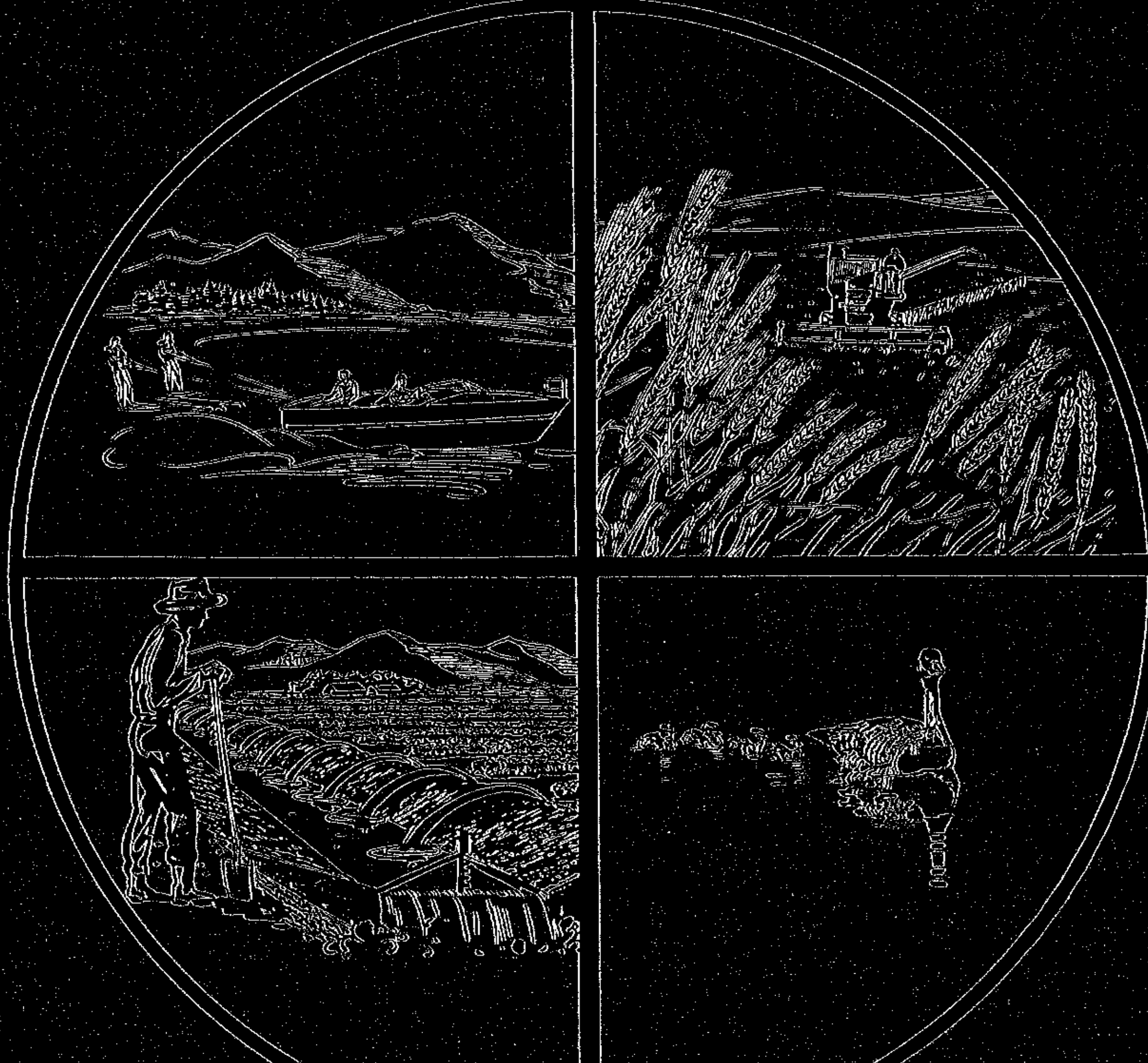
MOSES LAKE CLEAN LAKE PROJECT
STAGE 1 REPORT



PREPARED FOR
MOSES LAKE IRRIGATION
AND REHABILITATION DISTRICT

MARCH 1984

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March 19, 1984

Mr. Clint Connelly, Chairman
Moses Lake Irrigation and
Rehabilitation District
P.O. Box 98
Moses Lake, Washington 98837

14-1225-03

Subject: Transmittal of Stage I Report for the Moses Lake Clean Lake Study on Watershed Controls

Dear Mr. Connelly:

Brown and Caldwell is pleased to submit the Stage I report for the Moses Lake Clean Lake Study which covers evaluation of nutrient sources in the watershed tributary to the lake. Our report integrates the off-farm water quality evaluations which Brown and Caldwell has conducted with Dr. Richard Horner of the University of Washington and on-farm evaluations conducted by Clean Lakes Project staff in Moses Lake and the many cooperative agencies involved.

The report includes an executive summary that reviews our findings on nutrient sources and describes suggested followup investigations in the watershed, including on-farm demonstrations of improved water and fertilizer management.

We appreciate the support and guidance the Board has provided during the course of this investigation and look forward to continuing these efforts for the purpose of improving Moses Lake water quality.

Respectfully submitted,

BROWN AND CALDWELL

Richard C. Bain, Jr.
Vice President

RCB:lb
Enclosure

MOSES LAKE CLEAN LAKE PROJECT

STAGE I REPORT

PREPARED FOR

MOSES LAKE IRRIGATION AND REHABILITATION DISTRICT

BY

BROWN AND CALDWELL

MARCH 1984

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EXECUTIVE SUMMARY

Moses Lake is a large, shallow, eutrophic lake located in the heart of the Columbia Basin, one of the richest agricultural areas in the Pacific Northwest. A natural lake, it is an integral part of the Columbia Basin Project, which supplies water to over 500,000 acres of farmland from the Columbia River. It serves as a supply route for water passing from the East Low Canal, north of Moses Lake, to the Potholes Reservoir, to the south, providing water to the lower part of the irrigation project.

Moses Lake has experienced extensive blue-green algae blooms for over two decades, resulting in diminished recreational use of the lake. The lake has been studied since the early 1960s to determine the source of the noxious blooms and to develop algae control mechanisms. During the late 1970s a restoration program involving dilution of the lake with low-nutrient Columbia River water was implemented. The success of the dilution program in reducing localized algae blooms resulted in the construction of a permanent dilution facility in 1981 to further distribute dilution water within Moses Lake.

Although the dilution program was successful in reducing algal blooms, it appeared desirable to reduce the nutrient load entering the lake. Because agriculture is the largest land use within the basin, it seemed feasible to investigate nutrient control measures aimed specifically at agricultural practices. In March 1982, a grant was obtained from the Washington State Department of Ecology (DOE) and the U.S. Environmental Protection Agency (EPA) to conduct an investigation of agricultural pollution sources in the Moses Lake watershed and the potential impact of these sources on Moses Lake water quality.

The goal of the project is to determine the sources of nutrients within the Moses Lake watershed, in order to develop effective nutrient control measures. The project is being performed in two stages: Stage 1 involves the development of a water quality monitoring program and definition of the cause-and-effect relationships between specific land uses and water quality in Moses Lake; and Stage 2 is the technical assistance for implementation of agricultural best management practices with followup monitoring throughout the watershed.

Upon completion of the Stage 1 monitoring program, the potential effectiveness of agricultural best management practices were evaluated. If it appears that nutrient loading can be significantly reduced by installation of selected agricultural best management techniques, Stage 2 will be implemented. The EPA will supply funds to local irrigation or conservation districts which can be provided to farmers for installation of best management programs, and the DOE/local agencies will support the project management effort and the post-implementation monitoring program.

CONCLUSIONS

Stage 1 was initiated in October 1982 and preliminary findings were made available in January 1984. Conclusions reached during Stage 1 are summarized below:

1. The nutrients of greatest concern to Moses Lake water quality are nitrogen and phosphorus. Nitrogen is currently the limiting nutrient to algae growth in Moses Lake; however, phosphorus was limiting for two years following the Mount St. Helens ashfall.

2. The primary sources of nitrogen are surface runoff and groundwater contributions from agricultural activities in the watershed. The greatest contributions of surface runoff enter Moses Lake from the lower Crab Creek system. Much of the nutrient load from upper watershed runoff is trapped within in-stream impoundments such as Brooks Lake. Recharge from Brooks Lake contributes to spring flow on Rocky Ford Creek.

3. The primary sources of phosphorus include Crab Creek and ground contributions as well as Rocky Ford Creek and the City of Moses Lake sewage discharge. Focky Ford Creek, which is fed by springs, represents the largest single contributor of phosphorus to Moses Lake. Springs feeding Rocky Ford Creek appear to have a phosphorus source that is different from other springs monitored in Stage 1. Sewage disposal practices near Ephrata and waterfowl waste and phosphorus-laden sediment deposited in Brooks Lake are two potential sources identified in this study.

4. Groundwater and surface water nutrient contributions are significantly affected by agricultural practices. This was demonstrated during the Stage 1 study in numerous ways, including observations of spring flows and quality changes reflecting irrigation and fertilizer practices, by neutron probe and soil fertility tests, and by observations of increasing nutrient loads in Crab Creek as it flows through the Block 40, 401, and 41 area.

5. Sewage effluent is particularly rich in phosphorus, and control of effluent discharge may cause phosphorus to become limiting in selected areas of Moses Lake such as Pelican Horn. Sewage effluent represents approximately 18 percent of the phosphorus loading to Moses Lake. Septic tanks around Moses Lake will continue to contribute additional nutrients to Moses Lake unless sewer hookups are required. These individual disposal practices account for approximately 5 percent of the phosphorus load to the lake.

6. Agricultural practices within the Block 40, 401, and 41 area appear to have the greatest impact on surface and groundwater loadings affecting Moses Lake. There are 20,954 acres of irrigated land within this area, of which 81 percent utilize sprinkler irrigation. The remaining 19 percent utilize furrow irrigation, which contributes 50 percent more nitrogen per acre to the area's groundwater due to over-irrigation. Although furrow irrigation accounts for less than one-fifth of the irrigated area, it contributes over one-third of the nitrogen leached via deep percolation.

7. Overall the portion of irrigated area ,excluding alfalfa, within Block 40, 401, and 41 receives an average of 161 pounds per acre of nitrogen and 66 pounds per acre phosphorus. Legume crops do not receive nitrogen fertilizer but do contribute to nitrogen losses. Based on water application rates, crop use, and accepted agricultural leaching equations, 23 pounds per acre per year of nitrogen is lost to deep percolation to groundwater. This represents a total loading of 245,000 pounds per year from agricultural fertilizers from this area alone. Measured nitrogen loading in the springs covered in the year-long monitoring program accounted for 300,000 pounds. Total nitrogen losses from irrigated agriculture in the lower Crab Creek watershed are in the 500,000 to 700,000 pounds range considering rotation and all crops involved.

8. Other sources of nutrients were identified during Stage 1, including wastes from cattle operations (e.g. feed lots and dairies), fish hatcheries, urban runoff, and potential contributions from in-lake recycling of nutrients from carp and decay of aquatic plants.

RECOMMENDATIONS

Recommended controls to be demonstrated in Stage 2 include both on-farm and off-farm programs. These are listed below.

On-Farm Controls

Controls are emphasized for irrigated farms in the Block 40, 401, and 41 area that involve cooperative demonstration programs. Dryland and other agricultural activities in Stage 2 are continued for further inventory and evaluation work.

On-Farm Irrigation Programs. On-farm programs include improved irrigation and fertilizer management as well as installation of improved irrigation systems to replace inefficient furrow systems. Management practices should involve participation by at least 75 percent of the farms under contract within the Stage 2 project area.

The recommended Stage 2 project area for on-farm programs is Block 40, 401, and the portions of Block 41 that are tributary to Moses Lake. Management practices to be incorporated in Stage 2 include soil testing for the purpose of identifying optimum fertilizer application scenarios and irrigation water scheduling. Soil tests will include soil nutrient measurements and neutron probe readings of soil moisture at various points in the soil profile above and below the root zone.

Irrigation system improvements will be demonstrated on selected farms where conversion of existing furrow systems is determined to be feasible and acceptable for demonstration purposes. At least two and preferably three fields will be converted to cablegation and additional fields may be converted to sprinkler systems if cost share money is available. These converted fields will be intensively monitored and managed as high visibility demonstration sites accessible to all interested parties. The Stage 2 public information program will be actively involved in publicizing these demonstration projects.

<u>On-Farm Dryland Programs</u>. Dryland farming practices will be inventoried further and evaluated to determine need for additional management. Information developed from this evaluation will be communicated to local farmers through the Stage 2 public information process.

Other Stage 2 Agricultural Programs

Inventory data will be gathered on hatcheries and cattle operations including major feed lots and dairies to determine practices and potential waste load contributions to groundwater and surface runoff. Information gathered will be incorporated in Stage 2 reports to assess overall effectiveness of nutrient controls in terms of Moses Lake water quality.

Off-Farm Controls

A list of off-farm evaluations and control projects have been identified which deal with nutrient load reduction in lake nutrient recycling and further evaluations of selected source impacts such as sewage disposal near Ephrata and effect recharge from in-stream impoundments such as Brooks Lake or groundwater quality. Better estimates of groundwater flow rates to Moses Lake are also needed so effectiveness of on-farm control can be predicted with more accuracy. A listing of off-farm programs considered for Stage 2 is provided below:

<u>In-stream Impoundments</u>. Sediment/nutrient traps could be designed for the lower Crab Creek system and for Rocky Ford Creek This approach should be preceeded by additional monitoring of flows into and out of existing impoundments to confirm their effectiveness.

Groundwater Evaluations. Specific evaluations of sources which may explain high phosphorus in Rocky Ford Creek springs are warranted. These include evaluation of the impact of sewage disposal practices near Ephrata and impact of recharge from the Brooks Lake impoundment. Also more accurate estimates of groundwater flow are needed which would require careful determination of aquifer permeability and groundwater levels to establish gradients and resultant flow rates for different seasons of the year.

Septic tank systems in urban areas near the lake should be hooked up to sewer systems wherever feasible. Many of the approximately 1,500 people within the City of Moses Lake that are not served by the city sewer are in lakeshore areas underlain by coarse gravels that drain easily to the lake. Also much of the urban development in the Moses Lake area is just outside the city limits; and we estimate that at least 2,000 people currently outside the city limits could be served by sewer extensions assuming financing could be secured and annexation or other institutional arrangements were possible.

In-Lake Controls. Several separate evaluations should be sponsored which deal with nutrients accumulated in bottom sediments to determine recycling rates due to carp or limnological factors such as reduced oxygen levels or wind-induced currents. Importance of nutrient rich sediments in upper Parker and Pelican Horns should be evaluated relative to weed growth to determine need for dredging in these areas. Circulation within Parker and Pelican Horn should also be evaluated to determine impact of bridges and causeways on water quality.

Evaluation of Controls. The Stage 2 program should include a quantitative evaluation of the effect of both on-farm and off-farm controls on Moses Lake water quality. Predictive models have been developed for Moses Lake which estimate algal growth for various nutrient loading levels.

SUMMARY OF STAGE 2 RECOMMENDATIONS

In summary, we recommend an integrated Stage 2 program incorporating elements from the on-farm and off-farm programs described above. We strongly believe that on-farm irrigation demonstrations should be implemented in the Block 40, 401, 41 area provided sufficient farmer participation can be mustered. To complement this effort, we believe the dryland and other agricultural practice inventories should proceed but without field demonstration or further monitoring. We further support field and evaluative efforts in selected off-farm programs, including carp impacts on water quality, impoundment and dredging feasibility studies, refined groundwater flow estimates, assessment of sewage disposal impacts from Ephrata/Soap Lake and Brooks Lake recharge on Rocky Ford Creek spring quality, and evaluation of ways to improve circulation around causeways and bridges within Moses Lake. A Stage 2 report will be prepared which will include an overall appraisal of the impact of these programs on Moses Lake water quality using predictive models developed by the University of Washington.

Nitrogen load reduction is the primary measure of the proposed source control program effectiveness since this is the limiting nutrient in Moses Lake. Estimates of up to 300,000 pounds of nitrogen (136,000 kg) can be saved annually through the on-farm irrigation program assuming the techniques demonstrated can be implemented on a large scale in the Block 40, 401, and 41 area and the other irrigated areas in the lower Crab Creek drainage. Further load reductions can be accomplished with off-farm controls, particularly through nutrient trapping in lower Crab and Rocky Ford Creeks and in sewage disposal improvements. The overall reduction in nitrogen load should approach at least 40 percent if the combination of in-stream impoundments and irrigation practice changes discussed are implemented. Similar phosphorus reductions would be expected from agricultural and in-stream controls. Over 50 percent of the phosphorus loading could be achieved if agricultural controls are matched by improved sewage disposal practices such as eliminating the City of Moses Lake discharge and septic tank sources near the lake.

The on-farm program involves changes to local irrigation practices, in effect, a social change. Success will depend on the effectiveness of the demonstration program and the willingness of farmers to participate and accept the management and irrigation system improvements suggested. Cost share incentives will help to get these practices implemented. The logic and economics of the changes and public information and education must do the rest.

We recommend Stage 2 proceed on the basis of the nutrient load reduction improvements that have been identified to improve the present situation and to provide a better example to further irrigated farm developments expected within the Columbia Basin in the coming years. As agricultural development becomes more intensive in the Moses Lake watershed the resulting impact on lake quality will ultimately increase eutrophication problems unless nutrient loads can be controlled more effectively. Practices suggested in this report will be helpful in protecting the lake.

CHAPTER 1

INTRODUCTION

Moses Lake is a large, shallow, eutrophic lake located in the heart of the Columbia Basin, one of the richest agricultural areas in the Pacific Northwest. Covering some 6,800 acres with 120 miles of shoreline, it is one of the State's most polluted bodies of water. A natural lake, it is an integral part of the Columbia Basin Project, which supplies water to over 500,000 acres of farmland from the Columbia River. The lake elevation is 1,046 feet with an average depth of 18.5 feet. It serves as a supply route for water passing from the East Low Canal, north of Moses Lake, to the Potholes Reservoir, to the south, providing water to the lower part of the irrigation project.

Moses Lake has experienced extensive blue-green algae blooms for over two decades, resulting in diminished recreational use of the lake. The lake has been studied since the early 1960s to determine the source of the noxious blooms and to develop algae control mechanisms. A pilot lake restoration program was conducted in Parker Horn in 1977 involving dilution of the lake with low-nutrient Columbia River water. The success of the dilution program in reducing localized algae blooms resulted in the construction of a permanent dilution facility in 1981 to distribute dilution water to the Pelican Horn area of Moses Lake.

Although the dilution program was successful in reducing algal blooms in Parker and Pelican Horns, it appeared desirable to reduce the nutrient load entering the lake. Because agriculture is the largest land use within the basin, it seemed feasible to investigate nutrient control measures aimed specifically at agricultural practices. In March 1982 a grant was obtained from the Washington State Department of Ecology (DOE) and the U.S. Environmental Protection Agency (EPA) to conduct an investigation of agricultural pollution sources in the Moses Lake watershed and the potential impact of these sources on Moses Lake Water quality.

Currently, there is little basis to establish the quantities of nitrogen and phosphorus generated by the various agricultural processes and transported to Moses Lake. The literature in this area is too general for a meaningful assessment, with breakdowns limited to unspecified cropping and pasturing. The wide variability reported in the literature also strongly suggests that nutrient yield is determined by local factors to the extent that generalization is very misleading. Further progress in alleviating the effects of eutrophication in Moses Lake, therefore, requires thorough attention to defining the role of the major potential nutrient sources through a field monitoring program.

The goal of the project is to determine the sources of nutrients within the Moses Lake watershed, in order to develop effective nutrient control measures. The project is being performed in two stages: Stage 1 involves the development of a water quality monitoring program and definition of the cause-and-effect relationships between specific land uses and water quality in Moses Lake; and Stage 2 is the technical assistance for implementation of agricultural best management practices with followup monitoring throughout the watershed. Stage 2 will be implemented only if Stage 1 investigations determine that best management practices are feasible and potentially effective in water quality improvement.

The specific objectives of Stage 1 include:

1. To document sources and loading rates of nutrient input to Moses Lake via Crab Creek, Rocky Ford Creek, Rocky Coulee Wasteway, and groundwater.

2. To document the pathways of nutrient movement into Crab Creek, Rocky Ford Creek, and Rocky Coulee Wasteway.

3. To evaluate nutrient control of blue-green algal blooms in Moses Lake.

4. To assess the potential impact of agricultural best management practices upon Moses Lake algal blooms.

5. To calculate the rate of nutrient release from the sediments.

Upon completion of the Stage 1 monitoring program, the potential effectiveness of agricultural best management practices will be evaluated. If it appears that nutrient loading can be significantly reduced by installation of selected agricultural best management techniques, Stage 2 will be implemented. The EPA will supply funds directly to farmers for installation of best management programs, and the DOE/local agencies will support the project management effort and the post-implementation monitoring program.

The goals of Stage 2 are:

1. To strengthen the overall resource protection programs operated by the various Conservation Districts in the area.

2. To demonstrate an irrigation water management system in the Columbia Basin.

The project requires interaction among the Washington State Department of Ecology (DOE), the U.S. Environmental Protection Agency (EPA), Moses Lake Irrigation and Rehabilitation District, and local Conservation Districts. Figure 1-1 summarizes agency interaction:

AERIAL VIEW of a portion of the City of Moses Lake showing a portion of Parker Horn at the top and Pelican Horn at the bottom. A portion of the dilution water released into Parker Horn through Crab Creek is pumped across the city and discharged into Pelican Horn.

DILUTION WATER for Parker Horn is pumped into Pelican Horn during the spring and summer months.

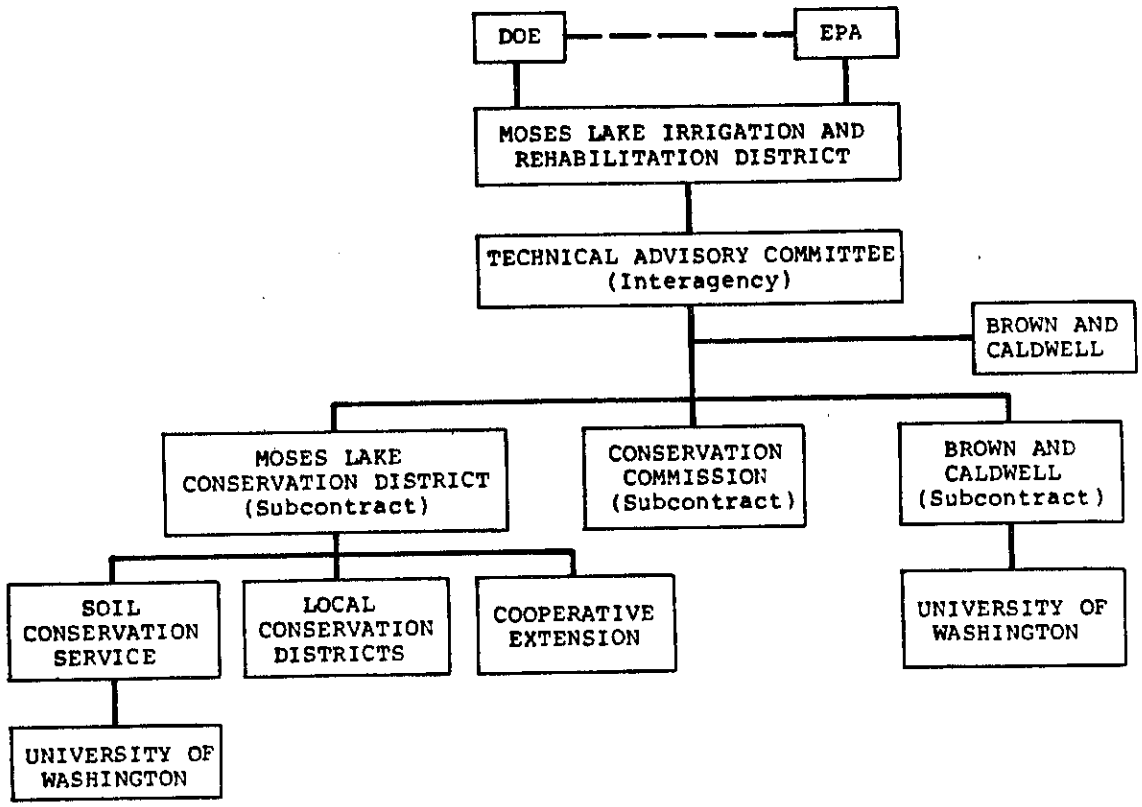


Figure 1-1. Interaction among Agencies

The total amount of funding for Stage 1 was $406,910, of which DOE paid 75 percent, EPA provided 18 percent, and the Moses Lake Irrigation and Rehabilitation District paid 7 percent. Total funding for Stage 2, if it is deemed feasible, will be $350,754, with the same breakdown of agency financial responsibility as Stage 1. The DOE will not provide funds for actual installation of BMPs, a responsibility assumed by EPA, but will direct the work effort.

Acknowledgments

This project has received financial, technical, and policy support from many agencies and individuals. Grant funds were provided to the Moses Lake Irrigation and Rehabilitation District by the Washington State Department of Ecology and the U.S. Environmental Protection Agency. Primary technical guidance

has been through a Technical Advisory Committee (TAC) comprised of participant agency staff representatives. Policy guidance has been obtained through a three-member council (commonly referred to as the Hub) which included one member each from the Moses Lake Irrigation and Rehabilitation District, the Moses Lake Conservation District, and the Upper Grant County Conservation District.

Members of the TAC and the Hub are acknowledged below:

TAC Members:

Tom Newcomb/Bob Bottman, co-chairmen
Washington State Conservation Commission

Ron Pine/Joanne Chance, Washington State
Department of Ecology

Karl Nadler, U.S. Environmental Protection Agency

Ed Forster, Grant-Adams County Cooperative
Extension Service

Shiraz Vira, Bill McGuire, and Karl Kler,
Soil Conservation Service

Council Members:

DeForest (Huck) P. Fuller,
Moses Lake Irrigation and Rehabilitation District

Bill Bellomy, Jr./Richard Weitman,
Moses Lake Conservation District

Les Rataezyk, Upper Grant County
Conservation District

On-farm project elements were directed from the Moses Lake Soil Conservation District office by Ernie Jager who served as Program Director for the Moses Lake Conservation District. His staff included Leigh Nelson, agricultural engineer, Bernie Kanoff, resource technician, and Betty Texmo, secretary. Public information and education was coordinated by Glen Blackburn who was supervised by Ed Forster of the Grant-Adams Cooperative Extension office in Ephrata. Off-farm elements were carried out by Brown and Caldwell, consulting engineers from Seattle, in association with Dr. Richard Horner of the University of Washington Department of Civil Engineering. Dr. Horner also assisted the on-farm program in the analysis of water samples.

The support of Clint Connelly, Huck Fuller, and Norm Estoos of the Moses Lake Irrigation and Rehabilitation District Board is gratefully acknowledged. The project received useful information from the City of Moses Lake and Grant County for use in evaluating non-farm nutrient inputs to Moses Lake. Technical guidance received from David Moffit of the Soil Conservation Service, West Technical Service Center in Portland and from Bill McGuire, District Conservationist from Moses Lake is also gratefully acknowledged.

CHAPTER 2

DATA COLLECTION

Water quality data were collected for representative agricultural practices, and at points throughout the flow network tributary to Moses Lake. The on-farm monitoring program, directed by the Soil Conservation Service, attempted to relate specific farming practices with nutrient loading. The off-farm monitoring program, directed by Brown and Caldwell, tracked nutrient transport through major surface pathways and groundwater. Nutrient loading to Moses Lake via septic tank discharge to groundwater was evaluated as was sediment nutrient recycling.

GENERAL WATERSHED DESCRIPTION

Figure 2-1 depicts the Moses Lake watershed and its major tributaries. The total watershed encompasses approximately 6,255 sq km, of which Crab Creek drains about 5,204 sq km. The major urban center in the watershed is the City of Moses Lake (population 10,300). The City and surrounding urban fringe account for a population of approximately 20,000 people. The urban centers of Ephrata-Soap Lake (population 10,400) which lie outside the watershed contribute to the underground flow tributary to Moses Lake. Although much of the urban and all the rural population is unsewered, there are sewer systems in Moses Lake, Ephrata, and Soap Lake.

Crab Creek has its source near Reardan in northeastern Lincoln County and flows generally south and then west near the southern county border. With its tributaries, such as Lords Creek, Lake Creek, Duck Creek, Goose Creek, and Coal Creek, the Crab Creek system drains much of Lincoln County. Entering northern Grant County, Crab Creek continues to flow generally west to the vicinity of Adrian, where it turns south toward Parker Horn of Moses Lake. An additional major tributary, Wilson Creek, joins the main stem at the town of the same name.

Several impoundments interrupt Crab Creek, including Sylvan Lake, Brook Lake, and Round Lake. Flow is intermittent upstream of Round Lake, although it is continuous in the vicinity of Irby (average discharge of 74 cfs) (U.S. Geological Survey, 1981). Round Lake normally discharges for only a few weeks during late winter runoff. Average discharge at Road 7 N.E., just north of Moses Lake, is not recorded because of the modified hydrology occurring after irrigation. The range during 1981 was 8.1 to 90 cfs (U.S. Geological Survey, 1981). Just downstream of that point, Rocky Coulee Wasteway, a drainage conduit for Block 40 irrigation returns, discharges to Crab Creek.

Although draining a much smaller catchment (7,660 acres), Rocky Ford Creek also is an important Moses Lake tributary (average discharge of 77 cfs (U.S. Geological Survey, 1981). Its mouth forms the Main Arm of the lake.

Climate

Key elements in this project are precipitation and the availability of irrigation water. The Crab Creek drainage basin is divided into four precipitation zones: 6 to 9 inches near Moses Lake, 9 to 12 inches from Wilson Creek to Odessa, 12 to 15 inches to Harrington, or the summer fallow areas, and 15 to 18 inches from Davenport to Medical Lake where 3- to 4-year rotations are standard. Approximately 60 percent of the moisture falls between November and March. Snow is the prevalent form of moisture at Davenport with an elevation of 2,370 feet. Most of the runoff and erosion occurs when winter or spring moisture falls on frozen ground.

The average winter temperature at Moses Lake is 34 degrees F with an extreme low of -33 degrees F. The average summer temperature is 71 degrees F with an extreme high of 106 degrees F. The growing season varies from 130 to 170 days long; it begins in April and runs to the first fall frost, usually in September. Snowfall varies from 7 to 22 inches and occurs from November through March.

In the upper end of the watershed, the average winter temperature is 32 degrees F, and the lowest temperature is -24 degrees F. In the summer the average temperature is 65 degrees F with an extreme high of 112 degrees F. The highest rainfall (24 hours) of record of 1.44 inches, and thunderstorms occur about 10 days each year. Snowfall averages about 46 inches and the record is 55 inches. The frostfree season varies from 110 to 130 days.

Geology. Two major distinct groundwater systems interact in the study area both of which are recharged by irrigation and discharge into Rocky Ford Creek, Crab Creek and Moses Lake. The upper system consists of unconsolidated glacio-fluvial sand and gravel which forms a mantle over the underlying basalt bedrock. The glacio-fluvial deposits generally vary from about 20 to 100 feet thick. The basalts exposed in the vicinity of Rocky Ford Creek are predominantly from the Rosa member of the Wanapum Formation.[1] This formation probably underlies most of the immediate area surrounding Moses Lake. East of the East-Low Canal, the Priest Rapids Member of the Wanapum Formation is dominant.[1] The mantle of sand and gravel in this area is generally thinner. In most areas the Priest Rapids basalt is covered by a thin veneer of soil (0 to 6 feet thick) and weathered basalt. The Rosa member underlies the Priest Rapids member. Both the Priest Rapids and the Rosa consist of successive volcanic flows stacked on top of one another. It is the highly fractured and weathered zones which occur between the volcanic flows which, when filled with water, form the basalt aquifers.

