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Septic System Performance Analysis King County, Washington Volume I

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KING COUNTY SEPTIC SYSTEMS PERFORMANCE ANALYSIS

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KING COUNTY SEPTIC SYSTEMS PERFORMANCE ANALYSIS

I. INTRODUCTION

This project was initiated in response to a request for technical support by Roger K. Mochnick, Acting Chief, Environmental Evaluation Branch, Region X Environmental Protection Agency. The Region X Office is currently involved in the preparation of an Environmental Impact Statement on water quality assessment and proposed wastewater treatment facilities in the greater Seattle area of King County.

A necessary initial step in the E.I.S. process is the determination of the present need for sewers and wastewater treatment facilities. This is accomplished primarily by assessing the number of individual septic system malfunctions, and determining their overall effect on the area's water quality. This determination of present need and assessment of the nature and number of individual septic system malfunctions can often be difficult especially if the issue is a controversial one within the community. The data acquired, in these cases, from questionnaire and ground-based surveys may not be completely reliable.

The Environmental Protection Agency's Environmental Photographic Interpretation Center (EPIC) has developed a remote sensing technique for determining septic system malfunctions and surfacing septic effluent. This technique employs color and color infrared aerial photography to detect changes in soil moisture, unusually lush growth, and other visible "signatures" that are characteristic of septic system malfunction. This program of aerial septic system analysis has been under continual development since 1974 and has been successfully implemented in several of the EPA's regions in support of Environmental Impact Statements, and has been utilized in several communities to satisfy the need documentation requirement (PRM 78-9) of the 201 Construction Grants Program.

II. COMMUNITY SURVEYS - LEGAL BASIS

As a result of the Federal Water Pollution Control Act (P.L. 92-500) and the 1977 Clean Water Act (P.L. 95-217), the Environmental Protection Agency was given the authority to grant funds for the construction of sewage collection systems. Under the eligibility requirements for the construction grants program, the law clearly states that the need for wastewater treatment facilities be proven by documenting the number of septic field failures within the existing target area, and assessing their effect on water quality and public health in general.

> "New collector sewers should be funded only when the systems in use (e.g., septic tanks or raw discharges from homes) for the disposal of wastes from the existing population are creating a public health problem, contaminating groundwater, or violating the point source discharge requirements of the Act. Specific documentation of the nature and extent of health, groundwater and discharge problems must be provided in the facility plan. Where site characteristics are considered to restrict the use of on-site systems, such characteristics, (e.g., groundwater levels, soil permeability, topography, geology, etc.) must be documented by soil maps, historical data and other pertinent information.
>
> The facility plan must also document the nature, number and location of existing disposal systems (e.g., septic tanks) which are malfunctioning. A community survey of individual disposal systems is recommended for this purpose, and is grant eligible."
>
> \- Construction Grants
> Program Requirements Memorandum
> PRM # 78-9

Originally, the only way to satisfy this program requirement was by use of the door-to-door survey. However, it soon became evident that this survey method required large committments of personnel, time, money and technical assistance. Also, there was often a question of validity because sewer projects are often controversial within the community. It soon became apparent that an alternative survey method was needed.

III. REMOTE SENSING AND SEPTIC SYSTEM ANALYSIS

History

Remote sensing was first used to analyze septic field problems in Greensboro, North Carolina in 1974. Although the results of this initial survey were not definitive, it did show promise that a specialized technique for septic system analysis could be developed. Therefore, the Environmental Protection Agency's Environmental Photographic Interpretation Center (EPIC) initiated a research project to develop and refine the interpretative and analytical technique for aerial septic field surveys. In 1977, working in conjunction with Wright State University in Dayton, Ohio, EPIC's imagery analysts discovered distinctive patterns of soil moisture and vegetation growth and stress that were characteristic of septic field overflows. By employing stereo pairs of "false-color" infrared and conventional color photography, an analytical technique was developed that has since been proven to be 75% to 95% accurate, depending on the climatic and soil conditions at time of overflight. After further refining the technique, EPIC developed and produced several photo interpretation "keys" on septic field analysis and tested them on seven communities in EPA Region V. Region V reported in the EPA Journal (May 1980) a cost saving of $36 million dollars from this technique. In early 1978 a test of EPIC's septic field technique was performed in Hawkins, Greene and Union Counties in Tennessee. These communities were chosen because of their geologic structure, soil and topographic conditions, and their pressing operational need. After the analysis and field check were performed, the results showed that EPIC's technique had a confirmed accuracy rate of 94.5% (55 suspected failures - 52 confirmed). As a result, the aerial survey confirmed the hypothesis developed from the analysis of soil and geologic data by public health officials: septic tank systems were not satisfactory for disposal of wastes within the 201 study area.

EPIC's remote sensing technique for septic field analysis has been widely used and has consistently performed in the 75% - 95% accuracy range. It has been used repeatedly by EPA Region III, IV, and V as an integral part of the 201 Construction Grants Process.

Technique

EPIC's remote sensing technique for determining failing septic drain fields requires the acquisition of both color (Ektachrome 2448) and color infrared (Ektachrome 2443) at a scale of 1:8,000. Each frame must be overlapped to a sufficient degree so that the analyst may place them in three dimensional stereo to acquire the necessary topographic information Each lot of each house in the non-sewered sections of the 201 study area in analyzed for signs of plant foliage distress and excessive soil moisture level.

