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A survey of federal and state agencies was conducted to determine the future need for water-quality data. This survey was used as the basis for constructing a water-quality data aquisition system applicable to any river basin. This study outlines the major components of an automatic water-quality monitoring system.

Seventy-one sites in the Willamette River basin of Oregon were selected as monitoring sites for a model monitoring system. VHF radio and telephone telemetry systems were designed to service the model monitoring system. Economic models of the telemetry systems were constructed and compared.

The results of this study show that:

1. Enough interest in water-quality monitoring exists to justify the construction of an automated monitoring system.

2. The model monitoring system developed in this study may be adapted to any river basin.

3. A combination of VHF radio and telephone will require the lowest operating cost per year.

COMMUNICATION SYSTEMS FOR WATER-QUALITY DATA AQUISITION

by

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COMMUNICATION SYSTEMS FOR WATER-QUALITY DATA AQUISITION

CHAPTER I

INTRODUCTION

The need for water-quality data has expanded greatly in recent years because of an increased national concern for effective water pollution control and water resources management. Krause states that the need for basic water-quality data has increased in "a geometric rather than a linear progression" (14). The large increase in the number of water-quality measurements included in recent editions of Standard Methods for the Examination of Water and Wastewater is evidence of the increasing demand for water-quality data (3).

In the early years of the water-quality control effort the types of analysis available were limited. These generally consisted of a variety of conventional wet chemical methods of analysis. The sampling of streams and pollution sources was generally performed by manual methods and hours or days often elapsed between the time of sampling and analysis. As the complexity and scope of water pollution problems increased, a greater degree of sophistication in analysis and sampling was required. Agencies involved in water-quality studies were faced with a task of measuring a greater number of quality parameters at an increasing number of locations. Continuous monitoring of water quality at selected sites was determined to be necessary as the variation of water quality with time became recognized as a critical factor in water resources management.

The automatic monitoring station was developed to meet the requirements of continuous water-quality monitoring. Early models of the monitors consisted of sensing units that could measure dissolved oxygen, pH, temperature, turbidity, and conductance and would log these values on strip chart recorders. Periodically the data from each station was collected for further analysis. This approach provided a continuous record of water-quality data for each monitoring site, but because of the time delay these data did not provide management with the tool that could be used to correct unsatisfactory conditions prior to the development of more serious problems.

Electronics applied to water-quality instrumentation and recording provided the next and most recent generation of equipment for monitoring stream quality. By the use of telemetry it is now possible to transmit and record reliable water resources data from a number of monitors to a central point for management purposes.

The first extensive use of continuous water-quality monitoring coupled with the use of telemetry to report data occurred in the

Ohio River Valley (7). In 1958 the Ohio River Valley Sanitary Authority constructed six monitoring stations at widely scattered points. Four to six water-quality measurements were reported over low-grade telegraph lines using line-interrupt techniques. Since the initial success of monitoring in the Ohio Valley, monitoring stations have been constructed at widely scattered points throughout the United States. Three monitoring stations are presently installed in the Willamette River basin of Oregon. The Federal Water Pollution Control Administration has stations at Swan Island and Oregon City. The Oregon State Sanitary Authority has a station at Newberg. These stations are not presently equipped for telemetering.

The establishment of a basin-wide monitoring system has not been discussed in detail in the literature, yet water-quality monitoring is assuming a greater importance in river basin management. This paper will consider such an expectation.

Purpose

The general purposes of this paper may be stated as three-fold:

1. To outline a general automated system for the aquisition, transmission, and processing of water-quality data.

2. To develop economical telemetry links and general specifications for the transmission of water-quality data.

3. To determine future needs for water-quality monitoring in the Willamette Basin of Oregon.

Scope

This paper develops, for a model water-quality data aquisition system, telemetry networks based on very high frequency radio and telephone data communication. A general discussion of establishing and operating a comprehensive monitoring system is considered with the selection of station locations and water-quality data outputs emphasized as factors which directly affect communications. Major emphasis is placed on the economic comparison of possible VHF radio and telephone networks based on a model monitoring system designed for the Willamette River basin of Oregon. The final recommendations drawn from this study represent a composite of extensive help and advice from federal and state agencies and feasibility studies of possible communication systems.

CHAPTER II

THE NATURE OF A WATER-QUALITY MONITORING SYSTEM

A water-quality monitoring system is basically a telemetry system which has been adapted for the special purpose of acquiring water-quality data. Any telemetry system is composed of certain basic parts. These parts include instrumentation, signal conditioning equipment, transmitters and receivers, and data processing equipment. The major influences affecting the construction of a telemetry system are the type of data to be acquired by the system and the ultimate uses to be made of this data. The adaption of a basic telemetry system for the purpose of water-quality monitoring is the subject of this section.

A Water-Quality Monitoring System

A water-quality monitoring system is designed to measure both the quantity and quality of water in streams, rivers, or lakes. The fundamental purpose of an automatic monitoring system is the acquisition of desired data from a remote site without human supervision. The concept of an automatic "system" implies more than one monitoring site. It includes in addition to the equipment required at each monitoring site, the telemetry equipment required to relay data from remote sites and the data processing and control equipment necessary to process the data quickly and accurately.

A basin-wide automatic water-quality monitoring system will serve agencies and users with differing and sometimes conflicting goals. Each agency has been delegated a specific mission by law. Each agency needs water-quality data for its own specific purposes. The task of merging the various agency goals, programs, and plans into a compatible and viable program is the ultimate concern of river-basin management. The automatic water-quality data system cannot by itself resolve conflicts between agencies, but it can help provide data leading to more informed and intelligent decisions on over-all river-basin management.

Uses of Water-Quality Monitoring Data

Although many specific agency uses for water-quality data exist, three broad major uses may be identified:

1. Control of water quantity and/or quality by the operation of facilities.
2. Enforcement of water-quality standards.
3. Research.

Control activities include the operation of multipurpose reservoir projects, river bank protection, sewage treatment plants and other projects that physically affect or control the flow of water or wastes within a river basin. Enforcement activities include the use of water-quality data in support of either legal action or voluntary co-operation to secure adherence to previously set minimum levels of water quality. Enforcement activities may be directed against municipalities, industries, or private citizens to achieve a minimum level of water pollution. Research covers a wide range of activities designed to yield a better understanding of chemical, biological and physical relationships between streams, plants, animals, and men.

As an example of the broad water-quality interest of major water-oriented agencies, the interests of agencies in the Willamette River Basin of Oregon are summarized in Table 1.

Table 1. Water-Quality Interests of Selected Willamette Basin Agencies

Agency	Biological Analysis	Physical-Chemical Analysis	Basic Hydrological Data	Meteorological Data
Oregon State Sanitary Authority	x	x	x	
Federal Water Pollution Control Administration	x	x	x	
U. S. Geological Survey		x	x	x
U. S. Army Corps of Engineers			x	x
Oregon State Fish Commission		x	x	
State Water Resources Board	x	x	x	
Research Agencies	x	x	x	x

The interests of agencies in other river basins may differ somewhat from this pattern. To indicate the number and variety of agencies interested in water resources and water-quality data, Appendix A lists agencies participating directly or indirectly in the Willamette Basin Task Force.

Components of a Water-Quality Monitoring System

As indicated, water-quality monitoring includes more than just a set of electrodes placed in a convenient river. The monitoring system is essentially a telemetry system. Figure 1 contains a block diagram of a generalized water quality monitoring system.

Cerni and Foster list five steps in the aquisition and processing of data (6).

1. Instrumentation
2. Amplifiers and signal conditioning
3. Analog to digital conversion (optional)
4. Telemetry and data transmission
5. Data handling and processing

Figure 1 represents these five steps by the distinct grouping of equipment. The instrumentation, amplifiers, signal conditions, analog to digital convertors, and telemetry transmission equipment are located at each monitoring station. The telemetry receivers and data processing equipment are located at the control center of

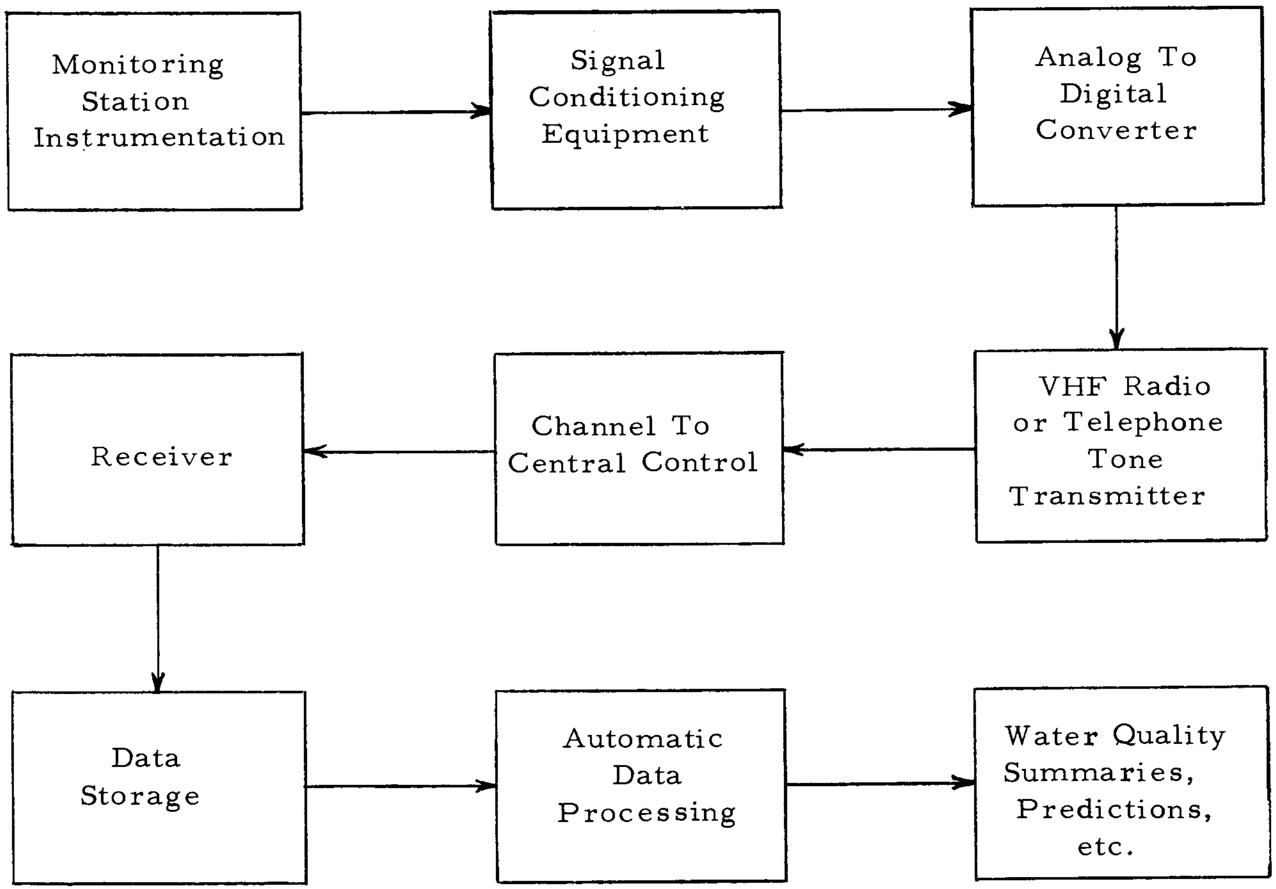


Figure 1. General water quality data aquisition system.

the monitoring system.

Instrumentation

The development of instrumentation to effectively monitor parameters can extend from simple temperature sensors at present to sophisticated equipment recording the passage of fish or counting Coliform bacteria in the future. It should be feasible to instrument most parameters which are or will be of concern to river basin management. Water-quality monitoring will extend to the detection, identification, and measurement of all organic or inorganic substances present in water. This will be extended to include data on meteorology, snow-pack, and other activities directly affecting the supply or consumption of water.

Water-quality and quantity data may be grouped into four classifications:

1. Biological
2. Chemical and Physical Analysis
3. Hydrological
4. Meteorological

Present water-quality measurement technology limits automatic monitoring to mainly physical mensuration together with some of the simpler chemical analyses. While many measurements may be performed in the laboratory (3), monitoring stations have been limited principally to conductivity, solar radiation, stage, turbidity, temperature, pH, dissolved oxygen, and chloride measurements. Table 2 lists suggestions for parameters to monitor which were made during this study. Work to develop new sensors for water-quality monitoring will be given added impetus as the need for water-quality data is recognized.

Table 2. Parameters for Water-Quality Monitoring

Hydrological	Meteorological	Chemical-Physical	
Reservoir - inflow	Air Temperature	Alkalinity	Nitrates
Reservoir - outflow	Snowfall	Ammonia	Organic Nitrogen
Reservoir - pool elevation	Solar Radiation	Biochemical Oxygen Demand	Organics
Stage	Wind Direction	Carbon Dioxide	Pearl Benson Index
	Wind Velocity	Chemical Oxygen Demand	Pesticides
		Chlorides	Phosphates
		Color	Radioactivity
		Conductivity	Sulfide
		Dissolved Oxygen	Suspended Solids
		Fish Identification and	Turbidity
		Counting	Volatile Solids
		Hardness	Water Temperature
		Heavy Metals	pH
		Nitrates	

The instrumentation should not be restricted in its design or principles of operation. From a systems standpoint, the only restrictions made are that each instrument output be expressible as an electrical quantity. Each instrument must also yield a unique reproducible output for each instrument input. The electrical output of the instrumentation will probably be analog in nature. An analog signal is a continuous function without discontinuities. The output of the instrumentation will generally serve as the input signals for the signal conditioners and amplifying equipment.

Amplifiers and Signal Conditioning

The output of the instrumentation may require amplification and signal conditioning before it is usable. Amplification allows the power level of the signal to be increased. This becomes increasingly important when a minimum power level is required to drive succeeding portions of the monitoring system.

Examples of signal conditioning may include zero suppression, filtering, impedance matching, or the performance of a mathematical operation such as differentiation, integration, addition, or the multiplication of two or more input signals. The signal conditioning equipment would probably be tailor-made for each instrument output. Signal conditioning equipment may be shared in common by two or more instrument outputs only if the output signals of each instrument are of equivalent magnitude and nature. The end result of signal conditioning must be a signal which is acceptable to the analog to digital encoding equipment. If analog to digital encoding equipment is not used, the signal must be acceptable to the telemetry transmitter.

Analog to Digital Encoders

The output of the instrumentation is analog. Analog signals can be transmitted for only limited distances before electrical noise and stability problems can introduce serious errors in the received analog measurements. Analog to digital conversion can partially or completely eliminate the error introduced by noise or drift.

Analog to digital conversion schemes are based on a quantization process wherein the complete range of instantaneous values of the analog signal is divided into a finite number of small subranges. Each of the subranges is represented by an assigned or quantized value within the subrange. A code word representing the subrange is then transmitted in place of the original analog signal. The quantization process introduces some error into the received signal, but this error may be reduced as much as desired--depending on the complexity of the encoding equipment (11, p. 70).

In this study it is proposed to transmit data over distances up to one hundred miles. This study will assume that all analog instruments outputs are converted to a corresponding binary digital code at each monitoring site. This takes advantage of the gain in accuracy of the received signal when an analog to digital conversion scheme is employed.

The digital code output from the analog to digital converter will consist of a string of binary pulses for each digit required to describe the quantization level corresponding to the original analog signal. A binary output from the analog to digital converter may allow simplification at later portions of the telemetry system. The selection of a particular analog to digital converter will depend on the data transmission rate, the number of digits transmitted for each measurement, and adaptibility to other equipment within the system.

Telemetry and Data Transmission

The selection of a suitable telemetry system depends on many factors, but the nature of the data to be transmitted must be the first consideration. Water-quality data normally consists of slowly varying parameters, i.e. changes are detectible only over a period of minutes or hours. Gunnerson (10) has stated that a monthly data profile of a normal stream can be reproduced by taking readings once every two hours. The data profile of a stream is determined by the relatively few data points required to reproduce slowly varying data profiles.

Even with a large monitoring system the amount of data generated would be small. Due to the slowly varying data a large bandwidth is not required to reproduce the data points needed to determine an adequate data profile. The data density generally does not require a high transmission rate. A bandwidth of one hundred Hertz is deemed adequate. Appendix C contains the calculations establishing this bandwidth.

Several types of communications systems meet the characteristics of water-quality data monitoring. This study investigates both telephone data transmission and VHF radio using frequency shift keying techniques. The use of microwave or similar large sized systems is not justified by the low density of water-quality data.

The binary coded digitized data from the analog to digital converter is used as the modulation signal for the VHF or telephone data transmitter. The transmission path (channel) from the transmitter to the receiver at a central station is either VHF radio or telephone land lines. The binary pulses received at the central station are stored on either paper punch tape, punch cards, or magnetic tape until used for data processing.

Data Handling and Processing

This study assumes that some type of computerized data processing will be available to handle the data received at the system control center. Worley has demonstrated that computer programs can be written to analyze and interpret water-quality data (19). It is a definite possibility that other computer programs will be written that can make recommendations for river basin operation and control based on the input of selected water-quality data.

Without adequate computer time available for analysis of reported water-quality data, human personnel would be hard-pressed to process the constant stream of data. A computer is essential to the operation of a monitoring scheme of any size.

Monitoring Stations

Monitoring stations contain a large share of the equipment associated with a monitoring system. They are the basic unit of the monitoring system. Each monitoring station is located near a river bank or on a lake front site selected in accordance with the need for water-quality data. A monitoring station basically contains a pump, water quality sensors, signal conditioners, analog to digital converter, and a recorder or telemetry equipment.

The pump is submerged in the middle of the stream and pumps a continuous stream of water up to the monitoring station. The water from the pump passes through the water-quality sensors which are housed in the monitoring station. The sensors produce a signal which is indicative of the present water quality of the stream. One monitoring station can contain as many sensors as desired.

The data output from the sensors passes through the signal conditioning equipment, the analog to digital converter, and into the telemetry transmitter. A strip chart recorder is used to record data if no telemetry facilities exist or a separate on-site record is desired.

The monitoring station equipment must be protected from the weather, floods, vandalism, and temperature extremes. This protection is secured by housing the monitoring station within a small air-conditioned building. A constant temperature-humidity environment is helpful for consistent operation of station equipment. The use of a small building also provides space for routine maintenance and record keeping.

The building site must be near the river bank to minimize the length of pipe required between the submerged pump and the sensors, yet above the flood stage, and accessible by foot or vehicle. In addition, proximity to a power line eliminates dependence on expensive battery power supplies and in some cases the location of communication facilities may influence the monitoring site selection.

The equipment used in a monitoring station should be standardized throughout the monitoring system. Individual equipment components should be built to facilitate ease of maintenance, replacement, and calibration. Some ability to interchange sensor units will be required during the lifetime of a monitoring station since the monitoring program for a station may be revised.

Operational Aspects of a Monitoring System

Some idea of the use of a monitoring system can be gained from describing a hypothetical water-quality data report. The report of water-quality data will entail the use of all components of the monitoring system previously discussed. For illustration purposes, assume that the system control center has determined that the temperature and stage readings (or any other data) are required from a monitoring station. The control center initiates the report by transmitting an interrogation signal through the telemetry system to the station. A receiver at the monitoring station receives and detects the interrogation signal. This in turn activates the transmission of data from the monitoring station back to the control center.

Ideally the instrumentation at the monitoring station would operate continuously and there would be no waiting period for the warm-up and stabilization of instrument outputs. If instrumentation must be activated at the monitoring station, the interrogation signal will serve to start the process. In such cases the transmission of data back to the control center would automatically occur following a delay for instrument warm-up and stabilization.

The output from each instrument is sampled, encoded, and transmitted serially. Each measurement consists of a transmission of four digits since four digit accuracy is commonly required for stage readings. In the case of temperature, the last two digits can be ignored in data processing unless a reading to the nearest hundreth of a degree is desired.

The monitoring station will transmit readings from all of the sensors even though only two measurements are desired. When the data is recorded back at the control center, the unneeded data can be eliminated. If desired the water-quality monitoring system may be constructed to allow the interrogation and reporting of only selected data without the transmission of other instrument outputs. This capability, however, introduces increased complexity and expense into the monitoring system.

In addition to the reporting of the instrument outputs, each station should transmit an identifying code corresponding to its station number. Included with the data can be reports on the voltage level of the station power supply and a reference voltage signal supplied by a Weston standard cell. The station voltage level indicates the present operational condition of batteries or other power supplies. Variations in the power supply may adversely affect the instrument outputs and produce erroneous results. The voltage signal from the standard cell provides a check on encoder, transmitter, and channel efficiency. Other service data on the operation of the monitoring station may be included.

The data from the monitoring station is recorded on magnetic tape as it is received at the control center. This data together with data from other monitoring stations is now available for automatic data processing. Data processing might include the tabulation of river temperatures throughout the basin or the calculation of flood stages from the stage data that has been reported. Many other types of water-quality data calculations are possible.

Any changes in instrument outputs which exceed a reasonable diurnal or seasonal variation could cause a monitoring station to be re-interrogated as part of an error detection scheme. The second set of readings may then be compared with the first set and the most valid data readings accepted. This process may also be used to detect equipment failure or drifts in calibration. The rules for the operation of an error detection scheme must be based on practical experience obtained from the operation of a monitoring system.

The calculations produced by the data processing equipment should be transmitted directly to the using agencies as soon as the data is available. Either the VHF radio or telephone system proposed in this study have the capacity to transmit the processed data in addition to the collection of water-quality monitoring data. Immediate access to water-quality data by the using agencies is a major factor in favor of the construction of a monitoring system.

The factors considered in this section may be applied to any monitoring system. The development of a specific monitoring system for the Willamette River of Oregon will be used in succeeding chapters of this study to further illustrate the steps required in the construction of a water-quality data aquisition system. It should be noted that a monitoring system such as considered here need not be limited to the reporting of water-quality data. Air pollution monitoring, snow-pack data, and meteorological functions may be considered as legitimate and expected uses of monitoring systems.

CHAPTER III

A MODEL WATER-QUALITY MONITORING SYSTEM

This chapter is concerned with the development of a model water-quality monitoring system. An actual river basin is employed as the basis of the model monitoring system. Waste loadings, geography, recommendations by water-quality agencies, and the projected capacity of monitoring stations are factors considered in the selection of monitoring sites. A rating system is developed to predict the relative importance of monitoring stations and actual monitoring sites are proposed for seventy-one stations.

Method of Study

This study uses the Willamette River basin of Oregon as a model river basin in the development of an automatic monitoring system which may be adapted to other river basins. Representatives of the agencies listed in Table 1 were interviewed to determine the basis for the selection of monitoring station sites concurrent with an identification of the water-quality parameters which were of interest to each agency. From this initial data the specifications for the construction of a communications system to serve the monitoring network were determined. This involved primarily a determination of the volume and frequency of water-quality data reports to be transmitted by the monitoring system. A list of seventy-one sites became the basis of the model monitoring system following their selection as suitable monitoring stations.

A tentative method of operation for the monitoring system was established based on the assumption that twenty-four hour monitoring coverage would be maintained and that a data processing computer would be available for the control and operation of the monitoring system. VHF radio and telephone data transmission were then selected as the communications systems most capable of meeting the requirements of the tentative method of operation, the predicted volume and frequency of data, and the geographical nature of the Willamette River basin.

Separate VHF radio and telephone systems were designed for the monitoring system. Extensive help from Pacific Northwest Bell Telephone and individuals familiar with VHF radio was utilized in the design of the telemetry systems and the development of an economic model for each. From the economic models a comparison of the two systems was performed and the factors governing the selection of the most economical communications system for water-quality data aquisition were identified.

The Willamette River Basin

The Willamette River has been chosen both for convenience in carrying out this study and for the variety of stream conditions to be found throughout the basin. Figure 2 is a map of the Willamette River basin. The basin drains into the Columbia River and extends south about 150 miles from Portland, Oregon. It is bordered on the west by the Coast Range and on the east by the Cascade Mountains. The basin averages 75 miles in width and contains about 11,200 square miles. Two-thirds of the land within the basin consists of mountainous forested regions. The remainder of the land consists of level or gently rolling valley floor.

Approximately 84 percent of the basin population of 1,170,000 is concentrated in the metropolitian areas of Portland, Salem, and Eugene. Major industries contributing to the waste loading of the basin are canneries, paper mills, forestry activities, and the extensive agricultural development of the Willamette Valley. Figure 2 indicates the major sources of waste loadings with the Willamette basin (18, 19).