Soils. The Crab Creek watershed consists mainly of two major physiographic areas, the loess mantled uplands and the channeled scablands.

Loess is a wind blown deposit of silt-sized particles, generally nonstratified. The prevailing southwest winds deposited the loess from 20 inches to several hundred feet in thickness. The Athena, Broadax, Bagdad, Renslow, Ritzville, and Shano are examples of soils formed in deep loess. Burke and Willis soils formed in thinner loess deposits over a lime-silica cemented duripan.

Soil in the channeled scabland formed in sand and gravel, glacial outwash, or basalt with a thin mantle of loess. The channeled scablands formed during the Pleistocene from floods of glacial meltwaters. The meltwaters stripped the loess to bedrock and were responsible for the creation of channels, undrained basins, basalt escarpments, terraces, and terrace escarpments. The Benge, Hesseltine, Stratford, Strat, Ephrata, and Malaga are examples of soils formed in glacial outwash with a thin mantle of loess on terraces and terrace escarpments. Where these soils are located in the Block 40 area, they are very well drained.

Also included in the watershed are lacrustrine or slack-water deposits from glacial meltwaters. Kennewick, Sagemoor, Farrell, and Warden are examples of soils formed in stratified lacrustrine or slack-water deposits that have a thin mantle of loess.

The coarse shallow soils predominant in the Crab Creek and Rocky Ford Creek watersheds, particularly in southern Grant County, allow significant percolation of precipitation. It is reasonable to assume that groundwater is affected by water percolating from agricultural lands.

Geohydrology. Recharge for both the unconsolidated glacio-fluvial aquifers and the basalt aquifers is primarily from irrigation. Groundwater discharge areas are Rocky Ford Creek, Moses Lake and Crab Creek.[2]

The recharge to the Rocky Ford stream area comes from the northwest (Epharata), the north (Soap Lake), and the northeast (Adrian). Recharge to lower Crab Creek is primarily from the east and northeast.[3] Direct groundwater recharge to Moses Lake is from both east and west.[2]

Many of area's older wells are constructed in the unconsolidated sediments. Transmissivities (T) in the glacio-fluvial aquifer range from 12,000 to 66,000 gallons per day per foot (gpd/ft). These are relatively moderate T values for unconsolidated sand and gravel aquifers. The basalt aquifers have a significantly greater range of transmissivities. The Rosa member generally exhibits T values on the order of 10,000-30,000 gpd/ft which is relatively low for basalt aquifers. The Priest Rapids member to the east typically exhibits T values in the range of 30,000 to 90,000 gpd/ft and higher. Transmissivity is primarily a reflection of the horizontal component of groundwater flow. The vertical component is harder to quantify particularly in basalt where vertical flow is via fractures and joints in the rock. However, due to head differentials, probably resulting from the heavier irrigation, downward vertical flows in the basalt east of its east low canal are 2 to 3 times higher than in basalts in the Ephrata and Soap Lake areas.[2]

The geohydrology of the Moses Lake area is quite complex and the interaction between the various basalt aquifers and the glaciofluvial aquifer poorly understood.

Hydrology. The flows in Rocky Ford Creek prior to 1952 (pre-Columbia basin project) generally averaged about 70 cfs, most of which is groundwater discharge from Rocky Ford Springs. During the period 1964-1980 (post Columbia basin project) the flows in Rocky Ford Creek ranged from about 63 to 83 cfs with a mean of about 76 cfs (Storet data). Flows during 1982 ranged from 42 to 92 cfs with a mean of 63 cfs. Low flows are in February-April increasing to highs in August and September. This cycle reflects the impact of irrigation beginning in May and continuing through summer. It is interesting to note that the flows in Rocky Ford Creek are substantially lower in 1982-1983 than in previous years.

Wildlife Habitat. As a result of glacial activity, numerous potholes, lakes, wet meadows, and drainageways are interspersed in the rangeland in general. Many of these areas contain aquatic plant communities, semi-aquatic herbaceous vegetation, or woody riparian plants. The basins and potholes provide good nesting areas for Canadian geese and a variety of geese and ducks. Shore birds, muskrats, and occasionally an otter or beaver also inhabit the wetlands and riparian areas. Woody riparian zones provide valuable winter food and cover for upland birds and mammals, particularly sharp-tailed grouse. Soils affect the kind and amount of vegetation that is available to wildlife as food and cover.

Habitat for rangeland wildlife consists of shrubs and wild herbaceous plants. Wildlife attracted to rangeland include mule deer, sharp-tailed grouse, sage grouse, meadowlark, jackrabbit, and red-tailed hawk.

Agricultural Land Use

Much of the land in the Crab Creek watershed is devoted to agriculture. There are three basic types of agriculture discussed: rangeland, irrigated cropping, and dryland agriculture. Irrigated cropping (sprinkler and flood application) predominates in the lower watershed, while dryland wheat farming and cattle range are the major agricultural activities in northern Grant County and Lincoln County. Dry crop and rangeland contribute solids and nutrients to the system during runoff, which occurs primarily in the late winter and early spring following snowmelt. There are also scattered "urban" developments throughout the basin, including Ephrata, Soap

Lake, Moses Lake, Wilson Creek, and other small communities. The following paragraphs describe the land use types in more detail. Figure 2-2 illustrates land use in the basin.

Rangeland. Approximately 630,000 acres of the Crab Creek drainage are native and revegetated rangeland. A complex of range sites consisting of the loamy, shallow, and very shallow sites in the 6-to-9, 9-to-12, and 12-to 15-inch precipitation zones are in the project area.

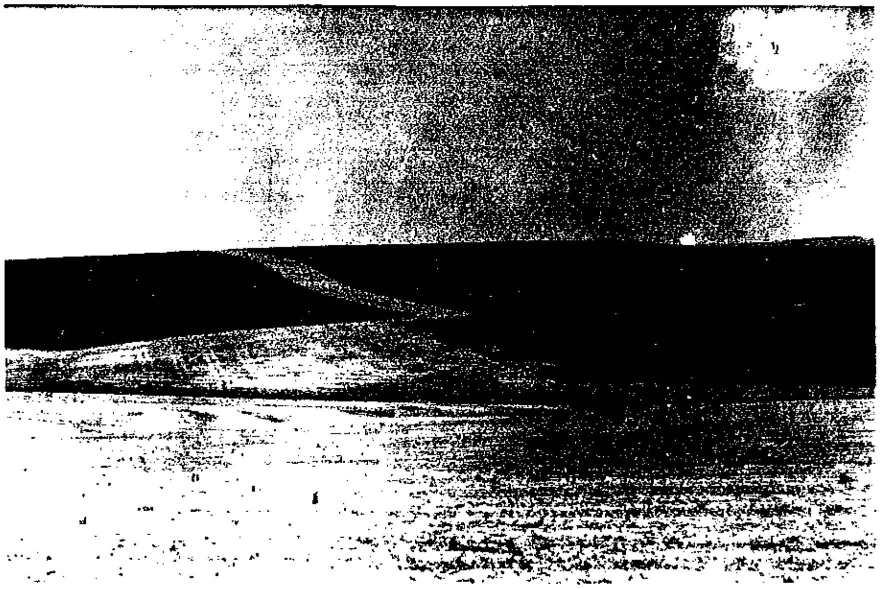
Most of the rangeland is channeled scablands, and extend throughout the project in a northwest-southwest configuration. The scabland soils are shallower than the cultivated soils on adjacent uplands. The scablands are the results of intensive scouring by glacial meltwater. They contain shallow soils that are underlain by soils formed in the loess over basalt or glacial outwash gravel, cobbles, and sand. Also included in these scablands are depressions and potholes containing wet meadows and alkaline soils.

In the scablands, the forage varies according to the average annual precipitation. This ranges from six inches in the southwest near Moses Lake to eighteen inches in the northeast near Reardan. The drier southwestern part supports a sparse natural community of wheatgrasses, primarily bluebunch wheatgrass, sandberg bluegrass, and forbs, and a few perennial shrubs, primarily big sagebrush and rabbit brush. There is a transition zone where bluebunch wheatgrass and Idaho fescue are associated with big sagebrush. Idaho fescue is on the north facing slopes and bluebunch wheatgrass on the south facing slopes. Further east treetip sagebrush is dominant. Ponderosa Pine is on some northen slopes where the effective moisture can support it. In areas that have similar climate and topography, the kind and amount of vegetation produced on rangeland is closely related to the depth of soil.

The soil and its hydrologic condition affect runoff more than any other single factor. The hydrologic condition of a soil is determined by its moisture content at the time of the event. Whether the soil is frozen or not, the amount of snow cover, the degree of saturation, the amount of vegetative cover, and the topography all affect the degree of runoff.

The rangelands of the Crab Creek drainage affect runoff in several ways. Rangeland vegetation and its foliage and litter help maintain the soil's ability to absorb water. This cover prevents the sealing of the soil by the impact of the raindrops. Also, this cover forms barriers for water moving on the surface of the ground and lengthens the time of runoff which reduces the peak flow.

Irrigated Cropland. The irrigated cropland in the Crab Creek watershed includes an area of 130,520 acres. It consists of: Lincoln County, 58,220 acres; Grant County, 51,300 acres; and Block 40, 401, and 41 of the Columbia Basin Project, 21,000 acres.



VIEW OF DRYLAND wheat area.

VIEW OF IRRIGATED area showing circles of crop land.

TYPICAL RANGELAND in the lower Crab Creek area.

The majority of the Upper Grant and Lincoln County areas are irrigated with water obtained from deep wells that is applied with center pivots, walking lateral, or sideroll-type sprinklers. Some water is also diverted directly from streams and applied with sprinkers. Irrigated crops are 80 percent small grains (wheat and barley) and 20 percent peas, beans, pasture, and hay. The Block 40, 401, 41 area is irrigated with water diverted from the Columbia River. This area grows numerous crops, but the major ones are alfalfa, wheat, corn, pasture, and seed. More than 80 percent of this area is irrigated with sprinklers, with the remainder irrigated by furrows. A summary of the land use and irrigation system types are shown in Tables 4-1 and 4-2 in Chapter 4, the on-farm evaluation section of this report.

Dry Cropland. There are 781,408 acres of dry cropland in the Moses Lake drainage area. This area is mainly in small grains. Yields vary according to precipitation. The soils are generally deep silt loams with winter wheat yields averaging around 50 bushels per acre. Fertilizer application ranges from 40 to 100 pounds per acre for nitrogen and about five pounds per acre for phosphorus depending on location and expected yields.

The number of tillage operations required for the year also increases with precipitation because of the increasing number of weeds. The crop rotations are winter wheat/summer fallow in the Upper Grant County area and winter wheat/spring grain/summer fallow in the Lincoln County portion of the watershed.

Conservation practices such as terraces, strip cropping, reduced tillage, and no-tillage are being applied to the area.

Little agriculture occurs in the Rocky Ford Creek catchment, most of which is state game land. The only evidence of agricultural activity in this area during the project was occasional grazing by a small number of cattle.

Large groundwater deposits underlie both the Crab Creek and Rocky Ford Creek subwatersheds, and wells and surface springs are common. With the coarse, shallow soils predominant, especially in southern Grant County, it is reasonable to assume that groundwater is affected by water infiltrating from agricultural lands.

OFF-FARM MONITORING PROGRAM

The off-farm monitoring program included nine stream sampling stations, two irrigation return locations, thirteen groundwater sites, and one sedimentation sampling location. Two of the stream stations were on Rocky Ford Creek and seven stations were located along Crab Creek. Stations were selected on the basis of accessibility and the location in relation to large blocks of representative land use.

Sampling Stations

Table 2-1 summarizes the off-farm monitoring program sampling station. Stations were designated as follows: streams: S; springs: SP; wells: W; Rocky Coulee Wasteway (agricultural return flows): AG. Figure 2-3 indicates the locations of major groups of stations for the off-farm portion of the project.

Stream Stations. Station S-1 is located in Rocky Ford Creek, downstream from the state fish hatchery. This station samples water quality in upper Rocky Ford Creek.

Station S-2 is located along Rocky Ford Creek, downstream from the creek crossing of highway SR17. It is an established monitoring site, having been used during previous programs, and characterizes the loading contributed downstream from the hatchery.

Station S-3 is an established station at the mouth of Crab Creek, and characterizes Crab Creek as it enters the lake.

Station S-4 is at the existing U.S. Geological Survey (USGS) gage and is located roughly 5 km north of the creek mouth. This also is an established station and characterizes the watershed between the South Willow Lakes area and the Air Force Base.

Station S-5 is along Crab Creek midway between Stratford and Moses Lake, just south of South Willow Lake. This area is largely unaltered rangeland, with little agricultural activity. Samples were taken at the spot where the stream crosses the road.

Station S-6 is located south of Adrian near the intersection of Road "E" and Road 20. Flow occurred at this station during the project year only in the late winter runoff period when Round Lake overflowed. Samples were taken biweekly from late February through late March. In adition, special storm runoff collections were made on one occasion in late March. The surrounding land use is largely wheat fields.

Station S-7, located at Stratford, where Crab Creek crosses under Stratford Road. Flow occurred at this station for several weeks longer than at S-6. Samples were collected biweekly from early February through late March and during two storm events. Surrounding agricultural land use is largely wheat cultivation.

Table 2-1. Off-Farm Program Sampling Stations

Station number	Location	Sampling frequency	Flow measurement
S-1	Rocky Ford Creek, downstream from hatchery	Biweekly 2/15 - 8/31 Monthly 9/1 - 2/14	Based on readings at S-1
S-2	Rocky Ford Creek at Rt. 17 (existing site)	Same as S-1	Current meter and staff gage
S-3	Mouth of Crab Creek (existing site)	Same as S-1	Current meter and staff gage
S-4	Crab Creek, upstream from wasteway (existing site)	Same as S-1	USGS gage
S-5	Crab Creek, midway between Stratford and Moses Lake	Same as S-1	Current meter
S-6	Crab Creek south of Adrian	Minimum 3 runoff events and routine during period of flow	Flow-weighted based on USGS gage at Irby; current meter on routine occasions
S-7	Crab Creek at Stratford	Same as S-6	Same as S-6
S-8	Crab Creek at confluence with Wilson Creek	Same as S-6	Same as S-6
S-9	Crab Creek at Irby	Same as S-6	USGS gage
AG-1	Mouth of Rocky Coulee Wasteway (existing site)	Biweekly 5/1 - 9/30 Monthly 10/1 - 4/30	Current meter and staff gage
AG-2	Tributary of Rocky Coulee Wasteway, upstream from railroad tracks	Same as AG-1	Current meter
SP-1	Spring at Game Dept. hatchery	Bimonthly	Game Dept. records
SP-2	Craig Springs	Bimonthly	Current meter
SP-3	Magpie Spring	Bimonthly	Timed level rise behind dam
SP-4	Spring at Rocky Ford Creek hatchery	Bimonthly	Current meter
W-1	Game Dept. hatchery well	Bimonthly	None
W-2	Grant County PUD well	Bimonthly	None
W-3	Parker well	Bimonthly	None
W-4	Simpson well	Bimonthly	None
W-5	City of Moses Lake	Bimonthly	None
W-6	Post well	Bimonthly	None
W-7	DeMille well (Stratford)	Bimonthly	None
W-8	Essex/Ayers well	Bimonthly	None
W-9	Hansen well	Bimonthly	None
Sed-1	Sediments at mouth of Crab Creek	Quarterly	None

Station S-8 is located at the confluence of Crab Creek and Wilson Creek, which characterizes the loading from Wilson Creek. As with Stations S-6 and S-7, the flow at this location is intermittent, but of longer duration than at the downstream locations. Biweekly monitoring was conducted from early February through late March, along with storm runoff monitoring on three occasions beginning in late January.

Station S-9 is located at Irby, at the location of an existing USGS gage. While Crab Creek in this area has water throughout the year, the stream becomes intermittent downstream and flows to Moses Lake only in the late winter. Sampling at S-9 was on the same schedule as at S-8.

Irrigation Return Flow Stations. Station AG-1 is located in Rocky Coulee Wasteway, just upstream from the discharge point into Crab Creek. An established station, this site represented the loading from irrigation return water.

Station AG-2 is located on a tributary to Rocky Coulee Wasteway, roughly 2 km to the east of Crab Creek. This station samples the contribution to the wasteway from a major irrigation return.

Groundwater Stations. Two major aquifers are of concern in this study: (1) the surficial sand and gravel aquifers which range from 25 to 100 feet thick and generally exhibit perched water table characteristics; and (2) the basalt aquifers underlying the surficial deposits, which are usually confined or artesian systems. In many parts of the study area, the basalt is at or just below the ground surface; however, the water bearing units or interflow zones are often deeper. Where interflow zones connect with the surface, springs often occur. Both springs and wells were sampled.

Station SP-1 is a spring serving the Washington State Department of Game hatchery along Road L N.E..

Station SP-2 is Craig Springs, located on the Craig property roughly 11 km north of the mouth of Crab Creek. The springs flow from a small hill into an open channel and ultimately into Crab Creek.

Station SP-3 is Magpie Spring, located on state game land about 21 km north of Moses Lake. It has been impounded and was sampled at the overflow.

Station SP-4 is a spring located upstream of the fish hatchery on Rocky Ford Creek. This sample indicates background water quality in the creek, and allows more accurate determination of the fish hatchery's loading contribution to the creek.

ROCKY COULEE WASTEWAY showing release water from East Low Canal.

SCENE ALONG Lower Crab Creek.

VIEW OF CRAB CREEK upstream of the Block 40-41 irrigated area.

A total of nine wells (W-1 through W-9) were sampled in the Crab Creek drainage area. A total of 226 well logs for the area were collected from the Department of Ecology in an effort to identify suitable monitoring wells. Logs were reviewed and qualified as potential monitoring wells based on the following criteria:

1. Location of well defined within a quarter-quarter section.

2. Legible writing on log.

3. Accessed or produced from sand and gravel aquifer or fairly shallow basalt aquifer.

4. Sufficient data with which to evaluate geohydrology of the area.

Using these criteria, 95 wells were qualified as potential monitoring wells. From the 95 qualified wells, 18 were selected by Brown and Caldwell's geohydrologist as having the most promise for potential monitoring wells. From those 18, 8 wells were designated "preferred," appearing to be in the most favorable locations with respect to the major water bodies and agricultural areas. From the list of potential and preferred wells, six were selected to monitor groundwater in irrigated areas, and three wells were sampled to monitor groundwater in dryland farming areas.

Sediment Station. Station SED-1 is a sediment sampling site at the mouth of Crab Creek. Samples were taken once every three months to determine seasonal variations in the sediment nutrient composition. Sediment samples have been gathered in past studies and in current Pelican Horn sampling. These data will also be used in the analysis of nutrient recycling.

Sampling Methodology

Samples were collected twice monthly from streams and irrigation return stations during the irrigation and winter runoff season, except for those stations that were typically dry during the summer. Samples were taken by the grab method. Springs and wells were grab-sampled every two months. Flow was determined by using a current meter staff gage, using USGS information, or other methods as described in Table 2-1.

Laboratory Analyses

After collection, samples were transported on ice to the University of Washington by the fastest possible means. For most off-farm and some on-farm samples, field personnel delivered the samples directly. Certain other off-farm and most on-farm samples were sent from Moses Lake to the University via intercity bus package express. Samples were filtered and preserved in almost all cases within 24 hours of collection, within 12 hours for those delivered directly to the University. Sample preservation and handling followed EPA (1979b) guidelines.

All samples were analyzed for total suspended solids (TSS), total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), nitrate + nitrite-nitrogen (NO_3+NO_2-N), and ammonia-nitrogen (NH_3-N). TSS analysis was by the gravimetric method (American Public Health Association, 1980). TP and SRP were measured according to the ascorbic acid method on unfiltered and filtered aliquots, respectively, the former after persulfate digestion (Americal Public Health Association, 1980), using a Perkin-Elmer Lambda 3 spectrophotometer. TN was determined by ultraviolet light oxidation followed by analysis of nitrate on a Technicon AutoAnalyzer II (Strickland and Parsons, 1972). NO_3+NO_2-N and NH_3-N were measured in filtered aliquots, the former by cadmium reduction on the AutoAnalyzer (U.S. Environmental Protection Agency, 1979b), and the latter according to the phenate method on the Perkin-Elmer Lambda 3 spectrophotometer (American Public Health Association, 1980).

Specific conductivity was determined in groundwater with a Barnstead conductivity meter. Thirty percent of all groundwater samples collected in the off-farm and on-farm programs were selected randomly for chloride analysis by argentometeric titration (American Public Health Association, 1980). Specific conductivity represents the electrical activity of all dissolved ions in solution, while chloride is a specific conservative anion. These two measurements were intended to indicate when samples from different collection points likely originated in a common aquifer.

Quality control was according to EPA (1979a) guidelines, including recommended sample labeling and handling, replication of analyses, and duplication of procedures.

ON-FARM MONITORING PROGRAM

The purpose of the on-farm monitoring program was to identify the sediment and nutrient contributions from agricultural practices within the Moses Lake watershed. The following potential nutrient pathways from agricultural lands to Moses Lake were identified and investigated:

1. Runoff to surface waters transporting soluble and particulate nutrients.

2. Infiltration (leaching) of nutrients into the soil layer and subsequent percolation to subsurface waters.

3. Airborne transport of nutrient-rich soil particles, with deposition in Moses Lake or its tributaries.

Sampling Stations

Figure 2-4 depicts all of the on-farm monitoring stations. Spring stations are designated SP, agricultural runoff stations are designated RO. Agricultural return stations are AG; wells are designated W.

For planning purposes, the study area was divided into three units: the Lincoln County Unit, the Upper Grant Unit, and the Lower Grant Unit. Each unit includes irrigated and dryland agriculture and rangeland. Table 2-2 summarizes the land use characteristics in each of the planning units.

Table 2-2. Land Use Characteristics

Surface runoff stations	Cropland		Rangeland	Total acres[a]
	Irrigated	Dry		
Lower Grant				
AG-3	1,690			1,690
RO-1	1,843			1,843
RO-2	1,587	2,458		4,045
RO-3		230		230
Upper Grant				
RO-5		614		614
RO-6			128	128
RO-7	13,696	174,465	99,276	287,438
RO-8	12,954	164,267	93,669	270,890
RO-9		589		589
RO-10	12,800	72,858	61,286	146,944
RO-11	154	102	205	461
RO-12			77	77
RO-13		62,439	13,542	75,981
RO-14	12,800	141,748	80,844	235,392
RO-15		307	77	384
Lincoln County				
RO-19		14,182		14,182
RO-20			23,296	23,296
RO-21	700	7,680	9,194	17,520
RO-22	956	14,080	74,116	89,152
RO-24		33,715	6,042	39,757

[a]Does not include total acreage in watershed, only those monitored.

Lower Grant Unit. Because of its proximity to Moses Lake, the Lower Grant Unit was suspected of being a primary nutrient contributor to the lake. Samples within that unit were primarily taken from springs below irrigated areas to determine nutrient leaching and movement through the groundwater, and from runoff from irrigated areas.

Ten major springs were sampled. Reffett Spring (SP-5), located above the Game Department Hatchery, and Zucker Spring (SP-6), located upradient from Rocky Coulee Wasteway, were sampled three times. Turner Spring (SP-7), located near Route 17 just east of Moses Lake, was sampled to determine nutrient loading from adjacent fields. This site was sampled six times. Stations SP-8, SP-9, and SP-10 were at the Skane Spring, located east of Crab Creek adjacent to fields. These stations were sampled seven times. SP-11 is Homestead Spring, located upgradient from the Skane Spring, in an area surrounded by rangeland, pasture, and fields. Station SP-12, located above Homestead Spring, is the northernmost spring sampled along Crab Creek. Three samples were taken at this site. SP-13 and SP-14 are located below the State Game Department Fish Hatchery, below and above a dairy, respectively.

Irrigation tailwater flows from furrow and sprinkler irrigated areas were sampled to determine the comparative nutrient contributions from each type of irrigation practice. It was suspected that furrow irrigation was a major contributor to deep percolation, because of the underlying shallow coarse soils. Station AG-3 was located below a livestock feedlot, and was sampled twice. AG-4, which was sampled five times, characterized overland flow in Turner Sump, just below Turner Spring. Station AG-5 was sampled once to characterize runoff from a field using furrow irrigation. Stations AG-6, AG-7, and AG-8 were located downstream from furrow irrigated fields. AG-6 monitored a field with spring wheat, while AG-7 and AG-8 were in cornfields. Stations AG-6 and AG-7 were sampled four and ten times, respectively, while AG-5 was sampled only once.

Stations AG-9 and AG-10 monitored tailwater ponds below center pivot irrigation fields where turnips and grains were grown, respectively. Station RO-1 was a drain sump into Rocky Coulee Wasteway draining several irrigated crops, including wheat, grain, alfalfa, and corn. It was sampled 11 times.

Runoff from agricultural sites was monitored to determine its relative nutrient contribution to Moses Lake. Station RO-2 monitored runoff from a seeded wheat field, RO-3 monitored wheat stubble, and RO-4 monitored rangeland and irrigated wheat. Each of these sites was sampled once.

Wells in the Lower Grant Unit were sampled. W-10 was located east of the East Low Canal in an irrigated cropland area, and sampled groundwater at a depth of 135 feet, which is below the basalt. This well was sampled five times. Five samples were also taken from W-11, a 72-foot-deep well below the basalt layer located upgradient from Rocky Coulee Wasteway. W-12 is a well located near a winter livestock operation, where three samples were taken.

Unfortunately, there is no well log for this well. Well W-13 is located midway between East Low Canal and Crab Creek, in an irrigated area. W-14 is also located in an irrigated area with some wildlife habitat, north of Rocky Coulee Wasteway. This well was sampled three times.

Station EL-1 in East Low Canal was sampled four times, representing irrigation flows from the surrounding area.

Upper Grant Unit. The Upper Grant Unit characterizes agricultural contributions from the Crab Creek watershed between Lincoln County and the Lower Grant Unit. Runoff from agricultural lands and wells were sampled.

Station RO-5, characterizing dryland, was sampled four times. RO-6 was located in rangeland and was not sampled because all the runoff percolated into the ground. RO-7, in Wilson Creek at the Town of Wilson Creek, was located near dryland what, rangeland and assorted irrigated crops and was sampled five times. RO-8, draining an area with both dryland and irrigated agriculture, was located on Wilson Creek. One sample was taken at this site. Station RO-9 characterized dryland agriculture and was sampled five times.

Station RO-10, at Wilson Creek in an area of dryland and irrigated agriculture, was sampled twice. RO-11 sampled runoff from irrigated cropland, and RO-12 characterized runoff from rangeland. Station RO-13 was located on Corbett Draw, a tributary to Wilson Creek. Four samples were taken at RO-13 and two each at RO-11 and RO-12. Station RO-14 was located on Wilson Creek in irrigated bottomland and was sampled three times. Station RO-16 characterized runoff from a feedlot along Wilson Creek. Stations RO-17 and RO-18 were located at Adrian above and below Round Lake to determine any nutrient trapping in that lake.

Nine wells were sampled in the Upper Grant Unit. W-16 is an old shallow well in a rangeland where no log is available. W-17 is the well for the Town of Almira and is 150 feet deep, with the water level 20 feet below the surface. W-18 and W-19 are domestic supply wells for the Town of Wilson Creek. Wells W-20, W-21, and W-22 are irrigation wells. W-23 is a domestic well in irrigated bottom land.

Lincoln County Unit. Lincoln County sites, although less likely to directly affect Moses Lake water quality, include mainly dryland agriculture and rangeland. Runoff and wells were sampled.

Station RO-19, at the Lord's Creek weir, represents dry cropland runoff in the higher rainfall areas of the Crab Creek drainage. Seven samples were taken at RO-19.

Station RO-20 characterized rangeland runoff and was located at Lake Creek. Seven samples were obtained here. Station RO-21 did not generate any runoff. Six samples were taken at RO-22, which characterized rangeland and dryland agriculture. Station RO-24 was in Duck Creek, characterizing dryland agriculture. Five samples were taken at RO-24. Stations RO-23 and RO-25 were in Crab Creek at Odessa; four samples were obtained at each site.

Two samples were taken at Station RO-26 in Goose Creek, which is tributary to Wilson Creek. Single runoff samples were taken at RO-27 and RO-28, both of which represent dryland wheat croplands in the Duck Creek drainage area. Station RO-29 represents overland flow from dryland wheat, and RO-30 at Lamona characterizes dryland wheat. One sample was taken at these sites. Stations RO-31 and RO-32 represent the inlet and outlet of Sylvan Lake. Two samples were obtained at the outlet (RO-31) and one sample was taken at the inlet to Sylvan Lake.

Well station W-24 characterizes dryland agricultural, W-25 characterizes rangeland, and W-26 represents pasture and dairy agricultural activities.

Table 2-3 summarizes the on-farm sampling stations.

Sampling Methodology

Runoff flows, representative of snowmelt runoff or summer storms, were sampled using a DH-48 Integrated Sampler and standard techniques. The intent of the runoff sampling was to obtain a composite (integrated) sample which consists of samples collected every few hours throughout the rise, peak, and fall of a storm event. This was done during three storm events of varying intensities and durations. Where integrated samples were not practical because of small flows or site conditions, individual grab samples were taken to characterize the flow at the time of sampling.

Grab samples of surface runoff from sprinkler irrigation were used to determine the nutrient contribution from this type of irrigation system. For surface (furrow) systems grab samples were taken at the end of the furrow and in the tailwater to be compared to water quality samples of the East Low Canal.

The quality of springs and wells was determined using grab samples collected at different intervals. They were taken to provide annual contributions from these sources.

Volume or flow mesurements by use of a current meter were used on springs, runoff, and wherever practical. Stream ratings and staff gauges were used wherever practical and feasible.

