WASHINGTON STATE
DEPARTMENT OF
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Lacamas Creek Watershed Total Maximum Daily Load Evaluation

March 1996
Publication No. 96-307

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by

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Waterbody No. WA-28-2020

March 1996
Publication No. 96-307

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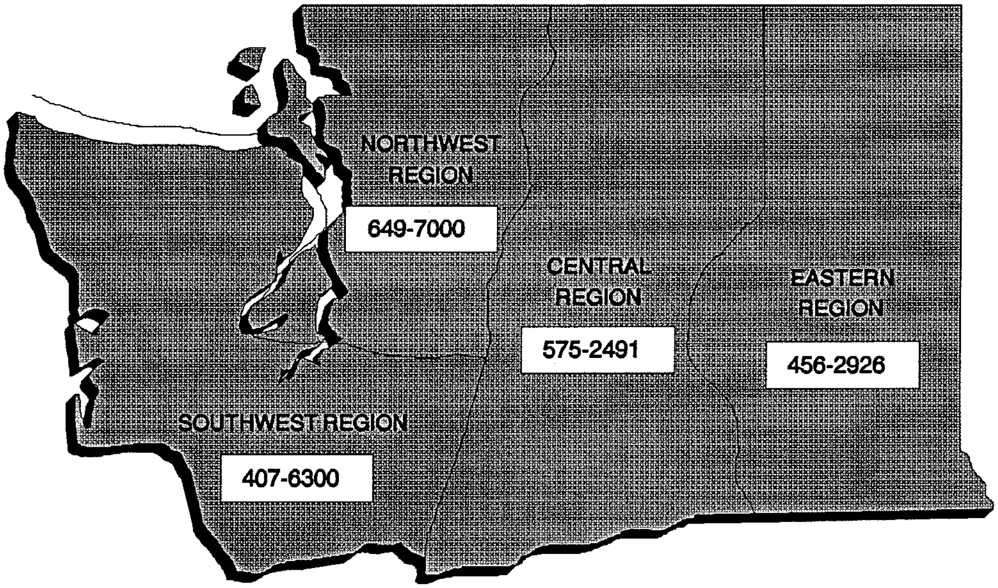

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Table of Contents

List of Figures

List of Tables

Abstract

Lacamas Creek, a small drainage in Clark County, Washington, violates state water quality standards for temperature, dissolved oxygen, pH, and fecal coliform. As a result, portions of the creek are included on the state's §303(d) list as requiring a Total Maximum Daily Load (TMDL). This report evaluates if past assessment and control activities in the watershed meet EPA's requirements for a TMDL. Each of the five elements of a TMDL— problem formulation, TMDL calculations, control actions, public involvement and monitoring— is addressed in terms of EPA requirements, work completed in the basin, and an evaluation of completeness. Lacamas Lake, which is fed by Lacamas Creek, has been the focus of restoration efforts to control phosphorus; such efforts may partially fulfill TMDL requirements for dissolved oxygen and fecal coliform for Lacamas Creek, although increased implementation of best management practices, involvement of the public, and documentation of monitoring may be required. No TMDL requirements for either temperature or pH have been met. However, unless recent data (1992-1995) show continued violations, pH in Lacamas Creek should be considered for removal from the state's §303(d) list. Much work remains to be done in the basin, including control of nonpoint pollution through broad-based implementation of effective best management practices.

Acknowledgements

We would like to thank several Ecology staff who were generous with their time and insights. Allen Moore lent his extensive knowledge of both the watershed and Ecology's grant process. Steve Butkus provided information on EPA's expectations of the TMDL process. John Tooley generated subbasin boundary and land use maps for the basin, and Dan Saul provided assistance with digitizing subbasin boundaries. Greg Pelletier reviewed the statistical methods used and offered valuable comments. Will Kendra provided helpful guidance throughout the project. Allen, Steve, Art Johnson, and Nora Jewett also played a valuable role by reviewing the draft of this document. Barbara Tovrea provided the finishing touches in preparing the document for publication.

We would also like to thank Gordon Franklin of the Natural Resource Conservation Service and Steve Keirn of Southwest Washington Health District for providing information on BMP implementation in the Lacamas drainage. Bob Hutton of Clark County Water Quality Division, Project Manager of Lacamas Lake Restoration, also provided information on activities, underway and planned, in the basin.

Introduction

Lacamas Creek, fed by five main tributaries, flows into Lacamas Lake, located at the southern end of the Lacamas Creek Watershed, in Clark County, Washington (Figure 1). Several of the mainstem and tributary stream segments of Lacamas Creek are listed on the Washington State §303(d) list for dissolved oxygen, temperature, pH, and fecal coliform (Table 1). Lacamas Lake also has documented water quality problems. Lake eutrophication was recognized in the 1970's, and a Phase I Diagnostic and Restoration study was completed in 1985. With a goal of improving water quality by reducing phosphorus loading, restoration efforts have included implementation of agricultural best management practices (BMPs) throughout the watershed. A wide range of other activities has coincided with BMP implementation, performing many of the functions of a total maximum daily load (TMDL) for Lacamas Creek.

Table 1. Ecology's 1994 §303(d) List for Lacamas Creek Basin

Water Body			Parameters			
Name	Segment #	Segment Description	T	DO	pH	FC
Lacamas Creek	WA-28-2020	Mouth to confluence of E.F. and N.F. (RM 16.8)	X	X	X	X
China Ditch	WA-28-2023	Mouth at Fifth Plain Creek RM 2.0 due north to headwaters near Hockinson		X		
Fifth Plain Creek	WA-28-2024	Mouth at Lacamas Creek RM 9.2 to headwaters		X	X	
Shanghai Creek	WA-28-2025	Mouth at Fifth Plain Creek RM 2.5 to headwaters		X	X	
Matney Creek	WA-28-2026	Mouth at Lacamas Creek RM 12.1 to headwaters		X	X	

The purpose of this report is to evaluate whether sufficient work has been done to the Lacamas Lake watershed to constitute a complete TMDL for the §303(d)-listed water bodies of Lacamas Creek. The U.S. Environmental Protection Agency (EPA) requires five elements in addition to a transmittal letter to constitute a complete TMDL package (Findley, 1993):

1. problem formulation
2. TMDL calculation and supporting studies
3. anticipated control actions and implementation schedule
4. public involvement
5. monitoring

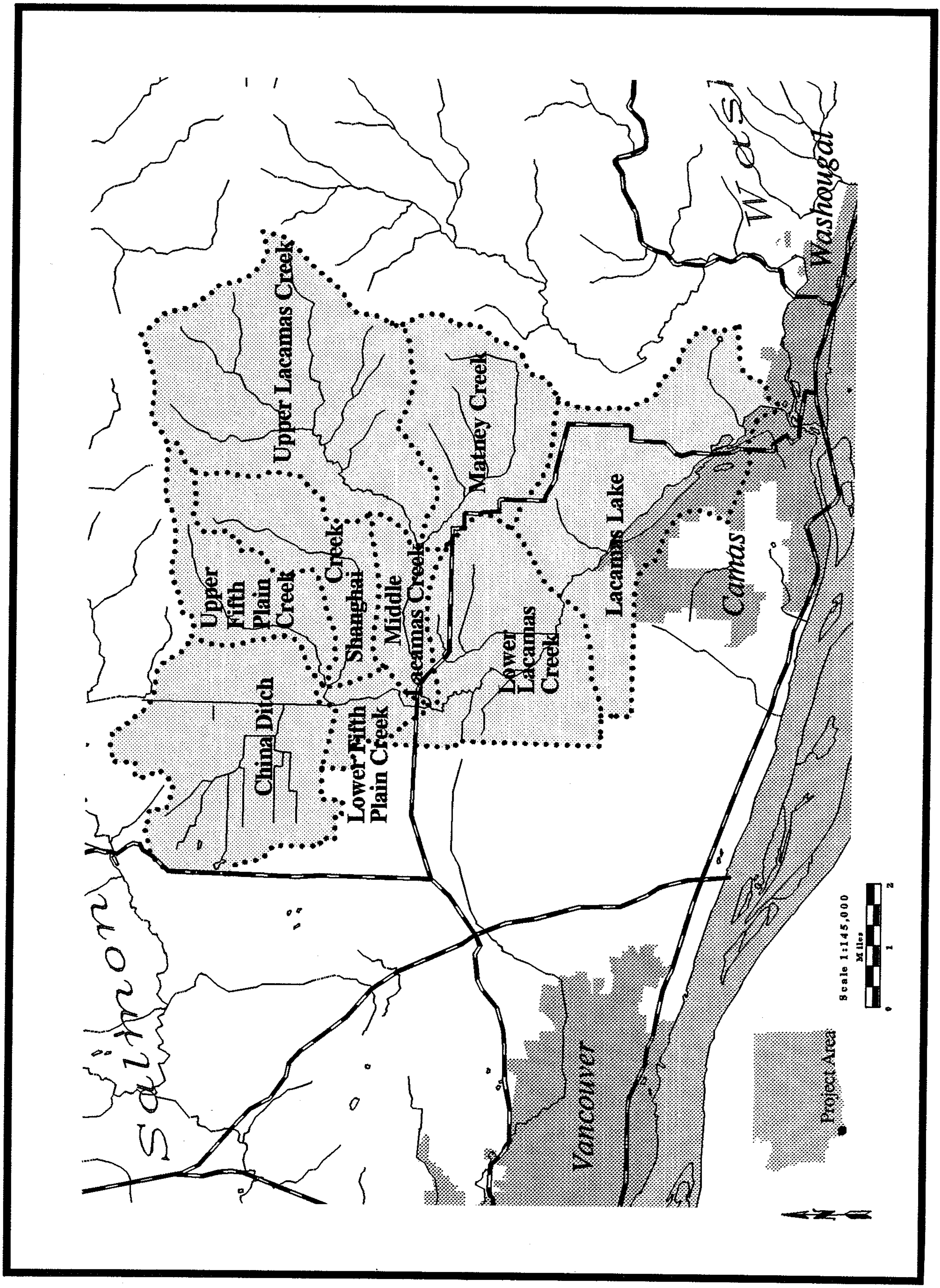

Figure 1. Lacamas Creek Watershed Subbasin Boundaries

This report begins with general information on the watershed, followed by a section for each TMDL element. Each section:

