Old)		Completely Developed Suburban (≥5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	18													
AGRICULTURE	79													
TREES	1													
EXPOSED SOIL	2													
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL														
LAWNS														
FIELDS/PASTURE	4	14	3	15	5	13	11	7	5	13	0	18	2	16
AGRICULTURE	20	59	13	66	28	51	24	55	32	47	0	79	8	71
TREES	0	1	0	1	0	1	0	1	0	1	0	1	0	1
EXPOSED SOIL	0	2	0	2	1	1	1	1	1	1	0	2	0	2
WATER														
TOTAL AREA P	24		16		34		36		38		0		10	
TOTAL AREA I		76		84		66		64		62		100		90

Watershed analysis data for Fort Logan, 1959

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (<5 Years Old)		Completely Developed Suburban (>5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE				1										
ASPHALT				6										
ROOFTOPS				9										
GRAVEL			2											
LAWNS			7											
FIELDS/PASTURE			67											
AGRICULTURE														
TREES														
EXPOSED SOIL			8											
WATER														
TOTAL AREA P			84											
TOTAL AREA I				16										

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ASPHALT	0	6	0	6	0	6	0	6	0	6	0	6	0	6
ROOFTOPS	0	9	0	9	0	9	0	9	0	9	0	9	0	9
GRAVEL	0	2	0	2	0	2	0	2	0	2	0	2	0	2
LAWNS	2	5	1	6	2	5	2	5	2	5	0	7	1	6
FIELDS/PASTURE	13	54	10	57	17	50	40	27	20	47	0	67	7	60
AGRICULTURE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TREES	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPOSED SOIL	2	6	1	7	2	6	5	3	3	5	0	8	1	7
WATER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL AREA P	17		12		21		47		25		0		9	
TOTAL AREA I		83		88		79		53		75		100		91

Watershed analysis data for Fort Logan, 1963

P = PERVIOUS
I = IMPERVIOUS

	Undeveloped Rural		Semideveloped Suburban		Completely Developed Suburban (<5 Years Old)		Completely Developed Suburban (>5 Years Old)		Business		Light Industry (Offices, Light Manufacturing)		Heavy Industry (Steel Mills, Refineries, Heavy Manufac.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE						2								
ASPHALT						26								
ROOFTOPS						21								
GRAVEL														
LAWNS					50									
FIELDS/PASTURE					1									
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P					51									
TOTAL AREA I						49								

P = PERVIOUS
I = IMPERVIOUS

	Winter or Spring Ground Bare and Partly Frozen		Spring Ground Almost Saturated with Water		Summer One Hr. After a 0.5 Inch Rainfall		Summer One Week After Rainfall		Autumn 2-3 Weeks Without Rain		Winter Ground Bare and Completely Frozen		Winter Ground Covered with Snow	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ASPHALT	0	26	0	26	0	26	0	26	0	26	0	26	0	26
ROOFTOPS	0	21	0	21	0	21	0	21	0	21	0	21	0	21
GRAVEL														
LAWNS	12	38	8	42	15	35	12	38	17	33	0	50	5	45
FIELDS/PASTURE	0	1	0	1	0	1	1	0	0	1	0	1	0	1
AGRICULTURE														
TREES														
EXPOSED SOIL														
WATER														
TOTAL AREA P	12		8		15		13		17		0		5	
TOTAL AREA I		88		92		85		87		83		100		95

Watershed analysis data for Fort Logan, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	1													
LAWNS	2													
FIELDS/PASTURE	5													
AGRICULTURE	89													
TREES	3													
EXPOSED SOIL														
WATER														
TOTAL AREA P	100													
TOTAL AREA I		0												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT														
ROOFTOPS														
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS	1	1	0	2	1	1	1	1	1	1	0	2	0	2
FIELDS/PASTURE	1	4	1	4	1	4	3	2	1	4	0	5	1	4
AGRICULTURE	22	67	15	74	31	58	27	62	36	53	0	89	9	80
TREES	1	2	1	2	1	2	1	2	1	2	0	3	0	3
EXPOSED SOIL														
WATER														
TOTAL AREA P	25		17		34		32		39		0		10	
TOTAL AREA I		75		83		66		68		61		100		90

Watershed analysis data for Hyatt Lake - N, 1959

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS		1												
GRAVEL	1													
LAWNS	2													
FIELDS/PASTURE	84													
AGRICULTURE	9													
TREES	1													
EXPOSED SOIL														
WATER	1													
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS	0	2	0	2	1	1	0	2	1	1	0	2	0	2
FIELDS/PASTURE	16	68	13	71	21	63	50	34	25	59	0	84	8	76
AGRICULTURE	2	7	2	7	3	6	3	6	4	5	0	9	1	8
TREES	0	1	0	1	0	1	1	0	1	0	0	1	0	1
EXPOSED SOIL														
WATER	1	0	1	0	1	0	1	0	1	0	0	1	0	1
TOTAL AREA P	19		16		26		55		32		0		9	
TOTAL AREA I		81		84		74		45		68		100		91

Watershed analysis data for Hyatt Lake - N, 1963

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS		1												
GRAVEL														
LAWNS	2													
FIELDS/PASTURE	15													
AGRICULTURE	79													
TREES	1													
EXPOSED SOIL	1													
WATER														
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL														
LAWNS	0	2	0	2	1	1	1	1	1	1	0	2	0	2
FIELDS/PASTURE	5	10	2	13	4	11	10	5	5	10	0	15	1	14
AGRICULTURE	27	52	11	68	18	61	52	27	75	4	0	79	5	74
TREES	0	1	0	1	0	1	1	0	1	0	0	1	0	1
EXPOSED SOIL	0	1	0	1	0	1	1	0	0	1	0	1	0	1
WATER														
TOTAL AREA P	32		13		23		65		82		0		6	
TOTAL AREA I		68		87		77		35		18		100		94

Watershed analysis data for Hyatt Lake - N, 1970

P = PERVIOUS I = IMPERVIOUS	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (<5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS		1												
GRAVEL														
LAWNS														
FIELDS/PASTURE	79													
AGRICULTURE	15													
TREES	4													
EXPOSED SOIL														
WATER														
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS I = IMPERVIOUS	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL														
LAWNS														
FIELDS/PASTURE	16	63	12	67	20	59	47	32	24	55	0	79	8	71
AGRICULTURE	4	11	3	12	5	10	5	10	6	9	0	15	2	13
TREES	1	3	1	3	1	3	1	3	2	2	0	4	0	4
EXPOSED SOIL														
WATER														
TOTAL AREA P	21		16		26		53		32		0		10	
TOTAL AREA I		79		84		74		47		68		100		90

Watershed analysis data for Hyatt Lake - S, 1959

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		1												
ROOFTOPS		1												
GRAVEL	1													
LAWNS	1													
FIELDS/PASTURE	91													
AGRICULTURE														
TREES	5													
EXPOSED SOIL														
WATER														
TOTAL AREA P	98													
TOTAL AREA I		2												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	1	0	1	0	1	0	1	0	1	0	1	0	1
ROOFTOPS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
GRAVEL	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LAWNS	0	1	0	1	0	1	0	1	0	1	0	1	0	1
FIELDS/PASTURE	18	73	14	77	23	68	55	36	27	64	0	91	9	82
AGRICULTURE														
TREES	1	4	1	4	2	3	1	4	2	3	0	5	1	4
EXPOSED SOIL														
WATER														
TOTAL AREA P	19		15		25		56		29		0		10	
TOTAL AREA I		81		85		75		44		71		100		90

Watershed analysis data for Hyatt Lake - S, 1963

P = PERVIOUS
I = IMPERVIOUS

	UNDEVELOPED RURAL		SEMIDEVELOPED SUBURBAN		COMPLETELY DEVELOPED SUBURBAN (≤5 YEARS OLD)		COMPLETELY DEVELOPED SUBURBAN (>5 YEARS OLD)		BUSINESS		LIGHT INDUSTRY (OFFICES, LIGHT MANUFACTURING)		HEAVY INDUSTRY (STEEL MILLS, REFINERIES, HEAVY MANUFAC.)	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT		2												
ROOFTOPS		2												
GRAVEL														
LAWNS	3													
FIELDS/PASTURE	70													
AGRICULTURE	21													
TREES	1													
EXPOSED SOIL	1													
WATER														
TOTAL AREA P	96													
TOTAL AREA I		4												

P = PERVIOUS
I = IMPERVIOUS

	WINTER OR SPRING GROUND BARE AND PARTLY FROZEN		SPRING GROUND ALMOST SATURATED WITH WATER		SUMMER ONE HR. AFTER A 0.5 INCH RAINFALL		SUMMER ONE WEEK AFTER RAINFALL		AUTUMN 2-3 WEEKS WITHOUT RAIN		WINTER GROUND BARE AND COMPLETELY FROZEN		WINTER GROUND COVERED WITH SNOW	
	P	I	P	I	P	I	P	I	P	I	P	I	P	I
CONCRETE														
ASPHALT	0	2	0	2	0	2	0	2	0	2	0	2	0	2
ROOFTOPS	0	2	0	2	0	2	0	2	0	2	0	2	0	2
GRAVEL														
LAWNS	1	2	0	3	1	2	2	1	2	1	0	3	0	3
FIELDS/PASTURE	22	48	10	60	23	47	60	10	25	45	0	70	5	65
AGRICULTURE	7	14	3	18	8	13	14	7	17	4	0	21	2	19
TREES	0	1	0	1	0	1	1	0	1	0	0	1	0	1
EXPOSED SOIL	0	1	0	1	1	0	1	0	1	0	0	1	0	1
WATER														
TOTAL AREA P	30		13		33		78		46		0		7	
TOTAL AREA I		70		87		66		22		54		100		93

Watershed analysis data for Hyatt Lake - S, 1970

APPENDIX E: LISTINGS OF FORTRAN PROGRAMS USED IN SPECTRAL BAND OPTIMIZATION

Three computer programs, all written in FORTRAN, were used in this study as a means for handling the data as it comes from the computer-controlled field spectrometer, for averaging data curves together, and for performing the Euclidean distance calculations for the spectral band optimization process. This appendix contains the listings for these programs, JOIN, AVER, OPTIM, and Appendix F contains their detailed flow diagrams. Several additional programs following OPTIM in this sequence are in the process of being perfected and will occur in a supplemental report.

JOIN This program reads the spectroreflectance paper tapes output from the field spectrometer and joins all segments (ultraviolet, visible, and infrared) into one continuous curve, joining the segments together at operator specified wavelengths. The program plots out the joined curve on an on-line, x-y plotter as an operator option and punches an output tape of the continuous curve for input into AVER.