Table 2-3. On-Farm Sampling Stations

Station number	Description	Number of samples taken
SP-5	Reffett Spring	3
SP-6	Zucker Spring	3
SP-7	Turner Spring	6
SP-8	Skane Fish Hatchery, inlet	7
SP-9	Skane Fish Hatchery, inlet	7
SP-10	Skane Fish Hatchery, discharge	7
SP-11	Homestead Spring	3
SP-12	Above Homestead Spring	3
AG-3	Discharge beflow feedlot	--
AG-4	Turner Sump--below Turner Spring	5
AG-5	Furrow irrigation runoff--(alfalfa)	1
AG-6	Furrow irrigation --spring wheat	7
AG-7	Furrow irrigation--corn	10
AG-8	Furrow irrigation--corn	1
EL-1	East Low Canal	4
AG-9	Tailwater pond below pivots	1
AG-10	Tailwater pond below pivots	1
RO-1	Drain sump into Rocky Coulee	11
RO-2	Seeded wheat above road	1
RO-3	Wheat stubble	1
RO-4	Range, irrigated wheat	1
W-10	Well below basalt (135 feet)	5
W-11	Well below basalt (42 feet)	5
W-12	Well near winter livestock operation (no log)	3
SP-13	Spring below dairy and fish hatchery	3
SP-14	Below hatchery, above dairy	2
W-13	Well	3
W-14	Well	3
RO-5	Runoff, dry cropland	4
RO-6	Rangeland (no runoff)	3
RO-7	Wilson Creek at town of Wilson Creek	5
RO-8	Wilson Creek--dry and irrigated cropland	1
RO-9	Dryland crops	5
RO-10	Wilson Creek--dry and irrigated cropland	2
W-15	Irrigation well (no log)	2
W-16	Shallow unused well (no log)	3
W-17	Town of Almira well (150 feet deep)	1
W-18	Town of Wilson Creek well	1
W-19	Town of Wilson Creek well	1
W-20	Irrigation well	3
W-21	Irrigation well	1
W-22	Irrigation well	4
W-23	Domestic well	1
RO-11	Runoff, irrigated	2
RO-12	Runoff, rangeland	2
RO-13	Corbett Draw (Wilson Creek tributary)	4
RO-14	Wilson Creek irrigated bottomland	3
RO-15	Before feedlot	2
RO-16	After feedlot	2
RO-17	Crab Creek above Brook Lake	1
RO-18	Crab Creek below Brook Lake	1

Table 2-3, continued

Station number	Description	Number of samples taken
RO-19	Lords Creek Weir	7
RO-20	Lake Creek, rangeland	5
RO-21	Lake Creek, cropland, dry	--
RO-22	Lake Creek, range/dry cropland, Highway 21	6
RO-23	Crab Creek at Odessa	7
RO-24	Duck Creek, dryland	5
RO-25	Crab Creek at Odessa	4
RO-26	Goose Creek at Wilbur	2
RO-27	Duck Creek, cropland	1
RO-28	Duck Creek, cropland	1
RO-29	Downs, overland flow	1
RO-30	Lanona	1
RO-31	Sylvan Lake Outlet	2
RO-32	Sylvan Lake Inlet	1
W-24	Lords Creek Well	3
W-25	Lake Creek Well	3
W-26	Odessa Well	3

CHAPTER 3

RESULTS

Water quality data were collected from the on- and off-farm monitoring stations from October 1982 to September 1983 (off-farm) and November 1983 (on-farm) The following sections describe the results of the sampling programs.

OFF-FARM MONITORING PROJECT

The off-farm monitoring project elements will be discussed in terms of potential nutrient pathways to Moses Lake: streams and surface water routes including Crab Creek and its tributary Rocky Coulee Wasteway, and Rocky Ford Creek; springs; and wells. The results of flow monitoring will be summarized followed by a discussion of nutrient concentrations.

Flow Monitoring Results

Flow monitoring was conducted at surface water stations on Crab Creek, Rocky Ford Creek, and Rocky Coulee Wasteway. Flow monitoring was conducted at the springs, respresenting ground-water flows.

Surface Water Flows. Figure 3-1 illustrates the average flows in Crab Creek at Station S-3 (near its discharge to Moses Lake in the upper creek section) during the 1983 water year. As illustrated on the figure, Crab Creek flows were highest in the

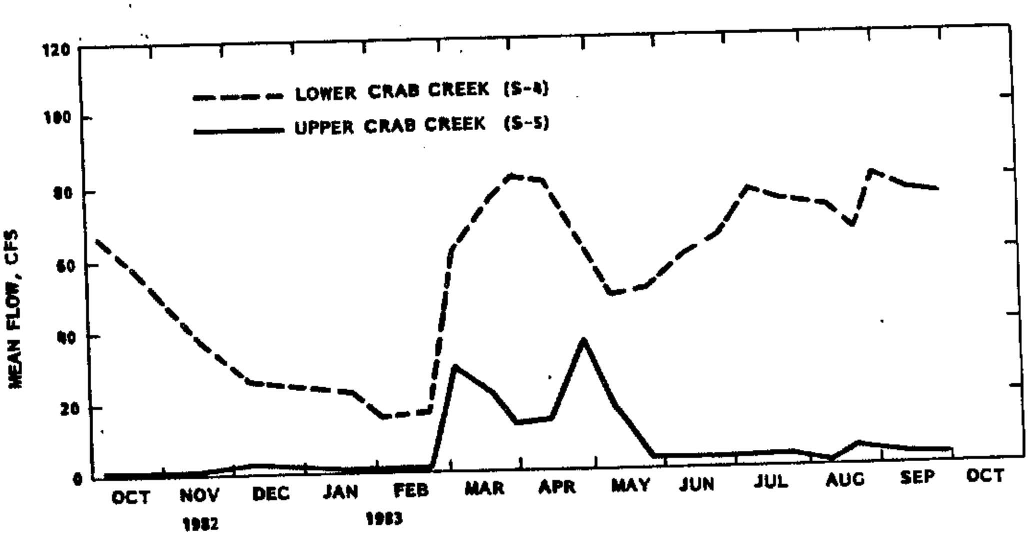


Figure 3-1. Stream Flow, Crab Creek

spring months, and the lowest flow levels occurred during the winter. The elevated flows during the spring were largely due to increased irrigation return flow in Rocky Coulee Wasteway. Rocky Coulee Wasteway flows, illustrated on Figure 3-2, contributed an average flow of 310 cfs during the spring out of the total average 370 cfs in lower Crab Creek. Much of this flow was released from East Low Canal as part of the Moses Lake dilution program. Rocky Coulee Wasteway flows dropped to 57 cfs in the summer and averaged 97 cfs during the winter.

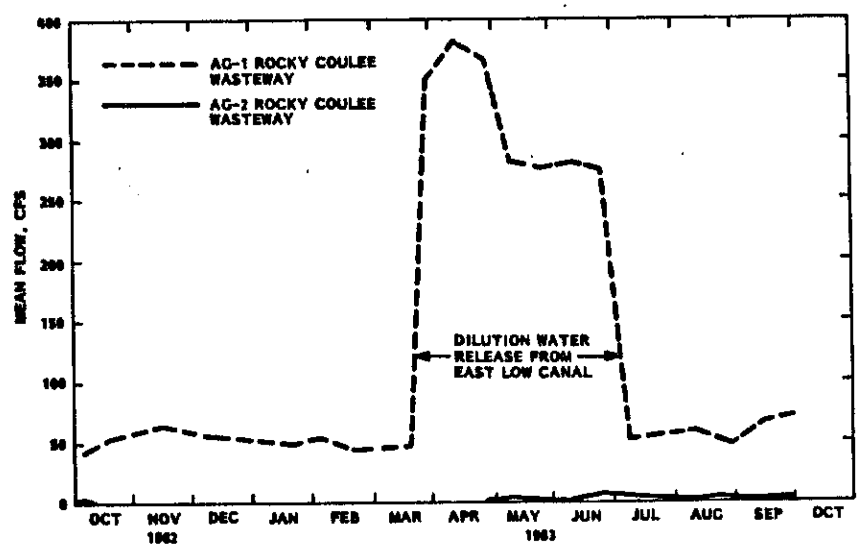


Figure 3-2. Measured Flow, Rocky Coulee Wasteway

Crab Creek flow in the upper watershed (above Round Lake) is intermittent, discharging to the lower watershed from roughly late February to mid May. Round Lake detains stream flows, reducing the average winter storm flow in the creek from roughly 180 cfs above the lake to 12 cfs downstream from the lake. According to the U.S. Bureau of Reclamation (USGS) approximztely 50,000 acre-feet of groundwater recharge is occurring from the lake which flows to Rocky Ford Creek.[a] Storm flows were very similar to nonstorm flows in upper Crab Creek, indicating very low runoff rates, flow modulation by in-stream lakes or impoundments, or a combination of both.

The annual flow pattern in Rocky Ford Creek is illustrated on Figure 3-3. Seasonal and storm flow variations were much less pronounced than in Crab Creek, largely due to the significant influence from groundwater. The creek originates from a spring located roughly 5-1/2 miles north of Moses Lake. As illustrated on Figure 3-3, the highest flow period in Rocky Ford Creek was from April through September which coincides closely with the irrigation period. Groundwater flows to Rocky Ford Creek from the

[a] U.S. Bureau of Reclamation, Columbia Basin Project, Washington, Final Environmental Statement, Volume 1. 1976.

north (Soap Lake) northwest (Ephrata) and northeast (Adrian). The lag time between the irrigation season and increased flows in Rocky Ford Creek was very short (approximately 1/2 month), indicating potentially high transmissivities in the creek's subsurface watershed.

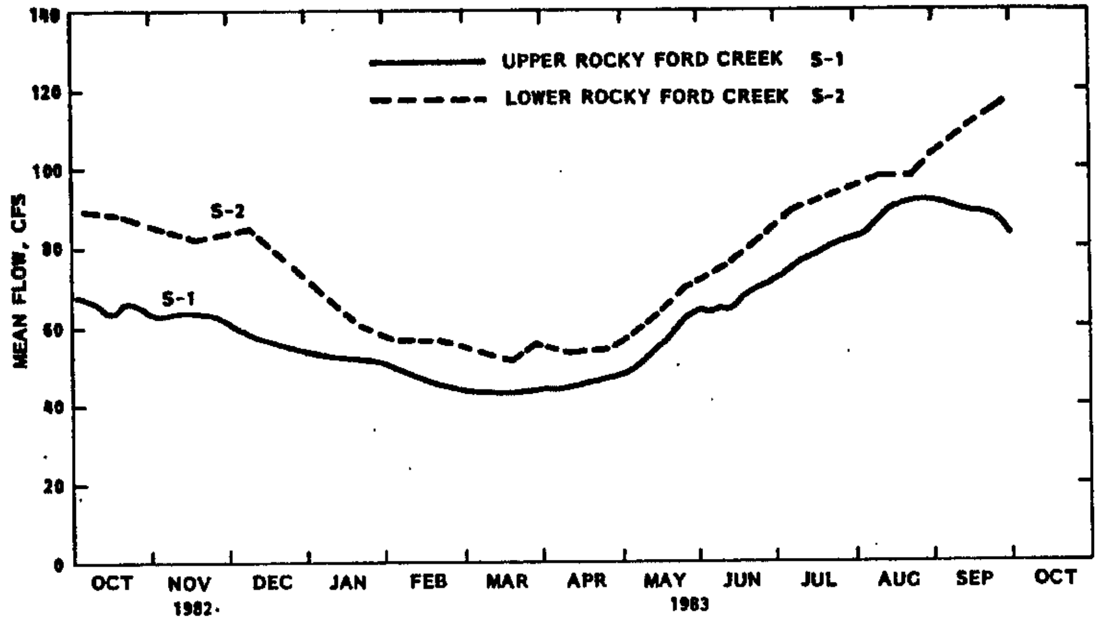


Figure 3-3. Stream Flow, Rocky Ford Creek, S1 and S2

Spring Flows. Three out of four springs monitored flowed year round in the study area. Figure 3-4 summarizes measured flows in the springs. Sampling Station SP-1 averaged 17 cfs throughout the entire year, with high flows of 24 cfs occurring in the summer and low flows of 9.8 cfs in the winter. This seasonal pattern indicates an influence by irrigation. Similar seasonal flow patterns have been observed at the spring that feeds the Columbia Basin Fish Hatchery. Springtime average flows are 11 cfs.

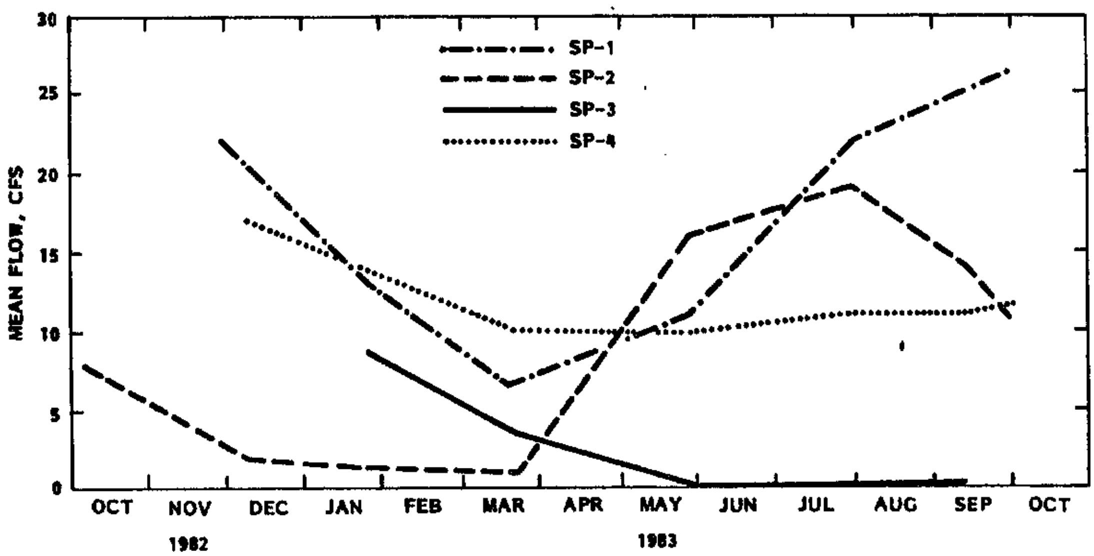


Figure 3-4. Measured Flow, Off-Farm Springs

Station SP-2 exhibited seasonal flow variations similar to SP-1, with highest flows in the summer. Station SP-2, located upgradient from SP-1 in an irrigated agricultural area, also had high flows during the spring, which may indicate rapid response to irrigation. Station SP-3 did not appear to be significantly influenced by irrigation since peak flows occurred during the winter when recharge occurs primarily through infiltrated precipitation. Station SP-4, located near the mouth of Rocky Ford Creek, maintained a relatively constant flow throughout the year with peak flows in the fall. The explanation for peak fall flows is not obvious, but it may represent a delayed peak resulting from irrigation upgradient in the watershed.

Wells. Groundwater flow data are not available because the project scope of work did not include the extensive groundwater monitoring necessary to determine groundwater flows. Estimates on groundwater flows, therefore, must be calculated by difference, where the input to the Moses Lake water budget not accountable to other sources is assumed to be groundwater. This method does not account for localized variations in groundwater movement throughout the basin, which are expected to be significant because of the wide variability in geological conditions. However, because of limited data available at this time, this is the method that was used.

Groundwater is known to be a significant contributor to Moses Lake and its tributary surface water systems. In 1980, Patmont determined that groundwater contributes roughly 40 percent of the total natural inflow to the lake. Based upon groundwater profiles and water budgets prepared over several years, Patmont concluded that the bulk of groundwater enters Moses Lake through Pelican Horn, principally during the fall. The estimated annual groundwater contribution to Moses Lake was roughly 115 million cubic meters in the 1983 water year.

Nutrient Concentrations

The results of the water quality analyses are presented in the following paragraphs and graphs. Because of the potential impact to lake eutrophication, the major focus of the discussion will be nitrogen and phosphorus, particularly the soluble forms, soluble reactive phosphorus (SRP) and nitrate and nitrite-nitrogen ($NO_3 + NO_2 - N$). The major nutrient pathways to Moses Lake will be discussed including Crab Creek, Rocky Coulee Wasteway, Rocky Ford Creek, and groundwater, including springs and wells. Past studies have been described in previous studies of Moses Lake and though not fixed it is generally agreed that the lake will improve as existing levels fall below 500 ug/l total nitrogen and 50 ug/l total phosphorus.

Data Analysis. Seasonal and overall annual means and standard deviations were computed for the pollutant concentration and flow rate data. Seasons were defined as follows: Fall--October through December; Winter--January through March; Spring--April through June; and Summer--July through September. This breakdown corresponds approximately to the schedule of major hydrologic and agricultural events in the watershed; e.g., irrigation occurs primarily in the summer, most storm runoff is in the winter, and spring is a transitional period between these two events. In computing statistics any data points available for the respective seasons were considered to represent the period. In some cases, particularly at certain on-farm stations, data points were sparse, and the seasonal means must be considered fairly rough estimates.

Crab Creek. Crab Creek is a major contributor of total suspended solids and nitrogen to Moses Lake. Maximum nitrate and nitrite-nitrogen concentrations occur in the winter, drop significantly in the spring, and rise again during the summer. Figure 3-5 illustrates $NO_3 + NO_2 - N$ concentrations in Crab Creek (Station S-3) near the outlet to Moses Lake during the 1982-1983 monitoring period. Total phosphorus (TP) concentrations fluctuated during January and February but generally were 100 to 150 ug/l higher than fall and summer concentrations, while soluble reactive phosphorus (SRP) concentrations were less variable, ranging from less than 2 ug/l to 50 ug/l. Figure 3-5 illustrates SRP, TP, and $NO_2 + NO_3 - N$ concentrations in Crab Creek at Station S-3, near the outlet to Moses Lake. Total suspended solids (TSS) remained below 70 mg/l for the entire year, except for a single occasion in March 1983, when TSS concentrations reached 269 mg/l. The peak winter total phosphorus concentration may be attributable to storm and snowmelt runoff, and surfacing of nutrient-rich groundwater. The following photograph illustrates typical in-stream impoundments along Crab Creek.

IMPOUNDMENTS along Crab Creek trap nutrients.

Most of the nutrient load entering Moses Lake from Crab Creek originates in the creek section below Adrian because flow is detained in Round and Brook Lakes, and other in-stream impoundments. Round Lake fills up with Crab Creek flow until its capacity

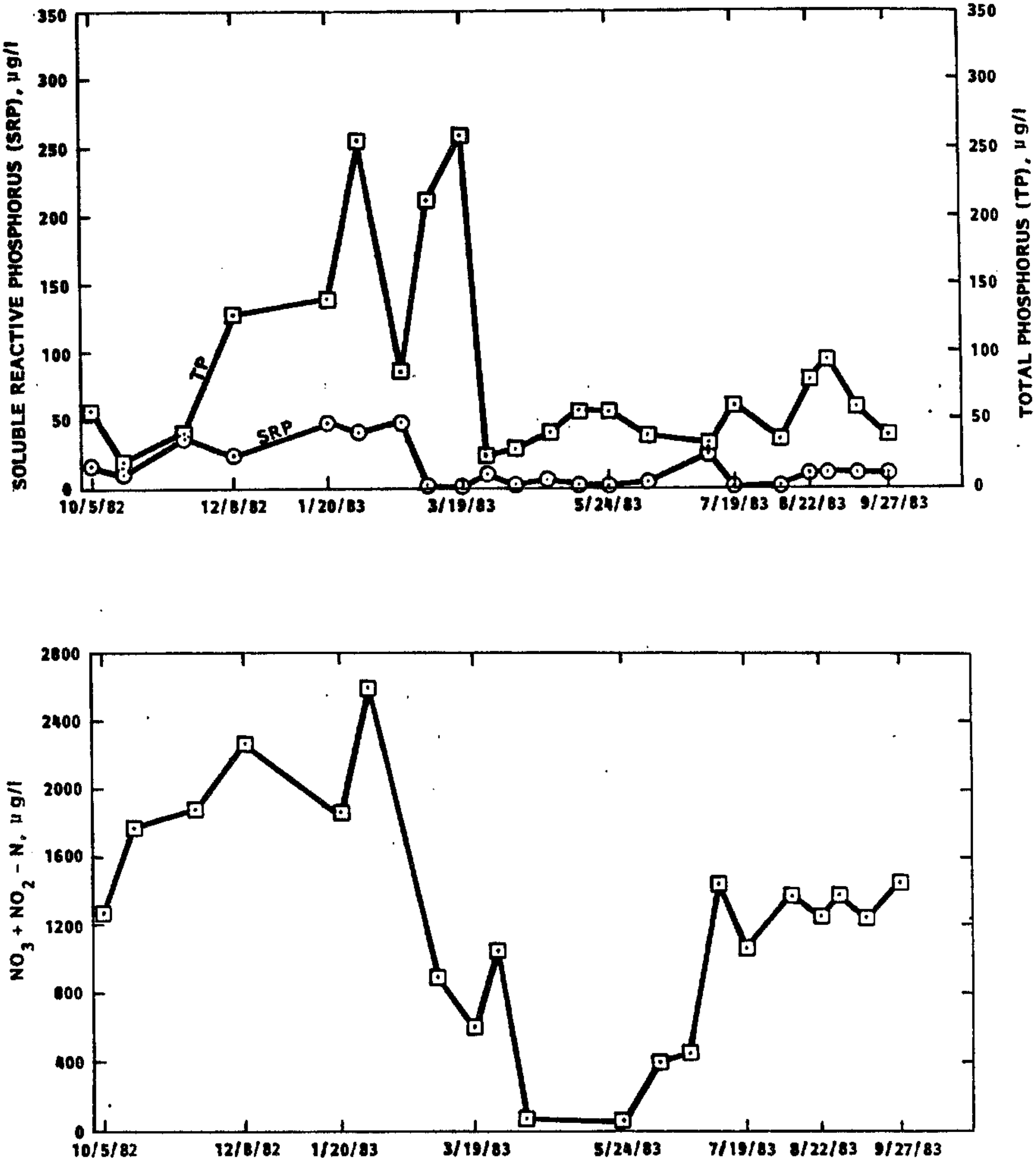


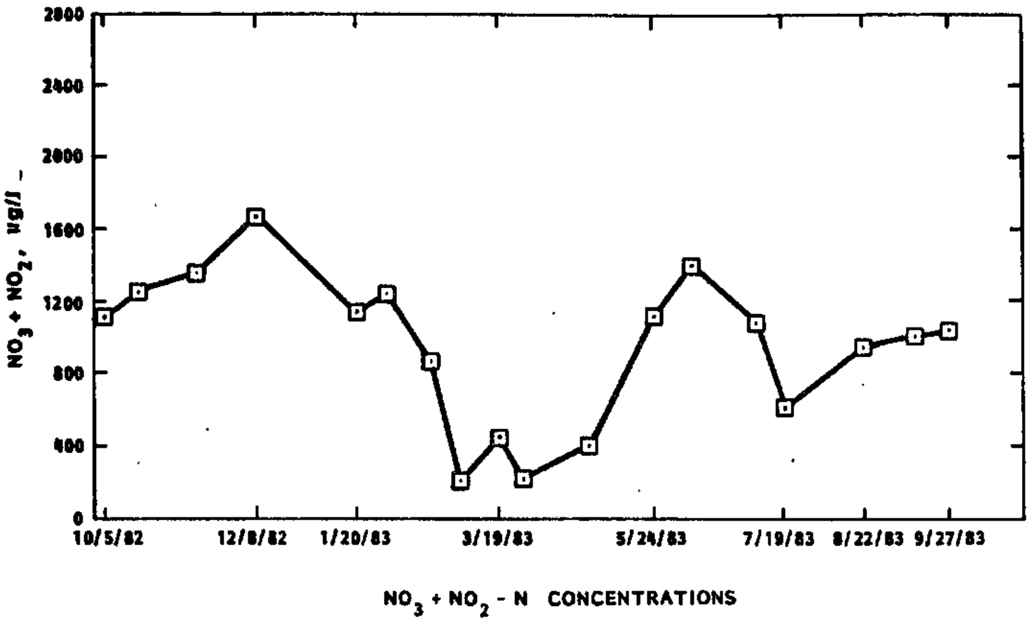
Figure 3-5. Nutrient Concentrations, Station S-3

is reached (usually in February) when it overflows into the lower creek. During the late winter and early spring Round Lake overflows and discharges to the lower creek section, resulting in nutrients generated in the upper watershed being discharged into Lower Crab Creek. Total phosphorus concentrations increased considerably more than nitrogen concentrations as a result of the release. Figures 3-6 and 3-7 illustrate concentrations at Stations S-4 and S-5, compared with concentrations illustrated on Figure 3-5 which illustrates Lower Crab Creek concentrations. As shown on the figures, nutrient concentrations build going downstream. Figure 3-8 illustrates nutrient concentrations at Stations S-6, S-7, and S-8, located in Upper Crab Creek. It is important to note the lower concentrations at Stations S-6, which is located downstream from Round Lake.

Rocky Coulee Wasteway. Rocky Coulee Wasteway contributes 84 percent of the total flow volume in Crab Creek during the spring, reflecting the addition of dilution flow from East Low Canal. This release of nutrient-poor flow from the canal to the wasteway resulted in lowered wasteway nutrient concentrations: TP concentrations ranged from 15 to 33 ug/l from April through June, compared with an average TP concentration of 108 ug/l in the fall and 160 ug/l in the winter. Spring $NO_3 + NO_2 - N$ concentrations averaged 89 ug/l compared with averages over 2,500 ug/l in the fall and winter. Figure 3-9 illustrates nitrate concentrations at Station AG-1, where Rocky Coulee Wasteway joins Crab Creek. The dilution of Rocky Coulee Wasteway water with nutrient-poor East Low Canal water during the spring months helps to lower the nutrient levels in Crab Creek downstream from Rocky Coulee Wasteway. Nitrate/nitrite-nitrogen levels are noticeably reduced in Crab Creek during April through June, dropping from levels exceeding 1,000 ug/l in March to 78 ug/l in April.

Although total phosphorus levels in Rocky Coulee Wasteway rarely exceeded 200 ug/l, $NO_3 + NO_2 - N$ concentrations averaged 2,800 ug/l from October through March. This $NO_3 + NO_2 - N$ concentration exceeds the level in Crab Creek downstream from Rocky Coulee Wasteway, and likely reflects runoff from agricultural activities as well as increased groundwater flow into the wasteway. Figure 3-10 illustrates total and soluble phosphorus concentrations in Rocky Coulee Wasteway.

Rocky Ford Creek. The pattern of nutrient concentrations in Rocky Ford Creek differs significantly from the trend in Crab Creek. Much of this difference is likely due to the major influence of groundwater in Rocky Ford Creek. Although Rocky Ford Creek is only 8 miles in length and has an average flow of 64 cfs at the outlet to Moses Lake, it is the major surface flow contributor of SRP and TP to Moses Lake during the summer and fall. Maximum SRP and TP concentrations occur in the fall at the upper creek station, as illustrated on Figure 3-11. Maximum $NO_3 + NO_2 - N$ concentrations occur during the summer in the upper creek station, as shown



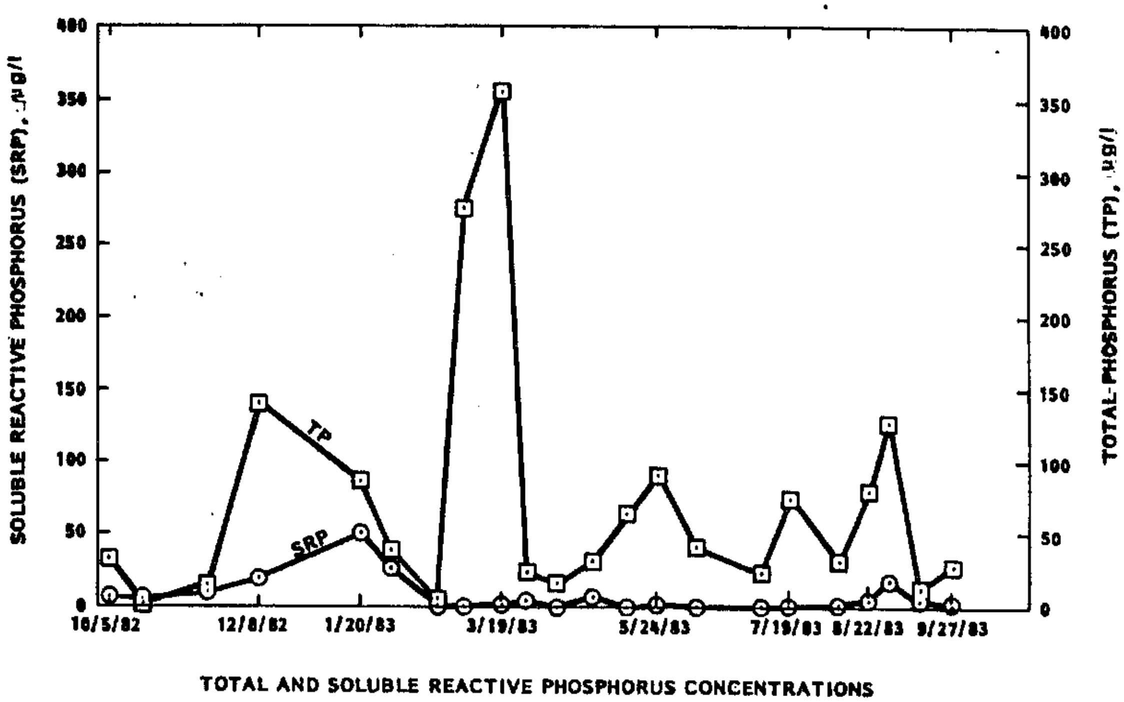
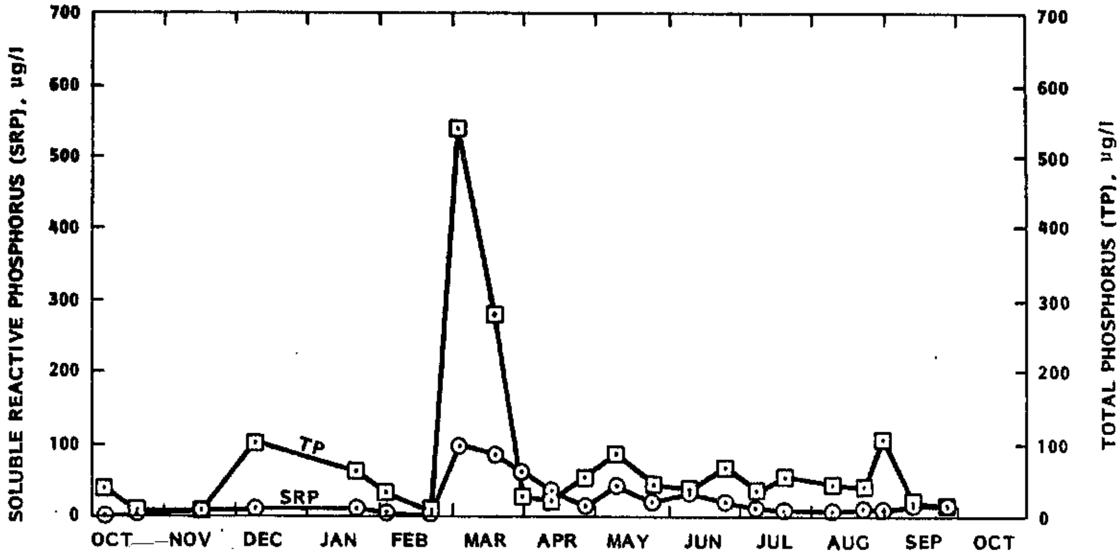
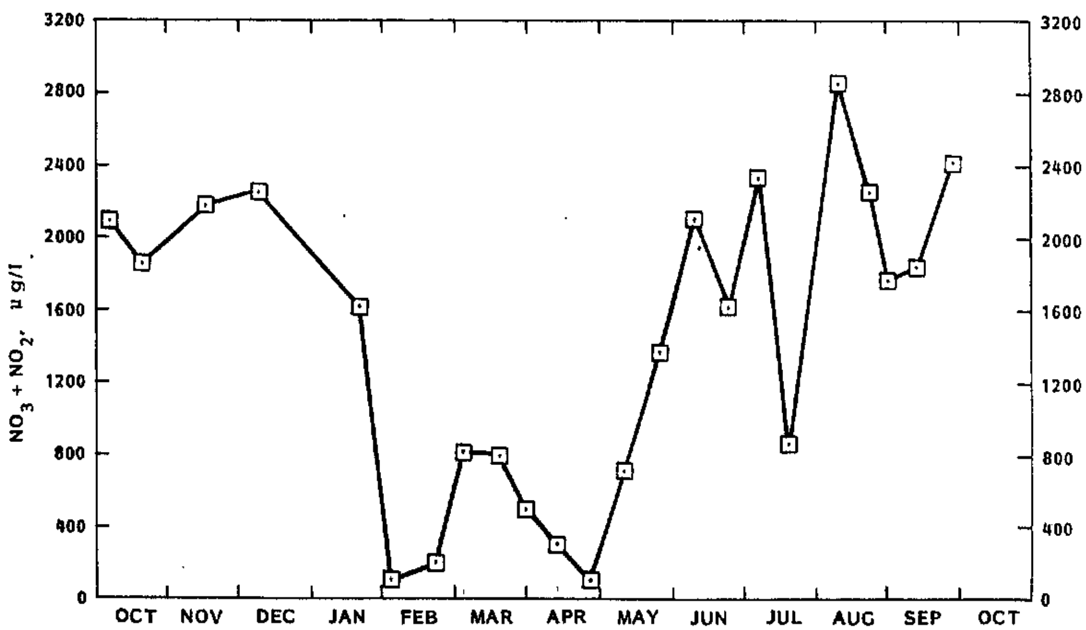