- describes the EPA guidance for the element (drawn from EPA, 1993a)
- discusses the corresponding work that has been completed in the Lacamas Creek watershed
- assesses the completeness of work conducted in the Lacamas Creek watershed for this element and identifies remaining work to be conducted

Setting

The Lacamas Creek drainage basin lies exclusively in Clark County, east of Vancouver and north of Camas, in the southwest corner of Washington State (Figure 1). The eastern flank of the basin lies along the forested foothills of the Cascades, drained by Upper Lacamas and Matney Creeks. To the north and west, the basin is more level, with open, rural residential areas being drained by China Ditch, Upper Fifth Plain Creek, and Shanghai Creek. Dwyer Creek flows directly into Lacamas Lake. Water flows from Lower Lacamas Creek into Lacamas Lake, and then into Round Lake, where roughly one-third is diverted to the James River pulp mill. The remaining waters flow through the town of Camas into the Washougal River, then the Columbia River (CH2M Hill, 1974; IRC, 1987). The basin receives an average of 58 inches of precipitation a year, with dry summers (BCI, 1985a). Streamflow is highest from November to April.

The study area for this report, referred to as the Lacamas Creek watershed, is defined as all the land that drains into Lacamas-Round Lakes, either through Lacamas Creek or other surface flows. The study area excludes the portion of the watershed that is downstream of the lakes, but does include all of the basin's §303(d) listed water bodies. Subbasins are defined as the areas depicted in Figure 1.

Land Use

The Lacamas Creek watershed is dominated by forestry (39%), agriculture (27%), and residential (16%) uses. Detailed land use information, including data sources, is presented in Appendix A. Land use varies widely among sub-basins. Forests dominate the Cascade-foothill subbasins of Upper Lacamas and Matney (63% each), gradually tapering off to the west, away from the hills and into more level plains. Agricultural lands increase as forested lands decrease, dominating the former wetlands of China Ditch (57%) but diminishing in the mixed hills of Upper Fifth Plain, Shanghai, Matney and Upper Lacamas. Residential land use is fairly consistent throughout the basin, representing between 10 and 20% of the land in each subbasin except sparsely populated Upper Lacamas (2%).

TMDL Element #1: Problem Formulation

EPA Requirements

The problem formulation section of a TMDL submittal is designed to focus on the water quality problem, pollution control actions already taken, and actions that remain to be taken. Available information is used to describe the problem. Applicable water quality standards, state and local regulations, pollutants or stressors of concern, and point and nonpoint pollution sources are to be identified.

Work Completed in the Lacamas Creek Watershed

The following problem formulation is drawn from previous studies (BCI, 1985a, 1985b; IRC, 1987; Lafer, 1994), and discussions with Bob Hutton (Clark County manager of the Lacamas Lake Restoration Project) and Allen Moore (Ecology grant officer for the Lacamas Lake Restoration Project).

Because Lacamas Creek and its tributaries flow into Lacamas and Round Lakes, they are defined as Class AA waters. Although monitoring suggests that water quality may be improving, several violations of water quality criteria persist. Water quality parameters of concern include temperature, dissolved oxygen, pH, and fecal coliform. Chapter 173-201A WAC states that for Class AA waters:

- temperature shall not exceed 16°C
- dissolved oxygen shall be at least 9.5 mg/L
- pH shall be within the range of 6.5-8.5
- fecal coliform bacteria shall have a geometric mean value less than 50 colonies/100mL, with no more than 10% of values exceeding 100 colonies/100mL.

The mainstem of Lacamas Creek violates Class AA criteria for dissolved oxygen, temperature, pH, and fecal coliform bacteria. China Ditch, Fifth Plain Creek, Shanghai Creek, and Matney Creek violate temperature, dissolved oxygen, and pH criteria, although not all violations appear on the 1994 §303(d) list (Table 1). Limited data suggest fecal coliform violations occur throughout the basin.

Pollution sources in the basin are exclusively nonpoint, including agriculture, septic systems, construction, and residential and urban activities. Agricultural inputs range from fertilizers applied to crops; animal waste from pasture, feedlots, waste storage facilities, and land application; and muddy runoff (sediment) from concentrated animal areas and stream access. Septic systems, when improperly located, not maintained, or failing, can contribute bacterial contamination and nutrients to streams through ground water or surface flows. Construction activities can lead to erosion, which contributes sediment and associated nutrients. The lawns, septic systems, pets, and waterfowl of residential and urban areas can contribute bacteria and nutrients. As development continues, contaminants and flows from stormwater runoff from roads, sidewalks, lawns and roofs will have the potential to become more significant.

Water quality data were obtained from lake restoration documents (Lafer, 1994; BCI 1985a, 1985b), and were found to have adequate precision for statistical use (Appendix B). The data reflect broad-based nonpoint pollution. All figures in this document reflect data collected during the 1991 and 1992 calendar years (from Lafer, 1994) and uses the 1983 water year for historical comparison (from BCI 1985a, 1985b). Temperature and nutrient levels are high, combining to produce low summer dissolved oxygen levels. Fecal coliform bacteria levels appear to be quite high, although data are limited. A more detailed discussion of these data by parameter follows.

Temperature

Every site exceeded the 16°C temperature criterion, with most sites violating the criterion from June through August each sampling year, frequently exceeding 20°C (Figure 2). High summer temperatures may relate to low summer flows or an absence of riparian vegetation. (The shading provided by vegetation may also explain the relatively low temperatures of Lower Fifth Plain Creek; the absence of shading, the high temperatures in Upper Lacamas Creek.) High summer temperatures limit dissolved oxygen, since 16°C water barely meets Class AA water quality standards for dissolved oxygen even when fully saturated (9.56 mg/L).

Dissolved Oxygen

All stream segments violated dissolved oxygen criteria in the warmer, drier months of June through August (Figure 2). Most streams recovered in September or October, although China Ditch was below compliance even in December and January of 1991-92. Temperatures in China Ditch were similar to other subbasins, but dissolved oxygen levels were much lower. While all subbasins suffer from high temperatures, China Ditch seemed to suffer additionally from a high biological oxygen demand or low re-aeration. The high nutrient values and high proportion of agricultural lands suggest that nutrient loading contributed to lower dissolved oxygen levels.

pH

Slight pH violations (below the 6.5 criterion but above 5.9) occurred throughout the basin, almost exclusively during November and December of 1991.