AVER This program reads up to six joined curves output by JOIN and calculates the average spectroreflectance and variance curves. The resulting average curve can be plotted on the x-y plotter as an operator option along with ± one standard deviation, also optional. This averaged spectroreflectance curve is punched as an output paper tape with the wavelength, mean, and variance values at each sample point for input into OPTIM.

OPTIM This program reads up to 10 statistical spectroreflectance curves output from AVER and accepts up to 12 spectral bands of any spectral bandwidth and location within the range of .3μm to 1.3μm. It calls for a number representing the optimum subset of the total number of bands entered and calculates the minimum, maximum, and average Euclidean distances for each band combination equal to the number of bands specified as the optimum subset. OPTIM follows the procedure given in the text for producing the Euclidean distances from which the best bands are chosen by human inspection. OPTIM prints out the reflectance averages over each of the total number of bands specified, and likewise the variance averages in the form of two matrices, and prints out a third matrix of squared reflectivity differences which result from an interim step in the Euclidean distance calculations. As final output each band combination is listed, followed by the minimum, maximum, and average Euclidean distances, as calculated for each respective combination. Following the program listing of OPTIM is a sample output list containing the three matrices as described above for 10 materials with 12 total bands and the beginning of a long list of four-band combinations out of 12 bands (495 in all) followed by the Euclidean distance calculations. OPTIM is being modified to punch out these data for entry into two additional programs which will assist the user in selecting the one best optimal spectral band combination. These modifications and new programs will be documented in a subsequent report.

```
      PROGRAM JOIN
      COMMON NAME(34),IWAVE(750),REF(750),L(6)
    5 WRITE(6,500)
  500 FORMAT("CURVE NAME")
      READ(1,501) NAME
  501 FORMAT(34A2)
      WRITE(6,502)
  502 FORMAT("NUMBER OF CURVE SECTIONS")
      READ(1,*) NSEC
      WRITE(6,503)
  503 FORMAT("BEGINNING AND ENDING WAVELENGTHS FOR EACH SEGMENT")
      DO 10 I=1,NSEC
      IC=I+1
   10 READ(1,*) L(I),L(IC)
      WRITE(6,504)
  504 FORMAT("LOAD CURVES, TURN ON PUNCH, --- PRESS RUN")
      PAUSE
      WRITE(4,505) NAME
  505 FORMAT(1H",34A2,2H ","1")
      NP=0
      DO 50 J=1,NSEC
      WRITE(4,506) L(J)
  506 FORMAT(I5)
      NJ=J+1
      READ(5,*) NCUR
      WRITE(4,506) NCUR
      READ(5,512)ID,IH,IM
  512 FORMAT(/,I3,1X,I2,1X,I2)
      WRITE(4,507) ID,IH,IM
  507 FORMAT(I3","I2","I2)
      READ(5,506)LIM
      DO 50 K=1,LIM
      READ(5,*) IW,DUM1,DUM2,R
      IF(ISSW(5))11,12
   11 WRITE(6,600) IW,R,LIM
  600 FORMAT(5X,I5,5X,F6.4,5X,I3)
   12 IF(IW-L(J))50,16,15
   15 IF(IW-L(NJ))20,20,40
   16 IF(J-1)50,20,50
   20 NP=NP+1
      IWAVE(NP)=IW
      REF(NP)=R
   40 IF(K-LIM)50,60
   60 IF(J-NSEC)70,50
   70 IK=J+1
      WRITE(6,510) IK
  510 FORMAT("LOAD CURVE SEGMENT"I2)
      PAUSE
   50 CONTINUE
      WRITE(4,508) NP
  508 FORMAT(I3)
      DO 100 I=1,NP
  100 WRITE(4,509) IWAVE(I),REF(I)
  509 FORMAT(I5,","F6.4)
      WRITE(6,511)
  511 FORMAT("FOR PLOT TURN ON SW 1 -- SET UP PLOTTER")
      PAUSE
      IF (ISSW(1))80,90
   80 DO 200 I=1,NP
      WAVE=IWAVE(I)
      WMAX=16000
      WMIN=1800
      WPLT=WMAX*(WAVE-WMIN)/(WMAX-WMIN)
      RMAX=1.
      CALL PLOT(WPLT,WMAX,REF(I),RMAX)
  200 CONTINUE
      WRITE(6,513)
  513 FORMAT("FOR ADDITIONAL PLOT, SET UP PLOTTER, SW 10 ON")
      PAUSE
      IF(ISSW(10))80,90
   90 PAUSE
      GO TO 5
      END
      END$
```

```
      PROGRAM AVER
      COMMON REF(4,300),NAME(20)
      WRITE(6,701)
  701 FORMAT("SW 1 ON FOR MEAN PLOT; SW 2 ON FOR STD DEV PLOT")
      WRITE(6,500)
  500 FORMAT("TOTAL NUMBER OF MATERIALS")
      READ(1,*) IC
      WRITE(6,501)
  501 FORMAT("NUMBER OF CURVES PER MATERIAL")
      READ(1,*) N
      WRITE(6,510)
  510 FORMAT("NUMBER OF RAW CURVE SEGMENTS")
      READ(1,*) NSEG
      WRITE(6,502)
  502 FORMAT("BEGINNING AND ENDING WAVELENGTHS; SAMPLE INTERVAL,
     1---",/"---ALL IN ANGSTROMS")
      READ(1,*) MINW,MAXW,INT
      LMAX=1+(MAXW-MINW)/INT
      CN=N
      M=N-1
      CM=M
      DO 90 II=1,IC
      WRITE(6,800) II
  800 FORMAT("NAME OF MATERIAL"I3)
      READ(1,801) NAME
  801 FORMAT(20A2)
      DO 100 I=1,N
      L=0
      WRITE(1,503) I,NAME
  503 FORMAT(1X,"LOAD TAPE FOR CURVE"I2" OF "20A2/,
     1"---TURN ON PUNCH---PRESS RUN")
      PAUSE
C---READ HEADER INFORMATION------
      Read(5,*)NO
      DO 700 JJ=1, NSEG
      READ(5,*) N1
      READ(5,*) N2
  700 READ(5,*) N3,N4,N5
      READ(5,*) N6
C---READ TAPE UP TO MIN WAVELENGTH WANTED---
   10 READ(5,*) IW,R
      IF(IW-MINW)10,15
   15 W=IW
      GO TO 25
   20 READ(5,*) W,R
   25 W=W/10000.
      R=R*100.
      AVE=0.
      VAR=0.
      IF(ISSW(5))50,60
   50 WRITE(6,600) W,R
  600 FORMAT(5X,"W="F6.4,"R="F6.2)
   60 L=L+1
      IF(I-N)30,40,30
   30 REF(I,L)=R
      IF(L-LMAX)20,100,20
   40 IF(1-L)42,41,42
   41 WRITE(4,505) NAME
  504 FORMAT(2H"20A2,3H"1)
   42 DO 110 J=1,M
  110 AVE=AVE+REF(J,L)
      AVE=(AVE+R)/CN
      DO 120 K=1,M
  120 VAR=VAR+(REF(K,L)-AVE)**2
      VAR=(VAR+(R-AVE)**2/CM
      IF(ISSW(5))70,80
   70 WRITE(6,601) W,AVE,VAR
  601 FORMAT(5X,"W="F6.4,"F6.3,"VAR="F6.3)
   80 WRITE(4,505) W,AVE,VAR
  505 FORMAT(F5.3","F7.3","F8.3)
      IF(ISSW(1))130,140
  130 WMAX=1.6
      WMIN=0.18
      WPLT=WMAX*(W-WMIN)/(WMAX-WMIN)
      RMAX=100.
      CALL PLOT(WPLT,WMAX,AVE,RMAX)
  140 IF(ISSW(2))150,160
  150 SIGMA=SQRT(VAR)
      SIGI=AVE+SIGMA
      SIG2=AVE-SIGMA
      IF(100.-SIGI)170,171
  170 SIGI=100.
  171 IF(0.+SIG2)172,173
  172 SIG2=0.
  173 WMAX=1.6
      WMIN=0.18
      WPLT=WMAX*(W-WMIN)/(WMAX-WMIN)
      RMAX=100.
      CALL PLOT (WPLT,WMAX,SIGI,RMAX)
      CALL PLOT(WPLT,WMAXSIG2,RMAX)
  160 IF(L-LMAX)20,100,20
  100 CONTINUE
   90 CONTINUE
      END
      END$
```

```
      PROGRAM OPTIM
      DIMENSION AV(10,12),AVAR(10,12),G(12,2),K(10)
      COMMON U(45,12)
      WRITE(6,900)
  900 FORMAT("NUMBER OF DATA CURVES")
      READ(1,*) IC
      WRITE(6,901)
  901 FORMAT("TOTAL NUMBER OF WAVELENGTH BANDS")
      READ(1,*) IB
      WRITE(6,902)
  902 FORMAT("WAVELENGTH SAMPLING INTERVAL (MICRONS)")
      READ(1,*) SINT
      WRITE(6,903)
  903 FORMAT("NUMBER OF OPTIMUM SAMPLING BANDS DESIRED")
      READ(1,*) IOPT
      WRITE(1,904)
  904 FORMAT("MIN AND MAX WAVELENGTH IN EACH BAND")
      DO 150 I=1,IB
  150 READ(1,*) (G(I,J),J=1,2)
      WRITE(1,701) ((G(I,J),J=1,2),I=1,IB)
  701 FORMAT(2F6.4)
      DO 10 IX=1,IC
      WRITE(1,899)IX
  899 FORMAT("INSERT DATA CURVE "I2" IN PHOTOREADER, PRESS RUN")
      PAUSE
      READ(5,*) NDUM
      DO 10 IY=1,IB
      T=0.
      VT=0.
      S=0.
   20 READ(5,*) W,R,VAR
      IF(ISSW(1))5,6
    5 WRITE(1,702) W,R,VAR
  702 FORMAT("W="F8.3,6X,"R="F8.3,5X,"V="F8.3)
    6 IF(W-(G(IY,1)-SINT/2.))20,20,25
   25 IF(W-(G(IY,2)-SINT/2.))27,27,30
   27 T=T+R
      VT=VT+VAR
      S=S+1
      IF(ISSW(1))7,8
    7 WRITE(1,703) T,S
  703 FORMAT("T="F8.3,5X,"S="F8.3)
    8 GO TO 20
   30 AV(IX,IY)=T/S
      AVAR(IX,IY)=VT/S
      IF(ISSW(2))31,10
   31 WRITE(1,704) IX,IY,G(IY,1),G(IY,2)
  704 FORMAT("IX="I2,"IY="I2,5X,F8.3,5X,F8.3)
   10 CONTINUE
      WRITE(6,905)
  905 FORMAT("BAND AVERAGES----ROWS=SAMPLE CURVES, COLUMNS=BANDS")
      DO 251 I=1,IC
  251 WRITE(6,906) (AV(I,J),J=1,IB)
  906 FORMAT(12(F5.2,1X))
      WRITE(6,915)
  915 FORMAT(/"VAR AVE "/)
      DO 253 I=1,IC
  253 WRITE(6,906) (AVAR(I,J),J=1,IB)
C
C       CALCULATION OF SQUARED AVERAGE REFLECTIVITY DIFFERENCES
C       OF ALL POSSIBLE 2-CURVE COMBINATIONS
C
      DO 40 I=1,IB
      IE=0
      IIC=IC-1
      DO 40 J=1,IIC
      ID=J+1
      DO 40 IK=ID,IC
      IE=IE+1
      U(IE,I)=(AV(J,I)-AV(IK,I))**2/((AVAR(J,I)+AVAR(IK,I))*.5)
   40 CONTINUE
      WRITE(6,907)
  907 FORMAT("MATRIX OF SQUARED CURVE COMBINATIONS",
     1" COLUMNS=BANDS, "/"ROWS=SAMPLE CURVE COMBINATIONS")
      DO 252 I=1,IE
  252 WRITE(6,906) (U(I,J),J=1,IB)

C
C       CALCULATION OF MIN, MAX, AND AVERAGE EUCLIDEAN DISTANCES
C
      IP1=IOPT-9
      IQ1=IOPT-8
      IR1=IOPT-7
      IS1=IOPT-6
      IT1=IOPT-5
      IU1=IOPT-4
      IV1=IOPT-3
      IW1=IOPT-2
      IX1=IOPT-1
      IY1=IOPT
      IP2=IB-9
      IQ2=IB-8
      IR2=IB-7
      IS2=IB-6
      IT2=IB-5
      IU2=IB-4
      IV2=IB-3
      IW2=IB-2
      IX2=IB-1
      IY2=IB
      If(IOPT-9)50,50,51
   50 IP1=-10
      IP2=-10
   51 IP=IP1
   52 IF(IP-IP2)53,53,540
   53 K(1)=IP
      IF(IOPT-8)54,54,55
   54 IQ1=-9
      IQ2=-9
```

```
   55 IQ=IQ1
   56 IF(IQ-IQ2)57,57,520
   57 IF(IQ-IP)500,500,58
   58 K(2)=IQ
      IF(IOPT-7)60,60,62
   60 IR1=-8
      IR2=-8
   62 DO 500 IR=IR1,IR2
      IF(IR-IQ)500,500,64
   64 K(3)=IR
      IF(IOPT-6)66,66,68
   66 IS1=-7
      IS2=-7
   68 DO 500 IS=IS1,IS2
      IF(IS-IR)500,500,70
   70 K(4)=IS
      IF(IOPT-5)72,72,74
   72 IT1=-6
      IT2=-6
   74 DO 500 IT=IT1,IT2
      IF(IT-IS)500,500,76
   76 K(5)=IT
      IF(IOPT-4)78,78,80
   78 IU1=-5
      IU2=-5
   80 DO 500 IU=IU1,IU2
      IF(IU-IT)500,500,82
   82 K(6)=IU
      IF(IOPT-3)84,84,86
   84 IV1=-4
      IV2=-4
   86 DO 500 IV=IV1,IV2
      IF(IV-IU)500,500,88
   88 K(7)=IV
      IF(IOPT-2)90,90,92
   90 IW1=-3
      IW2=-3
   92 DO 500 IW=IW1,IW2
      IF(IW-IV)500,500,94
   94 K(8)=IW
      IF(IOPT-1)96,96,98
   96 IX1=-2
      IX2=-2
   98 DO 500 IX=IX1,IX2
      IF(IX-IW)500,500,100
  100 K(9)=IX
      DO 500 IY=IY1,IY2
      IF(IY-IX)500,500,108
  108 K(10)=IY
C
C       BEGIN MIN-MAX SORTING ROUTINE
C
      SM=1000.
      B=0.
      T=0.
      WRITE(6,908)
  908 FORMAT("BANDS=====")
      II=11-IOPT
      DO 200 IH=II,10
  382 WRITE(4,385) K(IH)
  385 FORMAT(I2)
  200 CONTINUE
      DO 400 IZ=1,IE
      F1=0.
      DO 300 M=II,10
      IJ=K(M)
      F1=F1+U(IZ,IJ)
  300 CONTINUE
      F=SQRT(F1)
      IF(F-B)112,112,110
  110 B=F
  112 IF(F-SM)114,116,116
  114 SM=F
  116 T=T+F
  400 CONTINUE
      E=IE
      A=T/E
      WRITE(6,910) B,SM,A
  910 FORMAT("MAX="F6.3"---MIN="F6.3"---AVE="F6.3//)
  500 CONTINUE
  510 IQ=IQ+1
      GO TO 56
  520 CONTINUE
  530 IP=IP+1
      GO TO 52
  540 CONTINUE
      STOP
      END
      END$
```

