Land Cover Analysis

Although various land uses are associated with particular activities that may influence water resources, it is the land cover (the type of vegetation or impervious surface) that affects how precipitation reaches the ground surface. Land cover information was assessed for the portions of the identified subbasins lying within Fort Lewis boundaries. Figure 3.3-2 illustrates the current land cover in the portions of the Murray/Sequalitchew watershed within the jurisdictional boundaries of Fort Lewis. This information was developed from geographic information system (GIS) data provided by Fort Lewis (Hall 2005) and was limited to areas within the Fort Lewis study area. Although Pierce County has its own land cover classification system, for the purposes of this analysis, the land cover in portions of the subbasins beyond the Fort Lewis boundary was labeled as unclassified. Table 3.3-3 provides the land cover acreages within each subbasin, and Table 3.3-4 presents the same information as the percentage of each land cover type relevant to the total subbasin area within the Fort Lewis study area.

Table 3.3-3 Land Cover Areas (acres) Within the Murray/Sequalitchew Watershed Study Area.

Subbasin	Developed Area	Forested Area	Grassland	Lake	Light Coniferous [a]	Mixed Grassland & Light Coniferous	Recreation Uses	Wetland	Other Unclassified Area [b]
Upper Murray	2	2,263	297	1	0	33	0	75	568
Middle Murray	185	984	66	0	9	16	26	18	0
Lower Murray	485	589	122	1	133	103	0	17	287
American Lake	499	413	12	1,087	134	44	42	16	3,919
Sequalitchew	2,051	2,326	829	81	171	221	72	130	89
Total	3,222	6,575	1,326	1,170	447	417	140	256	4,863

[a] Light coniferous is urban forested areas.
[b] The subbasin areas beyond the Fort Lewis boundary were labeled as unclassified because land use information for these areas was grouped according to a different classification.

Table 3.3-4 Land Cover Percentages Within the Murray/Sequalitchew Watershed Study Area.

Subbasin	Developed Area	Forested Area	Grassland	Lake	Light Coniferous	Mixed Grassland & Light Coniferous	Recreation Uses	Wetland	Other Unclassified Area [a]
Upper Murray	0.1	69.9	9.2	0.0	0.0	1.0	0.0	2.3	17.5
Middle Murray	14.2	75.5	5.1	0.0	0.7	1.2	2.0	1.4	0.0
Lower Murray	27.9	33.9	7.0	0.1	7.7	5.9	0.0	1.0	16.5
American Lake	8.1	6.7	0.2	17.6	2.2	0.7	0.7	0.3	63.6
Sequalitchew	34.4	39.0	13.9	1.4	2.9	3.7	1.2	2.2	1.5
Total	17.5	35.7	7.2	6.4	2.4	2.3	0.8	1.4	26.4

[a] The subbasin areas beyond the Fort Lewis boundary were labeled as unclassified because land use information for these areas was grouped according to a different classification.

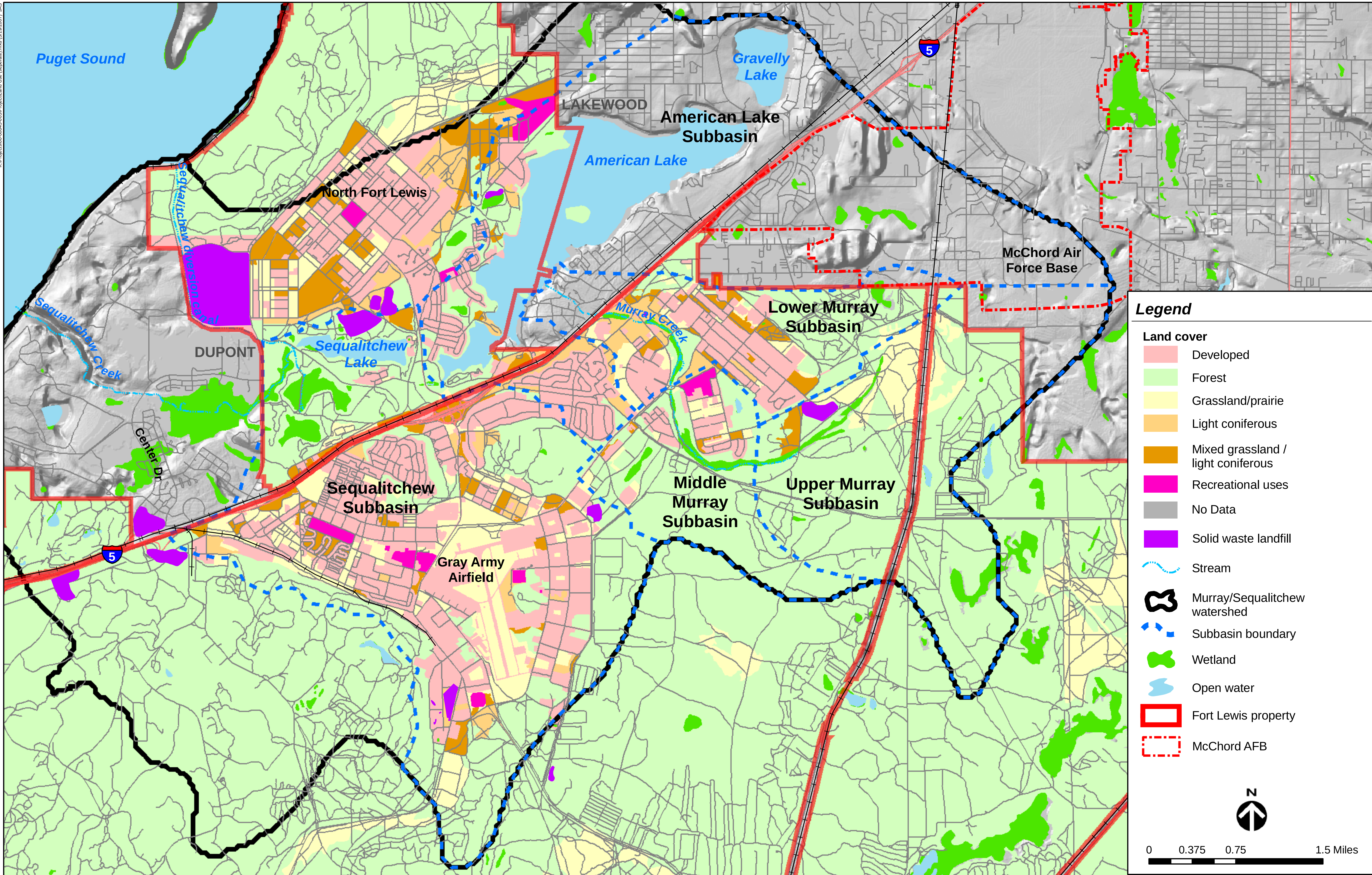

Figure 3.3-2 Existing Land Cover Within the Fort Lewis Jurisdictional Area of the Murray/Sequalitchew Watershed.