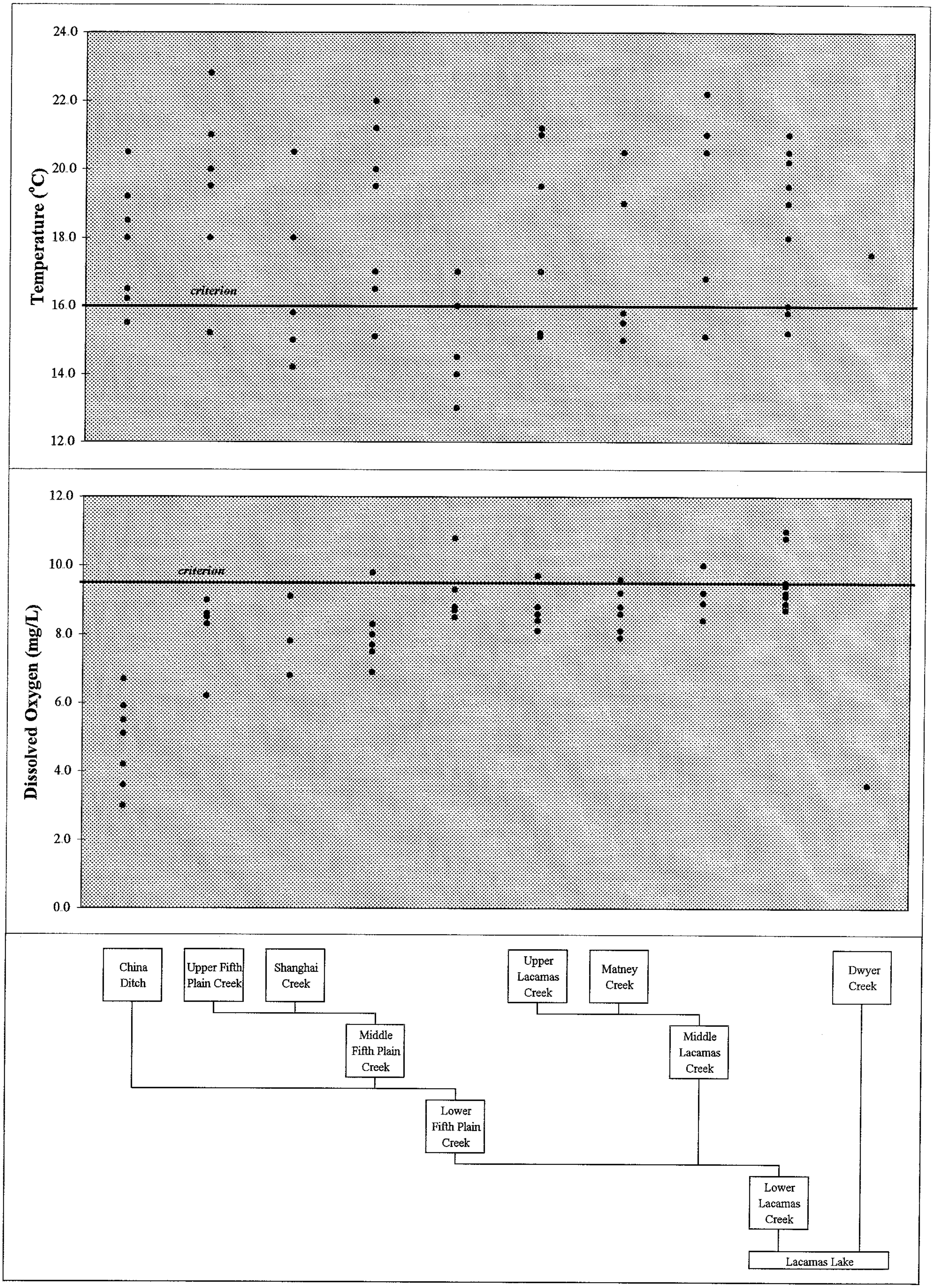

Figure 2. Summer Temperature and Dissolved Oxygen Levels

Bacteria

Although fecal coliform data are limited, sample results were high, violating state water quality standards at every location except Upper Lacamas and Shanghai Creeks in 1991-92. Fecal coliform values ranged from below detection limits to 930 cfu/100mL, with a geometric mean of 138 cfu/100mL.

Nutrients

Phosphorus, nitrate, and ammonia levels were high, especially in the heavily farmed China Ditch and Lower Fifth Plain Creek subbasins (Figure 3).

Viewing the water quality data in light of land use suggests that agriculture, including animal waste, is a significant source of nutrient loading. Ammonia, which is rapidly oxidized to nitrite and then nitrate, and phosphorus often indicate the presence of animal waste. Soluble reactive phosphorus values correlate strongly (r=0.82) with ammonia, suggesting that ammonia and dissolved phosphorus loading may be occurring concurrently, perhaps from animal waste. (Appendix C discusses and includes all water quality correlation coefficients.) Concerns that phosphorus is being contributed through eroding sediment from recent development are not supported by the 1991-1992 data, in which total phosphorus and total suspended sediments correlate poorly (r=0.26).

TMDL Completeness Assessment

The problem description is complete, with the exception that data collected by Clark County since 1992 (not yet available to Ecology) need to be reviewed to confirm that the assessed problem has not changed significantly. A review of recent (1992-1995) data would help address the following issues related to the problem formulation:

- the degree and extent of pH and fecal coliform problems
- the trends in nutrient levels
- verification that temperature and dissolved oxygen continue to violate water quality criteria

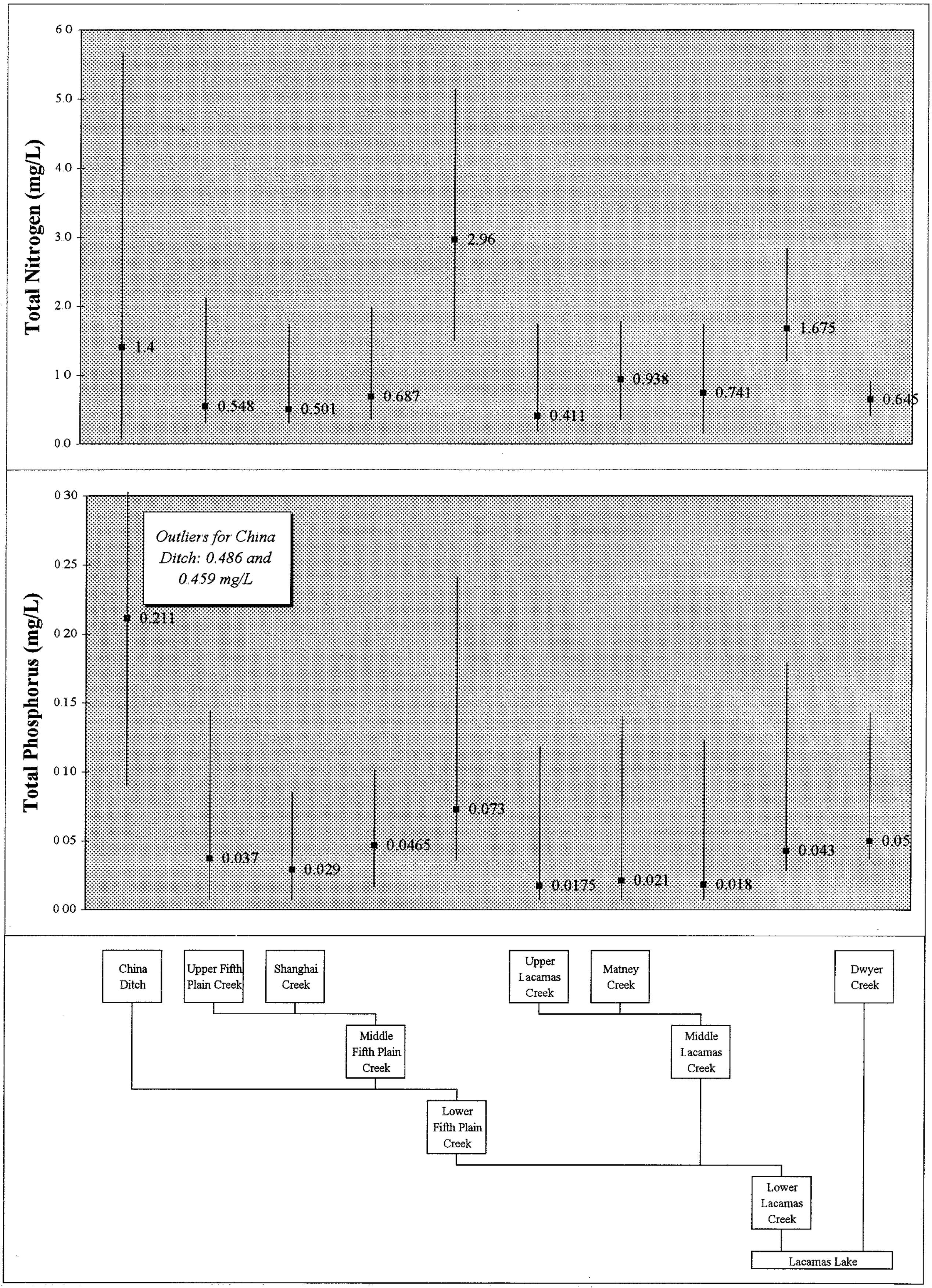

Figure 3. Phosphorus and Nitrogen Ranges and Medians

TMDL Element #2: TMDL Calculations and Supporting Studies

EPA Requirements

A TMDL package must include wasteload and load allocations, and may include (with justification) a margin of safety or reserve for future growth. Each submittal should include technical reports and calculations used to determine the allocation components of a TMDL, including water body loading capacity and allocation scheme. Each submittal should also include the rationale for safety margins or future reserves, modeling information, and model assumptions.

Work Completed in the Lacamas Creek Watershed

The 1983-84 Lacamas Lake Diagnostic and Restoration Analysis (BCI, 1985a) measured phosphorus loading to the lake and estimated target loading levels using Vollenweider's (1976) nutrient loading-trophic level model. In the 1984 water year, the lake received 15,046 kg of total phosphorus: 95.6% from Lacamas Creek, 4.0% from Dwyer Creek, and 0.4% from precipitation. The diagnostic study recommended reducing the lake's phosphorus external loading 84% to reduce its trophic status with 90% certainty, which corresponds to an overall target lake concentration of 0.012 mg/L and a target concentration of 0.015 mg/L for Lacamas Creek.

Additional sources of phosphorus have emerged since 1985, and future sources can be expected. The 1985 target load levels may still be considered valid, however, because expected increases are likely minimal compared to existing loading. The land use-phosphorus loading model of Reckhow *et al.* (1980) predicts that neither recent nor future development would increase loading to the lake by significant amounts. A rough estimate shows that 441 acres of unused land would need to be developed into residential areas with septic tanks to increase phosphorus loading one percent (Appendix D). Thus, if all lands in the Lacamas Lake subbasin (Figure A-1) assessed as vacant, mixed, or open (1,575 acres) were to be developed, an increase in phosphorus loading of only 3.6% would be expected. Care should still be taken, however, to keep additional inputs of phosphorus to a minimum.