Selection of Monitoring Sites

To facilitate the selection of monitoring sites in the Willamette River basin, the river system has been divided into five sections:

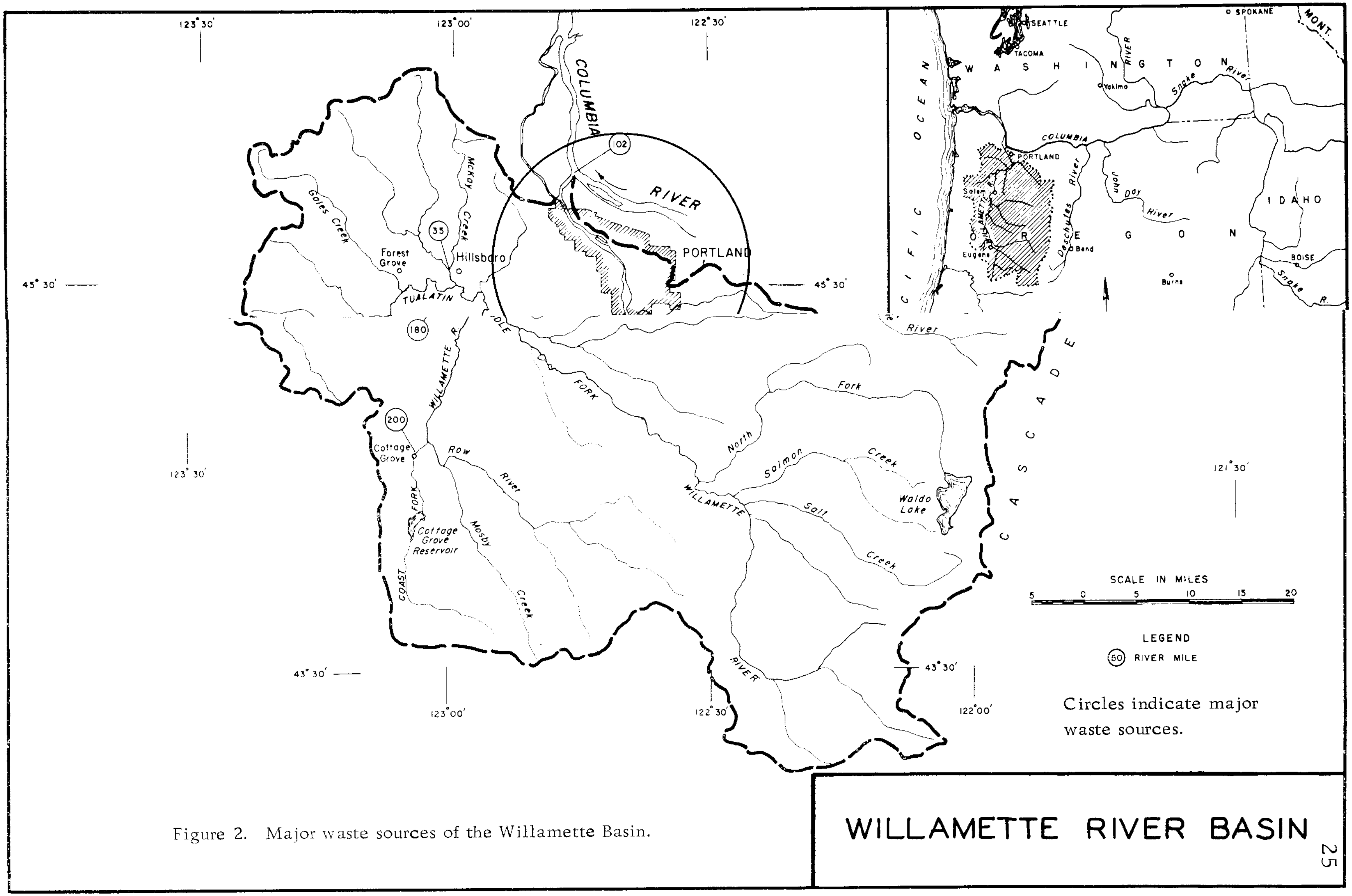


Figure 2. Major waste sources of the Willamette Basin.

Table 3. Division of the River Basin

1.	Main stem (Columbia River to Eugene)
2.	Major tributaries (Santiam, McKenzie, Coast and Middle Forks of the Willamette)
3.	Minor tributaries
4.	Reservoirs (13 sites)
5.	Reservoir tributaries

The main stem ultimately carries all wastes and water originating within the basin. Major emphasis in the monitoring system is placed on this section of the river. Due to the complexity of the main stem, all types of parameters will be monitored. The general method adopted for the selection of monitoring sites on the main stem is to bracket major or potential waste sources with monitoring stations upstream and downstream. For example Figure 2 shows Salem, Oregon as a major waste source. By placing a monitoring station to the south of Salem at Independence and a station to the north of Salem at Wheatland, a check on the river water quality before and after Salem wastes have been added to the river is achieved.

The major tributaries contain most of the multi-purpose projects which provide some control over river flow and water quality, but the major tributaries normally do not contribute large quantities of wastes to the main stem. The emphasis on the major tributaries shifts to basic hydrological data although some water-quality data is required as a check on water entering the main stem. Since the biggest portion of river flow on the main stem originates from major tributaries, monitoring stations on the major tributaries become integral to the proper interpretation of data supplied by stations on the main stem.

Minor tributaries normally do not greatly affect the main stem due to the dilution of tributary waters by the much larger quantities of main stem flow. Small waste loadings which would be barely noticeable in a large stream may greatly affect a small stream. Emphasis on minor tributaries returns to all types of water-quality data although the need for basic hydological data continues. Minor tributaries in populated areas may be the first to show the effects of over-loading of wastes.

Reservoirs are normally considered sources of relatively pure water. Since reservoirs act as the primary flow control devices on the river, monitoring at reservoirs emphasises basic hydrological data. Since rainfall or drought can seriously affect reservoir levels, meteorological data assumes an increasing importance at such sites. The need for intensive monitoring of waste loadings should not arise at reservoirs because of the absence of population centers and heavy industry. In some cases agricultural activity or lumbering may introduce wastes, but this is not expected as a general rule.

Most sites located on reservoir tributaries are in mountainous undeveloped regions. These sites provide important meteorological and hydrological data relative to control of the reservoirs and the entire river basin. Intensive waste loadings are not expected in this area of the basin.

While emphasis in various sections of the river basin may lean more toward monitoring hydrological data than water-quality data, this does not preclude the monitoring of any parameter at any site. As research on stream behavior is continued new types of parameters for monitoring will undoubtedly be suggested.

It is now possible to consider the relative importance of the various sections of the river basin listed in Table 3. Table 4 represents the development of a point system summarizing the relative importance of each section of the river basin. The influence of the cooperating agencies is equalized by awarding one point for each monitoring site each time it is recommended by any of the agencies.

Table 4. Relative Importance of River Basin Sections

Station Location	Points Assigned
Main Stem	10
Major Tributaries	8
Reservoirs	6
Minor Tributaries	4
Reservoir Tributaries	2
Each Agency Recommendation	1

The points for each station site are summed by adding the appropriate number of points for the location of the station plus one point for each time the station site is recommended by an agency. The point totals for each station may be interpreted with the aid of Table 5.

Table 5. Interpretation of Point Totals

Class	Pt. Total	Interpretation
I	11 - 13	To be built within an immediate 5 yr. period.
II	7 - 10	To be built within 5 to 15 years.
III	3 - 6	Stations eventually included in a comprehensive monitoring system.

Stations are designated as Class I, II, or III. Class I stations are the most important in the monitoring system and would be the first to be constructed. Class II stations are of intermediate importance and would be constructed following completion of the Class I stations. Class III stations include all sites that would ultimately be needed in the development of a comprehensive monitoring system. Table 6 lists the points awarded each of the seventy-one proposed monitoring stations and designates the class of each. The station numbers listed in Table 6 correspond to the numbers used in Figure 3 and listed in Table 8.

Size of Monitoring Stations

To complete the selection of proposed monitoring sites some consideration must be given to the number of parameters that might be monitored at each site. Three station sizes are considered adequate.

1. A large 22 parameter monitor for use principally on the main stem at locations with complex monitoring needs.

2. An intermediate 14 parameter monitor for general purpose use.

3. A small 8 parameter monitor for use where a minimum of data is gathered.

It is apparent that most stations will monitor more parameters as new instrumentation is developed. To meet this growth a planned program for the expansion of monitor capacity must be developed. Since the expansion of the monitoring system has already been planned in three stages, the expansion of monitoring capacity will be co-ordinated with the growth of the monitoring system. Table 7 indicates the expansion of the monitoring capacity of various types of stations. This expansion should insure that adequate monitoring capacity is available for the needs of the monitoring system.

Table 6. Summary of Station Point Totals

Station Number*	Total Points	Class	Station Number	Total Points	Class	Station Number	Total Points	Class
1	13	I	25	4	III	49	11	I
2	6	III	26	4	III	50	3	III
3	8	II	27	8	II	51	4	III
4	4	III	28	4	III	52	5	III
5	6	III	29	4	III	53	10	II
6	6	III	30	9	II	54	4	III
7	8	II	31	8	III	55	13	I
8	4	III	32	4	III	56	8	II
9	7	II	33	8	II	57	4	III
10	10	II	34	4	III	58	13	I
11	6	III	35	4	III	59	13	I
12	10	II	36	12	I	60	4	III
13	8	II	37	8	II	61	7	II
14	4	III	38	4	III	62	6	III
15	8	II	39	4	III	63	12	I
16	4	III	40	9	II	64	11	I
17	8	II	41	4	III	65	10	II
18	6	III	42	12	I	66	6	III
19	4	III	43	10	II	67	6	III
20	6	III	44	7	II	68	13	I
21	8	II	45	6	III	69	11	I
22	4	III	46	8	II	70	13	I
23	13	I	47	4	III	71	7	II
24	8	II	48	7	II			

*See Figure 3 for location of each station.

Table 7. Expansion of Monitoring Capacity

Type of Station	5 yrs.	15 yrs.	Completed system
1. Main stem and mouth of major tributaries	14	14	22
2. Mouths of minor tributaries in populated areas	0	14	22
3. Reservoirs and upstream on tributaries in populated areas.	0	14	14
4. Mouths of minor tributaries and rivers with large fish runs.	0	0	14
5. Re-regulating dams and reservoir tributaries	0	0	8

Location of Monitoring Sites

Figure 3 locates the seventy-one monitoring sites proposed for the Willamette River basin. Table 8 indicates the location of each monitoring site and indicates the monitoring capacity assigned to each station. The numbering of stations in Table 8 corresponds to that of Table 6 and Figure 3.

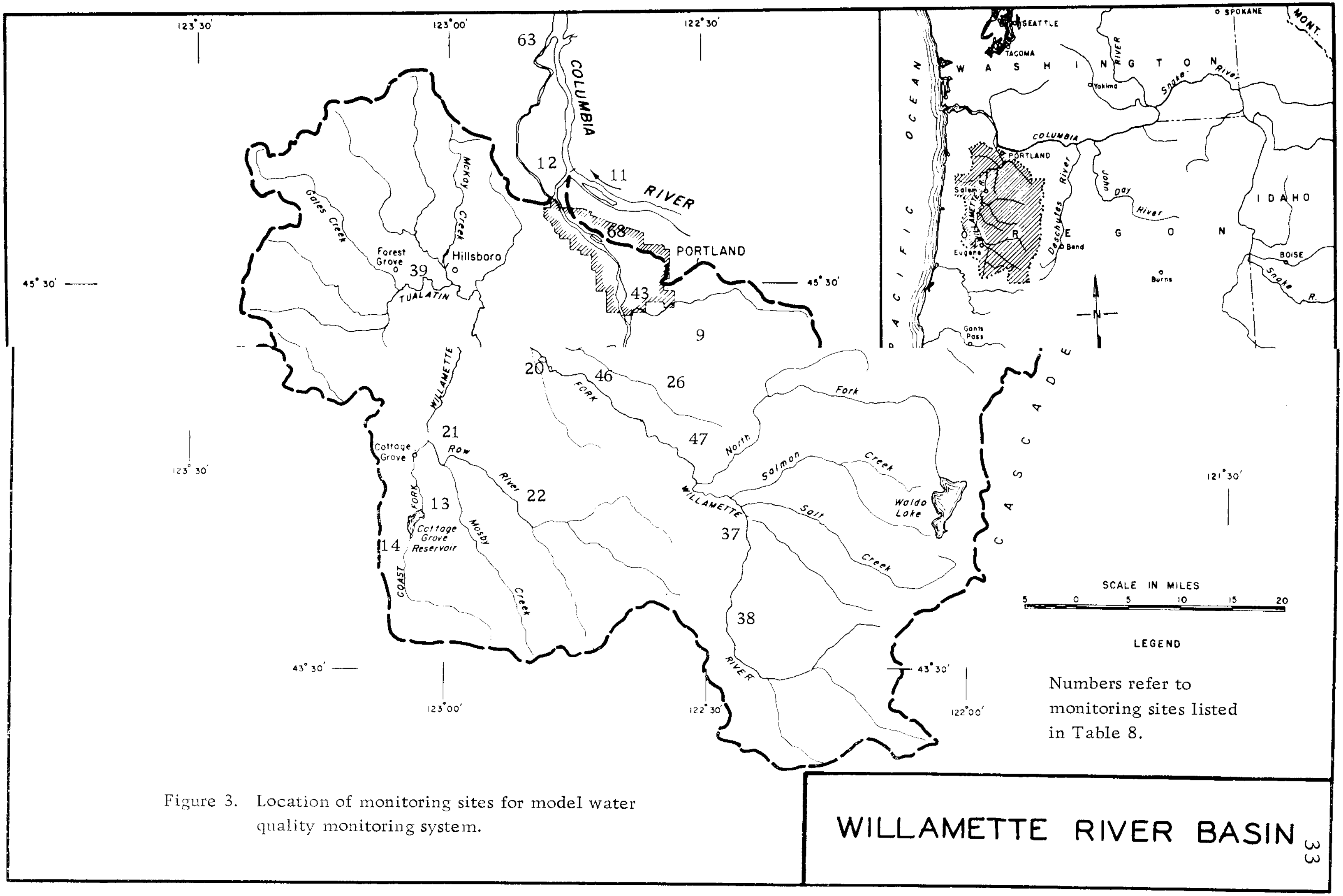


Figure 3. Location of monitoring sites for model water quality monitoring system.

Table 8. Monitoring Sites

Name and Location*	River	Parameter Capacity		
		5 yrs.	15 yrs.	Ultimate
1. Albany USGS Gauge 1740 mi. 119.31	Willamette	14	14	22
2. Big Cliff Dam mi. 58.1	N. Santiam	0	0	8
3. Blue River Dam mi. 1.7 - Damsite	Blue River	0	14	14
4. Blue River-Upper Reaches USGS Gauge 1611 mi. 8.7	Blue River	0	0	8
5. Calapooya-Mouth of River USGS Gauge 1735 mi. 3.0	Calapooya	0	0	14
6. Canby USGS Gauge 2000 mi. 8.11 - Aurora	Molalla	0	0	14
7. Cascadia Damsite USGS Gauge 1850 mi. 45.8	S. Santiam	0	14	14
8. Cascadia Reservoir Upper Reaches mi. 57.0	S. Santiam	0	0	8
9. Clackamas Mouth USGS Gauge 2110 mi. 4.8	Clackamas	0	14	22
10. Coast Fork Mouth USGS Gauge 1575 mi. 6.0	Coast Fork Willamette	0	14	14
11. Columbia River Interstate Bridge mi. 106.5	Columbia	0	0	14
12. Columbia Slough mi. 0.2	Willamette	0	14	22
13. Cottage Grove Dam mi. 29.7	Coast Fork Willamette	0	14	14

Table 8. (Continued)

Name and Location	River	Parameter Capacity		
		5 yrs.	15 yrs.	Ultimate
14. Cottage Grove Reservoir Upper Reaches USGS Gauge 1525 mi. 35.9	Coast Fork Willamette	0	0	8
15. Cougar Dam mi. 3.7	McKenzie (South Fork)	0	14	14
16. Cougar Reservoir Upper Reaches USGS Gauge 1592 mi. 10.4	McKenzie (South Fork)	0	0	8
17. Detroit Dam mi. 60.9	N. Santiam	0	14	14
18. Detroit Reservoir Upper Reaches Gauge 1790 mi. 2.0	Breitenbush River	0	0	8
19. Detroit Reservoir Upper Reaches USGS Gauge 1780 mi. 70.7	N. Santiam	0	0	8
20. Dexter Dam mi. 203.8	Middle Fork Willamette	0	0	8
21. Dorena Dam USGS Gauge 1550 mi. 28.3	Row River	0	14	14
22. Dorena Reservoir Upper Reaches USGS Gauge 1545 mi. 33.9	Row River	0	0	8
23. Eugene mi. 181.2	Willamette	14	14	22
24. Fall Cr. Dam mi. 7.0	Fall Creek	0	14	14
25. Fall Cr. Reservoir USGS Gauge 1503 mi. 14.4	Fall Creek	0	0	8

Table 8. (Continued)

Name and Location	River	Parameter Capacity 5 yrs.	15 yrs.	Ultimate
26. Fall Cr. Reservoir USGS Gauge 1508 mi. 4.4	Winberry Creek	0	0	8
27. Fern Ridge Dam USGS Gauge 1680 mi. 25.7	Long Tom River	0	14	14
28. Fern Ridge Reservoir Upper Reaches USGS Gauge 1665 mi. 37.4	Long Tom River	0	0	8
29. Fern Ridge Reservoir Upper Reaches USGS Gauge 1670 mi. 3.8	Coyote Creek	0	0	8
30. Foster Dam mi. 37.7	S. Santiam	0	14	14
31. Gate Creek Dam Damsite - mi. 0.4	S. Fork Creek on McKenzie River	0	0	14
32. Gate Creek Dam Upper Reaches mi. 4.5	S. Fork Creek	0	0	8
33. Green Peter Dam mi. 45.7	Middle Fork Santiam River	0	14	14
34. Green Peter Reservoir Upper Reaches USGS Gauge 1858 mi. 16.0	Middle Fork Santiam River	0	0	8
35. Green Peter Reservoir Upper Reaches USGS Gauge 1859 mi. 6.6	Quartzville Creek	0	0	8
36. Harrisburg USGS Gauge 1660 mi. 161.2	Willamette	14	14	22

Table 8. (Continued)

Name and Location	River	Parameter Capacity		
		5 yrs.	15 yrs.	Ultimate
37. Hills Creek Dam mi. 232.5	Middle Fork Willamette	0	14	14
38. Hills Creek Reservoir Upper Reaches USGS Gauge 1448 mi. 241.3	Middle Fork Willamette	0	0	8
39. Hillsboro mi. 55.0	Tualatin	0	0	14
40. Holley Damsite USGS Gauge 1720 mi. 45.4	Calapooya	0	14	14
41. Holley Reservoir Upper Reaches mi. 60	Calapooya	0	0	8
42. Independence mi. 95.2	Willamette	14	14	22
43. Johnston Creek mi. 1	Johnston Creek	0	14	22
44. Leaburg mi. 33.7	McKenzie	0	14	22
45. Long Tom Mouth of River USGS Gauge 1700 mi. 6.8	Long Tom	0	0	14
46. Lookout Point Dam USGS Gauge 1490 mi. 206.9	Middle Fork Willamette	0	14	14
47. Lookout Point Reservoir Upper Reaches USGS Gauge 1480 mi. 220.2	Middle Fork Willamette	0	0	8
48. Luckiamute Mouth of River mi. 6.0	Luckiamute	0	14	22

Table 8. (Continued)

Name and Location	River	Parameter Capacity		
		5 yrs.	15 yrs.	Ultimate
49. McKenzie Mouth of River USGS Gauge 1655 mi. 7.1	McKenzie	14	14	22
50. McKenzie Bridge USGS Gauge 1590 mi. 69.9	McKenzie	0	0	8
51. McMinnville USGS Gauge 1940 mi. 27.91 (From Willamette)	Yamhill	0	0	14
52. Mary's River mi. 0.3	Mary's River	0	0	14
53. Middle Fork USGS Gauge 1520 mi. 195.0	Middle Fork Willamette	0	14	14
54. Molalla Up Stream USGS Gauge 1985 - Site mi. 32.2	Molalla	0	0	14
55. Newberg Existing Station mi. 50	Willamette	14	14	22
56. North Fork Dam mi. 31.1	Clackamas	0	14	14
57. North Fork Reservoir Upper Reaches USGS Gauge 2095 mi. 47.8	Clackamas	0	0	8
58. Oregon City (Below Falls) mi. 25.0	Willamette	14	14	22
59. Oregon City Above Falls-Existing Station mi. 27	Willamette	14	14	22

Table 8. (Continued)

Name and Location	River	Parameter Capacity 5 yrs.	15 yrs.	Ultimate
60. Pedee USGS Gauge 1900 mi. 29.7	Luckiamute	0	0	14
61. Pudding River USGS Gauge 2020 mi. 9.0	Pudding River	0	14	14
62. Rickreall Creek mi. 0.5	Rickreall Creek	0	0	14
63. St. Helens mi. 0.2	Multnomah Channel	14	14	22
64. Santiam USGS Gauge 1890 mi. 9.62	Santiam River	14	14	22
65. South Santiam mi. 8.0	South Santiam	0	14	14
66. Stayton USGS Gauge 1841 mi. 14.61	North Santiam	0	0	14
67. Strube Dam mi. 2.5	South Fork McKenzie River	0	0	8
68. Swan Island Existing Station mi. 9.0	Willamette	14	14	22
69. Tualatin USGS Gauge 2075 mi. 1.8	Tualatin River	14	14	22
70. Wheatland mi. 73.5	Willamette	14	14	22
71. Yamhill mi. 5.0 (Dayton)	Yamhill River	0	14	22
				1020

*Source: 2, 4, 5, 16, 18

CHAPTER IV

THE USE OF VHF RADIO FOR DATA TRANSMISSION

Radio has frequently been used in providing communications with inaccessible sites similar to some envisioned in the model water-quality monitoring system. The technical problems of transmitting binary digital data have mainly been solved and eliminated in relation to the requirements of water-quality monitoring. The use of radio is reduced to mainly economic and physical considerations which will be discussed in this section.

Very High Frequency Radio

The VHF radio frequency range extends from 30 to 300 mega-Hertz. In the United States some VHF radio frequencies have been allocated for hydrological purposes. In addition, frequencies have been reserved for the use of a number of the federal and state agencies interested in water-quality monitoring.

The use of particular radio frequencies depends on the allocation of the radio frequencies by either the Federal Communications Commission or the Intergovernmental Radio Allocation Committee. These bodies govern non-federal and federal radio allocations respectively. The author was assured by an FCC representative (15) that frequencies would be available for the development of water-quality monitoring if VHF radio were chosen as a communications method. The final selection of frequencies in the VHF range of 140-180 megahertz would depend on the location of the transmitters, power of the transmitters, proximity to other transmitters and the expected use of the radio.

Several models of VHF radios are currently used to report gauge heights and stream flow data within the Willamette basin. These VHF radios are limited primarily to line-of-sight transmission. The obstruction of the signal by a hill or building can seriously affect the reliability of the system. If line-of-sight conditions do not exist between the originating and receiving stations, a relay station must be provided. In this situation the transmitted signal is received at an intermediate point which must have line-of-sight visibility to both the originating and receiving points.

Most of the VHF radios being installed at the present time are built with solid-state components. The use of solid-state transmitter/receivers can reduce both power and maintenance requirements. Batteries have been found sufficient to operate a solid-state radio receiver continuously and a transmitter intermittently for a period of six months (9). The use of solid-state components in radios has not yet produced reliable data on the expected lifetime of such equipment. It is now apparent that a significant increase in the lifetime of solid-state radios over that of tube-type radios may be expected.

A reliable power supply will be required to operate the equipment at each monitoring station. For VHF radio equipment, power would be required to operate the receiver continuously and the transmitter intermittently. The receiver is required to detect the interrogation signals needed to initiate the data reports. In most cases a transmitter power of five watts or less has proven sufficient to transmit a frequency shift-keyed carrier up to forty miles (13). The power supply may be either battery, fuel-cell, or commercial power. If available, commercial power is most economical.

Design of VHF Radio System

The VHF radio system was designed to provide line-of-sight transmission to all monitoring stations. In some situations a number of relay stations are required to reach very remote monitoring sites. Figure 4 shows the main VHF radio relay systems required to connect the complete monitoring system. Appendix B contains more detailed information on the coverage provided for each monitoring site.