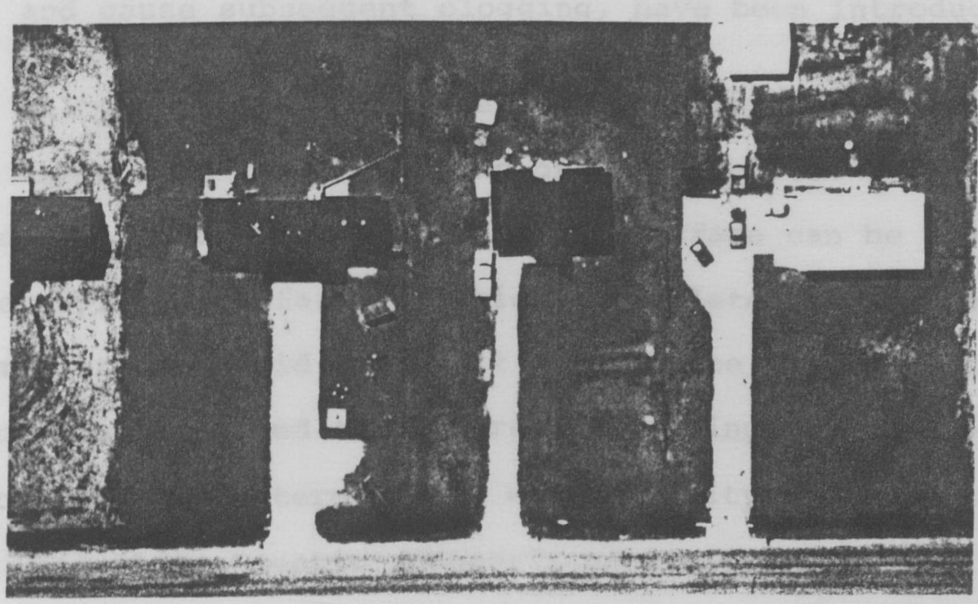
Distressed foliage appears different than the surroundings in both color and color infrared photography. Where there is a high source of nutrients, as in septic field failure, the enhanced growth is indicated by a brighter red color in the color infrared photography. As the septic effluent nears the surface, the overabundance of nutrients causes the vegetation to be stressed with a high growth rate until it finally dies which would show as a pale gray or tan spot. Any actual surface outbreak with standing septic effluent would appear as dark blue or black. The classic septic system failure signature would display the following characteristics:

(1) Pink/red stripes outline the tile field.

(2) Perpendicular to the tile field, at one or more locations, is a deep red plume, which flows downhill, as indicated by the

stereo interpretation.

(3) At the center and at one or more locations within the plume, are gray or black spots which show dead vegetation and the surfacing effluent.



The actual failure signatures are seldom obvious and training is required to produce a proficient interpreter. Similar signatures can be caused by common occurances such as manure piles, compost heaps and animal droppings. For these reasons field checking a percentage of the area is always recommended.

Failure of septic tank systems can usually be attributed to one or more of the following causes:

(1) The soil in the absorption field has too slow a percolation rate to allow for adequate assimilation, filtration, and biodegration of sewage effluent flowing into it.

(2) The septic system is installed too close to an underlying impervious layer.

(3) The septic system may have been installed in an area where the seasonal water table is too high for its designed use.

(4) The soil in the absorption field has too high a percolation rate for effective attenuation of the septic effluent prior to its reaching the underlying groundwater.

(5) Mechanical malfunctions, or breakage, in the septic tank, distribution box, and/or drainfield pipes have occured.

(6) Caustic, toxic or otherwise harmful substances which could kill bacteria in the septic tank and/or absorption field, and cause subsequent clogging, have been introduced into the septic system.

(7) All or part of the system has been improperly installed.

With respect to remote sensing of septic system failures, only those malfunctions which are noticeable on the surface can be detected by aerial imagery. Those failures which are related to sewage backing up in the home, or too rapid transport through the soil into the groundwater, cannot be detected through remote sensing. In these cases, septic failures can only be determined by water quality analysis and/or the use of a soil lysimeter, "septic snooper", or similar apparatus.

Based on the work undertaken to date, it has been determined that all the primary surface manifestations that are associated with septic tank and/or absorption field failures are the result of the upward movement of partially treated or untreated wastwater to the soil surface, and usually appear either directly above or adjacent to the component parts of the septic system (i.e. the septic tank, the distribution box, and the absorption field). More often than not, two or more of these malfunctions will occur simultaneously at any given homesite. In some cases, depending on the soil makeup of a given area, the outline of the drainfield of a properly functioning septic system can still be distinguished on aerial imagery. This points to the need for tailoring "photo-interpretation keys" to specific geographic areas.

NOTE: At present, there is no photo-interpretation key for septic systems performance analysis in the Pacific Northwest/EPA Region X area. It had been hoped that this project would result in at least the initiation of a key for this area. However, the fact that remote sensing of septic field problems has never been attempted in this area does not mean that the overall technique is invalid, but simply untested. Any given geographic area has individual, climatic, geologic and soil characteristics that, once defined and understood, will affect the interpretative process to some degree - but not necessarily the validity of the overall technique. For example, it is possible in shallow soils to find clear definition of septic systems by lush growth, even though the system is functioning properly. However, this has been observed in the past to be a result of a very dry climate, or an extended period of little or no rainfall, when the grass roots will reach for available moisture. Since these conditions did not exist in King County at the time of overflight, clear definition of the system is still considered to be an indication of seasonal failure.

IV. REMOTE SENSING AND ENVIRONMENTAL MONITORING - LIMITATIONS

Although aerial sensing systems are one of the most important environmental monitoring applications of the future, they are not without drawbacks and limitations, some of them serious. A few of these are:

WEATHER - Almost all sensing systems are affected a great deal by meteorological conditions. Rain, snow, haze, clouds, temperature, etc., all affect the availability, clarity and resolution of the imagery. Often conditions must be just right for acquisition to take place, high winds and other weather factors may prohibit the flight of the aircraft itself.

SEASONS - Naturally, when dealing with environmental factors, the seasonal aspect is often of paramount importance. Stages of growth, death, change, water table, water supply and a host of other variable seasonal factors are central to any analysis that deals with vegetation stress and growth.

TREE/CLOUD COVER - Almost all imaging systems of high resolution are still handicapped totally by cover characteristics. Heavy clouds, thick haze, and extensive tree/crown cover prohibits interpretation of all underlying characteristics.

