2007 Stormwater Needs Assessment Program

Mill Creek
Subwatershed Needs Assessment Report

Clark County Public Works Clean Water Program

May 2008

For other formats
Clark County ADA Office, **Voice** (360) 397-2000
Relay (800) 833-6384, **E-mail** ADA@clark.wa.gov

2007 Stormwater Needs Assessment Program
Table of Contents

PAGE

2007 Stormwater Needs Assessment Program
Table of Contents

Appendices

Figures

Tables

Responsible County Officials

Program Name:	Stormwater Needs Assessment Program
Project Code:	SNAP
Department:	Clark County Public Works Water Resources
Funding source:	Clark County Clean Water Fee
Reporting Category:	4420 000 531 534 245 011403
Client:	Earl Rowell, Clean Water Program manager
SNAP manager:	Rod Swanson, Senior Planner Contact: 360-397-6118 x4581 rod.swanson@clark.wa.gov
Subwatershed Lead:	Jeff Schnabel, Natural Resource Specialist III Contact: 360-397-6118 x4583 jeff.schnabel@clark.wa.gov

Acknowledgements

Development of Stormwater Needs Assessment reports is a team effort involving many individuals implementing various tools and tasks as described in Stormwater Needs Assessment Program, Volume I.

Thank you to staff who contributed chapters or support for this report, including: Chad Hoxeng, Bob Hutton, Trista Kobluskie, Fereidoon Safdari, Henry Schattenkerk, Cindy Steinbarger, John Tyler, Ian Wigger.

Special thanks to the many local agency staff and interested parties who provided discussion, coordination, and project suggestions, including:

Patrick Lee, Clark County Office of Conservation Lands Management

Joel Rupley, Clark County Endangered Species Act

Jeroen Kok, Clark Parks and Recreation

Bill Dygert, Fish First

Steve Manlow, Lower Columbia Fish Recovery Board

Karen Streeter, Clark County Public Works Environmental Permitting

Heath Henderson, Clark County Public Works CIP

Tonnie Cummings, Washington State Department of Ecology

The following firms were instrumental in completing various field tasks and assisting with compilation of the final report:

Herrera Environmental Consultants (special thanks to Matt Klara, Dave Felstul, and Jennifer Schmidt)

Otak, Incorporated (special thanks to Tim Kraft and Jeannine Johnson)

Acronyms and Abbreviations

B-IBI	Benthic Macroinvertebrate Index of Biological Integrity
BOCC	Board of County Commissioners
BMP	Best Management Practices
CCD	Clark Conservation District
CIP	Capital Improvement Program
CPU	Clark Public Utilities
CRFPO	Columbia River Fisheries Program Office
CWA	Clean Water Act
CWC	Clean Water Commission
CWP	Clean Water Program
EIA	Effective Impervious Area
EDT	Ecosystem Diagnostic and Treatment model
EMAP	Environmental Mapping and Assessment
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FPIA	Focused Public Investment Area
FWS	Fall, Winter, Spring
GCEC	Gee Creek Watershed Enhancement Committee
GIS	Geographic Information System
GMA	Growth Management Act
HPA	Hydraulic Project Approval
IDDE	Illicit Discharge Detection and Elimination
LCFEG	Lower Columbia Fish Enhancement Group

LCFRB	Lower Columbia Fish Recovery Board
LID	Low-Impact Development
LiDAR	Light Detection and Ranging
LISP	Long-term Index Site Project
LWD	Large Woody Debris
MS4	Municipal Separate Storm Sewer System
MOP	Mitigation Opportunities Project
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NTU	Nephelometric Turbidity Unit
NWIFC	Northwest Indian Fisheries Commission
ODEQ	Oregon Department of Environmental Quality
OWQI	Oregon Water Quality Index Scores
SCIP	Stormwater Capital Improvement Program
SCIPIT	Stormwater Capital Improvement Program Involvement Team
SCMP	Salmon Creek Monitoring Project
SCWC	Salmon Creek Watershed Council
SNAP	Stormwater Needs Assessment Program
SWMP	Stormwater Management Program
SWMMWW	Stormwater Management Manual for Western Washington
TIA	Total Impervious Area
TIP	Transportation Improvement Program
TIR	Technical Information Report

TMDL	Total Maximum Daily Load
TP	Total Phosphorus
UGA	Urban Growth Areas
UIC	Underground Injection Control
USFWS	U.S. Department Fish and Wildlife Services
VBLM	Vacant Buildable Lands Model
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WSDOT	Washington Department of Transportation

Executive Summary

Study Area

This Stormwater Needs Assessment report includes the Mill Creek subwatershed, tributary to Salmon Creek in west central Clark County.

Intent

Stormwater Needs Assessment reports compile summary information relevant to stormwater management, propose stormwater-related projects and activities to improve stream health, and assist with adaptive management of the county's Stormwater Management Program. The assessments are conducted at a subwatershed scale, providing a greater level of detail than regional WRIA or ESA plans. Stormwater Needs Assessments are not comprehensive watershed plans or stormwater basin plans.

Findings

Watershed Conditions

The table on the following page summarizes conditions in the Mill Creek subwatershed, including water quality, biological health, habitat, hydrology, and the stormwater system.

Ongoing projects and involvement

The Salmon Creek Watershed Council, Clark Public Utilities, and Ecology are actively involved in improving and protecting Mill Creek through local grass roots organizing, widespread riparian enhancement work, and ongoing TMDL adaptive management, respectively. The lowermost reaches of Mill Creek flow through the WSU Vancouver campus and provide a popular outdoor classroom. Clark County Clean Water Program (CWP) participates in the TMDL process through implementation of the NPDES permit, provides water quality monitoring, and supports various local organizations working within the Mill Creek area. The watershed continues to benefit from the efforts of these groups.

A major WSDOT highway construction project is planned for SR502 between I-5 and Battle Ground, potentially beginning construction in 2012.

There are several potentially significant TIP projects on the County's 20-year CIP list, including NE 179th Street, NE 72nd Avenue, NE 50th Avenue, NE 29th Avenue, and Salmon Creek Avenue.

There are no Clark County CWP stormwater projects in Mill Creek under the 2007-2012 Stormwater Capital Improvement Program.

Category	Status
Water Quality	
Overall	• Poor to Very Poor
Fecal coliform bacteria	• Included in Salmon Creek fecal coliform TMDL • Does not meet state criteria
Temperature	• Does not meet state criteria, but among the cooler streams monitored by Clark County
Sediment	• Meets state criteria for turbidity, but shows an increasing trend
Biological	
Benthic macroinvertebrates	• Low to moderate biological integrity
Anadramous fish	• Presumed use by fall Chinook, Coho, and winter steelhead • Low to moderate regional recovery priority (LCFRB Tier 4, Group D)
Resident fish	• Unknown
Habitat	
Reference condition	• Overall habitat similar to a Category C (degraded) Willamette Valley reference stream
NOAA Fisheries criteria	• Forest cover, road density, and impervious area percentage fall into the Non-Functioning category
Riparian	• Large Woody Debris recruitment potential low to moderate • Overall shade below state targets • Many recent and ongoing riparian planting projects
Wetland	• Concentrated in mid-upper subwatershed and riparian zones • Suitable for wetland restoration
Hydrology and Geomorphology	
Overall hydrology	• Impacted; typical of a flashy urban or unforested rural watershed
Channel stability	• May be in transition from stable to unstable stream channels
Future condition	• Projected impervious area will cause increased rate of channel incision, bank failures, and accelerated channel migration in various areas unless adequate runoff controls are in place
Stormwater (Unincorporated areas)	
System description	• Mix of piped infrastructure, road-side ditches, and field drains • 62 public and private stormwater facilities currently mapped
Inventory status	• Incomplete (estimated 80 percent)
System adequacy	• Marginally adequate control and inadequate treatment • Projected impervious area indicates need for updated control standards with considerable investment in new and retrofit infrastructure
Condition	• 95 percent of public stormwater facility components in compliance with state standards at time of inspection • 105 public outfalls discharging to critical areas; one causing significant erosion • 231 outfalls inspected for illicit discharges; one intermittent bacteria source discovered

Opportunities

Projects listed in the SNAP report represent only a small part of those required to protect and restore Mill Creek. Immediate priorities based on current conditions and local program capabilities are listed. Numerous opportunities exist for stormwater-related watershed improvement, including the following:

- Focused outreach to streamside landowners between NE 29th Avenue and NE 50th Avenue south of 179th Street for riparian enhancement
- Potential retrofit of one existing public stormwater facility for enhanced control and treatment
- Repair and maintenance of existing stormwater infrastructure
- Evaluation of potential wetland enhancement or advanced mitigation projects within tax-exempt parcels.
- Inspection of one potentially at-risk earthen dam
- Cleanup of three illegal dump sites
- Investigation of one potential sanitary sewer leak
- Potential capital improvement projects including ditch retrofits, large-scale riparian enhancements, and regional facilities
- Potential purchase or protection of ~100 acres intact forest and wetland within a Priority Habitat Buffer
- Updates to stormwater infrastructure database
- Evaluation of potential fish barriers in the middle watershed
- Technical assistance visits to landowners with potential source control and water quality ordinance issues.

Non-project stormwater management recommendations address areas where county programs or activities could be modified to better address NPDES permit components or promote more effective mitigation of stormwater problems. Management recommendations relevant to the Mill Creek subwatershed include:

- Complete the stormwater infrastructure inventory.
- Coordinate and leverage opportunities with groups and agencies active in Mill Creek improvement.
- Encourage the use of Low Impact Development techniques for new development, and runoff reduction techniques for existing development.
- Confirm that county ditch maintenance practices minimize vegetation removal; provide education for private landowners on appropriate ditch maintenance.
- Replace missing or deteriorated stream name signs at road crossings.
- Encourage removal of invasive plants and riparian restoration through education, technical assistance and/or financial assistance.

- Encourage removal of fences across the stream channel.
- Promote protection of first-order tributary streams. Consider the use of habitat buffers, establishment of conservation easements, and increased control of existing stormwater and agricultural runoff.
- Collaborate on stormwater activities between Clark County, City of Battle Ground, and Vancouver-Clark Parks and Recreation in the upper watershed.

Introduction

This report is a Stormwater Needs Assessment for the Mill Creek (Salmon) subwatershed. The Clean Water Program (CWP) is gathering and assembling information to support capital improvement project (CIP) planning and other management actions related to protecting water bodies from stormwater runoff.

Purpose

The Stormwater Needs Assessment Program (SNAP), initiated in 2007, creates a system for the CWP to focus activities, coordinate efforts, pool resources, and ensure the use of consistent methodologies. SNAP activities assess watershed resources, identify problems and opportunities, and recommend specific actions to help meet the CWP mission of protecting water quality through stormwater management.

The overall goals of the SNAP are to:

- Analyze and recommend the best and most cost effective mix of improvement actions to protect existing beneficial uses, and to improve or allow for the improvement of lost or impaired beneficial uses consistent with NPDES objectives and improvement goals identified by the state GMA, ESA recovery plan implementation, TMDLs, WRIA planning, flood plain management, and other local or regional planning efforts.
- Inform county efforts to address the following issues related to hydrology, hydraulics, habitat, and water quality:
    - Impacts from current or past development projects subject to lesser or non-existent stormwater treatment and flow control standards
    - Subwatershed-specific needs due to inherent sensitivities or the present condition of water quality or habitat
    - Potential impacts from future development

The CWP recognizes the need to translate assessment information into on-the-ground actions to improve water quality and habitat. Facilitating this process is a key requirement for the program's long-term success.

Results and products of needs assessments promote more effective implementation of various programs and mandates. These include identifying mitigation opportunities and providing a better understanding of stream and watershed conditions for use in planning county road projects. Similar information is also needed by county programs implementing critical areas protections and salmon recovery planning under the state Growth Management Act (GMA) and the federal Endangered Species Act (ESA).

Scope

This report summarizes and incorporates new information collected for the SNAP as well as pre-existing information. In many cases, it includes basic

summary information or incorporates by reference longer reports which may be consulted for more detailed information.

SNAP reports produce information related to three general categories:

- potential stormwater capital projects for county implementation or referral to other organizations
- management and policy recommendations
- natural resource information

Descriptions of potential projects and recommended program management actions are provided to county programs, including the Public Works CWP and Stormwater Capital Improvement Program (SCIP), several programs within the Department of Community Development, and the county's ESA Program. Potential project or leveraging opportunities are also referred to local agencies, groups, and municipalities as appropriate.

Assessment Approach

Priorities for Needs Assessment in Mill Creek

Clark County subwatersheds were prioritized into a five year schedule for the 2006-2011 SNAP using the procedures described in Prioritizing Areas for Stormwater Basin Planning (July 2006).

The Mill Creek subwatershed falls into the "Unincorporated UGA watersheds" category established in the above document. Subwatersheds in this category typically include significant areas of development and potential new development inside the Vancouver UGA of unincorporated Clark County where the county controls development permitting. These are high priority subwatersheds for stormwater needs assessment considering development pressure, subwatershed characteristics and likely NPDES permit requirements. A wide range of SNAP tools may be used in assessing subwatersheds in this category.

Assessment Tools Applied in Mill Creek

The SNAP utilizes a standardized set of tools for subwatershed assessment, including desktop mapping analysis, modeling, outreach activities, and a variety of field data collection. Tools are based on existing protocols where feasible, and cover a range of information important to stormwater management. Though not every tool is applied in every subwatershed, the use of a standard toolbox ensures the consistent application of assessment activities county-wide.

Table 1 lists the set of tools available for use in the SNAP. Tools marked with an asterisk (*) are those for which new data or analyses were conducted during the course of this needs assessment. The remainder of the tools were assessed based on pre-existing information.

Table 1: Stormwater Needs Assessment Tools

Stakeholders *	Geomorphology And Hydrology *
Outreach And Involvement *	Riparian Assessment
Coordination with Other Programs *	Floodplain Assessment
Drainage System Inventory *	Wetland Assessment
Stormwater Facility Inspection *	Macroinvertebrate Assessment *
Review Of Existing Data *	Fish Use And Distribution
Illicit Discharge Screening *	Water Quality Assessment
Broad Scale GIS Characterization *	Hydrologic Modeling *
Rapid Stream Reconnaissance *	Hydraulic Modeling *
Physical Habitat Assessment	

Assessment Actions

Outreach Activities

Outreach activities were limited and focused on raising awareness about the SNAP effort. The following activities were completed:

- July 2007 – press release to local media
- August 2007 – article in "Planning Stormwater Projects" flyer distributed at Clark County fair and other public events.
- September 2007 – article in Clean Water Program E-Newsletter
- Clean Water Program web pages updated to include the SNAP and SCIP.
- March 31 of each year, a description of the SNAP is included in Clark County's stormwater management program plan submitted to Ecology

Clark County Clean Water Commission members were also updated periodically on SNAP progress.

Coordination with Other Programs

Purpose

Coordination with other county departments and with local agencies or organizations helps to explore potential cooperative projects and ensure that the best available information is used to complete the assessment.

Coordination is a two-way relationship; in addition to bringing information into the needs assessment process, coordinating agencies may use needs assessment results to improve their programs.

Methods

The CWP maintains a list of potential coordinating programs for each subwatershed area. The list was reviewed in early 2007 and general communications were planned. Coordination took the form of phone conversations, meetings, or electronic correspondence, and was intended to solicit potential project opportunities, encourage data and information sharing, and promote program leveraging.

Potential opportunities for coordination exceeded the scope of CWP and SNAP resources; therefore, not all potentially relevant coordination opportunities were pursued. Coordination was prioritized with departments and groups most likely to contribute materially to identify potential projects and compiling information to complete the needs assessment.

Results

See Analysis of Potential Projects for an overall list and locations of potential projects gathered during the needs assessment process. Projects suggested or identified through coordination with other agencies are included.

The following list includes departments, agencies, and groups contacted for potential coordination during the course of the Mill Creek needs assessment:

- Clark County Endangered Species Act program
- Lower Columbia Fish Recovery Board
- Clark County Transportation Improvement Program
- Clark County Legacy Lands Program
- Vancouver/Clark County Parks and Recreation
- Washington Department of Ecology
- Clark County Weed Management
- City of Battle Ground
- Salmon Creek Watershed Council
- Washington State Department of Transportation

Review of Existing Data

Data and information review is incorporated throughout this report in pertinent sections. A standardized list of typical data sources created for the overall SNAP effort is supplemented by subwatershed-specific sources as they are discovered. Data sources consulted for this report include, but are not limited to those listed below:

- LCFRB Habitat Characterization (2004)
- LCFRB 6-Year Habitat Workplan
- CC LISP/SCMP/ Project data
- CC Volunteer project data
- Ecology 303(d) list
- CC 2003 Salmon Cr temperature
- CPU Salmon Creek WS Plan 2002
- MGS Salmon Creek Model
- WRIA 27/28 Plan
- CC consproj GIS layer (conservation projects)
- CC 6-Year and 20-Year TIP
- Ecology EIM data
- CC Mitigation Opportunities Project
- CC 2004 Subwatershed summary
- CC 2004 Stream Health Report

Broad-Scale GIS Characterization and Metrics

The broad-scale characterization is a GIS-based exercise providing an overview of the biophysical setting for each subwatershed, background information for use in implementing other SNAP tools, and identification of potential acquisition or project sites. GIS data describes many subwatershed characteristics such as topography, geology, soils, hydrology, land cover, land use, and GMA critical areas. A standard GIS workspace, including shape files for over 65 characteristics, forms the basis for the characterization.