NUMBER OF DATA CURVES
10
TOTAL NUMBER OF WAVELENGTH BANDS
12
WAVELENGTH SAMPLING INTERVAL (MICRONS)
.005
NUMBER OF OPTIMUM SAMPLING BANDS DESIRED
4
MIN AND MAX WAVELENGTH IN EACH BAND
.40,.44
.44,.46
.46,.48
.48,.50
.50,.52
.52,.55
.55,.58
.58,.62
.62,.66
.66,.72
.72,.80
.80,1.00
.4000 .4400
.4400 .4600
.4600 .4800
.4800 .5000
.5000 .5200
.5200 .5500
.5500 .5800
.5800 .6200
.6200 .6600
.6600 .7200
.7200 .8000
.80001.0000
INSERT DATA CURVE 1 IN PHOTOREADER, PRESS RUN *sugar beets*
PAUSE
W= .180 R= 5.818 V= 1.712
W= .185 R= 5.960 V= 1.520
W= .190 R= 5.960 V= 1.657
INSERT DATA CURVE 2 IN PHOTOREADER, PRESS RUN *wheat*
PAUSE
INSERT DATA CURVE 3 IN PHOTOREADER, PRESS RUN *asphalt*
PAUSE
INSERT DATA CURVE 4 IN PHOTOREADER, PRESS RUN *forest*
PAUSE
INSERT DATA CURVE 5 IN PHOTOREADER, PRESS RUN *shingles*
PAUSE
INSERT DATA CURVE 6 IN PHOTOREADER, PRESS RUN *fallow fields*
PAUSE
INSERT DATA CURVE 7 IN PHOTOREADER, PRESS RUN *gravel*
PAUSE
INSERT DATA CURVE 8 IN PHOTOREADER, PRESS RUN *grass*
PAUSE
INSERT DATA CURVE 9 IN PHOTOREADER, PRESS RUN *concrete*
PAUSE
INSERT DATA CURVE 10 IN PHOTOREADER, PRESS RUN *bare soils*
PAUSE

(items in script for information only - not part of I/O)

BAND AVERAGES---ROWS=SAMPLE CURVES, COLUMNS=BANDS

4.63	6.02	6.26	7.62	11.54	14.96	13.35	10.87	7.87	10.26	41.66	40.71
4.42	5.77	6.89	8.07	8.91	10.57	12.58	14.74	13.92	13.81	19.26	21.39
8.05	8.84	9.73	9.63	10.57	11.56	12.91	13.79	14.59	16.23	19.84	20.28
2.18	2.95	2.93	3.34	5.17	7.57	6.51	5.87	4.56	7.18	29.31	30.08
18.65	22.17	21.65	21.15	21.08	21.38	21.30	21.03	22.43	23.75	26.70	24.03
6.98	8.75	9.66	10.57	11.54	12.97	14.42	15.44	15.35	14.75	22.19	23.66
10.70	12.80	13.04	13.78	15.00	16.91	19.13	21.00	19.90	21.33	32.26	31.73
2.88	3.37	3.90	4.61	5.94	7.31	7.80	8.08	7.95	8.36	23.14	26.71
19.24	21.54	23.86	24.46	27.12	29.55	32.78	34.94	36.90	38.08	42.33	40.33
8.87	10.66	11.33	12.17	12.84	15.02	16.52	18.29	19.45	20.39	34.79	34.57