Figure 3-6. Nutrient Concentrations, Station S-4



TOTAL AND SOLUBLE REACTIVE PHOSPHORUS
CRAB CREEK STATION S-5



NITRATE + NITRITE - NITROGEN CONCENTRATIONS
CRAB CREEK STATION S-5

Figure 3-7. Nutrient Concentrations, Crab Creek, Station S-5

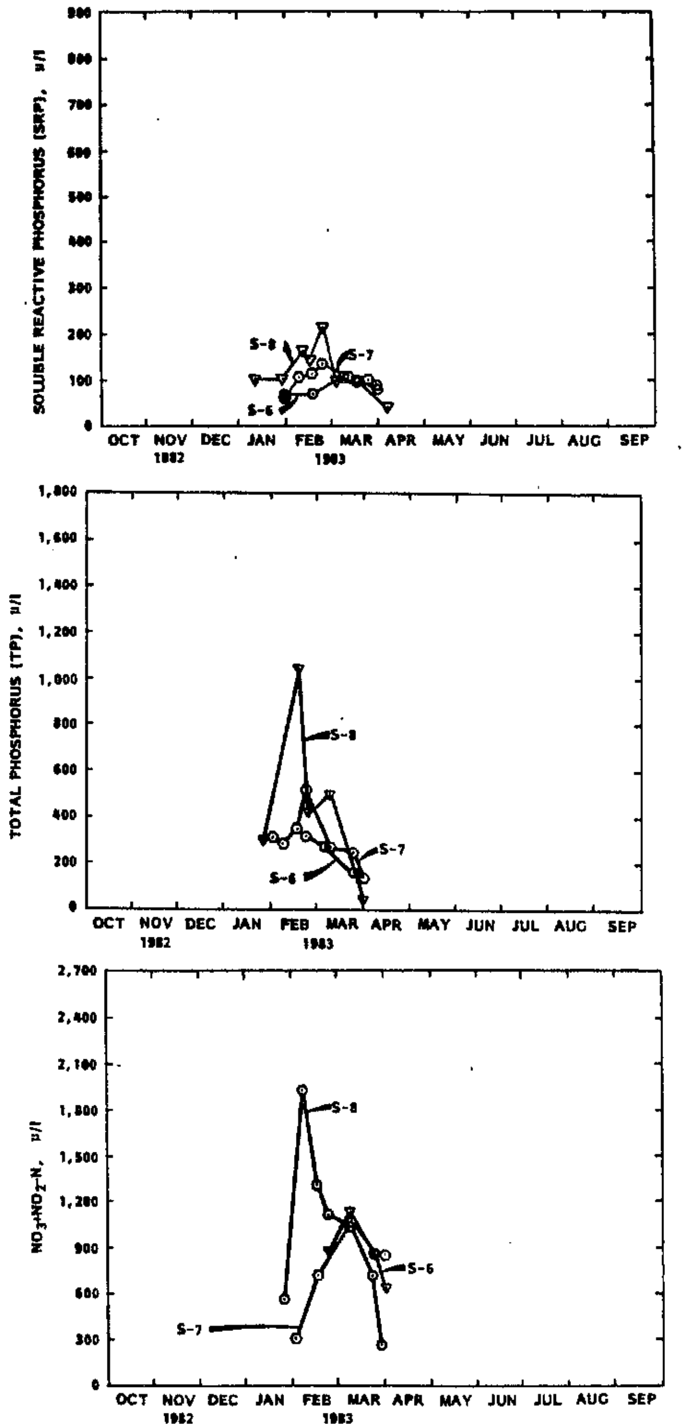


Figure 3-8. Nutrient Concentrations, S6, S7, S8, Upper Crab Creek

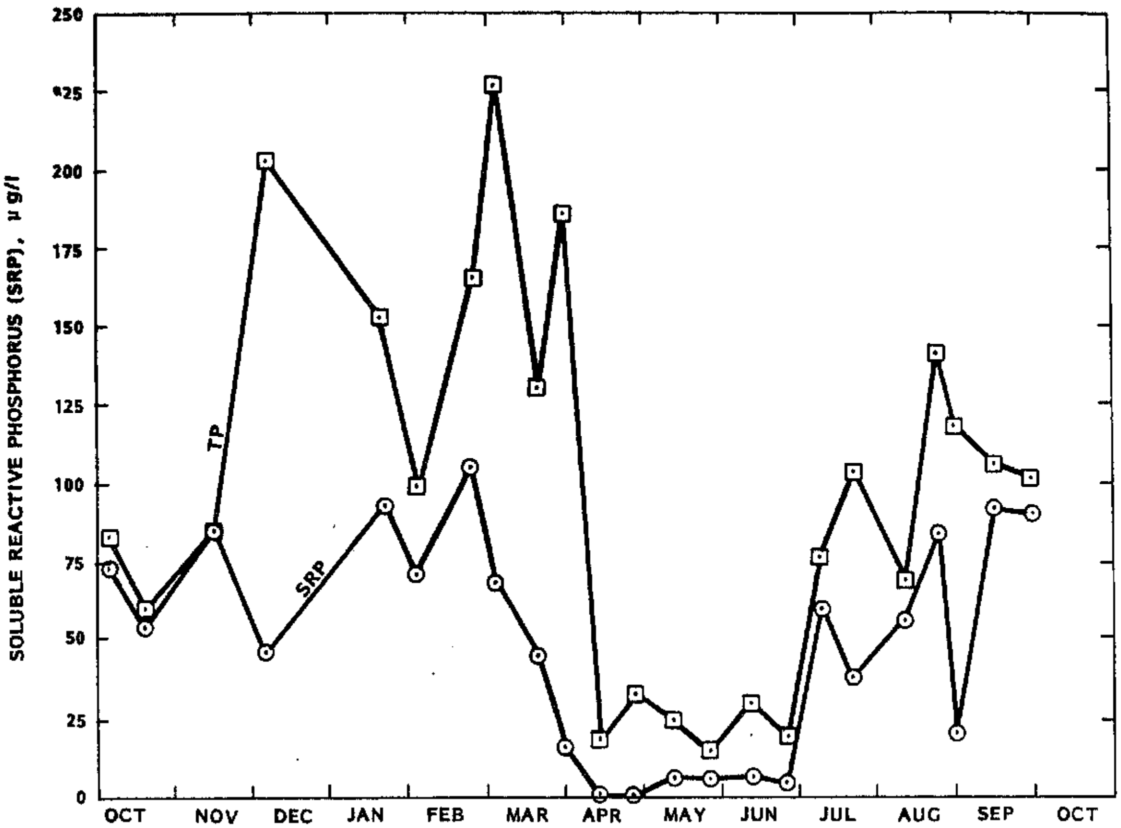


Figure 3-9. Phosphorus Concentrations, Rocky Coulee Wasteway

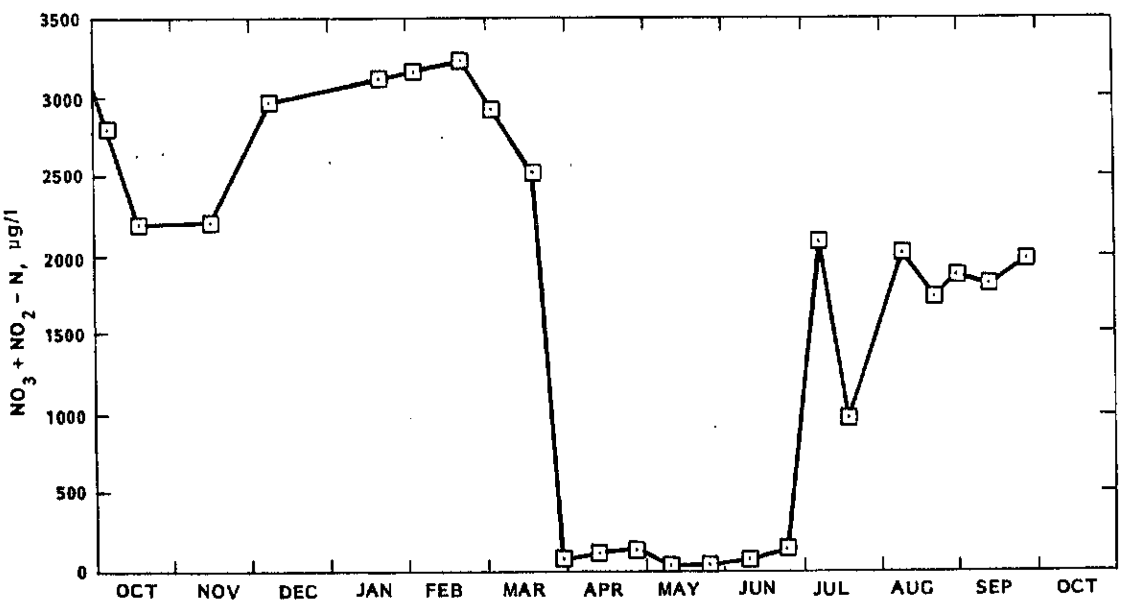
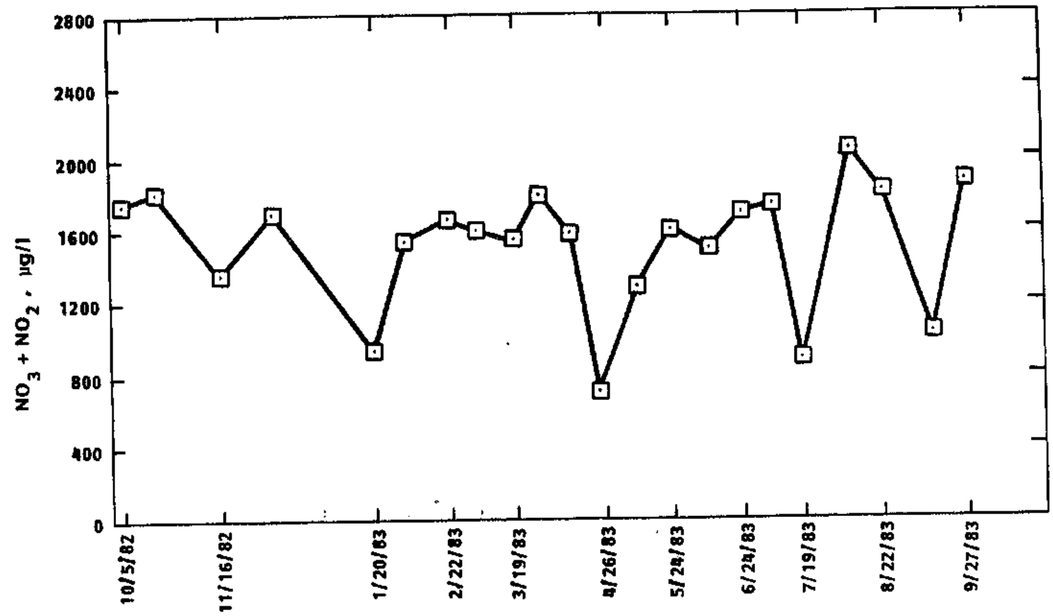
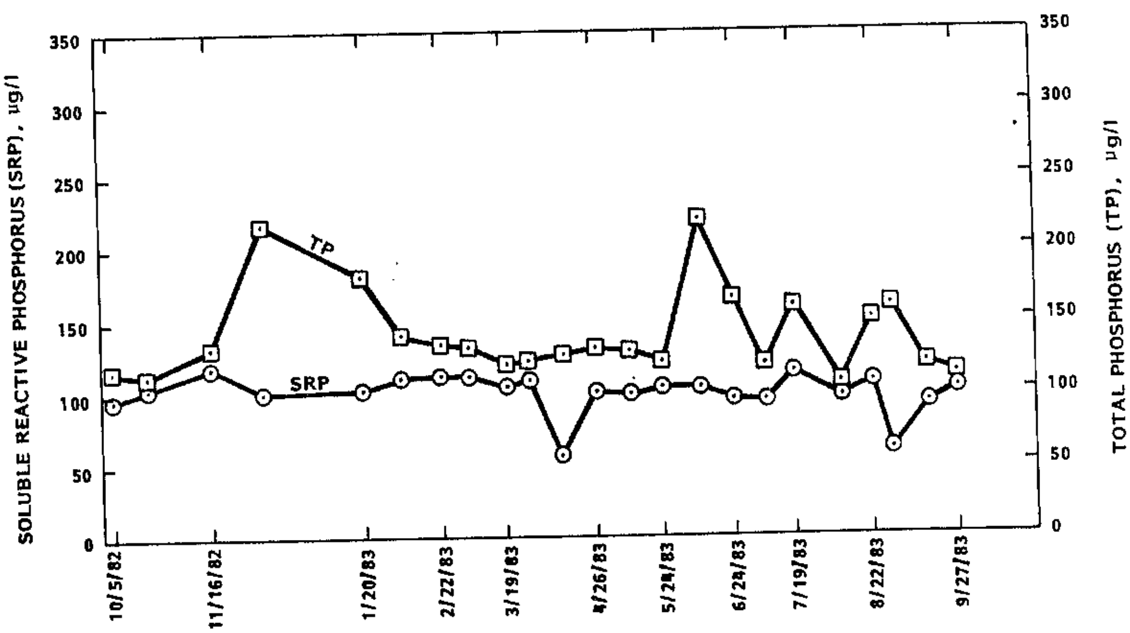


Figure 3-10. Nitrogen Concentrations, Rocky Coulee Wasteway



$NO_3 + NO_2$ - N CONCENTRATIONS
ROCKY FORD CREEK STATION S-1



TOTAL AND SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS
ROCKY FORD CREEK STATION S-1

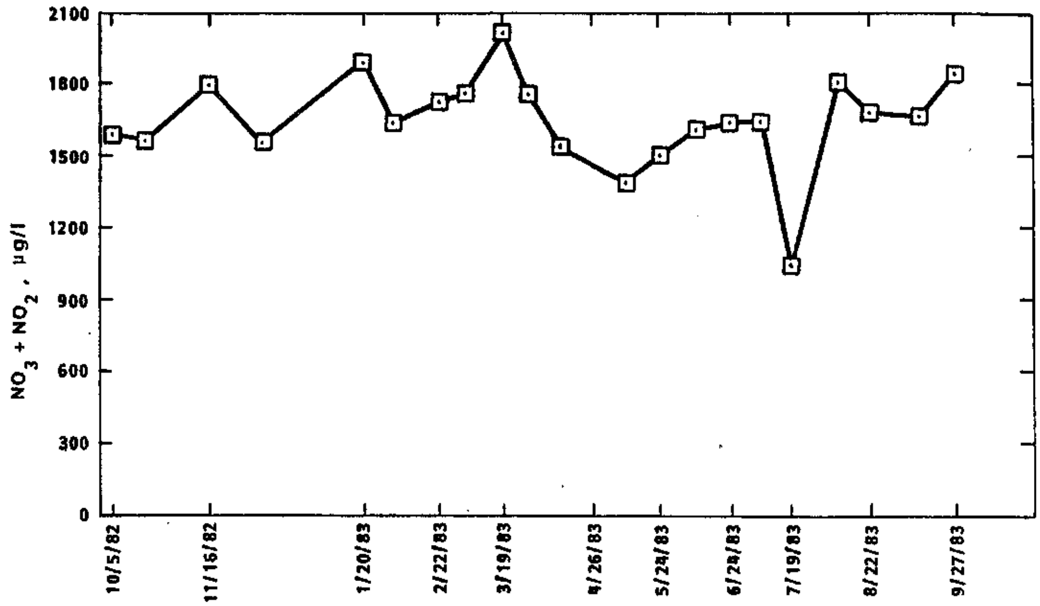
Figure 3-11. Nutrient Concentrations, Upper Rocky Ford Creek on Figure 3-11, coincident with the irrigation season. Peak SRP and $NO_3 + NO_2$ - N concentrations at the spring-fed source of Rocky Ford Creek do not coincide with downstream peaks at the creek's outlet to Moses Lake (S-2). This is illustrated on Figure 3-12. At the upper station (S-1), SRP, TP, and $NO_3 + NO_2$ - N concentrations are highest in the summer and lowest in the winter; while at the lower station concentrations of these constituents are highest in the winter, suggesting input from runoff.

Soluble and total phosphorus concentrations ranged from 20 percent to 60 percent higher in station S-2 than in S-1; flows also increased in the downstream station by roughly 30 percent. In contrast, nitrate and nitrite nitrogen and total supsended solids concentrations were comparable between S-1 and S-2. This suggests there are additional sources of phosphorus in the lower stretches of the Rocky Ford Creek watershed. However, the concentration of soluble and total phosphorus seems inexplicably high, considering the low level of agricultural activity within the creek's watershed. Unlike Crab Creek, phosphorus levels in Rocky Ford Creek remain relatively stable throughout the year, which is not typical of seasonally-influenced nutrient sources such as runoff or percolation of nutrient-rich irrigation water. It appears likely that the phosphorus is entering the creek largely through groundwater. The potential sources of phosphorus in the groundwater are discussed in a later section describing geohydrology.

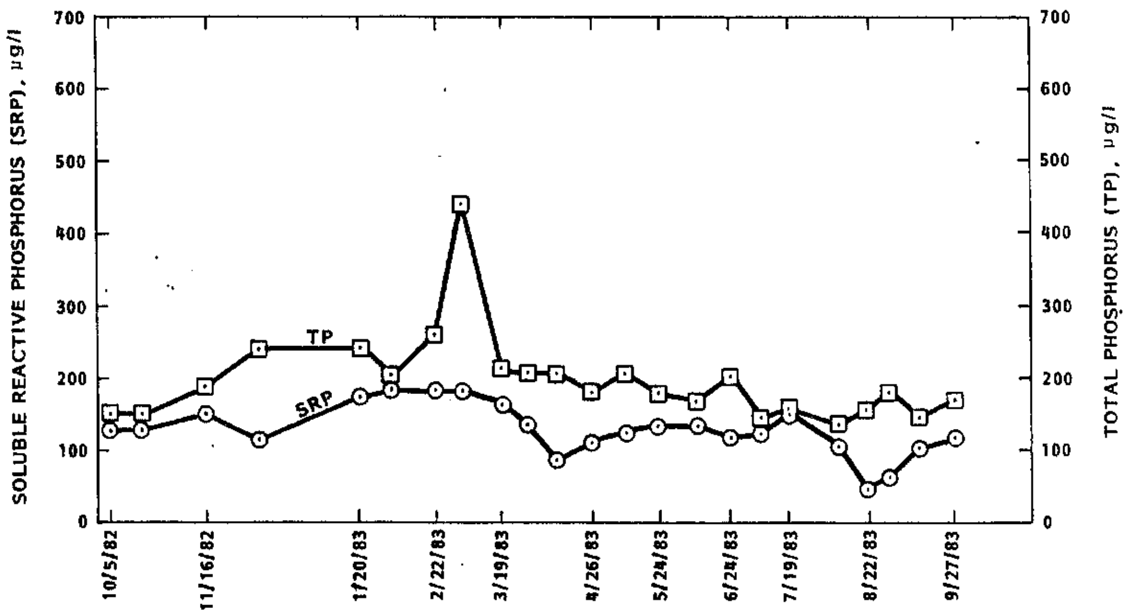
Springs. Springs sampled in the off-farm project gave an indication of groundwater quality, especially the shallow groundwater system. Four springs in the lower Crab Creek watershed were sampled. Spring SP-1, which flowed year-round, had fairly stable soluble and total phosphorus concentrations, both of which averaged 42 ug/l annually; while $NO_3 + NO_2$ - N concentrations averaged from roughly 2,000 to 2,400 ug/l. Peak $NO_3 + NO_2$ - N concentrations occurred in winter; however, winter concentrations were only 20 percent higher than summer concentrations. The $NO_3 + NO_2$ - N levels in SP-1 were roughly twice as great as the other three springs monitored, indicating percolation of nitrates from fertilizer. Figure 3-13 illustrates measured concentrations of SRP and TP, and $NO_3 + NO_2$ - N concentrations in the four springs.

Spring station SP-2 had high total phosphorus concentrations in the fall and winter, which may be the result of agricultural runoff. Nitrate concentrations during the fall and winter were relatively low compared to SP-1.

Station SP-3 is low in SRP concentrations compared to TP concentrations, possible indicating a greater percentage of phosphorus in the particulate phase. However, total suspended solids concentrations were negligible except in summer, when an average 5.0 mg/l was measured. Nitrate at SP-3 was the lowest of all the springs measured, especially during the spring season. The minor seasonal variation indicates a neglibile influence from agricultural activities in the vicinity of the spring.



$NO_3 + NO_2 - N$ CONCENTRATIONS
ROCKY FORD CREEK STATION S-2



TOTAL AND SOLUBLE REACTIVE PHOSPHORUS
ROCKY FORD CREEK STATION S-2

Figure 3-12. Nutrient Concentrations, Lower Crab Creek

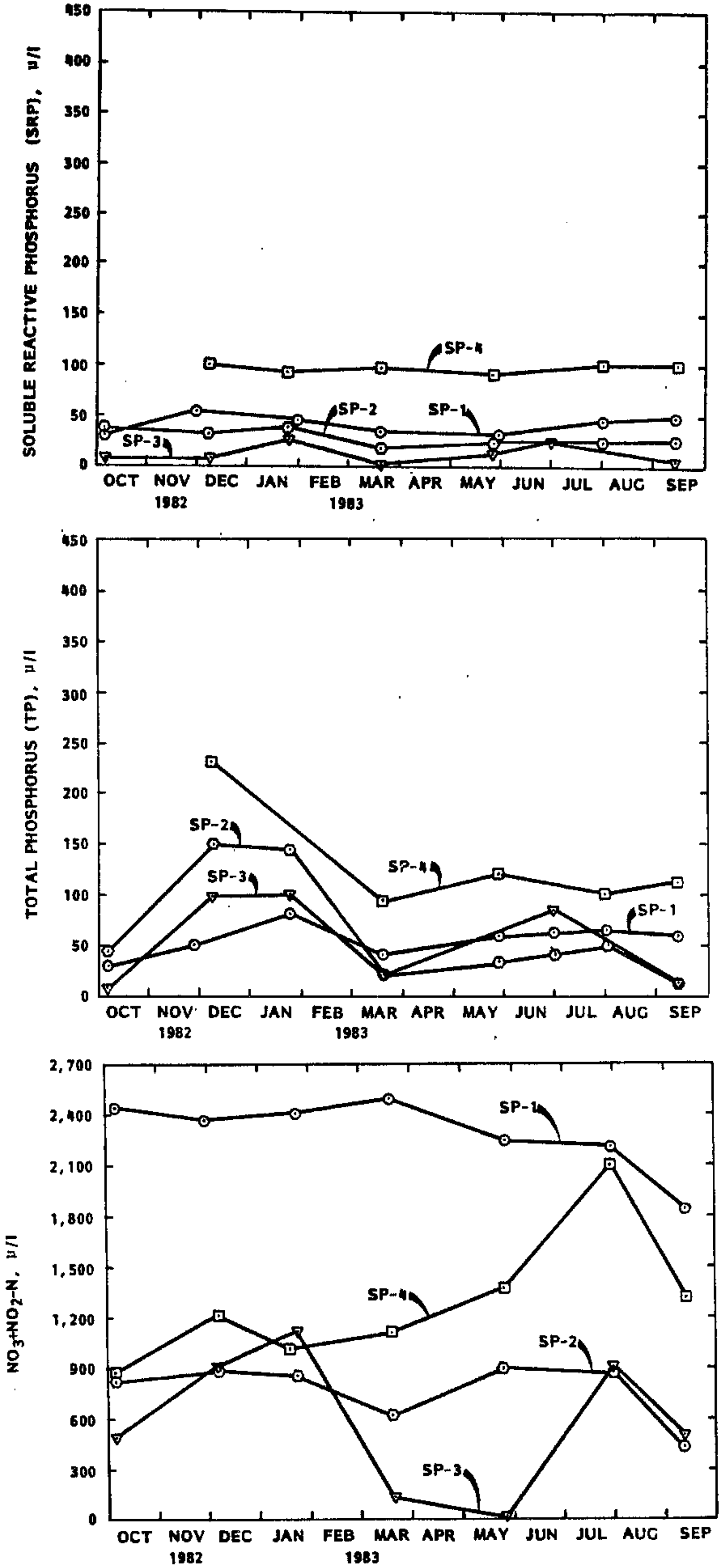


Figure 3-13. Nutrient Concentrations, SP-1, SP-2, SP-3, and SP-4 Springs

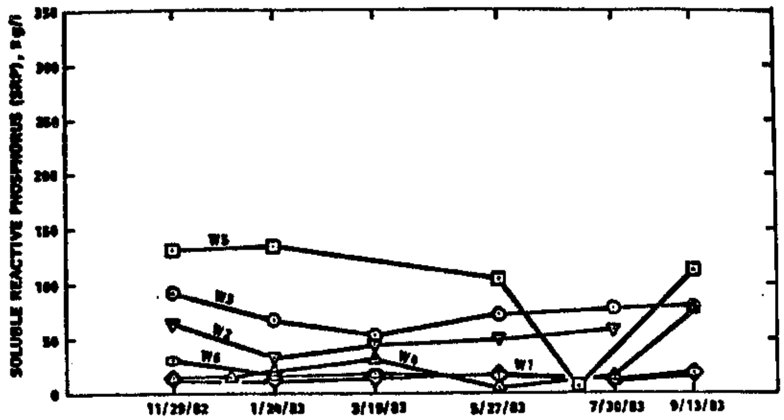
Spring station SP-4, located at the mouth of Rocky Ford Creek, had notably high SRP and TP concentrations compared to the spring stations along Crab Creek. The concentrations remain relatively stable throughout the year, which differs from the seasonal nutrient variations in the Crab Creek springs, and is not indicative of agricultural-influenced nutrient loading. Spring SP-4 is contributing to the constant phosphorus concentrations in Rocky Ford Creek, but the source of the phosphorus is not clear at this time. Nitrate and nitrite concentrations at SP-4 are also higher than the springs in the Crab Creek drainage. The high $NO_3 + NO_2 - N$ concentrations appear to be anomolous because there is very little agricultural activity in the Rocky Ford Creek drainage area. However, $NO_3 + NO_2 - N$ concentrations appear to be anomalous because there is very little agricultural activity in the area. However, $NO_3 + NO_2 - N$ concentrations peak in the spring and summer, coincident with the irrigation season, which indicates a possible link between irrigated agriculture and the elevated nitrate levels. Possible sources of phosphorus and nitrogen are agriculture and sewage disposal practices upgradient in the Soap Lake and Ephrata area.

Wells. A discussion of the groundwater system is essential to an understanding of nutrient loading to Moses Lake. The following paragraphs summarize the results of well monitoring in the off-farm project. Discussion of the data centers around phosphorus and nitrate concentrations and conductivity. Figure 3-14 illustrates total phosphorus, soluble reactive phosphorus, and nitrate + nitrite nitrogen concentrations, respectively, in Wells 1 through 6.

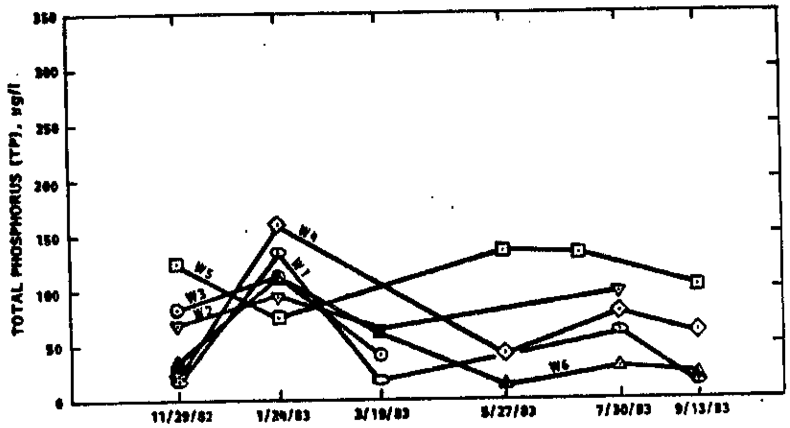
Well Station W-1, located in rangeland downgradient from alfalfa fields, was consistently low in soluble reactive phosphorus and total phosphorus, with the exception of a total phosphorus peak of 134 ug/l in January 1983. Nitrate values, however, were elevated from November until March. Late spring and summer values were as much as 4,000 ug/l lower than the winter values. High conductivities, which would indicate surface water contamination of the well, are not present. The high winter values may reflect the percolation of dissolved nitrates during the winter rainy season.

Well Station W-2 was relatively low in SRP and TP, with peaks of TP concentrations near 100 ug/l in the winter and summer. Nitrate concentrations ranged between roughly 2,000 ug/l and 3,000 ug/l, and did not significantly vary from season to season. Conductivity ranged from 388 umhos to 525 umhos, which does not indicate surface contamination. The well is surrounded by rangeland, corn fields, and alfalfa fields.

Well Station W-3, located within a developed residential area, remained fairly constant in soluble reactive phosphorus, ranging between 50 ug/l and 73 ug/l. Total phosphorus concentrations



SOLUBLE REACTIVE PHOSPHORUS CONCENTRATIONS
OFF-FARM MONITOR WELLS W1-W6



TOTAL PHOSPHORUS CONCENTRATIONS
OFF-FARM MONITOR WELLS
W1-W6

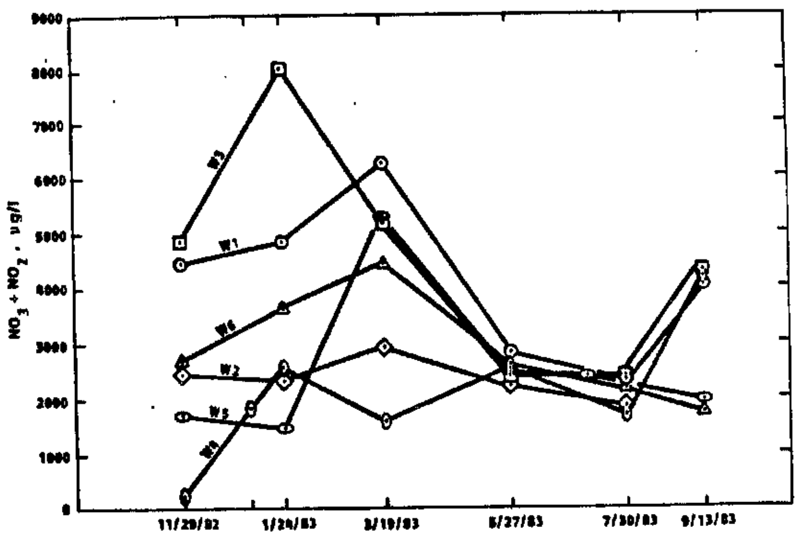


Figure 3-14. Nutrient Concentrations, Off-Farm Monitor Wells W1 through W6

peaked in January at 118 ug/l. $NO_3 + NO_2$ - N concentrations were also highest during this month, at 7,543 ug/l. The corresponding conductivity measurement was 590 umhos, which does not indicate surface contamination of the well water. The highest conductivity reading, 831 umhos, was measured during November, 1982, and indicates surface runoff contamination of the well. The nitrate + nitrite-nitrogen concentration measured in November was 4,833 ug/l. The winter nitrogen levels in Well W-3 were from 3,000 to 5,000 ug/l higher than the single nitrate measurement taken in spring. The high nitrate concentrations during winter may indicate septic tank contamination during the winter when the water table level is elevated.