GIS data is generally used as a tool to complete the report and not presented in the report itself. Summary metrics are taken from existing reports and data; for example, Wierenga (2005) summarized many GIS characteristics for Clark County subwatersheds.

Many of these characteristics are described in greater detail in later sections. For example geology and soils form the cornerstone of the Geomorphology and Hydrology section.

The characterization includes three components:

- A set of three standard map products as paper maps for SNAP use
- A summary table of selected subwatershed-scale metrics
- A brief narrative including comparison of metrics to literature values, conclusions about general subwatershed condition and potential future changes, and potential mitigation or improvement site identification.

Map Products

Three standard SNAP map products are: 1) Stormwater Infrastructure and Hydrologic Soil Group, 2) Critical Areas information, and 3) Vacant Buildable Lands within UGAs. These maps are printed out for tabletop evaluations.

General Conditions and Subwatershed Metrics

General Geography

Mill Creek is a major tributary of Salmon Creek. It flows west from the Battle Ground area then south through the Washington State University campus and into Salmon Creek (Figure 1). Mill Creek subwatershed covers 11.5 square miles, receiving on average 48 inches of precipitation annually. The upper portions of the subwatershed are relatively subtle terrain and have been converted from forest to a mix of agricultural, forest, and residential uses. Average parcel size is 1.9 acres. Population density is 730 people per square mile. Approximately three square miles of uppermost Mill Creek subwatershed lies within the City of Battle Ground and its Urban Growth Area (UGA), and about 2.5 square miles of the lowermost part of the basin is within the Vancouver UGA.

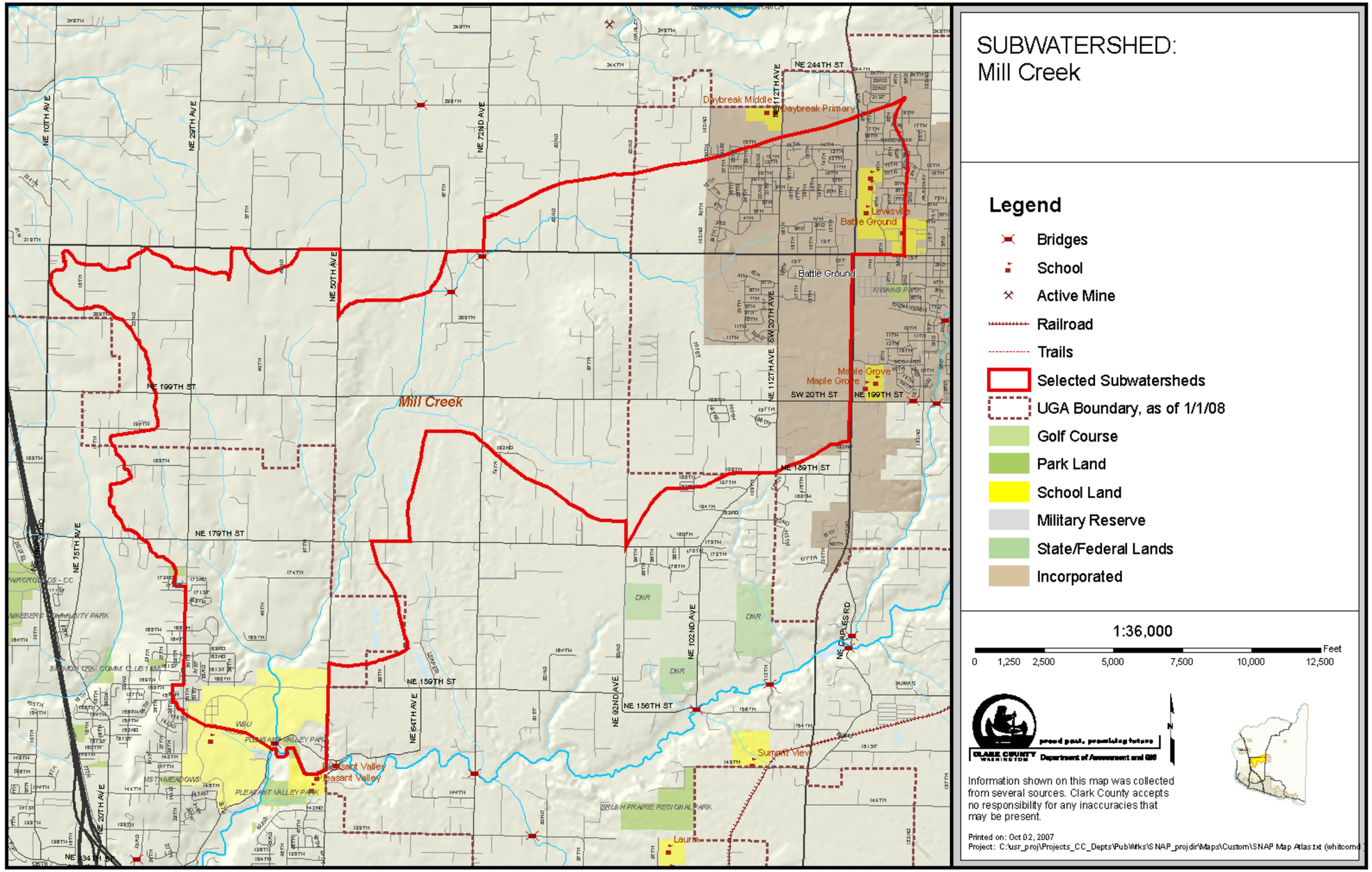


Figure 1: Subwatershed Map: Mill Creek (Salmon Creek)

Topography

Mill Creek drains a largely flat area between its mouth at Salmon Creek and Battle Ground. Most of the subwatershed is between 200 and 280 feet elevation, except hills in the southwest and a small hill at Dollars Corner that rise to just over 400 feet. Mill Creek begins to form a channel valley south of 199th Street, where surface elevation is 190 feet, then drops into a shallow valley the last two miles before entering Salmon Creek at 130 feet above sea level.

Geology and Soils

Geology and soils influence stream channel type, the size and amount of sediment in the channel, wetland formation, and overall hydrologic framework. Mill Creek is underlain by two geologic units, older semi-consolidated sandy gravel commonly referred to as the Troutdale Formation or Troutdale gravels and sandy to silty cataclysmic Ice Age flood deposits. Fine-grained alluvium underlies Mill Creek's flood plains. Geology is described in greater detail in the geomorphology and hydrology section

The Troutdale Formation is sandy, gravelly ancestral Columbia River deposits that underlie the entire watershed and are the only source of coarse gravelly sediment in the basin. Where the top of the Troutdale Formation is less than about 300 feet elevation, it is covered by Ice Age cataclysmic flood deposits. It is also exposed where Mill Creek cuts through the Ice Age flood deposits. The Troutdale Formation is much older than the Ice Age flood deposits causing the uppermost beds to be deeply weathered to clay and silt. Weathered surface provides a barrier to downward groundwater flow and may be a principal cause of wetlands in low lying areas of the Ice Age flood deposits.

The fine grained Ice Age cataclysmic flood deposits mantle most of the study area below 300 feet elevation, ranging in depth from a few feet to perhaps 70 feet thick at the east and west margins. These deposits are about 14,000 to 12,000 years old and were deposited by a succession of giant floods of the Columbia River caused by ice dam failures in the Missoula, Montana area. Between 219th Street and 50th Avenue, Mill Creek follows part of a shallowly sloped, south to north Ice Age flood drainage way between the Orchards area and the East Fork Lewis River.

Soils formed on the Troutdale Formation and fine-grained cataclysmic flood deposits tend to be fairly clayey. Soils on modern alluvium tend to be sandier, more permeable, and easily eroded as stream banks. The predominant soils in Mill Creek subwatershed are classified as Hydrologic Soil Group C and D, which have low permeability. Hydrologic Soil Group D soils are often associated with wetlands and are present in about half the basin area east of 50th Avenue.

Hydrology

Mill Creek originates in the City of Battle Ground storm sewer system and then flows west as a channel to large depressional wetlands south of 219th Street where it is a manmade channel for approximately one mile. Shortly upstream of 179th Street, Mill Creek begins to form a shallow canyon and flood plain, which deepens and enlarges downstream. In flatter areas of the basin, drainage is primarily by field ditches and roadside ditches. Wetlands are a significant hydrologic feature, with depressional wetlands common in the upper half of the area. The geomorphology and hydrology report section describes hydrology in greater detail.

While lower Mill Creek is a perennial stream, it typically dries up above 179th Street during the summer.

Clark County has operated a stream gauge near the mouth of Mill Creek since 2003. Data from the stream gauge suggests that Mill Creek is a relatively flashy stream. Examination of a simple hydrology metric, the TQmean, showed that only 25 to 30 percent of the daily flows were greater than the mean daily flow. This is indicative of a flashy urban or unforested rural watershed. Results from hydrologic modeling by MGS (March, 2003) found that Mill Creek hydrology was at a point suggesting a transition from stable to unstable conditions.

Subwatershed Metrics

Subwatershed scale metrics provide a simple way to summarize overall conditions. Metrics are calculated from Landsat land cover analysis and current GIS data. Benchmarks for properly functioning, and not properly functioning are based on NOAA fisheries standards for salmon protection and restoration (1996 and 2003).

Overall, subwatershed scale metrics suggest that Mill Creek has characteristics associated with degraded aquatic habitat (Table 2). The biggest challenge will be to manage stormwater for expected growth in the Vancouver and Battle Ground Urban Growth Areas to minimize adverse impacts.

Forest Cover

The proportion of a watershed in forest is known to have a profound influence on watershed processes. Forest cover estimates are taken from a report summarizing land cover for Clark County (Hill and Bidwell, January 2003). Research in the Pacific Northwest has shown that when forest cover declines below approximately 65 percent, watershed forming processes become degraded (Booth and Jackson, 1997). These include reduced riparian shade, less wood debris delivery to streams, increased stormwater runoff, and increased fine sediment delivery due to mass wasting. The same research indicates that when forest cover drops below 50 percent watershed forming processes are non-functioning.

Table 2: Mill Creek Metrics			
Metric	**Value**	**Functioning Criteria**	**Non-Functioning Criteria**
Percent Forested (2000 Landsat)	16	> 65 %	< 50 %
Percent TIA (2000 Landsat)	23	< 5 %	> 15 %
Road Density 2007 data (miles/mile2)	8	< 2/mile	> 3/mile
Stream Crossing Density (crossings per stream mile)	1.9	< 3.2/mile	> 6.4/mile
Percent EIA estimated from the Comprehensive Plan	23	< 10 %	> 10 %

The Mill Creek subwatershed has low forest cover (16 percent), and is categorized as "non-functioning". Most of the forest is found in stream canyons and scattered tracts of woodlands. A comparison of recent aerial photos to 1955 photos showed very similar patterns of forest cover. Much of the basin was in agricultural use.

TIA (Total Impervious Area)
Total impervious area is one of the most widely used indicators of urbanization and coincident watershed degradation (Center for Watershed Protection, March 2003). Total impervious area is estimated from land cover data in Hill and Bidwell (January 2003). While various organizations and publications categorize stream condition based on TIA, the NOAA fisheries standard of less than five percent as fully functional and greater than 15 percent as non-functional habitat is a reasonable indicator of habitat quality. Mill Creek has an estimated 23 percent TIA. In some cases, the interpretation of the satellite images tends to overestimate the level of urbanization and the actual amount of TIA could be lower.

Road Density
Road density, including all public and private roads, is an easily calculated development measure. Based on criteria set by NOAA Fisheries to protect salmon habitat, almost all of Clark County is non-functioning. Urban streams have road densities approaching 15 to 20 miles per square mile. Mill Creek road density of eight miles per square mile is typical for urbanizing rural areas, which places it in NOAA Fisheries non-functioning habitat category.

Stream Crossing Density
Stream crossing density is easily measured using available road and stream channel data. The salmon protection standard considers larger fills over 60 feet wide, which would be approximately five to ten foot high road fill. According to NOAA Fisheries standards Mill Creek East Fork is functional for salmon habitat.

Future Effective Impervious Area
Effective impervious area is the amount of impervious area that actually drains to a water body. Depending on factors such as soil types and level of development, effective impervious area is about half (lower intensity development) to almost equal (high intensity development) the TIA value.

The 2008 Comprehensive Plan guides development for the next few years and when used to estimate effective impervious area can provide a metric for expected hydrologic impacts due to development. Future effective impervious area estimated for Mill Creek under the 2008 Comprehensive Plan is estimated to be 23 percent. At this level, a significant amount of stormwater infrastructure is required to mitigate for new stormwater impacts.

Estimated Channel Stability Based on Forest and EIA
In a recent publication by Booth, Hartley, and Jackson (June 2003), a relationship between forest and percent EIA was presented as graphic (Figure 2). According to this figure, Mill Creek subwatershed is predicted to have predominantly unstable channels under current and future conditions if increased runoff is not managed properly.

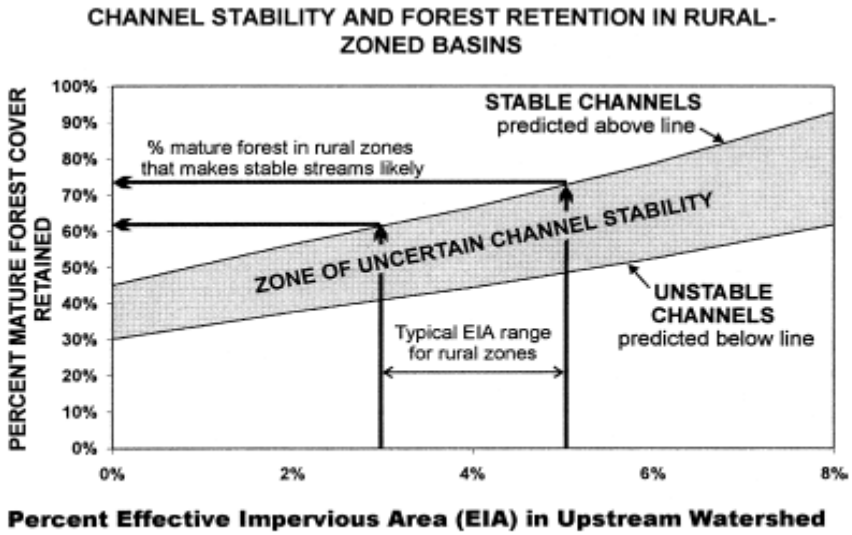


Figure 2: Channel Stability in Rural Areas (Booth, Hartley, and Jackson, June 2002)

Water Quality Assessment

This section briefly summarizes and references available water quality data from the Mill Creek subwatershed. A description of applicable water quality criteria is included, along with discussions of beneficial use impacts, likely pollution sources, and possible implications for stormwater management planning.

Water Quality Criteria

For a full explanation of current water quality standards see the Ecology website at:

http://www.ecy.wa.gov/programs/wq/swqs/index.html

Under current Washington state water quality standards, Mill Creek is to be protected for the designated uses of: Core Summer Salmonid Habitat; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values" (WAC 173-201A-600, Table 602).

Table 3 summarizes currently applicable water quality criteria for Mill Creek.

Table 3: Applicable Water Quality Criteria for Mill Creek (November 2006)

Characteristic	2006 Ecology criteria
Temperature	≤ 16 °C (60.8 °F)
Dissolved Oxygen	≥ 9.5 mg/L
Turbidity	shall not exceed 5 NTU over background when background is 50 NTU or less
pH	6.5 – 8.5 units
Fecal coliform bacteria	Geometric mean fecal coliform concentration not to exceed 100 colonies/100mL, and not more than 10% of samples exceeding 200 colonies/100mL.
Aesthetics	Aesthetic values must not be impaired by the presence of materials or their effects… which offend the senses of sight, smell, touch, or taste
Toxics	Toxic substances shall not be introduced… which have the potential…to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent upon those waters, or adversely affect public health

Source: Washington Department of Ecology (http://www.ecy.wa.gov/programs/wq/swqs/index.html)

303(d) Listed Impairments

The 2002/2004 303(d) list of impacted waters may be found on the Ecology website at:

http://www.ecy.wa.gov/programs/wq/303d/index.html

Mill Creek is included in the existing Salmon Creek TMDL for fecal coliform (listed for fecal coliform under Category 4a). Additionally, some segments of Mill Creek are Category 2 listed (Waters of concern) for dissolved oxygen and pH. Under Category 1 (meets tested standards for clean waters), Mill Creek is listed for ammonia-nitrogen and temperature.

Clark County Stream Health Report

In 2004, the CWP compiled available data and produced the first county-wide assessment of general water quality.

Based on a limited available dataset including fecal coliform bacteria, general water chemistry (temperature, pH, and dissolved oxygen), and benthic macroinvertebrate scores, overall stream health in the Mill Creek subwatershed scored in the "fair" range.