VAR AVE

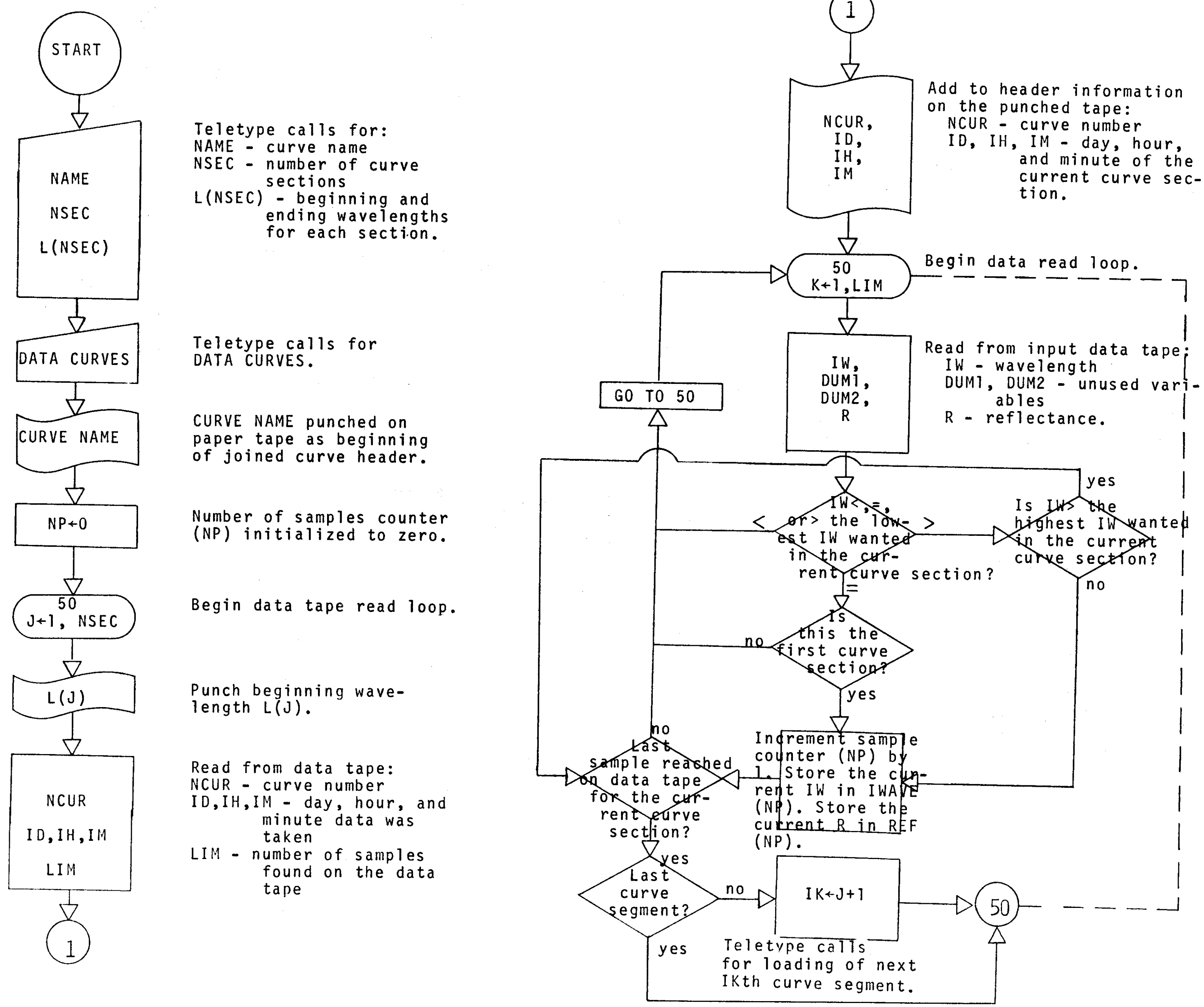
.57	.52	.83	1.36	3.10	3.38	3.93	3.35	2.76	.79	50.67	79.49
.04	.04	.04	.06	.25	.57	.36	1.83	1.15	.45	.42	1.98
8.88	11.62	9.99	15.64	19.11	24.82	33.43	37.88	43.53	46.24	54.80	59.97
.11	.23	.28	.43	.71	.96	1.39	1.17	.67	3.23	16.92	28.38
249.2	370.4	361.3	343.4	329.6	326.2	318.5	317.8	375.6	325.7	325.1	262.1
.17	.08	.16	.19	.19	.28	.41	.50	.51	.46	1.29	1.60
6.78	5.41	6.45	5.17	5.10	8.51	11.21	14.93	19.31	11.11	25.32	12.55
.47	.68	1.23	1.56	1.12	1.30	3.14	6.00	8.28	5.68	18.36	20.12
9.05	10.09	24.39	21.67	24.48	30.55	27.94	37.33	47.61	33.30	27.64	29.46
9.57	12.96	15.56	15.70	19.01	26.66	42.63	72.18	61.40	105.3	159.4	130.8

MATRIX OF SQUARED CURVE COMBINATIONS COLUMNS=BANDS,
ROWS=SAMPLE CURVE COMBINATIONS

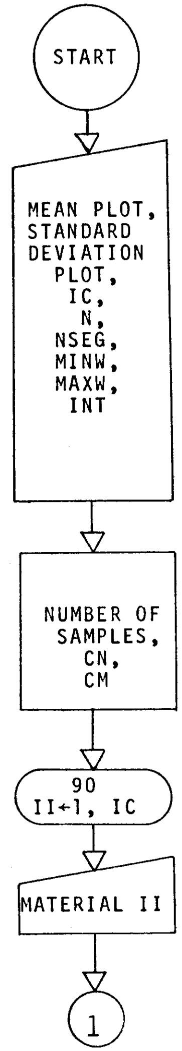
.14	.21	.92	.29	4.15	9.77	.28	5.78	18.72	20.27	19.65	9.17
2.48	1.31	2.23	.47	.09	.82	.01	.41	1.95	1.51	9.03	5.98
17.68	25.22	19.98	20.46	21.38	25.19	17.64	11.07	6.37	4.74	4.51	2.09
1.57	1.41	1.31	1.06	.55	125	.39	.64	1.12	1.11	1.19	1.63
15.02	24.74	23.28	11.30	.00	2.15	.52	10.84	34.33	32.18	14.59	7.17
10.05	15.47	12.65	11.62	2.92	.64	4.41	11.23	13.11	20.58	2.33	1.75
5.84	11.67	5.37	6.19	14.91	25.03	8.72	1.66	.00	1.12	9.94	3.93
44.36	45.40	24.56	24.62	17.60	12.54	23.67	28.47	33.48	45.40	.01	.00
3.55	3.19	3.14	2.42	.15	.00	.43	1.46	4.18	1.93	.45	.36
2.95	1.61	1.61	.31	.28	.08	.01	.05	.02	.25	.01	.04
68.05	59.78	97.73	90.86	29.31	11.82	42.02	52.48	95.96	23.90	11.66	4.98
1.62	1.45	1.21	1.00	.90	.72	.48	.25	.38	.61	.34	.05
63.23	146.5	73.87	51.13	31.45	13.69	8.80	.42	2.50	1.96	10.05	2.88
11.57	18.08	11.67	12.46	13.89	8.88	7.43	4.68	3.50	9.79	13.14	14.71
9.27	15.99	13.99	14.75	12.93	11.42	13.01	11.33	7.55	9.67	1.61	2.57
48.27	49.08	23.56	24.71	26.82	23.15	28.83	20.83	21.68	34.92	37.94	22.83
4.11	3.67	2.53	2.13	1.60	1.46	.73	.34	.98	.82	3.02	2.62
7.67	5.86	9.02	4.92	2.95	1.24	2.36	3.21	4.55	3.31	2.50	2.18
.87	.93	.76	.74	.63	.55	.40	.30	.29	.30	.25	.09
.25	.00	.00	.11	.10	.16	.13	.14	.03	.09	.20	.37
.90	1.84	1.34	1.66	1.62	1.72	1.73	1.97	.90	.91	3.85	3.61
5.71	4.87	6.06	2.92	2.12	1.39	1.43	1.48	1.70	2.39	.30	1.03
13.96	14.86	11.61	11.79	12.57	11.68	12.86	11.89	10.93	12.00	12.27	8.99
.07	.27	.20	.41	.27	.47	.34	.37	.45	.23	2.09	2.14
2.18	1.99	1.94	1.84	1.53	1.17	1.37	1.44	1.70	1.67	.04	.25
166.8	219.4	205.2	168.5	89.81	47.28	69.64	109.7	197.1	31.09	5.57	2.76
21.11	34.39	30.44	38.80	33.32	18.46	25.32	28.46	23.53	27.94	.41	.13
1.71	.39	1.26	1.62	.65	.06	.74	1.37	2.57	.32	2.16	.47
63.53	67.02	35.52	40.34	38.27	30.67	47.06	43.88	43.33	52.29	7.60	3.63
9.25	9.02	8.92	9.65	5.97	4.02	4.56	4.21	7.14	3.22	.34	.25
1.09	.97	.79	.65	.55	.43	.30	.20	.27	.50	.12	.00
.49	.47	.40	.31	.22	.12	.03	.00	.03	.03	.18	.43
1.99	1.91	1.74	1.58	1.39	1.21	1.13	1.04	1.09	1.43	.07	.05
.00	.00	.03	.06	.21	.37	.76	1.09	.99	1.14	1.39	1.82
.74	.69	.56	.45	.39	.23	.13	.04	.04	.05	.27	.57
3.99	5.97	3.45	3.84	4.55	3.53	3.83	4.02	2.08	7.48	7.62	9.20
52.50	75.79	47.53	40.57	47.68	40.76	24.68	16.64	12.47	13.29	.09	.86
32.58	32.19	16.41	17.64	19.69	17.82	23.77	20.11	19.30	32.23	28.03	17.90
.73	.56	.35	.32	.18	.31	.21	.22	.54	.60	1.98	1.80
16.87	29.16	21.76	24.95	26.43	18.83	17.90	15.96	10.34	20.03	3.81	1.54
9.20	9.87	7.58	8.49	9.93	8.17	9.51	7.43	8.64	12.63	3.83	3.52
.41	.50	.27	.25	.39	.20	.25	.17	.01	.02	.07	.11
56.16	61.31	31.08	33.89	35.06	31.06	40.13	33.28	30.00	45.31	16.00	7.48
7.14	7.80	6.57	6.61	4.74	4.26	3.32	2.67	3.79	2.61	1.53	.82
11.54	10.27	7.85	8.09	9.38	7.38	7.49	5.06	5.59	4.52	.61	.41

```
BANDS=====
          1
          2
          3
          4
MAX=27.566---MIN=  .300---AVE= 6.430
BANDS=====
          1
          2
          3
          5
MAX=26.099---MIN=  .486---AVE= 6.324
BANDS=====
          1
          2
          3
          6
MAX=25.271---MIN=  .636---AVE= 6.240
BANDS=====
          1
          2
          3
          7
MAX=25.710---MIN=  .624---AVE= 6.231
BANDS=====
          1
          2
          3
          8
MAX=26.478---MIN=  .629---AVE= 6.256
BANDS=====
          1
          2
          3
          9
MAX=28.079---MIN=  .531---AVE= 6.390
BANDS=====
          1
          2
          3
         10
MAX=24.949---MIN=  .590---AVE= 6.367
```

FLOWCHART FOR PROGRAM JOIN



Flowchart for Program AVER

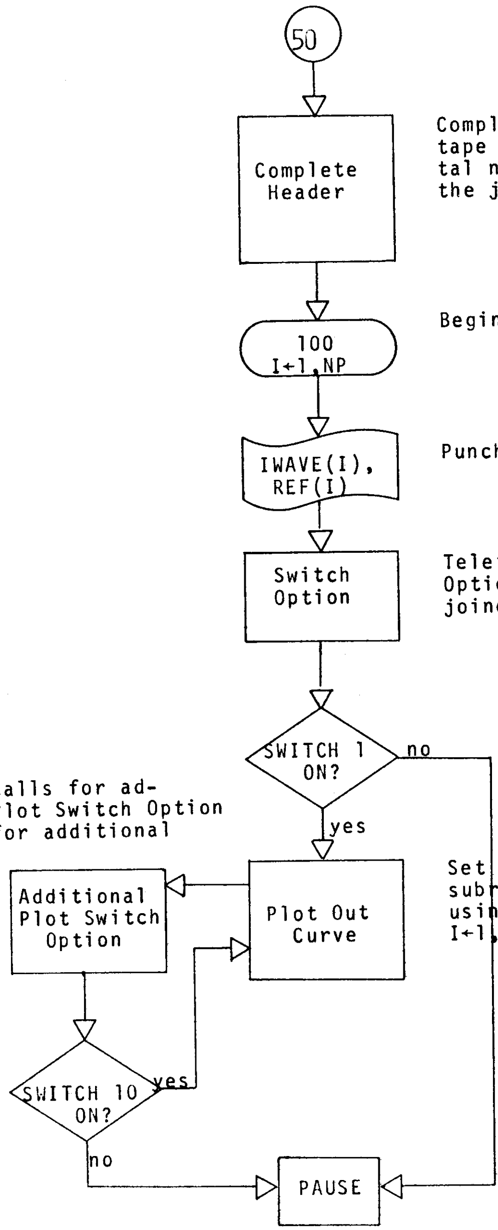


Teletype calls for:
switch options for MEAN PLOT (SW1) and STANDARD DEVIATION PLOT (SW2).
IC - total number of materials.
N - number of curves per material.
NSEG - number of raw curve segments.
MINW, MAXW - beginning and ending wavelengths.
INT - sample interval.