Therefore, while remote sensing techniques provide an excellent vehicle for monitoring and assessing environmental conditions and standards, it is not a simple process and can only be accomplished correctly with a great deal of forethought and planning. Depending on the user requirements, there is almost certainly a significant period of time that must lapse between the planning stage and the actual acquisition of the imagery. This is required so that the proper meteorological and/or seasonal requirements can be met. This period of time is often months and can extend over an entire year. If the imagery is acquired at the wrong time or under the wrong conditions, the information will be reduced significantly in value. It must be kept in mind that the use of remote sensing is a fragile process and that the final product will only be as good as the planning and preparation that preceeded imagery acquisition.

King County, Washington
Analysis of Environmental Conditions
(source: U.S. Department of Agriculture, Soil Conservation Service.)

INTRODUCTION

The landform types and environmental conditions in the Puget Sound area represent a dramatic departure from the eastern seaboard and midwest regions where EPIC's remote sensing technique for septic systems performance analysis was originally developed and refined. Unfortunately, the full scope of these differences in soil types, geologic structure and climatic conditions, was far greater than originally anticipated, and seriously impacted the overall quality of this study. The main reason that these differences were not fully anticipated was primarily because there has been little or no environmentally-based remote sensing conducted in the Pacific Northwest and no definitive methodology has been established. As noted earlier, a full understanding of various environmental factors is critical to both the interpretation process and the timing of film acquisition. This section will deal with the relevance of these environmental factors on general septic system performance and remote sensing analysis.

CLIMATE/TEMPERATURE/PRECIPITATION

Climatic conditions are extremely critical to any attempt at environmental analysis via remote sensing. The primary focus here is predictable patterns of vegetation growth. In septic system performance analysis, the main concern is involved with the identification of unusual patterns of vegetation growth and stress, caused by the upward and/or lateral movement of sewage effluent in the general location of the septic system filter field.

Climatic conditions in the study area are typical of the mild, moist climate of the Puget Sound area. This climate is controlled by major air movements over the Pacific Ocean as they are influenced by major land forms, particularly the Olympic and Cascade mountains. The maritime air has a moderating influence, bringing warm moist air to the region from the Southwest in the winter and spring, and cool, drier air from the Northwest in the summer and fall. Because of this, there is a well-defined dry season in the summer and rainy season in the winter. Annual precipitation ranges from 35 inches in the lowlands to 150 inches or more in the surrounding mountains. Fifty percent of the annual precipitation falls during the four month period from October to January and seventy-five percent during the six month period from October thru March, with only five percent of total rainfall occuring in the months of July and August.

Temperatures in the region containing the study area are considerably moderate in comparison to other regions at similar latitudes in the nation. In the warmest summer months, temperatures are generally in the 70's with occassional short-term bursts into the 80's. Temperatures above 85 degrees are reached less than fifteen days per year. Winter temperatures are in the 40's in the lowlands and decrease with altitude, approx. 3 degrees F. for every 1000 feet of elevation. This would indicate that a span of nearly 8 F. in average temperatures is likely across the study area, which ranges in elevation from 11 feet near the Renton Treatment Plant to 2757 feet on the summit of Tiger Mountains. Local temperature conditions vary considerably in the study area depending on air, drainage, elevation, solar radiation, and distance from the Sound. Mean annual temperatures for eleven recording stations in and around the study area are illustrated in figure 1.

Rainfall in the region containing the study area is generally less intense than in most other parts of the nation, but the frequency of precipitation is greater. Total annual precipitation generally increases with elevation. Precipitation is light in the summer, increases in the fall, peaks in winter, then falls through spring, with a sharp drop noted in early July (see figure 3).

During the wet season, rainfall is usually light to moderate in intensity and continues for extended periods of time. Figures 4 & 5 contain information on average precipitation levels in and around the study area.

Snowfall within the study area is generally very light, with snow seldom remaining on the ground for more than a few days (except at the higher elevations).

SOIL STRUCTURE/GEOLOGY

The soil types and underlying geologic structure are tremendously important to both area-wide, on-site sewage disposal and remote sensing analysis thereof. The types of soils and their relative percolation rates, as well as the permeability of the underlying geologic structure, affect not only septic system performance but also the type and occurrance of failure that the remote sensing analyst might expect to see.

GEOLOGY

The soil types and land features of the King County area were formed largely by deposits of glacial drift laid down during the Vashon Period of the Fraser glaciation late in the Pleistocene era. The majority of material left by the glacier are till, recessional outwash, pro-glacial lacustrine and outwash sediments. Following deglaciation, alluvium accumulated in the valleys, and mudflow from Mount Ranier (Osceola mudflow) covered a large area in the vicinity of Enumclaw. Figure 8 shows the general location of the major geologic material in the study area.

This study's primary concern with the geologic structures is the permeability of the substratum and its subsequent ability to adequately filter sewage effluent prior to reaching groundwater supplies. This is critical to water quality planning because, irregardless of the soil structure, if the substratum is relatively impermeable, then a high occurrance of on-site septic system failure can be expected; if the substratum is too porous, then ground-water contamination can be expected. However, because of the close association between soil types and geologic material underneath - a discussion of the soils is also necessary.

SOILS

There are 39 soil series and 7 basic soil associations in the King County area. However, the most predominant are the Alderwood soils which occupy 52% of the study area. Alderwood soils are gravelly-sandy loams with a thickness of 24 to 40 inches. Almost without exception, the underlying substratum is a consolidated glacial till which has a very low permeability or slow percolation rate. Since these soils are very shallow, there are severe restrictions for on-site septic disposal. Another major association is composed of mostly Everett soils and occupies approximately 14% of the study area. Everett soils are also gravelly sand that has a very high or rapid percolation permeability through the substratum, creating a potential for groundwater contamination from on-site septic disposal due to inadequate attenuation of the effluent prior to reaching the groundwater. The remainder of the study area is composed of minor percentages of the other soils-but over 90% are still classified by Soil Conservation Service as having severe restrictions for septic tank filter fields because of either:

- Permeability through substratum
- Seasonal high water table
- Extreme Slope
- Permeability/pollution hazards
- Flood Hazard

A. Project Plan

On February 7, 1980, USEPA Region 10 submitted a request to the Office of Monitoring and Technical Support, EPA, to initiate an analysis of aerial photography for portions of King County, Washington for failing septic systems. Final approval of costs and funding by Region 10 was completed April 11, 1980.