Information on land cover and land use was used to provide an estimate of the total and effective impervious area for the portions of the subbasins located within the Fort Lewis boundary. The total impervious area is the sum of the paved or hard surfaces, such as rooftops and parking lots, within each subbasin. The effective impervious area is the sum of those impervious areas that drain directly to the storm drainage network. Lowering the percentage of effective impervious area can help to mitigate the instream impacts of high volumes of runoff during storms.

For each subbasin, digitized aerial photographs (U.S. Geological Survey [USGS] 2002) and a GIS shapefile of the storm drainage network were used to determine the imperviousness of randomly sampled areas within each land use category. This information was used to provide estimates of the percent total impervious area and effective impervious area for each land use category and each subbasin. For instance, the land use labeled as *housing* in the GIS data was found to be characterized by about 60 percent total impervious area, nearly all of which is effective impervious area directly connected to the drainage system. About 40 percent of the *housing* land use is pervious area.

A subsample was made of the land cover category labeled as *developed* in the GIS data. This category is widely dispersed throughout the cantonment area. Although the developed land cover was found to have 100 percent total impervious area, only about 40 percent of that impervious area is effective impervious area directly connected to the storm drainage network. The summary of the total impervious area and effective impervious area percentages in the developed land use categories is shown in Table 3.3-5.

Table 3.3-5 Percentages of Total Impervious Surface Area and Effective Impervious Surface Area for Various Land Use Categories.

Land Use Category	Percentage of Total Impervious Area	Percentage of Effective Impervious Area
Developed	100.0	38.0
Housing	58.4	57.7
Recreation	67.1	41.3
Schools	35.2	0.0 [a]

[a] GIS maps of storm sewers show no connections to school property.

The derived percentages of total impervious area and effective impervious area for the land use categories were then applied to the percentages of the subbasins dedicated to those particular land use and land use categories. In this way, the effective impervious area and total impervious area percentages could be estimated for the portions of the subbasins located within Fort Lewis (Table 3.3-6). Portions of the subbasin beyond the installation boundary were not factored into these percentages.

Throughout the watershed, the effective impervious area percentages increase as one moves downstream (generally west) because most of the development and storm drainage networks are located in the western portion of the watershed. Therefore, the Upper and Middle Murray Creek subbasins have less effective impervious surface than the American Lake and Sequalitchew subbasins, which are more likely to be adversely affected by runoff from developed areas. Degraded habitat and water quality conditions occur where untreated runoff is conveyed directly from developed areas to surface water bodies within the watershed.

Table 3.3-6 Percentages of Total Impervious Surface Area and Effective Impervious Surface Area Within the Study Subbasins.

Subbasin	Percentage of Total Impervious Area	Percentage of Effective Impervious Area
Upper Murray	0.1	0.0
Middle Murray	15.3	7.4
Lower Murray	33.3	12.5
American Lake	20.6	15.6
Sequalitchew	33.7	17.3

Note: The subbasin areas beyond the Fort Lewis boundary are not factored into these percentages.

Land Use Characterization by Subbasin

Upper, Middle, and Lower Murray Subbasins

The Upper, Middle, and Lower Murray subbasins encompass approximately 6,280 acres. These subbasins are located almost entirely within the Fort Lewis boundary, with small portions contained within the City of Tillicum and McChord Air Force Base. The Murray subbasins receive runoff from MAMC, the Joint Reserve Center, the Special Forces compound, and the Evergreen housing development, which are all served by stormwater facilities that detain and treat stormwater runoff (Shapiro 1997a).

Much of the Upper Murray subbasin is undeveloped, with mixed coniferous-deciduous forest stands as land cover. Additionally, there are several secondary dirt roads located in the northern portion of the watershed that are used for Reserve Officer Training Corps (ROTC) training exercises (Shapiro 1997a).

American Lake Subbasin

Military land use (including Camp Murray, Fort Lewis, and McChord Air Force Base) comprises approximately 90 percent of the total area draining to American Lake (Woodward-Clyde 1997a). Much of this military land use is located in the subbasin draining directly to the lake, as shown in Figure 3.3-2. The land bordering the east side of American Lake has undergone extensive development. As part of a 1993 lake restoration study, a shoreline and sanitary survey analysis was conducted to identify which land uses surrounding American Lake could be impacting water quality (KCM 1993). Some problematic land uses that were identified included lakeshore construction activities, lakeside lawns and the nearby golf courses, as well as the extensive road network within the lake's drainage basin. The surrounding residential areas in Lakewood, which rely on on-site septic systems for wastewater treatment, were identified as potentially problematic. Many of these land uses could affect the quality of ground water. Because ground water flows from east to west towards the lake, polluted ground water would have a large impact on the lake and its many recreational activities, such as fishing, golfing (along the shoreline), swimming, boating, and waterskiing.

Sequalitchew Subbasin

The total drainage area of the Sequalitchew subbasin within Fort Lewis (Figure 3.3-2) is 5,970 acres, or 9.3 square miles. The diversion dam built by Fort Lewis around 1950 is located at the headwaters of Sequalitchew Creek, just as it emerges from Sequalitchew Lake. Land use near Sequalitchew Lake includes the Fort Lewis water treatment plant on Sequalitchew Springs, just east of Sequalitchew Lake, and a small complex of buildings used to store supplies and home and yard maintenance equipment located to the southeast side of the lake. There are several roads near Sequalitchew Lake that are used by the military and by recreational fishermen (ENSR 1998a). Downstream of Sequalitchew Lake, Sequalitchew Creek continues as a nearly level and slow-moving channel across its 1-mile reach through Fort Lewis. The creek feeds a major 130-acre wetland called Edmond Marsh, which is located between Fort Lewis and the City of DuPont (Andrews and Swint 1994).