Calculate the NUMBER OF SAMPLES within the wavelength interval specified.
CN←number of curves averaged.
CM←1-number of curves averaged.

Material Read Loop

Teletype calls for name of MATERIAL II.



Complete Header on punched tape by writing NP, the total number of samples on the joined tape.

Begin data punch loop.

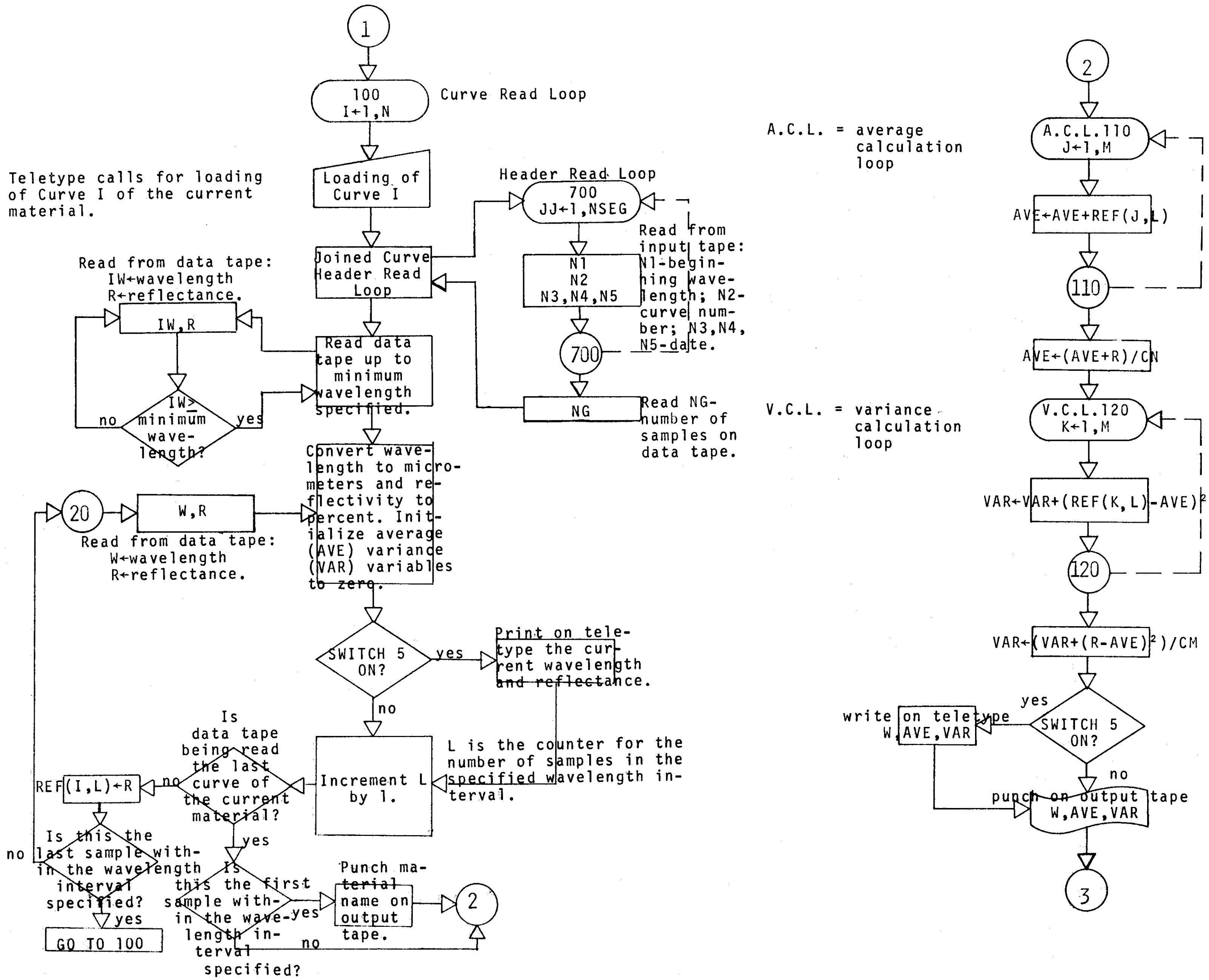
Punch IWAVE(I) and REF(I).

Teletype calls for Switch Option for plotting of the joined curve.

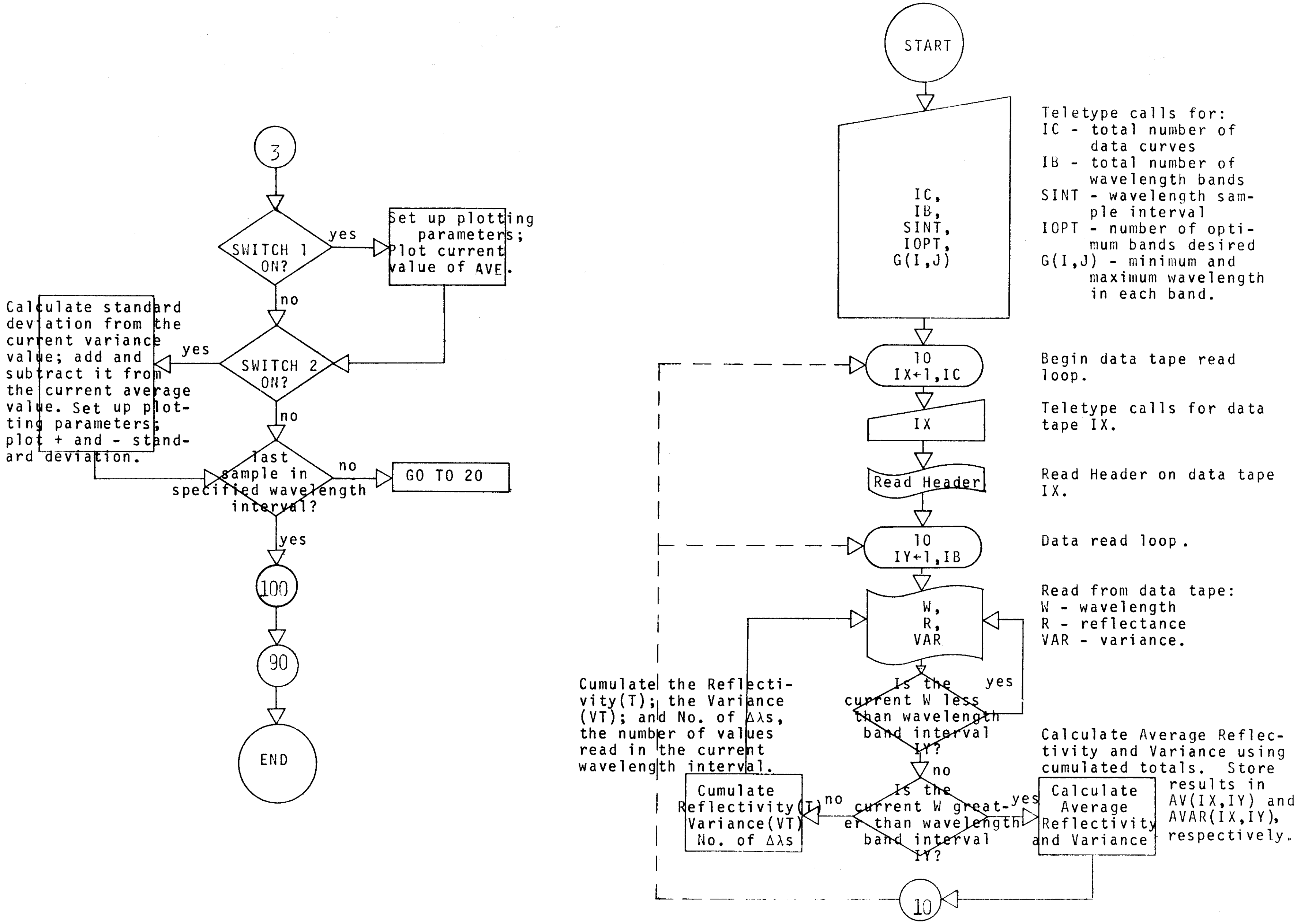
Teletype calls for additional Plot Switch Option (SW10 on for additional plot).