The McKenzie River portion of the model monitoring system will be examined in detail and a comparison made between VHF radio and telephone. Figure 5 is a map of the McKenzie River and

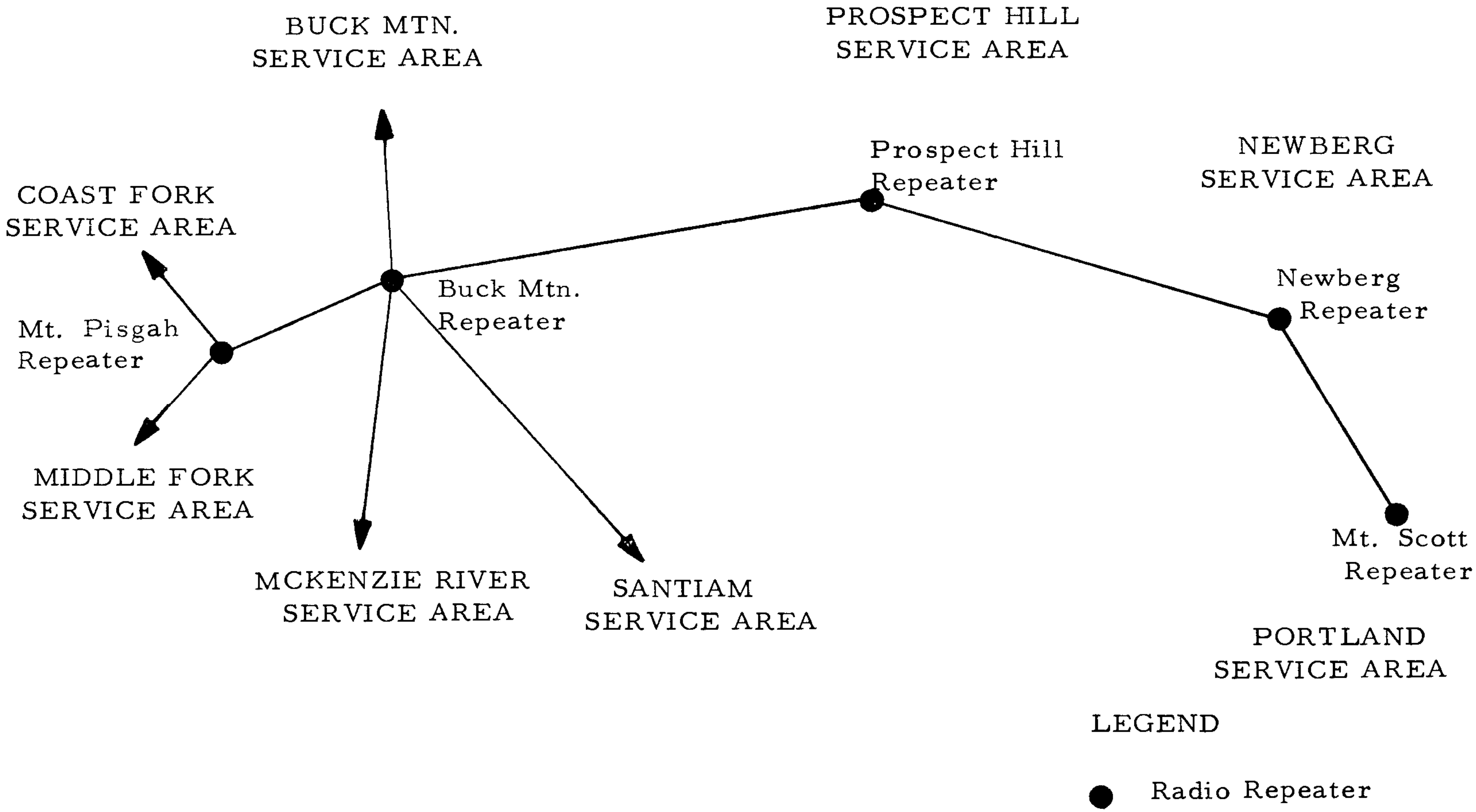


Figure 4. VHF radio service areas and repeaters.

the nine monitoring stations located on it. This figure indicates the three radio relay points required to allow complete coverage of the nine McKenzie stations.

Economics

The costs of buying and maintaining VHF radios are outlined below. All costs are given in terms of 1966 prices.

Capital Costs: A transmitter/receiver set including a tone transmitter will cost $3000. This price includes the cost of installation and initial calibration.

Depreciation: An eight year depreciation period is allowed by the Internal Revenue Service for the tax write-off of electrical equipment (8, 13, 17; p. 19). The straight line method of depreciation is used due to its simplicity.

Rate of Return on Capital: Water-quality monitoring is a non-profit activity. However, a six percent interest cost on the remaining undepreciated capital is treated as a yearly expense (8).

Power: If no commercial power is available, $135 per year must be allotted as the cost of batteries. This applies mainly to very remote sites (9).

Maintenance: Yearly maintenance costs are assumed to increase with the age of the radio equipment as shown in Table 9 (8). Maintenance should be mainly "preventive" and include periodic

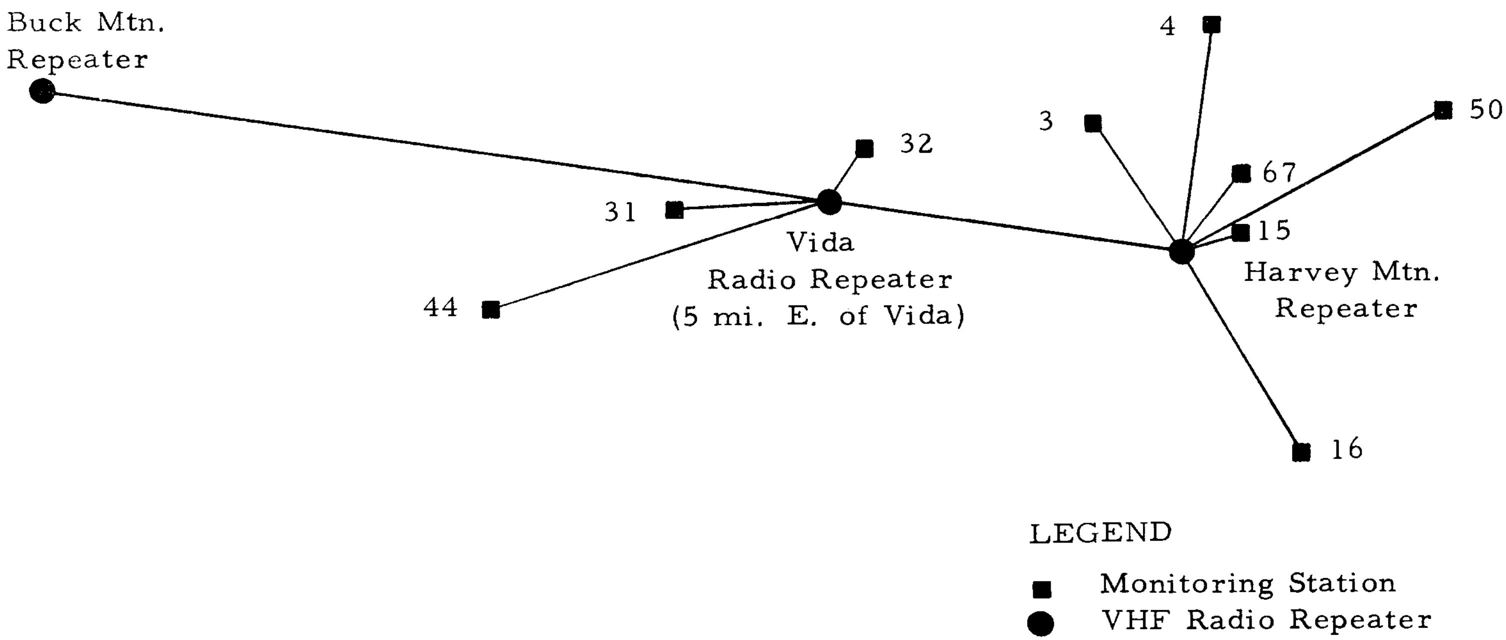


Figure 5. VHF radio service for the McKenzie River service area.

calibration of equipment.

Table 9. Maintenance Costs per Year

Age of Equipment	Cost as % of Original Cost
1	0.625%
2	1.250%
3	1.875%
4	2.500%
5	3.125%
6	3.750%
7	4.375%
8	5.000%
9	6.000%
10	7.000%
11	8.000%
12	9.000%
13	10.000%
14	11.000%

Assuming commercial power is available, the average cost of operating a VHF radio over an eight year period is presented in Table 10. This can be considered the cost of VHF telemetry for one monitoring site.

If the calculations are based on an extended equipment lifetime beyond the initial eight year tax write-off period, the average cost/ year will change. Figure 6 indicates this change in the average yearly cost of a VHF radio.

For the McKenzie river system shown in Figure 5, the cost for eleven VHF radios is $6190 per year. The cost of batteries for power at remote sites is $540 per year for a total of $6730 per year.

The cost of a VHF radio system to serve the entire model water-quality monitoring system is shown in Table 11.

Table 10. Operational Cost of a VHF Radio

Year	Capital Cost	Depreciation	Maintenance	Interest on Capital	Total
1	$3000	$375	$ 19	$180	$574
2	----	375	37	158	570
3	----	375	57	135	567
4	----	375	75	113	563
5	----	375	94	90	559
6	----	375	112	67	554
7	----	375	132	45	552
8	----	375	150	28	553
			Average Cost/Year	$562/Station	

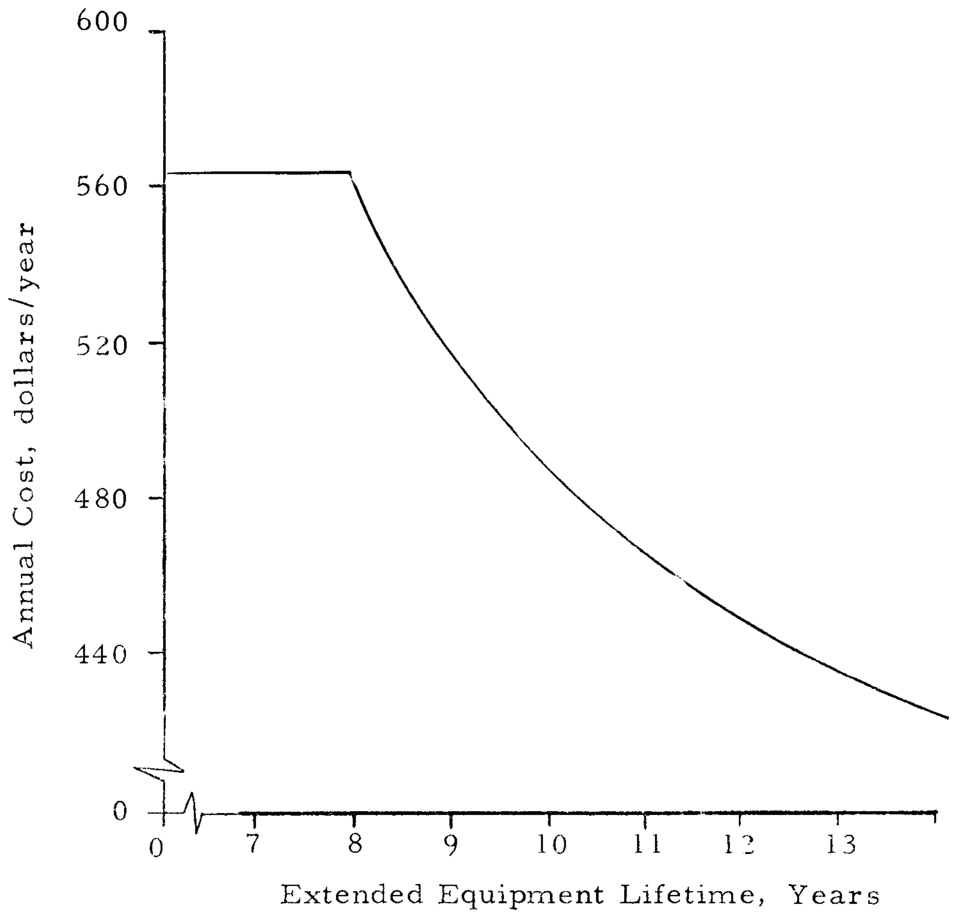


Figure 6. Average annual cost of operating VHF radio with increased equipment lifetime.

Table 11. Cost of VHF Communication System

Service Area	# of radios Transmitter/receivers	# of remote sites	Costs/yr.	Batteries	Total/yr.
Buck Mtn.	8	0	$4500	0	$4500
Coast Fork	9	4	5060	540	5600
McKenzie	11	4	6190	540	6730
Middle Fork	11	4	6190	540	6730
Newberg	9	2	5060	270	5330
Portland	12	1	6750	135	6885
Prospect Hill	10	0	5620	0	5620
Santiam	16	6	9000	810	9810
				TOTAL	$51, 205/yr.

CHAPTER V

THE USE OF TELEPHONE FOR DATA TRANSMISSION

Telephone service can be provided for any of the monitoring sites considered in the model monitoring system. In most instances existing facilities can provide service but some additional new telephone lines would be required in remote areas. Telephone data communications, similar to VHF radio, presents no special technical problems. The adaption of telephone service to water-quality monitoring is primarily a problem in economics.

Telephone Data Transmission

Telephone service is available in many forms. The initial step in the selection of proper equipment for data transmission is the determination of the minimum circuit bandwidth required to provide an acceptable level of service. Bandwidth is defined as the difference between the highest and lowest frequencies to be transmitted. For telephone data transmission the assumption will be made that the lowest frequency to be transmitted is zero Hertz. This assumption will hold for most tone channels and circuits considered in this study. The highest frequency transmitted by the circuit determines the required bandwidth. The highest frequency transmitted in a telephone data circuit is usually determined by the speed of data transmission.

The charges made for the use of a telephone circuit depend on the bandwidth required to transmit the data. For comparison, normal voice conversations require a 2500 Hertz bandwidth. A 100 Hertz bandwidth is adequate for water-quality monitoring. One hundred Hertz allows the water-quality data to be transmitted at a satisfactory rate for monitoring purposes. Appendix C contains the calculations supporting this choice of bandwidth.

Design of a Telephone Data System

The design of the telephone monitoring system consists of providing a separate 100 Hertz telephone channel for each major area of the basin. Ten separate channels have been used to serve from five to nine monitoring stations each. Figure 7 shows the channel service areas which originate locally in Eugene, Albany, and Portland. A 2500 Hertz channel provides contact between the local channels terminating in each city and the system control center. The control center can be located conveniently within any of the three cities.

The use of separate local telephone channels compared with the use of a single 2500 Hertz channel for the entire system simplifies control problems. By use of separate local channels, it

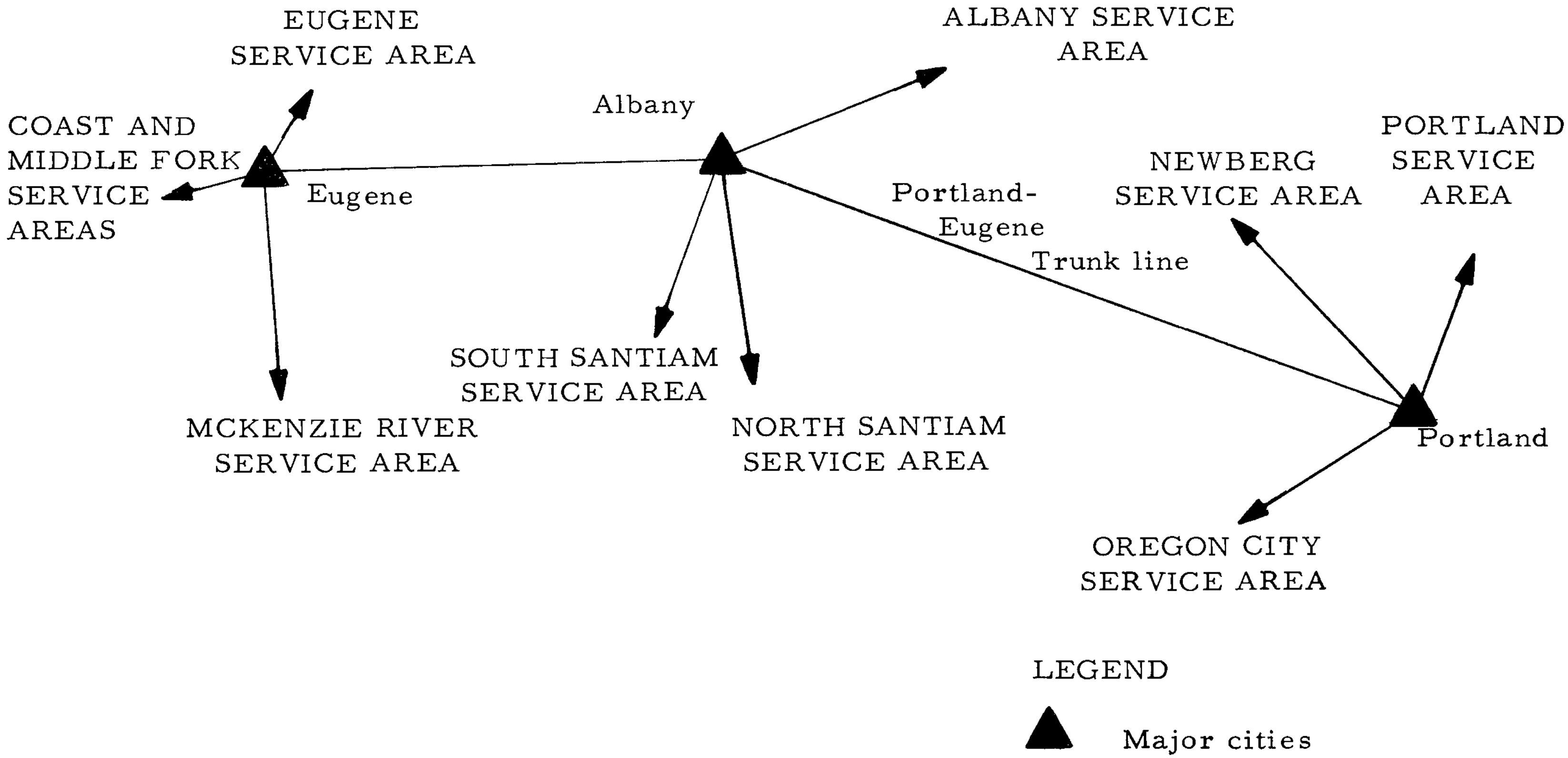


Figure 7. Telephone data transmission system for the Willamette Basin.

is possible to identify the reporting stations with greater certainty. The problem of station identification is reduced to differentiating between nine stations at a maximum. Also the possibility of the wrong station answering an interrogation signal is reduced. The service area of the McKenzie River channel is shown in Figure 8. Diagrams of the other telephone channel service areas may be found in Appendix D.

New Telephone Line Construction

A factor in the use of telephone data transmission for water-quality monitoring is the need for new telephone line construction at remote stations. The charges for the construction of these new lines will be shown to be an important factor in the cost of telephone service. Seventeen locations have been identified as requiring new telephone lines to provide service to a monitoring station. Table 12 contains the location of these sites and information on the cost to construct new lines.

The airline mileage used in Table 12 is the distance in a straight line from the end of existing telephone line to the monitoring station site. A factor of 1.3 is used to calculate the approximate ground distance (12). The cost of the lines is computed by multiplying the ground mileage times a cost of $1870 per mile (1). These figures are approximations and detailed on-site surveys would be

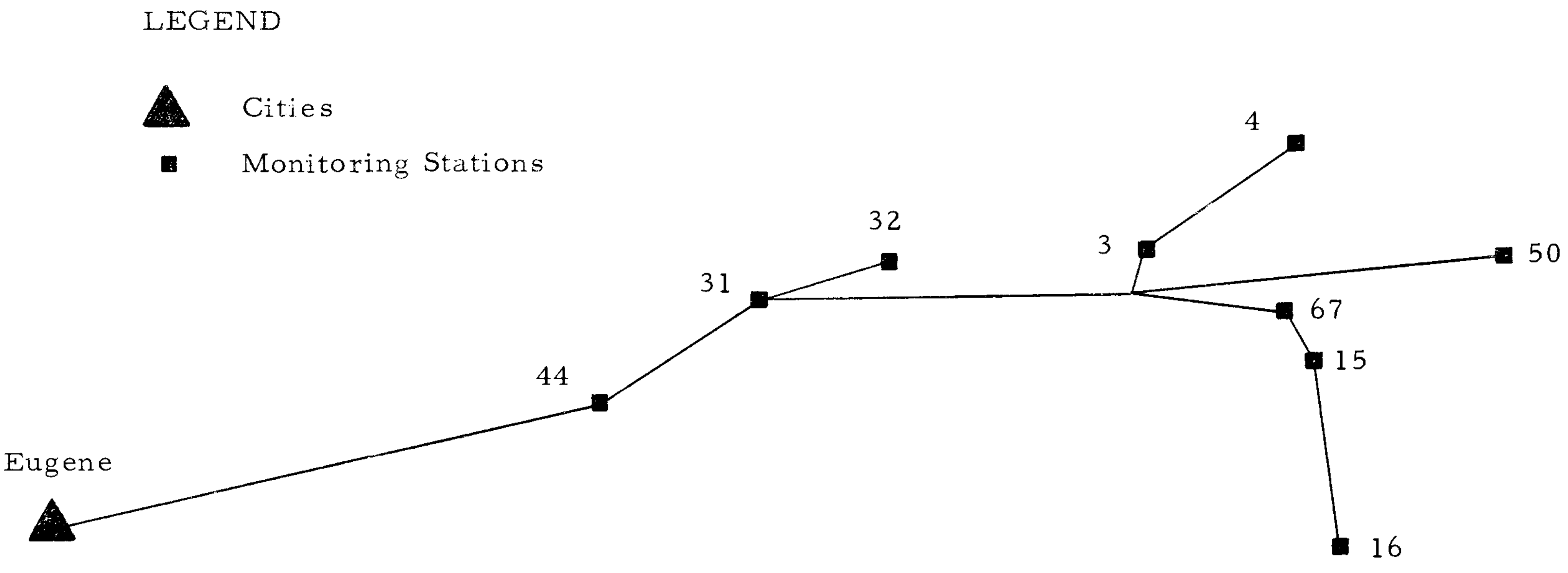


Figure 8. Telephone system for the McKenzie River service area.

Table 12. Location of New Construction for Telephone Lines

Location	Airline Mileage	Calculated Distance*	Cost**
1. Fern Ridge Dam to Coyote Cr. Sta. 29	1.5 mi.	1.9 mi.	$3,550.
2. Fern Ridge Dam to Noti Sta. 28	0.2 mi.	0.3 mi.	570.
3. Dayton to a point on the Yamhill south of McMinnville Sta. 71	6.3 mi.	6.5 mi.	800.
4. Glen Avon to a point of the upper Molalla River Sta. 54	5.6 mi.	7.3 mi.	13,650.
5. Green Peter Dam to a point on the Middle Fork of the Santiam Sta. 34	9.8 mi.	12.7 mi.	22,650.
6. Green Peter Dam to a point on Quartzville Cr. Sta. 35	8.9 mi.	11.6 mi.	20,600.
7. From Detroit up the Breitenbush Sta. 18	1.2 mi.	1.5 mi.	2,700.
8. Albany to mouth Luckiamute Sta. 48	0.9 mi.	1.2 mi.	2,250.
9. Corvallis to Pedee Sta. 50	1.0 mi.	1.3 mi.	2,450.
10. Gate Creek Dam to upper end of the reservoir Sta. 32	5.5 mi.	7.1 mi.	13,280.
11. Cougar Dam to upper end of the reservoir Sta. 16	6.3 mi.	8.2 mi.	15,320.
12. Blue River Dam to upper end of reservoir Sta. 4	5.2 mi.	6.7 mi.	12,550.
13. Fall Creek Dam to a point up Fall Cr. Sta. 25	6.5 mi.	8.5 mi.	15,500.
14. Fall Creek Dam to a point up Winberry Cr. Sta. 26	4.4 mi.	5.7 mi.	10,350.
15. Hill Cr. Dam to the upper end of the reservoir Sta. 38	8.4 mi.	10.9 mi.	20,100.

Table 12. (Continued)

Location	Airline Mileage	Calculated Distance	Cost
16. Cottage Grove Dam to the upper end of the reservoir Sta. 14	6. 2 mi.	8. 1 mi.	14,100.
17. Dorena Dam to the upper end of the reservoir Sta. 22	5. 6 mi.	7. 3 mi.	13, 600.