The City of DuPont continues to plan and develop its Northwest Landing mixed-use community along Sequalitchew Creek for the land uses indicated in Table 3.3-7 (DuPont 2005). This community population, when added to the City, will be composed of the land uses indicated in Table 3.3-7. DuPont’s population in 2005 is estimated to be about 5,300.

Table 3.3-7 Planned Land Use for the City of DuPont.

Land Use	Area (acres)	Percent of Total
Residential Areas	1,048	28
Business Areas	1,039	28
Parks, Recreation & Sensitive Areas	1,144	30
Public Facilities	524	14
Total	3,755	100

Source: City of DuPont (2005).

3.3.3 Current and Proposed Development

Other land use changes are expected throughout the Murray/Sequalitchew watershed. Fort Lewis has developed a strategy to address the development and locating of certain land uses within the Fort. The *Fort Lewis Real Property Master Plan, Volume I* (U.S. Army 1997a) includes a discussion of projected land use changes for each area. Some of the planning objectives listed in the Master Plan include enhancement of training, elimination of land use conflicts, creation of a responsive living environment, and preservation of unique installation features. Land use planning issues that have arisen over time include changes in the type and size of military equipment used on the installation, automobile impacts, single soldier housing needs, command and control facility needs, and long-term needs for power production.

Strategic planning objectives include the following:

- Developing part of North Fort Lewis into a troop complex for the U.S. Army Corps of Engineers (USACE) and selected tenant units. This will be driven by the new units to be stationed at Fort Lewis as part of the Army's recent redeployment efforts.

- Renovating and extending the existing division area.

- Converting garrison area barracks, headquarters, and motor pools into administration and community support facilities.

- Redeveloping the Logistics Center to integrate state-of-the-art maintenance, storage, material handling, deployment, and transportation facilities into an industrial area that simultaneously supports ongoing maintenance and logistics support activities.

- Actively and continuously pursuing improved utilization and creative revitalization of existing structures and facilities.

- Providing for construction needs of present and potential tenants by designating an area for industrial development and providing a logical basis for expansion within that area.

- Integrating non-appropriated fund community support activities within the master plan framework.

Landscape development at Fort Lewis is governed by a landscape development plan (USACE 1996) that consists of three sections:

- The analysis and evaluation section, which identifies the character-defining landscape features that describe the historical Fort Lewis landscape.

- The design development section, which consists of general and detailed design recommendations for planting and nurturing of historical vegetation.

- The historical landscape presentation section, which provides Fort Lewis staff with guidelines and strategies for maintaining vegetation and traffic and pedestrian circulation features in the historic district.

Other land use changes are expected in the City of DuPont as the Northwest Landing development nears completion (City of DuPont 2005) and the existing Glacier Northwest aggregate production facility in DuPont undergoes expansion. Throughout the planning and development of these projects, local residents and environmental advocacy groups have expressed their concerns for preservation of the rare natural landscape in the vicinity of Sequalitchew Creek. In response, the City of DuPont (1994) comprehensive plan update recommended a measure to change the "urban window" along the creek and Puget Sound shoreline to a conservancy zone. This change eliminated the planned use of the north bluff of Sequalitchew canyon for gravel conveyor belts, thus potentially reducing the effects on local wildlife (Andrews and Swint 1994).

3.3.4 Data Gaps

A comprehensive land use and land cover analysis has not been completed for the entire Murray/Sequalitchew watershed. Similar to previous studies, the present study has gathered land use information with a particular focus on the subbasins described in this plan. This would be an improvement over simply showing developed areas on maps, as at present. In order to support watershed-wide analyses of the potential pressures on water resources related to land use differences, an overall effort could be made to classify land uses within the installation according to the Pierce County land use classification scheme. This would enable preparation of a broader assessment of land use effects on receiving waters throughout the watershed, similar to what is documented above in section 3.3.2 for areas within Fort Lewis. Many land uses within the Fort Lewis cantonment area, such as commercial or recreational uses, could easily be matched to a similar land use category used by Pierce County. Other land uses, such as those occurring within training areas, would be specific to Fort Lewis and would remain as unique classes.

For an overall land cover assessment, Landsat satellite imagery could be used with the Hill et al. (2003) land cover classification categories applied. The 1998 Landsat satellite imagery covers Pierce County, as well as Fort Lewis.

We are not aware of any ongoing or proposed studies or research projects related to land use within the Murray/Sequalitchew watershed.

3.3.5 Key Land Use Issues

A key land use issue is preserving the installation as a combat training facility, while protecting the Murray/Sequalitchew watershed. Fort Lewis manages its land as needed to meet military training objectives, which will require redevelopment within the cantonment area and expanded activities within training areas as the military population and training needs increase.

Another key issue is the need to formalize many of the policies that are currently in place to reduce the impacts of development. Additional protective measures, such as the 50-meter buffer zone around wetlands and streams, established by Army Regulation 200-1 (U.S. Army 1997b), should be encouraged. Stormwater BMPs containing infiltration components are currently being used in new residential developments. The use of similar BMPs should be encouraged when retrofitting existing facilities. Additional measures that are in use, but that have not been officially noted should be identified and added to the appropriate development codes and regulations and tracked upon implementation. These steps will simplify the quantification of their benefits to water quality. Without formal adoption of these policies, their benefits may be lost if there is a change in the personnel involved in their conception and implementation.

3.3.6 Potential Solutions for Land Use

All potential solutions to land use issues should be consistent with the *Fort Lewis Real Property Master Plan*, *Volume I* (U.S. Army 1997a), the *Landscape Development Plan* (USACE 1996), and other strategic plans for land use or natural resources management, to ensure compatibility.