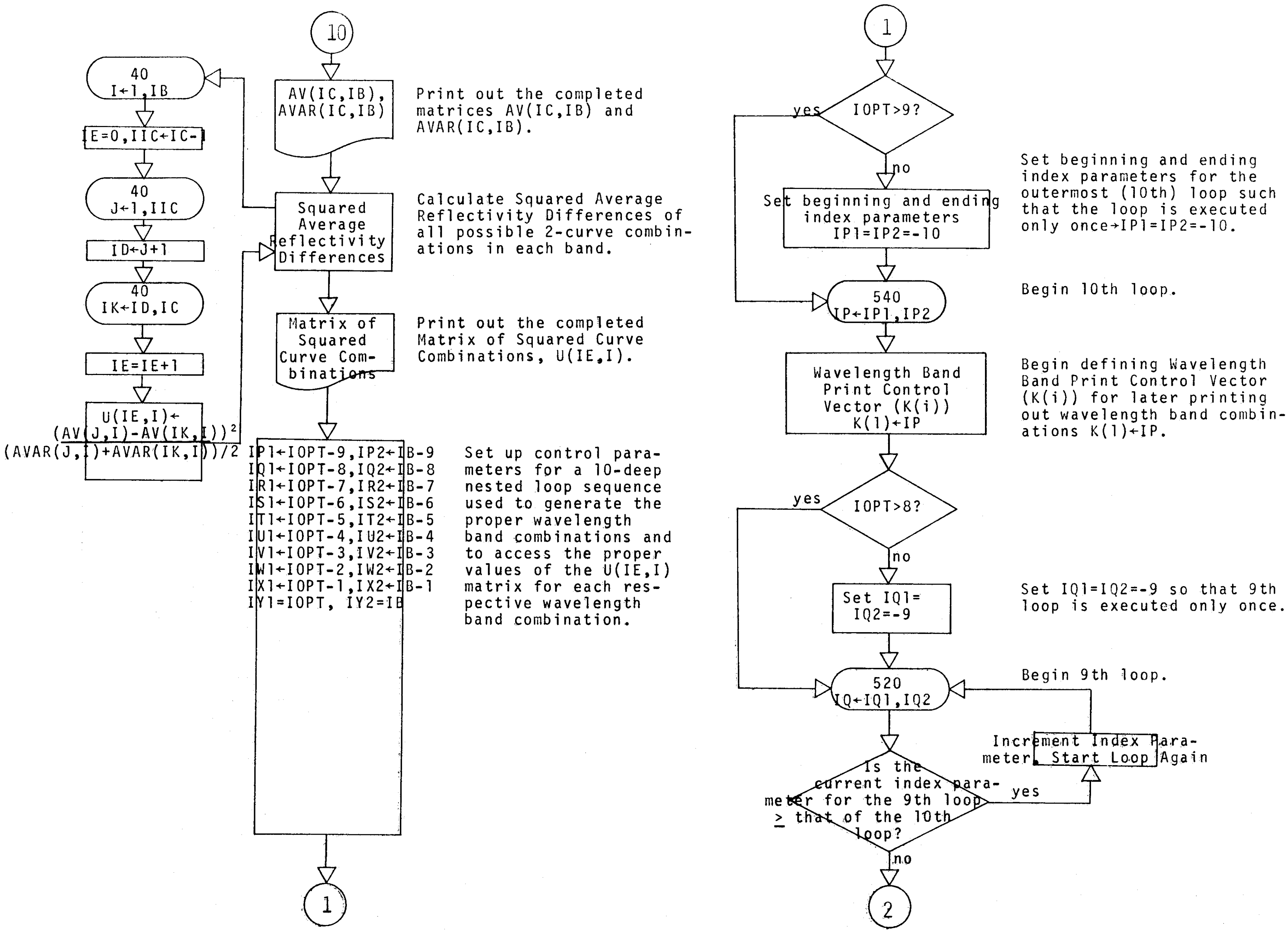
Set up parameters for plot subroutine. Plot Out Curve using a do loop 200, I←1,NP

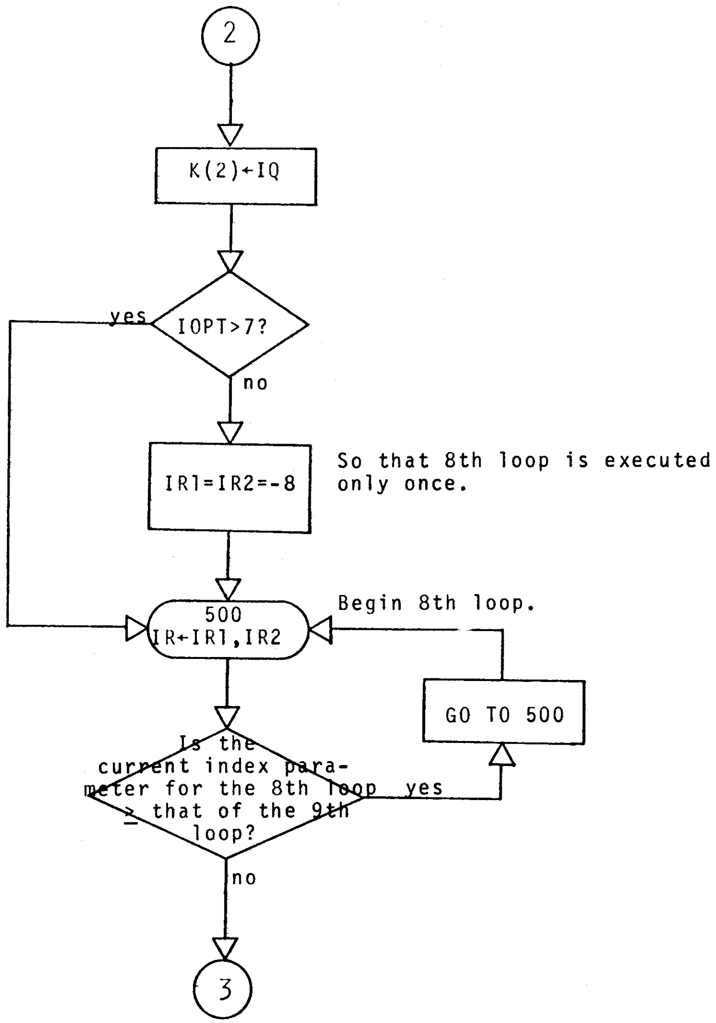
Go to beginning of program.

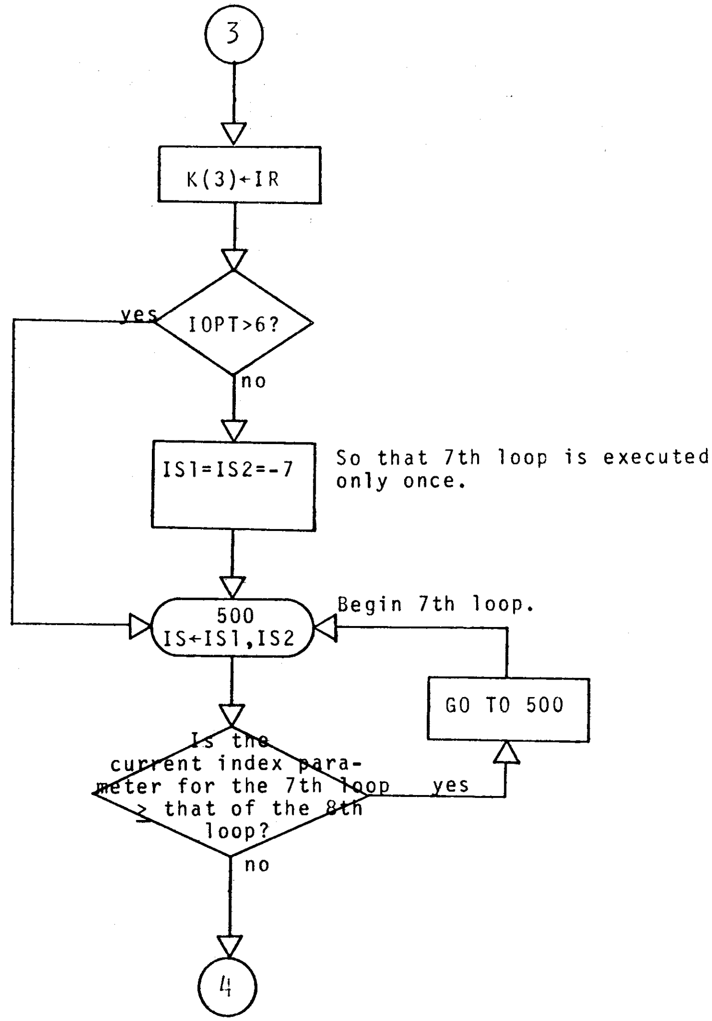

1
100
I←1,N
Curve Read Loop
Teletype calls for loading of Curve I of the current material.
Loading of Curve I
Header Read Loop
700
JJ←1,NSEG
Joined Curve Header Read Loop
N1
N2
N3,N4,N5
Read from input tape: N1-beginning wavelength; N2-curve number; N3,N4, N5-date.
700
NG
Read NG-number of samples on data tape.
Read from data tape: IW←wavelength R←reflectance.
IW,R
Read data tape up to minimum wavelength specified.
IW≥ minimum wavelength?
no
yes
Convert wavelength to micrometers and reflectivity to percent. Initialize average (AVE) variance (VAR) variables to zero.
20
W,R
Read from data tape: W←wavelength R←reflectance.
SWITCH 5 ON?
yes
Print on teletype the current wavelength and reflectance.
no
Increment L by 1.
L is the counter for the number of samples in the specified wavelength interval.
Is data tape being read the last curve of the current material?
no
REF(I,L)←R
yes
Is this the last sample within the wavelength interval specified?
no
yes
GO TO 100
Is this the first sample within the wavelength interval specified?
yes
no
Punch material name on output tape.
2
A.C.L. = average calculation loop
2
A.C.L.110
J←1,M
AVE←AVE+REF(J,L)
110
AVE←(AVE+R)/CN
V.C.L. = variance calculation loop
V.C.L.120
K←1,M
VAR←VAR+(REF(K,L)-AVE)²
120
VAR←(VAR+(R-AVE)²)/CM
SWITCH 5 ON?
yes
write on teletype W,AVE,VAR
no
punch on output tape W,AVE,VAR
3