The Environmental Photographic Interpretation Center scheduled a photo mission to cover the study area at the first photo-weather window. The photography was acquired on the 1st and 3rd of May, 1980. The study area (see volume II, page 2), designated by Region 10 in coordination with METRO (Municipality of Metropolitan Seattle), was photographed with both conventional color film (Ektachrome 2448) and color infrared film (Ektachrome 2443); a Zeiss aerial camera with a 9" format and a 6" focal length was used. The scale of the imagery varied from 1:8,500 to 1:10,000. The overall quality and resolution of the imagery was excellent.

B. Problems:

The most significant problem encountered was the short period of time between project approval and the required completion date. Due to this scheduling, imagery acquisition had to be completed at a less than optimum time. Ideally, imagery for this type of study is flown when the water table is at a seasonal high, and it has been at least 3 days since the last rain. In this case, the water table was approaching a seasonal low and it had rained on May 2nd, (the day between flights). This lead to a problem of excessive surface moisture and areas of standing water.

A second desired condition when planning a photo mission for a septic study is that the photography be acquired at a time prior to full leaf-on conditions for the trees. If the trees in the area have leafed-out, in the denser areas it becomes extremely difficult to analyze the imagery. These conditions all combined in the King County study to form a situation where the standard failing septic signatures were masked or camouflaged. The signs of failing septic systems were not as strong, nor did they occur with the frequency that was expected (considering the poor soil and geologic conditions of the area).

A preliminary analysis of the imagery concluded that signatures of septic-related problems could be identified. However, when field checked, a number of these signatures proved to be unrelated to septic system failures. Signatures indicating "seasonal stress" (see volume II, page 3) were identified in an area that was sewered. (Sewered areas are not usually included in study areas.)

In early May the King County Health Department had conducted an extensive door-to-door survey in the Lake Desire area. EPIC's analysis indicated that there were 25 signatures of surface failures in this area. Only one of these corresponded with the Health Department survey. A detailed explanation of the definition of a surface failure and how the signatures appear on the imagery improved this correlation.

Further research, coordination and field checking resulted in an agreement that the following factors contributed to a below-average number of failure identifications:

1. Scheduling requirements which resulted in the acquisition of the photography at a less than optimum time.

2. The inconsistent definition of the terms "surface", "seasonal", and "stressed" septic failure. This inconsistency occurred between EPIC's definitions for analytical purposes, and the Health Department's

definitions for legal purposes.

3. The unique climate and geology of the Puget Sound area.

Overall, EPIC's technique for the discovery of septic problems was hampered by excessive moisture, a low water table and extensive tree canopy throughout much of the study area. Figure 1 shows that even with these problems, EPIC was able to identify a total of 121 surface failures, 220 seasonal failures, and 463 signatures of seasonal stress. The predominance of seasonal stress signatures was the result of the conditions (discussed earlier) which effectively masked and/or reduced the strength of the signatures. (See volume II for specific signature locations and example photographs.)

While a vast array of problems surrounded this project, it is the general opinion of the EPIC analysts that this report will provide valuable information for future studies of this type in the Northwest, and will be helpful in making long-range water-quality planning decisions.

RESULTS

Septic Systems Performance Analysis
King County, Washington

QUAD SHEET	SURFACE FAILURE	SEASONAL FAILURE	SEASONAL STRESS	TOTAL
AUBURN	24	30	39	93
BLACK DIAMOND	1	13	12	26
BOTHELL	3	8	14	25
ISSAQUAH	31	38	55	124
KIRKLAND	3	21	25	49
MALTBY	8	9	59	76
MAPLE VALLEY	15	41	77	133
MERCER ISLAND	12	8	11	31
REDMOND	7	23	35	65
RENTON	17	29	136	182
TOTALS	121	220	463	804

NOTE: The number of signatures applies only to the study area portion of each quad sheet. See LOCATION DIAGRAM in Volume II for a graphic outline of the study area and each individual quad sheet.

FIGURE 1.

TEMPERATURE AVERAGES AND EXTREMES (°F)