While lake restoration loading targets were specific to phosphorus, a rough correlation can be made between phosphorus loading and loading for biochemical oxygen demand (BOD) and fecal coliform. Many of the nonpoint sources of phosphorus (e.g., animal wastes or failing septic tanks) are also sources of biochemical oxygen demand and fecal coliform. Joy *et al.* (1991), in modeling the Snoqualmie River system, derived from the literature the following concentrations of phosphorus, BOD, and fecal coliform as being representative of livestock waste: 4,000 µg phosphorus/L, 90 mg BOD/L, and 30,000 fecal coliform/100 mL. Thus if phosphorus source loading to the lake were reduced 84%, as recommended by the lake restoration plan, commensurate reductions in BOD and fecal coliform might also be expected.

Whether this level of reduction in BOD and fecal coliform would be sufficient to meet water quality standards in the streams is difficult to predict. In areas where water quality criteria are close to being met (such as Upper Lacamas Creek), this level of reduction would likely be sufficient. In areas where criteria are far-exceeded (China Ditch), additional reductions would likely be necessary.

TMDL Completeness Assessment

The TMDL calculations and supporting studies element of a TMDL package has been partially satisfied for dissolved oxygen and fecal coliform for the Lacamas Creek watershed. TMDL calculations need to predict the effects of proposed reductions to meet water quality standards. More source identification work, however, is recommended on both of these parameters before submittal as TMDLs would be appropriate. No TMDL calculations have been made for either pH or temperature. The pH violations occurred in consecutive months, and may represent an instrument failure or environmental anomalies. Recent (1992-1995) data should be reviewed to determine if violations persist and whether TMDL calculations are necessary.

TMDL Element #3: Control Actions

EPA Requirements

Copies of anticipated control strategies (including farm plans, nutrient management plans, and city and county ordinances) should be provided to EPA as part of a TMDL submittal. Intergovernmental agreements that outline implementation roles and responsibilities should also be included, and supporting information should document how anticipated controls would result in attaining water quality standards. The implementation schedule should be included as well.

Work Completed in the Lacamas Creek Watershed

In 1989, after establishing an administrative framework and gathering funding, implementation of BMPs outlined in the 1985 diagnostic study began and has progressed steadily. BMPs have focused on the agricultural sector throughout the basin. This strategy appears to be most appropriate, since agricultural land use is associated with water quality degradation in the Lacamas Creek watershed. (Appendix E discusses associations between land use and water quality.) Clark County Natural Resource Conservation Service is currently drafting a report documenting BMP efforts in the watershed.

The BMPs implemented in the basin to date have been motivated by phosphorus loading concerns. However, most agricultural BMPs designed for phosphorus reductions will reduce BOD and fecal coliform as well. For example, Table 2 shows that some agricultural BMPs that reduce phosphorus loading are also expected to reduce fecal coliform loading based on summaries of available literature. Although no estimates of BOD reduction are given by this source, it is likely that BOD would also be substantially reduced by these types of BMPs.

Since 1990, over 50 agricultural BMPs have been implemented on dairies and large farms in the Lacamas watershed with assistance from the Clark County Natural Resource Conservation Service. Structures and management practices implemented include stream fencing and livestock exclusion, water troughs and tanks, manure handling (pumps, gutters, waste storage ponds, land application, runoff systems, and drystacks), channel vegetation, fish stream improvement, tree planting, and wetland and upland habitat management. The Clark County Natural Resource Conservation Service is currently revising their farm plan format, making plans more concise, consistent, and easier to use. The Service is planning on focusing future efforts on small-scale farming, although no official BMP implementation programs for these types of farms have begun.

Table 2. Nonpoint Pollution Control BMP Effectiveness Estimates (EPA, 1993a)[1]

BMP	Total Phosphorus Reduction (%)	Fecal Coliform Reduction (%)
Animal waste system (includes methods for collecting, storing and disposing of runoff and process-generated wastewater)	90	85
Filter strips (includes all practices that reduce contaminant losses using vegetative control measures)	85	55
Containment structures (includes such practices as waste storage ponds, waste storage structures, and waste treatment lagoons)	60	90

[1] based on summaries of available literature

TMDL Completeness Assessment

The EPA requirements are not fully satisfied. Current and proposed nonpoint pollution control actions need to be more fully documented.

Current levels of BMP implementation may be insufficient to demonstrate improvements in water quality. The Rural Clean Water Program has found that a majority of farmers need to participate in BMP programs in order to detect changes in water quality, based on long-term, nonpoint pollution control studies across the country. In agricultural basins, a minimum of roughly 75% of farms are needed to implement BMP systems to improve water quality significantly; in basins where dairies contribute the majority of nonpoint pollution, virtually 100% of farms must participate (Gale *et al.*, 1993). Given that several large, streamside dairies and many small farms neither have farm plans nor have implemented BMPs, a detectable change in water quality may not occur, and additional control actions (e.g., the dairy waste permitting program) may need to be implemented.

TMDL Element #4: Public Involvement

EPA Requirements

Copies of public notices or statements that public participation was conducted according to state public participation procedures should be attached as part of a TMDL submittal package. Either copies or a summary of public comments and the state's response should also be included.

Work Completed in the Lacamas Creek Watershed

Clark County Water Quality Division, which is responsible for overseeing restoration efforts in the Lacamas Lake basin, is beginning public involvement efforts. Starting with an informational kiosk in Lacamas Lake Park (adjacent to Round Lake), educational work will continue with interpretive trails and signs around the lakes. Public involvement and education efforts will also try to reach the basin's small-scale farmers through mailing and surveys, hoping to educate the public and assess actual numbers of animals in the basin. The public has direct access to the Lacamas Lake Policy Advisory Committee, which holds open meetings several times each year.

TMDL Completeness Assessment

Stronger efforts to involve the public in control actions will be required to meet EPA's expectations.

TMDL Element #5:
Monitoring

EPA Requirements

Information on the water quality monitoring program and TMDL evaluation process should be included in a TMDL submittal package. The evaluation process should include a timeline for TMDL modification, if the evaluation shows it is warranted.

Work Completed in the Lacamas Creek Watershed

Clark County Water Quality Division is scaling back its water quality monitoring program for Lacamas Creek to reserve funding for special lake studies, such as bathymetry, chlorophyll *a*, phytoplankton, and sediment. Monthly ambient monitoring will continue at selected sites, and some monitoring of BMP effectiveness in the basin is planned.

TMDL Completeness Assessment

Although EPA's requirements for monitoring may be satisfied, additional monitoring in the Lacamas Creek watershed is recommended for both ambient sampling and intensive surveys. Monthly ambient monitoring provides a data base for assessing compliance with water quality standards and performing trend analysis. Ambient monitoring should, at a minimum, include: temperature, dissolved oxygen, pH, fecal coliform, soluble reactive phosphorus, total phosphorus, ammonia, nitrate-nitrogen, total nitrogen, total suspended solids, and flow. Intensive water quality surveys would provide data for evaluating the effectiveness of specific BMP implementation projects.

Conclusions and Recommendations

To meet the requirements of a compete TMDL for Lacamas Creek, the current Lake Restoration activities need to be broadened in scope to cover all §303(d)-listed water bodies. The actions required to submit complete TMDL packages are detailed below:

Fecal Coliform and Dissolved Oxygen

The lake restoration efforts, focused on phosphorus reductions, will only partially fulfill TMDL requirements for fecal coliform and dissolved oxygen. Items that need to be completed to present EPA with a complete TMDL submittal include:

- a review of recent (1992-1995) data and a nonpoint source identification to complete the problem formulation
- more complete BMP implementation to meet water quality standards, which may include a focus on buffer strips to reduce transport of nutrients and bacteria (Todd, 1995)

- calculations demonstrating that BMP implementation will reduce loads and meet water quality standards
- increased public involvement to increase project acceptance, participation, and compliance
- a documented monitoring program to determine when water quality goals have been met or that additional control actions are needed.

Temperature

No elements of a TMDL submittal package have been completed. To present EPA with a complete TMDL package for temperature, the following actions are needed:

- review the recent (1992-1995) water quality data to update the problem formulation
- establish a target maximum temperature of 16°C in lieu of TMDL calculations
- implement control actions, such as buffer strips and riparian revegetation projects, to provide shading, and assure that the level of control actions will meet the criterion
- increase public involvement to generate project acceptance, participation, and compliance
- monitor water quality to determine when temperature goals have been met or that additional control actions are needed.

pH

Violations of pH criteria have been limited in degree and frequency. The most recent data should be evaluated; if no new pH violations have occurred, recommendations should be made for delisting, and no TMDL submittal would be required. If pH violations have recurred, all the actions described above for temperature will need to be taken to submit a complete TMDL package for pH.

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Appendix A: Land Use Data

Complete tables of basin land use are included in the following pages. Tables A1 and A2 reflect existing land use, while Tables A3 and A4 summarize assessed land use. Tables A1 and A3 list total acreage by land use for each subbasin, and Tables A2 and A4 provide the relative proportions of land uses within each subbasin. Figures A1 and A2 depict the land areas corresponding to the tables for existing and assessed land uses, respectively. Land use data sets were provided by Clark County Department of Assessment and GIS. Clark County also provided separate GIS layers of land application areas, septic systems, and some subbasin boundaries.

Assessed land use (Tables A3 and A4) represents how parcels are taxed. Residential categories were divided into residential, rural-residential, and rural, depending upon lot size. Parcels greater than one acre but not greater than five were classified as rural-residential. Smaller plots were categorized as residential; larger plots, as rural. Other classifications are self-evident. The data set is current as of March 1995.