*The calculated distance is obtained by multiplying the airline mileage by 1. 3. This is a factor used by the Rural Electrification Administration to estimate actual ground distance from airline mileages (12).

**The cost is obtained by multiplying the calculated distance times an average cost/mile of $1870.

required to determine the actual costs.

Economics

The user of telephone services never owns or buys the telephone equipment. Thus the user is not concerned with depreciation charges and capital outlay for equipment. The telephone company also assumes the responsibility and expense of maintaining the equipment. The customer is required only to pay a regular monthly charge for telephone service based on the simplified scale shown in Table 13.

All charges are based on exclusive twenty-four hour use of the telephone channels. A charge of $5 is made for the initial installation of each station. Based on Table 13, Table 14 contains a detailed breakdown of the monthly charges made for telephone service for the

McKenzie River monitoring stations. (Figure 8)

Table 13. Simplified Schedule of Telephone Charges*

Tone Transmitter/Receiver	$25.50 per month
Interexchange Channel (100 Hertz)	1.81 per mile per month
Voice Grade Channel (2500 Hertz)	3.00 per mile per month
Subscriber Channel (100 Hertz)	2.50 per mile per month
Local Channel (one per station)	3.75 per month

*Source: (1)

Table 14. Telephone Charges for the McKenzie River Service Area

9 Tone Transmitter/Receivers @ 25.50 ea.		$229.50
9 Local Channels @ 3.75 ea.		33.75
37 miles Interexchange Channel @ 1.81 per mile		77.06
24.75 Subscriber Channel miles @ 2.50 per mile		61.88
	per month	$402.19 or
	per year	$4,826.

Appendix E contains the detailed breakdown of the cost estimates for each of the other service areas. Table 15 provides a summary of the monthly costs for each service area. The telephone charges in Table 15 show the equivalent cost of telephone service for each of the VHF radio service areas as defined in Appendix B and Table 11.

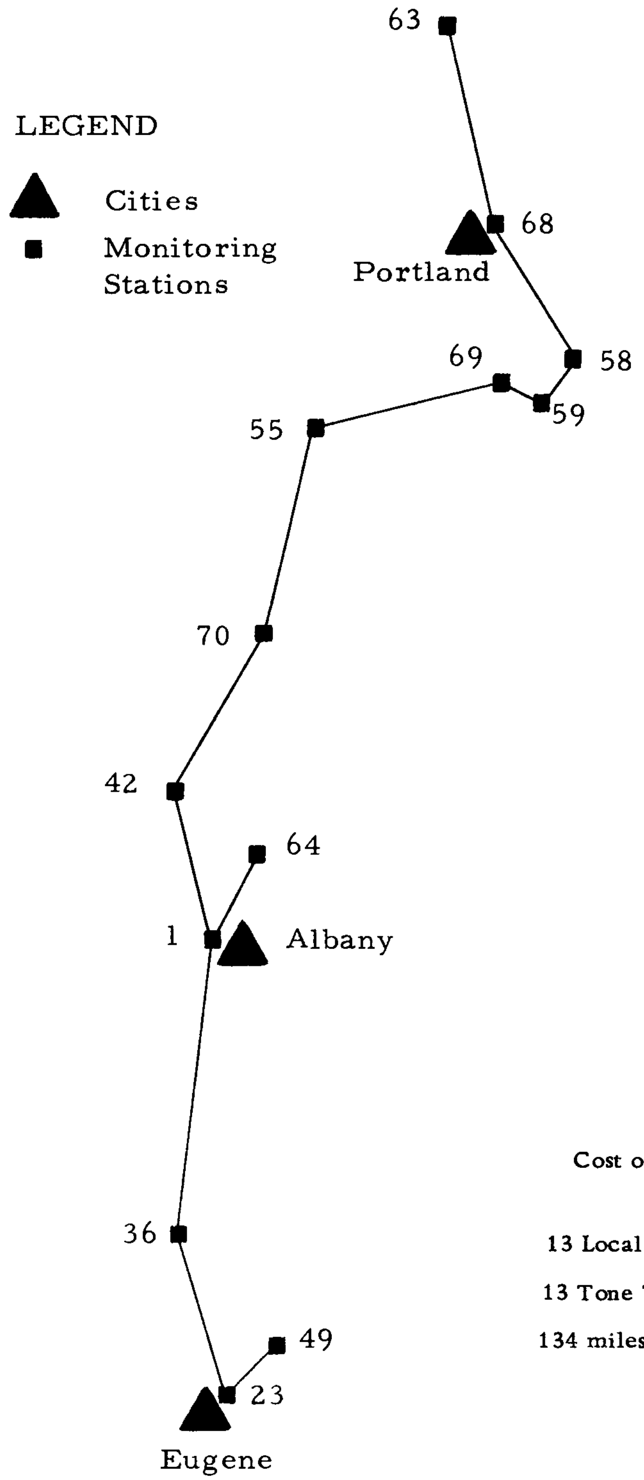
Table 15. Cost of Telephone Service by VHF Radio Service Areas

Service Area	mi. of new line construction	New Construction Charges	Yearly Operating Charges
Buck Mountain	2.2	$ 4,120	$3000
Coast Fork	15.4	28,700	2359
McKenzie	22.0	41,150	4826
Middle Fork	25.1	45,950	4855
Newberg	7.7	14,450	3720
Portland	---	---	7032
Prospect Hill	2.5	4,700	5416
Santiam	25.8	48,300	7470
Trunk Line (2500 Hertz)	---	---	3770
TOTAL	100.7 miles	$188,100	$42,448

Data Transmission for Class I Monitoring Stations

The VHF radio and telephone data transmission systems designed so far have been intended to serve the entire monitoring system. At first the monitoring system would consist of only Class I stations. The thirteen Class I stations by themselves do not warrant the construction of either the VHF radio or telephone data systems proposed in this study. Initial communications systems for the Class I stations are proposed in Figures 9 and 10. As the monitoring system is enlarged, either the VHF radio or telephone data systems proposed for the complete monitoring system may be used to provide the needed service.

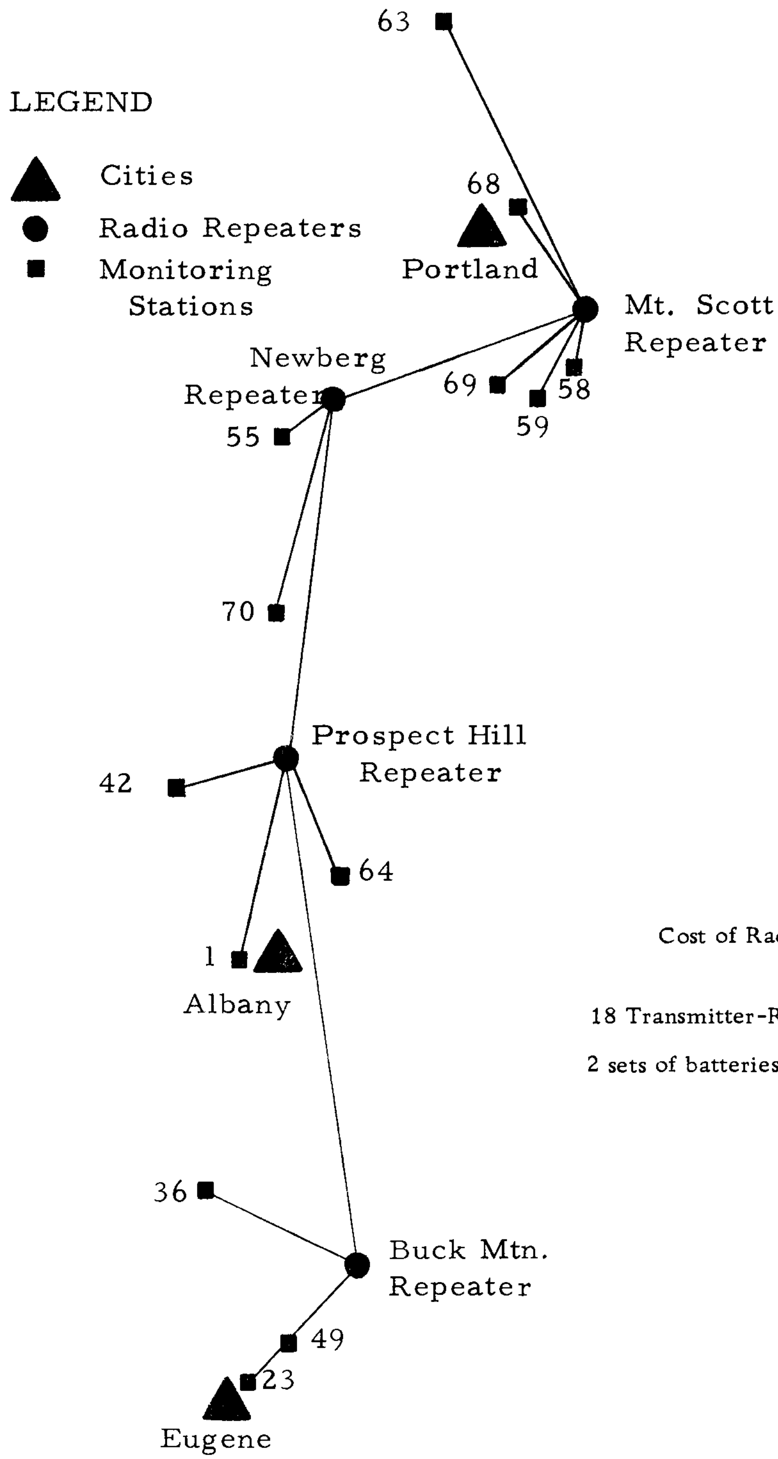
Figure 9 shows a 100 Hertz telephone channel linking the thirteen Class I stations. The VHF radio system shown in Figure 10 consists of 18 radio transmitter/receiver sets. The cost of the VHF radio system would be $10,395 per year while the cost of the telephone channel would be $7475 per year.



Cost of Telephone Service

13 Local Channels	$ 48. 75
13 Tone Transmitter Receivers	331.50
134 miles Duplex Channel	242. 54
	$622. 79/mo.
	or $7475 per year

Figure 9. Telephone service for class one stations.



Cost of Radio Service

18 Transmitter-Receivers	$10,125
2 sets of batteries	270
	$10,395 per year

Figure 10. VHF radio service for class one stations.

CHAPTER VI

JOINT VHF RADIO-TELEPHONE DATA TRANSMISSION SYSTEMS

Some situations exist where a combination of VHF radio and telephone may be used more economically than either VHF radio or telephone systems alone. The average yearly cost for telephone is usually less than the corresponding charges for radio. Table 12 showed, however, that charges for the construction of new telephone lines are significant at many of the more remote monitoring sites. The cumulative combination of the initial charges for new line construction and the yearly charges for telephone service is greater in some cases than the corresponding cumulative charges for VHF radio. This chapter will examine the possibility of using joint VHF radio and telephone service to reduce total costs.

Identification of Stations Using Joint Service

Table 16 summarizes the annual charges for VHF radio and telephone. The new telephone line charges associated with a telephone system are shown.

Figure 11 graphs the charges for the McKenzie River service area. The initial charge of $41,000 for new telephone line construction maintains the cumulative charges for telephone at a higher level than those for VHF radio for over twenty years. Monitoring sites with high initial new line construction charges will be considered in the selection of sites for joint VHF radio-telephone service.

Table 16. Summary of VHF Radio and Telephone Charges

Service Area	Yearly Charges		New Construction Charges for telephone lines
	VHF Radio	Telephone	
Buck Mountain	4500	3000	4120
Coast Fork	5600	2359	28700
McKenzie	6730	4826	41150
Middle Fork	6730	4855	45950
Newberg	5330	3720	14450
Portland	6885	7032	----
Prospect Hill	5620	5416	4700
Santiam	9810	7470	48300

Table 12 lists seventeen stations as having new telephone line construction charges. The charges for monitoring stations 18, 28, 29, 48, 50, and 71 are small and will be neglected. The possibility of reducing the costs caused by stations 14, 16, 22, 25, 26, 32, 34, 35, 38, and 54 will be investigated.

Design of Joint VHF Radio-Telephone Systems

Joint VHF radio-telephone systems can combine the merits of both systems. For example telephone can be used where existing telephone facilities make the use of telephone most economical.

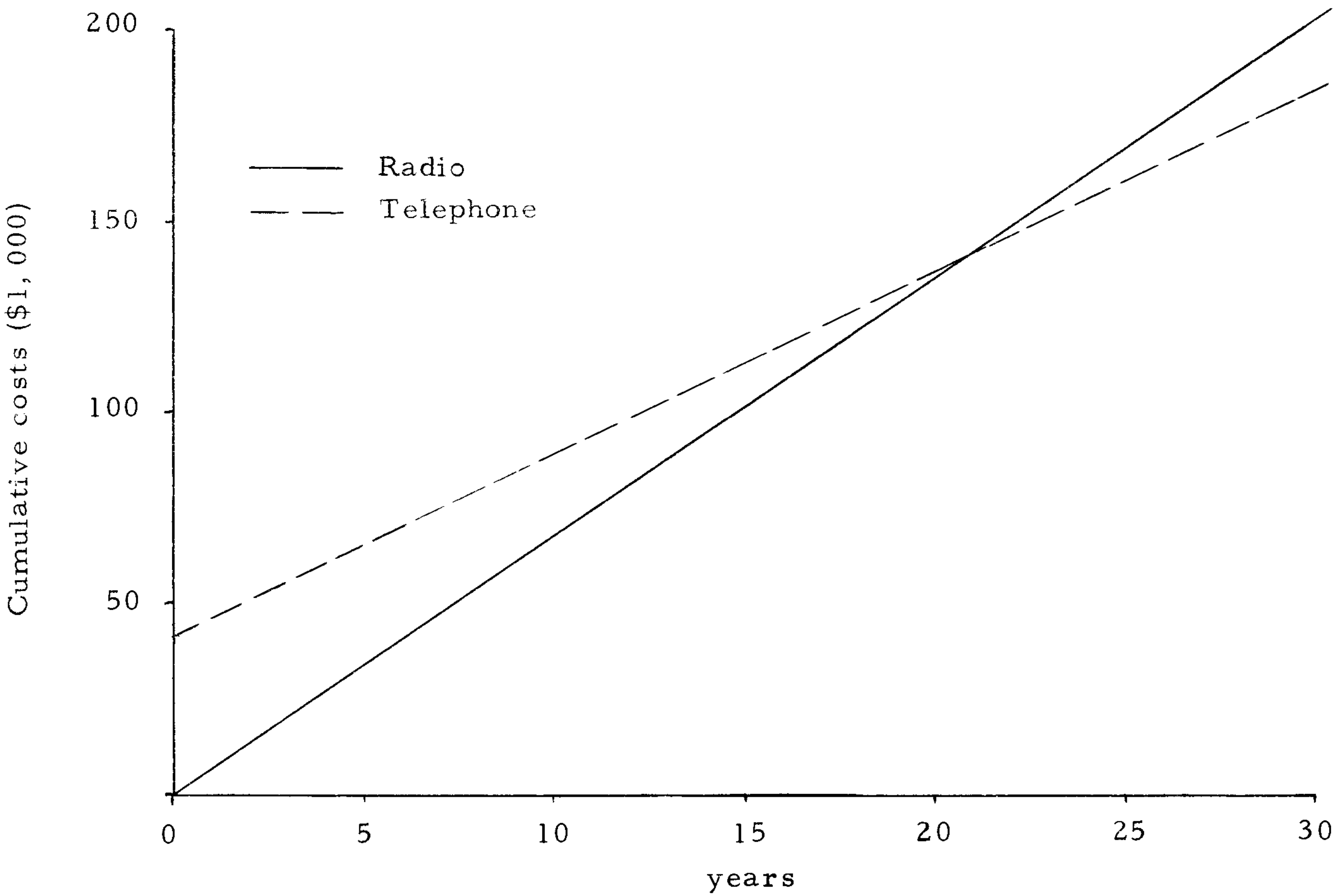


Figure 11. Comparison of cumulative costs for VHF radio and telephone for the McKenzie River service area.

In situations requiring the construction of extensive new telephone line, the use of VHF radio can eliminate the construction charges. VHF radio can by-pass many miles of telephone ground line in one transmission hop between stations. However, if a number of VHF repeaters are needed due to broken terrain, all advantages of economy may be lost.

Where joint VHF radio-telephone service is contemplated, a VHF radio transmitter/receiver and a telephone data transmitter/receiver must both be placed at the inter-tie point. Figure 12 diagrams a possible system for joint service.

Since the annual cost of telephone is normally less than the cost of radio, the assumption will be made that a telephone monitoring system initially exists to serve all monitoring sites. To determine the effect of joint service on the cost of the monitoring system, VHF radio will be substituted for telephone at the eleven stations selected previously. The VHF radio sites used to provide service will be the same as selected for the VHF radio system discussed in Chapter IV.

Economics of Joint VHF Radio-Telephone Systems

The cost of joint VHF radio-telephone service is based on the cost figures tabulated in Chapters IV and V and Appendices E and F. The cost of joint service for each service area is calculated by

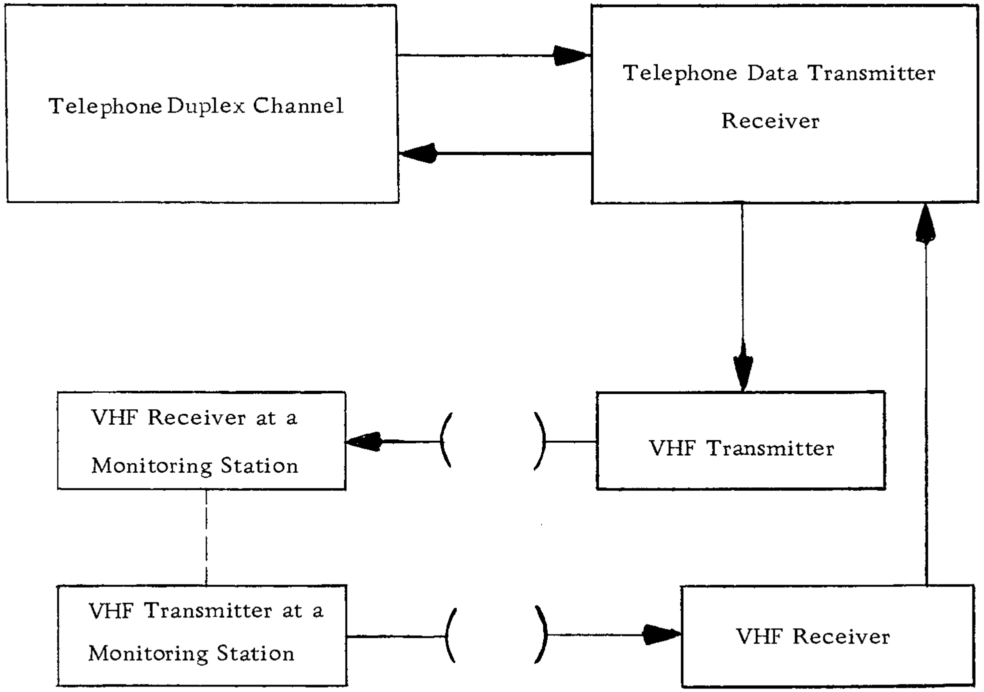


Figure 12. Equipment required to provide inter-tie between VHF radio and telephone.

subtracting the cost of the telephone service to be replaced by VHF radio from the cost of telephone service for the complete service area. The cost of VHF radio is then added to the cost of telephone for the remaining stations. The cost of new telephone line construction is then calculated for any new construction remaining after the establishment of joint service. Stations 4, 16, and 32 will be used as examples of this process. Table 17 lists the telephone and radio charges for stations 4, 16, and 32.

Three possibilities for substituting radio service for telephone service at stations 4, 16, and 32 exist. Radio service may be substituted for telephone at station 32 only, at stations 4 and 16 only, or at stations 4, 16, and 32. The calculation of the operating costs follows in Table 18.

Appendix F contains the calculations of the costs of joint VHF radio-telephone service for the Coast Fork, Middle Fork, and Santiam service areas. Table 19 summarizes the costs of the use of joint VHF radio-telephone service for the eleven stations selected in this chapter.

Table 17. Telephone and Radio Charges for Stations 4, 16 and 32

Telephone Charges	
Station 4	
1 Tone Transmitter-Receiver	$25.50
1 Local Channel	3.75
3.25 miles of Subscriber Channel	8.13
	$37.38/mo. or $449/year
Station 16	
1 Tone Transmitter-Receiver	$25.50
1 Local Channel	3.75
4.25 miles of Subscriber Channel	10.63
	$39.88/mo. or $479/year
Stations 4 and 16 combined Cost $927./yr.	
Station 32	
1 Tone Transmitter-Receiver	$25.50
1 Local Channel	3.75
4.00 miles of Subscriber Channel.	10.00
	$39.25/mo. or $471/year
Radio Charges	
Stations 4 and 16	
Both stations are served by a common repeater station. Therefore, the costs of both stations are lumped together.	
4 Transmitter-Receiver VHF Radios	$2250.
3 Sets Batteries	405
	$2655 per year
Station 32	
3 Transmitter-Receiver VHF Radios	$1687
2 Sets Batteries	270
	$1957 per year

Table 18. Calculation of Cost of Joint Service for Stations 4, 16, and 32

1. Radio Service - Station 32 only

Cost of telephone service - McKenzie Service Area (except sta. 32)	$4355
Cost of radio (Sta. 32)	1947
	$6302 per year

New Construction Charges for Sta. 4 & 16 total $ 27,870.

2. Radio Service - Stations 4 and 16 only

Cost of Telephone service - McKenzie Service Area (except sta. 4 and 16)	$3899
Cost of Radio Service (Sta. 4 & 16)	2655
	$6554 per year

New Construction Charges for Sta. 32 total $13,280.

3. Radio Service - Stations 4, 16, and 32 only

Cost of Telephone service - McKenzie Service Area (except sta. 4, 16, & 32)	$3428
Cost of Radio Service (Sta. 4, 16, & 32)	4612
	$8040 per year

No new construction charges

Table 19. Summary of Cost of Joint VHF Radio-Telephone Service

Service Area	VHF Radio for Stations	Cost of Joint Service	New Construction Cost
Coast Fork	14 and 22	$5154	$ none
McKenzie	32 only	6302	27,870
	4 and 16 only	6554	13,280
	4, 16 and 32	8040	none
Middle Fork	38 only	6250	25,850
	25 and 26 only	6568	20,100
	25, 26, and 38	7963	none
Santiam	34 and 35	8940	2,700

CHAPTER VII

ECONOMIC COMPARISON OF DATA TRANSMISSION SYSTEMS

Several alternative data transmission systems have been proposed for the model water-quality monitoring system. These consist of either all VHF radio or all telephone systems or a combination of both. The selection of the best system has been reduced to a consideration of economics. Factors governing the selection of the most economical system include new telephone line construction, the degree of development of the present telephone system, and the expected equipment lifetime of solid-state VHF radios.

Comparison of Systems

The cumulative yearly costs for the use of telephone, VHF radio, and joint service radio-telephone systems will be used to select the most economical system. Figure 13 graphs the cumulative costs for each of the five systems which have been proposed for the McKenzie River service area. Graphs of the data for the other service areas may be found in Appendix G.

The most economical communications systems at periods of 2 1/2, 5, 10, 20, and 30 years may be selected with the aid of Figure 13 and Appendix G. Table 20 summarizes these predictions.