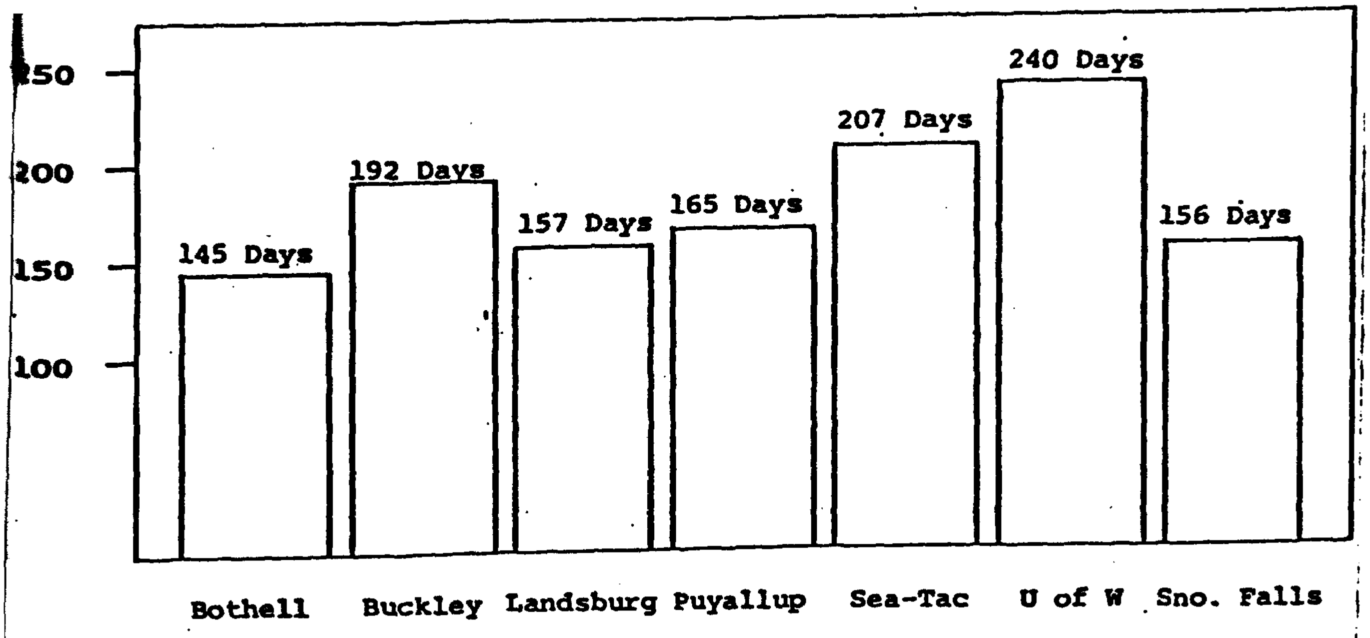
Station	Data	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Bothell	Av. Max.	44.3	48.3	52.8	59.7	66.0	69.7	75.6	75.1	70.8	60.8	51.1	46.8	60.1
	Av. Min.	30.6	31.9	33.8	37.2	41.9	46.2	48.2	50.0	44.9	40.9	35.6	33.8	39.6
	Mean	37.5	40.1	43.3	48.5	54.0	58.0	61.9	62.6	57.9	50.9	43.9	40.3	49.9
	Highest	67	71	76	88	90	100	100	97	99	86	75	68	100
	Lowest	-10	-6	8	20	23	31	35	33	28	21	0	5	-10
Buckley	Av. Max.	43.7	47.5	52.4	59.4	65.8	70.3	76.4	75.3	69.7	59.4	49.7	46.0	59.6
	Av. Min.	31.9	33.3	35.2	38.6	43.4	47.0	49.8	49.9	46.8	42.2	36.6	34.6	40.8
	Mean	37.8	40.4	43.8	49.0	54.6	58.7	63.1	62.6	58.3	50.8	43.2	40.3	50.2
	Highest	70	69	76	84	88	96	102	98	95	87	68	65	102
	Lowest	-3	1	10	26	30	37	37	38	33	24	2	8	-3
Kent	Av. Max.	45.9	49.8	54.5	62.6	68.8	73.0	78.8	77.8	72.2	62.5	52.0	47.7	62.1
	Av. Min.	32.2	33.9	35.5	39.0	43.6	48.2	50.9	50.5	46.7	42.5	36.0	34.4	41.1
	Mean	39.1	41.9	45.0	50.8	56.2	60.6	64.9	64.2	59.5	52.5	44.0	41.1	51.6
	Highest	70	69	77	88	90	100	100	98	95	87	71	64	100
	Lowest	3	-5	10	23	27	33	34	37	30	24	6	8	-5
Landsburg	Av. Max.	43.4	47.9	52.8	60.0	66.1	70.2	75.8	75.0	70.2	60.4	50.2	45.5	59.8
	Av. Min.	30.5	31.7	33.8	36.7	41.5	45.6	48.0	47.6	44.6	40.3	35.0	33.1	39.0
	Mean	36.9	39.8	43.3	48.4	53.8	57.9	61.9	61.3	57.4	50.3	42.6	39.3	49.4
	Highest	68	70	80	85	90	101	101	100	93	84	76	72	101
	Lowest	1	1	12	23	25	31	34	34	30	22	4	8	1
Palmer	Av. Max.	41.6	45.6	50.3	58.5	65.6	69.7	76.3	75.4	70.1	60.0	49.3	43.8	58.9
	Av. Min.	30.2	31.6	33.5	37.0	42.2	46.1	49.8	49.8	47.1	42.4	36.5	33.6	40.0
	Mean	35.9	38.6	41.9	47.8	53.9	57.9	63.1	62.6	58.6	51.2	42.9	38.7	49.4
	Highest	66	66	78	88	91	100	101	101	95	85	74	64	101
	Lowest	0	4	12	22	30	32	38	38	32	21	6	10	0

FIGURE 2.

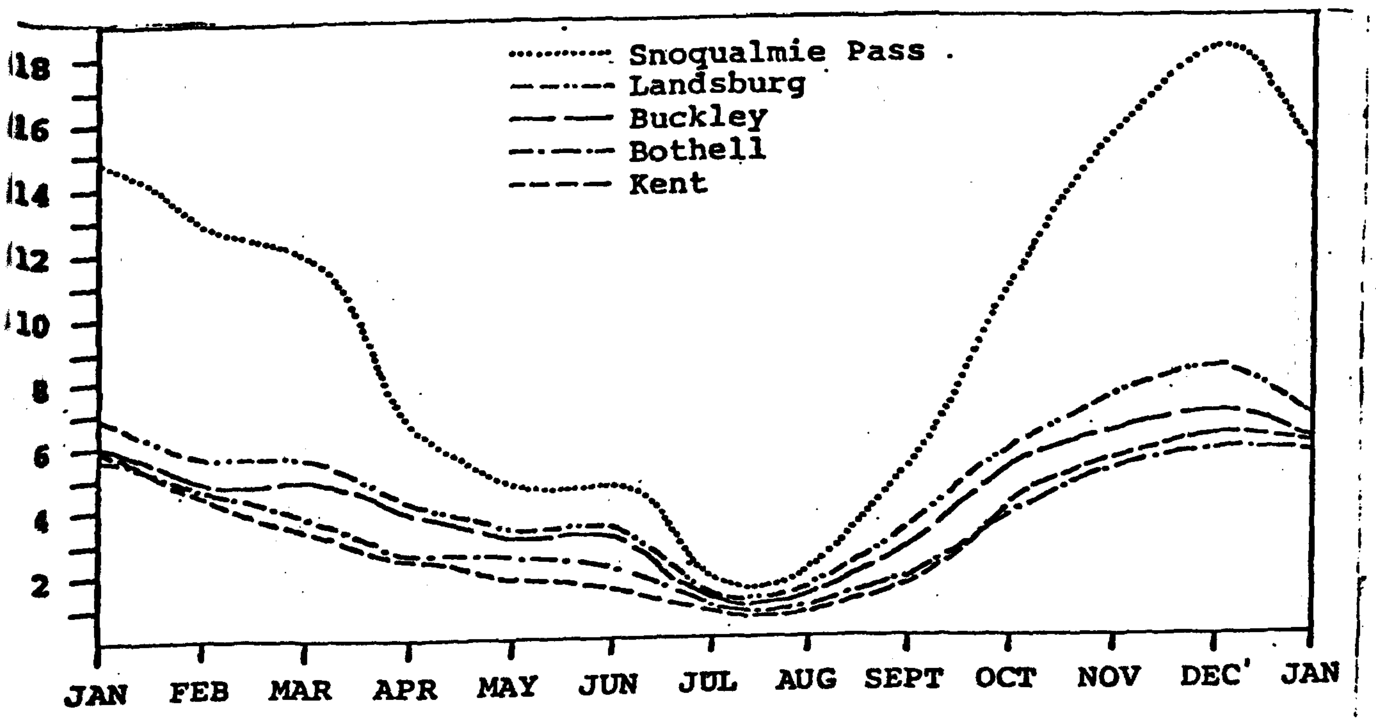
FIGURE 3.