The 2004 Stream Health Report may be viewed on the county website at http://www.clark.wa.gov/water-resources/stream.html.

Available Data

Data and information sources reviewed or summarized as part of this water quality characterization are listed in Table 4.

Table 4: Available Data

Source	Data and/or Report
Clark County Clean Water Program	2002-2006 Long-term Index Site Project Volunteer Monitoring Program 2004 Stream Health Report and draft reports Salmon Creek Watershed: Summer 2003 stream temperature
Ecology	303(d) List of impaired water bodies Station 28J070 data (Mill Cr @ Salmon Cr Avenue)

Water Quality Summary

The following water quality summary is based primarily on monthly data collected between May 2002 and December 2006 at Mill Creek station MIL010 located at Salmon Creek Avenue. Additional results are included from volunteer-collected data near this station and from continuous temperature readings collected during the summers of 2002 through 2006.

The data are presented in terms of a multi-characteristic water quality index, followed by summaries of several individual characteristics. Summarized water temperature data collected from approximately May through September between 2002 and 2006 are also included. Figure 3 shows the approximate location of monitoring station MIL010.

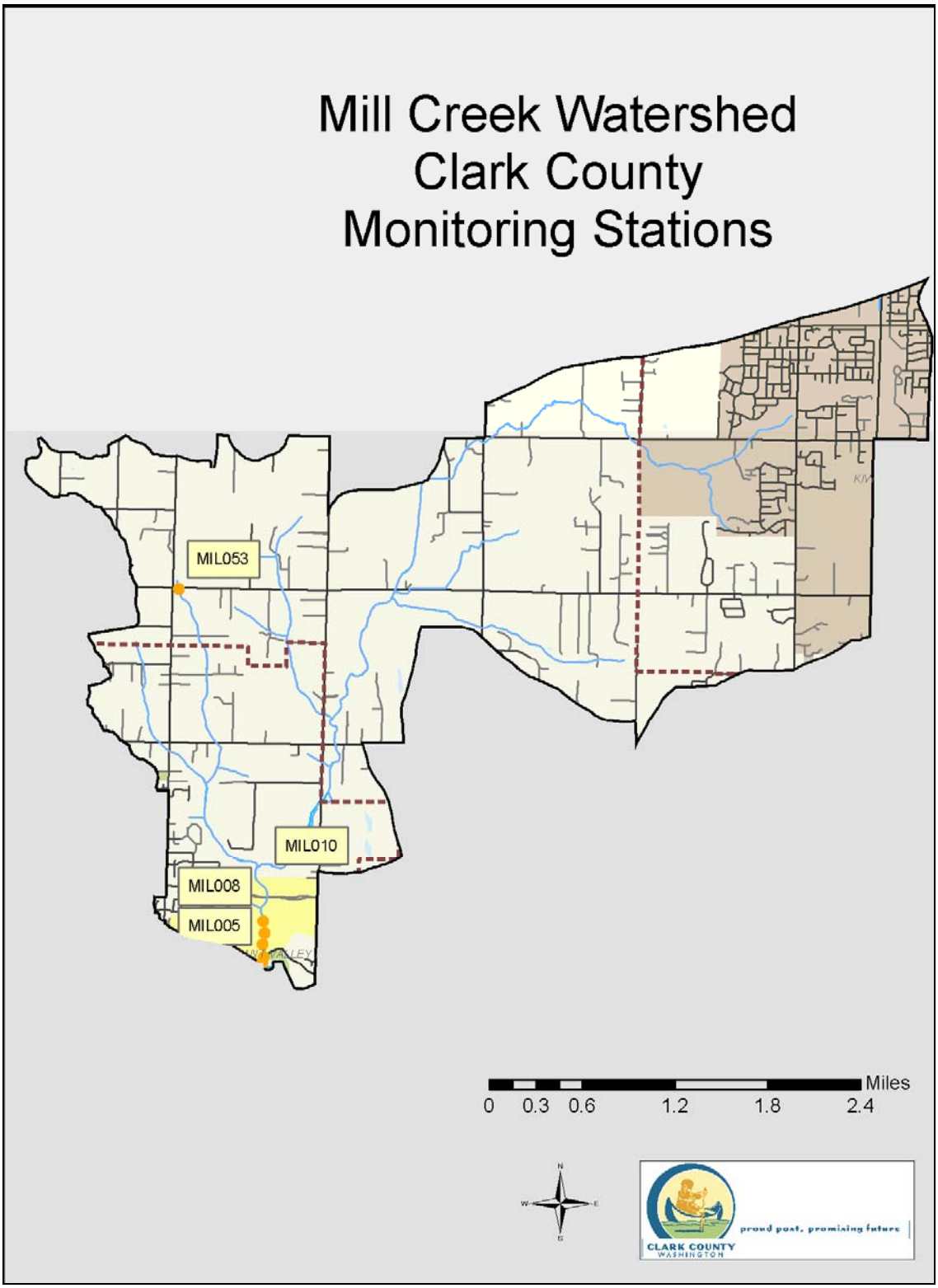


Figure 3: Mill Creek Watershed and Location of Monitoring Stations

Oregon Water Quality Index (OWQI) Scores

The OWQI was developed by the Oregon Department of Environmental Quality (ODEQ) as a way to improve understanding of water quality issues by integrating multiple characteristics and generating a score that describes water quality status (Cude, 2001). It is intended to provide a simple and concise method for expressing ambient water quality.

The OWQI integrates eight water quality variables: temperature; dissolved oxygen; biochemical oxygen demand; pH; ammonia + nitrate nitrogen; total phosphorus; total solids; and fecal coliform. For each sampling event, individual sub-index scores and an overall index score are calculated. Overall index scores are aggregated into low flow (June through September) and high flow (October through May) seasons and a seasonal mean value is then calculated.

Index scores are categorized as follows:

very poor = 0 to 59; poor = 60 to 79; fair = 80 to 84; good = 85 to 89, and; excellent = 90 to 100.

Figure 4 shows seasonal mean OWQI scores for station MIL010 from 2002 through 2006. Among 15 long-term monitoring stations county-wide, station MIL010 ranked ninth in overall water quality during this time period (Hutton and Hoxeng, 2007), placing it near the center of the range of water quality observed in Clark County.

Monthly OWQI values since 2002 ranged from Very Poor to Good, although for most months (34 out of 54 months sampled) OWQI values were in the Poor category. Monthly scores in the Fair to Good categories typically occurred during the winter months, primarily December through March. Monthly sub-index scores for total solids and total phosphorus were consistently poor or very poor, while scores for inorganic nitrogen ranged from poor to fair and showed wide seasonal variation. Fecal coliform scores were typically good to excellent, with scattered poor and very poor values particularly in 2005 and 2006. Sub-index scores for water temperature, dissolved oxygen, and pH were consistently good to excellent.

Trends over Time

An analysis of potential statistical trends in OWQI scores based on the 2002 through 2006 dataset found two significant trends at the MIL010 station (Hutton and Hoxeng, 2007).

A downward trend was evident in fecal coliform scores at the 95 percent confidence level. The magnitude of this trend is sufficient enough to result in a projected decrease in overall OWQI category from fair to poor in approximately two years.

Turbidity values at MIL010 showed an increasing trend, indicating a decrease in water quality. This trend was also statistically significant at the 95 percent confidence level.

In the 2007 analysis, only nine statistically significant trends were identified county-wide out of 45 potential trends evaluated (15 monitoring stations and an analysis of potential trends in three parameters including overall OWQI, fecal coliform, and turbidity). The fact that two of these nine trends were located in Mill Creek, and that both trends indicated degrading water quality, suggests that Mill Creek is at increased risk of immediate water quality degradation compared to most other monitored streams in Clark County.

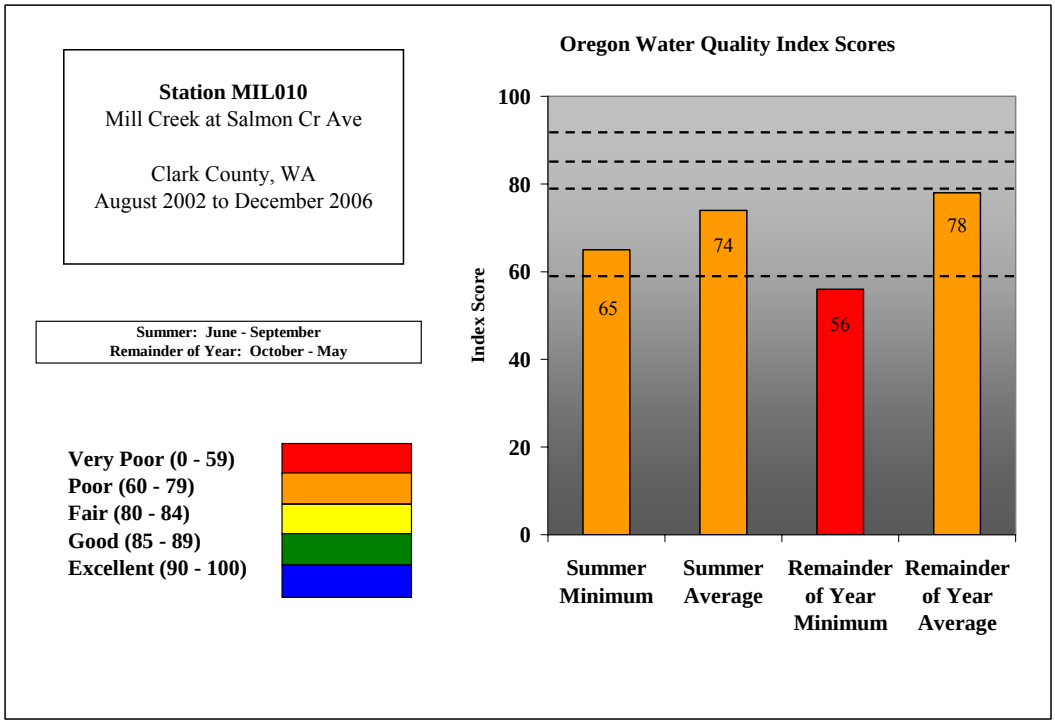


Figure 4: Average Water Quality, Mill Creek station MIL010, 2002 through 2006, Oregon Water Quality Index

Fecal Coliform Bacteria

The overall range of sample values at station MIL010 was 4cfu/100mL to 1060 cfu/100mL.

Figure 5 shows seasonal geometric mean fecal coliform values from June 2002 through December 2006. Based on 16 sampling events, the summer (June through September) geometric mean was 105 cfu/100mL, slightly exceeding the state geometric mean criterion of 100 cfu/100mL. Based on 35 sampling events, the FWS (October through May) geometric mean was 71 cfu/100mL, meeting the state criterion.

Despite meeting or nearly meeting the geometric mean criterion, station MIL010 failed to meet the 10 percent criterion during both seasons, with 31 percent of summer samples and twenty percent of FWS samples exceeding 200 cfu/100mL.

The 10 percent criterion may also be evaluated by examining the 90th percentile values. The criterion is met if the 90th percentile value is 200 or lower. For the MIL010 dataset, the summer and FWS 90th percentile values were 273 and 605, respectively.

As noted above, fecal coliform values appear to be increasing significantly at station MIL010 over the past five years.

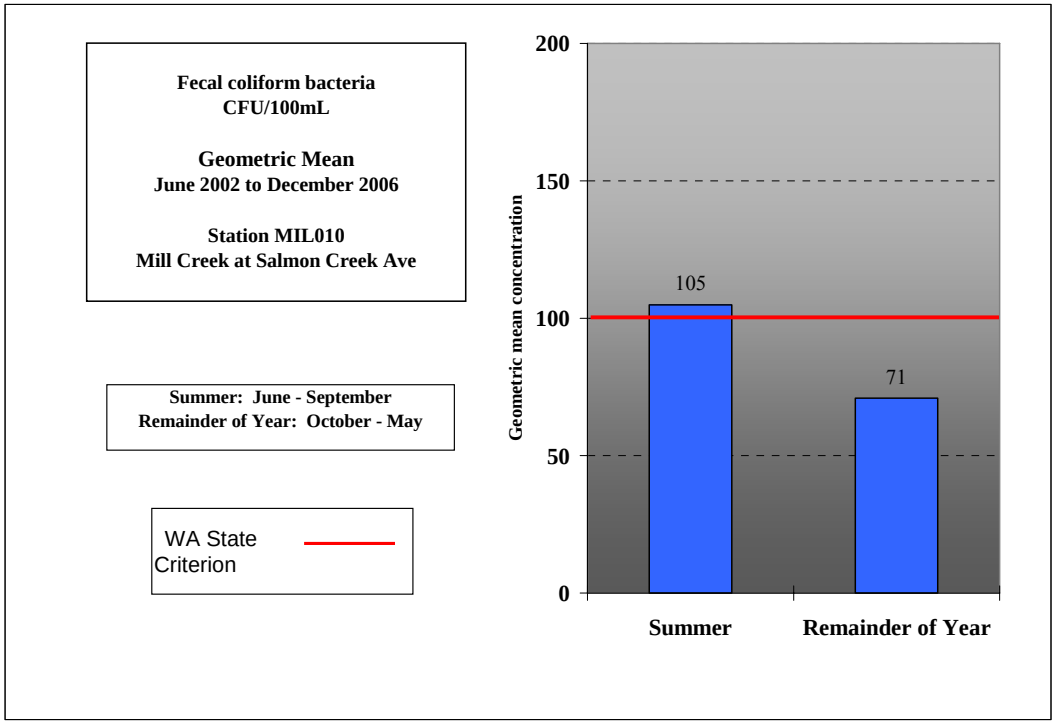


Figure 5: Seasonal Geometric Mean Fecal Coliform, Mill Creek station MIL010, June 2002 through December 2006

Nutrients

Nutrient criteria are not established for Washington streams. US EPA suggests a total phosphorus criterion of 0.100 mg/L for most streams, and 0.050 mg/L for streams which enter lakes (EPA, 1986). EPA nitrate criteria are focused on drinking water standards and are not generally applicable to aquatic life issues.

Phosphorus and nitrogen in excess may contribute to elevated levels of algal or plant growth, especially in slower moving, low gradient streams, or in downstream water bodies.

Total phosphorus samples from MIL010 between May 2002 and December 2006 ranged from 0.038 mg/L to 0.202 mg/L, and 77 percent of samples exceeded the EPA criterion. Total phosphorus concentrations typically vary seasonally in many locations; however, seasonal median values in Mill Creek are relatively similar:

- Summer median = 0.130 mg/L
- FWS median = 0.113 mg/L

Turbidity

It is difficult to establish an exact background turbidity level for Mill Creek because no data exists from a time when Mill Creek was not impacted by human activities. However, based on data from the least-impacted streams monitored by CWP, we estimate that natural background turbidity in most Clark County streams would have been in the range of 0.5 to 2 NTU. Based on this estimate, the turbidity criterion for Mill Creek is likely between 5.5 and 7 NTU.

Since May 2002, the median of 56 turbidity samples at MIL010 is 3.9 NTU, with individual samples ranging from 1.4 NTU to 22 NTU. Turbidity varies seasonally, with the FWS median nearly three times the summer median:

- Summer median = 2.3 NTU
- FWS median = 6.5 NTU

Higher turbidity readings in the 20 to 40 NTU range are common in Clark County streams during storm events. Very high turbidity values (typically 100 or greater) often indicate a specific sediment source. Routine monthly monitoring at MIL010 has not detected turbidity values over 22 NTU since 2002.

Among 15 long-term monitoring stations county-wide, Mill Creek station MIL010 ranked 5th best in average turbidity from 2002 through 2006. As noted above, turbidity values have shown an increasing trend at MIL010 over the past five years.

Stream Temperature

In addition to the routine monthly temperature readings which are incorporated into OWQI calculations, continuous temperature loggers recorded hourly temperature values between May and October during 2002 through 2006. Continuous readings provide a more complete picture of temperature dynamics than monthly grab samples.

Table 5 summarizes the continuous temperature data. The 7-Day average maximum value is the maximum of the 7-day moving average of daily maximum temperatures. The 2006 Ecology standards utilize this metric to determine temperature compliance (Mill Creek criterion is 60.8° F). Maximum daily ΔT is the maximum daily temperature fluctuation, and gives some indication of the susceptibility of the stream to changes in heat input.

Table 5: Seasonal Maximum 7-day Moving Average and Maximum Daily Temperature Change at Mill Creek station MIL010, 2002 through 2006			
7-Day average Date	**Maximum**	**Maximum daily ΔT Date**	**Value**
MIL010:			
07/23/02	66.0	07/09/02	7.6
07/20/03	66.2	06/25/03	6.9
07/25/04	68.2	07/12/04	8.3
07/29/05	66.8	07/27/05	5.9
07/24/06	68.0	06/30/06	6.5

Summer stream temperature at MIL010 was relatively consistent and exceeded the 60.8 degrees F state criterion by 6 to 8 degrees F in each year monitored.