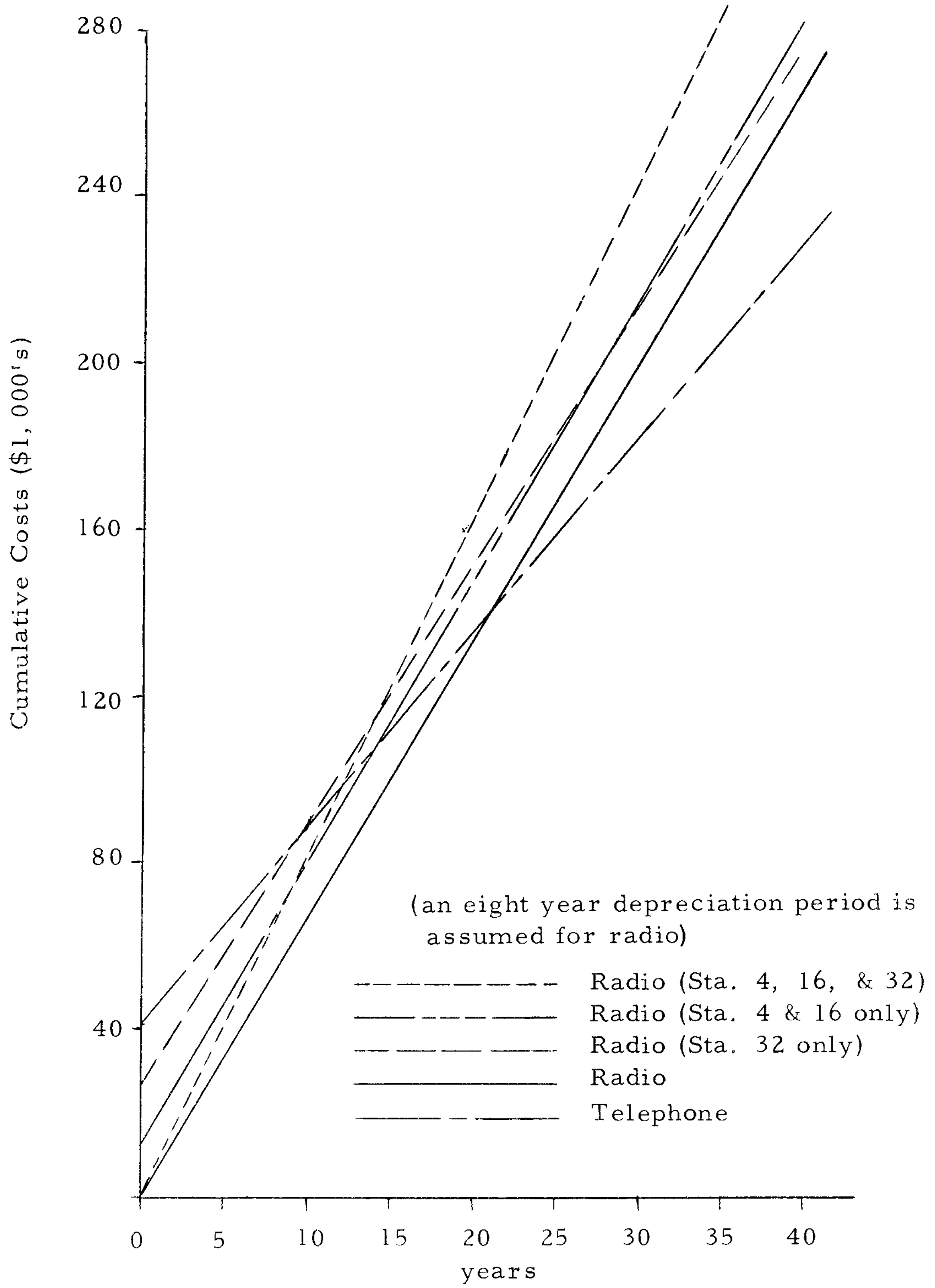


Figure 13. Comparison of costs of proposed telemetry systems for the McKenzie River service area.

In Table 20 the letters T, R, and J may be interpreted as telephone, radio, and joint respectively.

Table 20. Selection of Most Economical Communication System

Service Area	Years				
	2 1/2	5	10	20	30
Buck Mountain	T	T	T	T	T
Coast Fork	J	J	T	T	T
McKenzie	R	R	R	T	T
Middle Fork	R	R	R	R	T
Newberg	R	R	R	T	T
Portland	R	R	R	R	R
Prospect Hill	R	T	T	T	T
Santiam	R	J	J	J	J

Significance of Predictions

Table 20 is based on conditions and prices existing in 1966. The future construction of new telephone line, increases in the expected lifetime of radio equipment, or other changes in cost may drastically alter these predictions. If the annual cost of radio decreases due to an increased radio lifetime the predictions in Table 20 could shift in favor of radio. If a reduction in the extent or cost of new telephone line construction occurs, the predictions could shift in favor of telephone. Future expansion of telephone service into remote areas preceding the need for water-quality monitoring will also shift the predictions in favor of telephone. Charges for new construction of line will not be made if the lines already exist prior to the construction of a monitoring station.

It would be required in many situations to maintain a monitoring station in one location for many years before the use of telephone became more economical than VHF radio. This effect is probably caused in part by charges for new telephone lines. If plans are made to place monitoring stations at sites for only short periods of time, (2 years or less), a radio system should be most economical.

In developed metropolitan areas such as Eugene or Salem, telephone service is the most economical system. This is caused by the existance of a well developed telephone system which eliminates new construction charges. In the Portland area of the model monitoring system, the selection of one central radio repeater capable of reaching a large number of monitoring sites caused radio to be more economical.

The use of VHF radio in mountainous areas becomes economical due to the absence of a well developed telephone system. In very broken terrain, the use and need of a number of radio repeaters to maintain line-of-sight operations can boost VHF radio costs. This factor became apparent in the calculation of joint radio and telephone costs for the McKenzie River service area. The cost of joint service for the Santiam and Coast Fork areas is an example where a minimum of repeater stations were needed and a reduction in costs was realized.

CHAPTER VIII

SUMMARY

A water-quality monitoring system is a valuable aid to river basin management. Major uses of water-quality data include control of river water quality and quantity, enforcement of minimum water-quality standards, and research.

This paper has developed a model water-quality data aquisition system which may be adapted to any river basin. A monitoring system is essentially a telemetry system which has been adapted for the task of water-quality monitoring. Basic components of a monitoring system include instrumentation, signal conditioning equipment, analog to digital encoders, and a telemetry transmitter at each monitoring station. The individual monitoring stations are linked to the system control center by the telemetry system.

Each monitoring station would be fully automated and would report data only upon receipt of an interrogation signal from the control center. Data from the instrumentation at each station would be encoded and transmitted in binary coded decimal to the control center. At the control center the data would be decoded and recorded until used as the input information for a variety of computer programs capable of predicting water-quality conditions throughout a river basin. The computer would make recommendations for the control of the river basin in accordance with the requirements of river basin management.

The Willamette River basin of Oregon was chosen as a model for the construction of a monitoring system. The federal and state agencies active in water resources within the Willamette Basin were surveyed to determine the location of monitoring sites and to establish criteria for the construction of an actual monitoring system. A monitoring network of seventy-one monitoring stations was proposed for the Willamette basin.

Based on the needs of the model Willamette monitoring system, VHF radio and telephone data transmission were selected as capable of supplying the needed communications capacity. Economic models and actual designs of VHF radio, telephone, and a joint VHF radio-telephone system were developed.

The equipment lifetime of solid-state VHF radios was an unknown factor in this study. If the expected equipment lifetime for radio is greater than that used in the economic models, the cost of VHF radio would decrease.

Conclusions

Five general conclusions may be drawn from this study:

1. Enough interest in water-quality monitoring exists to justify the

construction of an automatic water-quality monitoring system.

2. The model water-quality monitoring system developed for the Willamette Basin may be adapted to other river basins.
3. VHF radio and telephone data transmission are both capable of providing adequate communications service to meet the predictable needs of automatic monitoring.
4. Major factors governing the selection of the most economical communications system include new telephone line construction and the expected equipment lifetime of solid-state VHF radio.
5. The use of automatic monitoring may well extend to areas other than water-quality monitoring. Air pollution, meteorological, and snow-pack monitoring are simple extensions of water-quality monitoring activities.

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APPENDICES

APPENDIX A

Agencies Active in Willamette River Basin Water Resources Planning and Development

State

Water Resources Board
Fish Commission
Game Commission
Sanitary Authority
Oregon State University
University of Oregon
Highway Department
Marine Board
Board of Forestry
State Engineer
Department of Agriculture
Department of Geology and Mineral Industries
Committee on Natural Resources
Department of Commerce
  Division of Planning
Board of Census
Soil Conservation Committee
Mapping Advisory Committee

Federal

Department of Army
  Corps of Engineers
Department of Interior
  Bureau of Reclamation
  Geological Survey
  Bureau of Commercial Fisheries
  Bureau of Sport Fisheries and Wildlife
  Bonneville Power Administration
  Bureau of Outdoor Recreation
  Bureau of Land Management
  Bureau of Mines
  Federal Water Pollution Control Administration
Department of Agriculture
  Soil Conservation Service
  Economic Research Service
  Forest Service
  Agricultural Stabilization and Conservation Service
  Farmers Home Administration
  Rural Electrification Administration
Department of Health, Education and Welfare
  Public Health Service
Department of Commerce
  Weather Bureau
  Bureau of Census
Federal Power Commission

APPENDIX B

VHF RADIO SERVICE AREAS

This appendix contains diagrams of the VHF radio network required to provide the VHF radio service discussed in Chapter IV.

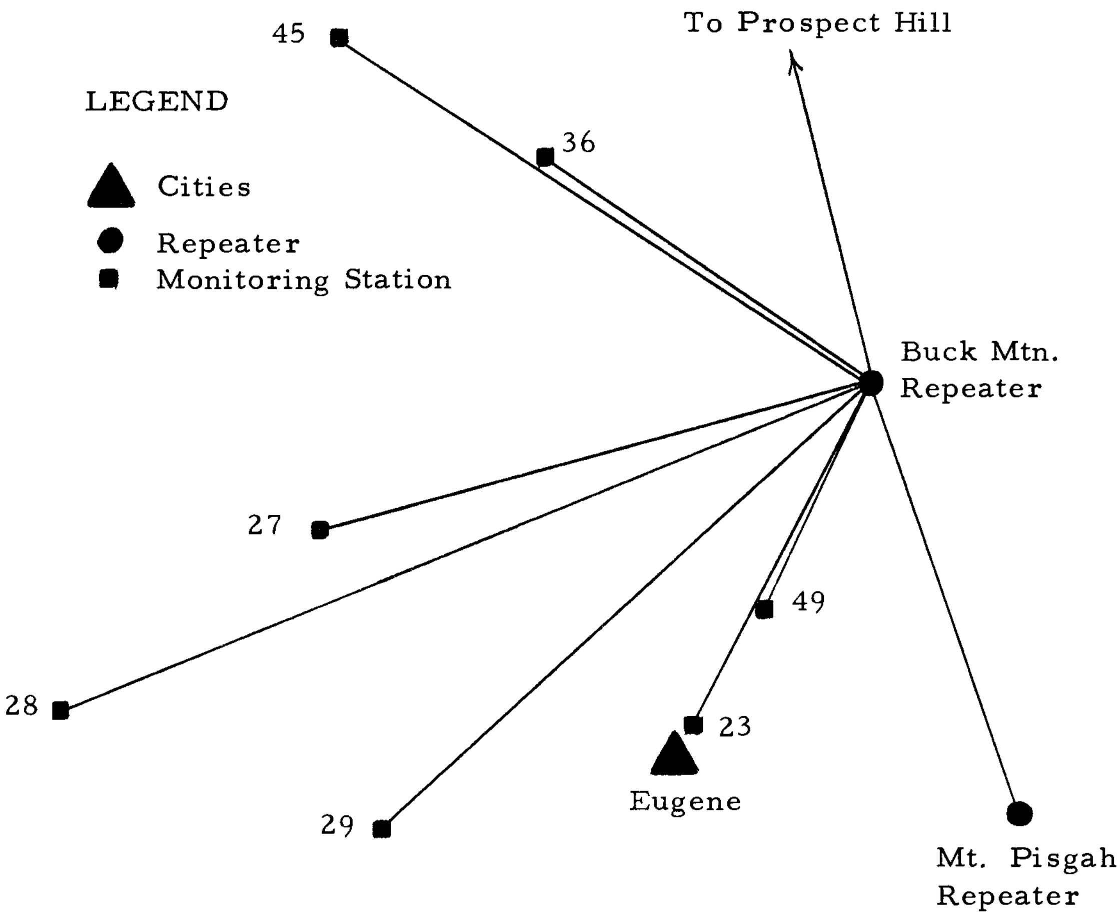

Figure 14. VHF radio for the Buck Mountain service area.

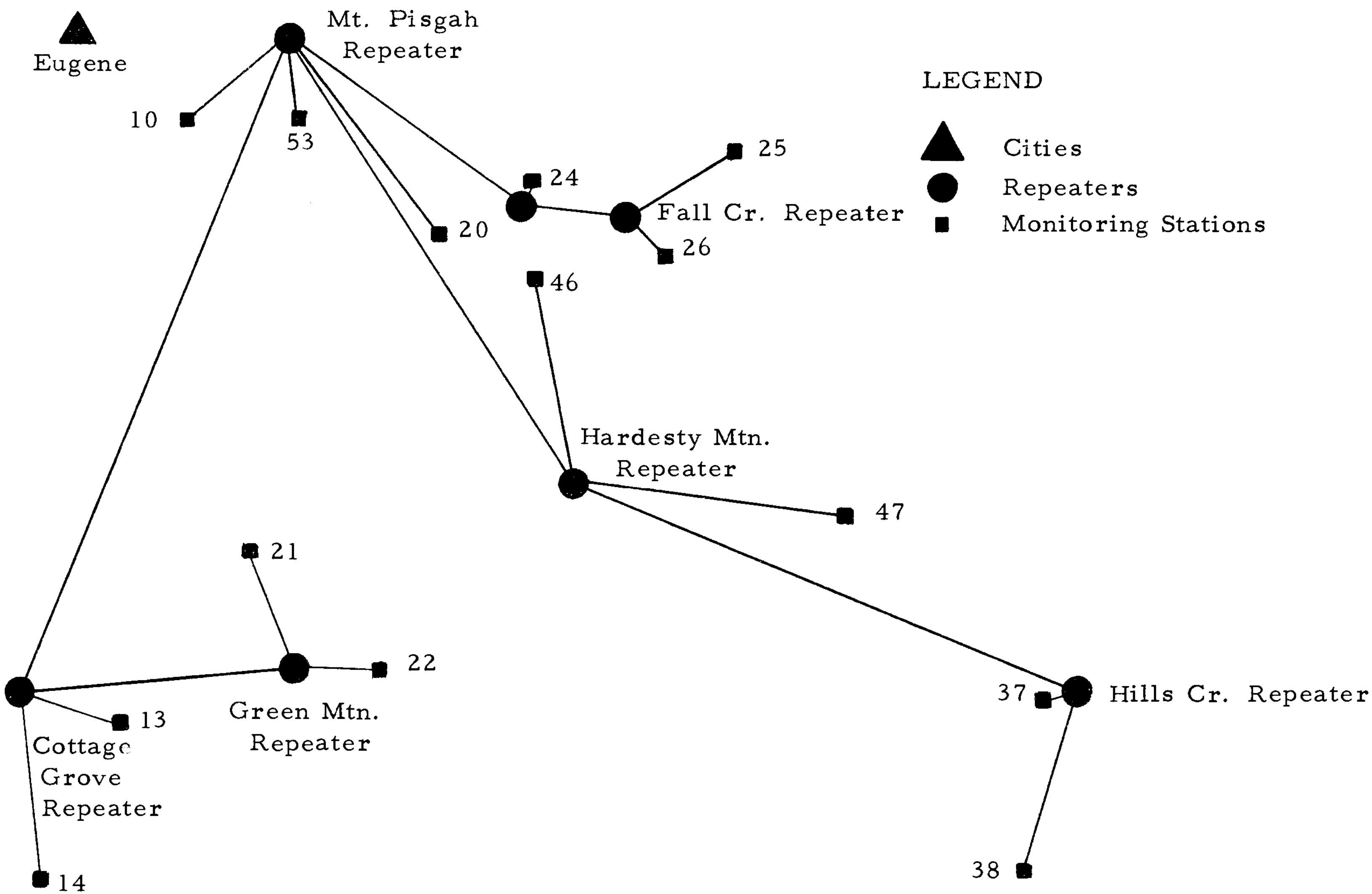

Figure 15. VHF radio service for the Coast and Middle Fork service areas.

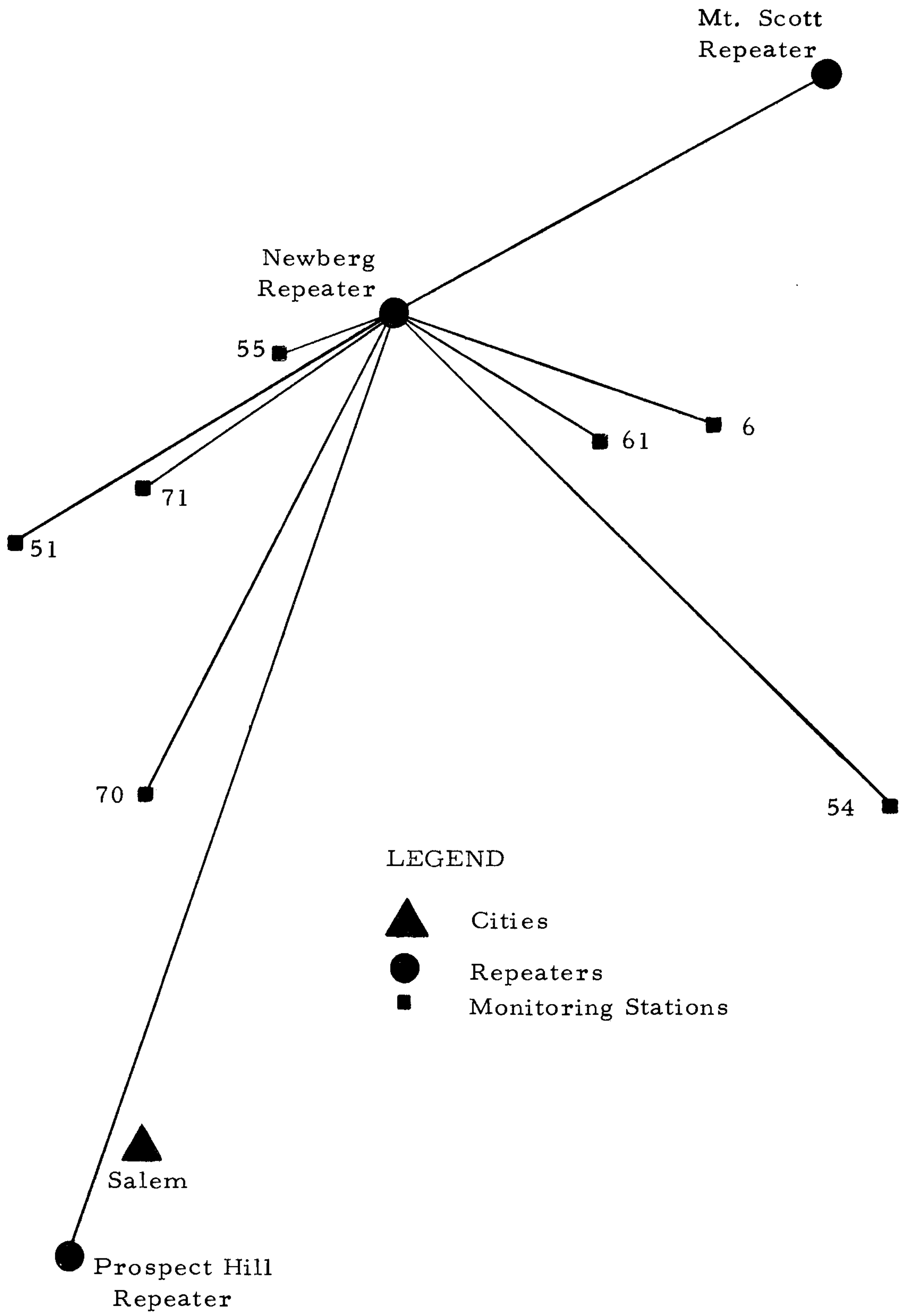

Figure 16. VHF radio for the Newberg service area.

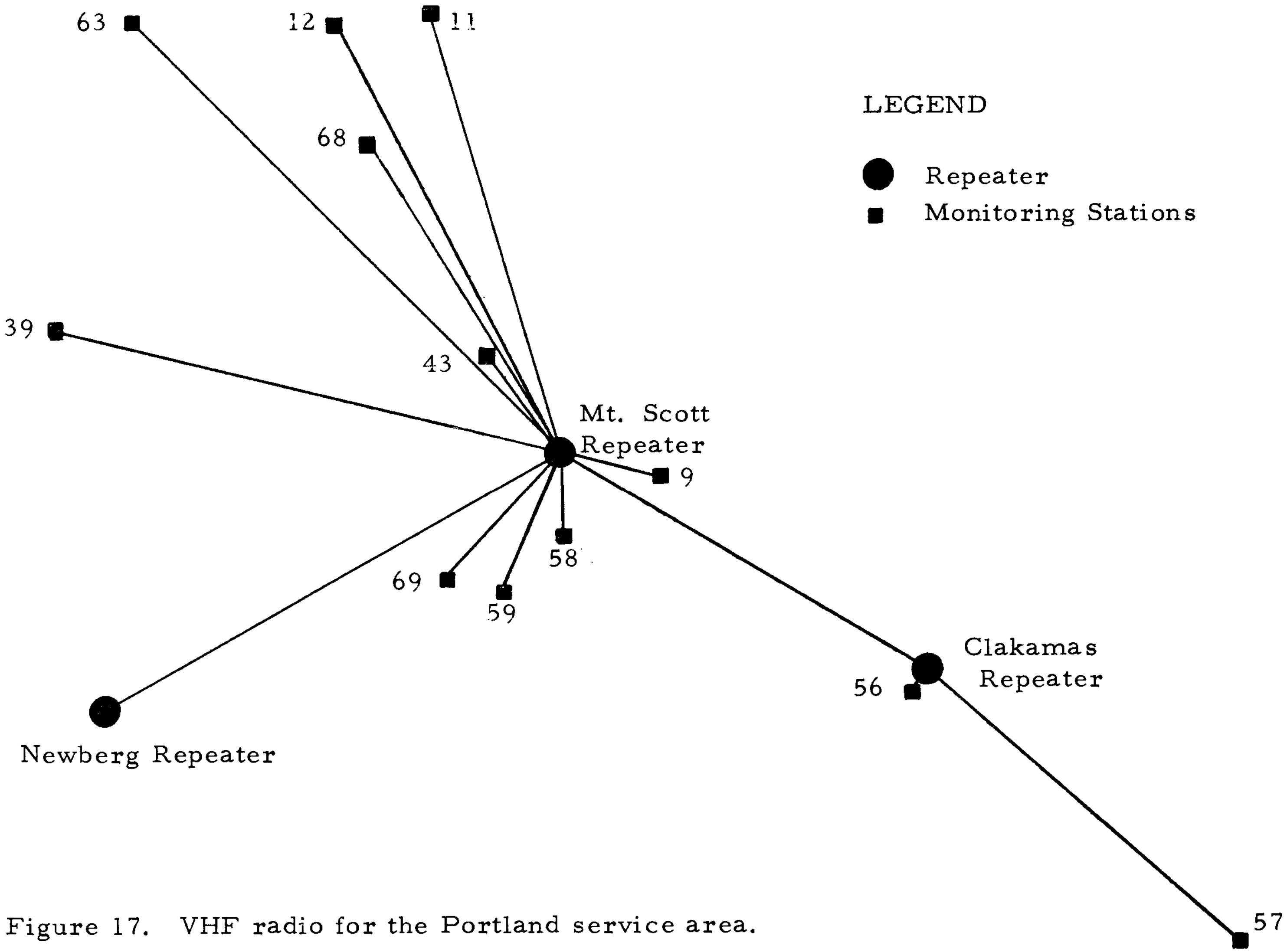

Figure 17. VHF radio for the Portland service area.