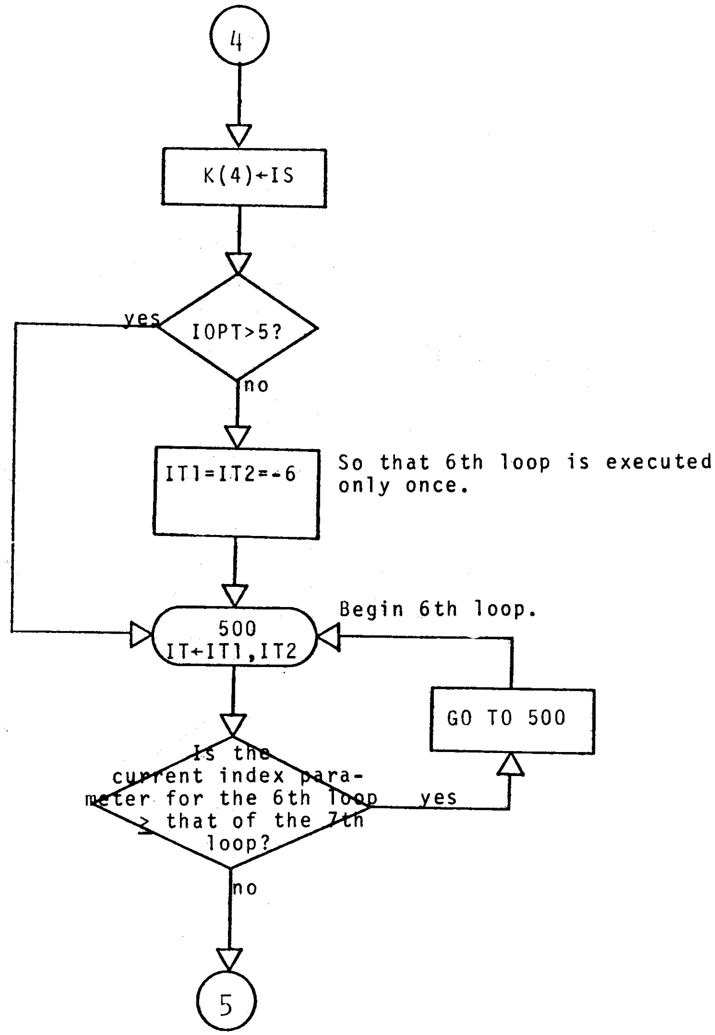
Flowchart for Program OPTIM

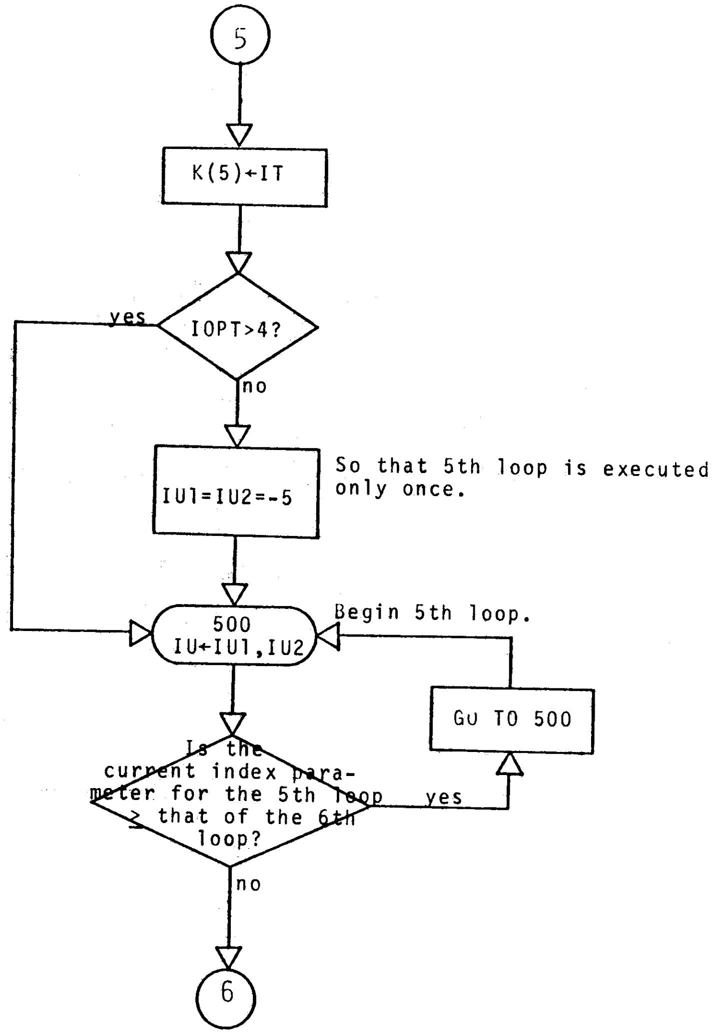


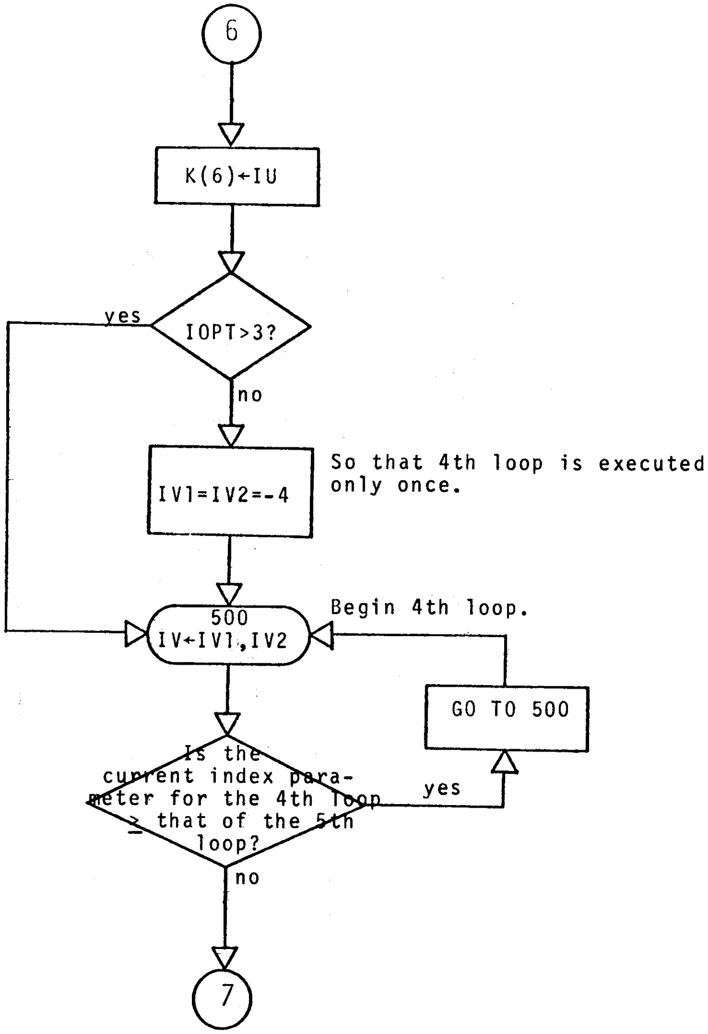

10
40
I←1,IB
IE=0,IIC←IC-1
40
J←1,IIC
ID←J+1
40
IK←ID,IC
IE=IE+1
U(IE,I)←
(AV(J,I)-AV(IK,I))²
(AVAR(J,I)+AVAR(IK,I))/2
AV(IC,IB),
AVAR(IC,IB)
Print out the completed matrices AV(IC,IB) and AVAR(IC,IB).
Squared Average Reflectivity Differences
Calculate Squared Average Reflectivity Differences of all possible 2-curve combinations in each band.
Matrix of Squared Curve Combinations
Print out the completed Matrix of Squared Curve Combinations, U(IE,I).
IP1←IOPT-9,IP2←IB-9
IQ1←IOPT-8,IQ2←IB-8
IR1←IOPT-7,IR2←IB-7
IS1←IOPT-6,IS2←IB-6
IT1←IOPT-5,IT2←IB-5
IU1←IOPT-4,IU2←IB-4
IV1←IOPT-3,IV2←IB-3
IW1←IOPT-2,IW2←IB-2
IX1←IOPT-1,IX2←IB-1
IY1=IOPT, IY2=IB
Set up control parameters for a 10-deep nested loop sequence used to generate the proper wavelength band combinations and to access the proper values of the U(IE,I) matrix for each respective wavelength band combination.
1
1
IOPT>9?
yes
no
Set beginning and ending index parameters IP1=IP2=-10
Set beginning and ending index parameters for the outermost (10th) loop such that the loop is executed only once→IP1=IP2=-10.
540
IP←IP1,IP2
Begin 10th loop.
Wavelength Band Print Control Vector (K(i)) K(1)←IP
Begin defining Wavelength Band Print Control Vector (K(i)) for later printing out wavelength band combinations K(1)←IP.
IOPT>8?
yes
no
Set IQ1= IQ2=-9
Set IQ1=IQ2=-9 so that 9th loop is executed only once.
520
IQ←IQ1,IQ2
Begin 9th loop.
Increment Index Parameter, Start Loop Again
Is the current index parameter for the 9th loop ≥ that of the 10th loop?
yes
no
2


2
K(2)←IQ
IOPT>7?
yes
no
IR1=IR2=-8
So that 8th loop is executed only once.
500
IR←IR1,IR2
Begin 8th loop.
GO TO 500
Is the current index parameter for the 8th loop ≥ that of the 9th loop?
yes
no
3

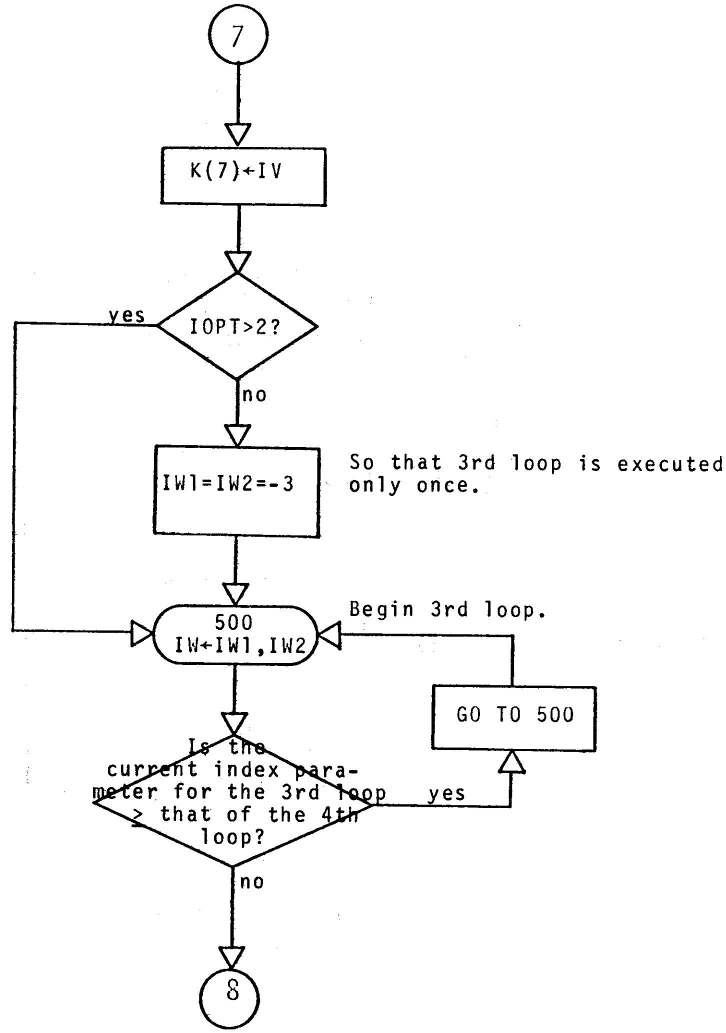

3
K(3)←IR
IOPT>6?
yes
no
IS1=IS2=-7
So that 7th loop is executed only once.
500
IS←IS1,IS2
Begin 7th loop.
GO TO 500
Is the current index parameter for the 7th loop ≥ that of the 8th loop?
yes
no
4


4
K(4)←IS
IOPT>5?
yes
no
IT1=IT2=-6
So that 6th loop is executed only once.
500
IT←IT1,IT2
Begin 6th loop.
GO TO 500
Is the current index parameter for the 6th loop ≥ that of the 7th loop?
yes
no
5