Due to the negative effects of chronic high temperatures on salmonids and other cold-water biota, the amount of time spent with elevated temperatures is also of interest. Figure 6 indicates the number of days on which the *daily* maximum temperature exceeded 64 degrees F at station MIL010. Sixty-four degrees is the Class A criterion prior to the November 2006 rule changes and is a threshold above which salmonids are known to suffer deleterious effects.

The number of days with temperatures exceeding 64 degree F has ranged from 23 to 57. Annual variations are likely attributable to differences in ambient air temperatures and stream flow. Regardless of variations between years and stations, the available Mill Creek data indicates stream temperatures remain elevated over a substantial time period each summer.

Impacts to Beneficial Uses and Potential Sources

General water quality in Mill Creek is poor according to the overall OWQI and other measures discussed above. Listed beneficial uses are directly impacted by several water quality characteristics, including: fecal coliform bacteria, stream temperature, turbidity, total phosphorus, and total solids.

Observed levels of these characteristics may have negative impacts on the listed beneficial uses of: core summer salmonid habitat; primary contact recreation; wildlife habitat; and aesthetic values. Table 6 at the conclusion of this section summarizes the primary water quality impacts to beneficial uses in Mill Creek, and probable sources of the observed impact.

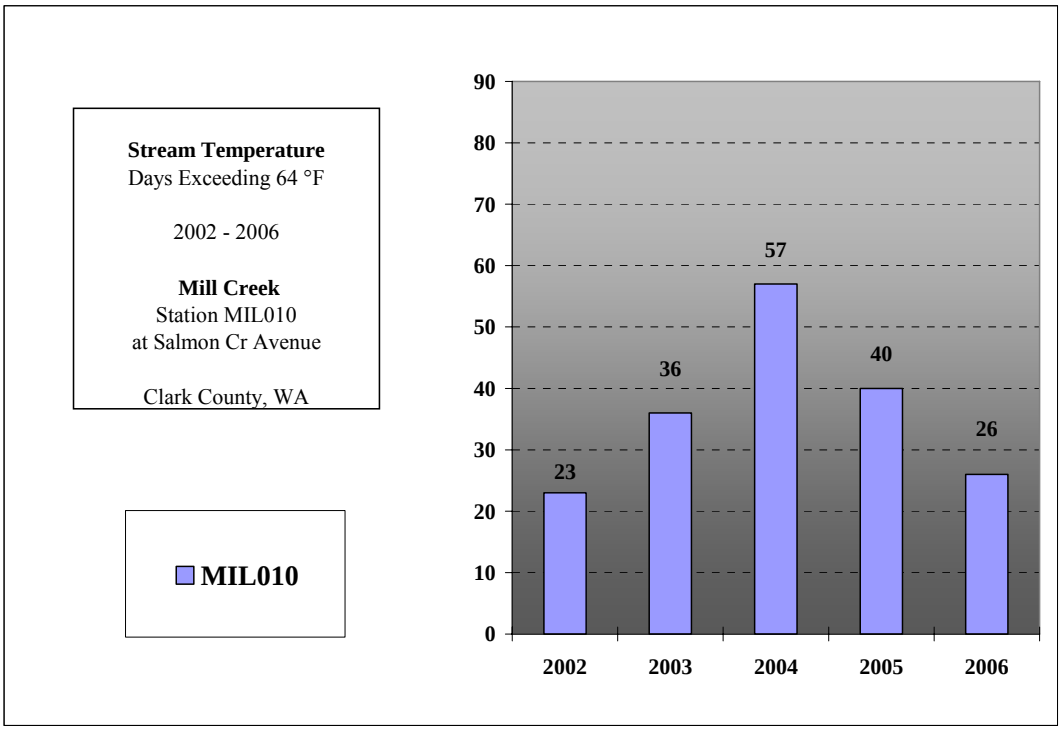


Figure 6: Days Exceeding 64° F, 2002 through 2006, Mill Creek station MIL010

Fecal Coliform Bacteria

Mill Creek has no developed swimming or wading areas, but it is likely that some local residents, particularly children, utilize the creek for recreation. Although water contact may take place year-round, elevated bacteria counts are of particular concern during the summer months when the majority of water contact recreation occurs.

For the most part, instances with substantially elevated bacteria levels in Mill Creek have tended to occur during the FWS period rather than during the summer. The five highest recorded bacteria counts all occurred during FWS. While this does not alleviate concern about slightly elevated levels during the summer, it does suggest that the period of highest risk occurs during seasons when water-based recreation is less common.

If current trends continue, increases in fecal coliform could result in elevated risk to recreational users.

Turbidity and Solids

Aesthetic enjoyment can be limited by high turbidity. Mill Creek exhibits relatively low routine turbidity levels based on county-wide monitoring data, but is likely susceptible to high short-term turbidity during rain events. The increasing trend in turbidity values in recent years is a concern.

The primary sources of turbidity in Mill Creek are probably soil and bank erosion-related. Both off-site erosion (development, agriculture, recreational

vehicle use) and in-stream erosion (bank scour, slumping, and re-suspension of sediments during high flows) likely contribute significantly to the elevated turbidity during rain events.

To a lesser extent, the elevated total phosphorus levels observed at station MIL010 have the potential to increase turbidity by contributing to excessive plant and algae growth, especially in ponded areas and downstream in Salmon Creek.

Elevated total solids concentrations are a concern. Sedimentation of the suspended solids component may compromise gravel spawning areas, smother eggs, and impact food availability by suppressing benthic macroinvertebrate populations. The available total solids and turbidity data suggests Mill Creek carries a higher than desirable load of dissolved solids.

Total Phosphorus (TP)
Currently, despite high nutrient levels, algae growth does not appear to contribute greatly to observed turbidity. However, the downstream impacts of high phosphorus concentrations may be more significant than local effects. When high-nutrient water enters slower-moving areas downstream, the nutrients are readily available for utilization by plants and algae.

The consistently elevated TP concentrations year-round indicate that a variety of sources are contributing at different times. Potential sources in Mill Creek include groundwater contributions, human or animal waste, and erosion of upland soils with high clay content. These sources may be transported to the stream through groundwater movement, as well as through the storm sewer system, overland runoff, and direct animal access (including wildlife).

Water Temperature
Water temperature may be an impediment to salmonid use in Mill Creek. In particular, elevated temperatures have a detrimental impact on salmonid rearing. Migration and spawning tend to occur during cooler times of the year, but juveniles are exposed to elevated summer temperatures during rearing.

Temperature-related impacts to salmonids begin to occur at stream temperatures greater than 64 degrees F. Impacts include: decreased or lack of metabolic energy for feeding, growth or reproductive behavior; increased exposure to pathogens; decreased food supply; and increased competition from warm-water tolerant species (ODEQ, 2004 draft).

Mill Creek is consistently among the cooler streams monitored by the CWP, though summer temperatures regularly exceeds 64 degrees F and significantly exceeds the current 60.8 degrees F state criterion. This suggests temperature moderation will be a necessary component in any plan to maintain and/or recover fish populations in Mill Creek.

Solar radiation is the primary driver of water temperature. The susceptibility of a stream to solar radiation is influenced by several factors including stream flow, channel form, canopy cover (shade), ponds, and the extent of groundwater influence. Below average summer stream flows over the past several years have made the stream more susceptible to temperature impacts.

Mill Creek has many sections which would benefit from riparian enhancement; fortunately, many of these are currently being addressed through restoration work by Clark Public Utilities and others.

Given the relatively dry summers in the Pacific Northwest, stormwater systems generally should not be a major factor in elevating summer temperatures. In some cases, storm sewers may even contribute cool water in the form of piped baseflow. However, urban runoff from summer storms can cause stream temperatures to spike well above the criterion for a short period of time.

Implications for Stormwater Management

Table 6 lists the primary known water quality concerns and potential solutions for each. Solutions listed in bold indicate areas where CWP activities can have a positive impact. It should be noted that CWP activities, though important, are not likely to achieve water quality improvement goals on their own. Other county departments, local agencies, and not least of all, the public must all contribute to water quality improvement.

Among the CWP activities most likely to have a positive impact on water quality are:

- effective stormwater system designs, retrofitting, and maintenance
- source detection and removal projects; and
- public education programs

Stormwater system design, retrofitting, and maintenance include a range of activities that can address specific pollutants of concern. Source detection and removal projects help eliminate specific contributions of pollutants. Education programs, though they rarely have a direct impact on water quality, are a critical element in modifying behavior and promoting better public stewardship of water resources.

Table 6. Known Water Quality Concerns, Sources, and Solutions for Mill Creek				
Characteristic	**Beneficial Use Affected**	**Potential Sources**	**Mechanism**	**Solutions (bold indicates direct Clean Water Program involvement)**
Fecal coliform bacteria	Primary contact recreation	failing septic systems	groundwater seeps storm sewers	**Storm sewer screening for source identification and removal** **Education programs** **Storm water facility designs/retrofits to optimize bacteria reduction (see Schueler, 1999)** Agricultural Best Management Practices Septic and sanitary sewer system inspection and maintenance
		sanitary sewer leaks	groundwater seeps storm sewers	
		livestock, pets, wildlife	overland runoff storm sewers direct access	
Water temperature	Core summer salmonid habitat	vegetation removal	direct solar radiation	**Stormwater infiltration to increase baseflow** **Streamside planting/vegetation enhancement/riparian preservation through acquisition** **Education programs** Pond removal or limitation
		ponds	direct solar radiation stagnation	
		low summer flows	decreased resistance to thermal inputs	
Total solids	Core summer salmonid habitat	erosion *(development projects; land clearing; cropland; impervious surfaces; channel erosion)*	overland runoff storm sewers channel dynamics	Erosion control regulations **Storm sewer system cleaning and maintenance** Agricultural Best Management Practices Stream bank stabilization/rehabilitation **Storm water outfall/facility retrofits to reduce flow-induced channel erosion**
Total phosphorus	Aesthetic enjoyment	natural groundwater	groundwater seeps	Erosion control regulations Septic system inspections and maintenance Sanitary sewer leak identification and removal **Storm sewer system cleaning and maintenance** **Storm water facility designs/retrofits to optimize settling and removal of suspended silt/clay** Agricultural Best Management Practices **Education programs (reduced fertilizer use)**
		fertilizers	overland runoff storm sewers	
		erosion	(see turbidity)	
		livestock, pets, wildlife	(see bacteria)	
		failing septic systems	(see bacteria)	
		sanitary sewer leaks	(see bacteria)	

Drainage System Inventory

Clark County's drainage system inventory resides in the StormwaterClk GIS database and is available to users through the county's Department of Assessment and GIS, or through the Digital Atlas located at:

http://gis.clark.wa.gov/imf/imf.jsp?site=digitalatlas&CFID=56651&CFTOKEN=98300052

The drainage system inventory is an ongoing CWP programmatic element focused on populating and updating the StormwaterClk database to include all existing stormwater drainage infrastructure.

Priority effort in the Mill Creek report area was directed toward identifying and mapping previously unmapped discharge points and stormwater facility polygons to support the Illicit Discharge Detection and Elimination Screening project (IDDE), and to a lesser extent the Public Facility Inspection project. Table 7 indicates the number of features previously inventoried in StormwaterClk prior to 2007 SNAP work, and the number of features added to the database as a result of 2007 SNAP implementation.

The drainage system inventory for the Mill Creek subwatershed remained incomplete at the conclusion of 2007 SNAP implementation. Staff availability was insufficient to complete this task as scheduled. Inventory completion is ongoing in 2008 and 2009 as part of a county-wide inventory update.

Table 7: Drainage System inventory Results, Mill Creek Watershed

Database Feature Category	Previously Inventoried	Added to Database During 2007 SNAP
Inlet	219	48
Discharge Point (outfall)	19	222
Flow Control	31	9
Storage/Treatment	205	20
Manhole	90	31
Filter System	4	1
Channel	381	174
Gravity Main	761	334
Facilities	58	4

Stormwater Facility Inspection

The Public Stormwater Facility Inspection project is designed to meet requirements of Clark County's 2007 NPDES permit which requires an ongoing inspection program for county stormwater treatment and flow control facilities.

The stormwater facility inspection process includes two components:

- a public stormwater facility inspection using state and county standards
- an off-site inspection to check for problems such as downstream bank erosion

Component 1: Public Stormwater Facility Inspection

Purpose

The purpose of Public Stormwater Facility Inspection project is to verify that maintenance activities are implemented, that facilities are properly functioning, and identify possible retrofit projects and major repairs.

Methods

The Public Stormwater Facility Inspection project is derived from county and state standards equivalent to maintenance standards specified in Chapter 4 of Volume V of the 2005 *Stormwater Management Manual for Western Washington*. The standards list the part or component of the facility that may need repairs, the condition when repair or maintenance is needed, and the expected results. Individual components of a facility are referred to as "facility objects" and are listed in Table 8.

The public stormwater facility inspection process involves inspecting all facility objects to determine if all maintenance is in compliance with the standards. If any facility object does not meet the maintenance standards, the entire facility is not in compliance. Non-compliant stormwater facilities are referred to the appropriate public works departments for repairs or maintenance.

Results

Based on the county's StormwaterCLK database, as of December 2007, there were 19 mapped public stormwater facilities in the Mill Creek subwatershed.

Figure 7 summarizes notable inspection activities including general facility location, compliant facilities and referrals of non-compliant facilities.

As listed in Table 8, 19 public stormwater facilities in the Mill Creek subwatershed were inspected, including a total of 74 facility objects. Seventy (95 percent) of the facility objects were in compliance. The remaining four (5 percent) of the facility objects were not in compliance.

The inspection process generated three referrals: one referral was to the Clark County Public Works Clean Water Program engineer, and two referrals were to Public Works Maintenance and Operations for needed maintenance activities.

Maintenance Referrals

Referrals made to public works maintenance and operations department have been either brought into compliance, or will be scheduled for repair or maintenance in early 2008. As of December 2007, public works maintenance and operations have brought one of the two non-compliant facilities into compliance, including three of the seven facility objects.

Once referrals are addressed, the CWP revisits facilities to conduct a second inspection to ensure compliance.

No major defects or hazardous conditions were discovered; non compliant issues included excess sediment depth and grate damage.

Retrofit Opportunities

The public facility inspection process in the Mill Creek subwatershed yielded one retrofit opportunity. This opportunity includes retrofitting a pond to better treat stormwater runoff.

Management Recommendations

No trend or commonality between defects existed between facility objects. Overall, public stormwater facilities in the Mill Creek subwatershed were well maintained.

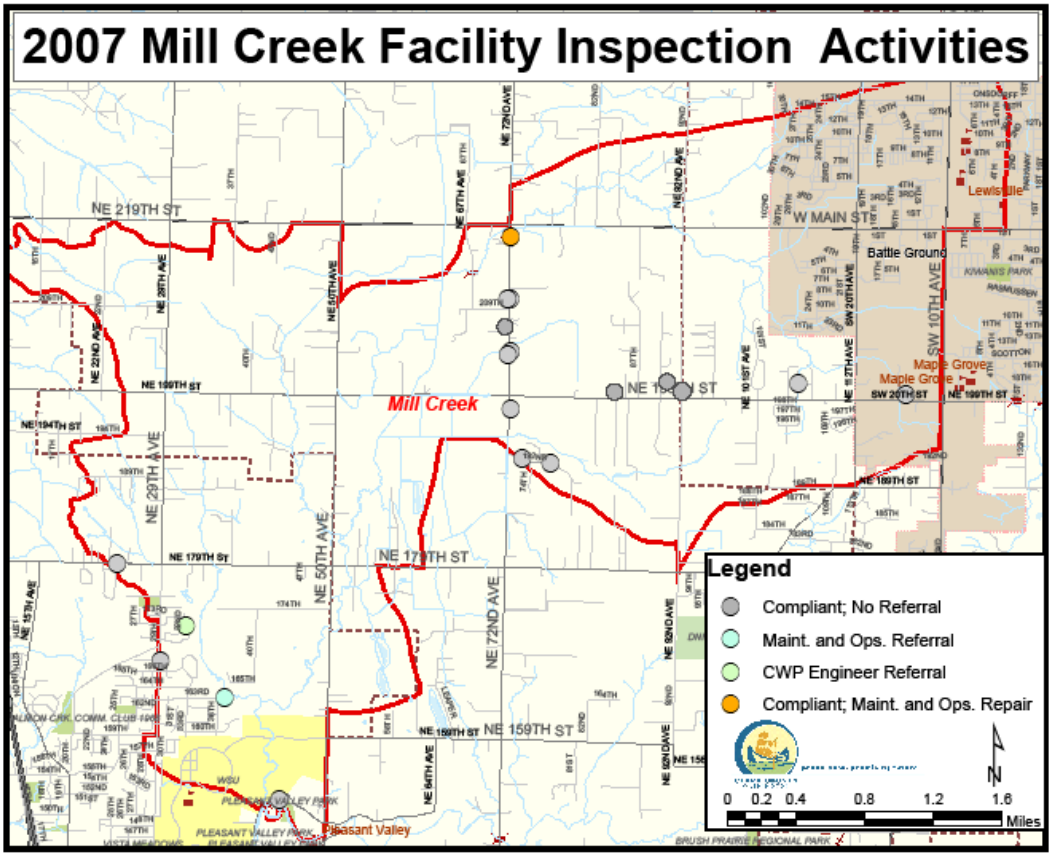


Figure 7: Summary of 2007 Public Stormwater Facility Inspection Activities in Mill Creek Watershed