TEMPERATURE AVERAGES AND EXTREMES (°F) continued

Station	Data	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Puyallup Exp. Sta.	Av. Max.	45.9	49.6	54.1	61.8	68.5	72.4	78.3	77.6	71.8	62.2	52.1	48.0	61.9
	Av. Min.	31.3	33.1	35.0	38.2	42.5	47.1	49.2	48.7	45.8	41.7	35.6	33.7	40.1
	Mean	38.6	41.3	44.5	50.0	55.5	59.8	63.7	63.1	58.8	51.9	43.8	40.8	51.0
	Highest	66	69	75	87	90	101	99	99	92	82	72	66	101
	Lowest	-3	1	12	23	25	34	38	33	30	22	0	7	-3
Seattle Boeing Field	Av. Max.	45.2	49.5	54.3	61.8	68.5	73.1	78.4	77.1	71.5	62.3	52.4	47.3	61.8
	Av. Min.	31.1	33.6	36.4	40.7	46.2	51.2	54.9	54.0	49.4	42.9	35.9	33.5	42.5
	Mean	38.2	41.6	45.4	51.3	57.4	62.2	66.7	65.6	60.5	52.6	44.2	40.4	52.2
	Highest	69	70	76	85	90	99	99	100	92	82	69	67	100
	Lowest	3	4	16	28	30	37	44	43	33	24	8	11	3
Seattle City	Av. Max.	45.6	48.8	52.7	59.4	65.7	69.6	75.1	73.9	69.0	60.4	51.8	48.0	60.0
	Av. Min.	36.8	38.3	40.1	44.1	49.0	53.1	56.1	56.1	53.3	48.3	41.9	39.5	46.4
	Mean	41.2	43.6	46.4	51.8	57.4	61.4	65.6	65.0	61.2	54.4	46.9	43.8	53.2
	Highest	66	70	75	87	92	100	100	97	92	78	70	65	100
	Lowest	11	12	22	31	35	45	48	48	42	30	13	21	11
Seattle-Tacoma Airport	Av. Max.	43.6	47.0	51.3	58.2	65.6	69.9	75.6	74.6	69.3	60.3	49.6	45.9	59.2
	Av. Min.	33.0	34.5	36.2	40.1	45.3	49.7	54.1	53.6	50.5	44.4	38.1	35.7	42.9
	Mean	38.3	40.8	43.8	49.2	55.5	59.8	64.9	64.1	59.9	52.4	43.9	40.8	51.1
	Highest	61	68	71	77	93	90	97	99	89	80	65	60	99
	Lowest	12	18	23	30	33	41	46	45	39	33	23	10	10
Seattle U of W	Av. Max.	45.6	49.2	53.7	60.8	67.0	71.5	76.6	75.7	70.7	61.8	51.8	47.8	61.0
	Av. Min.	34.6	36.0	38.1	41.8	46.9	51.2	54.8	54.7	51.5	46.4	40.2	37.6	44.5
	Mean	40.1	42.6	45.9	51.3	57.0	61.4	65.7	65.2	61.1	54.1	46.0	42.7	52.8
	Highest	68	71	75	88	90	98	98	96	96	88	67	65	98
	Lowest	6	8	17	30	34	36	41	46	39	29	10	15	6
Snoqualmie Falls	Av. Max.	43.8	47.7	52.8	60.8	67.1	71.1	77.1	76.3	70.2	60.3	50.5	46.0	60.3
	Av. Min.	31.5	32.7	34.2	37.6	41.8	46.1	48.9	48.5	45.2	41.1	36.1	34.5	39.9
	Mean	37.7	40.2	43.5	49.2	54.5	58.6	63.0	62.4	57.7	50.7	43.3	40.3	50.1
	Highest	66	67	77	90	90	99	99	102	93	84	75	64	102
	Lowest	-1	-3	8	24	26	31	36	35	30	23	2	6	-3



Mean Growing Season (Days)



Average Monthly Precipitation (inches)

FIGURE 4.