Potential solutions include the following:

- The environmental policies and actions that Fort Lewis is taking to protect water resources are described in numerous documents, including environmental assessments, management plans, Fort Lewis regulations, and the Sustainability Implementation Plan. Formalizing the following policies in a single document would ensure awareness and continuity of these effective measures in the event that personnel changes occur:
    - Enforce and protect (e.g., by means of increased signage) buffer zones (50 meters) established around sensitive areas.
    - Prohibit additional runoff from future development, to add formal enforceability to support this further.
    - Preserve trees and existing vegetation during new construction.
- Incorporate low-impact development techniques as temporary or obsolete buildings are modified or replaced with permanent ones:
    - Seek use of porous pavement in parking areas where appropriate.
    - Investigate removing curbs and allowing runoff to reach permeable areas, thus reducing effective impervious surface area (curb cuts may be an option in some locations).
    - Remove downspout connections to the storm drain network, and locally disperse roof downspout runoff to encourage infiltration to the soil where appropriate.
- Continue to encourage collaboration and coordination among stakeholders in the land use planning process.
- Continue to incorporate into the GIS database the as-built information on existing low-impact development facilities.

- Use GIS tools to implement land use categories equivalent to Pierce County boundaries, which would allow whole-watershed land use analysis.

3.4 Surface Water Resources

Protecting the quantity and quality of surface waters within the Murray/Sequalitchew watershed is integral to the many aquatic uses within the watershed. Surface water resources are important for maintaining ecosystem health and supporting both aquatic (i.e., salmon) and terrestrial biology (i.e., forest stands). In addition, American Lake is host to a variety of recreational uses including swimming, fishing, and boating.

This section describes existing and historical conditions of surface water quantity (flow) and quality within the Murray/Sequalitchew watershed. Ground water, marshes, geomorphology, and fish habitat are briefly addressed here where appropriate (other sections of this plan discuss these topics in greater detail). This section also addresses ongoing and proposed efforts by Fort Lewis and other stakeholders within the watershed to protect surface water quality and quantity, fill data gaps, and address problems that threaten the water resources.

3.4.1 Historical Surface Water Conditions

Historical information on surface water quantity and quality within the Murray/Sequalitchew watershed was compiled from various studies and supplemented or clarified through conversations with Fort Lewis staff.

The oldest study for which comprehensive water quality information was collected and documented was for a survey completed by the Washington Department of Social and Health Services (WDSHS). Conducted between November 1980 and January 1981, this survey of surface water and ground water quality was completed for the entire Chambers Creek/Clover Creek drainage basin in Pierce County after ground water used for drinking supply in the area was found to contain contamination in increasing amounts. Of the 21 creek sample locations, sites relevant to the Murray/Sequalitchew watershed include one on Murray Creek at Camp Murray, and another on Sequalitchew Creek at the outlet of Sequalitchew Lake. Five samples were taken at each of these sites. One sample also was taken from American Lake, and one from Sequalitchew Lake. All samples were "grab" samples, meaning discrete samples of water taken at one point in time, rather than composite samples.

For the creek locations, the monitored parameters included turbidity (measured in nephelometric turbidity units, or NTU), total suspended solids (TSS, milligrams per liter [mg/L]), chemical oxygen demand (COD, mg/L), total ammonia-nitrogen (mg/L), nitrite-nitrogen (mg/L), nitrate-nitrogen (mg/L), orthophosphate-phosphorus (mg/L), total phosphate-phosphorus (mg/L), chloride (mg/L), and fecal coliform bacteria (colonies per 100 milliliters [mL]). For the lake sites, monitored parameters included color (units), total ammonia-nitrogen (mg/L), nitrite-nitrogen (mg/L), nitrate-nitrogen (mg/L), orthophosphate-phosphorus (mg/L), total phosphate-phosphorus (mg/L), chloride (mg/L), and fecal coliform bacteria (colonies per 100 mL; WDSHS 1981). The results from this study are discussed in the following subsections.

Murray Creek

Murray Creek streamflow originates from springs and seeps at the toe of slope areas along the upper reaches of the creek near Kinsey Marsh. Throughout much of the length of the creek there is high hydraulic connectivity with ground water. Base flow is strongly influenced by the amount of ground water seepage into and out of the creek.

Hydrology

Discharge monitoring data from 1987 (Robinson and Noble, Inc.) show that Murray Creek gained approximately 80 percent of its base flow between a monitoring location in the Upper Murray subbasin and a monitoring location in the Middle Murray subbasin. Approximately 50 percent of the flow was lost between monitoring sites located in the Middle Murray and the Lower Murray subbasins.

Shapiro (1996) expanded on information on the ground water/surface water relationship. Similar to results of Robinson and Noble, Inc. (1987), the stream channel in the Upper Murray subbasin (including Kinsey Marsh) was identified as a perennially gaining reach, meaning that it receives base flow from shallow ground water year-round. Portions of the stream channel in the Middle Murray subbasin were identified as perennially gaining and mixed, meaning the channel alternately loses base flow to ground water and receives base flow from ground water at different times of the year. The stream channel in the Lower Murray subbasin was identified as a perennially losing reach.

Flow rates were measured in Murray Creek during 1995 and 1996 as part of the Fort Lewis Surface Water Program. Flows were measured at three stations: at the headwaters at Kinsey Marsh (monitoring station Murycr03), at the Interstate 5 crossing of Murray Creek (monitoring station Murycr02), and at American Lake (monitoring station Murycr01; Shapiro 1996). Table 3.4-1 summarizes the measured discharge rates at each station. The Shapiro study found that streamflow patterns for Murray Creek are typical of lowland western Washington streams, with the highest flows occurring between November and March, and low flows during the summer, sustained by ground water base flow.

The Shapiro (1996) study attributed the loss in streamflow in 1996 to drawdown in the surface aquifer resulting from pumping wells for the cooling system at MAMC that increased the seepage rate through the stream channel. The study concluded that increased impervious area within the watershed was not significantly affecting flow rates in the creek.

Observed flow rates at the downstream station (American Lake) and the upstream station (Interstate 5) are consistent with findings that the section of Murray Creek between Interstate 5 and the downstream outlet to American Lake is typically a losing reach (Shapiro 1996). Flows decreased between Interstate 5 and American Lake during all sampling events, except on April 8, 1996, and August 22, 1996. It is unclear why flows between the two stations were not observed to decrease during these two sampling events.

Table 3.4-1 Flow Rates Recorded at Three Murray Creek Monitoring Stations by the Fort Lewis Surface Water Program (cubic feet per second).