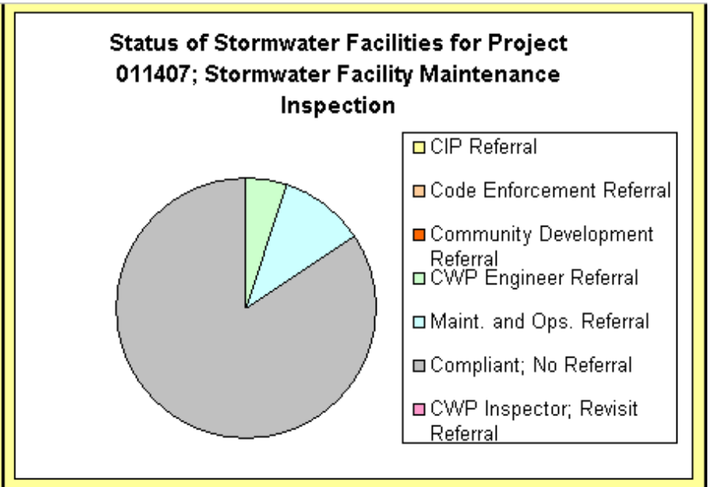
Table 8: 2007 Public Stormwater Facility Inspection Project Activity of the Mill Creek Watershed

SNAP Public Stormwater Facility Inspections (maintained by Public Works)

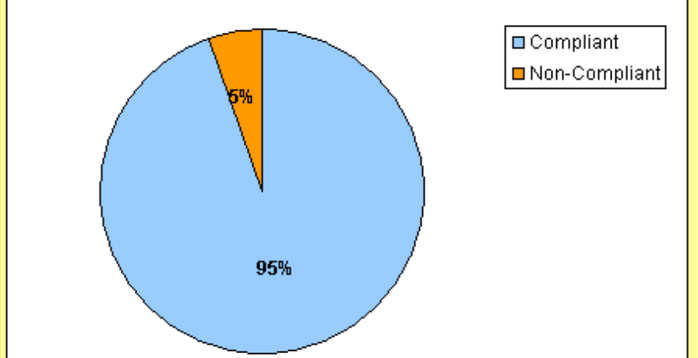
Subject: Mill Creek Subwatershed; Project 011407 Stormwater Facility Maintenance Inspection Initial Results

Total SNAP SWF Inspections	
Maintained by Public Works	**19**
Compliant	**16**
Non-Compliant	**3**
Not Visited (Under Construction)	**0**

Referrals of Non-Compliant SWF's as December 2007		**Referral Addressed and Facility Compliant as of December 2007**
CIP Referral	0	n/a
Code Enforcement Referral	0	n/a
Community Development Referral	0	n/a
CWP Engineer Referral	1	1
Maint. and Ops. Referral	2	2
Compliant; No Referral	16	n/a
CWP Inspector; Revisit Referral	0	0



Facility Objects Inspected	**Initial Inspections**		**Defect**	**Maintence Trigger**	**Facility Objects Repaired as of December 2007**
	Compliant	**Non-Compliant**			
Access Road or Easement	13	0	N/A	N/A	N/A
Catch Basin	7	0	N/A	N/A	N/A
Closed Detention System	1	0	N/A	N/A	N/A
CONTECH StormFilter	0	0	N/A	N/A	N/A
Control Structure / Flow Restrictor	7	2	metal grate damaged or missing	N/A	N/A
Debris Barrier	0	0	N/A	N/A	N/A
Detention Pond	6	1	sediment & debris	Accumulated sediment exceeds 10% of the designed pond depth	N/A
Drainage Trench	2	0	N/A	N/A	N/A
Drywell	0	0	N/A	N/A	N/A
Energy Dissipater	4	0	N/A	N/A	N/A
Fence, Gate or Water Quality Sign	4	0	N/A	N/A	N/A
Field Inlet	4	0	N/A	N/A	N/A
Infiltration Basin	0	0	N/A	N/A	N/A
Infiltration Trench	0	0	N/A	N/A	N/A
Inlet / outlet storm pipe	0	0	N/A	N/A	N/A
Sediment Trap	0	0	N/A	N/A	N/A
Typical Biofiltration Swale	19	0	N/A	N/A	N/A
Wet Biofiltration Swale	3	1	water depth	N/A	N/A
Wetland	1	0	N/A	N/A	N/A
Wetpond	0	0	N/A	N/A	N/A
Wetvaullt	0	0	N/A	N/A	N/A
Total SWF Objects	**70**	**4**			
Total Percentage	**95**	**5**			



Component 2: Offsite Assessment

Purpose

Stormwater outfalls can cause moderate to severe erosion as stormwater moves from the outfall, through the riparian zone, and to the receiving water. The erosion creates a source of sediment to the stream due to incision and slope failures.

The purpose of the Offsite Assessment project is to detect possible offsite or downstream problems associated with the county's municipal separate storm sewer system (MS4), particularly from facility outfalls that discharge to critical areas.

Methods

County owned and operated stormwater outfalls meeting one or more of the following criteria were included in the offsite assessment:

- within 200 feet of a critical area such as stream channel
- within 300 feet of a headwater stream
- Located on public land
- Discharges stormwater from a public-dedicated facility that is currently under the two year private maintenance warranty bond

The Offsite Assessment project is based on county and state standards equivalent to the maintenance standards specified in Chapter 4 of Volume V, of the 2005 *Stormwater Management Manual for Western Washington*. The standards list general design criteria and outfall features critical to reducing the chance of adverse impacts due to concentrated discharges from pipe systems and culverts, both onsite and downstream.

The offsite assessment process involves inspecting all outfalls that discharge into critical areas, as well as a 300 foot survey downstream of the outfall to look for any adverse impacts that may be caused by stormwater discharges.

If any outfall fails to meet the general outfall design criteria or is contributing to aggravation or creation of a downstream erosion problem, the outfall is not in compliance. Non-compliant outfalls are referred to the appropriate Public Works program for maintenance or repair.

Results

Based on the County's StormwaterCLK database, as of August 2007, there were 105 mapped outfalls in Mill Creek subwatershed that discharged into critical areas.

Figure 8 summarizes notable outfall assessment activities including critical areas and general outfall locations.

As summarized in Table 9, 105 outfalls that discharged into critical areas were assessed. One hundred and four outfalls were found to be in compliance. One outfall was not in compliance due to a serious erosion and instability problem.

Potential Projects

The outfall assessment project initiated one referral to a Clean Water Program Engineer. It was discovered that a serious erosion problem was occurring at Outfall 227. The repair of this outfall is included in the Analysis of Potential Projects section.

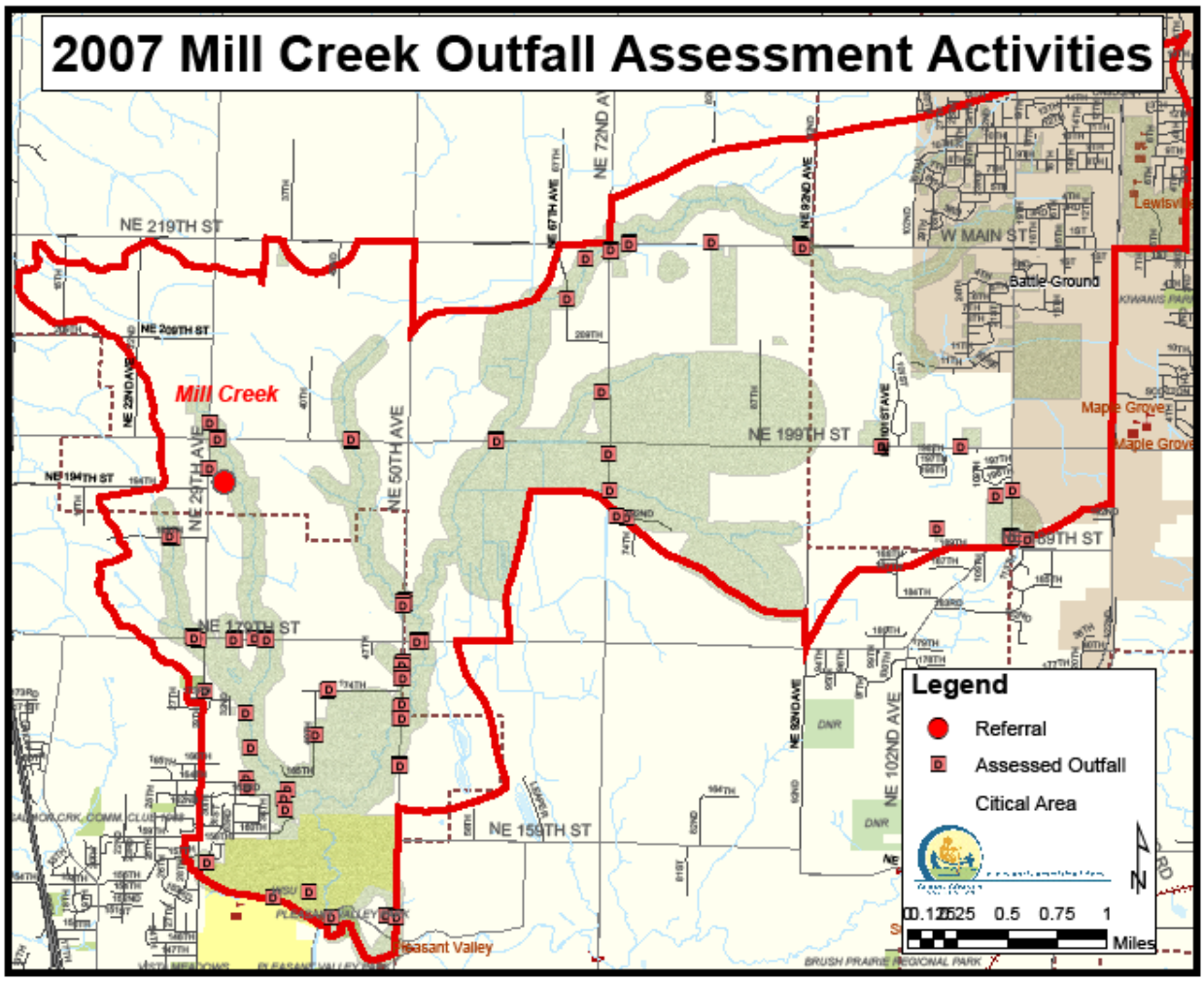


Figure 8: Summary of 2007 Outfall Assessment Activities in Mill Creek Watershed

Table 9: 2007 Outfall Assessment Project Activity Summary of Mill Creek Watershed	
Metric	Number
# of outfalls assessed	105
# of outfalls compliant	104
# of noncompliant outfalls	1
# of referrals initiated	1
# of referrals ongoing	1
# of outfalls fixed	0

Illicit Discharge Detection and Elimination (IDDE) Screening

Purpose

The purpose of the IDDE Screening project is to detect, isolate, and eliminate illicit connections and illicit discharges to Clark County's municipal separate storm sewer system (MS4).

The IDDE screening project is designed to meet the requirements of Clark County's 2007 NPDES permit, which requires identifying and removing illicit connections to the county's MS4.

Methods

IDDE screening includes checking every stormwater outfall for potential illicit discharges, conducting follow-up investigations to track down suspected discharges or connections, and referrals to the proper agencies for termination. Field work is primarily conducted during the dry summer season.

IDDE Screening activities were completed in the Mill Creek subwatershed during 2007.

Results

Based on the county's StormwaterCLK database, as of August 2007, there were 231 mapped stormwater outfalls in the Mill Creek subwatershed consisting primarily of pipe outfalls and roadside ditches.

Figure 9 summarizes notable screening activities including general outfall locations, outfalls where water samples were collected, follow-up investigations performed, referrals made, and sources removed for the Mill Creek subwatershed.

As summarized in Table10, 231 outfalls were screened and samples were collected at two outfalls. Follow-up investigations were conducted for one location. In this case, follow-up investigation samples did not indicate ongoing illicit discharges. This location will be re-visited during the 2008 screening to check for recurrence and/or the presence of intermittent discharges.

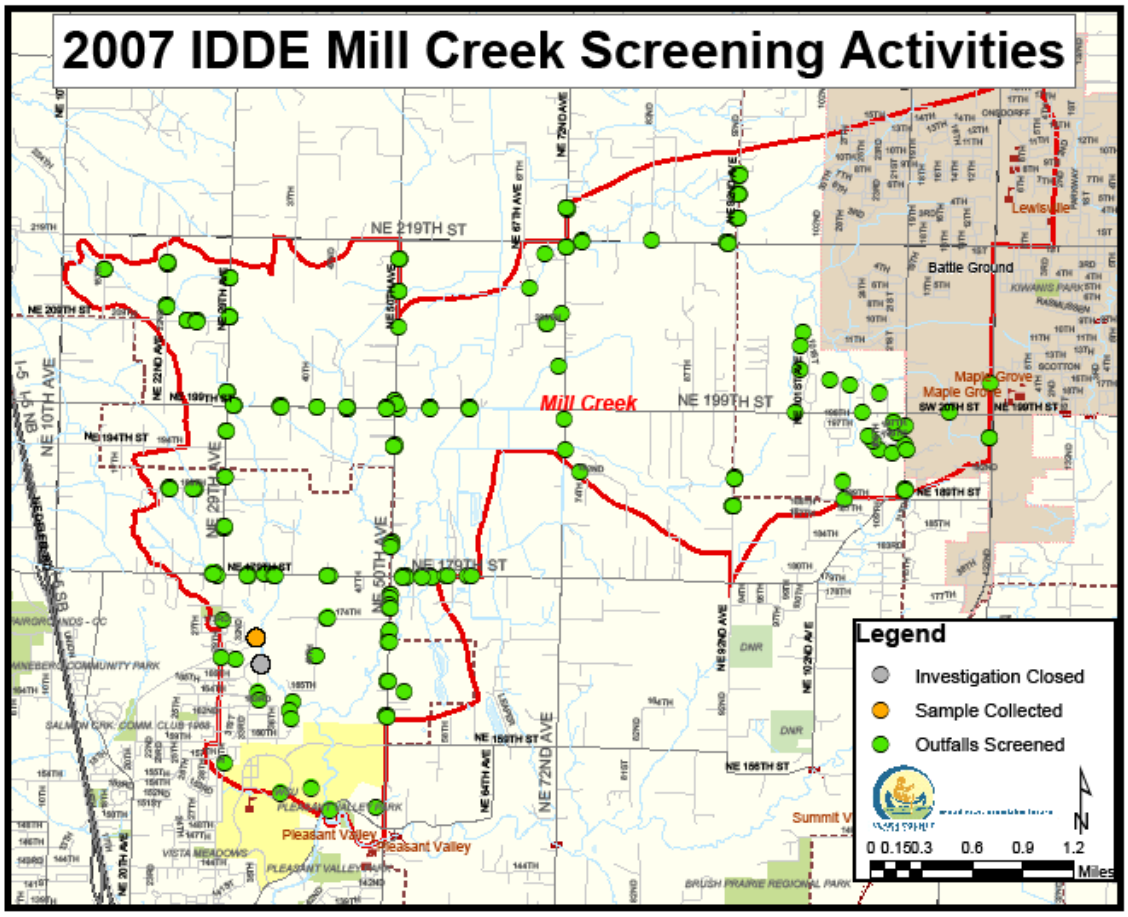


Figure 9: Summary of 2007 IDDE Screening Project Activities in Mill Creek Watershed

Table 10: IDDE Screening Project Activity Summary of Mill Creek Subwatershed as of December 2007	
Metric	**Number**
# of outfalls screened	231
# of outfalls with sufficient flow to collect water samples	2
# of suspected illicit discharges	1
# of suspected illicit connections	0
# of investigations initiated	1
# of illicit discharge sources located	0
# of illicit connections identified	0
# of outfalls to be re-visited in 2008	1
# of referrals	0
# of illicit discharges removed	0
# of investigations and referrals ongoing	0
# of illicit connections terminated	0
# of cases closed without resolution	0

Samples were collected at two flowing outfalls, and a follow-up investigation was performed at one outfall. Laboratory results confirmed an illicit discharge for fecal coliform

An on-site investigation of pipe outfall and the upstream pipe conveyance storm sewer system was conducted by Clean Water Program staff. Investigation samples collected did not indicate ongoing illicit discharges (see Case Study 176).

2007 IDDE Screening Project

Case Summary: 176
Date: September 2007

Stormwater Outfall ID: 176
Investigation ID: 77

Stormwater Outfall Description:
Pipe outfall, CMP, 36"

Drainage area: ~30 ac

Initial screening:
Initial screening was completed on July 31, 2007 (Figure 10). Flowchart analysis of fecal coliform concentration indicated the slight possibility of a sanitary wastewater source (Table 11). Estimated flow at the outfall at the time of sampling was low (< 0.02 cfs).