Well Station W-4 was low in measured SRP and $NO_3 + NO_2$ - N concentrations. This well is located in an area surrounded by rangeland, and SRP and $NO_3 + NO_2$ - N concentrations would indicate little nutrient contribution from surrounding land use. Total phosphorus concentrations were high (18 ug/l and 49 ug/l) in December and March, respectively, which is mostly not in the soluble phase. Conductivity measurements were low during the period of peak total phosphorus concentrations, so surface contamination does not appear to be the source. Percolation of surface-applied fertilizer may be the source of the phosphorus.

Well W-5 is owned by the City of Moses Lake and is located at the Grant County Airport. Concentrations of soluble reactive phosphorus and total phosphorus were consistently high, while nitrate concentrations were moderate. A source of phosphorus may be continued leaching from an abandoned community septic system and drainfield located near the airport. The reduced mobility of phosphorus compared with nitrate movement may account for the phosphorus concentrations.

Well W-6, located near 9th Northeast east of Crab Creek, is surrounded by corn and alfalfa fields and pasture land. Soluble reactive phosphorus levels were consistently less than 25 ug/l; total phosphorus peaked at 103 ug/l in the winter. The total phosphorus peak in January did not coincide with the peak in nitrate concentration which occurred in May. Irrigation of surrounding corn and alfalfa fields may result in percolation of nitrates during this season; however, the $NO_3 + NO_2$ - N level dropped during the summer. The peak $NO_3 + NO_2$ - N concentration in the spring may reflect a "first flush" of nitrates as irrigation began with increased uptake by plants and dilution as the irrigation season continues.

Figure 3-15 illustrates phosphorus and $NO_3 + NO_2$ - N concentrations in Wells W-7, W-8, and W-9. These wells are located at the upper and lower boundaries of the off-farm project area.

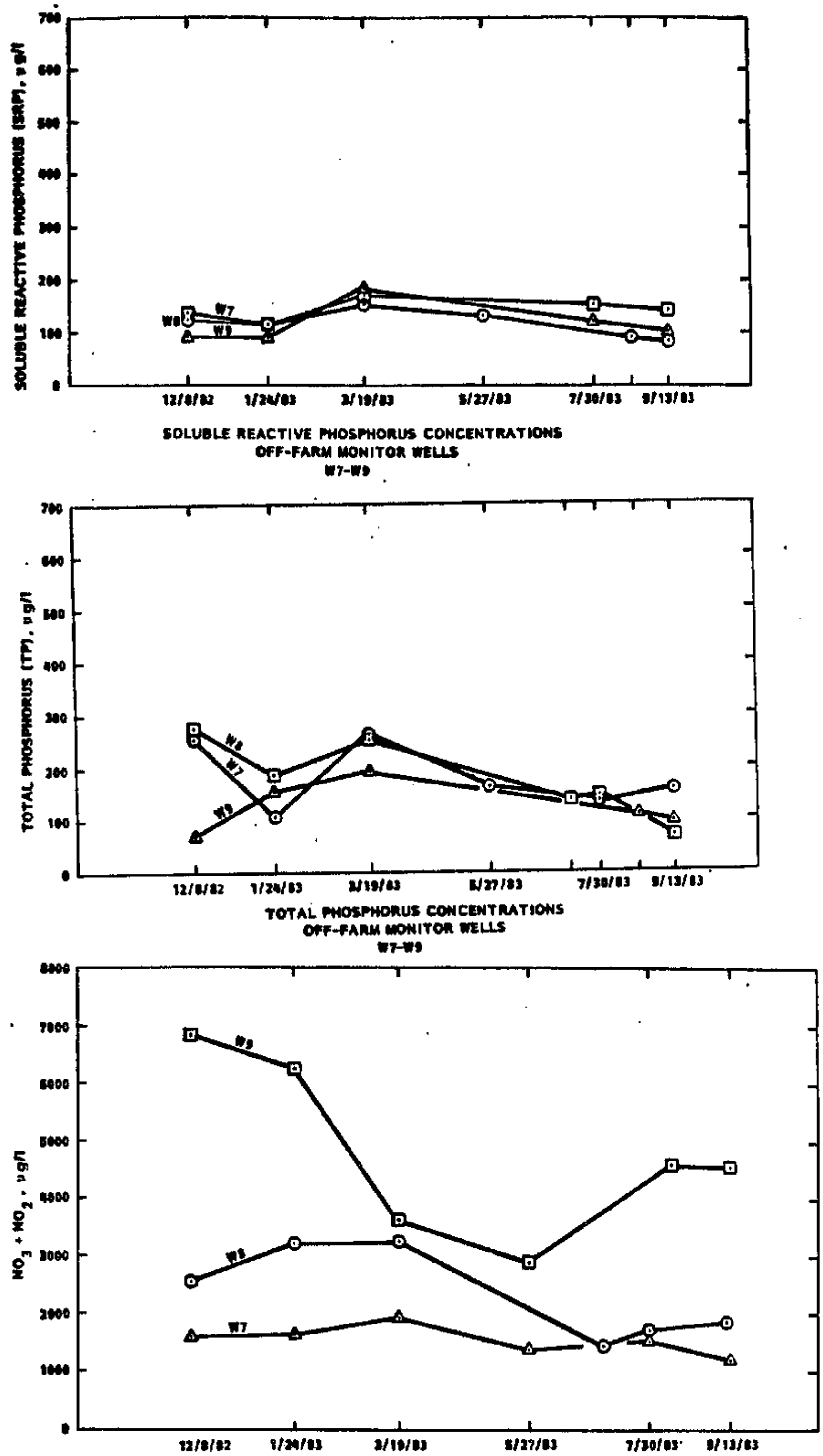


Figure 3-15. Nutrient Concentrations, Off-Farm Monitor Wells W7 through W9

Well W-7 is located at Stratford, surrounded by rangeland and interspersed alfalfa fields. Soluble reactive and total phosphous levels were consistently high throughout the year. SRP concentrations ranged from 138 ug/l to 172 ug/l with the peak levels occurring in the spring. The peak total phosphorus concentration occurred in March, coincident with the peak nitrate concentration and a slight increase in total suspended solids (from 0 mg/l to 7 mg/l). The elevated phosphorus level is likely to be an indication of phosphorus-rich fertilizer application of the alfalfa fields. Nitrate levels ranged between 1,396 ug/l and 1,962 ug/l, which is moderate compared to other wells within the Crab Creek watershed. Conductivity measurements were within the range of natural groundwaters.

Well W-8 is located just east of the main arm of the lake within the city limits of Moses Lake. Surrounding land use is low-density residential, not currently served by sanitary sewers. Fall and winter were the seasons with peak SRP, TP, and NO_3 + NO_2 - N concentrations, which may indicate leachate from septic tanks in the gravelly soil. Total phosphorus concentrations in particular were high in the winter, with a peak of 272 ug/l. The peak NO_3 + NO_2 - N concentrations of 3,460 occurred in March.

Well W-9, located in a residential subdivision surrounded by rangeland, had high nitrate concentrations during the fall and winter. Total and soluble phosphorus concentrations were also relatively high, with peak concentrations for both parameters occurring in the winter. This may indicate an influence from septic tanks during periods of high water table, because there is almost no fertilization of agricultural land in the areas surrounding the well.

<u>In-Lake Nutrient Sources</u>. In addition to nutrient sources in the Moses Lake watershed, nutrients enter the water column from within the lake system itself. Nutrients are released from sediments, (including releases as a result of carp activity and macrophytes). Sediment recycling is potentially important as a nutrient resource especially in the southern poertion of the lake. Nutrient-rich sediment transported into the lake via runoff settles out, forming a rich layer of silt on the lake bottom. The silt layer is enriched by sinking algae and decomposing zooplankton and macrophytes. The average phosphorus concentration of sediment at Station SED-1 was 1,127 mg/kg; wind-caused turbulence, boating activity, and fish can stir the sediments, resulting in resuspension of nutrients and availability for algal uptake.

The common carp <u>Cyprinus carpio</u> is abundant in Pelican Horn and have been observed frequently throughout the entire lake. Carp spawning activity occurred in Upper Pelican Horn in late June and early July (Welch, 1983). Carp are important to nutrient dynamics in Moses Lake because: (1) they are detrital feeders and can recycle large quantities of phosphate and ammonia through excretion; and (2) their benthic feeding habits continually stir the sediments which can cause remineralization of particulate nutrient forms. Sylvester and Oglesby (1964) suggested that much of the turbidity in Moses Lake was caused by carp. The high turbidity and phosphorus concentrations in Pelican Horn are likely related to carp activities. Dr. Eugene Welch at the University of Washington has developed a proposal to study the impact of carp upon nutrient levels in the lake and develop potential controls.

Extensive macrophyte beds (Potomageton pectinatus) are located in the shallow areas (generally less than one meter in depth) in Upper Pelican Horn. Macrophytes are potential sources of nutrients to the water column through releases during plant decay. Lehman and Sandgren (1978) reported an increase in water column soluble phosphorus following senescence and decay of Poromogeton spp. in monomuti Egg Lake in western Washington. Simultaneous increses in phytoplankton chlorophyll a were observed and corrrelated to macrophyte-induced nutrient releases. However, macrophytes have also been shown to reduce sediment and nutrient concentrations. Wetzel (1975) cited a detailed study of the influence of submersed macrophytes on phytoplankton, showing that phytoplankton productivity decreased 60 percent in the presence of Potamogeton pectinatus. Shading and excreted inhibitory organic compounds by the macrophytes were seen as probable causes of the inhibitory effect. Wetzel suggested a possible inhibition of phytoplankton productivity by a reduction of free CO_2 which occurs in dense stands of activity photosynthesizing submersed macrophytes.

ON-FARM MONITORING PROJECT

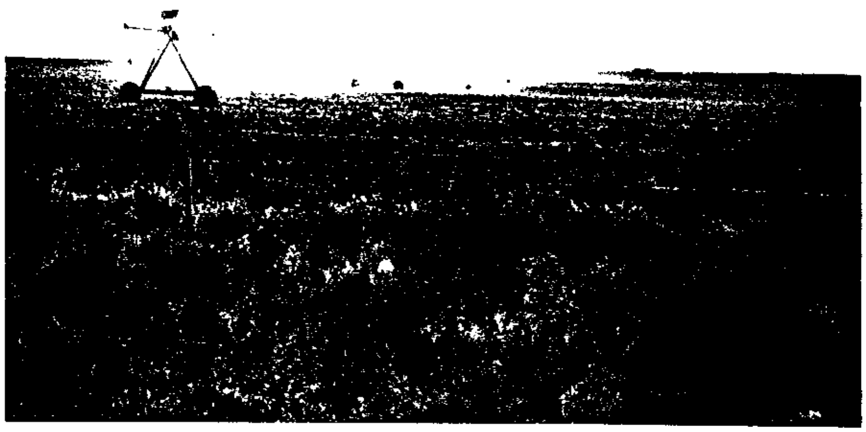
The on-farm monitoring project elements are discussed in terms of potential agricultural sources of nutrients which enter Moses Lake. Agricultural sources include stormwater runoff from irrigated crop and pasture land, dryland wheat, and range and irrigation return flows. In addition, various springs and wells were monitored as part of the on-farm program. The results of flow monitoring are summarized, followed by a discussion of observed nutrient concentrations from the various source and groundwater stations.

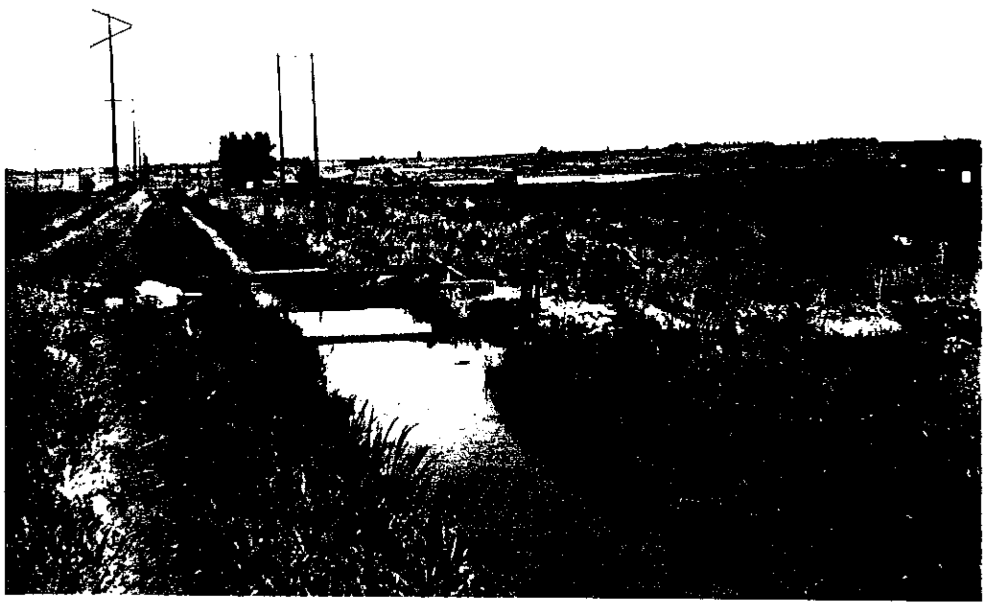
Flow Monitoring Results

Snowmelt and storm runoff flows were monitored for the on-farm project along with surface runoff from sprinkler irrigation and springs.

RILL IRRIGATION
system.

SPRINKLER IRRIGATION
showing center pivot
circle equipment.





TYPICAL IRRIGATION
feed canal.

Surface Runoff Flows. Figure 3-16 illustrates relative flow rates determined at the various runoff monitoring sites. The quantities graphed represent either overall mean flow rates or a single value if only one event was monitored. Most measurements were taken in the winter (January-March) and Spring (April-June) months, although several stations had flow in other seasons and also were monitored then.

As discussed in the off-farm project section, flow rates in Upper Crab Creek were significantly reduced by Round Lake and other in-stream impoundments. The measured flow rate during the winter was 81 cfs above Round Lake (one measurement) compared with an average winter flow rate of over 41 cfs below Round Lake. Round Lake discharged to Crab Creek during February and March in 1983, at a potentially critical period in terms of additional nutrient loading to Moses Lake.

Flows in the creek increased from 140 cfs above Brook Lake to 183 cfs below Brook Lake during the winter. However, storm flows below Brook Lake were essentially the same as non-storm flows, indicating the flow regulating function of the lake during runoff periods.

Irrigation Runoff. Of the three types of irrigation systems used in this area (center pivot, sideroll, and furrow), only furrows have any measurable runoff. This is because of the way furrows are currently being irrigated which requires excess water be applied to the lower end of the field in order to obtain proper application amounts. Runoff from sprinkler irrigation is negligible due to the more uniform application of water and the high intake capability of the soil. The project scope did not include flow rate measurement at irrigation return stations. Monitoring at these stations generally occurred at a point upslope of the collection of return flow in one stream.

Groundwater. Spring flows were monitored as part of the on-farm project to determine the potential nutrient loading from groundwater. No flow monitoring was conducted in wells.

Ten springs were monitored, all in the vicinity of Moses Lake. Sampling occurred in all seasons at stations SP-7, SP-8, SP-9, and SP-10, while the others were monitored less regularly.

Stations SP-11, SP-12, SP-13, and SP-14 exhibited substantially elevated flows during the summer relative to the previous winter, possibly indicating irrigation influence. All four springs are located within the lower Grant Unit near irrigated agricultural areas. Peak summer flow rates ranged from 16 cfs at SP-11 to 35 cfs at SP-13. Smaller summer peaks occurred at Stations SP-2, SP-8, SP-9, and SP-10, which are located in areas less intensely irrigated, Peak summer rates ranged from 1.0 cfs in SP-7 to 7 cfs in SP-10.

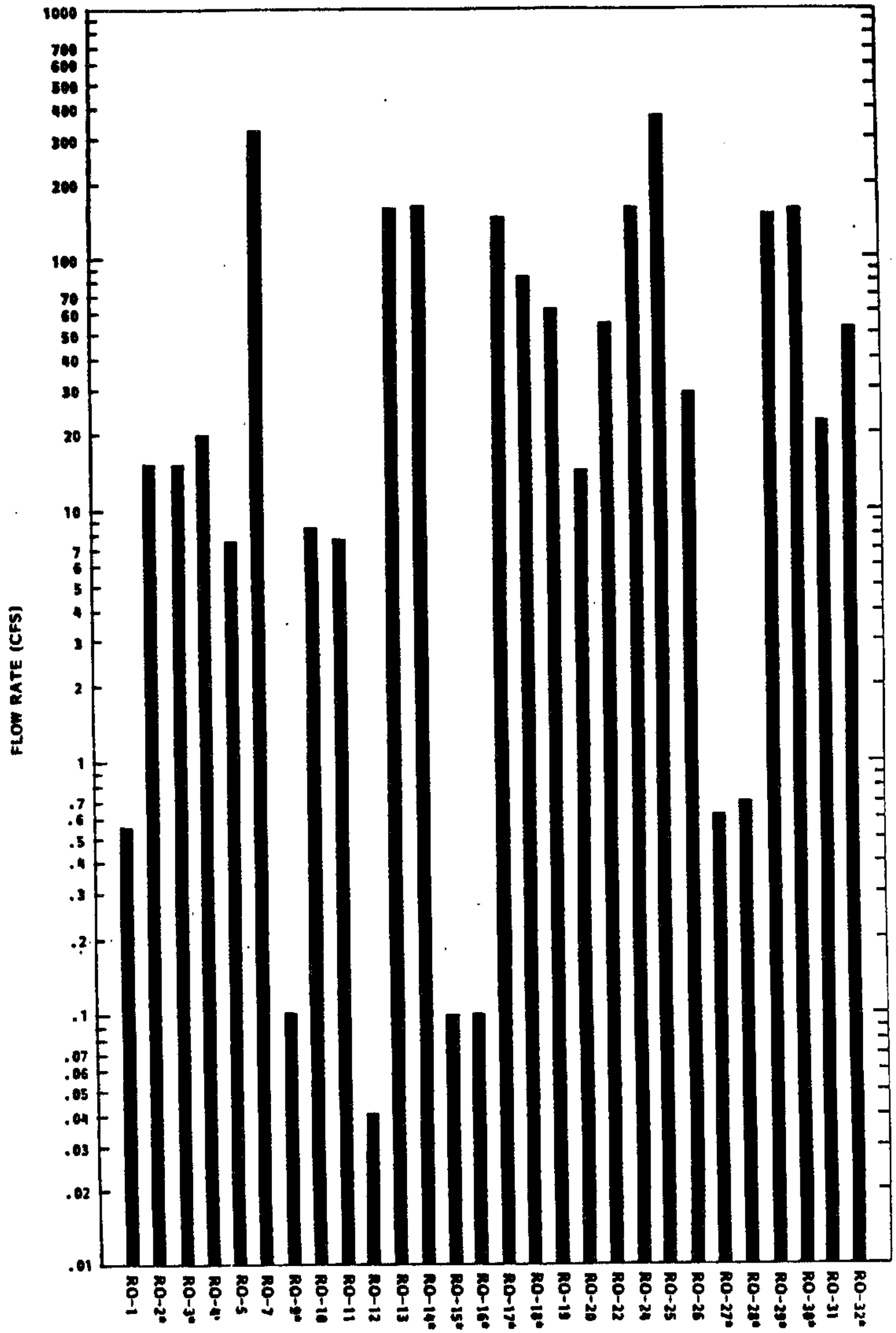


Figure 3-16. Comparison of Flow Rates at Runoff Monitoring Sites

*Based on a single measurement.

Nutrient Concentrations

This section will present the results of water quality analyses, with particular emphasis on the soluble forms of nitrogen and phosphorus. Major potential nutrient sources to Moses Lake or its tributaries will be discussed, including irrigation returns, stormwater runoff, springs, and wells.

Stormwater Runoff. Runoff samples typically contained very large TSS concentrations with some notable exceptions. Range areas tended to contribute less solids to runoff than croplands. Dry croplands were the highest contributors of total suspended solids, especially in the northeastern watershed where rainfall is higher. Despite the fact that certain samples were relatively low in TSS, all runoff monitored contained very elevated SRP and TP concentrations. The lowest concentration of TSS and SRP was from a terraced dryland subwatershed, indicating the potential impact of terracing upon runoff nutrient concentrations.

Most runoff samples had $NO_3 + NO_2$ - N less than 1,000 ug/l. Those having higher concentrations generally did not exceed this level by much. Therefore storm runoff on the whole exhibited lower $NO_3 + NO_2$ - N concentrations than stream flow and groundwater monitored during the project.

Considering these observations, it is apparent that phosphorus was concentrated in storm runoff, while nitrogen generally was diluted. A hypothesis to explain this trend is that phosphorus is usually bound tightly to soils and is released in large quantities only through the erosive and solubilizing force of storms. Nitrogen, however, is more loosely held by soils and infiltrates to deeper layers along with water percolation, or is released rapidly at the onset of runoff.

Runoff from a feedlot on Wilson Creek contained the highest phosphorus concentrations measured at any time in the two projects. The phosphorus concentration at RO-1 was 195 ug/l compared with 18,192 ug/l downstream from the feedlot.

The Sylvan Lake inflow (RO-32) and outflow (RO-31) data indicates that this impoundment trapped solids effectively but did not substantially reduce phosphorus transport. The total phosphorus concentration was 115 ug/l at the inlet and 207 ug/l at the outlet. Soluble reactive phosphorus increased similarly but $NO_3 + NO_2$ - N concentrations were reduced from 1,257 ug/l at the inlet to 920 ug/l at the outlet.

Irrigation Returns. The various irrigation return stations exhibited a considerable range of concentrations for each of the pollutants. $NO_3 + NO_2$ - N, overall, was lower in these samples than in other categories (stream flow, groundwater, and storm runoff). Exceptionally low $NO_3 + NO_2 - N$ concentrations (less than 500 ug/l) occurred at AG-5 (furrow-irrigated alfalfa), AG-6 (furrow-irrigated spring wheat), AG-7 (furrow-irrigated corn), AG-8 (furrow-irrigated corn), and AG-10 (turnips). Soluble N present on the fields presumably tends to be taken up by crops or to infiltrate into the soil rather than to be removed by irrigation water.

In contrast to N, relatively high P concentrations were the rule in irrigation returns. Exceptionally high values (from 700 ug/l to 1,995 ug/l total P occurred at AG-3 (feedlot and pasture), AG-7 (corn), AG-9, (turnips), AG-10-(turnips), and RO-1 (drain sump). Substantially lower values, in the range of 67 ug/l to 105 ug/l occurred at AG-4 (overland flow), AG-5 (alfalfa), AG-5 (spring wheat), and AG-8 (corn). SRP generally made up a minority of the TP in the irrigation return samples. Thus, soluble P species followed a trend similar to that noted above for soluble N, although their concentrations were proportionately higher than those of N.

Evaluations conducted over time at stations AG-6, AG-7, and AG-8 generally demonstrated pollutant concentration decreases from very high values at first application to considerably lower levels at subsequent times. This result suggests a "first-flush" of solids and nutrients from irrigated farm fields somewhat like that frequently noted in the case of storm runoff from various land uses.

Springs. Ten springs monitored in the vicinity of Moses Lake represent the quality of the shallow groundwaters in the area. Chloride and specific conductivity results indicated that all spring samples were similar in ionic character (generally less than 20 mg/l chloride and 300 to 700 umho conductivity). Four of the ten springs (SP-8, SP-9, SP-13, and SP-14) exhibited noticeably elevated TSS during the wet season, indicating the direct effect of surface processes in these cases. Stations SP-13 and SP-14 flow at substantially lower rates during the winter to 120- 130 less than summer flows.) Runoff is apparently contributing to spring flows in the winter. Figure 3-17 illustrates seasonally averaged nutrient concentrations in the lower section of Block 40, and Figure 3-18 illustrates concentrations in the upper section of the watershed.

Most stations exhibited mean TP in the range of 25 to 100 ug/l, exceptions to this statement occurred all during the fall and winter. Station SP-6, downstream from heavily-irrigated areas near Rocky Coulee Wasteway and SP-7, near the Crab Creek outlet to Moses Lake both exceed 125 ug/l TP in the fall. SP-13, slighly upstream from S-6, reached 132 mg/l TP in the winter. $NO_3 + NO_2 - N$ values generally ranged 1,000 to 3,000 ug/l although SP-7 had a concentration in excess of 5,000 ug/l in the winter. Maxima occurred during the winter or spring at four of the six stations which had data available for at least three seasons. There was no equivalent trend for phosphorus.

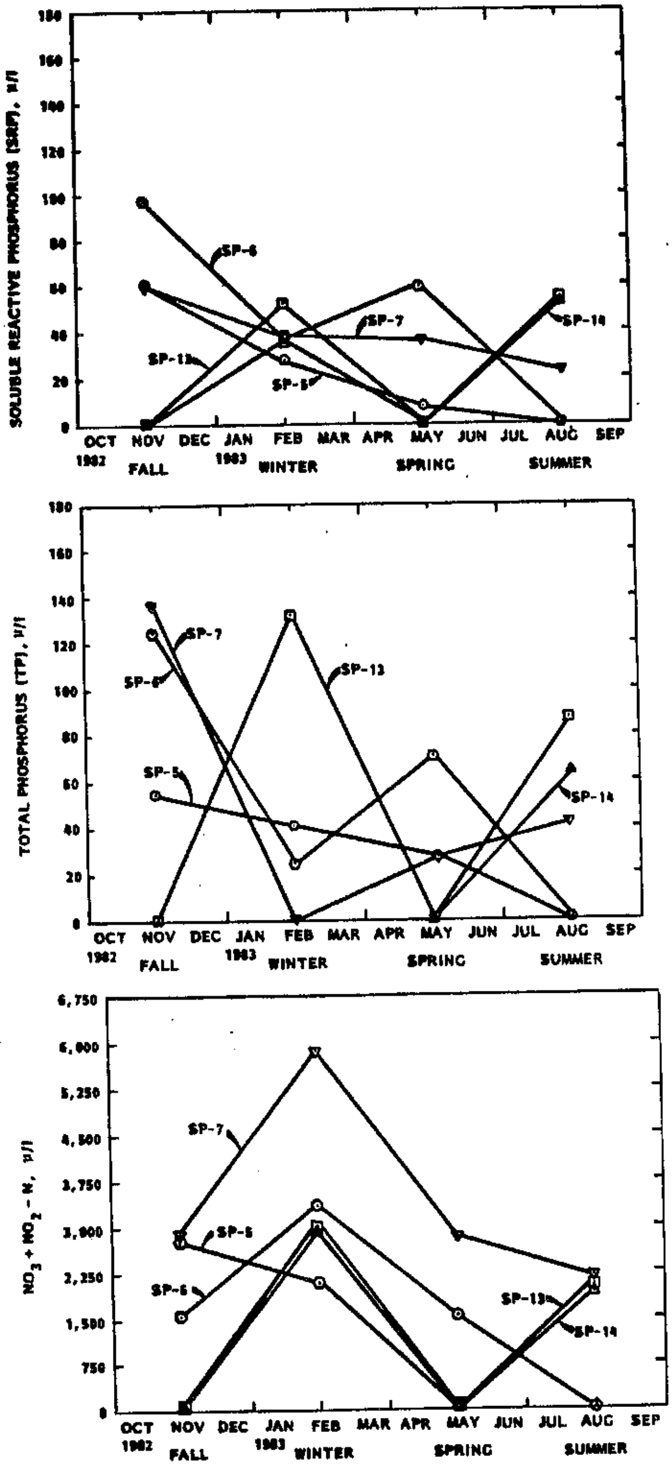


Figure 3-17. Seasonally Averaged Nutrient Concentrations, SP-5, SP-6, SP-7, SP-13, SP-14, Lower Crab Creek Basin

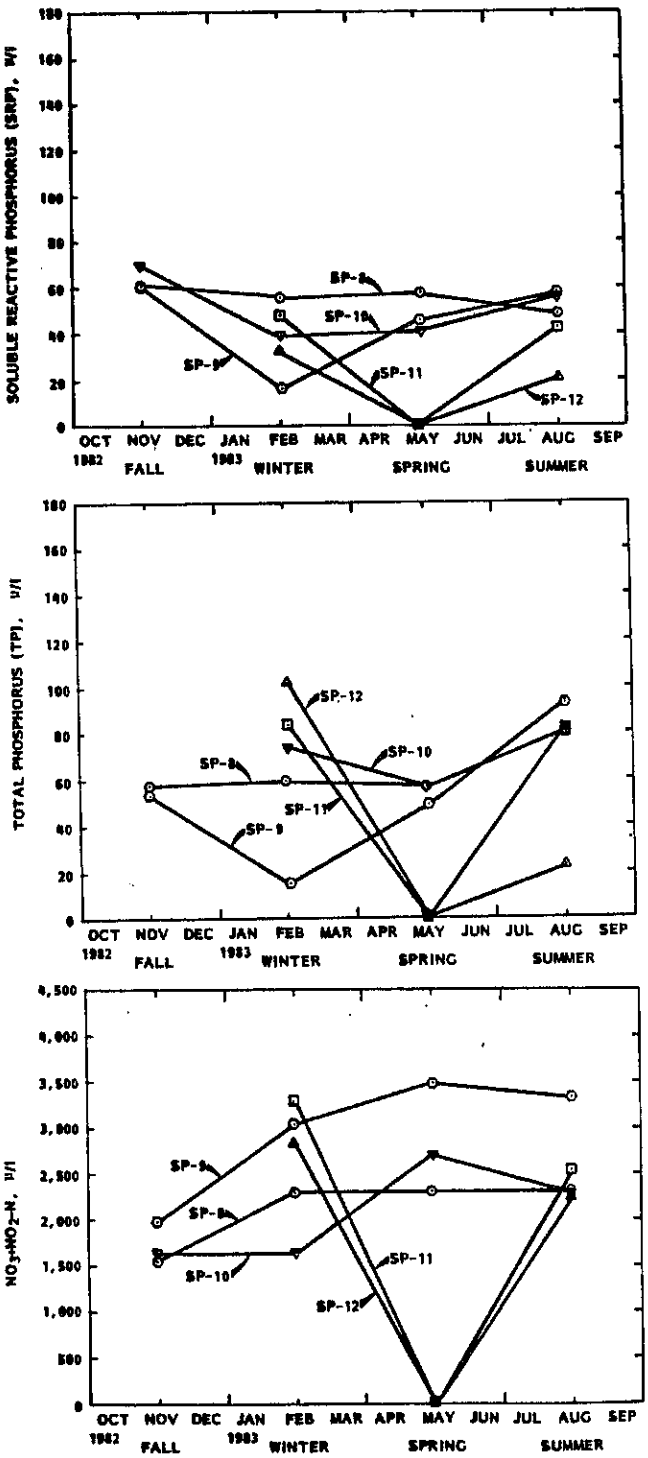


Figure 3-18. Seasonally Averaged Nutrient Concentrations, SP-8, SP-9, SP-10, SP-11, SP-12, Upper Crab Creek

Wells. Sixteen wells were monitored for the on-farm project. Five of the wells, Stations W-10 through W-14, were located in the Lower Grant unit. Figure 3-19 illustrates seasonal averages for Wells W-10, W-11, W-12, W-13, and W-14.