Existing land use (Tables A1 and A2) is a modified version of assessed land use. Interpretation of aerial photography was used to enhance the tax parcel-based map. Actual land cover attributes were used for all parcels of five acres or more. In this coverage, rural-residential land may be broken down into its components: homes and yards are classified as residential, crops or grazing areas as agriculture, and woodlots as forests. The most recent fly-over was in 1990, so this data set is less current than tax parcels, but gives a more accurate picture of actual land use as it might affect water quality.

Basin boundaries were enhanced by including additional subbasin delineations, using USGS topographical maps to approximate subbasin boundaries. The subbasin delineations were digitized into the existing GIS basin boundary coverage. By intersecting the basin boundary coverage with land use coverage, actual area of each land use within each subbasin was computed.

Table A1. Lacamas Creek Watershed Existing Land Use: Total Acres by Subbasin

Subbasin Name	Forest	Vacant	Agricul-ture	Residen-tial	Park/ School	Public Facilities	Commer-cial	Industry	Roads	Unknown	Water	Total
China Ditch	1350.3	257.8	3650.7	879.3	34.8	5.9	3.0	4.8	225.6	7.6	13.7	6433.5
Upper Fifth Plain	1287.7	103.2	664.8	543.8	10.8	0.0	0.0	0.0	74.7	5.0	3.4	2693.3
Shanghai	1493.7	100.0	687.5	551.2	1.8	62.6	0.0	0.0	67.3	0.3	3.8	2968.4
Lower Fifth Plain	160.9	41.8	589.5	150.7	0.0	0.0	0.0	0.0	35.2	0.0	3.2	981.3
Upper Lacamas	5521.0	56.2	18.6	175.3	17.1	2947.7	0.5	0.0	23.9	9.5	1.4	8771.2
Matney	2622.5	135.3	575.1	659.9	0.0	27.5	4.4	0.1	160.8	0.0	1.9	4187.4
Middle Lacamas	458.1	31.0	677.7	264.2	0.1	24.2	0.4	14.0	33.0	0.0	1.4	1504.2
Lower Lacamas	1427.3	281.6	2370.9	535.7	50.0	41.8	3.9	224.5	366.2	2.9	31.4	5336.2
Lacamas Lake	1993.5	617.8	2101.2	1017.6	460.0	64.0	2.1	165.7	503.1	11.4	373.6	7309.9
Total	16315.0	1624.8	11336.0	4777.6	574.7	3173.7	14.3	409.1	1489.7	36.7	433.9	40185.4

Table A2. Lacamas Creek Watershed Existing Land Use: Percentage Land Use by Subbasin

Subbasin Name	Forest	Vacant	Agricul-ture	Residen-tial	Park/ School	Public Facilities	Commer-cial	Industry	Roads	Unknown	Water	Total
China Ditch	21.0	4.0	56.7	13.7	0.5	0.1	0.0	0.1	3.5	0.1	0.2	100.0
Upper Fifth Plain	47.8	3.8	24.7	20.2	0.4	0.0	0.0	0.0	2.8	0.2	0.1	100.0
Shanghai	50.3	3.4	23.2	18.6	0.1	2.1	0.0	0.0	2.3	0.0	0.1	100.0
Lower Fifth Plain	16.4	4.3	60.1	15.4	0.0	0.0	0.0	0.0	3.6	0.0	0.3	100.0
Upper Lacamas	62.9	0.6	0.2	2.0	0.2	33.6	0.0	0.0	0.3	0.1	0.0	100.0
Matney	62.6	3.2	13.7	15.8	0.0	0.7	0.1	0.0	3.8	0.0	0.0	100.0
Middle Lacamas	30.5	2.1	45.1	17.6	0.0	1.6	0.0	0.9	2.2	0.0	0.1	100.0
Lower Lacamas	26.7	5.3	44.4	10.0	0.9	0.8	0.1	4.2	6.9	0.1	0.6	100.0
Lacamas Lake	27.3	8.5	28.7	13.9	6.3	0.9	0.0	2.3	6.9	0.2	5.1	100.0
Total	38.6	4.7	26.9	16.1	2.9	3.3	0.4	0.7	5.6	0.1	0.6	100.0

NOTES:

Headwater tributaries are shaded. Receiving waters are indented.

Table A3. Lacamas Creek Watershed Assessed Land Use: Total Acres by Subbasin

Subbasin Name	Forest	Vacant/ Mixed/ Open	Agricul- ture	Pasture	Rural	Rural Residen- tial	Residen- tial	Parks/ Schools/ Recr	Public Facilities	Institu- tional	Commer- cial	Light Industry	Heavy Industry	Roads	Total
China Ditch	489.6	1230.5	483.7	63.6	2773.0	802.1	312.0	9.9	5.8	1.2	4.2	0.1	11.6	13.5	6200.8
Upper Fifth Plain	386.7	655.6	54.1	0.0	754.4	703.5	55.3	2.6	0.0	0.0	7.2	0.0	0.0	1.6	2621.0
Shanghai	423.3	912.4	91.9	9.7	683.7	665.6	49.2	0.0	62.6	1.8	0.0	0.0	0.0	6.0	2906.3
Lower Fifth Plain	21.8	125.5	109.2	0.0	526.5	115.0	46.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	944.7
Upper Lacamas	4743.5	376.9	0.0	0.0	307.6	250.6	99.2	0.0	2947.2	17.1	0.5	0.0	0.0	0.0	8742.5
Matney	840.0	823.5	34.5	8.7	1235.8	907.5	212.0	0.0	27.4	0.0	4.4	0.0	0.1	0.9	4094.9
Middle Lacamas	0.0	310.3	88.8	9.8	617.2	374.4	31.7	0.0	24.2	0.1	0.4	14.0	0.0	0.0	1471.0
Lower Lacamas	421.9	1712.8	466.2	542.6	977.9	487.5	224.6	17.5	71.6	9.6	8.6	11.5	230.5	1.6	5184.5
Lacamas Lake	298.6	1557.6	758.6	24.8	1534.1	956.8	569.8	372.9	64.0	46.1	29.1	25.4	140.2	13.2	6391.2
Total	7625.3	7705.2	2087.0	659.3	9410.1	5262.9	1600.6	402.9	3202.9	75.9	54.4	51.1	382.4	36.8	38557.0

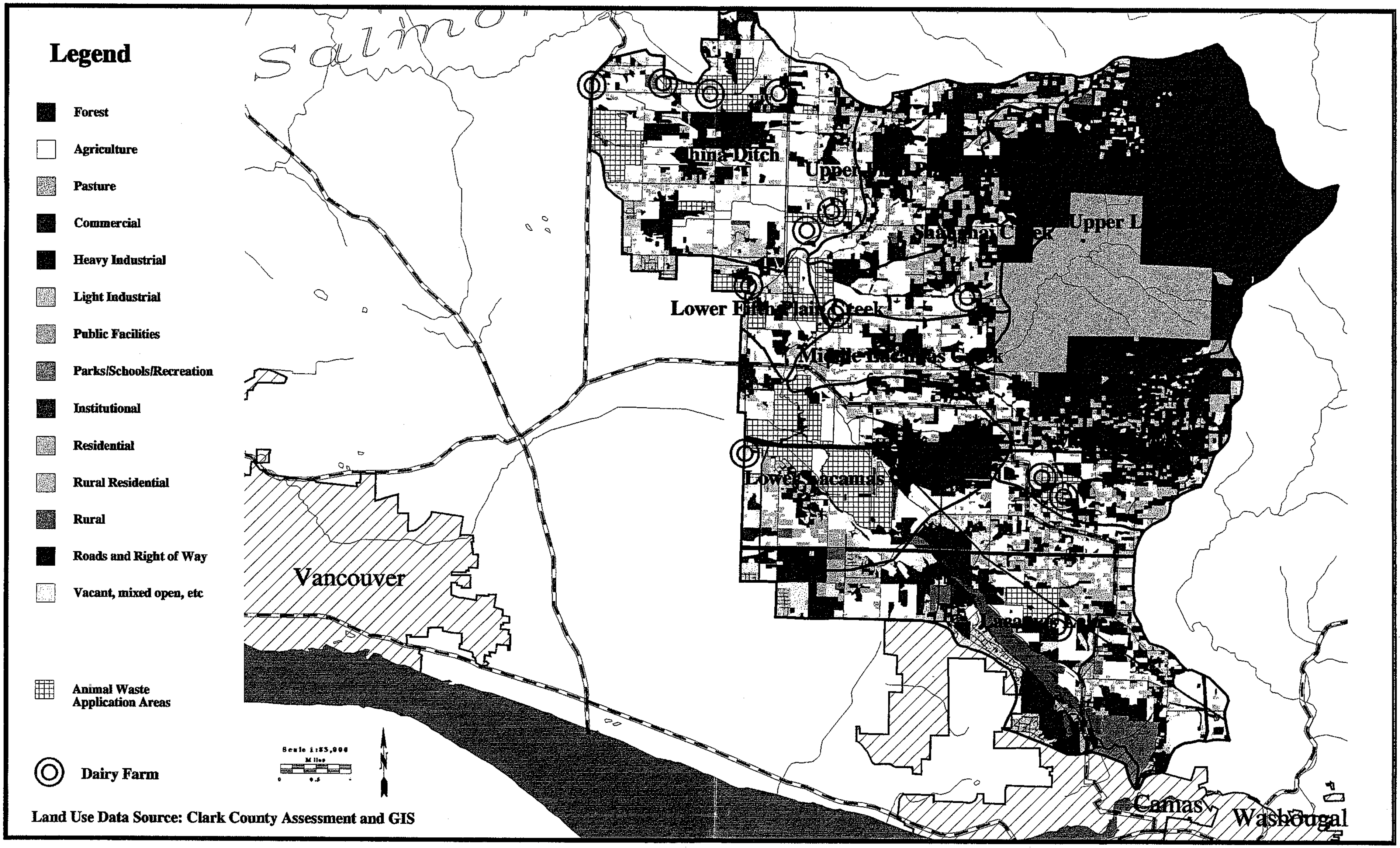
Table A4. Lacamas Creek Watershed Assessed Land Use: Percentage Land Use by Subbasin