Table 11: August 15th Laboratory Results

Flowchart	Result (cfu/100mL)	Trigger (cfu/100mL)
Fecal coliform	570	>500

Investigation:
Lab report stating a fecal coliform value of 570 was received on August 15, 2007. New investigation and follow up sampling was conducted by Water Resources on August 16, 2007.

Outfall #176 was re-sampled for fecal coliform to confirm the presence of elevated levels. Four additional samples were collected from the storm system upstream from outfall #176 (Figure 11) as part of a network investigation.

Fecal coliform concentrations were very low at all testing locations on August 16th (Table 12) suggesting an intermittent or transitory source, potentially wildlife related.

Although follow up fecal coliform concentrations results were very low, this stormwater outfall was located in the vicinity of a sewer pump station making potential for bacteria loading high. Therefore, an additional sample was taken September 11, 2007 at discharge point 176. This sample also yielded very low (21/100mL) fecal coliform concentrations. Due to these low fecal coliform concentrations, no additional investigation was performed.

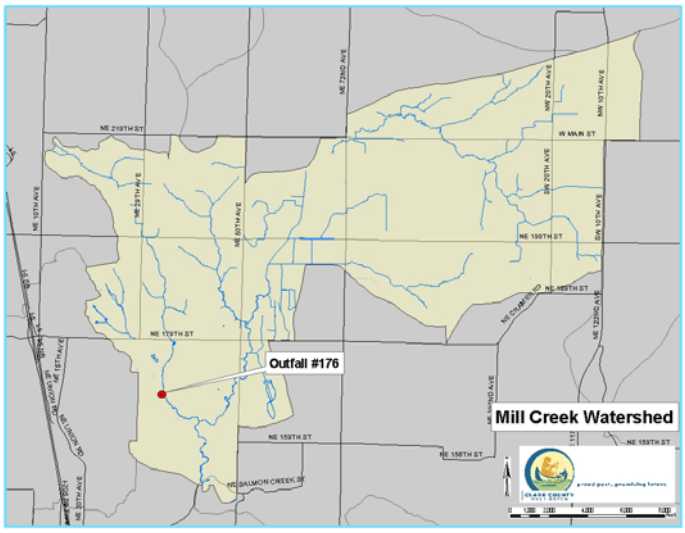


Figure 10: General location of Outfall #176

Referral:
No referral was necessary in this case.

Responsible Party:
None

Corrective Action:
None

Effectiveness Monitoring:
None

Outfall status:
OK

Additional Actions/Discussion:
This location will be revisited in 2008.

Table 12: August 16th Fecal Coliform Values

Site	Fecal coliform (cfu/100mL)
176	15
A	3
B	9
C	9
D	2

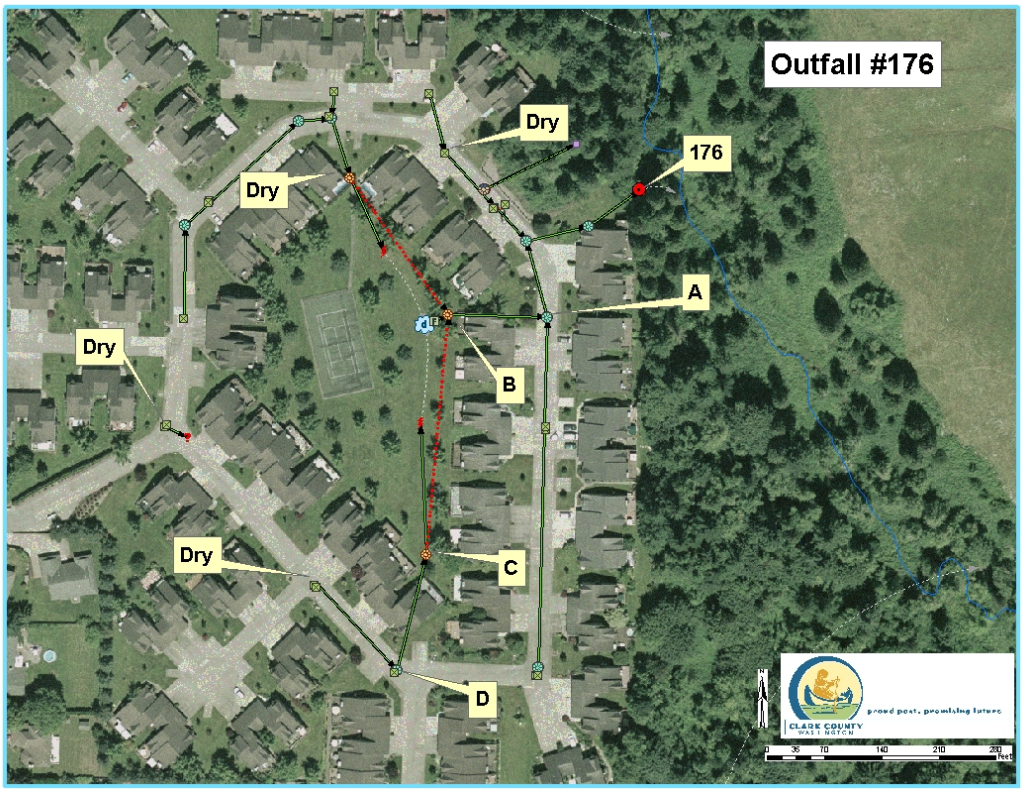


Figure 11: Investigation map of discharge point 176 conducted on August 16, 2007.

Stream Reconnaissance and Feature Inventory

Reach Reconnaissance Survey

No rapid reach assessment was completed for Mill Creek

Feature Inventory Summary – Mill Creek Subwatershed

Purpose

The Feature Inventory records the type and location of significant stream impairments, potential environmental and safety hazards, and project opportunities in selected stream reaches. Feature Inventory results are used primarily to document conditions, and identify potential improvement projects or management actions for implementation by the CWP or other agencies.

Methods/Limitations

The Feature Inventory project is not intended to be an exhaustive inventory of all human alterations to the stream corridor. Rather, the project seeks to identify the most significant features pertaining to stormwater management and potential stormwater mitigation projects.

The County, with input from Herrera Environmental Consultants, established geographic scope of the Feature Inventory by taking into consideration projected TIA, DNR water types, stream gradient, zoning, Clark County development permitting authority, and land ownership.

The Feature Inventory recorded significant conditions in the stream corridor relevant to SNAP components. Feature types are listed in Table 13.

The in-stream assessment approach allowed investigators to observe stream corridor features that are not always identifiable through other desk methods such as analysis of existing aerial photographs and GIS data.

A GPS position, digital photos, and relevant attribute information were collected for each logged feature. All data and linked photos are stored in the Feature Inventory Geodatabase located on the Clark County server at: W:\PROJECT\011418, Stream Reconnaissance SNAP\GIS\Data\Geodatabase. Feature data includes field observations, estimated measurements, and/or notes describing important feature characteristics or potential projects.

Feature dimensions and other attribute data are estimates, and should not be utilized for quantitative calculations.

For additional information pertaining to the Feature Inventory SNAP tool, see Volume 1 of the SNAP.

Study Area

The extent of the completed Feature Inventory in Mill Creek subwatershed is shown in Figure 12. Approximately six miles of the stream corridor were assessed in the subwatershed. No notable stream reaches were omitted from the planned extent of the Feature Inventory survey.

Results/Findings

A total of 71 features were identified in the Mill Creek subwatershed. A breakdown of recorded features by type is presented in Table 13. Stream crossings were the most prevalent feature type identified, followed by impacted stream buffers, stormwater outfalls, and access points. Mill Creek had a more diverse set of features than the other subwatersheds that were inventoried, which is reflected in a broader range of potential projects.

Table 13: Summary of Features Recorded in Mill Creek Subwatershed

Feature Type	Number of Recorded
AP – Access point	5
ER – Severe bank erosion	1
CM – Channel modification	2
IB – Impacted stream buffer	21
IW – Impacted wetland	1
MI – Miscellaneous point	5
MB – Miscellaneous barrier	1
OT – Stormwater outfall	5
SC – Stream crossing	24
TR – Trash and debris	2
UT – Utility impact	1
WQ – Water quality impact	3
Total	**71**

A map showing the location and type of all recorded features is shown in Figure 13. A larger, poster-sized version of the same map is on file at the County. In addition, specific information collected at each feature can be accessed by using the Feature Inventory Geodatabase.

The following subsections contain general descriptions of Mill Creek subwatershed conditions. The descriptions include observations, trends, and issues that were identified either during the field work or during subsequent review of collected information.

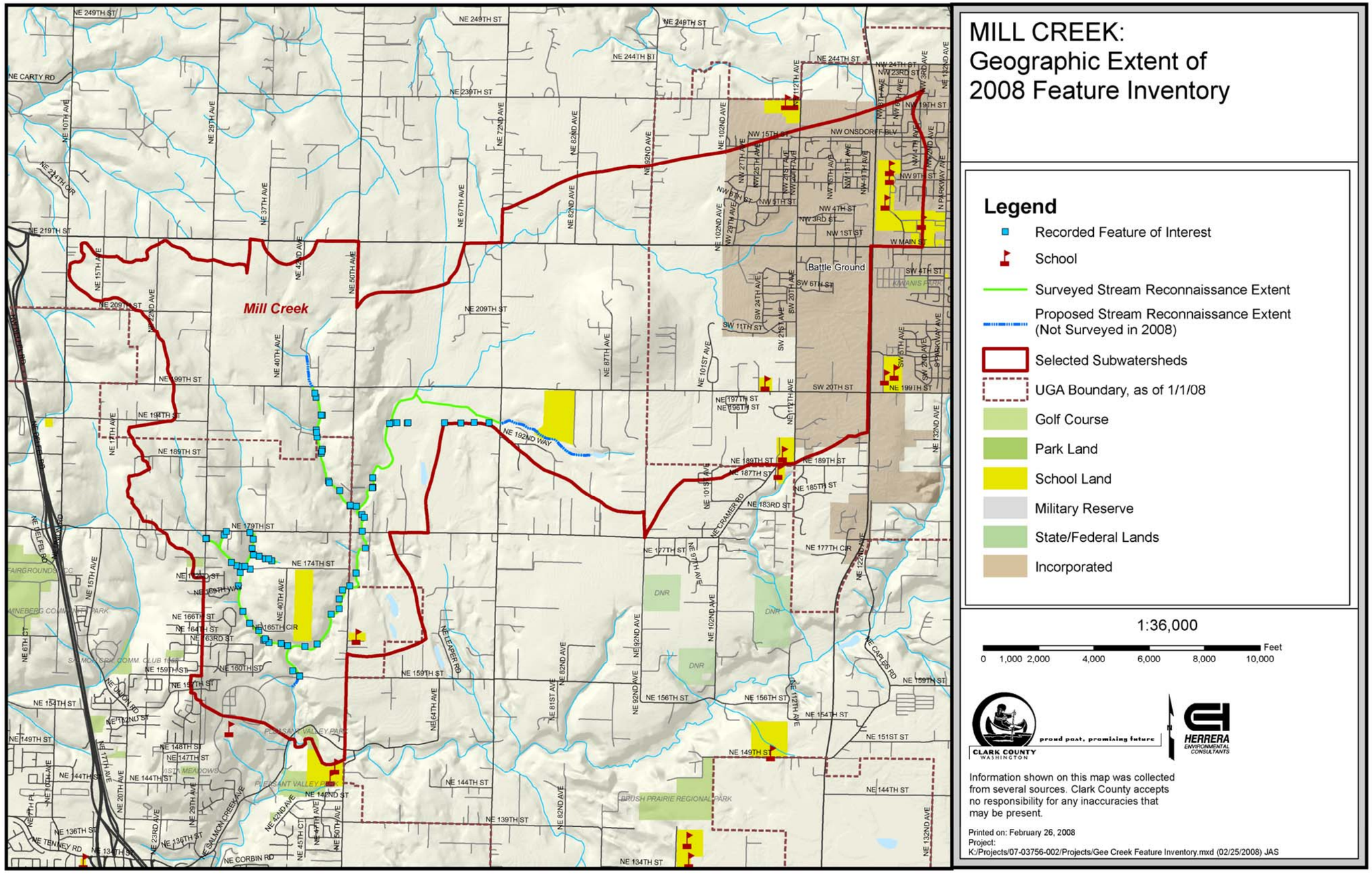


Figure 12: Extent of Field Effort and Location of Recorded Features

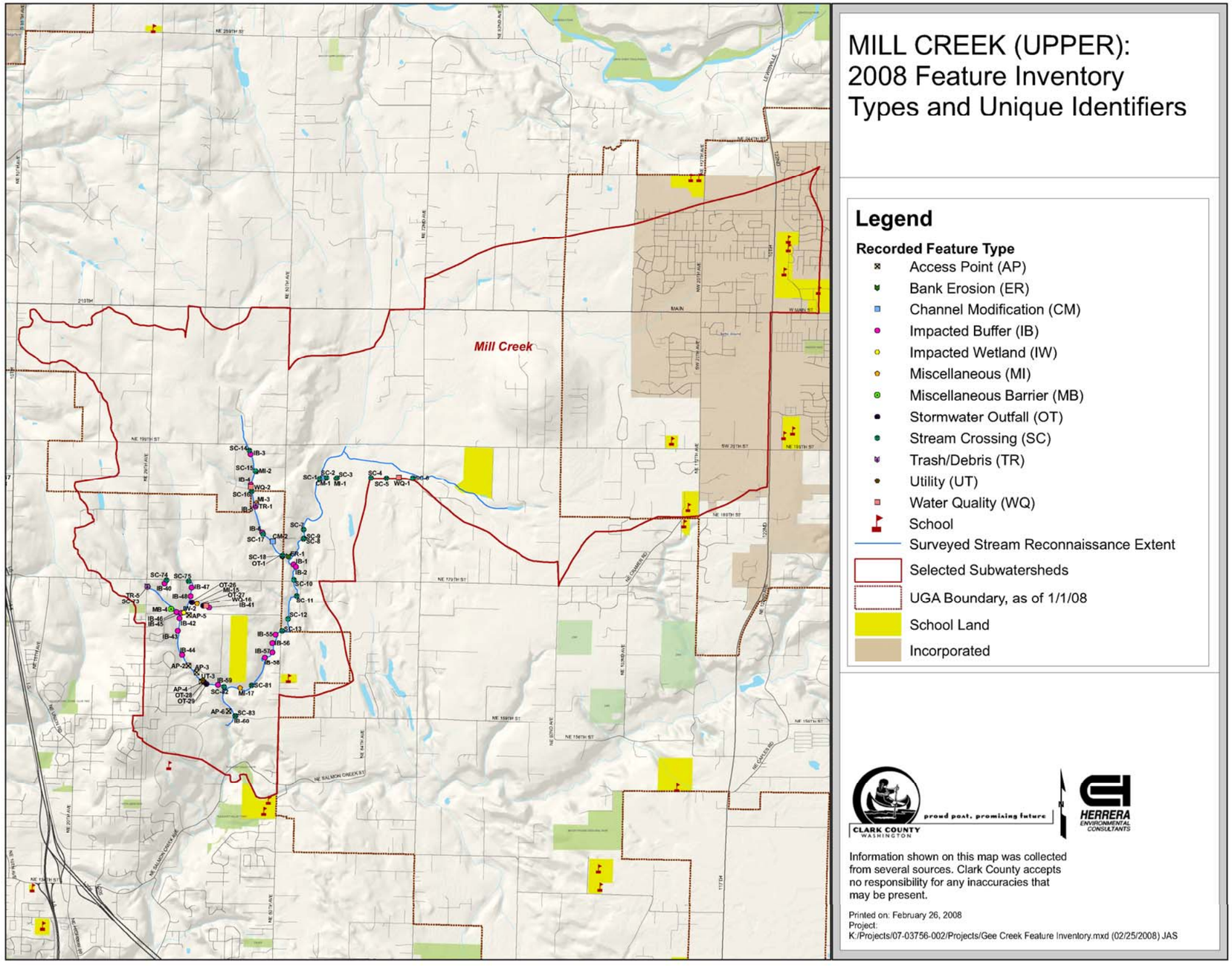


Figure 13: All Recorded Features with Feature Type

Stormwater Infrastructure

Stormwater conveyance to surveyed reaches of Mill Creek and its tributaries are mainly via roadside ditches, with occasional piped inputs originating in residential areas. Flows in the subwatershed are predominately north to south. The predominant source of stormwater in the surveyed areas of the subwatershed is road surfaces, with a smaller contribution from impervious surfaces related to residential development.

Riparian Vegetation

Riparian vegetation conditions are highly variable in the Mill Creek subwatershed. Vegetation ranges from cleared agricultural land with invasive species on stream banks, to mature and seemingly old growth forest in some isolated areas. The most common condition encountered was partial riparian forest canopy with widespread invasive plant species for undergrowth. Impacted stream buffers are prevalent in the Mill Creek subwatershed where invasive plant species – typically reed canary grass and/or blackberry – dominate the riparian area. A large expanse of mature riparian forest exists on private property upstream of the Washington State University Vancouver Branch Campus. Clark Public Utilities is actively involved in revegetation efforts along many stream reaches in the Mill Creek subwatershed. In the past few years, extensive areas have been planted with native woody vegetation and are being managed to control invasive plant species.