Date	Monitoring Station		
	Upstream Station Murycr03 (Kinsey Marsh)	Murycr02 (Interstate 5)	Downstream Station Murycr01 (American Lake)
April 24, 1995	2.4	4.3	3.8
July 25, 1995	0.6	0.6	0.1
January 18, 1996		3.7	3.5
February 28, 1996	7.9	11.4	8.2
April 8, 1996	6.4	9.1	9.5
June 11, 1996	2.5	6.4	0.9
July 7, 1996	2.0	4.9	3.9
August 22, 1996	1.0	3.2	3.5

Source: Shapiro (1996).

Hydraulic Structures/Channel Modifications

As part of a study aimed at identifying alternatives for restoring base flow to Murray Creek, Herrera Environmental Consultants completed a field reconnaissance in January 1998 that included observation of existing culverts. Most of the culverts along Murray Creek were inadequately sized, with water accumulating upstream of the culverts (ENSR 1998b).

Murray Creek was disturbed by sewer repair activities at a sewer crossing located near Interstate 5 in the early 1990s. Sewer line repair activities, that were performed at this location between October 1990 and May 1993, reportedly resulted in removal of streambed materials from approximately 100 feet of the creek channel immediately upstream of Interstate 5. According to the USACE, fine-grained sediments were largely removed from this length of the stream, and subsequent localized stream water loss was observed (Satter 1996). Streambed restoration along the impacted area was conducted in November 1995 to replace the fine-grained sediments along the impacted section of the creek and improve the marsh/wetland area near the Interstate 5 crossing of the creek. However, natural siltation had replaced the lost sediments, effectively reducing the loss of streamflow through the channel bottom (Shapiro 1996).

Water Quality

The WDSHS found that Murray Creek met the Washington state Class A standards for temperature, turbidity, fecal coliform bacteria, and dissolved oxygen. Observed nitrate-nitrogen concentrations were high enough to support algal blooms where phosphate concentrations also were adequate for algal growth. However, phosphate concentrations were low, limiting algal bloom potential at that time (WDSHS 1981).

Temperature

Temperature data collected in the early 1990s indicate that water temperatures for August and September in Murray Creek ranged between 51°F and 58°F. Sampling conducted in January 1998 found stream temperatures of 48°F, 50°F, and 52°F for locations at the headwaters, the Interstate 5 culvert, and the mouth at American Lake, respectively (ENSR 1998b).

Previous base flow restoration studies for Murray Creek have noted the potential impacts that flow augmentation might have on Murray Creek stream temperatures. Cooling water used by MAMC is currently held in ponds before infiltrating to ground water. Temperature is the primary water quality constituent of concern limiting use of this discharge to augment Murray Creek base flow. When water is discharged from the MAMC cooling system into the cooling ponds, its temperature is approximately 70°F (ENSR 1998b), which exceeds Washington state standards. Although the ponds likely achieve adequate cooling of the MAMC discharge during the fall and winter months, summer air temperatures potentially prevent the cooling ponds from sufficiently reducing water temperatures to levels that comply with state water quality standards. The water temperature would need to be within 4°F of the water temperature of Murray Creek to meet the state standards for flow augmentation discharge during the summer months (WAC 173-201A).

Nutrients

In 1998, it was observed that the cooling ponds at MAMC contained algae growth, which was attributed to excess nutrient concentrations. Although avian fecal matter and fertilizers used in MAMC landscaping were considered potential nutrient sources, they were deemed incapable of producing a high enough nutrient load in the MAMC water to make it unsuitable for discharge to Murray Creek (ENSR 1998b).

Toxic Pollutants

An evaluation was made for restoring base flow to Murray Creek by routing discharge from the pump and treat system treating the solvent plume under the Logistics Center (ENSR 1998b). However, this alternative could potentially introduce trichloroethylene (TCE) to the stream. At the time the evaluation was made, no USEPA standards existed for a recommended lowest observed effect level (LOEL) for TCE. However, the federal standard for the maximum contaminant level that can be present in drinking water is 5 parts per billion (ppb), or 0.005 mg/L, with a maximum contaminant goal of 0.0 (Code of Federal Regulations, 40 CFR 141.61). Quarterly testing of water leaving the TCE treatment system found that effluent generally had concentrations between 0.5 and 1.5 ppb.

Continued sampling would be necessary to ensure that such a discharge to Murray Creek from the pump-and-treat system meets federal standards for drinking water, because Murray Creek is highly connected to local ground water, which serves as the drinking water source for the area. In addition, the discharge would need to meet water quality criteria for surface waters.

American Lake

Murray Creek discharges to American Lake, the largest natural lake in Pierce County. American Lake has a surface area of approximately 1,100 acres, 12 miles of shoreline, and an average depth of 53 feet. The lake volume is approximately 60,000 acre-feet (Woodward-Clyde 1997a).

Hydrology

The annual inflow volume to American Lake is estimated at approximately 25,451 acre-feet, consisting of 65 percent ground water, 15 percent precipitation, and 20 percent streamflow. Approximately 90 percent of the outflow from American Lake is through seepage into the aquifer along the western shoreline, with evaporation accounting for the remainder of water loss from the lake (Woodward-Clyde 1996).

According to Fort Lewis personnel and aerial photographs, American Lake had no surface water outlet prior to the 1960s, when an overflow to Sequalitchew Lake was constructed (Johnston 2005). The overflow consists of a weir constructed and managed by Pierce County (Crown 2005a). The weir overflows to a channel, which is connected via a culvert to an unnamed stream that flows into the southeast corner of Sequalitchew Lake (Shapiro 1997a). The weir is designed to overflow to Sequalitchew Lake if the level of American Lake rises significantly, but Fort Lewis personnel were unaware of any overflows to Sequalitchew Lake in the recent past (Crown 2005a).

Water Quality

The WDSHS study (1981) found that American Lake was phosphorus-limited for algae growth, based on a total inorganic nitrogen to orthophosphate-phosphorus ratio greater than 10. American Lake had low nitrate and phosphate concentrations, relative to other lakes, making it less at risk for algae blooms. The report noted that American Lake exhibited good water quality, and that lake water quality results were generally in agreement with results obtained by U.S. Geological Survey samples on American Lake in the early 1970s.