AVERAGE NUMBER OF DAYS WITH PRECIPITATION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
.01 or more													
Buckley	19	16	17	16	13	12	5	6	10	14	17	19	164
Kent	17	14	13	10	9	7	3	4	7	12	17	16	129
Puyallup Exp. Sta.	18	15	16	12	10	8	3	4	7	12	16	18	139
Seattle City	19	15	16	13	11	9	5	6	8	14	17	19	151
Snoqualmie Falls	20	17	19	16	14	11	5	6	10	16	20	21	175
Snoqualmie Pass	19	16	18	14	12	11	5	6	9	14	17	21	162
.10 or more													
Buckley	13	12	13	10	9	8	3	4	6	10	13	15	116
Kent	14	11	10	8	5	4	2	3	5	10	12	14	98
Puyallup Exp. Sta.	13	11	11	8	6	5	2	3	5	9	12	14	99
Seattle City	12	10	10	8	5	4	2	3	4	8	14	13	93
Snoqualmie Falls	15	12	14	10	8	7	3	4	7	11	14	16	121
Snoqualmie Pass	18	15	16	12	11	9	4	4	8	12	15	18	131
.50 or more													
Buckley	4	3	2	2	2	2	1	1	2	3	5	5	32
Kent	4	3	2	1	1	1	1	*	*	2	4	4	23
Puyallup Exp. Sta.	4	2	2	1	1	*	*	1	1	2	4	4	22
Seattle City	4	2	1	1	*	*	*	*	1	2	4	3	18
Snoqualmie Falls	7	4	4	3	2	2	1	1	2	4	6	6	42
Snoqualmie Pass	13	10	9	6	4	2	1	2	3	7	11	13	81
1.00 or more													
Buckley	1	1	*	*	*	*	0	*	*	1	1	1	5
Kent	1	1	*	*	0	0	*	0	0	1	1	1	5
Puyallup Exp. Sta.	1	1	*	*	0	0	*	*	*	*	1	1	4
Seattle City	1	1	0	*	0	*	0	0	*	*	1	1	4
Snoqualmie Falls	2	1	1	*	*	*	*	*	1	1	3	1	10
Snoqualmie Pass	6	4	4	2	1	*	*	*	2	4	6	6	35

FIGURE 5

AVERAGE MONTHLY AND ANNUAL PRECIPITATION (Inches)

Station	Elevation	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Bothell	100	5.59	4.35	3.84	2.47	2.40	2.15	.81	.99	1.88	3.80	5.18	5.82	39.28
Buckley	685	5.59	4.71	4.94	3.86	3.13	3.36	1.25	1.41	2.77	5.15	6.23	6.91	49.31
Kent	40	5.81	4.16	3.69	2.37	1.82	1.67	.84	.89	1.76	4.06	5.26	6.15	38.48
Landsburg	535	6.97	5.63	5.76	4.02	3.23	3.31	1.34	1.64	3.39	5.80	7.26	8.13	56.48
Puyallup Exp. Sta.	50	5.63	4.66	4.14	2.64	2.02	1.81	.81	.96	2.03	3.95	5.45	6.40	40.50
Seattle Boeing Field	14	5.46	4.21	3.53	2.15	1.58	1.43	.66	.81	1.83	3.50	5.22	5.73	36.11
Seattle City	14	5.19	3.90	3.32	1.97	1.59	1.41	.63	.74	1.65	3.28	5.00	5.42	34.10
Seattle Maple Leaf Res.	422	4.98	4.12	3.11	2.08	1.76	1.57	.77	.85	1.62	3.28	4.87	4.77	33.78
Seattle Naval Air Sta.	21	4.85	3.73	3.20	2.09	1.80	1.59	.65	.89	1.86	3.44	4.75	5.24	34.09
Seattle-Tacoma Airport	386	5.73	4.24	3.79	2.40	1.73	1.58	.81	.95	2.05	4.02	5.35	6.29	38.94
Seattle U of W	112	5.02	3.93	3.28	2.16	1.84	1.62	.74	.75	1.72	3.42	5.01	5.47	34.96
Snoqualmie Falls	440	7.85	6.35	6.14	4.00	3.20	3.21	1.29	1.43	3.18	6.15	8.38	9.12	60.30
Snoqualmie Pass	3,020	14.77	12.74	11.72	6.39	4.68	4.86	1.67	2.03	4.81	10.46	15.41	18.06	107.60

FIGURE 6.