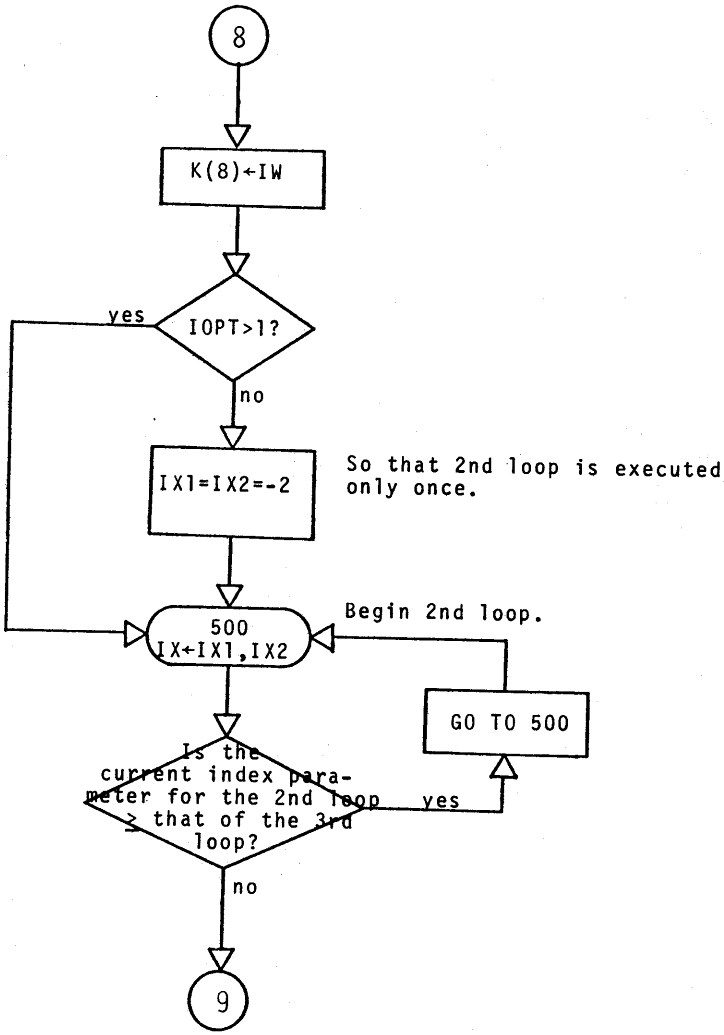

5
K(5)←IT
IOPT>4?
yes
no
IU1=IU2=-5
So that 5th loop is executed only once.
500
IU←IU1,IU2
Begin 5th loop.
GO TO 500
Is the current index parameter for the 5th loop ≥ that of the 6th loop?
yes
no
6

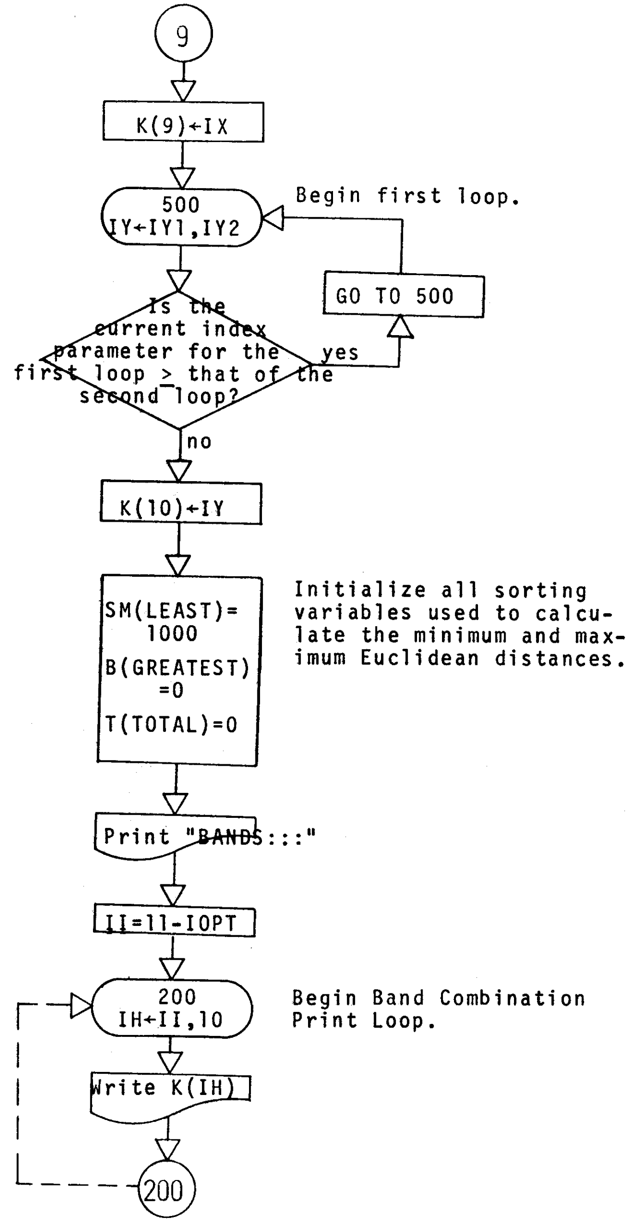


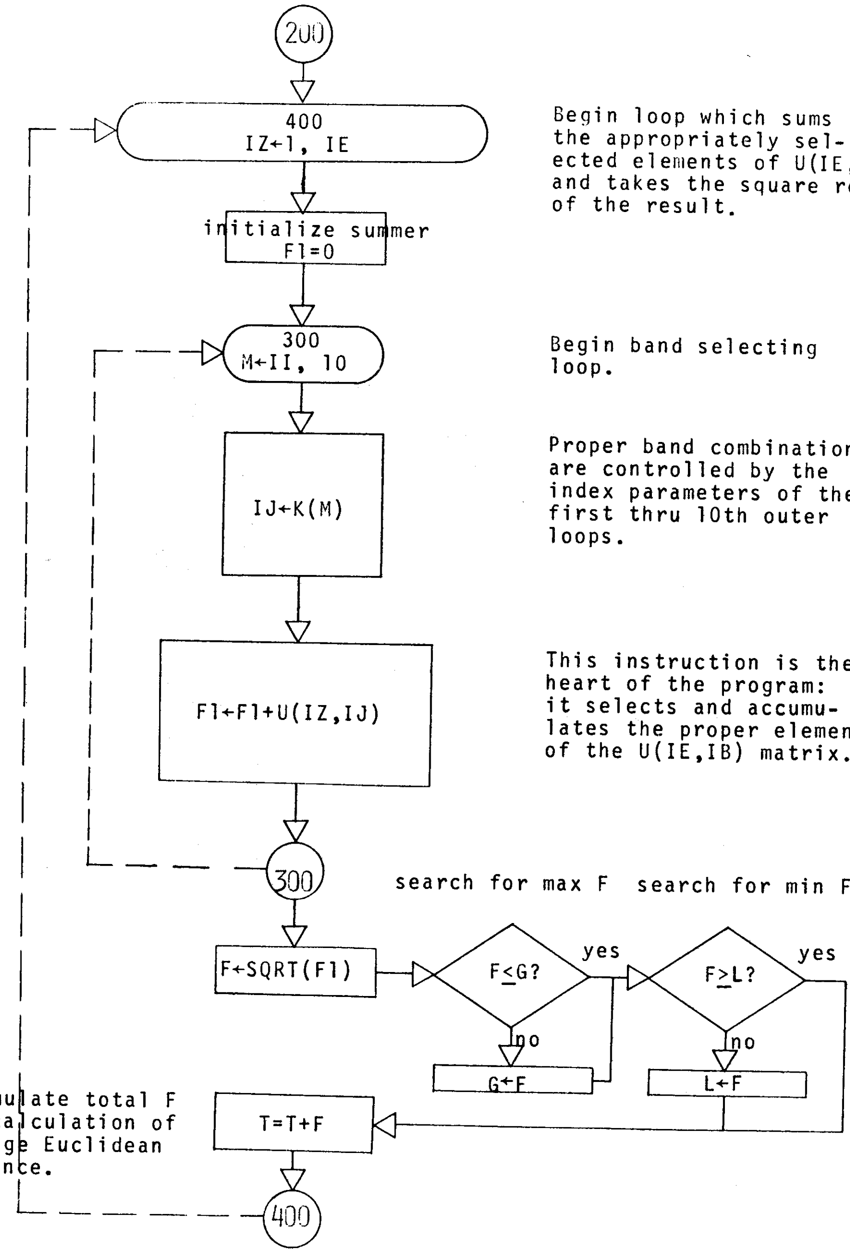
6
K(6)←IU
IOPT>3?
yes
no
IV1=IV2=-4
So that 4th loop is executed only once.
500
IV←IV1,IV2
Begin 4th loop.
GO TO 500
Is the current index parameter for the 4th loop ≥ that of the 5th loop?
yes
no
7



7
K(7)←IV
IOPT>2?
yes
no
IW1=IW2=-3
So that 3rd loop is executed only once.
500
IW←IW1,IW2
Begin 3rd loop.
GO TO 500
Is the current index parameter for the 3rd loop ≥ that of the 4th loop?
yes
no
8


8
K(8)←IW
IOPT>1?
yes
no
IX1=IX2=-2
So that 2nd loop is executed only once.
500
IX←IX1,IX2
Begin 2nd loop.
Is the current index parameter for the 2nd loop ≥ that of the 3rd loop?
yes
GO TO 500
no
9


9
K(9)←IX
500
IY←IY1,IY2
Begin first loop.
Is the current index parameter for the first loop ≥ that of the second loop?
yes
GO TO 500
no
K(10)←IY
SM(LEAST)=1000
B(GREATEST)=0
T(TOTAL)=0
Initialize all sorting variables used to calculate the minimum and maximum Euclidean distances.
Print "BANDS:::"
II=11-IOPT
200
IH←II,10
Begin Band Combination Print Loop.
Write K(IH)
200



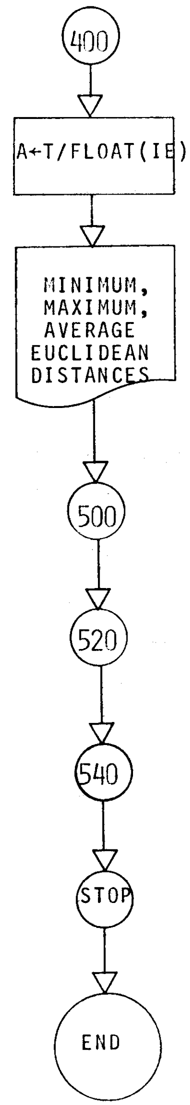
Begin loop which sums the appropriately selected elements of U(IE,IB) and takes the square root of the result.

Begin band selecting loop.

Proper band combinations are controlled by the index parameters of the first thru 10th outer loops.

This instruction is the heart of the program: it selects and accumulates the proper elements of the U(IE,IB) matrix.

Accumulate total F for calculation of average Euclidean distance.



Calculate average Euclidean distance.

Print out the MINIMUM, MAXIMUM, and AVERAGE EUCLIDEAN DISTANCES for the current wavelength band combination.