Subbasin Name	Forest	Vacant/ Mixed/ Open	Agricul- ture	Pasture	Rural	Rural Residen- tial	Residen- tial	Parks/ Schools/ Recr	Public Facilities	Institu- tional	Commer- cial	Light Industry	Heavy Industry	Roads	Total
China Ditch	7.6	19.1	7.5	1.0	43.1	12.5	4.8	0.2	0.1	0.0	0.1	0.0	0.2	0.2	96.4
Upper Fifth Plain	14.4	24.3	2.0	0.0	28.0	26.1	2.1	0.1	0.0	0.0	0.3	0.0	0.0	0.1	97.3
Shanghai	14.3	30.7	3.1	0.3	23.0	22.4	1.7	0.0	2.1	0.1	0.0	0.0	0.0	0.2	97.9
Lower Fifth Plain	2.2	12.8	11.1	0.0	53.7	11.7	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.3
Upper Lacamas	54.1	4.3	0.0	0.0	3.5	2.9	1.1	0.0	33.6	0.2	0.0	0.0	0.0	0.0	99.7
Matney	20.1	19.7	0.8	0.2	29.5	21.7	5.1	0.0	0.7	0.0	0.1	0.0	0.0	0.0	97.8
Middle Lacamas	0.0	20.6	5.9	0.7	41.0	24.9	2.1	0.0	1.6	0.0	0.0	0.9	0.0	0.0	97.8
Lower Lacamas	7.9	32.1	8.7	10.2	18.3	9.1	4.2	0.3	1.3	0.2	0.2	0.2	4.3	0.0	97.2
Lacamas Lake	4.1	21.3	10.4	0.3	21.0	13.1	7.8	5.1	0.9	0.6	0.4	0.3	1.9	0.2	87.4
Total	19.0	19.2	5.2	1.6	23.4	13.1	4.0	1.0	8.0	0.2	0.1	0.1	1.0	0.1	95.9

NOTES:

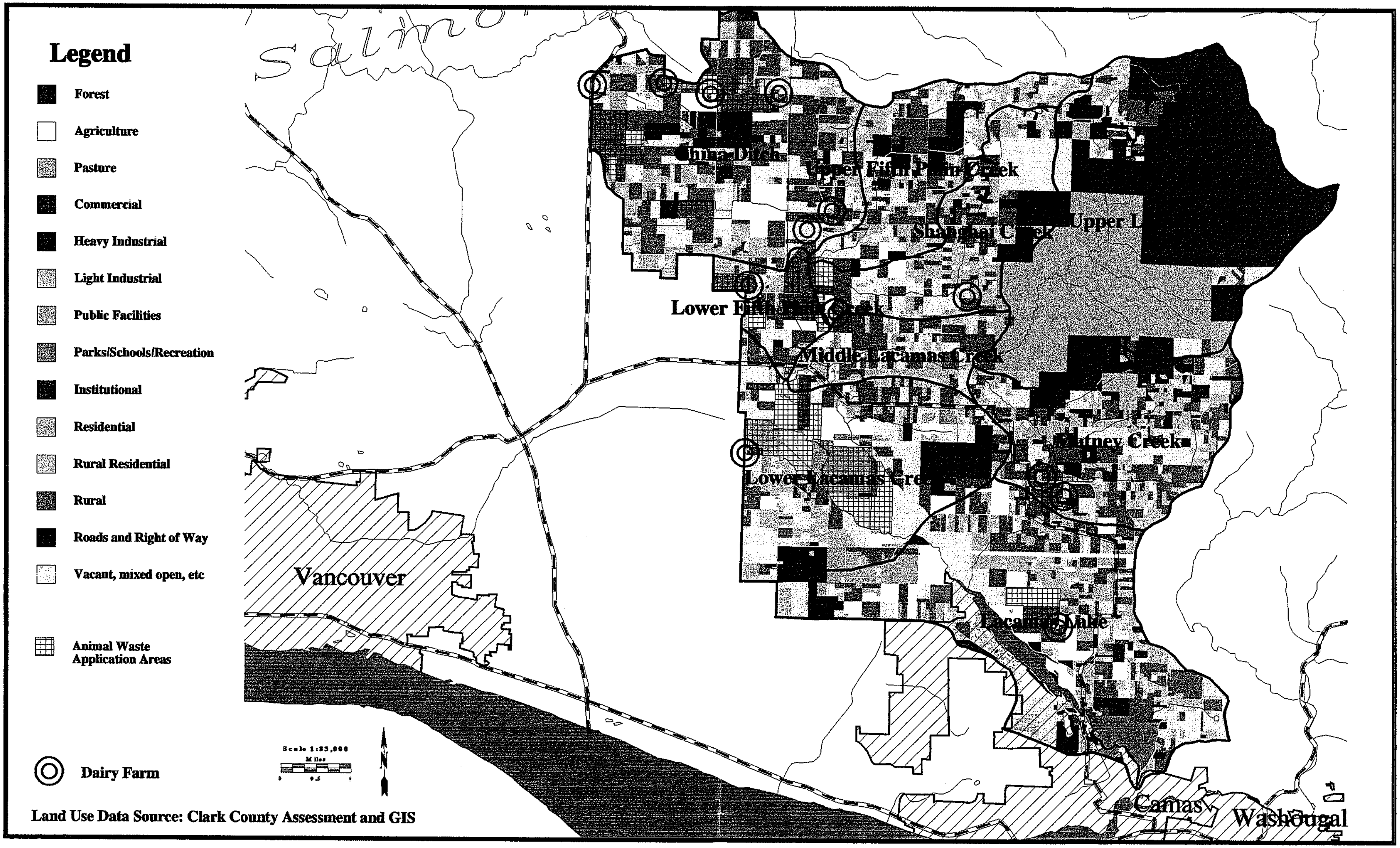
Headwater tributaries are shaded. Receieving waters are indented.

Percentages for land use are based upon total area for the subbasin, not the total assessed land. Totals therefore do not equal 100%.



Land Use Data Source: Clark County Assessment and GIS

Figure A1. Lacamas Creek Watershed, Existing Land Use



Land Use Data Source: Clark County Assessment and GIS

Figure A2. Lacamas Creek Watershed, Assessed Land Use

Appendix B: Quality Assurance

Southwest Washington Health District sampling data were obtained from Lafer (1994) and entered into the Excel spreadsheet software program. Data were verified by Clark County, and 100% of data were reviewed for entry errors by Ecology's Watershed Assessments Section. A single datum was suspect (128 mg/L total nitrogen on Upper Fifth Plain Creek) and excluded from analysis.

Field measurements for the Lacamas Lake Restoration Project (Lafer, 1994) followed equipment manufacturer's recommendations, and all laboratory analysis was performed at Clark County Water Quality Laboratory, which is accredited by Ecology. Twelve pairs of replicate samples were collected as part of the sampling program; replicate results generally demonstrate excellent precision. A pooled precision estimate for each of eight water quality variables was made by taking the root mean square of the coefficient of variation for each replicate pair (Table B1). It was assumed that replicates are distributed normally, so values were not log transformed.

Table B1. Field Replicate Precision

Parameter	# of Replicates	Root Mean Square of the Coefficient of Variation (%)
Ammonia	12	47.8
Nitrate-Nitrogen	12	6.7
Total Nitrogen	12	6.4
Soluble Reactive Phosphorus	9	2.8
Total Phosphorus	12	8.0
pH	8	1.2
Total Suspended Solids	9	7.8
Turbidity	10	4.6

With the exception of ammonia, all variables of concern had acceptable pooled variation estimates (below 10 percent). Pooled variation is strongly influenced by large outliers, which frequently occur when sample values are at or near detection limit. This was the case for ammonia; its high variation was the product of two outliers that increased the pooled variation from 8.31% to 47.80%. Therefore the precision for ammonia was also considered acceptable.

Appendix C: Correlation Statistics

Table B1 shows correlation coefficients (r) for 1991-2 data from the Lacamas Creek basin. Fecal coliform data have been omitted because bacteria were seldom sampled concurrently with other parameters. All other parameters have between 145 and 234 data pairs serving as the basis for correlation. Table B2 shows the coefficients of determination (r^2) for all sampling sites and dates. It should be noted, however, that these tables are not appropriate for use in determining the significance of relationships, since concurrent testing of multiple hypotheses vastly increases the chances of obtaining Type I (false positive) errors.