As illustrated on Figure 3-19, SRP and TP concentrations were comparable in Wells W-10 through W-13, but were higher in W-14. Station W-14 is located near an irrigated area where alfalfa is grown, which may be a reason for elevated phosphorus levels. This particular farm may have received additional fertilizer application, or may have received more irrigation water.

Nitrate concentrations vary seasonally in each of the wells, indicating an influence from irrigation and fertilization, and possibly septic tanks. The pattern of seasonal $NO_3 + NO_2 - N$ concentrations varies among the wells. Well W-10 is located at a depth of 135 feet, which is below the protective basalt layer, yet fall $NO_3 + NO_2 - N$ concentrations were five times as high as winter concentrations. This may indicate delayed contamination by nitrates from surface-applied fertilizer, however, this is difficult to ascertain. It does indicate that the lower aquifer is potentially being contaminated by surface activities.

In contrast to W-10 in W-11 $NO_3 + NO_2 - N$ concentrations peaked in the winter and were lowest in the fall. This pattern of low $NO_3 + NO_2 - N$ concentrations in the fall followed by significant increases in the winter and spring was repeated in Wells W-13 and W-14. W-11 is located below the basalt layer at a depth of 72 feet; however, the elevated nitrate concentrations indicate contamination of the lower aquifer. Water table levels are typically highest in the winter; this is also the season of highest precipitation and accompanying potential for contamination of the wells by surface runoff.

Well Stations W-15 through W-23 were located in the Upper Grant Unit.

Soluble reactive phosphorus and total phosphorus concentrations were notably high in W-16 in the winter. This well is very shallow, located in rangeland, and likely represents contamination by surface runoff. Well W-18, a domestic supply well for the town of Wilson Creek located near wheatfields, was relatively high in SRP and TP in the summer, which may be a delayed peak from winter percolation of rainfall-leached phosphorus. Well W-22, an irrigation well surrounded by alfalfa and wheat fields, was high in phosphorus in the spring and summer. This elevated phosphorus level likely represents leached phosphorus applied to the surrounding fields.

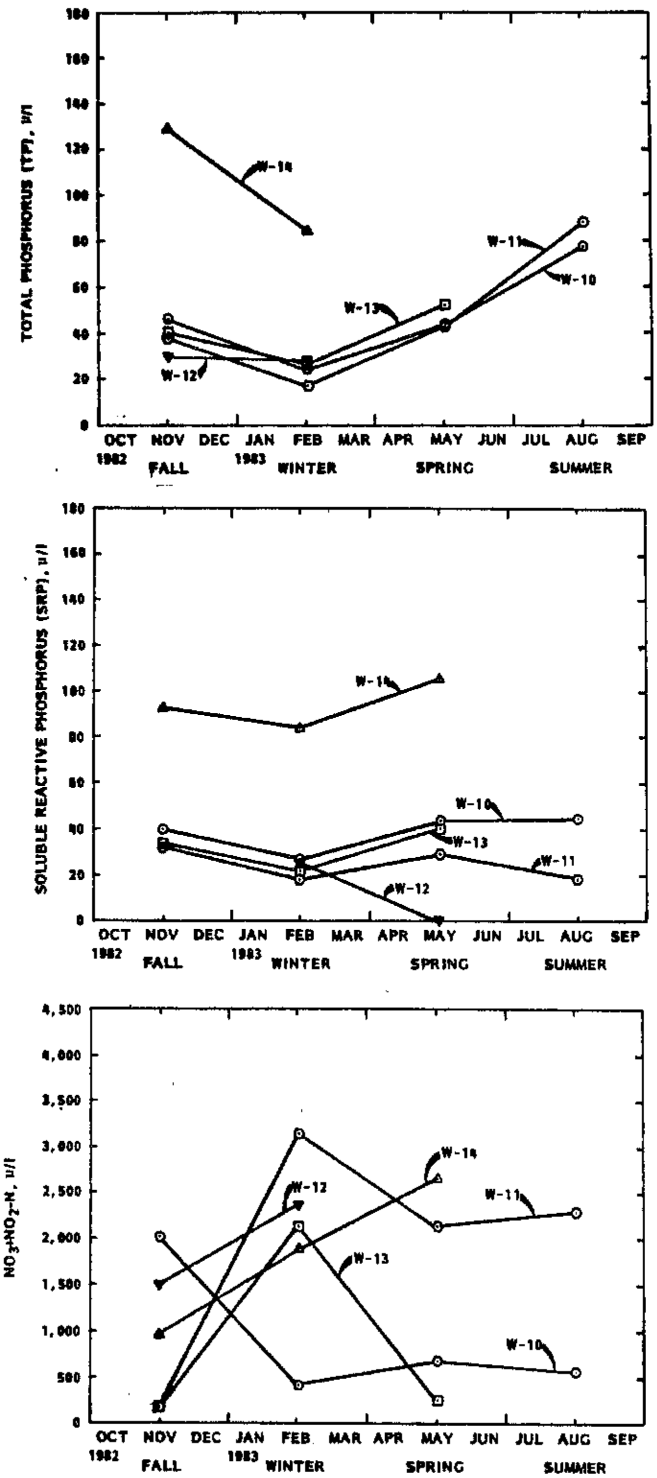


Figure 3-19. Seasonally Averaged Nutrient Concentrations, Wells W-10, W-11, W-12, W-13, and W-14

Nitrate + nitrite-nitrogen concentrations were particularly high in shallow well W-16 in the spring, likely representing a "first flush" effect from spring rains on the rangeland. Well W-17, a 150-foot deep well, showed significantly elevated concentrations during the winter. This well may be contaminated by surface water; unfortunately, conductivity information is not available to aid in this evaluation. Well Station W-20, an irrigation well near alfalfa and wheat fields, had a spring NO_2 + NO_2 - N concentration exceeding 4,000 ug/l and more than 10 times greater than the summer concentration. This may indicate a "first flush" of dissolved nitrogen at the onset of irrigation.

Three wells were sampled in the Lincoln County unit. Table 3-1 illustrates seasonally averaged nutrient concentrations.

Table 3-1. Seasonally Averaged Nutrient Concentrations Monitor wells in the Low Grant Unit

Station	SRP	TP	NO_3 + NO_2 - N
W-24			
Winter	57	6	4,077
Spring	44	20	2,625
W-25			
Winter	96	413	6,875
Spring	336	357	--
W-26			
Winter	19	20	51,700[a]
Spring	336	357	--

[a]May be erroneous laboratory results.

Well stations in the Lincoln County unit indicate contamination by nitrogen and phosphorus sources. Station W-25 had the highest concentration of soluble and reactive phosphorus of any groundwater sample in the study. These concentrations, occurring in the spring, indicate contamination by leached fertilizer. Station W-25 is located in an area surrounded by rangeland and dry cropland.

Nitrate + nitrite-nitrogen concentrations were high in all three wells exhibiting significant seasonal variation. Winter appeared to be the season of peak NO_3 + NO_2 - N concentrations, especially in W-26 where concentrations exceeded 51 mg/l. This high concentration appears questionable, and may be the result of laboratory error. Conductivities in this well were roughly 900 umho, indicating surface contamination of the well. This well is located in an area of rangeland and dry cropland, and could have been contaminated by livestock grazing near the well. Station W-25 NO_3 + NO_2 - N concentrations were high in winter, as they were in W-24. Percolation of rainfall and the accompanying transport of soluble nitrates is a likely source.

NUTRIENT LOADING

Seasonal and annual nutrient loadings were estimated by multiplying nutrient concentrations by the measured or estimated flow rate. Loading estimates were made for both on-farm and off-farm monitoring projects. An overall representation of water inputs to Moses lake is summarized in Table 3-2. Inflows from Crab Creek, Rocky Coulee Wasteway, and Rocky Ford Creek were estimated using flow monitoring information compiled during the off-farm and on-farm projects. Sewage treatment flows were provided by the City of Moses Lake, National Water Service data was used to compute precipitation, and groundwater estimates were made by averaging estimated groundwater inputs for 1979 and 1980. More recent information is not currently available.

Table 3-2. Season Inflow Sources to Moses Lake ($m^3 \times 10^6$)

Inputs	Fall	Winter	Spring	Summer	Total
Crab Creek	22.9	31.5	78.9	29.17	162.4
Rocky Coulee Wasteway[a]	(12.6)	(21.3)	(69.4)	(12.6)	(115.9)
Rocky Ford Creek	18.9	12.6	15.0	22.9	69.4
Sewage treatment[b] plant	0.4	0.4	0.4	0.4	1.6
Groundwater[c]	53.1	0.92	7.2	22.8	84
Precipitation	2.4	3.1	1.1	0.8	7.4
Total	97.7	48.8	102.6	76.1	324.9

[a] Rocky Coulee Wasteway flows included in Crab Creek flows; shown here to illustrate RCW contribution to Crab Creek.

[b] City of Moses Lake Public Works Department data.

[c] Estimated using average groundwater flow for 1979 and 1980.

Using the seasonal summary of water inputs to Moses Lake, a nutrient budget was developed. Total nitrogen and total phosphorus inputs to the lake were estimated. Table 3-3 summarizes the major sources of phosphorus to Moses Lake, and Table 3-4 summarizes the major nitrogen sources to the lake, according to seasonal variations. Table 3-5 summarizes loadings above and below Brooks Lake for both nitrogen and phosphorus.

The point and non-point sources tributary to the major nutrient pathways are discussed in the following paragraphs.

Off-farm Loading

The sources of nitrogen and phosphorus loading to Crab Creek and its tributaries are discussed in the following paragraphs:

Table 3-3. Average Seasonal Phosphorus Loading, Kg

Season	Crab Creek	Percentage of seasonal load	Rocky Coulee Wasteway[a]	Rocky Ford Creek	Percentage of seasonal load	Groundwater	Percentage of seasonal load	Storm drainage/ septic tank leachate	Percentage of seasonal load	Treated sewage	Percentage of seasonal load	Precipitation	Percentage of seasonal load	Total[b]
Fall	1,420	10	(1,360)	3,420	25	5,995	45	540[c]	4	1,848	14	36.81	0.2	13,260
Winter	5,080	44	(3,410)	3,300	29	—	0	1,281[d]	11	1,894	16	45.93	0.4	11,551
Spring	3,150	30	(1,600)	2,850	26.6	2,105	19.7	540[c]	5	2,013	18.9	16.57	0.1	10,675
Summer	1,690	15	(1,290)	3,540	31	3,410	30.2	540[c]	4.7	2,093	18.5	11.43	0.1	11,284
Annual	11,340		7,660	13,110		11,510		2,901		7,980		110.74		46,770

[a] Rocky Coulee Wasteway flows tributary to Crab Creek; included here to show relative contribution.

[b] Rocky Coulee Wasteway flows not included.

[c] Estimated population of 4,500 persons on septic tanks in Moses Lake vicinity.

[d] Storm drainage contribution assumed during winter only.

Table 3-4. Average Seasonal Total Nitrogen Loading, Kg

Season	Crab Creek	Percentage of seasonal load	Rocky Coulee Wasteway[a]	Rocky Ford Creek	Percentage of seasonal load	Groundwater	Percentage of seasonal load	Storm drainage/septic tank leachate	Percentage of seasonal load	Treated sewage	Percentage of seasonal load	Precipitation	Percentage of seasonal load	Total
Fall	21,500	9.6	(27,200)	17,400	7.8	174,100	78	1,410[d]	0.6	5,400	2.4	3,200	1.4[c]	223,010[b]
Winter	85,300	61	(62,200)	41,100	29	--	0	4,315[e]	3	5,400	3.8	3,900	2.7	140,015
Spring	80,100	39.5	(46,600)	33,600	16.5	80,000	39.4	1,410[d]	0.6	5,900	2.9	1,400	0.6	202,610
Summer	65,000	23.0	(29,700)	58,000	20.5	150,000	53.3	1,410[d]	0.5	6,200	2.2	1,000	0.3	281,610
Annual	252,000		(165,600)	150,100		404,300		8,545		22,900		9,500		847,345

[a] Rocky Coulee Wasteway figures are tributary to Crab Creek and are included to illustrate contributions from that section of the watershed.

[b] Rocky Coulee Wasteway flows not included.

[c] Percentage of total seasonal flow.

[d] Estimated population of 4,500 persons on septic tanks in Moses Lake vicinity.

[e] Storm drainage contribution assumed during winter only.

Table 3-5. Nutrient Loadings Above and Below Brooks Lake[a]

Crab Creek station	Phosphorus (kg)	Nitrogen (kg)
S-3	5,080	46,000
S-4	1,360	7,040
S-5	384	1,650
S-6	656	2,380
S-7	13,240	34,500
S-8	9,970	38,100
S-9	4,890	29,100

[a]Winter runoff measurements only.

Crab Creek. Crab Creek contributed 44 percent of the total phosphorus load to Moses Lake during the winter, 30 percent of the spring phosphorus load, and dropped to 15 percent and 10 percent respectively, during the summer and fall. Most of the phosphorus load appeared to be correlated with surface runoff because the peak loading season is the peak runoff season. Roughly 88 percent of the total phosphorus load, and 83 percent of the soluble reactive phosphorus load transported by Crab Creek to Moses Lake originated downstream from Round Lake. Brook Lake removed roughly 4,110 kg of SRP and 11,600 kg of TP from the Upper Crab Creek load during the winter runoff season. Round Lake (downstream of Brook Lake) removed an additional 266 kg of SRP and 1,004 kg of TP from the winter phosphorus load in the creek. Therefore nearly the entire phosphorus load from Crab Creek to Moses Lake originates in the watershed below Round Lake. In-stream impoundments are effectively removing significant phosphorus loads from stream flows.

Rocky Coulee Wasteway. This agricultural wasteway supplied a significant percentage of the total phosphorus load in Crab Creek throughout the year. During the fall, Rocky Coulee Wasteway contributed 95 percent of the Crab Creek phosphorus load; in winter the Rocky Coulee Wasteway contribution was 67 percent; the spring contribution (diluted by East Low Canal water) was 51 percent, and summer contributions comprised 76 percent of the Crab Creek load. Irrigation and fertilization practices in the area tributary to Rocky Coulee Wasteway are the source of significant phosphorus loading to Crab Creek and Moses Lake. Similar to Crab Creek, the peak phosphorus loading occurred during the peak runoff season indicating a correlation with surface runoff.

Rocky Ford Creek. Rocky Ford Creek contriuted a fairly uniform phosphorus load throughout the year, ranging beteeen 2,8950 kg and 3,540 kg. The phosphorus load from Rocky Ford Creek, however, varied in terms of the percentage of the total load to Moses Lake. Winter and summer were peak phosphorus loading periods when Rocky Ford contributed nearly one-third of the total phosphorus load to the lake. Rocky Ford Creek contributed signinficantly greater phosphorus loads to Moses Lake than Crab Creek during the summer and fall. Phosphorus concentrations remained relatively constant throughout the year but the increased flow in the creek during the summer and fall (coincident with the irrigation season) resulted in increased loading. The phosphorus load carried by Rocky Ford Creek roughly doubled from the upstream station to the downstream station, as a result of both flow and concentration increases in the lower creek. Station. The source of the flow and concentration increases in the lower watershed is not clear because of the limited amount of surface activity in the Rocky Ford Creek watershed. The dramatic phosphorus increase from the upper to lower creek section is not seen for any other constituent (i.e., nitrogen or TSS) which may indicate unknown sources of surface-applied phosphorus in the watershed.

Groundwater. Subsurface flow was the major source of phosphorus to the lake during the fall and was a significant phosphorus source during the spring and summer. It follows Rocky Ford Creek in terms of total annual phosphorus load to the lake, but exceeds Crab Creek slightly. Groundwater flow into the lake during the winter is typically negligible, hence the lack of loading during that period.

The three springs monitored in the Crab Creek drainage system (SP-1, SP-2, SP-3) contributed a phosphorus load of 308 kg to the Crab Creek system in the fall, which was the peak loading period. For the springs this represented 22 percent of the fall Crab Creek load, and 2 percent of the total load to Moses Lake during the fall. Springs are an avenue for groundwater-borne phosphorus to surface waters and contribute to the overall loading in the lake. Numerous springs discharge in the lower Crab Creek watershed and must be considered potentially significant sources of phosphorus.

The spring at the head of Rocky Ford Creek (SP-4) contributed roughly 16 percent of the TP load and 18 percent of the SRP load at the upper Rocky Ford Creek station (S-1). This constituted 4 percent of the total phosphorus load to Moses Lake during the fall. This stream is an indicator of the potential loading contribution from groundwater in the Rocky Ford Creek drainage area.

Subsurface flows were a major source of nitrogen loading to Moses Lake. The peak loading periods were the summer and fall, following the irrigation season. During the fall, groundwater contributed over 4 times as much nitrogen to Moses Lake as Crab Creek and Rocky Ford Creek combined, comprising 78 percent of the total nitrogen load to the lake. Groundwater flow into the lake is greatest during the fall and this factor combined with elevated nitrogen concentrations (likely due to infiltrated surface-applied nitrogen) caused the high load. Groundwater was also the major source of nitrogen during the summer, coincident with the irrigation season. During the summer, when nitrogen supply is critical to algal growth, groundwater supplied 53 percent of the total nitrogen load to the lake. During the spring, groundwater contributed nearly 40 percent of the total load, the same as Crab Creek loading. Winter is the lowest season because there is no net flow of groundwater into the lake.

Septic Tanks. Septic Tanks discharge significant quantities of phosphorus to groundwater although adsorption by soil and microbial degradation removes much of the nutrient loading. Dissolved phosphorus can migrate into the water table and enter Moses Lake. Septic tanks are regulated as "non point sources" however in the Moses Lake watershed because their numbers and locations are known.

An inventory of septic tanks located near the shores of Moses Lake was provided by the City of Moses Lake Planning Department. Approximately 1,500 people within the City are on septic tank systems, many of these are located near the lake shore. A larger number of homes on septic tanks are located just outside the City, at least 2,000 people are in high-density development. For estimating loading by septic tank, a total population of 4,500 persons on septic tanks was used.

The phosphorus contribution for each septic tank was estimated at 0.88 kg/year with 80 percent soil retention, based upon work done by Robert Gilliom at the University of Washington. It was assumed that seasonal septic tank phosphorus contributions would not vary significantly. The phosphorus load contributed by septic tanks comprised roughly five percent of the total phosphorus load.

Estimated nitrogen loading was calculated at 20 mg/l with 20 percent soil retention; or 2.3 kg/capita/year. This loading rate was estimated using historical sanitary water concentrations (Metcalf & Eddy, Wastewater Engineering, based on water usage of 130 gallons/capita/day. Septic tanks represent less than one percent of the total nitrogen load to the lake.

Storm Drainage. Surface runoff contributes nutrients to surface waterways and ultimately to Moses Lake. The peak runoff season is during the winter, when most of the rainfall occurs. Runoff is generated by impervious surfaces. Within the Moses Lake area an estimated 15 square mile area is considered "developed" containing roughly 25 percent impervious surfaces. For the estimation of runoff loading, 9,600 acres were considered developed with an average of 25 percent impervious area. Therefore 2,400 acres generated runoff. Average nutrient concentrations were determined using Municipality of Metropolitan Seattle data obtained over several years of monitoring in low-to-medium density residential areas.

The loading figures represent surface runoff only and do not reflect loading by downward percolation of surface-applied fertilizers. Nutrients applied to lawns and gardens in excess of plant needs percolate downward beyond the root zone and can enter the underlying aquifer. These nutrients would then enter the lake via groundwater. Studies done in Long Island, New York quantified nitrogen in the soil column following application to turf. The researchers concluded that significant quantities of nitrogen may be leached from turf grass areas. With medium fertilizer application (21.5 to 4.5 pounds per 1,000 feet), nitrogen concentrations averaged 5.8 ppm, on a dry soil weight basis, at 9 to 16 inches of soil depth. At 0 to 2 inches of soil depth, the content was 22.5 ppm. The areas with no fertilizer application averaged 2.1 ppm at 9 to 16 inches of soil depth.

Treated Sewage. Sewage effluent enters Moses Lake at an average rate of 1.0 mgd. Total phosphorus typically averages roughly 5.1 mg/l in treated sewage. As a result, roughly 7,800 kg of total phosphorus from treated sewage enters Moses Lake. Spring and summer were the peak phosphorus loading seasons, when sewage contributed 19 percent of those seasons' phosphorus loads. Removal of the treated effluent will reduce the phosphorus load to the lake accordingly.

Sewage effluent represents 2 percent of the total nitrogen loading to Moses Lake in the fall, 3 percent of the nitrogen load in the winter, 3 percent in the spring, and 2.5 percent of the total nitrogen load in the summer. Removal of this source will help to reduce overall loading in the lake and is especially important to Pelican Horn where the City of Moses Lake sewage effluent is discharged. However, from a total lake loading perspective, the sludge discharge is more significant as a phosphorus soruce. It is not a major nutrient source.

Precipitation. Dissolved phosphorus in precipitation is a minor component of the phosphorus load to the lake, comprising a maximum of roughly 0.4 percent of the load.

Dissolved nitrogen in precipitation contributes roughly one percent of the total annual nitrogen load to the lake. Winter, the season of maximum precipitation, is the peak loading season.

ON-FARM LOADING

Although the total loading to Moses Lake is summarized in Tables 3-3 and 3-4, the component nutrient contributors are not identified. The goal of the on-farm monitoring project was to identify the specific activites within the Crab Creek watershed contributing to the nutrient load in Moses Lake, and to determine the relative importance of these activities in terms of nutrient loading.

The Crab Creek watershed was divided into subwatersheds according to predominant land use activities. Monitoring data was evaluated for runoff stations, springs, and wells.

Runoff. Because surface runoff typically yielded high concentrations of suspended solids associated pollutants, data from the runoff stations were evaluated to determine correlations between land use and sediment and nutrient yields. There were eight sites with sufficient data to allow preparation of a weighted analysis of nutrient and suspended solids yields per acre per day.

Table 3-6 summarizes the findings of the comparison.

Table 3-6. Land Use/Suspended Solids-Nutrient Yield Relationship

Greatest suspended solids/nutrient yields[a]	Site	Percent dryland	Percent rangeland	Percent irrigation
1	RO-19	100	0	0
2	RO-13	83	17	0
3	RO-5	100	0	0
4	RO-20	0	100	0
5	RO-24	85	15	0
6	RO-7	61	34	5
7	RO-22	1	83	16
8	RO-9	100	0	0

[a]No. 1 is highest; 8 is lowest.

The subwatersheds with the greatest percentages of dryland agriculture were generally the highest contributors of nutrient and suspended solids to runoff. The stations that yielded the greatest loads were those located in the Lincoln County Planning Unit, where precipitaiton is higher than in the lower units. The relationship between nutrient/sediment yielded and precipitation was direct: greater rainfall yielded greater nutrients. There was, however, an exception to this trend at Site 9, which is a dryland area that produced a low yield. This site was in a low precipitation area compared to the other sites, and was predominantly terraced. The low nutrient/sediment yield from the terraced site indicates the potentially beneficial impacts of terracing upon nutrient loading in runoff. The impact of dryland agriculture on the lake appears minimal. Although the dryland areas discharge nutrients and sediment to runoff, their impacts on Moses Lake are reduced significantly by impoundments and distance from the lake.

Springs. Irrigation in the lower Crab Creek watershed (Block 40) has a dramatic impact upon the flow patterns of springs that surface below Block 40. In general, spring flows increase 10 to 20 times after the irrigation season begins. The nutrient loading from springs generally fluctuates with irrigation . The concentration of $NO_3 + NO_2 - N$ and SRP generally decreased during the summer but the total load increased, indicating the soluble nutrients are being leached below the root zone into the underlying spring stations SP-9, SP-10, SP-11, SP-12, SP-13, and SP-14 yielded significantly greater phosphorus loads in the summer than in the winter, all of which are located near irrigated areas. All of these springs (except SP-11) exhibited similarly high nitrate concentrations in the summer.)

Wells. As previously stated no flow monitoring was conducted in wells, so loadings were not calculated. A discussion of nutrient concentrations in the monitored wells in included in the Results section.

CHAPTER 4

EVALUATION

Results of the off-farm and on-farm monitoring programs provide new information on the relative importance of different farming practices and other land based activities on nutrient loadings and resultant algal productivity in Moses Lake. This chapter includes a brief discussion of phytoplankton dynamics within Moses Lake followed by an evaluation of on-farm programs as related to the influence of fertilizer practices and irrigation methods on nutrient loadings to groundwater in the lower Crab Creek drainage. Also included is an evaluation of off-farm observations with some suggestions of possible sources of the elevated phosphorus concentrations found in the Rocky Ford Creek area.

PHYTOPLANKTON DYNAMICS

Nutrient loading generated throughout the watershed is important because it is ultimately one of the major determinants of algal productivity in Moses Lake. Algal productivity is affected by numerous controlling factors, including nutrient availability, temperature, light, andf zooplankton grazing and sinking, among others. Variations in growth kinetics exist among different phytoplankton species, green, blue-greens, etc. The phytoplankton community varies in abundance with time (seasonal succession) and space. Three predominant algal populations have been identified in Moses Lake (Bush, 1971): a population dominated by diatoms, a predominantly blue-green algae population, and a predominantly green algae population. The diatom and green algal populations were found consistently in the upper basin of Parker Horn and northern section of Pelican Horn, respectively; these populations did not vary seasonally during Bush's analyses period. The remaining area of the lake exhibited a successional pattern resulting in a summer predominance of blue-green algae. The majority of the lake continues to exhibit seasonal patterns of diatom and crystomonad dominance in the spring followed by blue-green species in the summer (Patmont, 1980), Brenner, 1983). It is the blue-green species, primarily the genera Aphanizomenon, Microciptis, and Anabena, that form foul-smelling scums and are consistently the focus of restoration efforts.

Dilution of Moses Lake with East Low Canal water has reduced the percentage of blue-greens from 97 percent in 1970 to roughly 60 percent during the dilution period. The blue-greens are reduced only as long as dilution water makes up a sizable fraction of the lake water. The lake water returns to predilution nutrient levels within roughly a month after dilution is discontinued (Welch and Tomasek, 1981, Brenner, 1983).

Prior to 1980, soluble inorganic nitrogen most frequently limited growth in Moses Lake (Patmont, 1980, Welch and Patmont, 1980, Welch and Tomasek, 1981, and Brenner, 1983). Soluble inorganic nitrogen is present primarily in the form of nitrate and ammonia. Plankton utilize both nitrate and ammonia; ammonia is often preferred over nitrate because it is a more reduced form of nitrogen. Ammonia concentrations measured in Moses Lake as part of the unpublished EPA National Eutrophication Study indicate that ammonia concentrations in surface inflows are roughly 5 percent of the nitrate concentrations. The EPA data indicated that nitrate concentrations were much greater than ammonia, but by the end of the summer, nitrate had been depleted by algae and ammonia exceeded nitrate . However, in terms of overall contribution to algal productivity, ammonia is considered a minor source when compared to nitrate.

Blue-green algae have an ability to fix atmospheric nitrogen when the inorganic nitrogen suppply is low and apparently growth-limiting. However, nitrogen fixation requires considerable energy and occurs only when sources of fixed nitrogen are depleted (National Academy of Science, 1978). Therefore, it appears that nitrogen fixation is significant only during periods of nitrogen limitation, usually during the period of maximum water temperature in late summer. Intense nitrogen fixation has not been regularly observed, but was seen during the summer of 1977 when nitrate concentrations declined to a low rate and remained there while chlorophyll a continued to rise. Subsequent years have not illustrated this trend. Nitrogen fixation may become more of a factor as nutrient sources to the lake are reduced.

Phytoplankton concentrations in Pelican Horn appeared to be determined by inflow concentrations of the limiting nutrients and in basin flushing rates. Dilution increased washout of algal cells when limiting nutrient concentrations were low. When the limiting nutrient concentrations increased, so did phytoplankton levels.

The purpose of Phase II efforts is to reduce agricultural-based nutrient loading to Moses Lake through surface and groundwater pathways. Reduced loading from agricultural practices will also help to offset increased nutrient contributions from the basin following increased development of the Columbia Basin project and the accompanying increase in irrigation returns and fertilizer loss through runoff and deep percolation.

By reducing influent nutrient concentrations the effectiveness of the dilution program will likely be improved and overall lake nutrient levels should be lowered. Reduced availability of nutrients from groundwater and surface water inputs, combined with lowered nutrient levels in the dilution water and increased algal washout rate will likely reduce algal biomass in the lake.

The magnitude of the projected improvement is difficult to predict because of the extremely complicated nature of phytoplankton dynamics within the lake. It is also difficult to predict the level of nutrient reduction from recommended agricultural management practices within the watershed because of the complex pathways of nutrient transport into the lake. However, several models are available to simulate phytoplankton responses within the lake under various nutrient scenarios. Welch and Carlson (1983) have predicted algal biomass based upon steady state conditions, and Diane Strayer Martin (1983) has developed a model to simulate algal changes in Moses Lake as a response to various limnological factors. These models may be used to estimate impacts to algal biomass as a result of reduced nutrient loading following implementation of agricultural best management practices. As estimates of nutrient loading reductions become available, one of these models, particularly the model by Martin, may be used to predict the impact upon the eutrophic status of the lake.

OFF-FARM EVALUATION

The following section will include a discussion of nutrient pathways from the land use types located within the off-farm project area. Overall trends of nutrient sources will be discussed. Surface as well as subsurface nutrient pathways will be characterized.

Surface Water Quality

Crab Creek flows, influenced by surface runoff, dominated winter loading to Moses Lake. As precipitation decreased in the spring and irrigation began, the source of loading shifted to groundwater. Both pathways are being affected by agriculture: surface-applied fertilizer washes off the land surface during rainfall events in the winter, and nutrients not utilized by plants percolate downward to reach underlying aquifers.

In general, runoff samples had a very high percentage of total nitrogen loading compared to nitrate loading (the dissolved portion) The relationship between soluble and total phosphorus is much the same: in runoff, most of the phosphorus load is contributed by total phosphorus as opposed to soluble phosphorus. Wells and springs, on the other hand, contributed a much larger portion of the soluble constituents, with nitrate and SRP constituting most of the load. This leads to the conclusion that runoff loading is largely particulate-laden pollutants, while percolation of soluble nitrogen and phosphorus is the major component of groundwater loading.

Surface water impoundments along the Crab Creek watershed prevented most of the surface water-transported nutrients generated in the upper watershed from reaching Moses Lake. This is illustrated on Figure 4-1. Therefore, the area of primary concern to prevent short-term nutrient enrichment in Moses Lake is the Lower Grant Unit. However, groundwater may migrate from the upper watershed to the lake, transporting significant quantities of dissolved nutrients.