Despite the findings by WDSHS that American Lake was at low risk for algal blooms, there have been documented toxic algal blooms in the lake's recent history. The first documented toxic algae bloom occurred in November 1989 and continued through February 1990. Eleven animals were reported to have been poisoned, and five of them were killed. The toxic blue green algal species was determined to be anabaena and the toxins produced were determined to be anatoxin A (a neurotoxin) and a hepatotoxin (a liver toxin) (KCM 1993, Woodward-Clyde 1996). A study completed by KCM (1993) after the documented toxic bloom found that the algal blooms were supported by phosphorus enrichment, with the primary pathway of phosphorus to American Lake through ground water. In response to the initial reports of algal toxicity in American Lake, Mike Crayton, a professor from Pacific Lutheran University, conducted annual mouse bioassays to assess toxicity from 1992 through 1996. Based on this information, it was determined that American Lake had experienced winter toxic anabaena blooms in 1992, 1993, 1994, and 1996 (Hanowell 2005 personal communication). The KCM report recommended that the lake be treated with alum (aluminum sulfate) to bind with and settle out phosphate from the water. However, the Washington Department of Ecology (Ecology) decided to refrain from alum treatment until watershed phosphorus sources could be identified and controlled (Woodward-Clyde 1996) and to our knowledge, the treatment has never been implemented.

American Lake has been classified as a moderately productive (mesotrophic) lake characterized by eutrophic periods (of higher biologic productivity) resulting from nutrient loading. Its overall characterization is based on average concentrations of total phosphorus, chlorophyll *a*, and Secchi transparency. The summary statistics for these parameters are shown in Table 3.4-2, based on the monitoring results completed for the KCM (1993) study between March 1991 and April 1992. However, further increases in nutrient loading are expected to exacerbate the problem of increased algal blooms and ensuing toxicity, pushing American Lake toward a eutrophic classification (KCM 1993).

Table 3.4-2 Summary Statistics for American Lake Trophic Status.

	Total Phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Secchi Disk Transparency (feet)
Mean summer epilimnion [a]	7	9	20
Mean summer whole-lake [b]	20	–	–
Mean winter whole-lake	29	23	15
Mean annual whole-lake	23	–	–

[a] The epilimnion is the top layer of a thermally stratified body of water.
[b] Whole-lake concentrations are based on samples taken from all depths of the lake, including the epilimnion and the hypolimnion, and then averaged.
µg/L = micrograms per liter.
Source: Based on monitoring between March 1991 and April 1992 (KCM 1993).

The monitoring program conducted between March 1991 and April 1992 helped to provide an understanding of the ecology and trophic status of American Lake. American Lake is a monomictic lake, with one period of complete circulation and mixing beginning in the late fall of each year. During the monitoring program, from early summer to late fall (May to November) the lake became stratified, forming a stable thermocline. This temperature barrier prevented deeper, cooler water of the lake (hypolimnion) from mixing with the warmer surface water (epilimnion), which prevented dissolved oxygen from reaching the hypolimnion. As anoxic (depleted oxygen) conditions developed in the hypolimnion, phosphorus was released from iron metals present in the sediments. This internal loading of phosphorus from the sediments combined with nutrient-laden ground water to cause elevated phosphorus concentrations in the water column of the hypolimnion. Nitrogen-to-phosphorus ratios for American Lake indicate that phosphorus is the limiting nutrient. However, stratification prevented phosphorus in the hypolimnion from reaching the algae growing in the epilimnion during the summer (KCM 1993).

When the lake began to mix in December 1991 and January 1992, measurements of lake total phosphorus began to increase, indicating that phosphorus from the hypolimnion was mixing with waters of the epilimnion. As a result, the lake experienced a large algal bloom during the winter. The dominant blue-green algae species, anabaena, present between September and December

1991 and again in February and March 1992, appeared to benefit from the excess phosphorus and contribute most to the toxic algae bloom (KCM 1993).

A nutrient budget was completed to characterize the relative sources of nutrients to the lake. Internal loading and ground water were determined to provide the two greatest sources of phosphorus to the lake. A ground water study found that the aquifer providing ground water to American Lake has a mean total phosphorus (TP) concentration of 87 micrograms per liter (µg/L) and an inorganic nitrogen concentration of 4,419 µg/L (KCM 1993). Table 3.4-3 summarizes the percentages of phosphorus loading contributions from various sources to American Lake.

Table 3.4-3 Percentage Contributions to the American Lake Phosphorus Budget.

Source	Percentage Contribution to Overall Nutrient Load
Streamflows	5
Precipitation	5
Fish pens	4
Ground water	43
Internal sources	42

Source: Monitoring data collected by KCM between March 1991 and April 1992 (KCM 1993).

A separate study was later completed by Woodward-Clyde (1996) to evaluate phosphorus sources, develop a phosphorus source monitoring plan, and complete a watershed characterization for American Lake. The monitoring results indicated that the dominant sources of phosphorus to American Lake were natural background sources. Although the wells used for the study were not situated in the best locations for determining the phosphorus inputs to American Lake, the study determined that the annual ground water phosphate load to American Lake was significantly lower than that previously estimated by KCM (1993). However, the surface water inflow volume and surface water phosphate loads estimated by Woodward-Clyde (1996) were consistent with the previous estimates. Because phosphorus inputs from human sources such as septic systems, stormwater drywells, and fertilizer use could not be discerned from the monitoring results, it was determined that human contributions to total phosphorus sources were small relative to background phosphorus levels (Woodward-Clyde 1995, 1997b). Phosphorus levels measured in ground water during this study in the vicinity of American Lake are addressed in the ground water section of this plan.

Sequalitchew Lake

The Sequalitchew Lake drainage basin comprises approximately 340 acres, including the approximately 75-acre lake surface area (Shapiro 1997a). Sequalitchew Springs provide surface water inputs to the lake. Although American Lake is connected to the east end of Sequalitchew Lake by an unnamed channel, there are no reports of surface water inputs to Sequalitchew Lake from this channel. Sequalitchew Lake is highly influenced by ground water and has been described as a “window” in the Steilacoom gravel upper aquifer, exposing the local water table (Meyer and Palmquist 1996). The maximum total ground water inflow to the lake ranges from approximately 0.58 to 1.74 cubic feet per second (cfs; AGI 1996).