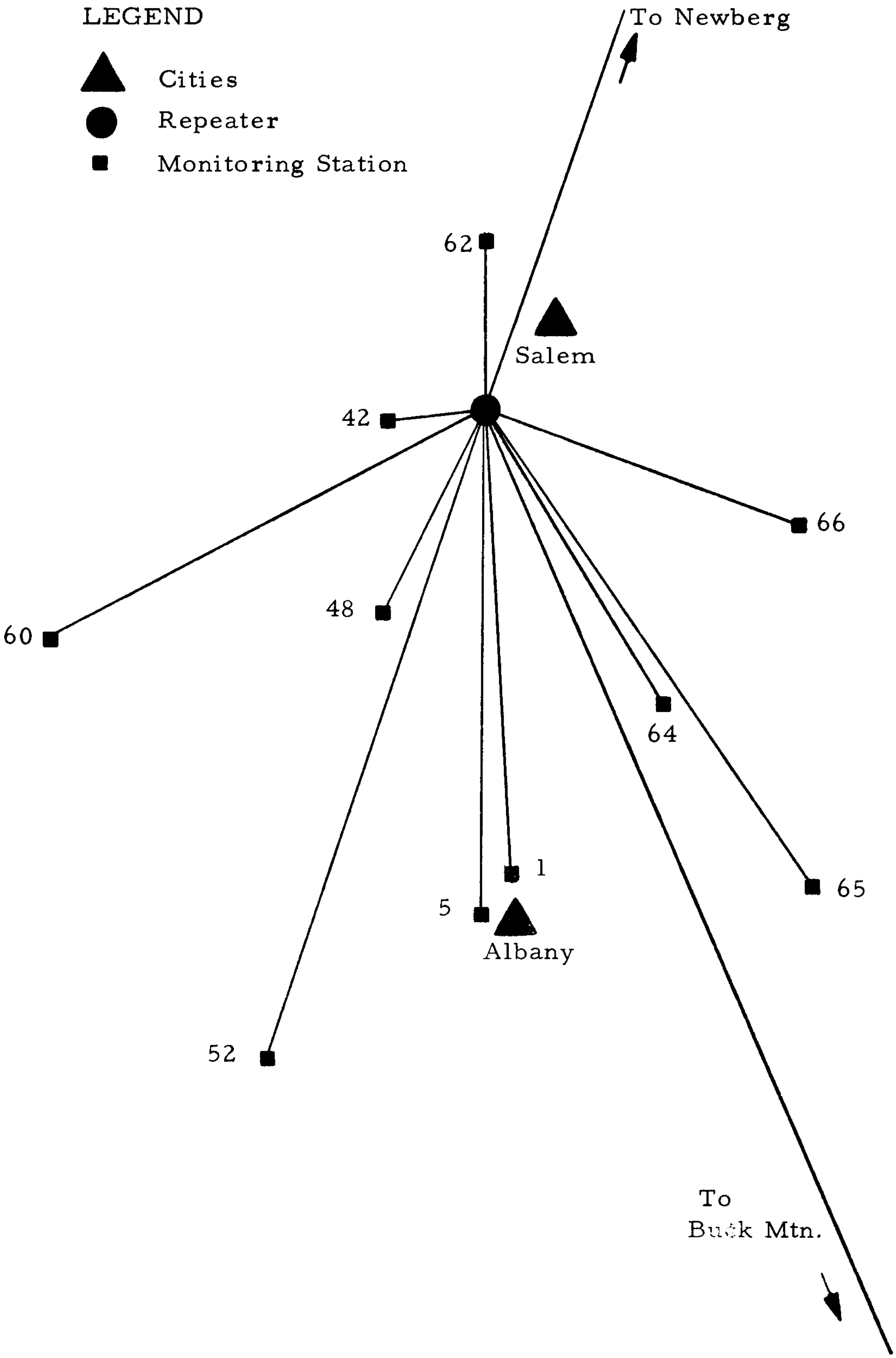

Figure 18. VHF radio for Prospect Hill service area.

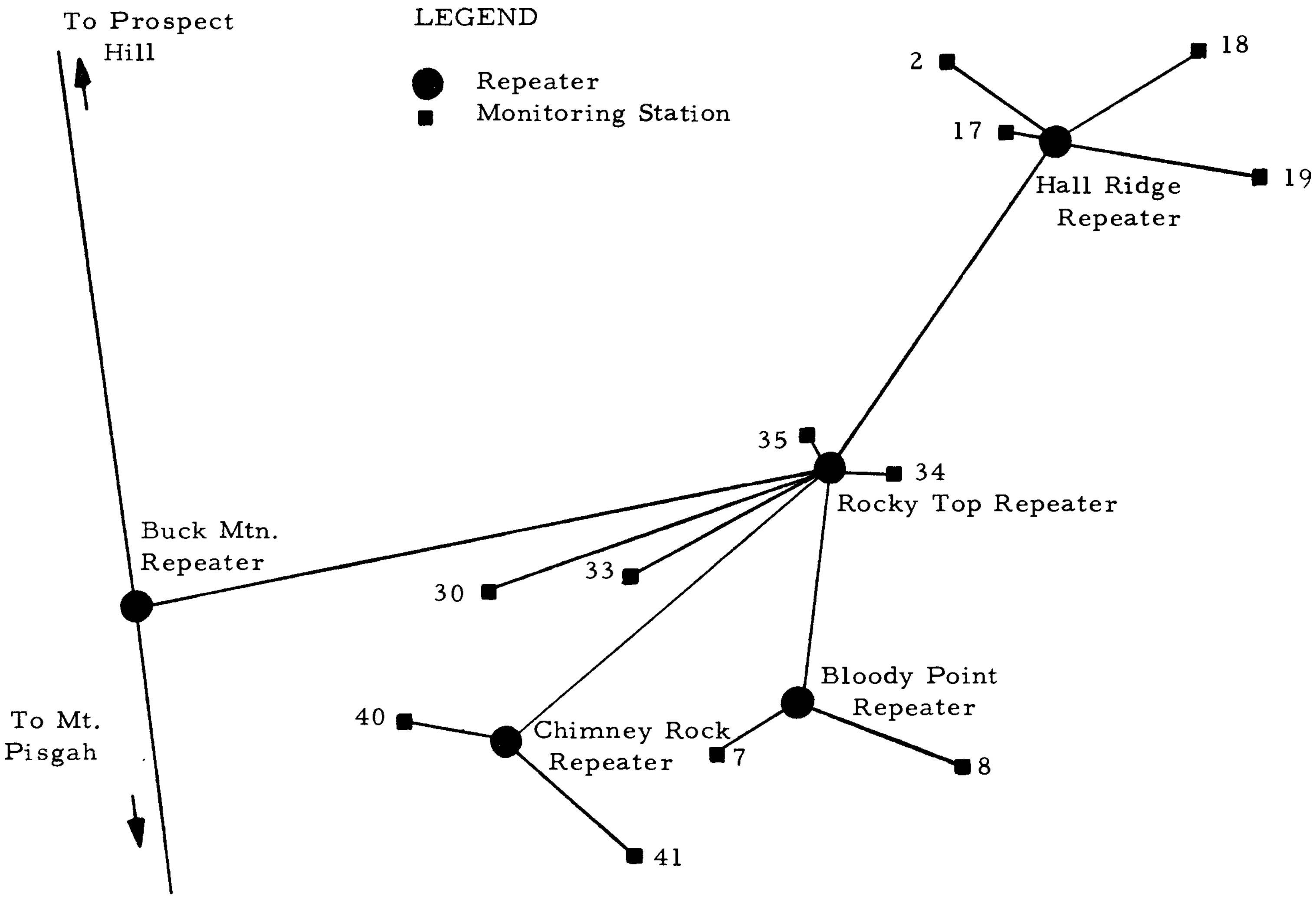

Figure 19. VHF radio for the Santiam service area.

APPENDIX C

Calculation of Bandwidth

A total of 1020 parameter reports can be generated by the complete model water-quality monitoring system as shown in Table 8.

For the purposes of these calculations we will assume a worst case situation.

We will assume that all 1020 parameters will be reported each hour and that in each case, the reports are repeated a second time as part of the error analysis scheme proposed in Chapter II (page 20). We will throw in a factor of 100% for spacing between reports, identification, and interrogation signals. Finally we will assume a possible 100% expansion of the monitoring system.

1020	Reports/hr.
x 2	
2040	Reports/hr. (Assuming repetition for error analysis)
2040	Add 100% for spacing between reports, identification and interrogation signals
4080	
4080	Assume 100% expansion of the system
8160	reports/hr.

Each report will consist of four digits.

$$8160 \frac{\text{reports}}{\text{hr.}} \times 4 \frac{\text{digits}}{\text{report}} = 32,640 \frac{\text{digits}}{\text{hr.}}$$

Each digit will consist of a binary word with four pulse positions.

$$32,640 \ \frac{\text{digits}}{\text{hr.}} \times 4 \ \frac{\text{pulses}}{\text{digit}} = 130,560 \ \frac{\text{pulses}}{\text{hr.}}$$

$$130,560 \ \frac{\text{pulses}}{\text{hr.}} = 36.3 \ \frac{\text{pulses}}{\text{sec.}}$$

If we assume the spacing between pulses to be equal to the width of a pulse, the total duration of a pulse in time will be:

$$T = \frac{1}{2(36.3)} = 0.0138 \text{ secs.}$$

The fundamental frequency associated with a pulse of this duration is:

$$F = \frac{1}{T} = \frac{1}{0.0138 \text{ sec.}} = 72.6 \text{ Hertz}$$

The type of telephone line most closely approximating this requirement is a 100 Hertz line. Although individual telephone channels may never experience a load approaching the magnitude suggested here, 100 Hertz is adopted as the minimum bandwidth for a number of reasons.

1. 100 Hertz allows flexibility in adjusting the speed of data transmission to accommodate various types of encoding and recording devices.
2. Bandwidth greater than 72.6 Hertz allows more frequent reporting of data than once per hour. Continuous monitoring could be established for some locations if

warranted.

3. 100 Hertz allows a large factor for the future expansion of the monitoring system.

APPENDIX D

TELEPHONE SERVICE AREAS

This appendix contains diagrams of the telephone data transmission system required to provide the telephone service discussed in Chapter V.

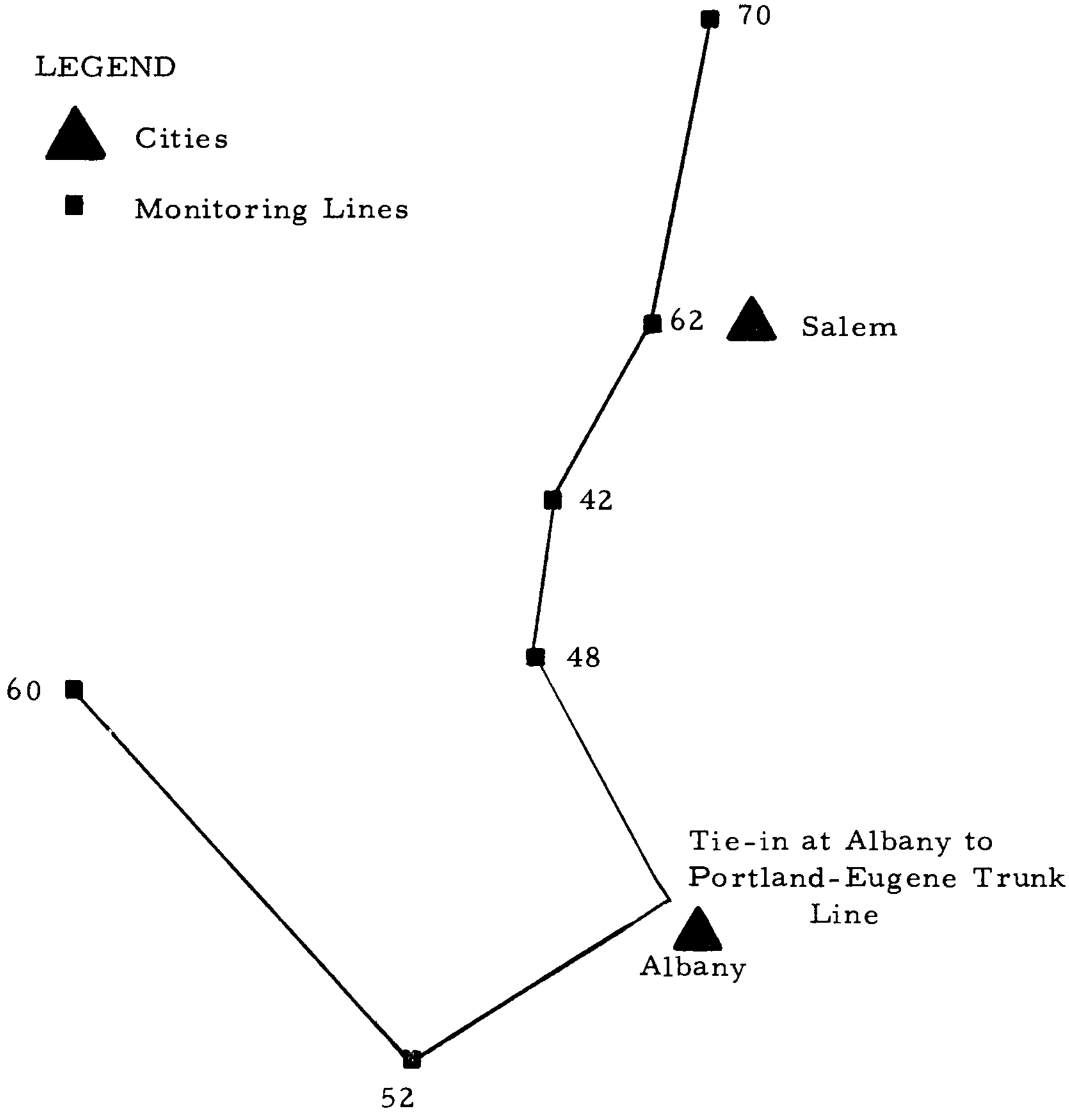

Figure 20. Telephone system for the Albany service area.

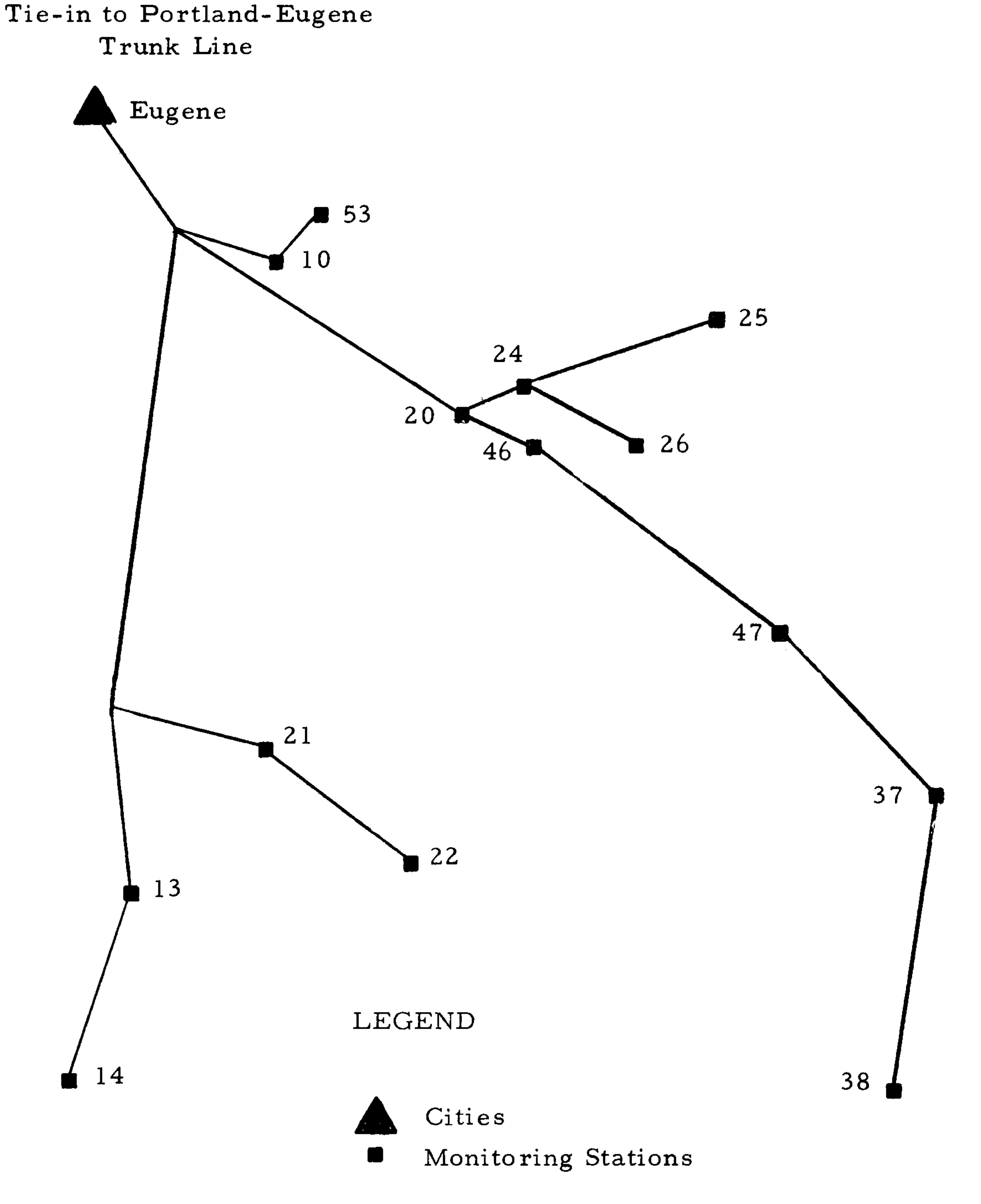

Figure 21. Telephone system for the Coast and Middle Fork service areas.

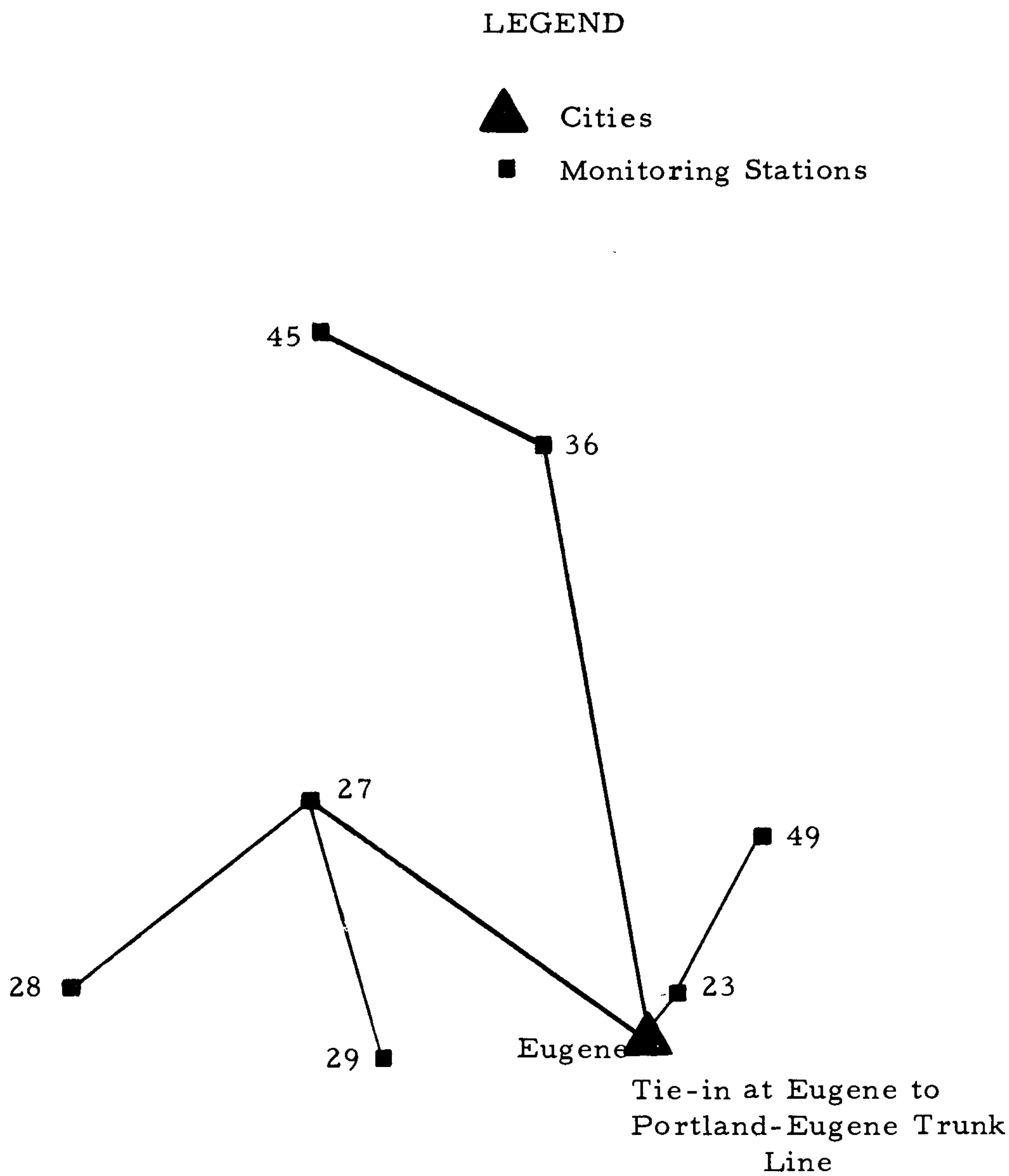

Figure 22. Telephone system for the Eugene service area.

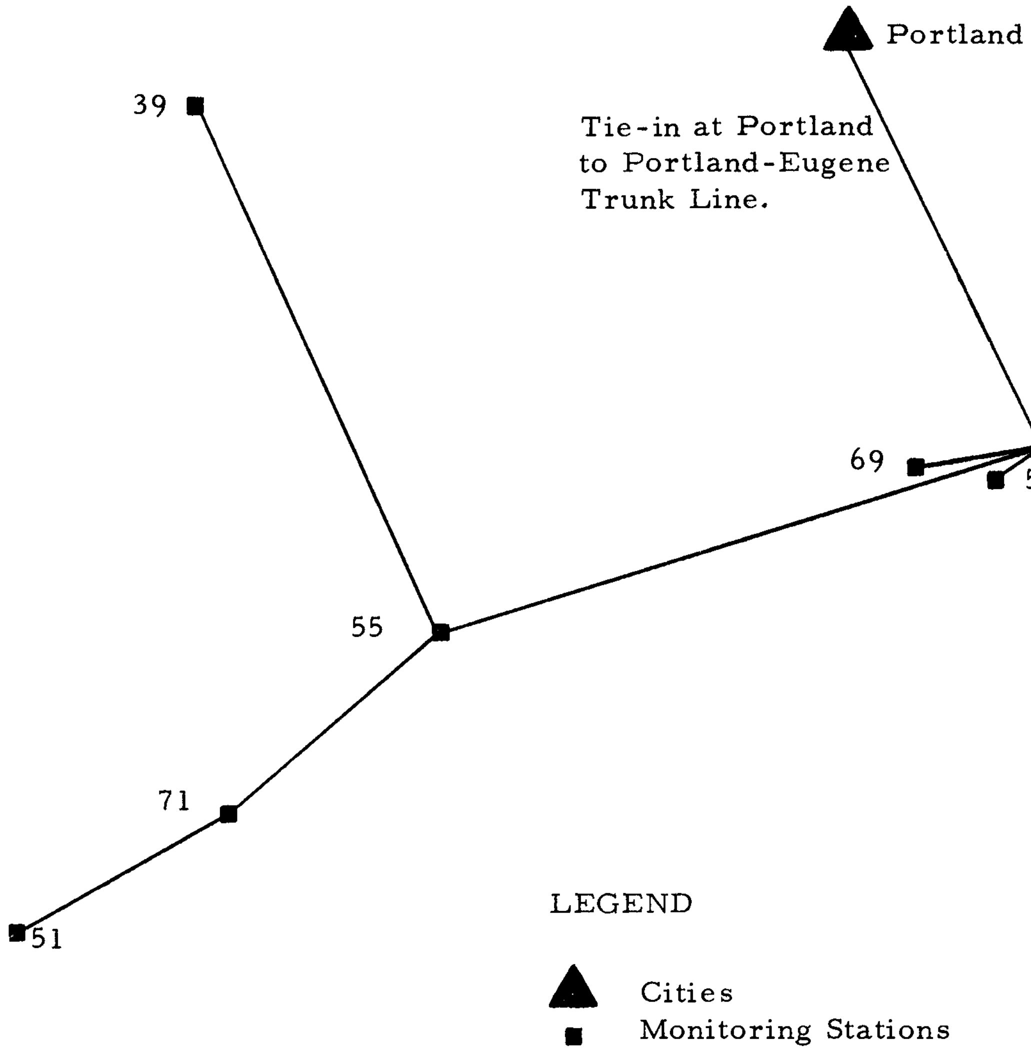

Figure 23. Telephone system for the Newberg service area.