Table C1. Correlation Coefficients (r), all dates and locations for Lacamas Creek Watershed

Parameter	*NH3*	*NO3*	*TN*	*SRP*	*TP*	*DO % Sat*	*Temp*	*DO*	*TSS*	*Turbidity*	*pH*
Ammonia (NH3)	1.000										
Nitrates (NO3)	0.207	1.000									
Total Nitrogen (TN)	0.030	0.945	1.000								
Soluble Reactive Phosphorus (SRP)	0.821	0.335	0.009	1.000							
Total Phosphorus (TP)	0.533	0.263	0.034	0.799	1.000						
Diss. Oxygen Percent Saturation (DO % Sat)	-0.190	0.103	-0.003	-0.495	-0.592	1.000					
Temperature (Temp)	-0.162	-0.259	-0.260	-0.064	-0.123	-0.161	1.000				
Dissolved Oxygen (DO)	-0.065	0.192	0.110	-0.350	-0.399	0.849	-0.652	1.000			
Total Suspended Solids (TSS)	0.213	0.042	0.084	0.022	0.259	-0.017	-0.290	0.139	1.000		
Turbidity	0.165	-0.041	0.005	0.049	0.316	-0.093	-0.347	0.118	0.811	1.000	
pH	-0.167	-0.215	-0.267	-0.153	-0.295	0.086	0.712	-0.292	-0.418	-0.457	1.000

Table C2. Coefficients of Determination (r^2), all dates and locations for Lacamas Creek Watershed

Parameter	*NH3*	*NO3*	*TN*	*SRP*	*TP*	*DO % Sat*	*Temp*	*DO*	*TSS*	*Turbidity*	*pH*
Ammonia (NH3)	1.000										
Nitrates (NO3)	0.043	1.000									
Total Nitrogen (TN)	0.001	0.894	1.000								
Soluble Reactive Phosphorus (SRP)	0.674	0.112	0.000	1.000							
Total Phosphorus (TP)	0.284	0.069	0.001	0.638	1.000						
Diss. Oxygen Percent Saturation (DO % Sat)	0.036	0.011	0.000	0.245	0.350	1.000					
Temperature (Temp)	0.026	0.067	0.067	0.004	0.015	0.026	1.000				
Dissolved Oxygen (DO)	0.004	0.037	0.012	0.122	0.160	0.721	0.425	1.000			
Total Suspended Solids (TSS)	0.045	0.002	0.007	0.001	0.067	0.000	0.084	0.019	1.000		
Turbidity	0.027	0.002	0.000	0.002	0.100	0.009	0.120	0.014	0.658	1.000	
pH	0.028	0.046	0.071	0.024	0.087	0.007	0.507	0.085	0.175	0.209	1.000

Appendix D: Modeling Land-Use Based Phosphorus Loading

Reckhow *et al.* (1980) assembled phosphorus loading rate information from historical studies around the globe. This reference provides numerous examples of loading rates under varying climates, soil types, and land uses. Using this information, rough estimates of nutrient loading were made for the Lake Lacamas subbasin. To estimate loading from future and recent development, this study makes the conservative assumption that previous phosphorus loading will continue, and that by adding estimated loading from residential land use near the lake the 1985 loading target can be adjusted as needed. The two primary components to address are septic systems and residential land use.

Studies of phosphorus inputs to septic systems had both a mean and median loading rate of 1.5 kg/capita/yr (not all of which enters the lake). In 1993 Washington State passed a law limiting the phosphorus content in commercial detergents. These data represent phosphorus loading before phosphate (which contributed an estimated 50-75% of phosphorus loading) was reduced. Therefore, this study assumes an input of only 0.5 kg/capita/yr. Not all input to septic tanks reaches water bodies, however. Generally, systems must be within 20-200 meters of a lake or tributary to impact the lake. Also, much phosphorus adsorbs to charged soil particles while moving through the soil (Reckhow *et al.*, 1980).

Based on Reckhow's work and using the following conservative assumptions:

estimated 25% permeation (25% of septic input reaches water bodies)
estimated 3 people per home
estimated 2 homes per acre
measured 24.6% of land within 200 meters of the lake or a tributary

the following equation generates a loading rate in kg/acre/yr.

(0.5 kg/capita yr) x (0.25 permeation) x (3 people/home) x (2 homes/acre) x
(0.246 proximity) = 0.18 kg/acre/yr from septic systems.

To estimate phosphorus loading from residential land use, studies of suburban and residential areas receiving similar amounts of rainfall as the Lacamas basin were considered. The three studies that most closely matched the Lacamas basin had loading rates of 0.43, 0.21 and 0.6 kg/ha/yr. The mean of 0.41 kg/ha/yr (0.16 kg/acre/yr) was used for this analysis.

Total phosphorus loading from development to the lake was then modeled by adding the expected impacts of septic systems and residential land use, for a total loading of 0.34 kg/acre/yr.

Lacamas Lake currently has a load of over 15,000 kg of phosphorus per year. Developing all available lands (all lands assessed as vacant, mixed or open, 1,575 acres) represents an increase in phosphorus loading of 3.6%. This small relative increase does not pose a significant risk to the lake. Also, sewer lines currently extend to the southern shore of Lacamas Lake, and may expand over time as residential growth continues.

Efforts should still be made to control phosphorus runoff from lake-side development. Near-lake development represents a loading source easily controlled by sediment BMPs, and loading from improperly designed or maintained septic tanks could have immediate impacts on the lake.

Appendix E: Land Use and Water Quality

While the information base for the Lacamas Creek Watershed is too small to permit powerful statistical analysis, quantitative assessments are possible using methods outlined in Hutton (1994). Those methods include using Spearman correlation coefficients for detecting associations between land use and water quality. In the East Fork of the Lewis River drainage (just north of Lacamas), strong associations were found between forestry, agriculture, and water quality. Temperature and nutrient levels were significantly lower in heavily forested subbasins, and dissolved oxygen levels were significantly higher. Agriculture had opposite impacts: it had strong positive correlations with nutrients and temperature, and a strong negative correlation with dissolved oxygen (Hutton, 1994).

Applying Spearman correlation analysis to the Lacamas Creek headwaters produces very similar results, but the sample size is too small to establish associations with confidence. Instead of quantitative analysis, this section focuses on graphic presentation of data trends. Figures D1 through D3 contrast water quality data with existing land use. The five headwater subbasins are aligned from left to right in order of the predominance of agriculture, which also mirrors their geographic configuration from west to east.

Despite their differences in land use, all five subbasins have similar ranges and distributions of water quality data, with the exception of China Ditch. China Ditch, dominated by agricultural usage, stands out on almost every graphic: its dissolved oxygen levels are much lower than any other subbasin (Figure D1), and its nutrient levels dwarf those of other subbasins (Figures D2 and D3). The data suggest the predominance of agriculture and the absence of forested buffers has led to water quality degradation in China Ditch. Originally Clark County targeted BMP efforts on agriculture, and the above trends well justify that initial approach.