Historically, Sequalitchew Creek was the sole surface water outlet for Sequalitchew Lake. Currently, there is a lake outlet diversion weir that diverts flow into a canal; the excess flow goes into Sequalitchew Creek. The outlet diversion weir, shown in Figure 3.4-1, is an 18-foot rectangular timber weir. A backflow prevention weir at the upper end of the lake at an elevation of 211.62 feet above MSL prevents lake water from submerging Sequalitchew Springs.

The outlet diversion weir was lowered in 1996 in response to increasing water elevations in Sequalitchew Creek. In January 1997, the lake level was recorded as 211.09 feet above MSL. At that time, beaver dams in Sequalitchew Creek were identified as influencing creek and lake flows and causing increased water levels in the lake (Shapiro 1997a).

During the winter months, Sequalitchew Springs, together with adjacent wells 12A and 12B, generally supplies all of the drinking water for Fort Lewis. During the summer months, other wells across Fort Lewis are used to supplement the water supply. Overflow from the springs drains to the lake via a 36-inch-diameter pipe to a backflow prevention weir, then through another 36-inch pipe to the lake. In the past, there have been incidences of water backing up from the lake over the backflow prevention weir and into the springs, posing water quality risks. These incidences were caused by unauthorized individuals raising the lake’s outlet diversion weir. A study aimed at protecting Sequalitchew Springs concluded that the vertical separation between the springs and the lake is inadequate (Shapiro 1997a).

The WDSHS (1981) study found that Sequalitchew Lake exhibited good water quality, and was phosphorus-limited for algae growth, based on a total inorganic nitrogen to orthophosphate-phosphorus ratio greater than 10. With low nitrate and phosphate concentrations, relative to other lakes, Sequalitchew Lake was found to be at less risk for algal blooms. Sequalitchew Lake was one of two lakes sampled that had ammonia-nitrogen concentrations that exceeded 0.2 milligrams per liter (mg/L), suggesting organic sources of pollution. However, neither compound approached concentrations that were toxic to stream biology, the water quality standard at the time of the study. Fecal coliform bacteria concentrations at the lake outlet were within the state standard for Class A streams. Sequalitchew Lake had elevated iron and manganese levels, meaning that the lake water could pose risks to aquatic species downstream in Sequalitchew Creek.

Between 1976 and 2003, hatchery coho salmon (*Oncorhynchus kisutch*) fingerlings were introduced to Sequalitchew Lake. The high quantities of nutrient-rich fish food that were added to the lake led to increased algae blooms and decreased dissolved oxygen in the lake. In 1994, a fish release limit was enacted, reducing fish release from one to two million fingerlings per year, to just 250,000 fingerlings per year to reduce the amount of food placed in the lake (Andrews and Swint 1994). The fish release program was discontinued in 2003 (Anderson 2006).

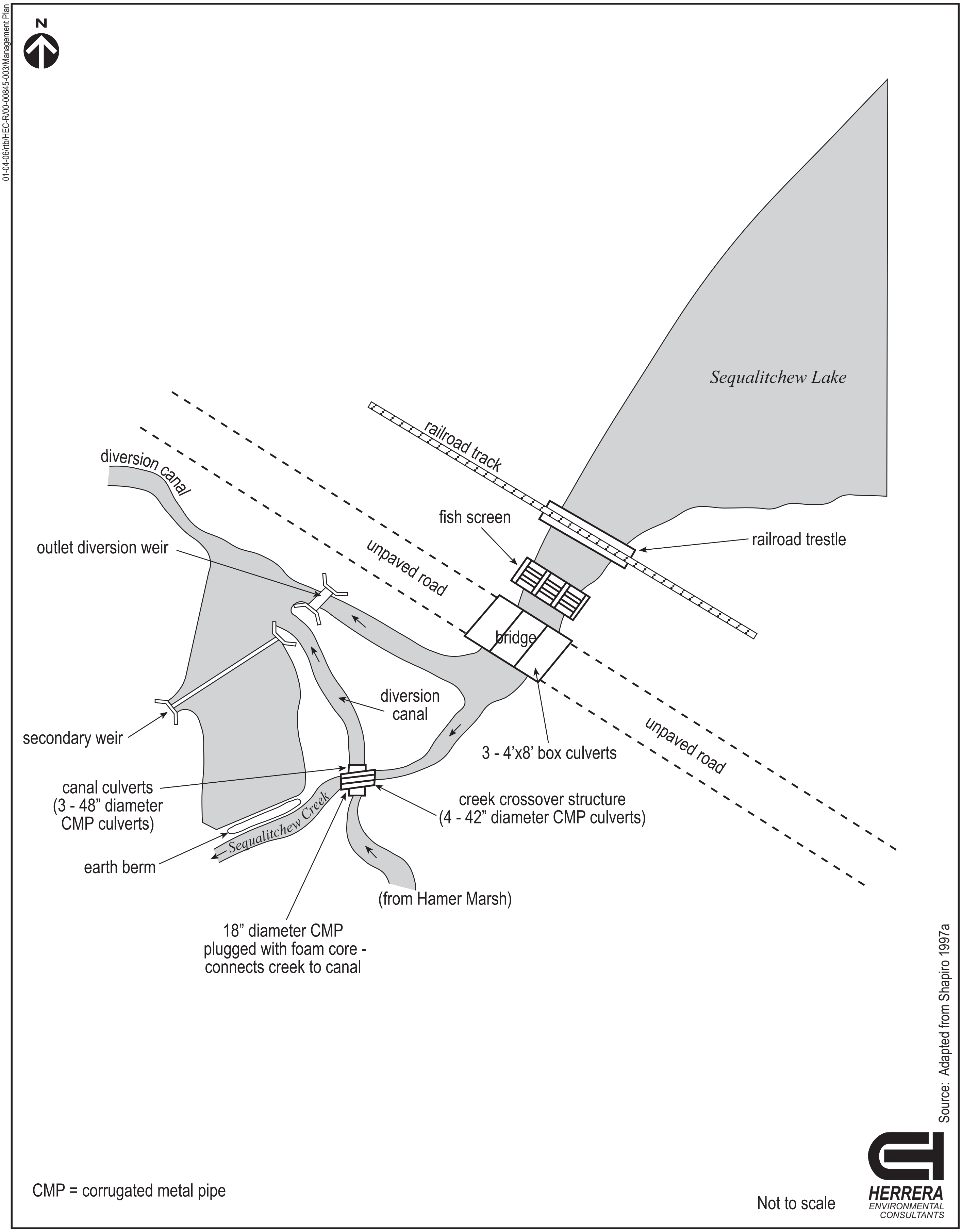

Figure 3.4-1 Sequalitchew Lake Outlet Diversion Weir.