Channel Condition

Two typical channel morphologies dominate the upper subwatershed. The primary channel morphology is planar, and the channel bed is structurally controlled by clay acting as weak bedrock. Inflections in the profile likely occur along jointing weaknesses. The bed is smooth, with low hydraulic roughness, resulting in supply limited conditions (high transport capacity relative to sediment supply). However, an alluvial veneer in the form of sand and gravel deposition is locally present near areas of increased hydraulic roughness such as flow obstructions. Bank erosion is limited due to root cohesion. The second typical channel morphology is best described as an E-type channel (Rosgen 1996) or, in other words, it is a stable, single-thread, sinuous channel with typically vertical, fine-grained cohesive banks and a low width-depth ratio. The bed is composed primarily of cohesive clay or gravel and sand in a clay matrix. Generally, stream channels within the surveyed reach are stable, but have a somewhat simplified cross-sectional and plan view geometry. The channel exhibits little diversity in bedforms and habitat. Sand and gravel deposition was observed in a limited number of locations. Surveyed reaches are not experiencing significant bank erosion.

Near the downstream extent of the Feature Inventory survey, the typical channel morphology transitions to a plane bed (Montgomery and Buffington 1997) with alluvial substrate consisting of gravel and small cobble. The stream channel is stable, but has a simplified cross-section and plan view geometry, and exhibits

little diversity in bedforms and habitat. A limited number of forced pool channel types (Montgomery and Buffington 1997) were observed in areas where woody debris was present in the channel. Most of the instances of woody debris in the channel were on Mill Creek downstream of NE 50th Avenue.

The best channel restoration potential exists in the remaining forested reaches on the mainstem of Mill Creek. The area is desirable for restoration because of the lack of development and other conflicting land uses within the floodplain. The area also represents a lengthy, contiguous reach where unfragmented habitat value may be greatly increased for a small investment. Engineered structures designed to facilitate bedform development and capture/sort gravels could improve conditions in the short-term, while the forest matures to the point where it can act as a significant source of natural woody debris. In areas where riparian forests have been removed or otherwise impacted, channel conditions would benefit greatly from reforestation of the adjacent floodplain and riparian corridor to increase recruitment of woody debris. In many areas of the subwatershed a significant effort is already being made to reestablish woody riparian vegetation. Engineered structures to facilitate bedform development and capture/sort gravels could improve conditions in the short-term. However, without reforestation and associated recruitment of woody debris from the riparian corridor, installation of engineered structures is not a self-sustaining solution in the long-term.

Additional Results

Features of interest were often discovered when field crews ventured up small, first-order tributary channels outside of the area defined by the geographic scope of work. An example in the Mill Creek subwatershed is the small stream that flows west, parallel to NE 174th Street (DRNWC_ID #62119). When located, these features were recorded in the same manner as other features. The discovery of numerous features of interest on small tributary channels indicates that significant stream impairments, potential environmental and safety hazards, and potential project opportunities may exist outside of the geographic scope of this Feature Inventory. This result may influence the CWP when determining the geographic scope of future stream reconnaissance efforts.

Numerous fences crossing the stream corridor were observed in the Mill Creek subwatershed. These fences fragment habitat along the riparian corridor and act as significant navigation hazards for wildlife. In addition, many of the fence crossings accumulate debris at higher flows, causing unfavorable hydraulic conditions, negatively impacting stream morphology and function, and potentially increasing flood hazards.

Potential Project Opportunities

Listed opportunities represent potential projects or project areas. They are not fully developed projects, and therefore require additional evaluation and development by Clark County or consultant staff prior to submittal to the SCIP process. Identifying them as potential projects in this document is the first step in the process of developing SCIP projects.

Potential project opportunities were identified based on the results of the Feature Inventory conducted in the Mill Creek subwatershed. The CWP will evaluate the potential projects for further development or referral to the appropriate organization. Each potential project is listed in Tables 15 through 20, including the basis for the project and a description of the potential project. The location of each potential project is shown in Figures 14 through 17. Potential project opportunities were categorized into six groups based on the nature of the potential work. A total of 45 potential projects were identified. A summary of identified project opportunities by potential project category is shown in Table 14.

Table 14: Breakdown of Potential Project Opportunities by Category

Potential Project Category	Potential Projects Identified
Emergency/Immediate Actions	3
Stormwater Facility Capital Improvement Projects	5
Stormwater Infrastructure Maintenance Projects	0
Habitat Restoration/Enhancement Projects	1
Property Acquisition for Stormwater Mitigation	1
Referral Projects for other Groups/Agencies	35

Emergency/Immediate Actions

Emergency/Immediate Actions require an immediate site response project to address a potential or imminent threat to public health, safety, or the environment. Emergency/Immediate Actions identified based on the results of the Feature Inventory are described in Table 15.