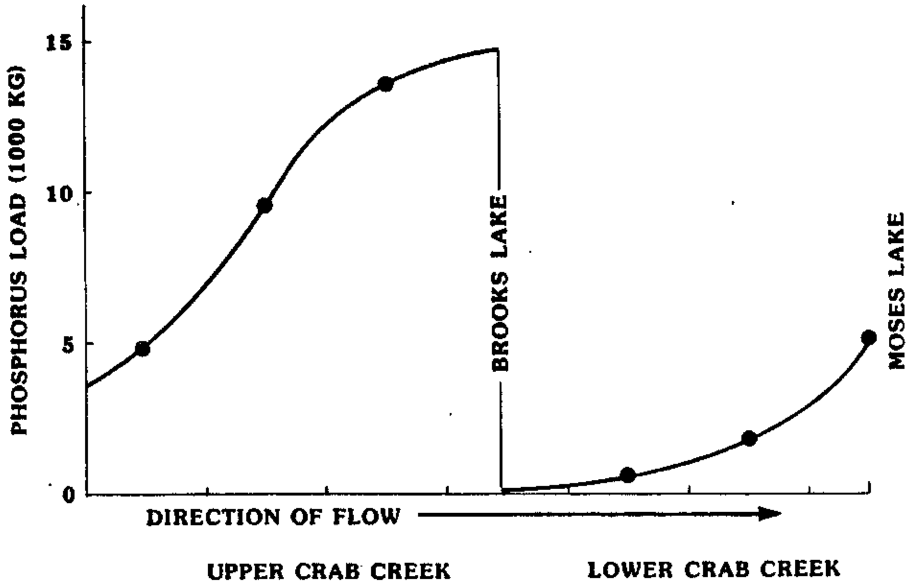


Figure 4-1. Phosphorus Loadings in Crab Creek

Subsurface Water Quality

Generally, naturally occuring phosphate concentrations in groundwater is usually less than 1 mg/l. Apatite (calcium phosphate) is the principal phosphate-bearing mineral and it occurs in almost all igneous rocks (including basalt). Apatite usually occurs as a secondary mineral and generally in very minor quantities. Major deposits of phosphate rich rocks are usually associated with shallow marine sediments (evaporites), the presence of which are highly unlikely in the Columbia Basin. Phosphates are readily adsorbed by clay materials in unconsolidated sediments and metal oxides, especially ferric hydroxide which is present in basalts. The adsorption process tends to keep naturally occurring phosphate concentrations in groundwater to less than a few tenths or hundreths of a milligram per liter. Typically orthophosphate constitutes about 10 to 30 percent of the total phosphorous in natural waters.[4]

With the exception of the breakdown of organic material (peat, wood, etc.), the presence of naturally occuring nitrate in groundwater due to hydrochemical activity of rock and water is rare. Therefore within the project area, nitrate in the groundwater can generally be attributed to the use of fertilizers, farm animal waste or the contributions from septic tank drain fields. Nitrate is highly mobile in groundwater and moves at or near the rate of ground water flow.

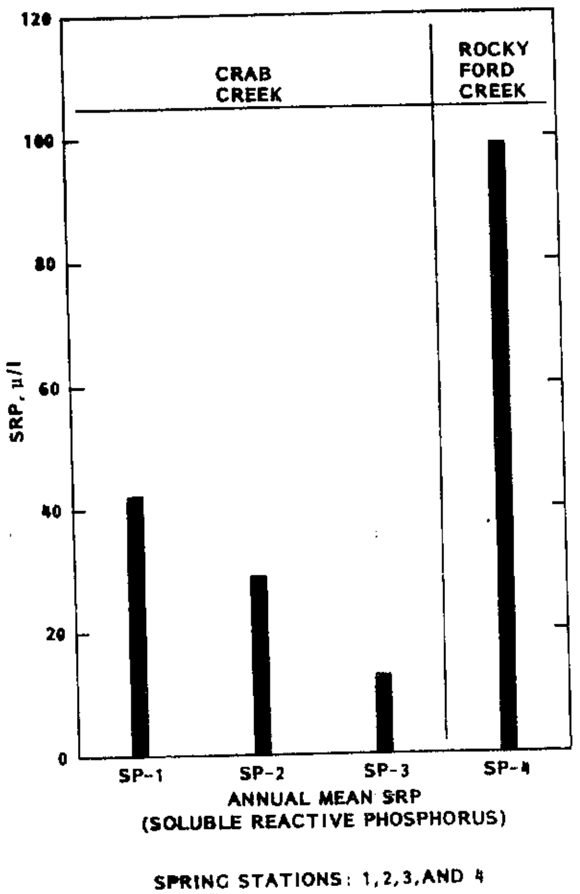
Conductivities for the area's groundwater are generally in excess of 300 micro MHOs which reflects a concentration of total dissolved solids. Conductivities of 300 to 500 micro MHOs are not unusual for discharging groundwaters. The long transit time and contact with subsurface materials results in high conductivities as compared with conductivities in the range of 100 to 150 micro MHOs for Columbia River water in the East Low canal. Three stations exceeded conductivities of 800 micro MHOs, indicating a high possibility of surface water contamination of the well or spring. In the case of wells this is quite typical of unsealed or improperly sealed wells.

The phosphate concentrations in groundwater are not unusually high, ranging from about 20 to 250 ug/l. Although levels of this magnitude could normally be attributed to naturally occurring phosphorus, the concentration distribution, reaction to recharge effects and variability would indicate that the phosphorus present in the groundwater (including Rocky Ford Creek) can probably be attributed to land use activities.

In virtually all of the sampling stations evaluated, the soluble reactive phosphorus (SRP) or orthophosphate component was usually 50 to 100 percent of the total phosphorus which is much higher than the 10 to 30 percent distribution normally found in groundwaters. The highest concentrations of phosphorus tend to occur during the first storm period of the year. This is the first flush phenomena characteristic of phosphorus. Apparently, phosphorus builds up in the soil or rocks due to adsorption or partial adsorption. The phosphorus (or most of it) is then dissolved or released by the first major storm of the season which creates a recharge pulse to the groundwater system. Phosphorus naturally occuring in the basalt would not be as likely to be adsorbed as readily as phosphorus in the soil and a recharge pulse from a storm or irrigation would be more likely to dilute the concentrations rather than increase them. In addition concentrations of naturally occurring phosphorus would tend to be more uniform.

Concentrations of soluble phosphorus and nitrogen increased downgradient in springs monitored in Lower Crab Creek. This is illustrated on Figure 4-2. Spring SP-3 (Magpie Spring) is approximately 4 miles north of the State Game Hatchery (SP-1). Craig Springs (SP-2) is approximately 3 miles north of the hatchery. The hatchery spring water is nearly triple the nutrient concentration of SP-2 and nearly four times the level in SP-3.

Nitrate concentrations in the groundwater usually ranged from 1,000 to 3,000 ug/l. However, recharge pulses due to storms and irrigation were also evident where concentrations increased to more



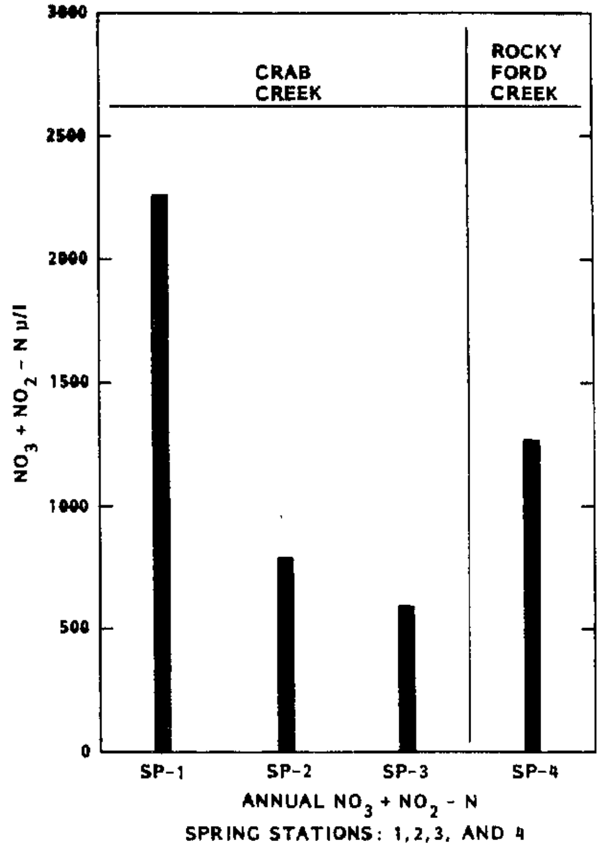


Figure 4-2. Soluble Nutrient Concentrations in Off-Farm Springs

than 7 mg/l with the highest being 51 mg/l. These higher concentrations indicate a high potential for surface water contamination of the wells and springs. Most of the wells east of Moses Lake in the vicinity of Crab Creek exhibited a wide range in nitrate fluctuations. Two to four mg/l fluctuations are not unusual. Rocky Ford Creek on the other hand exhibited a fluctuation range of less than 1.5 mg/l.

Clearly irrigation practices affect the groundwater quality. However the concentrations observed in the wells sampled may or may not be indicative of the area's groundwater quality. The data indicates some surface water contamination of wells is probable. Most of the wells in the vicinity of Crab Creek or heavily irrigated areas increase their nitrate concentrations in response to both the stormwater and irrigation recharge pulses. W-5, which is a municipal well near the airport and generally removed from the heavily irrigated areas only responded to the stormwater recharge pulse.

Water quality in Rocky Ford Creek, which is fed by springs, is representative of much of the region's groundwater quality. However, since Rocky Ford Creek receives most of its recharge from the Ephrata, Soap Lake and Adrian areas, it may reflect land use activities in these areas rather than the farming practices east of Moses lake. Groundwaters are also fed from Round Lake which serves as a nutrient trap in the Crab Creek system and this source should be investigated further as related to nutrient influences from dryland runoff and waterfowl in the lake. It is possible that the nitrate and phosphate concentrations observed in Rocky Ford Creek are in part due to the waste discharges of the Ephrata and Soap Lake wastewater treatment plants which discharge wastes either directly into the ground or by means of effluent irrigation. Phosphorus levels are relatively high and nitrogen:phosphorus (N:P) ratios are relatively low through all seasons which suggests different origins than irrigation land where groundwater quality fluctuates with seasonal irrigation cycles and where N:P ratios are notably higher.

ON-FARM EVALUATION

The original monitoring plan for the project required that ten farms be evaluated during the irrigation season to determine water movement and losses and nutrient movements. The ten farms were selected from the irrigated area in the Lower Grant Unit. This area was suspected of being the primary contributor. The on-farm evaluations, as described below, show this water and nutrient movement.

The on-farm portion of the report includes a number of studies developed to determine the movement of nitrogen and phosphorus in the Block 40, 401, and 41 area. This area is within the Columbia Basin Irrigation Project and includes 20,954 acres of surface and sprinkler irrigated land. The soils are Malaga and Ephrata-Malaga complex. The upper 12-24 inches varies in texture from fine sandy to cobbly sandy loam over a very gravelly coarse sandy loam. Coarseness of this soil is the key to the movement of fertilizer in the profile. A more complete description is in the soils section of this report.

The land use from 1970 to 1982 in the irrigated area is as shown in Table 4-1. This indicates a change to crops which use more fertilizer, e.g. pasture to wheat. During this time period approximately 50 percent (10,000 acres) of the land area converted from furrow or surface irrigation to sprinkler irrigation as shown in Table 4-2.

Water Movement

Water movement on the irrigated area was evaluated by SCS procedures as outlined in the National Engineering Handbook (Chapter 5 for furrows and Chapter 11 for sprinklers). The furrow evaluations measured the water in and out during the time of the irrigation. This was used to compute the gross application, net

Table 4-1. Land Use--Blocks 40, 401, and Portion of 41[a]

Year	Wheat		Alfalfa hay		Pasture		Corn		Seed[b]		Miscellaneous[c]		Total Acres
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	
1970	580	3	10,046	52	4,637	24	773	4	1,932	10	1,352	7	19,319
1971	771	4	10,024	52	4,434	23	1,157	6	1,928	10	964	5	19,277
1972	958	5	9,771	51	4,407	23	1,533	8	1,533	8	958	5	19,159
1973	2,351	12	9,209	47	4,506	23	1,763	9	1,176	6	588	3	19,593
1974	4,363	22	8,130	41	3,768	19	1,388	7	1,586	8	595	3	19,830
1975	4,203	21	8,607	43	3,403	17	1,201	6	1,401	7	1,201	6	20,016
1976	5,253	26	8,889	44	3,232	16	1,414	7	808	4	606	3	20,202
1977	3,056	15	10,593	52	2,852	14	1,426	7	1,019	5	1,426	7	20,371
1978	2,825	14	10,088	50	2,825	14	1,211	6	1,614	8	1,614	8	20,176
1979	5,439	26	8,368	40	3,556	17	1,255	6	1,255	6	1,046	5	20,920
1980	5,194	25	9,557	46	2,909	14	1,662	8	831	4	831	4	20,775
1981	4,278	21	9,575	47	2,241	11	1,630	8	815	4	1,834	9	20,372
1982[d]	4,610	22	10,058	48	2,515	12	1,676	8	419	2	1,676	8	20,954

[a]From ARS census studies for 1970 to 1981 and Moses Lake Clean Lake farm inventory for 1982.
[b]Inclusions: alfalfa, peas, clover, corn, onion, bean, carrot, and sunflower seed crops.
[c]Inclusions: sugarbeets, potatoes, soybeans, Christmas trees, apples, oats, barley, and beans.
[d]Acreage computed from 55 percent farm inventory.

Table 4-2. Conversion in Irrigation Systems Types, 1970 through 1982--Block 40, 401, and Portion of 41[a]

Year	Gravity		Sprinkler		Total Acres
	Acres	Percent	Acres	Percent	
1970	12,930	67	6,389	33	19,319
1971	12,354	64	6,923	36	19,277
1972	11,475	60	7,684	40	19,159
1973	11,754	60	7,839	40	19,593
1974	10,001	50	9,829	50	19,830
1975	9,007	45	11,008	55	20,016
1976	8,436	42	11,766	58	20,202
1977	6,532	32	13,839	68	20,371
1978	6,154	31	14,022	69	20,176
1979	5,839	28	15,081	72	20,920
1980	5,547	27	15,228	73	20,775
1981	4,834	21	16,012	79	20,372
1982	3,981	19	16,973	81	20,954
Inventory	1,876	19	7,775	81	9,651

[a]From Bureau of Reclamation records and Moses Lake Clean Lake farm inventory.

application runoff, deep percolation, and the intake family. The sprinker evaluations were can tests (catch containers on a 10-foot by 10-foot grid under a sprinker nozzle) which were used to compute the gross and net application flow per nozzle, pressure and efficiency. Other tests performed included water quality analysis on furrows that measured the actual sediment and nutrient movement in the soil profile, and soil samples that traced the fertilizer movement below the root zone. Steel neutron probe tubes were used because of the rocks encountered while trying to auger in the aluminum tubes. Because of these difficulties points were put on the pipe and a jackhammer was used to drive the tubes to refusal, or five feet, whichever was greater.

Evapo-transpiration (ET) using the modified Blaney-Criddle methods was computed. The ET was compared to the consumptive use for various crops from the Columbia Basin Irrigation Guide, Climatic Zone 7. The calculated ET, when compared against the Irrigation Guide values were nearly identical and thus established Irrigation Guide values were used.

In the ten fields selected to conduct irrigation evaluations, neutron probe tubes were placed to show water movement and deep percolation. These were used during the evaluations. Of the ten fields, five were furrow irrigated and five were sprinkler irrigated (three with siderolls and two with center pivots).

From the farm inventory, it was determined that the areas irrigated with sprinklers were all similar in design (application rate, spacing, frequency, etc.). It was concluded that even though 81 percent of the total area was sprinkler irrigated, the information obtained from the five sprinkler fields could be directly applied to the remainder of the area. It was also assumed that furrow irrigation was a major contributor to deep percolation with these shallow, coarse soils.

The on-farm data provides an estimate of the water use and movement in the Block 40, 401, and 41 areas. This information can then be used to estimate the amount of nitrogen leached. A summary of that information, covering the 1982 Consumptive Use for Block 40, 401, and 41, is shown in Table 4-3. This Consumptive Ise is the amount of water used by the plants for the crops shown, for the irrigation season.

Table 4-3. 1982 Consumptive Use

Crop	Acres[a]	Consumptive use,[b] inches	Volume, acre-feet
Alfalfa	10,058	35.9	30,090
Corn	1,676	26.1	3,645
Wheat	4,610	23.9	9,181
Pasture	2,515	31.3	6,560
Seed	419	18.0	628
Miscellaneous	1,676	18.0	2,514
Total	20,954		52,555
Weighted Mean		30.1	

[a]Moses Lake Clean Lake Farm Inventory 1983
[b]Columbia Basin Irrigation Guide, SCS, 1973

From the 1982 Consumptive Use, the 52,555 acre-feet of water used in the Block 40, 401, and 41 areas is being applied on 20,954 acres. This produces a weighted average of 30.1 inches of water (used by the crops) over the entire area. In this area water measurement structures are installed at least at every farm unit with some on smaller field areas depending on topography and lateral layouts. Bureau of Reclamation records for 1982 indicate that 83,208 acre-feet of water was diverted to individual turnouts. This 83,208 acre-feet over the 20,954 acres yields an average depth of 47.7 inches of water diverted.

The total amount of water diverted, minus the amount used by the crops, would be the water lost. This is 47.7 inches minus 30.1 inches or 17.6 inches of water lost. Water lost includes three components: 1) direct surface runoff; 2) deep percolation; and 3) evaporation during application.

Direct Surface Runoff. In the Block 40, 401, and 41 area, there is only a small area which has direct surface runoff to Moses Lake or any of its tributaries. Because of the coarse texture of the soil profile in this area, the Bureau of Reclamation determined at the time of construction that artificial drainage of irrigation water would not have to be provided for. There are a number of springs located between the irrigated areas and Crab Creek. The flow from all of these springs is not known, but from those sampled, it was common to see variations of 10 to 20 times more water in summer versus winter, with the increases beginning two to three weeks after irrigation water is turned into these blocks. Most of these springs developed after the Columbia Basin Irrigation Project was built; therefore, deep percolation of excess irrigation water and lateral loss is concluded to be the source of these springs.

Deep Percolation. The neutron probe was used to measure daily water withdrawal and movement for the major crops and the irrigation types. The amount of deep percolation is computed from the neutron probe data collected during the irrigation evaluations. This can be checked by looking at the evaporation and runoff amounts.

An example of neutron probe work data is provided on Figure 4-3 which illustrates the rapid water movement in project area soils. Moisture, as expressed in inches of water per foot of soil, is monitored with probes placed at intervals in the soil column ranging from 8 to 36 inches below the field surface. These data collection points occur both above and below the root limit of the crop; in this example this depth was 24 inches. Irrigation water was applied continuously over a 12-hour period and then monitored for post irrigation readings. Soil moisture readings before and immediately following irrigation are shown in the top part of the figure. The shaded area between the pre and post irrigation readings represents the net water applied. The lower portion of the figure shows soil moisture 6 hours after irrigation has ceased. Actual water measurements show losses from the upper probes (8 to 12-inch depths) where soil moisture has fallen off and soil moisture increases at the 36-inch depth. The increases at depth represent additional deep percolation which occurred over the 6-hour period after irrigation

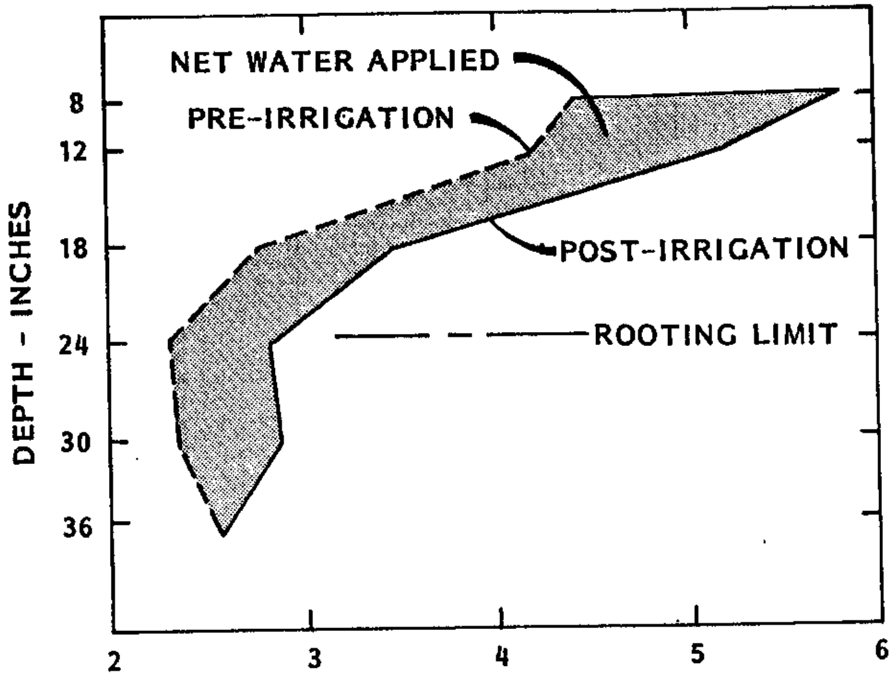


FIGURE 1a SOIL MOISTURE– POST IRRIGATION

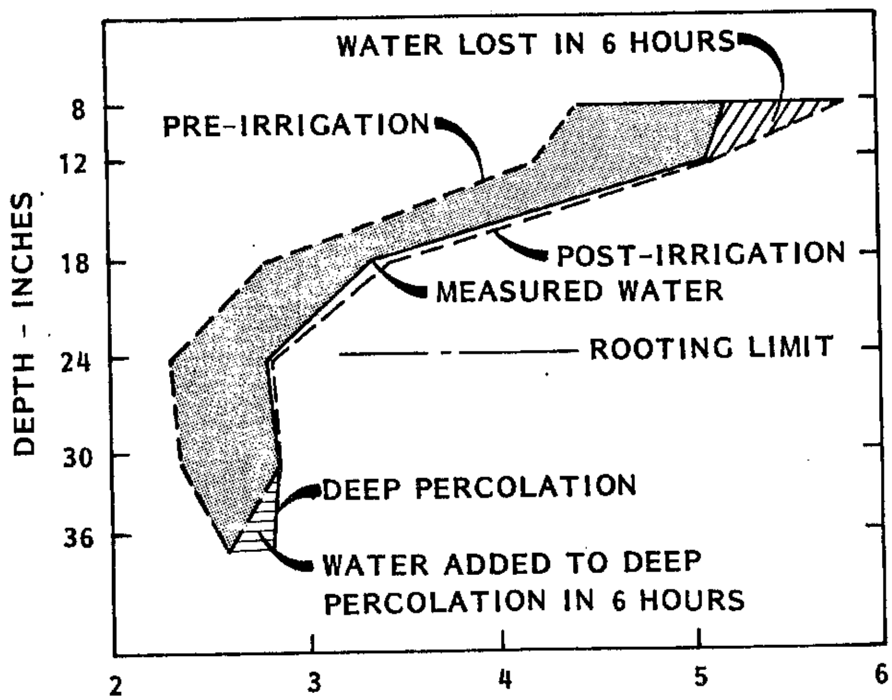


FIGURE 1b SOIL MOISTURE - 6 HOURS AFTER IRRIGATION

Figure 4-3. Water Movement in the Soil Profile based on Neutron Probe Data ceased. Measurements of soil moisture were continued through a 10-day period. Additional details on this work are contained in Appendix C of the Soil Conservation Services Draft Report for Stage 1 of the On-Farm Project.[1] Table 4-4 was developed using neutron probe data from different irrigation systems. These data were then used to estimate deep percolation for the Block 40, 41, and 401 areas.

Table 4-4. Deep Percolation as Measured by the Neutron Probe

System	Deep percolation/irrigation, inches
Center Pivot	0.3
Sideroll	0.5
Furrow	0.6 to 6.9[a]

[a]The amount of deep percolation varies with furrows due to soil intake. The 6.9 is the first irrigation of the season and the 0.6 would be for the rest of the irrigations deep percolation amounts.

The number of irrigations for the season can be estimated from application amounts and the land use for the three types of systems. Using the number of irrigations and the deep percolation amounts for each irrigation from Table 4-4, the total deep percolation for the systems can be calculated. The weighted average amount of deep percolation for the season was determined to be 7.05 inches over the Block 40, 401, and 41 areas. See Table 4-5.

Table 4-5. Total Deep Percolation Amounts for the Irrigation Season

System	Number of irrigations	DP/irrigation	Total DP
Center Pivot	22	0.3	6.6
Sideroll	12	0.5	6.0
Furrow	8	6.9 +(7)(0.6)	11.1
Weighted mean			7.05 inches

Evaporation Loss. Evaporation for sprinkler irrigated fields usually ranges from 5 to 15 percent. The 15 percent level will be assumed in this report because of the high winds and temperatures found in this area. Direct surface runoff from sprinklers in the Block 40, 401, and 41 area was not observed during the evaluations. Therefore, due to the texture of the soils and relatively flat slopes, it was assumed to be zero.

Summary of Irrigation System Water Losses

Irrigation runoff occurs only in the furrow irrigated fields which cover 19 percent (3,981 acres) of this area. It is estimated that 29 percent of the water applied to these fields leaves as tailwater. These waters are allowed to run their natural course, gradually disappearing to deep percolation (which would be added to deep percolation in the field), evaporation, and weed growth. Of the furrow fields, only 800 acres (approximately) have tailwater reaching Crab Creek. A summary of the water losses is quantified for the systems in Table 4-6.

Table 4-6. Summary of Water Losses by Irrigation System

Water distribution	Sprinkler (inches)	Furrow (inches)	Weighted average (inches)
Plant use	30.1	30.1	30.1
Evaporation during application	8.1	3.5	7.1
Irrigation runoff	0.0	17.0	3.4
Deep percolation	6.1	11.1	7.1
Total	44.3	61.7	47.7

It should be noted that no estimates of the water losses that occur in the canals and laterals which supply the individual turnouts have been made in this report. It is assumed there is deep percolation from these sources shown by the early increase in flow in the springs adjacent to Crab Creek.

This initial increase starts about two weeks after the supply system is filled and prior to the actual start of the on-farm irrigation season (mid-April-May). Later (May-July) the flow from the springs then seems to get additional flow from the irrigated areas and continues to increase until the irrigation water needed is reduced.

Irrigation water management can be altered to reduce losses; however, there are limits which must be understood. For example, plant use can only be changed by the land operators' growing plants requiring less water. This is not a practical alternative. Also, due to the arid climatic conditions, evaporation during application cannot be changed significantly with current technology. Also any change would not significantly affect the nutrient loading to Moses Lake.

felt that the 17-inch average runoff can be reduced about one-half with better water management. It must also be noted that reducing the irrigation runoff will reduce deep percolation both on and off the field.

Nutrient Movement

Using the deep percolation amounts summarized in Table 4-6, the amount of nitrogen applied on the land, nutrient requirement of crops and the nitrogen percolation regression equation, an estimate of the pounds of nitrogen leached can be made. The nitrogen percolation regression equation was developed by Pfeiffer and Whittlesey. This equation is:

$$N_L = .029\ (Na)^{1.05}\ (Qd)^{0.7}$$

where N_L = Nitrogen leached/acre/year in pounds
Na = Nitrogen applied/acre/year in pounds
Qd = Deep percolation in inches/acre/year

From the on-farm inventory conducted in this area, estimates of the amount of fertilizer applied have been made. This is shown in Table 4-7, Fertilizer Application.

Nitrogen fertilizers were not applied to alfalfa seed and established alfalfa hay stands, because alfalfa is a legume and fixes its own nitrogen from the atmosphere. This reduces the area that the total pounds of nitrogen was applied to 10,477 acres, which is an average application rate of 161 pounds/acre. The phosphorus is not applied to the seed crops and no data was obtained on the miscellaneous crops.

The nitrogen leaching equation was used to compute the predicted amount of fertilizer that would leach (see Table 4-8).

From this table, it can be shown that although furrows cover less than one-fourth of the project area, this method of irrigation contributes over one-third of the predicted nitrogen leached. Therefore, furrow irrigation is a significant contributor and needs to be treated along with sprinkler areas. Similar findings have been reported by Washington State University researchers in a study located on the Royal Slopes area which has evaluated on-farm improvements to reduce sediments and nutrients in irrigation return flow.

Table 4-7. Fertilizer Application, Block 40, 401, and 41[a]

Crop	Acres	Nitrogen pounds/acre	Nitrogen Total pounds	Phosphorus Pounds/acre	Phosphorus Total pounds
Wheat	4,610	172	792,920	60	276,600
Alfalfa hay	10,058	--	--	80	804,640
Corn	1, 676	238	398,888	65	108,940
Alfalfa seed	419	--	--	--	--
Miscellaneous	1,676	80	134,080	--	--
Pasture	2,515	142[b]	357,130	23[c]	57,845
		Total pounds nitrogen	1,683,018	Total pounds phosphorus	1,248,025
		Total acres	10,477		18,859
		Nitrogen pounds/acre average	161	Phosphorus pounds/acre average	66

[a]From on-farm inventory data.

[b]Combination commercial and fresh manure estimates.

[c]Fresh manure estimates.

(Fresh manure estimates are made from SCS Agricultural Waste Management Manual).

The predicted nitrogen leached from the Block 40, 401, and 41 areas is all calculated from the actual field deep percolation. As already mentioned, a portion of the surface runoff deep percolates after leaving the furrow irrigated field and there is deep percolation in the supply laterals and canals. Neither of these two amounts have been estimated in the predicted deep percolation amounts but would also contribute nutrients. It should also be noted that there is also additional land with similar soils outside the Block 40, 401, and 41 aras which would also contribute.

From the loadings developed by Dr. Richard Horner,[1] the springs that were sampled yielded over 308,000 pounds of nitrate-nitrite nitrogen. This 308,000 pounds would only be a portion of the total load because not all of the springs were sampled and the nitrate-nitrite nitrogen is only a part of the total nitrogen. The amount of the nitrogen leached from the Block 40 irrigated area and the amount shown by the spring loadings are very similar. They are both only a portion of the total, but the magnitudes indicate that the nitrogen in the springs can be explained by the nitrogen leached.

Table 4-8. Nitrogen Leached

System	Deep percolation,[a] inches	Predicted nitrogen leached,[b] pounds/acre	Acres	Total predicted nitrogen leached, pounds
Sprinklers	6.1	21.3	8,486	180,752
Furrows	11.1	32.5	1,991	64,519
Total			10,477	245,271
Weighted mean	7.1	23.4		

[a]From Table 4-6.

[b]Predicted by SCS Econ. No. 1 Tech. Note.

The movement of phosphorus in the soil profile is not easy to quantify. Phosphorus has generally been considered as not leachable, however, the water quality from the springs sampled indicated that there is phosphorus in the water. There are no known natural sources of phosphorus in the area. In looking for a source of the phosphorus in the springs, soil pits were dug in the Block 40 area on Malaga soils with the idea being to determine if leaching of phosphorus is possible. Information obtained from the soil pits indicated that, with the pH and coarse soil texture, there could be greater leaching of phosphates than normally expected. A more in-depth explanation of this soil pit information is found in the appendix.

Since it is not conclusive concerning phosphorus leaching, the nitrogen will be used for economic evaluations. Conclude that the same practices which would give a reduction in the leaching of nitrogen will also result in a reduction of phosphorus leaching. The nitrogen leaching will be addressed in alternatives described in the following chapter. Economics will be developed for reducing the deep percolation and subsequently the amount of nitrogen leached.