Sampling conducted by Fort Lewis in 1993 indicated that Sequalitchew Lake was experiencing degraded water quality conditions (Clothier et al. 2003). A pH measurement collected in August 1993, was unusually high at 9.6. Nutrient concentrations also were relatively high, with ammonia, nitrate, and phosphorus achieving maximum concentrations of 0.815 mg/L, 1.84 mg/L, and 0.118 mg/L, respectively, although only phosphorus exceeded state standards. Dissolved oxygen concentrations during that year ranged from 6.14 mg/L to 12.6 mg/L. The lower concentrations are undesirable, but not likely to be lethal to aquatic life.

Sequalitchew Creek and the Diversion Canal

Historically, Sequalitchew Creek contained large numbers of beaver dams and likely meandered through wetlands for approximately 2 miles before flowing through a canyon into Puget Sound. An environmental assessment prepared for the *Sequalitchew Lake Level Management Plan* suggested that after settlement by Native Americans, beaver dam construction along the creek was probably limited due to trapping by Native Americans and, later, by early settlers and trappers (ENSR 1998a). The elimination of trapping has resulted in an increase in the beaver population and a subsequent increase in beaver dams.

Water quality parameters were measured in Sequalitchew Creek in 1977 (Clothier et al. 2003). These results indicated that water temperatures ranged from 37.2ºF to 65.3ºF. The upper reaches of Sequalitchew Creek exhibited fairly low dissolved oxygen concentrations. The authors speculated that this was the result of stagnant waters in nearby Edmond and Hamer marshes, or the presence of degraded water quality from the fish pens in Sequalitchew Lake. Dissolved oxygen levels were reported as good near the mouth of Sequalitchew Creek, although no concentrations were provided. Nutrient concentrations in Sequalitchew Creek were relatively high, with phosphorus ranging between 0.009 and 0.117 mg/L and nitrate ranging between 0.926 and 6.64 mg/L. The report suggested that the nitrate concentrations may have been elevated at the time because of the former DuPont explosives manufacturing facility that was located south of the creek, which could have been leaching nitrate into the creek (Clothier et al. 2003). In August 1977, fecal coliform bacteria counts were low in upper Sequalitchew Creek but exceeded the state standard near the mouth. The study suggested that beaver activity in the Edmond Marsh area could have contributed to the elevated fecal coliform bacteria levels (Runge et al. 2003).

Various studies published over the last 25 years provide information on the historical water quality within the Sequalitchew subbasin. A draft environmental impact statement produced by Weyerhaeuser in 1978 indicated that where water flow was sufficient, water quality was generally good in the creek (Dice et al. 1979 as cited by Andrews and Swint 1994). The WDSHS (1981) study found that Sequalitchew Creek water met the state Class A standards for temperature, turbidity, fecal coliform bacteria, and dissolved oxygen. In 1985, an investigation by Weyerhaeuser found extensive contamination within the proposed Northwest Landing development area to the south of Sequalitchew Creek. In particular, the north bluff of Sequalitchew Creek was contaminated with lead. All toxic waste was required to be cleaned up before the development could proceed.

The diversion canal begins at Hamer Marsh which is located to the south of Sequalitchew Lake and east of Sequalitchew Creek. The diversion canal then flows north from the marsh, crossing below Sequalitchew Creek in three 48-inch-diameter culverts (see Figure 3.4-1). Water discharging from Sequalitchew Lake over the diversion weir flows into the diversion canal downstream of these culverts. The diversion canal continues to flow in a northwesterly direction and discharges into Puget Sound near Solo Point. According to Fort Lewis staff, the diversion canal was constructed in the 1950s to avoid sending excess stormwater through the creek when the creek capacity is exceeded.

The diversion weir was originally constructed to regulate the lake level, preventing the lake from rising to an elevation that could back up to Sequalitchew Springs, threatening the Fort's potable water supply. However, under current conditions, beaver activity within Sequalitchew Creek frequently causes the creek to back up, occasionally even causing the creek to flow in the reverse direction. As a result of beaver activity and associated increased water elevations in the creek, flow to the diversion canal frequently exceeds flow discharging to the creek. Sequalitchew Creek flow may be less than 1 cfs (Andrews and Swint 1994). Base flow rates through the diversion weir ranged from 9.4 to 11.4 cfs during late 1996. During April 1998, flow went over the diversion weir to the canal despite little flow in the creek (ENSR 1998a).

3.4.2 Existing Surface Water Conditions

Figure 3.4-2 shows major surface water features, an approximate delineation of surface water drainage basins, and hydraulic structures within the Murray/Sequalitchew watershed. To protect the quality and quantity of stormwater that enters these surface water bodies, Fort Lewis has relied upon guidance in the Washington Department of Ecology *Stormwater Management Manual for Western Washington* (Ecology 2005; Johnston 2005). The state stormwater manual provides guidance for meeting state and federal requirements for stormwater discharges, as well as technical instructions for developing stormwater pollution prevention plans and designing source control and runoff treatment best management practices (BMPs; Ecology 2005).

According to Fort Lewis personnel, new development at Fort Lewis typically is designed to infiltrate stormwater runoff. For example, new parking areas are constructed with gravel, rather than paved, where feasible. There have been a number of pilot projects by Fort Lewis investigating the effectiveness of permeable pavement and other low-impact development measures. The intent of these measures is to generate no additional runoff, in order to meet criteria of the state stormwater manual (Ecology 2005).

To assess water quality conditions, available historical and recent water quality data can be compared with the Washington state standards (Washington Administrative Code, Chapter 173-201A [WAC 173–201A]). The water quality standards vary depending on the specific designated uses established for the particular water body. The major water bodies within the Murray/Sequalitchew watershed (i.e., Murray Creek, American Lake, Sequalitchew Lake, and Sequalitchew Creek) have not been assigned a specific water quality designation by the Department of Ecology. Therefore, by default (WAC 173-201A), the designated uses of the