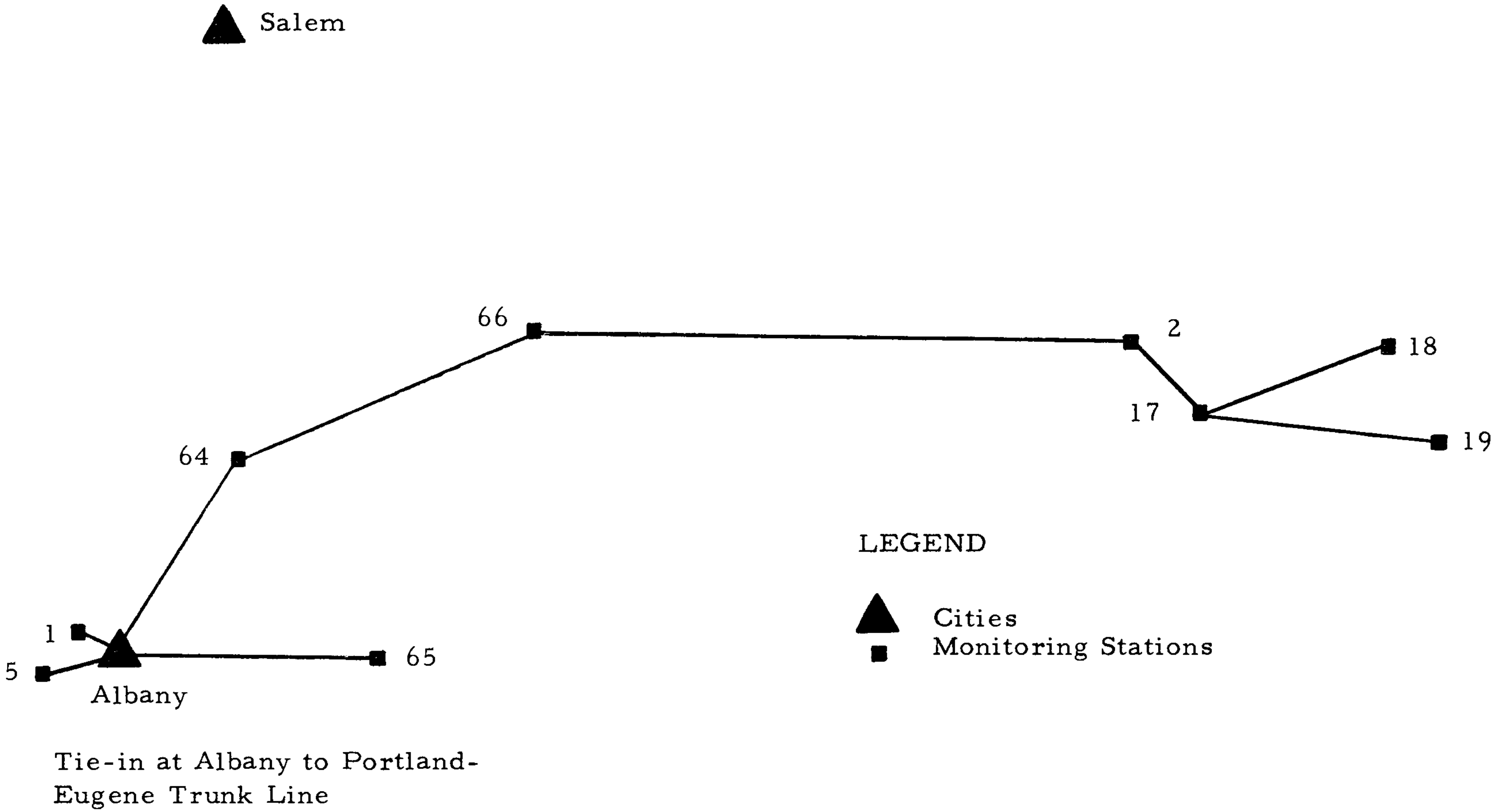

Figure 24. Telephone system for the North Santiam service area.

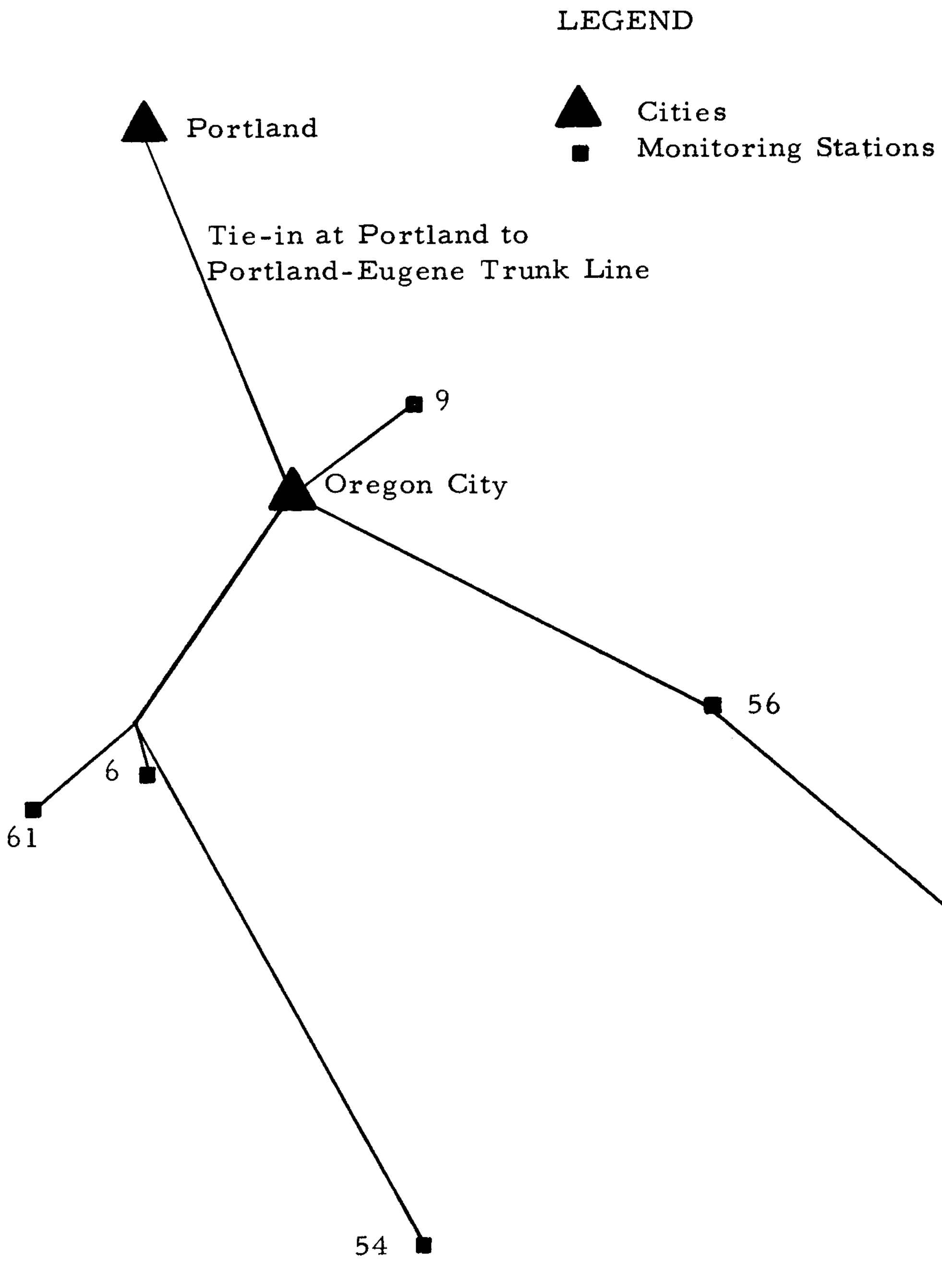

Figure 25. Telephone system for the Oregon City service area.

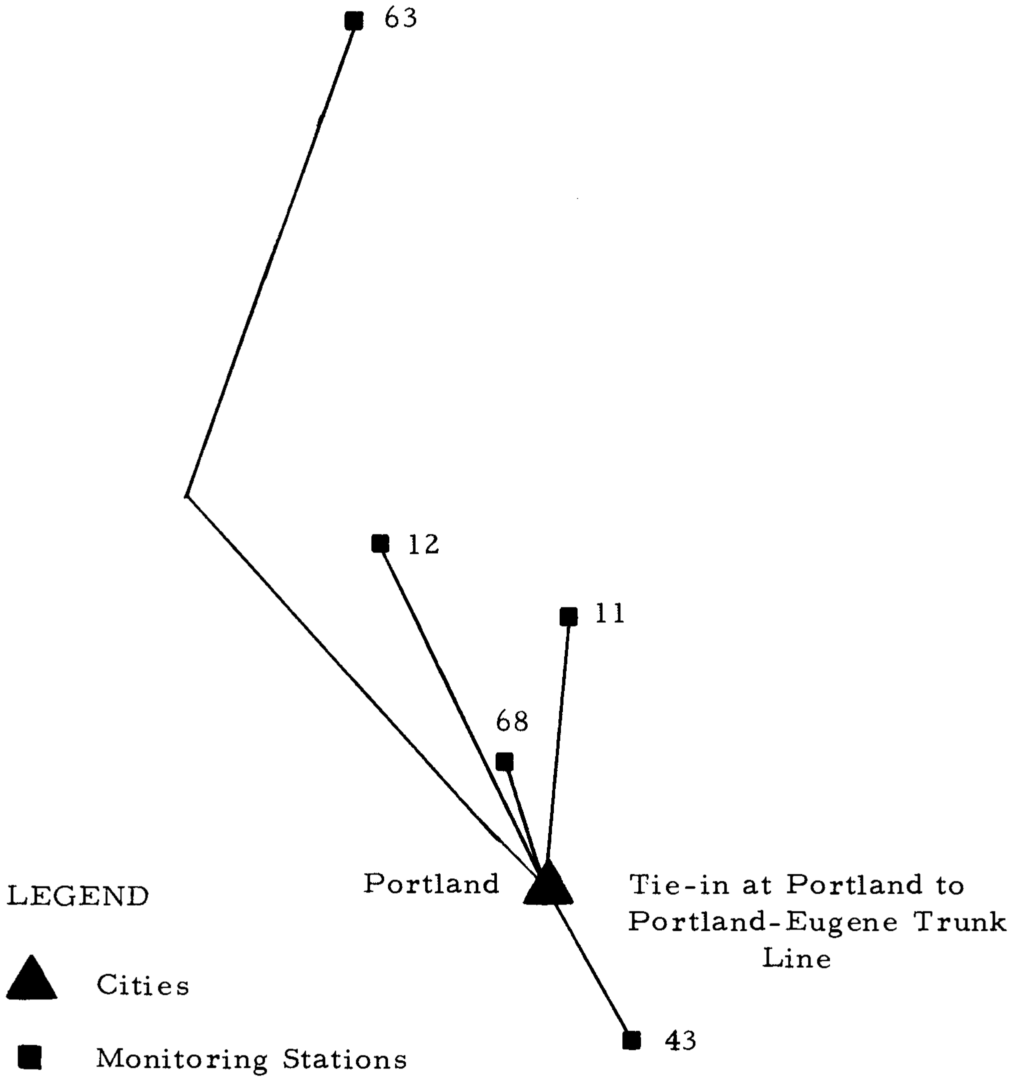

Figure 26. Telephone system for the Portland service area.

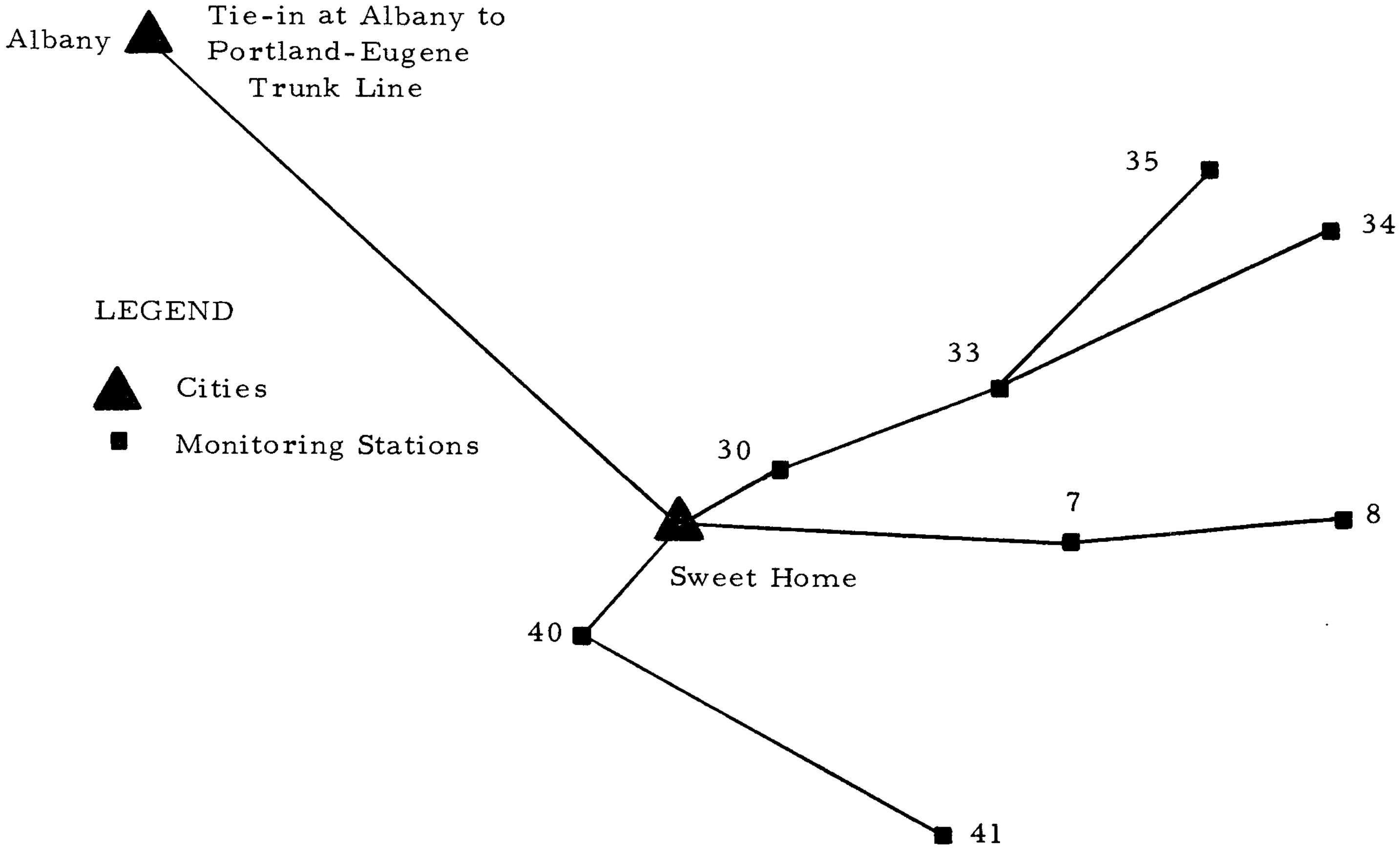

Figure 27. Telephone system for the South Santiam service area.

APPENDIX E

Cost of Providing Telephone Service by Radio Service Areas

The cost of providing telephone service is broken down for each radio service areas as used in Table 15 (1).

Buck Mountain Radio Service Area

7 tone transmitter-receivers		$ 178.50	
7 local channels		26.25	
15 miles of Interexchange channel		27.19	
7.25 miles of subscriber channel		18.13	
		$ 250.07	per month
	or	$3000.00	per year

Coast Fork Radio Service Area

4 tone transmitter-receivers		$ 104.00	
4 local channels		15.00	
18 miles of interexchange channel		32.58	
18.00 miles of subscriber channel		45.00	
		$ 196.58	per month
	or	$2359.00	per year

McKenzie River Radio Service Area

9 tone transmitter-receivers		$ 229.50	
9 local channels		33.75	
37 miles of interexchange channel		77.06	
24.75 miles of subscriber channel		61.88	
		$ 402.19	per month
	or	$4826.00	per year

Middle Fork Radio Service Area

10 tone transmitter-receivers		$ 255.00	
10 local channels		37.50	
17 miles of interexchange channel		30.82	
32.50 miles of subscriber channel		81.25	
		$ 404.57	per month
	or	$4855.00	per year

Newberg Radio Service Area

7 tone transmitter-receivers		$ 178.50	
7 local channels		26.25	
16 miles of interexchange channel		29.00	
30.50 miles of subscriber channel		76.25	
		$ 310.00	per month
	or	$3720.00	per year

Portland Radio Service Area

12 tone transmitter-receivers		$ 306.00	
12 local channels		45.00	
75 miles of interexchange channel		135.75	
39.75 miles of subscriber channel		99.40	
		$ 586.15	per month
	or	$7032.00	per year

Prospect Hill Radio Service Area

10 tone transmitter-receivers		$ 255.00	
10 local channels		37.50	
47 miles of interexchange channel		85.07	
29.50 miles of subscriber channel		73.75	
		$ 451.32	per month
	or	$5416.00	per year

Santiam Radio Service Area

12 tone transmitter-receivers		$ 306.00	
12 local channels		45.00	
54 miles of interexchange channel		97.74	
69.50 miles of subscriber channel		173.76	
		$ 622.50	per month
	or	$7470.00	per year

Trunk Line

104 miles @ $3.00 per mile		$ 312.00	per month
	TOTAL	$3,536.38	per month
	or	$42,448.00	per year

APPENDIX F

Cost of Joint VHF Radio-Telephone Service

This section contains a breakdown of the costs for the joint VHF radio-telephone system considered in Chapter VI for the Santiam, Coast Fork, and Middle Fork service areas.

Coast Fork Service Area

Cost of telephone service for sta. 14 & 22.

2 tone transmitter-receivers	$ 51.00
2 local channels	7.50
5 miles of subscriber channel	12.50
	$ 71.00 per month
	or $850.00 per year

Cost of radio service for sta. 14 & 22.

6 VHF transmitter-receivers	$3375
2 sets of batteries	270
	$3645 per year

Cost of joint VHF radio-telephone service for the Coast Fork Service Area.

Cost of telephone service (except sta. 14 & 22)	$1509
Cost of radio service (sta. 14 & 22)	3645
	$5154 per year

No new construction charges.

Middle Fork Service Area

Cost of telephone service for sta. 25 & 26.

2 tone transmitter-receivers	51.00
2 local channels	7.50
8 miles of subscriber channel	20.00
	78.50 per month
	or $942.00 per year

Cost of telephone service for sta. 38.

1 tone transmitter-receiver	$25.50
1 local channel	3.75
7 miles of subscriber channel	17.50
	$46.75 per month
or	$562.00 per year

Cost of Radio Service for sta. 25 & 26.

4 VHF transmitter-receivers	$2250
3 sets of batteries	405
	$2655 per year

Cost of radio service for sta. 38.

3 VHF transmitter-receivers	$1687
2 sets of batteries	270
	$1957 per year

Three joint radio-telephone systems may be considered for the Middle Fork service area. These are radio for sta. 38 only, radio for sta. 25 & 26 only, or radio for sta. 25, 26, & 38.

Cost of joint service (radio-sta. 38 only)

Cost of telephone service (except sta. 38)	$4293
Cost of radio service (sta. 38 only)	1957
	$6250 per year

New construction charges for sta. 25 & 26 are $25,850.

Cost of joint service (radio-sta. 25 & 26 only)

Cost of telephone service (except sta. 25 & 26)	$3913
Cost of radio service (sta. 25 & 26)	2655
	$6569 per year

New construction charges for sta. 38 are $20,100.

Cost of joint service (radio-sta. 25, 26 & 38)

Cost of telephone service (except sta. 25, 26, & 38)	$3351
Cost of radio service (sta. 25, 26, & 38)	4612
	$7963 per year

No new construction charges.

Santiam Service Area

Cost of telephone service for sta. 34 & 35.

2 tone transmitter-receivers		$51.00
2 local channels		7.50
15.75 miles of subscriber channel		39.40
		$97.90 per month
	or	$1187.00 per year

Cost of radio service for sta. 34 & 35.

4 VHF transmitter-receivers	$2250
3 sets of batteries	405
	$2655 per year

Cost of joint service (radio-sta. 34 & 35)

Cost of telephone service (except sta. 34 & 35)	$6285
Cost of radio service (sta. 34 & 35)	2655
	$8940 per year

New construction charges for sta. 7 are $2700.

APPENDIX G

Comparisons of Cumulative Costs

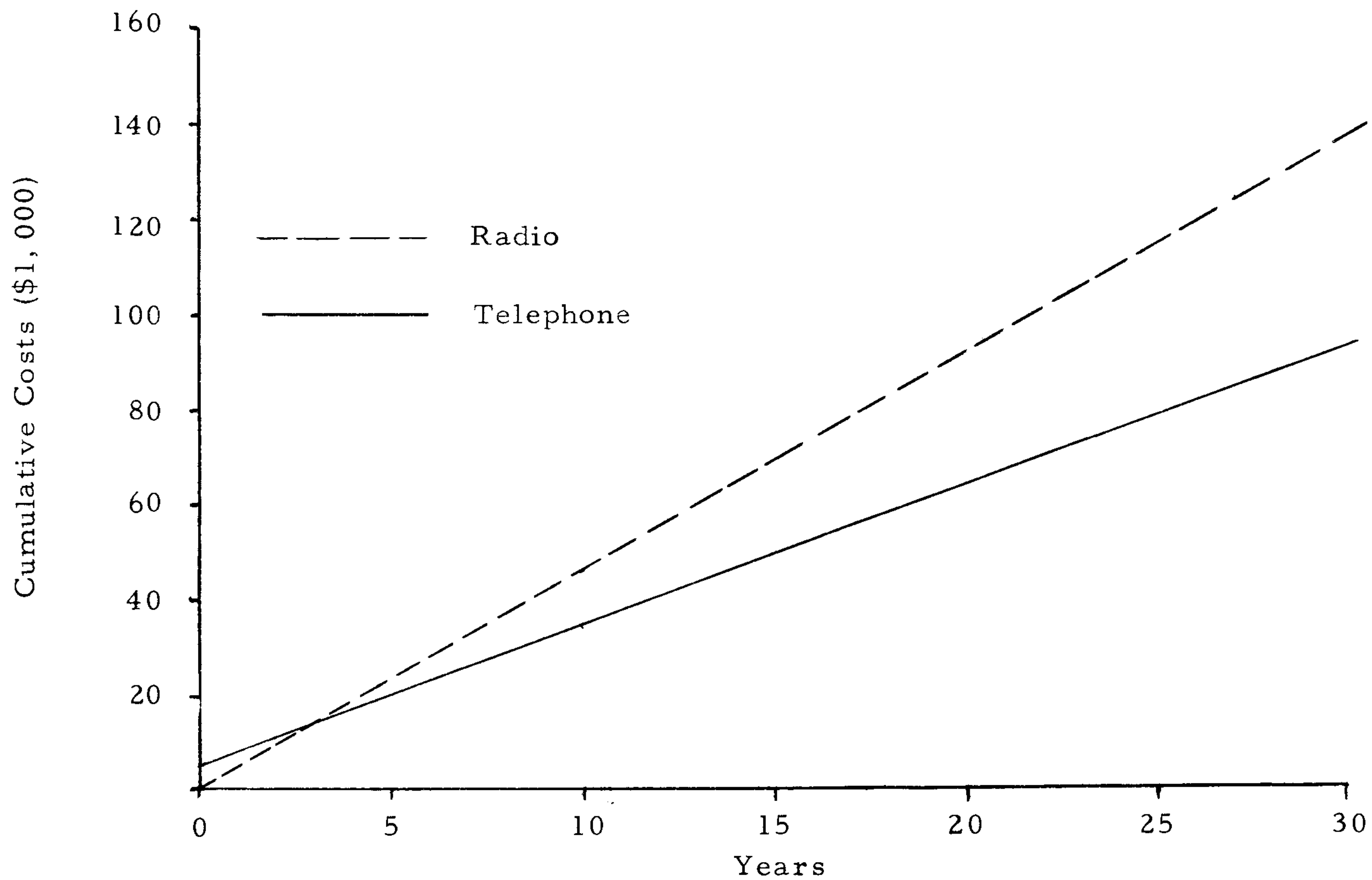

Figure 28. Comparison of cumulative costs for VHF radio and telephone for Buck Mountain service area.