CHAPTER 5

CONTROL APPROACHES

Controls are necessary to improve water quality of Moses Lake. Two significant actions have already occurred which deal directly with the lake's eutrophication problem. These include the dilution program described in Chapter 1 and the construction of facilities to allow removal of the City of Moses Lake sewage effluent from Pelican Horn. The dilution program reduces concentrations of algal nutrients and the effluent removal reduces both nitrogen and phosphorus loadings. Further controls to reduce nutrient loadings are considered necessary to improve water quality. This study has shown that nutrient loadings from agricultural sources are significant and are controllable through improved management techniques. Future development of the Columbia Basin Project will increase irrigated acreage in the Moses Lake watershed and inevitably increase nutrient loadings to Moses Lake unless agricultural management improvements and other source controls can be designed to offset the effects of further development.

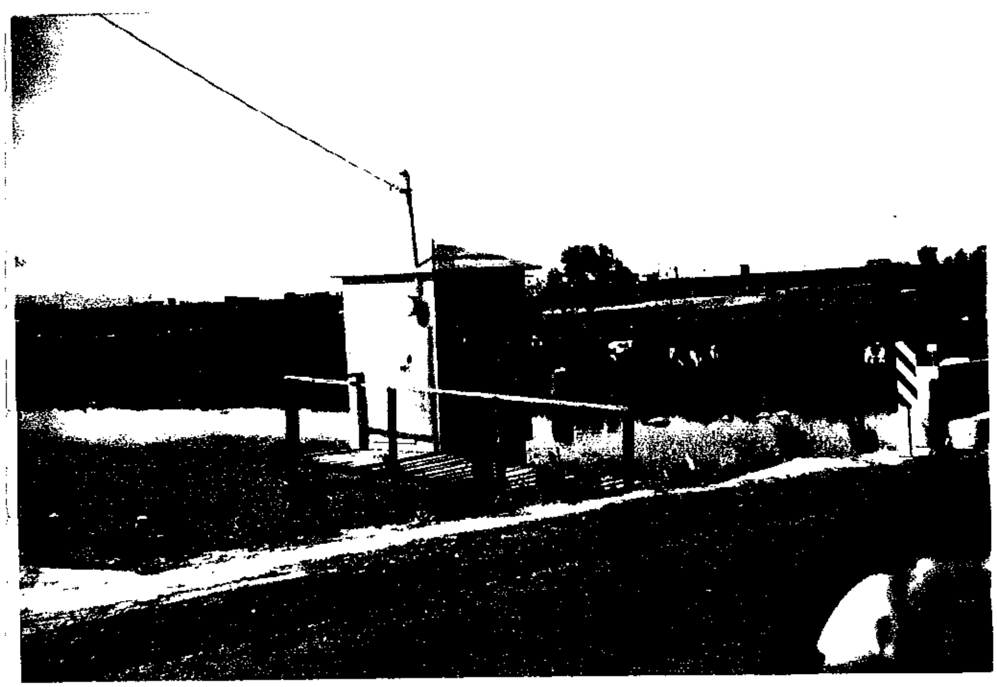
AGRICULTURAL SOURCE CONTROLS

An agricultural management program is recommended under Stage 2 of the Moses Lake Clean Lake Study to demonstrate the effectiveness of on-farm control practices. The economics of this program are based on a three-year demonstration of a combination of management and conservation practices to reduce the amount of nitrogen leached into groundwater. The management practices would be for both furrow and sprinkler irrigated fields and would include, at a minimum, soil testing, scheduling, and fertilizer management. Crop changes would also be evaluated in terms of irrigation (e.g., peas, beans are cold-weather crops that use less water. Soil testing would be used to measure the actual movement of nitrogen and phosphorus during the irrigation season in the soil profile. The scheduling component of the management practices would be used to ensure that only the water the crops need is applied through irrigation. The fertilizer management would control the timing and depth of application and the use of liquid fertilizer through the irrigation system. The management cost has been computed at $10 per acre per year or $30 per acre for Stage 2, with furrows and sprinklers. The conservation practices applied would vary for the furrow and sprinkler systems.

The existing sprinkler systems are in fairly good condition with only some maintenance required to improve their condition to reduce deep percolation. This would include a minimum of installation of a flow meter with possibly other items that would insure a uniform application of water, i.e., renozzle, pressure gauges. The cost for this is estimated at $10 per acre, a higher figure would be associated with furrow irrigation.

POTATO HARVESTER operating in the Block 41 irrigation area.

VIEW OF SIDEROLL (wheel line) irrigation system.



U.S. GEOLOGICAL SURVEY stream gaging station on Lower Crab Creek.

Methods for reducing the deep percolation on furrow systems have been broken into three groups: (1) management practices only; (2) convert to a cablegation system,[a] and (3) convert to a sprinkler system. The use of management practices on furrows alone would give a limited reduction of the amount of nitrogen leached compared to cablegation and sprinklers and is shown to allow flexibility in the program because of the lower initial cost. The use of cablegation and sprinkler systems does allow for a greater savings in deep percolation at a higher cost. A typical cablegation system is illustrated on Figure 5-1.

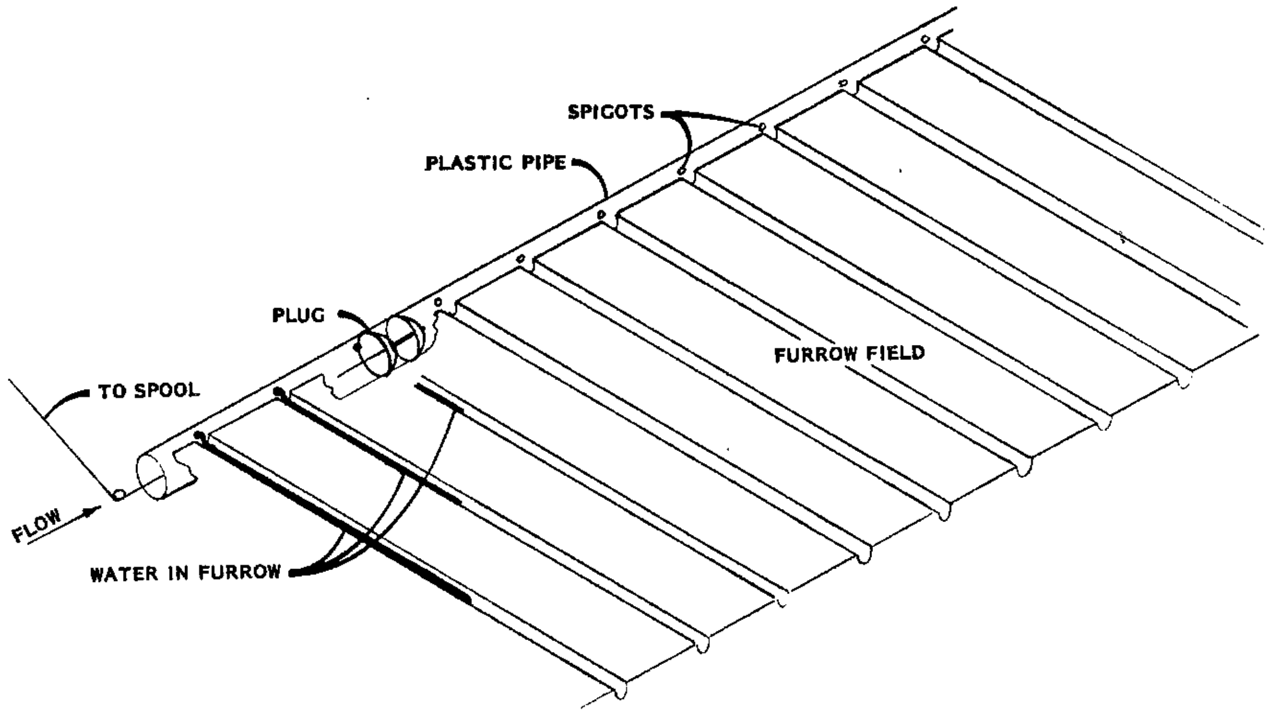


Figure 5-1. Typical Cablegation System

The cost of the furrow systems would be $30 per acre for the management practices, $300 per acre for the cablegation practices, and $530 per acre for the sprinkler practices for Stage 2. The sprinkler systems would only be recommended on locations where it has an advantage over the use of cablegation; for example, on steep slopes.

Table 5-1 shows the costs and Table 5-2 shows the amounts of nitrogen saved from leaching. The tables are based on 100 percent program participation for the Block 40, 401, and 41 area and anticipated field application.

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[a]Cablegation: Automated irrigation method for furrow systems. Uses gated pipe with a slow-moving plug to allow the release of water through adjustable outlet valves in the irrigation pipe generally spaced every furrow.

Table 5-1. Cost of Applied Practices, Stage 2, Block 40, 401, 41

Existing system	Planned practice	Percent land area	Acres	Installation cost/acre	Management cost/acre	Total installation + management	Total cost
Furrows	Management	8	1,676	0	30	30	50,280
	Cablegation	9	1,886	270	30	300	565,800
	Sprinklers	2	419	500	30	530	222,070
Sprinklers	Management	81	16,973	10		40	678,920
Total acres			20,954			Total cost	1,417,070

The average cost is $67.63 per acre.

This cost is computed from the total Block 40, 401, and 41 area while the savings in nitrogen leached is only for the area the nitrogen is applied to. Nitrogen is normally applied to all the acres in a four-year period because of the crop rotations. The 9.2 pounds per acre average over the 20,954 acres (including legume crops) yields a total savings in nitrogen leached of 191,750 pounds for Block 40,401, and 41. Implementation of practice changes on the additional irrigated land in lower Crab Creek would increase the total to nearly 300,000 pounds.

Table 5-2. Nitrogen Leaching Amount Saved, where Applied, Block 40, 401, and 41 Area[a]

Existing system	Planned practice	Area, acres	D.P. saved, inches	N saved, pounds
Furrows	Management	896	3	6,000
	Cablegation	896	8	17,300
	Sprinkler	199	8	3,840
Sprinklers	Management	8,486	3	68,800
Total		10,477		96,000[b]

[a]This table summarized nitrogen saved from non-legume crops only.

[b]Average of 9.2 pounds per acre saved where nitrogen applied.

There is irrigated land in the watershed with soils similar to those in the Block 40, 401, and 41 area. These areas would have the same deep percolation and nitrogen leaching potential. No estimate of this current number of acres has been made.

There is some contribution to Moses Lake from dryland. The dryland has been shown to be a minor contributor even though the highest loading per acre from runoff occurred in this area. There is high erosion in the dryland but ponding losses reduce this problem to the lake. More practice inventory information must be collected to show nutrient movement with possibility demonstrations of conservation practices such as terraces, reduced tillage, fertilizer management, and others to reduce this runoff.

There is irrigated land in the watershed with soils similar to those in the Block 40, 401, and 41 area. These areas would have the same deep percolation and nitrogen leaching potential. No estimate of this current number of acres has been made.

The nutrient from sources such as feedlots, fish hatcheries, and other agri-business activities need to be inventoried and monitored on a case-by-case basis to define the problems. The use of a combination of BMPs would then be used to reduce and control the amount of nutrient movement to Moses Lake.

The expansion of the Columbia Basin Project is another concern which should be addressed as a potential problem. An area adjacent to the Block 40, 401, and 41 area is proposed to be included. This area is currently dryland with some irrigation from deep wells. The soils are similar for portions of this area with proximity and land use making it critical to the water quality of Moses Lake.

The total cost of $1,417,000 would save 96,000 pounds per year of nitrogen leached (approximately 39 percent of the total), and treats the entire Block 40, 401, and 41 area. Reduction of the nutrient levels will add greatly to the social and recreational value of the lake. No monetary value has been assigned to this aspect. This total does not include any administration costs which would be necessary.

OTHER CONTROLS

Phase 2 programs should also evaluate effectiveness of other control approaches and implement those found to be feasible. Several types of control approaches should be considered, including surface water impoundments to trap nutrients and sediments, groundwater evaluations and controls, and in-lake remedies.

Surface waters carry significant nutrient loading to the lake. Impounded reaches of Crab Creek that have been evaluated in Phase 1 actually hold much of the runoff from the upper watershed and serve as sediment and nutrient traps. The extent of this trapping should be further defined and considered as a water quality control feature during Phase 2 for both Crab Creek and Rocky Ford Creek. Monitoring of flows into and from Brooks Lake and/or Round Lake would be useful to establish the value of these in-stream impoundments in reducing nutrient loads. Also, their influence on groundwater recharge should be considered since it has been shown by the U.S. Bureau of Reclamation that Brooks Lake recharges 50,000 acre-feet to the Rocky Ford Creek spring system. Also, waterfowl contribution to nutrients entering these groundwaters should be evaluated to determine if this is a major phosphorus source. Nutrient trapping may also be occurring in Parker Horn in the reach between the mouth of Crab Creek and the Alder Street Fill which effectively blocks circulation between this portion and the balance of Parker Horn. Weed growth is also a concern in this reach.

Groundwater evaluations are needed to better define the flow rates and aquifer contributions to Moses Lake. Improved estimates of groundwater flow during various seasons will improve nutrient budget estimates and allow more accurate assessment of the impact of nutrient aspects of deep percolation controls on irrigated farms. Models available for predicting impacts on algal growth from nutrient reductions are identified in Chapter 4. The groundwater work will require accurate measurement of well levels and selected quality parameters to arrive at improved groundwater flow rates. At present the flow rates are estimated by differences in the water budget.

Another element of the groundwater evaluation is an assessment of the impact of sewage disposal practices on groundwater quality, especially as regards the elevated phosphorus found in Rocky Ford Creek springs. This aspect and the influence of Brooks Lake on the Rocky Ford spring discharge may provide important information leading to control of the major phosphorus source in the watershed.

In-lake evaluations are also needed to assess internal sources and determine feasibility of controls of these sources. Three in-lake aspects are currently identified for consideration in Stage 2. These include evaluation of carp impacts on lake transparency and nutrient recycle, sediment deposition and nutrient content influence on weed growth, and sediment contributions to internal recycle of nutrients for algal growth. Controls to be evaluated include eradication of carp, dredging of nutrient-rich sediments, and circulation improvements around causeways and bridges such as the Alder Street Fill in Parker Horn and the Railroad Bridge in Pelican Horn. Dredging may be especially helpful to improve transparency and reduce weed growth in the upper ends of Parker Horn and Pelican Horn.

IMPLEMENTATION

Implementation will require some activity during 1984 on both off-farm and on-farm elements. Off-farm elements are reasonably straightforward since these involve specific data gathering efforts to determine feasibility and sites of impoundments, sewage controls and in-lake remedies. These can be more precisely scoped in the Phase 2 work planning process.

On-farm implementation requires a gathering of farm community support to carry out management practices and irrigation system changes described. Approximately 75 percent of the Block 40, 401, and 41 area farmers need to be directly involved in this program.

Ultimately, the implementation program needed to significantly reduce nutrient movement requires accelerated application of conservation practices pertinent to the Block 40, 401, and 41 area and the cooperative effort of federal, state, and local agencies. To achieve full potential reduction, two conditions must be satisfied: (1) recommended irrigation water management practices must be followed to a high degree of precision; and (2) all recommended improvements to the irrigation system must be installed.

Seven actions have been identified as being essential to a successful implementation program. These are:

1. Authorize a continuing level of funding that provides incentive for voluntary and continued participation of the farm operators to achieve early completion of the recommended plan.

2. Development of a conservation plan for complete resource management system for each farm. The conservation plan will identify practices consistent with established priorities for nutrient control and will reflect the owner's decisions for making improvements to meet his objectives as well as objectives of the program.

3. Where possible, schedule the implementation program so that structural works are installed prior to application of management practices.

4. Obtain a long-term commitment from farm operators to begin an improvement program based on individual conservation plans and to accelerate that program consistent with established priorities for early completion of improvements.

5. Continue the program for evaluating irrigation methods to determine applicability and limitations of various irrigation systems under local conditions of soil, climate, crops, and economics.

6. Initiate a program to monitor and evaluate the effectiveness of on-farm improvements and to verify that objectives of the program have been achieved.

7. Initiate an information and education program to disseminate results of project monitoring and new developments in irrigation equipment and practices which can aid farmers in practicing proper water management.

A long-term cost-share program to apply conservation and management practices is required to convert the current operation to methods which will cause a reduction in deep percolation. The use of this type of program is necessary to insure the continual benefits from the applied practices.

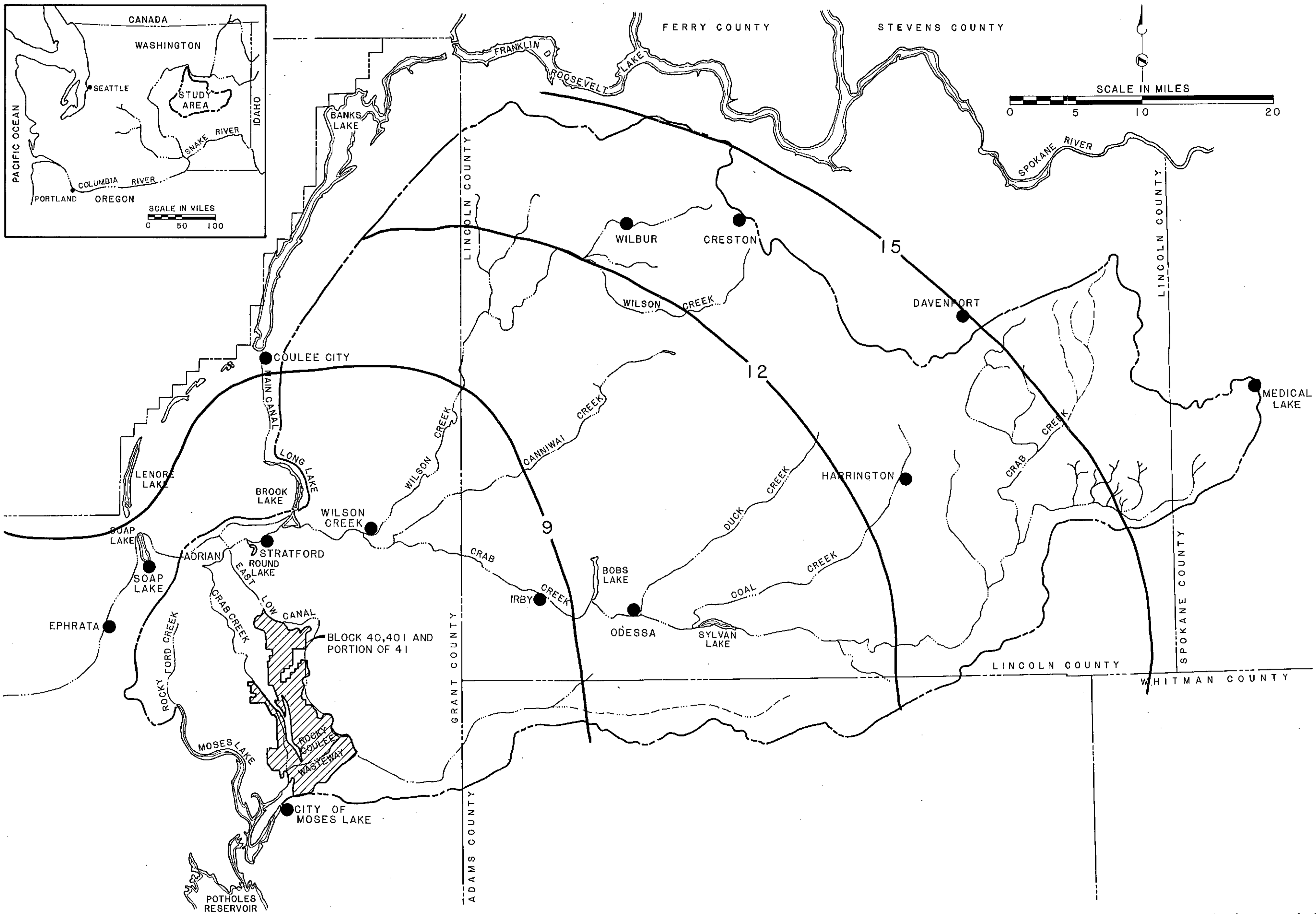

Figure 2-1 Study Area and Precipitation Zones

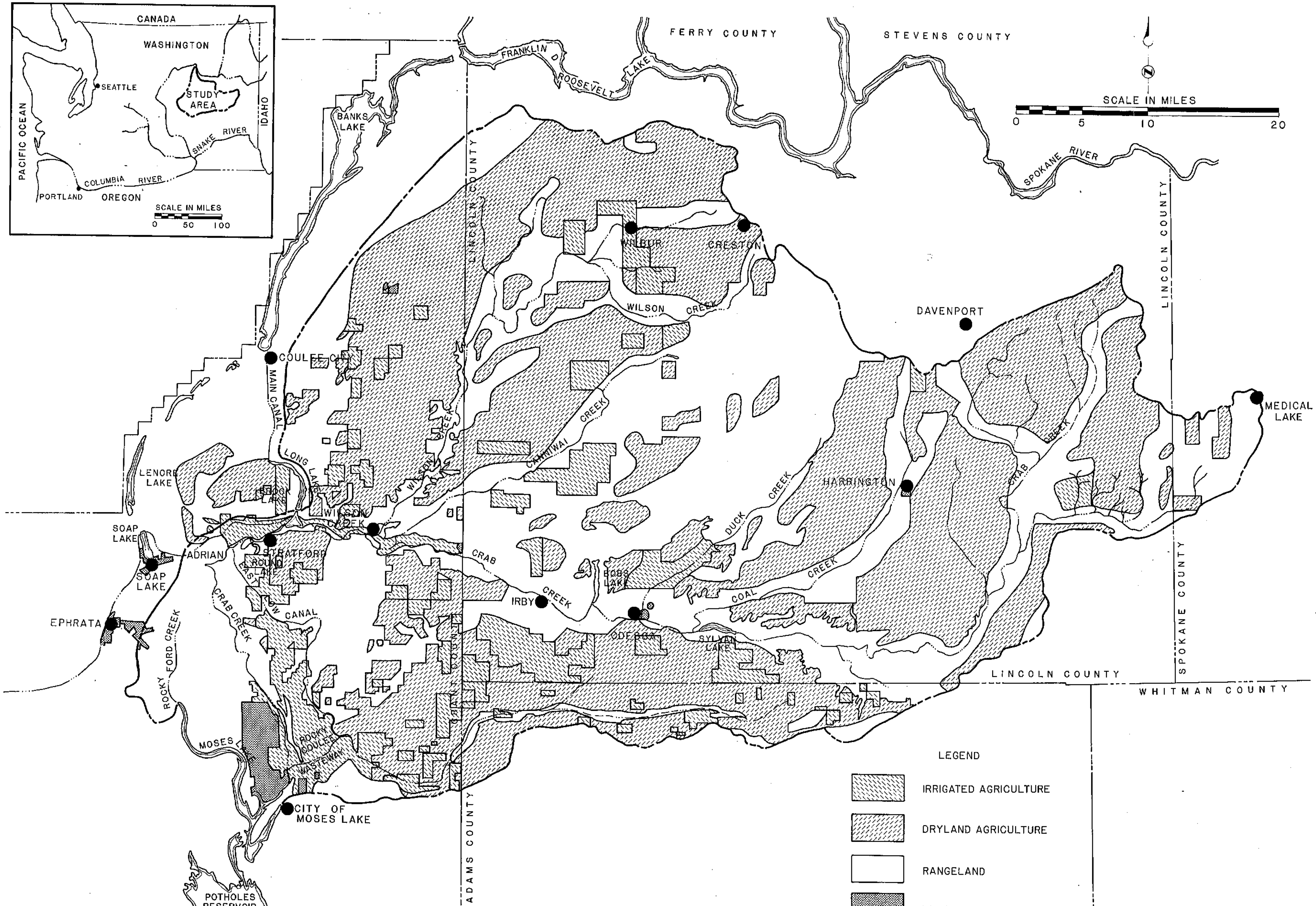

Figure 2-2 Land Use, Crab Creek Watershed

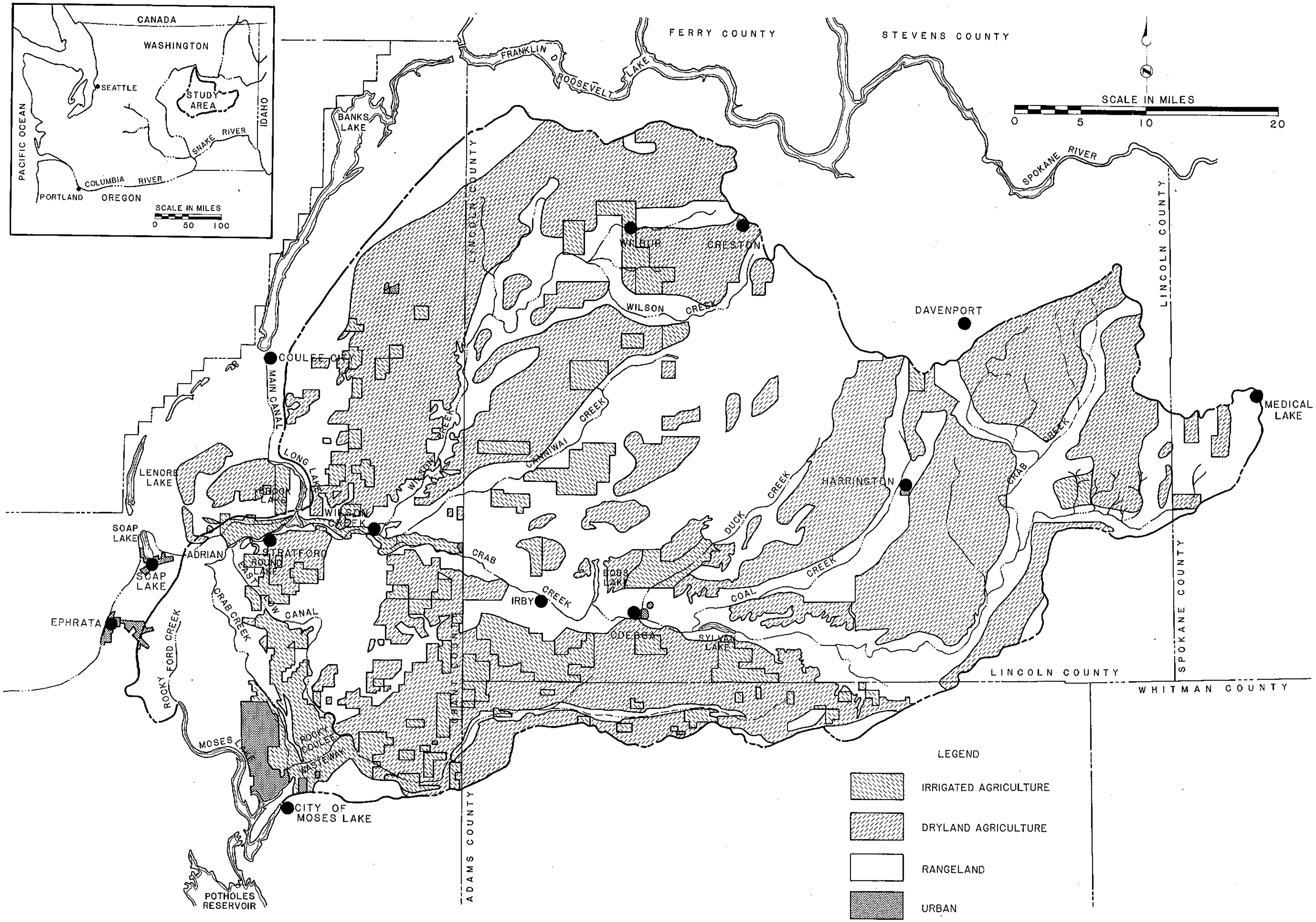

Figure 2-2 Land Use, Crab Creek Watershed

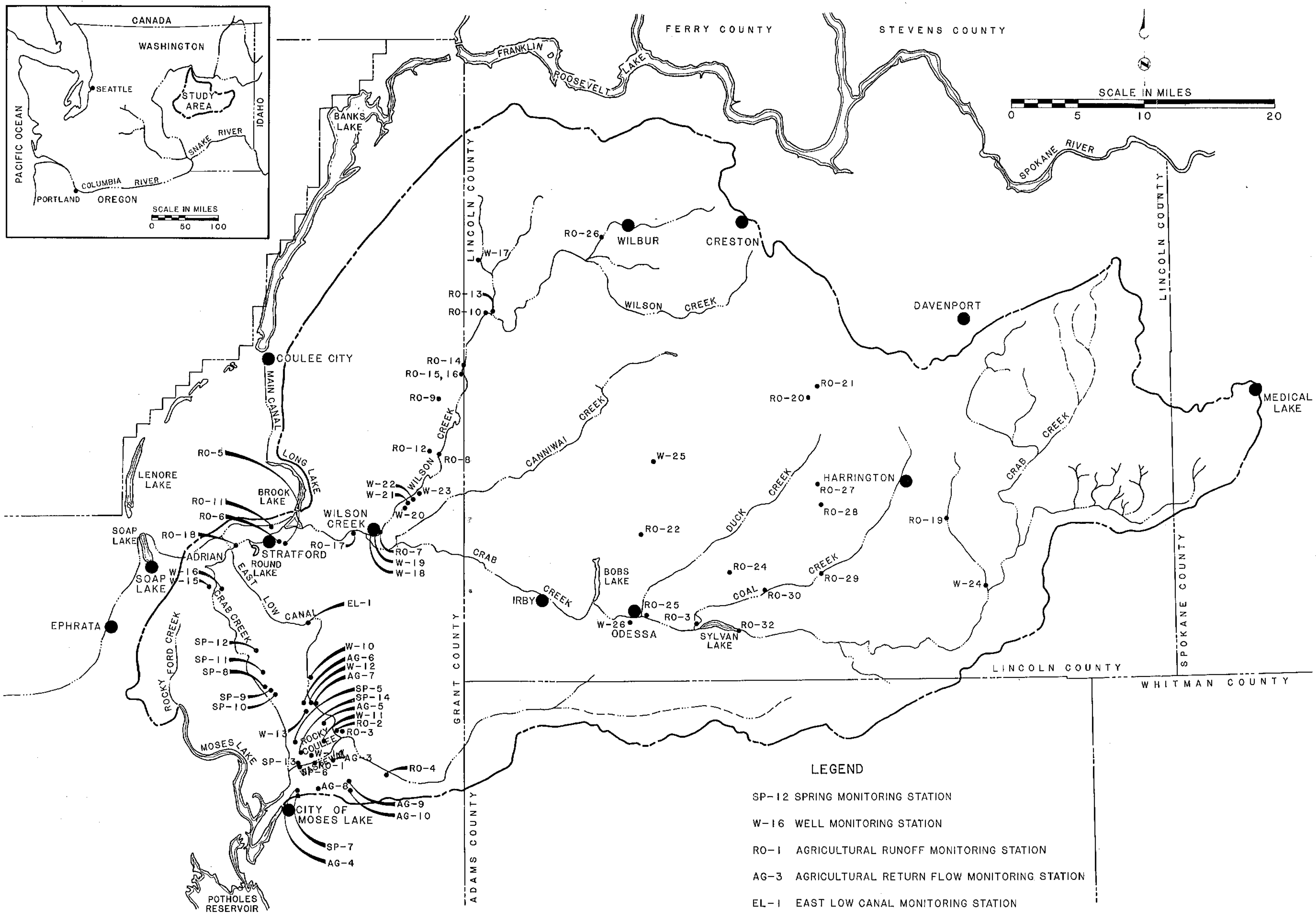

Figure 2-4 On-Farm Monitoring Stations