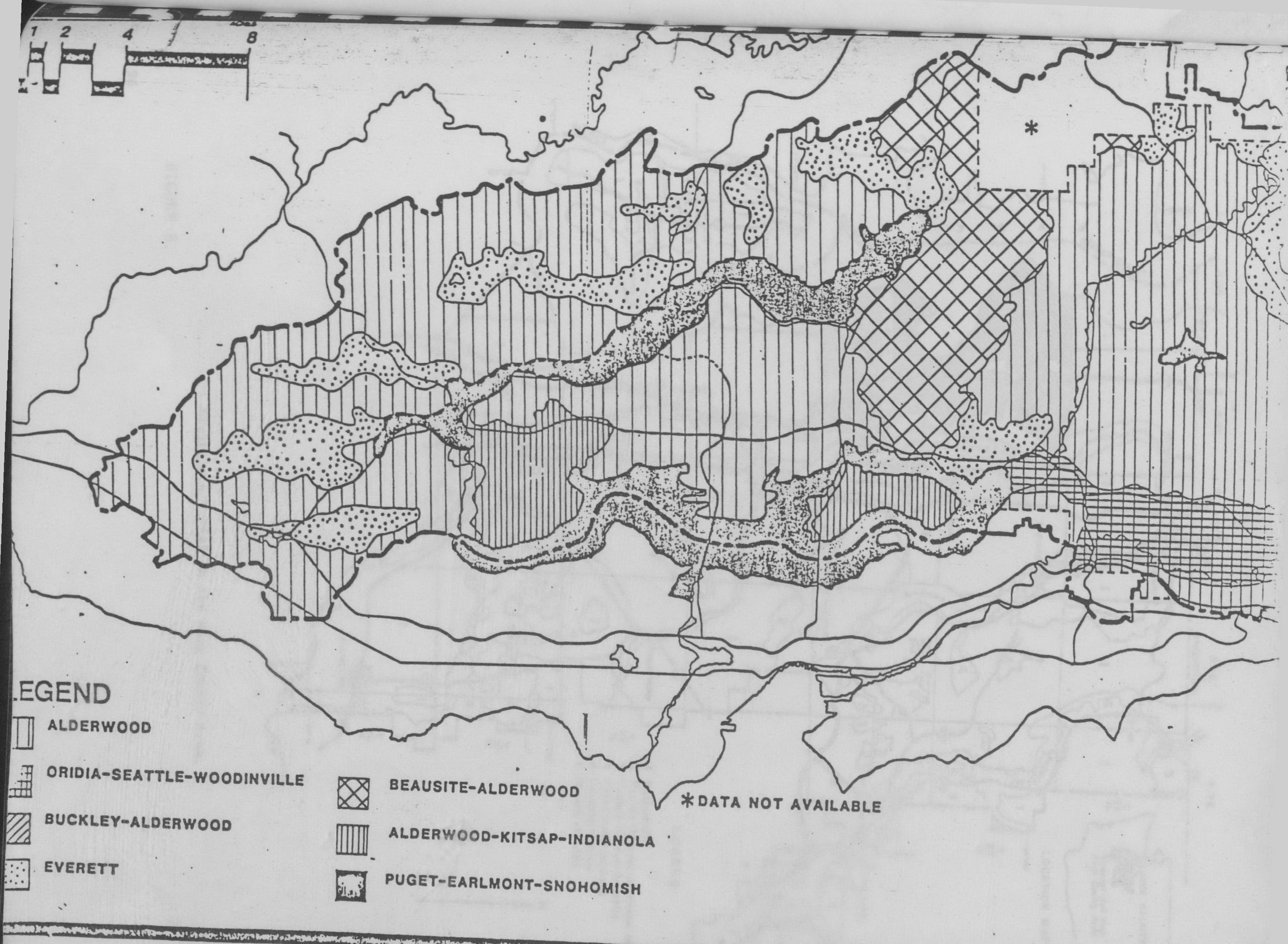
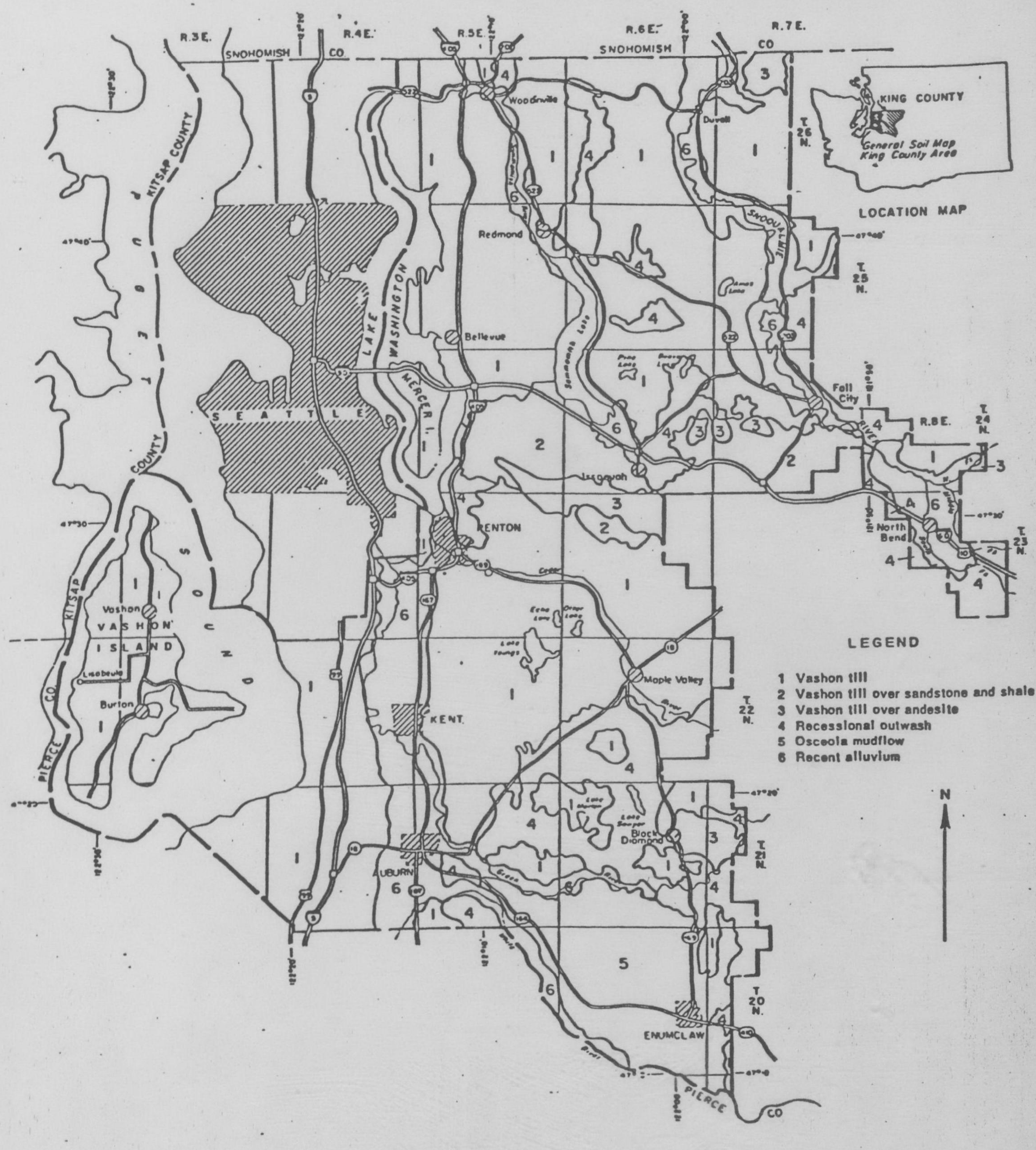

1
2
4
8
*
LEGEND
ALDERWOOD
ORIDIA-SEATTLE-WOODINVILLE
BUCKLEY-ALDERWOOD
EVERETT
BEAUSITE-ALDERWOOD
ALDERWOOD-KITSAP-INDIANOLA
PUGET-EARLMONT-SNOHOMISH
*DATA NOT AVAILABLE

FIGURE 7.



--Geologic material in the King County Area.

FIGURE 8.