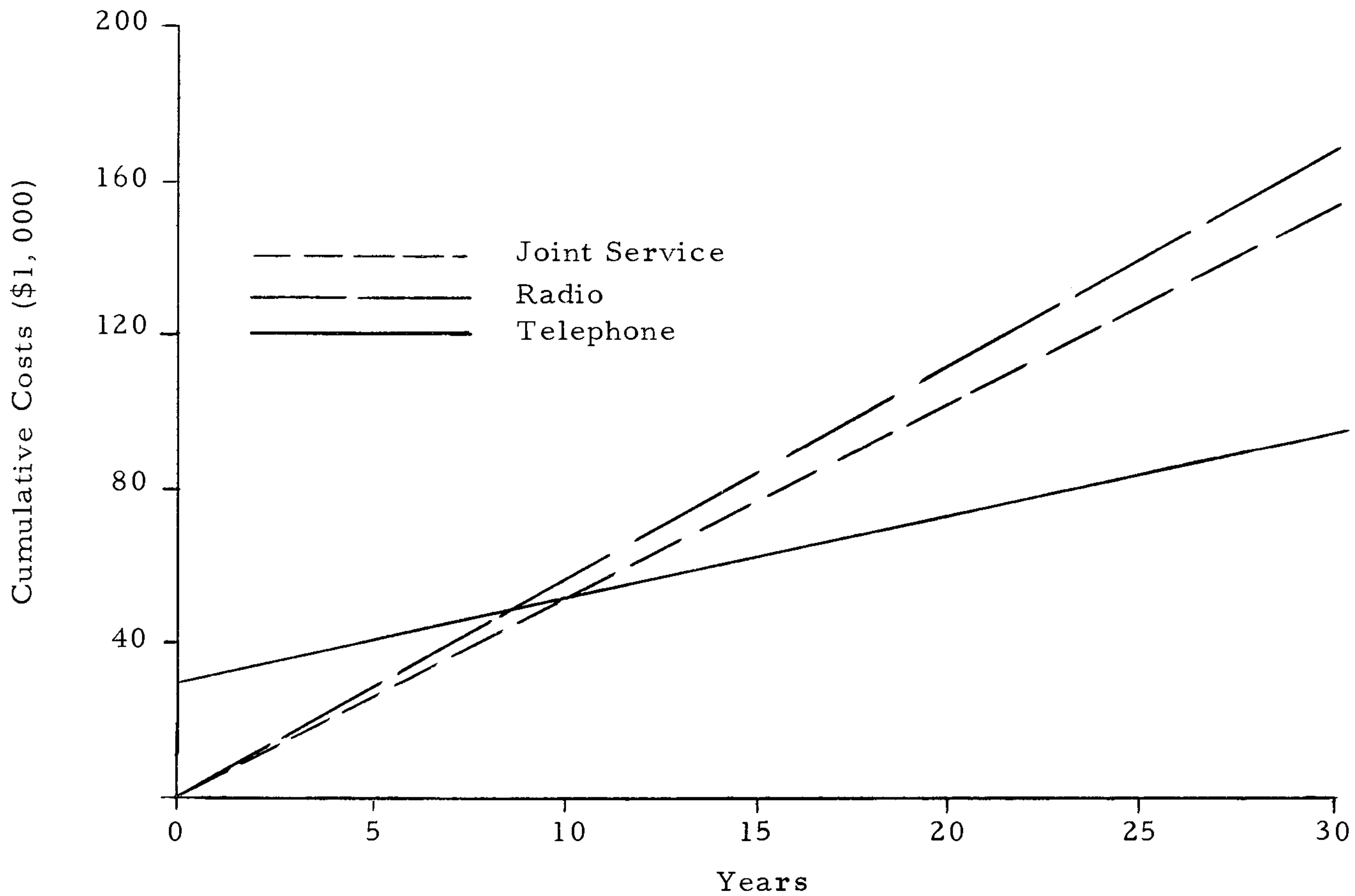

Figure 29. Comparison of cumulative costs for VHF radio, telephone and joint service systems for the Coast Fork service area.

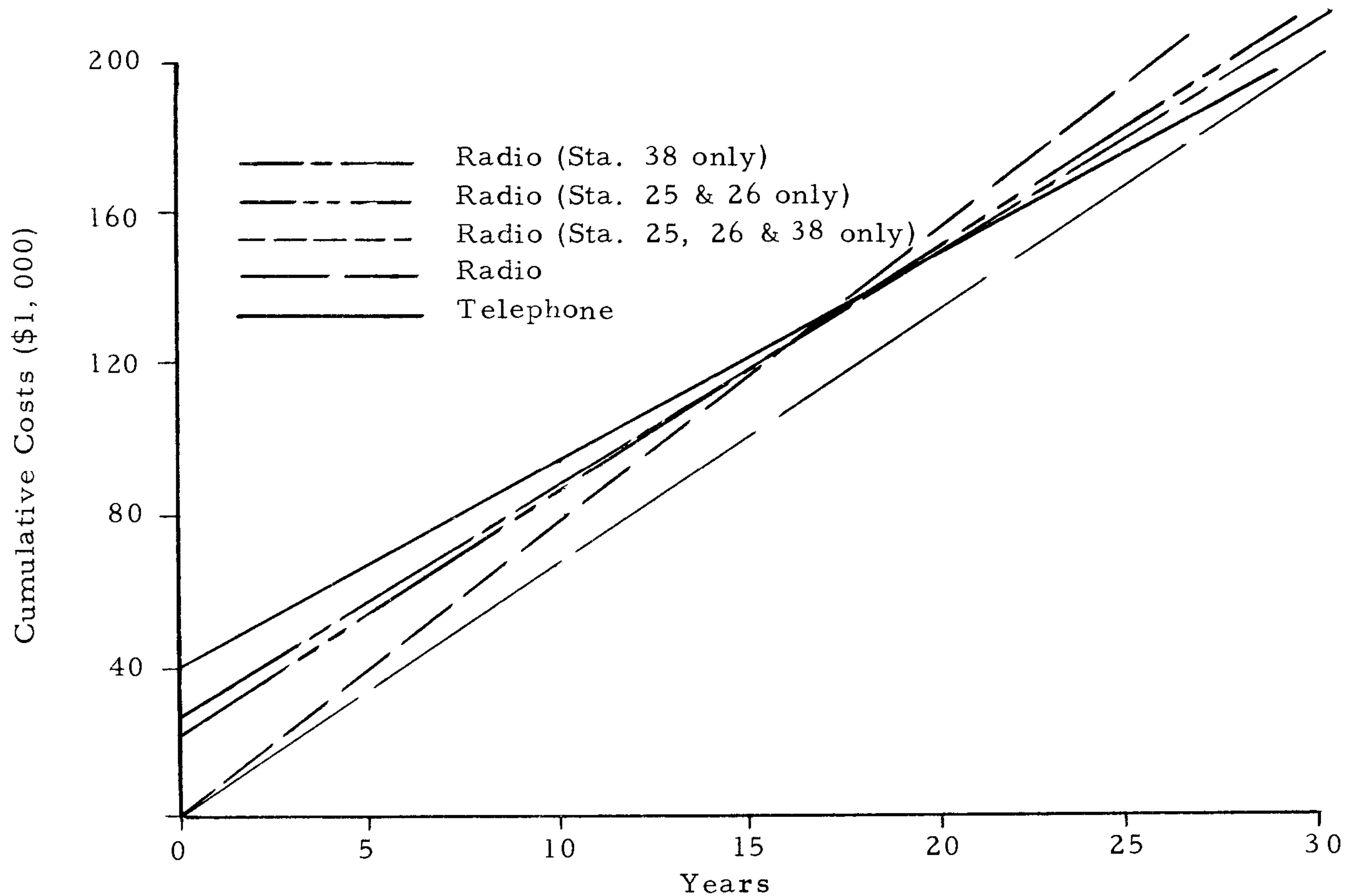

Figure 30. Comparison of cumulative costs for VHF radio, telephone, and joint services for the Middle Fork service area.

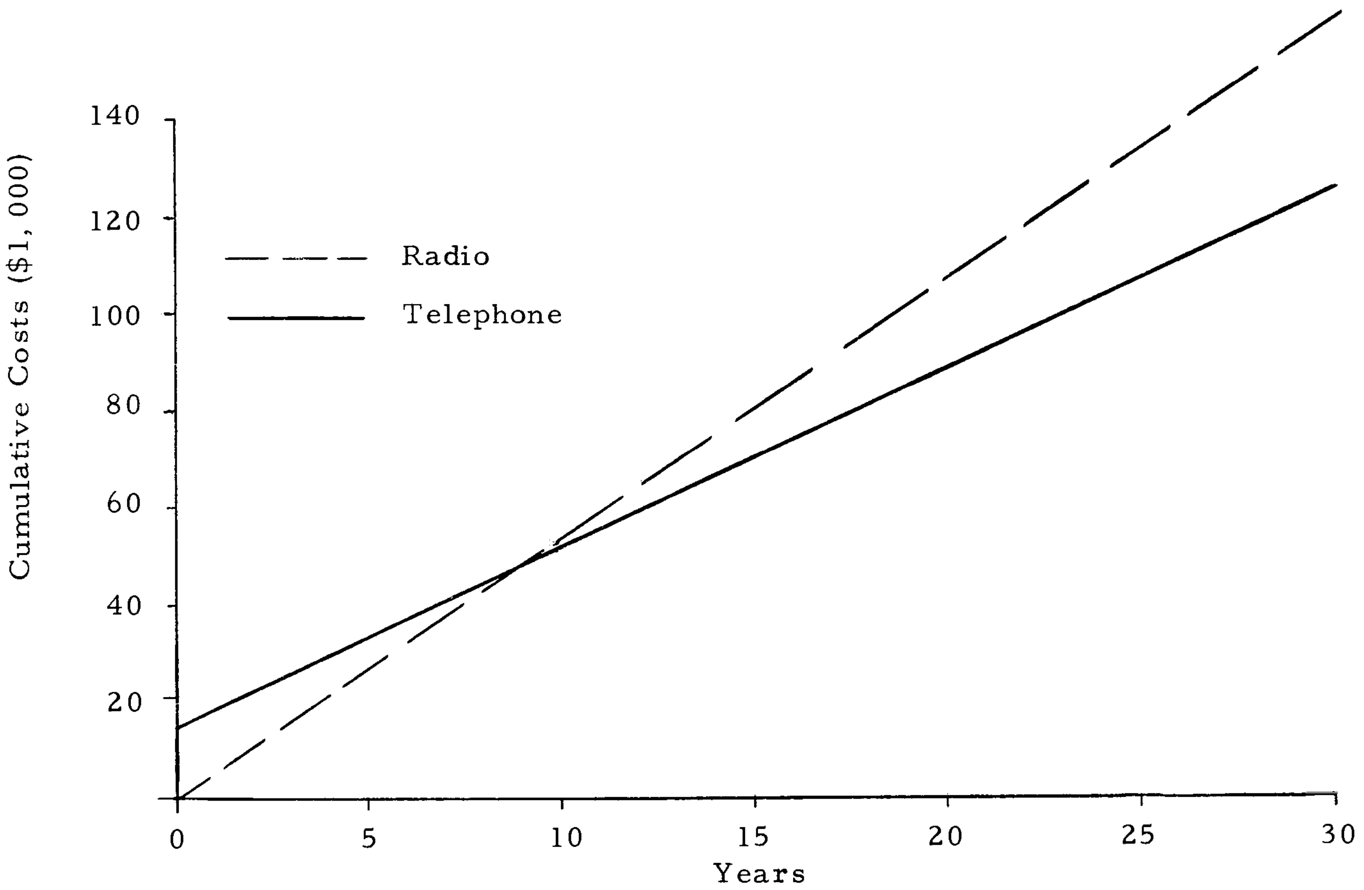

Figure 31. Comparison of cumulative costs for VHF radio and telephone for the Newberg service area.

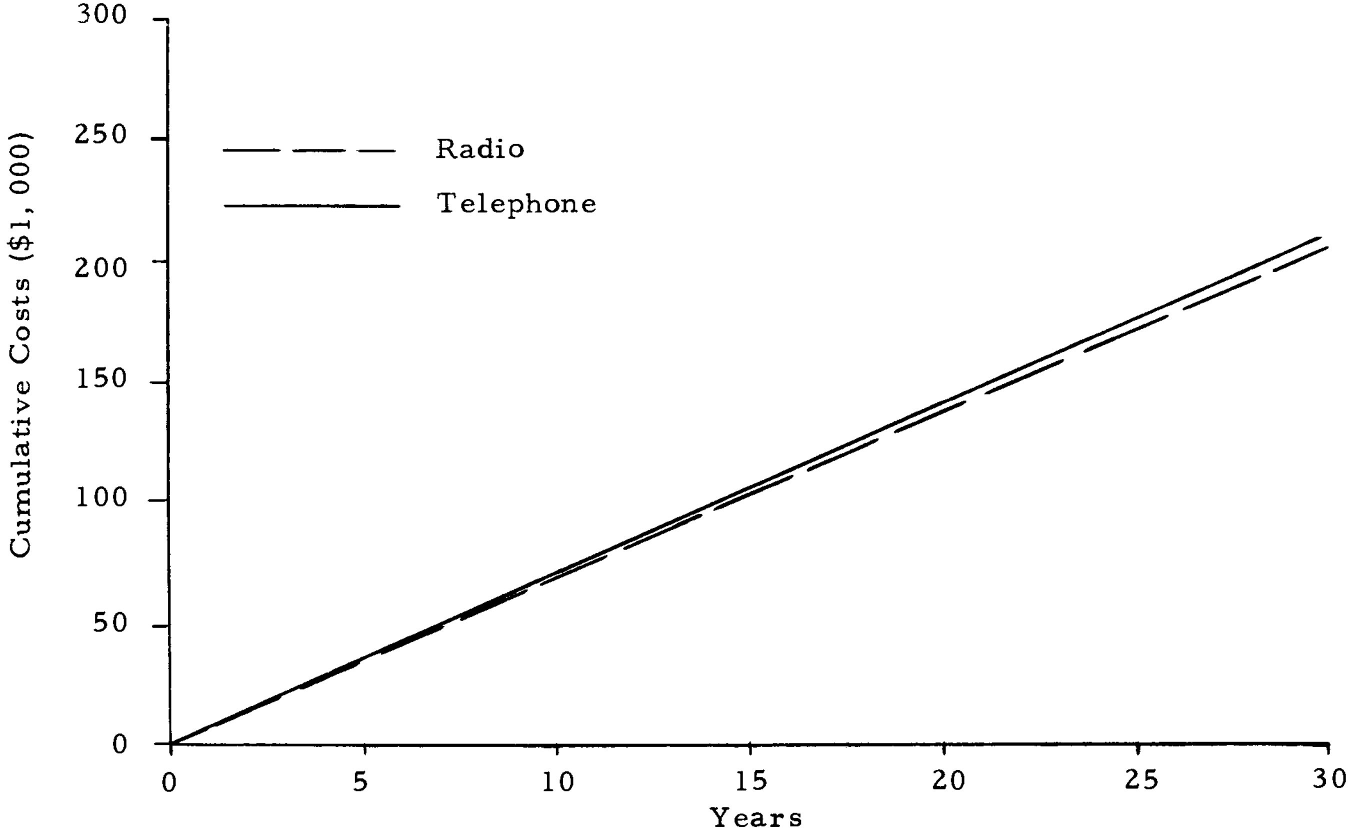

Figure 32. Comparison of cumulative costs of VHF radio and telephone for Portland service area.

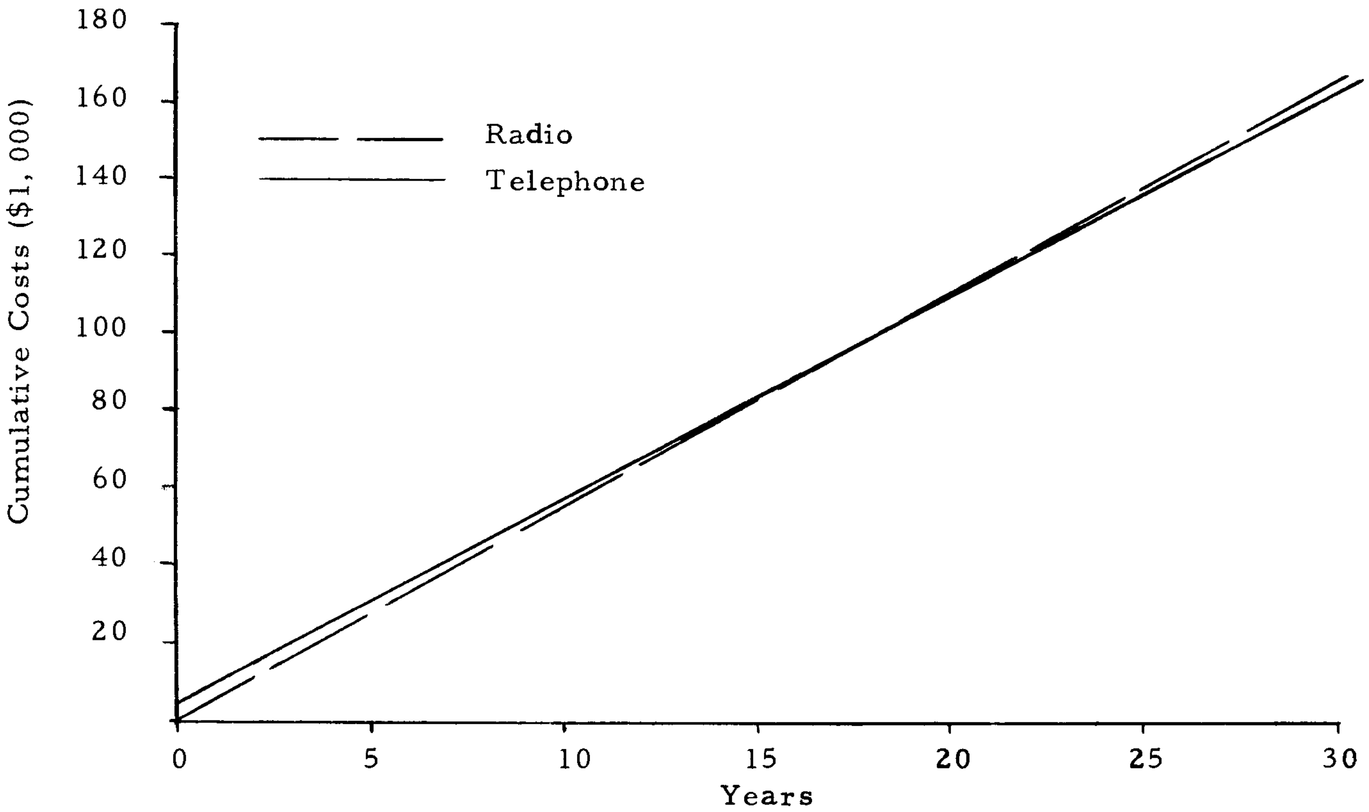

Figure 33. Comparison of cumulative costs of VHF radio and telephone for Prospect Hill service area.

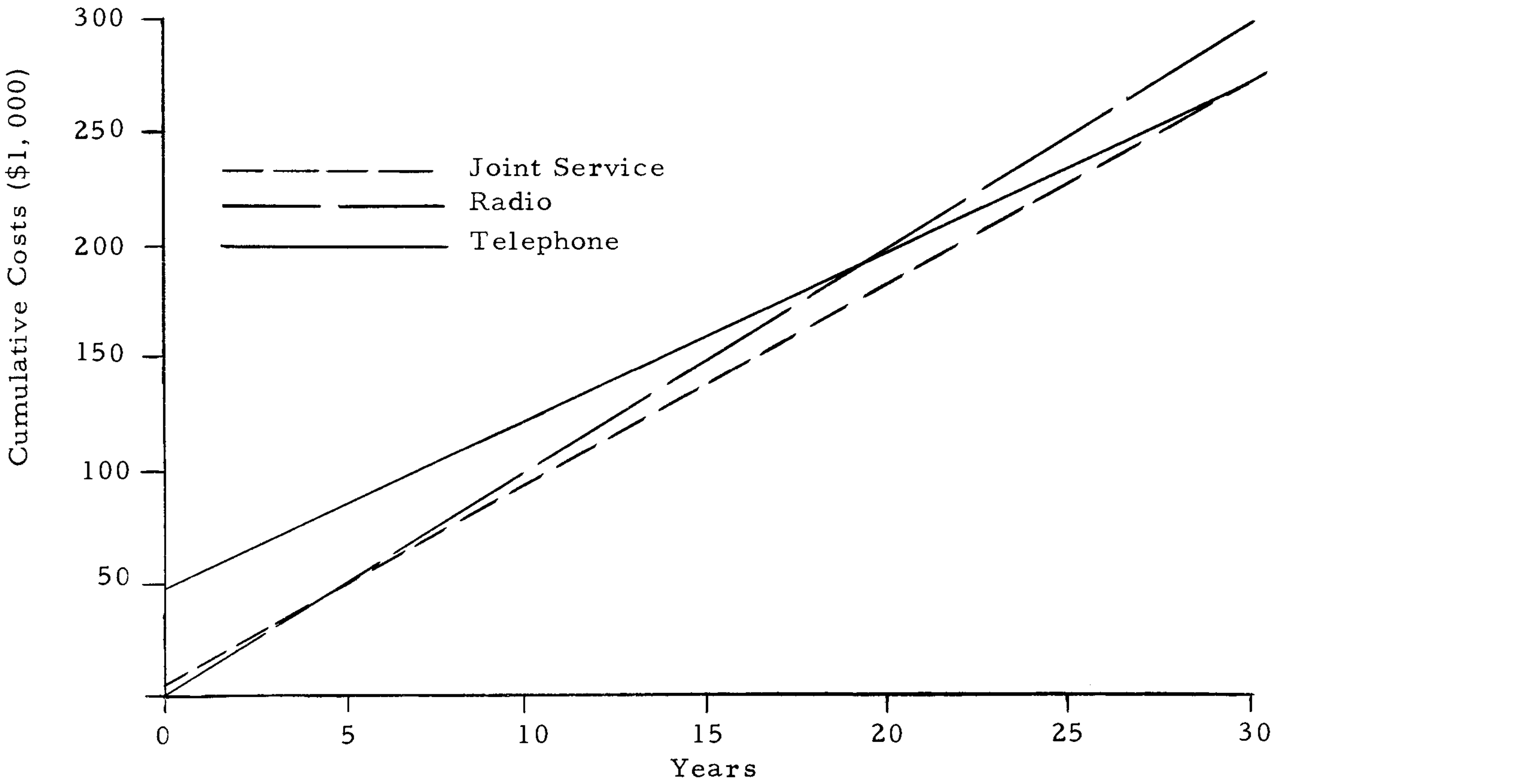

Figure 34. Comparison of cumulative costs of VHF radio, telephone, and joint service for the Santiam service area.

APPENDIX H

Glossary

1. Amplifier - A device which can increase the power level of a signal.

2. Analog Signal - A continuous and stepless function without discontinuities or breaks.

3. Analog to Digital Encoder - A device which converts an analog signal to a digital signal by means of quantization.

4. Binary pulse - Momentary flow of energy of short time duration.

5. Digital Signal - A function consisting of a series of discrete pulses. A unique set of pulses is assigned to each number to be transmitted.

6. Frequency-shift-keying - A system in which the frequency being transmitted deviates plus or minus X Hertz from a nominal center frequency. A deviation of plus X Hertz may correspond to the presence of a pulse while the deviation of minus X Hertz would correspond to the absence of the pulse.

7. Hertz - One cycle per second equals one Hertz.

8. Interexchange Channel - A telephone circuit linking two central offices.

9. Interrogation Signal - A signal transmitted to a monitoring station to initiate the transmission of data.

10. Instrumentation - Equipment used to detect changes in the behavior of a parameter.

11. Line-Interrupt - A technique for the transmission of binary pulses by the interruption of a constant flow of current.

12. Line-Of-Sight - An uninterrupted view between two points.

13. Local Channel - A telephone circuit linking a central office with a monitoring station.

14. Main Stem of the Willamette - From river mile 185 at Eugene to the mouth of the river.

15. Parameter - A quantity whose behavior can be explained by the application of scientific laws. Table 2 lists parameters of interest to water-quality monitoring.

16. Repeater - A station which receives and relays a radio signal. Repeaters are commonly used to maintain line-of-sight transmission between distant radio stations.

17. Signal Conditioning- The process of converting an electrical signal into a more usable form.

18. Solid-State - Refers to the use of active semiconductor components. Germanium and silicon are semiconductor materials. Transistors and diodes are examples of semiconductor components.

19. Stage - Depth of water in a stream or river.

20. Subscriber Mileage - Telephone circuit mileage required to extend a local channel beyond the base rate area. The base rate area normally consists of the area containing the developed telephone system in and around a town.

21. Telemetry - "the process by which the quantity measured is transferred to a remote location to be recorded, displayed, actuate a process, . . ." (6, p. 277)

22. Telephone data communications - The transmission of data, usually in a digital form, over telephone circuits.

23. Very High Frequency Radio - Radio transmission in the 30 to 300 megahertz range.

24. Weston Standard Cell - An electrolytic cell yielding a precisely known e.m.f. of 1.0183 V at 25° C. The Weston cell is based on the invariant activity of cadmium and mercurous ions in solution at a constant temperature.