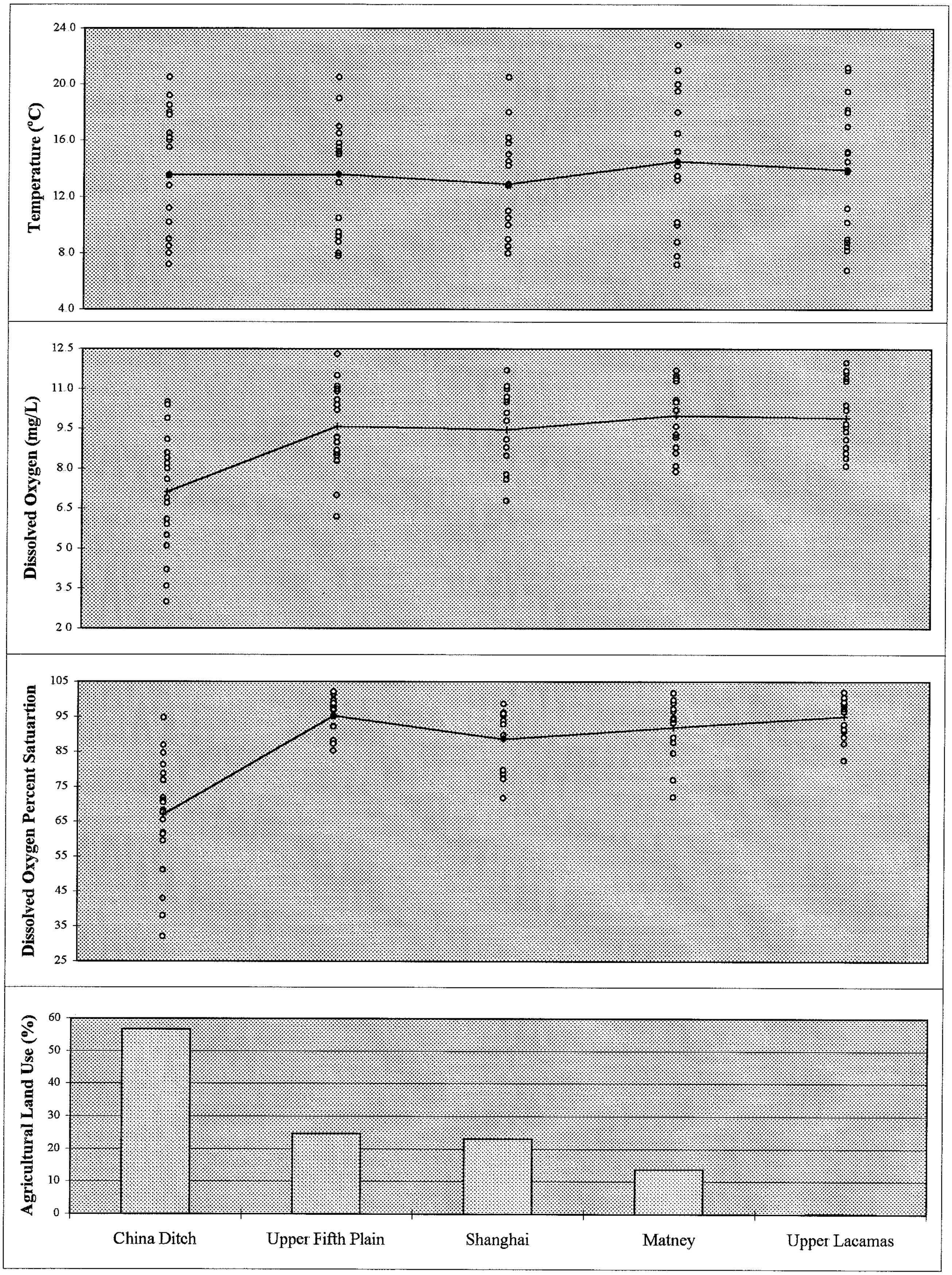


Figure E1. Temperature, Dissolved Oxygen and Existing Land Use.

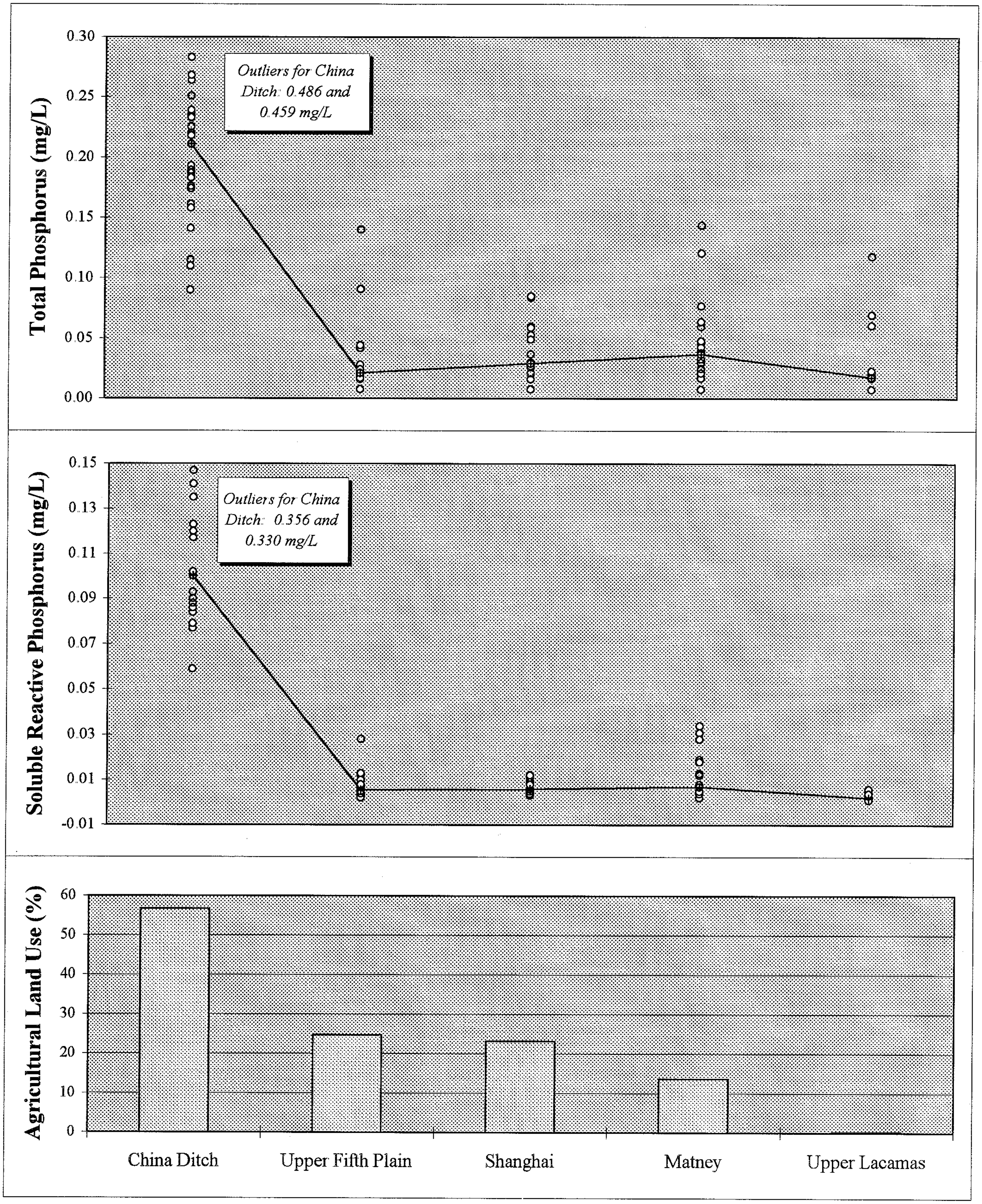
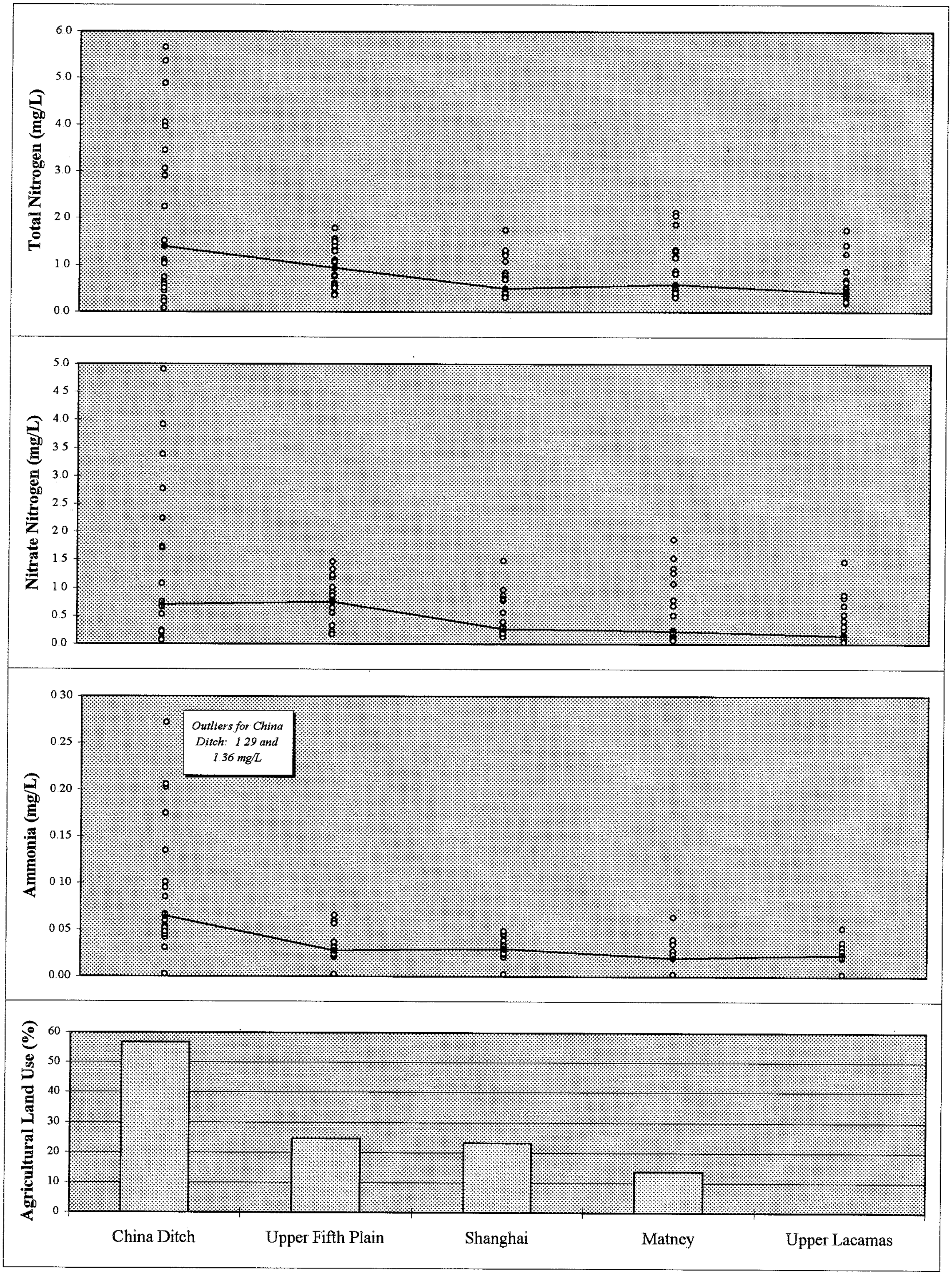


Figure E2. Phosphorus and Existing Land Use.



Outliers for China Ditch: 1.29 and 1.36 mg/L

Figure E3. Nitrogen and Existing Land Use