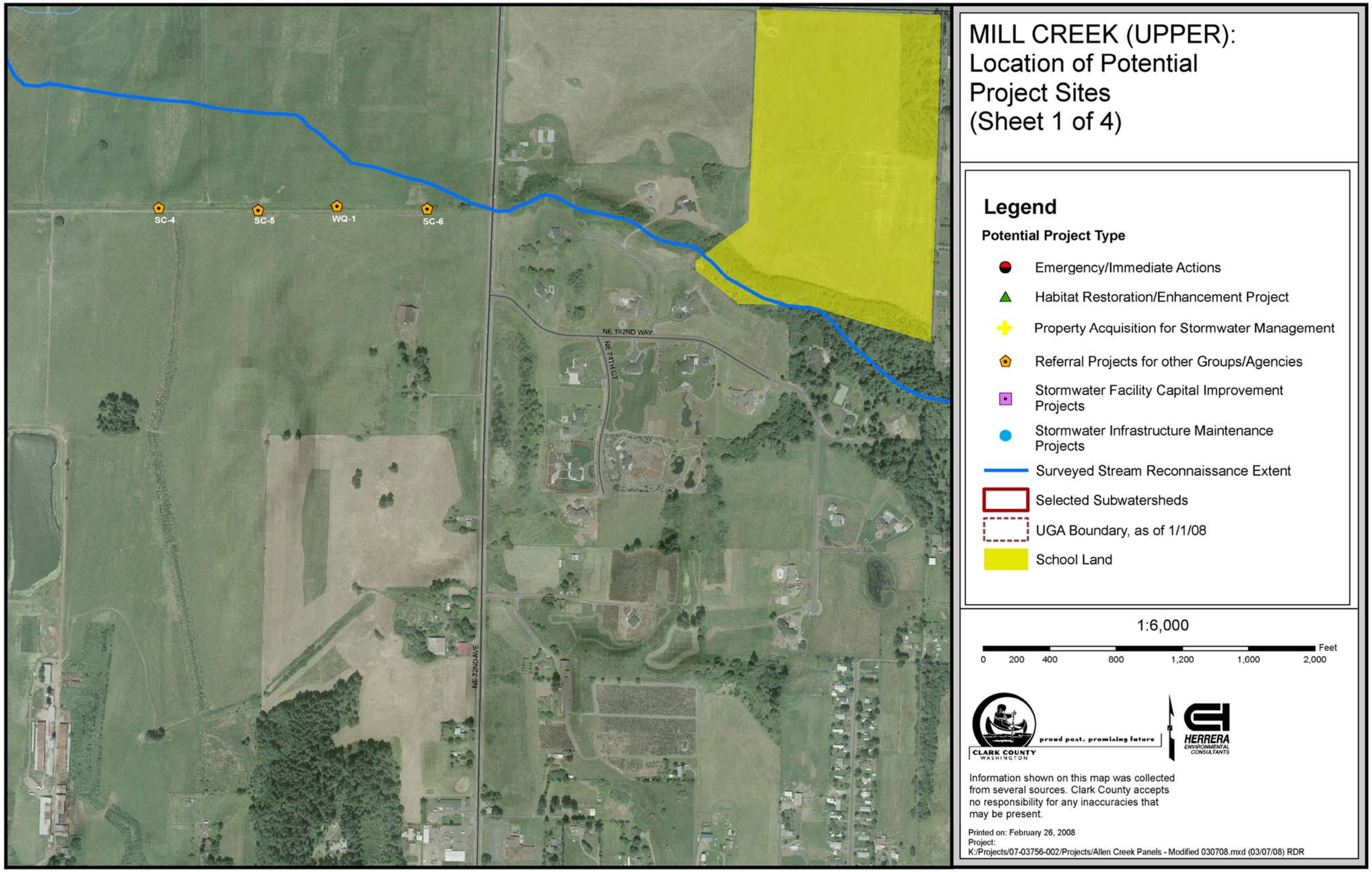


Figure 14: Potential Projects Noted in Feature Inventory

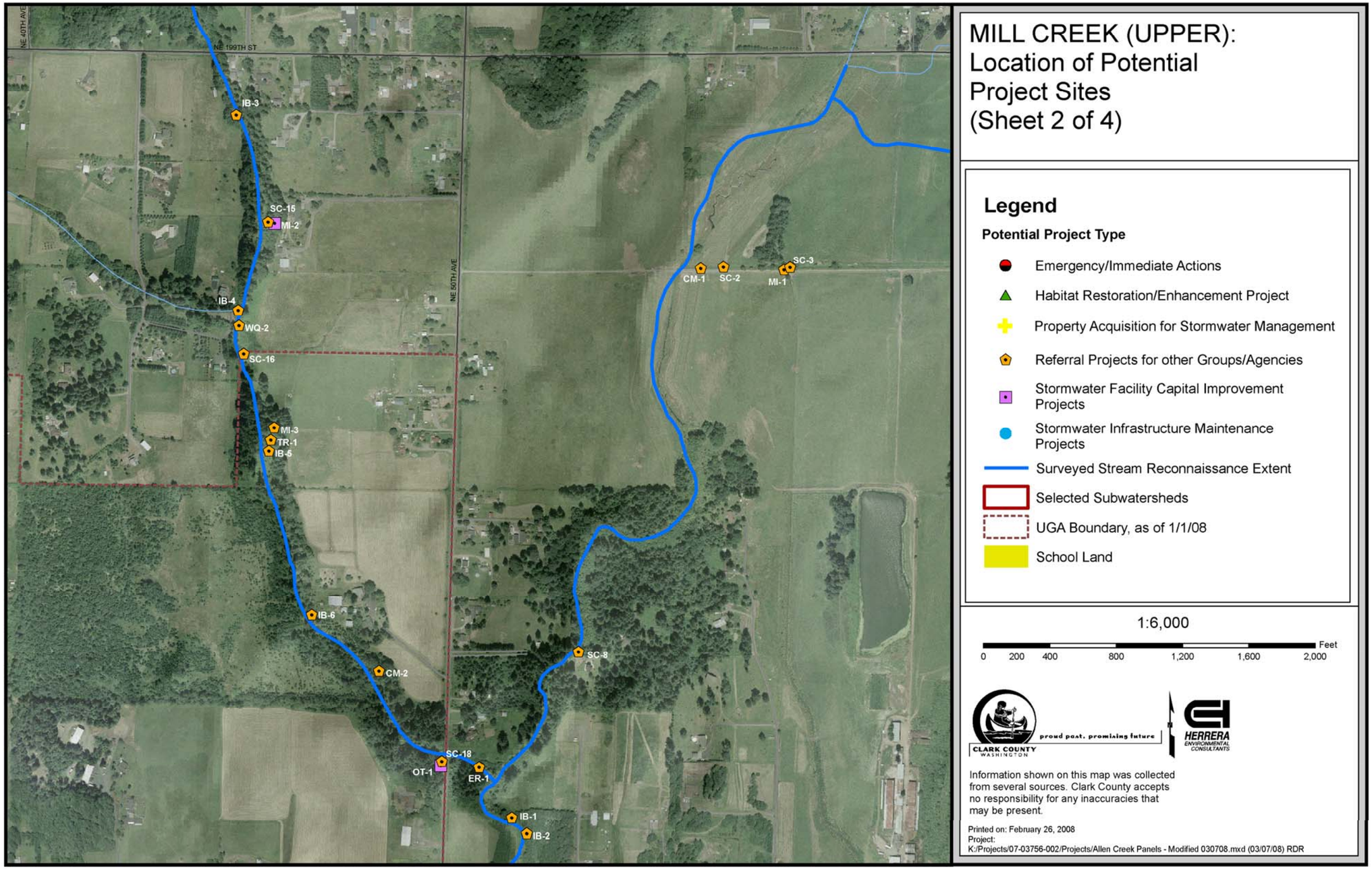


Figure 15: Potential Projects Noted in Feature Inventory

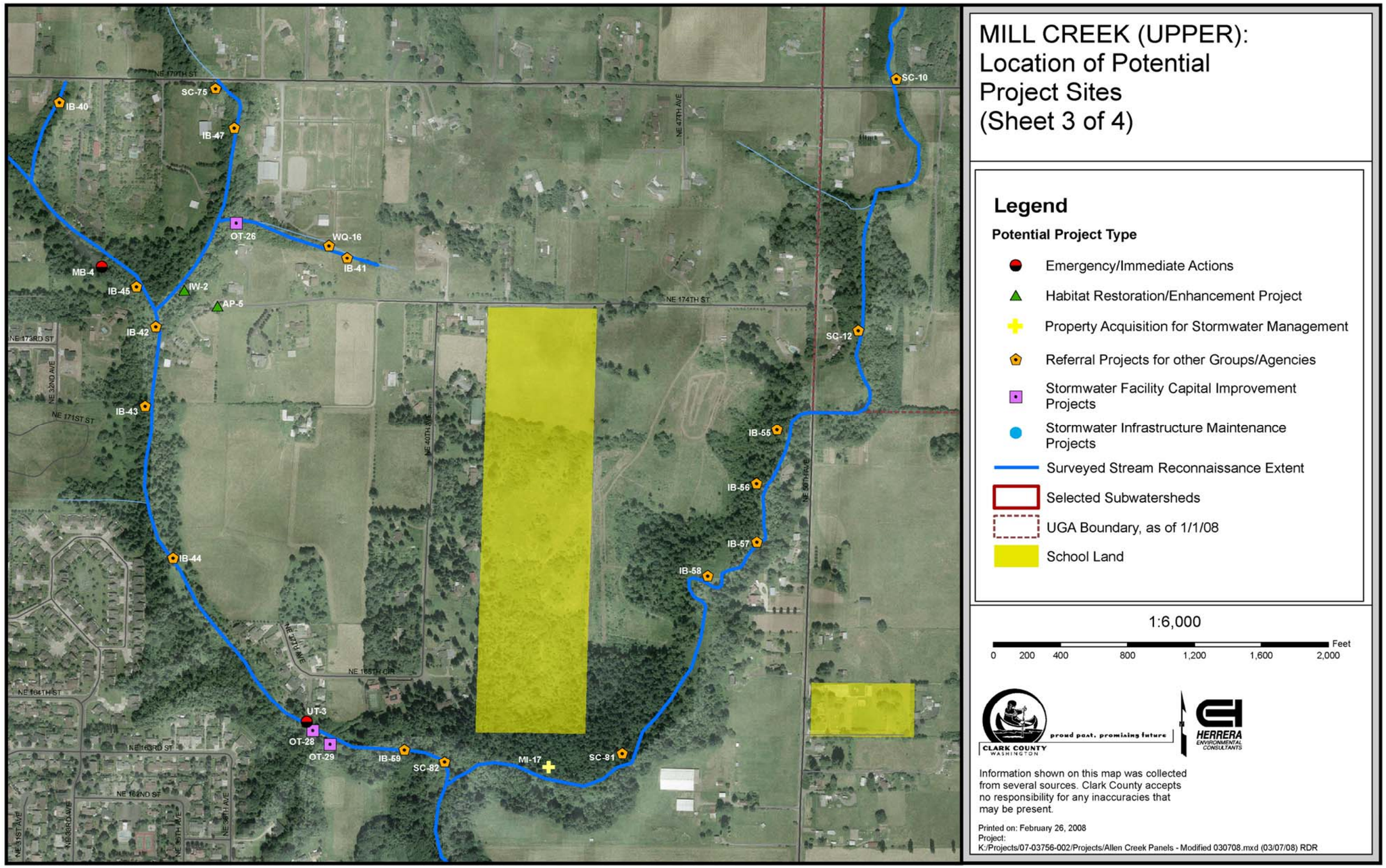


Figure 16: Potential Projects Noted in Feature Inventory

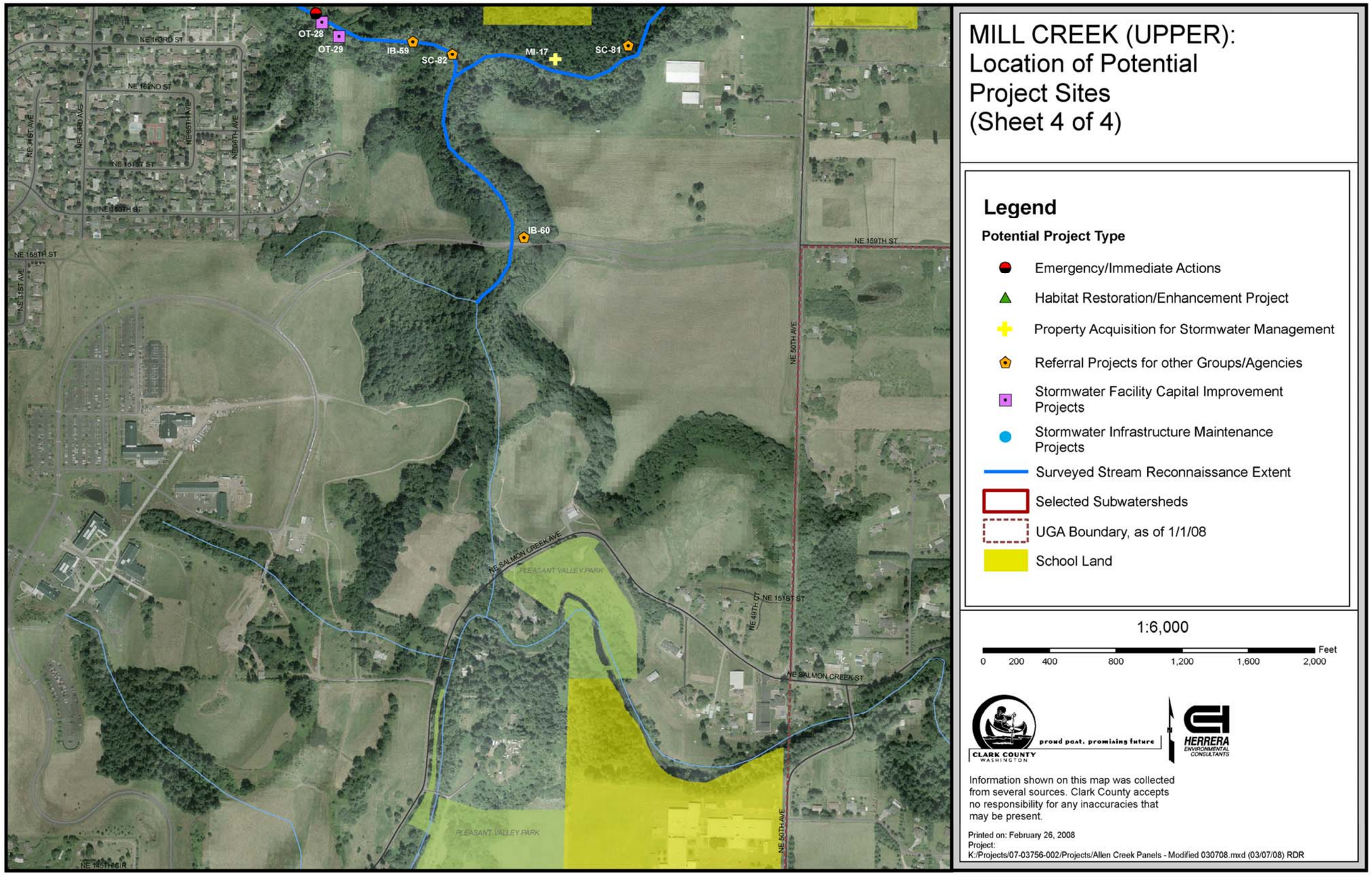


Figure 17: Potential Projects Noted in Feature Inventory

Table 15: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
UT-3	Exposed manhole for sewer line. May be leaking. Excess water and dense algae on footpath.	Immediate site inspection by engineering staff to determine integrity of sewer line.
MB-4	An 18-foot-high earthen dam is impounding a private pond on the channel. Backwater extends approximately 700 feet upstream. Outlet works are in disrepair and there is evidence of piping through the dam. A potentially serious hazard to downstream landowners and the environment. Pond may be acting as a source of thermal loading. Dam is an impassable barrier to fish.	Immediate site inspection by engineering staff to determine structural integrity of the dam. May warrant removal of dam and restoration of tributary stream. At minimum, project should appropriately mitigate for thermal and fish passage impacts of the dam.
TR-5	Car battery dumped in stream from road crossing.	Remove battery from stream immediately and dispose of properly.

Stormwater Facility Capital Improvement Projects

Stormwater Facility Capital Improvement Projects are projects that create new or retrofit existing stormwater flow control or treatment facilities. Facility retrofits include projects that will increase an existing facility's ability to control or treat stormwater in excess of the original facility's design goals. Stormwater Facility Capital Improvement Projects identified based on the results of the Feature Inventory are described in Table 16.

Table 16: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
MI-2	Hay bales serving unknown purpose on hill slope above toe-slope wetland area. Wetlands appear mostly non-impacted.	Investigate area further for stormwater, septic, or water quality issues.
OT-1	Roadside ditch delivers untreated stormwater to stream from NE 50th Avenue.	Investigate source of stormwater and construct a new stormwater facility to detain and treat runoff appropriately.
OT-29	Paved cul-de-sac at end of power line access road. Direct overland flow of untreated stormwater to creek.	Investigate source of stormwater and construct a new stormwater facility to detain and treat runoff appropriately.

Table 16: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
OT-28	A one foot diameter plastic pipe outfall. Drains a basic swale that collects stormwater from subdivision into stream. Rust colored stain in pipe.	Investigate source of stormwater and construct a new stormwater facility or modify the existing facility to detain and treat runoff appropriately.
OT-26	A 4-inch-diameter plastic pipe draining stormwater from an unidentified source on private property, down hill slope into stream.	Investigate source of stormwater and construct a new stormwater facility to detain and treat runoff appropriately. If source is rain gutters, encourage landowner to disconnect downspouts and infiltrate stormwater if possible.

Stormwater Infrastructure Maintenance Projects
Stormwater Infrastructure Maintenance Projects include potential projects which address and repair maintenance defects affecting existing stormwater infrastructure. Infrastructure maintenance projects are required by the County NPDES municipal stormwater permit. Projects in this category with estimated costs exceeding $10,000 are considered under the SCIP process. Projects addressing simpler maintenance defects are referred directly to the County Public Works Operations and Maintenance staff.

No projects of this type were identified in surveyed reaches of the Mill Creek subwatershed.

Habitat Restoration/Enhancement Projects
Habitat Restoration/Enhancement Projects include potential projects which result in the restoration or enhancement of wetlands, upland forest, or riparian habitat. In-stream channel habitat and bank protection projects do not fall within the scope of Clark County's CWP, and are placed under the category of Referral Projects for other Groups/Agencies. Habitat Restoration/Enhancement Projects identified based on the results of the Feature Inventory are described in Table 17.

Table 17: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
IW-2 and AP-5	Vehicles have access to floodplain via AP-5 and are impacting floodplain wetlands. Clark Public Utilities is doing a revegetation project in the area and may be responsible for the impacts.	Re-establish native riparian vegetation through plantings. Limit future vehicle access to the floodplain.

Property Acquisition for Stormwater Mitigation

Property Acquisition for Stormwater Mitigation Projects includes potential acquisitions of properties for any purpose that meets permit requirements to mitigate for stormwater impacts. This includes preservation or restoration of upland forest and riparian habitat zones. Property Acquisition Projects identified based on the results of the Feature Inventory are described in Table 18.

Table 18: Description of Potential Project Opportunities

ID	Basis for Project	Project Description
MI-17	Large expanse of riparian forest in relatively good condition. Minimal invasive plant species.	Look into various ways to protect this property, including property acquisition, conservation easements, etc.

Referral Projects for Other Groups/Agencies

Referral Projects for other Groups/Agencies includes potential projects that do not fall within the defined scope of Clark County's CWP. This includes, but is not limited to in-channel restoration, agricultural BMPs, fish-passage barrier removals, and invasive plant management. It also includes referrals within Clark County departments for projects such as trash removal, stream culvert repairs/maintenance, and drainage projects. Referral Projects for other Groups/Agencies identified based on the results of the Feature Inventory are described in Table 19.

Table 19: Description of Potential Project Opportunities

ID	Basis for Project	Project Description
CM-1 SC-2 SC-3 SC-4 SC-5 SC-6 WQ-1 and MI-1	A 4,000 foot long reach of tributary stream extending from the confluence with Mill Creek upstream to NE 72nd Avenue has been realigned and straightened for agricultural development. Invasive plant species are prevalent along the entire length. Reed canary grass and blackberry. The channel is currently acting as a drain ditch and is lowering the local groundwater table. Two other ditches, both smaller, but in similar condition, feed the tributary stream from the south near points MI-1 and SC-4.	Excellent channel/watershed restoration project opportunity. Excavate an inset floodplain surface and construct a meandering channel. Combine earth and channel work with LWD placement and an aggressive riparian revegetation program. Entire project would be on one tax lot. The property is currently the site of a large scale restoration project on the mainstem of Mill Creek and extensive revegetation work being done by Clark Public Utilities (CPU). Investigate project potential with landowner. Review of aerial photos shows a large off channel pond on the same property

Table 19: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
		which may offer project potential.
SC-8	Abutment of private bridge being undermined.	Investigate stability of bridge and recommend solution to scour problem to private landowner.
SC-15	Culvert hydraulics may be limiting fish passage through culvert, particularly during low flows. Triple barrel culvert crossing. Some debris in front of all barrels. Undersized, with significant drop at outlet.	Conduct additional barrier analysis to determine if culvert retrofit, removal, or replacement is required.
SC-16	Perched outlet and culvert hydraulics may be limiting fish passage through culvert. 4-foot-diameter corrugated metal culvert. Crossing appears abandoned or unused based on blackberry growth. Culvert bottom is rusted through near outlet. Extreme expansion scour downstream of culvert.	Conduct additional barrier analysis. Remove or replace crossing as soon as possible. Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
SC-18	Perched outlet and culvert hydraulics may be limiting fish passage through culvert. 3-foot-diameter concrete culvert, not flow-aligned, has no streambed sediment in it bottom, and is set at a relatively steep grade. Extreme expansion scour and deposition downstream of culvert.	Conduct additional barrier analysis to determine if culvert retrofit or replacement is required.
SC-10	Double-barrel concrete culvert at NE 179th Street. One barrel is typically carrying flow. Greatly undersized for flow capacity or prone to clogging based on evidence of extensive backwater during most recent flood event. Extensive reed canary grass in area.	Conduct additional barrier analysis to determine if culvert retrofit or replacement is required. Conduct additional hydraulic analysis to determine if recent flood backwater was the result of undersized culverts or blockage.
SC-12	Culvert hydraulics may be limiting fish passage at moderate to high flows. Double-barrel corrugated metal culvert crossing. Undersized culverts. Crossing overtops at moderate flows.	Conduct additional barrier analysis to determine if culvert retrofit, removal, or replacement is required.
SC-81	Wooden bridge on private land damaged by high flows.	Repair or remove at landowner's expense.

Table 19: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
SC-82	Culvert crossing (all-terrain vehicle trail) on private land with failing embankments.	Repair or remove to reduce erosion and eliminate sediment source.
SC-73	Outlet end of culvert under NE 29th Avenue is severely damaged (embankment has eroded and last segment of the 2-foot-diameter concrete pipe has fallen off into the stream) limiting hydraulic capacity and potential for fish passage.	Repair or replace culvert with consideration for fish passage if appropriate.
SC-75	Perched outlet and culvert hydraulics may be limiting fish passage through culvert under NE 179th Street. Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Conduct additional barrier analysis to determine if culvert retrofit or replacement is required. Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-1 and IB-2	Widespread invasive plant species within and immediately adjacent to the floodplain from GPS point downstream to NE 179th Street. Predominantly reed canary grass. Left bank was recently clear cut at IB-2 reducing canopy cover and shading.	Eradicate reed canary grass. Re-establish native undergrowth and canopy vegetation on floodplain and adjacent hillslopes to shade out invasive plants and enhance riparian habitat.
IB-3	Widespread invasive plant species within and immediately adjacent to the floodplain from GPS point upstream to NE 199th Street. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-4	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-5	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-6	Widespread invasive plant species within and immediately adjacent to	Eradicate reed canary grass, blackberry, ivy, and nightshade.

Table 19: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
	the floodplain. Reed canary grass, blackberry, ivy, and nightshade.	Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-55	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly reed canary grass with some blackberry.	Eradicate reed canary grass and blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-56	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly reed canary grass with some blackberry.	Eradicate reed canary grass and blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-57	Bamboo plants on left bank.	Eradicate bamboo plants.
IB-58	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly reed canary grass with some blackberry.	Eradicate reed canary grass and blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-59	Widespread invasive plant species beginning to encroach on riparian corridor. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth.
IB-44	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly reed canary grass with some blackberry.	Eradicate reed canary grass and blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-42	Widespread invasive plant species within and immediately adjacent to the floodplain from GPS point upstream to NE 199th Street. Predominantly blackberry with reed canary grass.	Eradicate blackberry and reed canary grass. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-43	Widespread invasive plant species within and immediately adjacent to the floodplain from GPS point upstream to NE 199th Street.	Eradicate blackberry and reed canary grass. Re-establish native undergrowth and canopy vegetation on floodplain to shade

Table 19: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
	Predominantly blackberry with reed canary grass.	out invasive plants and enhance riparian habitat.
IB-45	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-40	Widespread invasive plant species within and immediately adjacent to the floodplain. Blackberry, ivy, holly, and nightshade.	Eradicate blackberry, ivy, holly, and nightshade. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-41	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-47	Widespread invasive plant species within and immediately adjacent to the floodplain. Predominantly blackberry.	Eradicate blackberry. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
IB-60	Widespread invasive plant species within and immediately adjacent to the floodplain from GPS point upstream to NE 199th Street. Predominantly blackberry with reed canary grass.	Eradicate blackberry and reed canary grass. Re-establish native undergrowth and canopy vegetation on floodplain to shade out invasive plants and enhance riparian habitat.
ER-1	Small head cut. Rate of migration is not clear. Channel is somewhat incised downstream. If incision reaches culvert, outlet may become perched and fish passage may be further reduced.	Investigate headcut more thoroughly to determine rate of migration and assess risk to culvert upstream. If required, stabilize channel with grade control to prevent headcut migration.
WQ-2	Large manmade pond drains to stream. Pond may be acting as a source of thermal loading and/or contributing to other water quality impairments.	Investigate the effects of the pond on water quality. Modify facility to achieve improved water quality. Look into modifying pond and using it to treat stormwater.
WQ-16	Ditch from horse pasture drains agricultural runoff to the stream from the right bank.	Investigate source of runoff. Apply source control and/or construct appropriate facilities to enhance

Table 19: Description of Potential Project Opportunities		
ID	**Basis for Project**	**Project Description**
		water quality (new stormwater facility to detain and treat runoff or agricultural water quality BMP).
MI-3	Washed out triple barrel culverts at fence crossing presently serving no purpose.	Remove culverts and debris.
TR-1	Numerous automobile tires and wheels in stream	Remove tires.
CM-2	Approximately 16 automobile tires, half-buried in sediment, with metal sheep fencing installed as an attempt to stop the stream from scouring under the roots of a large cedar tree.	Remove tires and fencing.

Stormwater Management Recommendations

A number of general stormwater management measures should be implemented throughout the Mill Creek subwatershed:

- In developing areas, emphasize stormwater management that focuses on reduction of runoff and diffuse infiltration close to the source rather than in centralized facilities. LID practices should be encouraged.
- Educate private landowners concerning importance of invasive plant removal, and suggest removal techniques.
- Educate private landowners on importance of native riparian vegetation and forest canopy for shading streams. Continue to encourage riparian planting efforts similar to those being conducted by Clark Public Utilities.
- Educate landowners to discourage disposal of yard debris in streams or other receiving waters.
- In residential areas, encourage landowners to adopt green solutions such as disconnecting gutter downspouts that encourage infiltration of stormwater close to the source.
- Provide a list of suggested plants for stream revegetation and local nurseries that stock them for distribution to landowners
- Encourage transmission of stormwater through open channels such as grass-lined conveyance ditches or bioswales rather than using piped systems.
- Confirm that county ditch maintenance practices minimize vegetation removal whenever possible.
- Post stream identification signs where roads cross streams. Repair or replace deteriorated signs, if necessary.

- Discourage building of private, ornamental ponds that may impact streams. This seems to be a common practice in this subwatershed.
- Do not overlook stormwater inputs to small tributary streams that were not surveyed as a part of this Feature Inventory. These inputs may be more numerous than originally anticipated.
- Promote protection of first-order tributary streams. Consider the use of habitat buffers, establishment of conservation easements, and increased control of existing stormwater and agricultural runoff.

Physical Habitat Assessment

Purpose

Physical habitat assessments provide direct measurements of stream channel morphology, habitat conditions, and riparian conditions for specific stream reaches. This information can be used for planning projects and interpreting hydrologic, macroinvertebrate, and geomorphologic information at reach and subwatershed scale.

Methods

Physical habitat measurements were made for Mill Creek at the Long-Term Index Site Project reach within the Washington State University Vancouver Campus. The survey was made in late summer 2002 using EPA EMAP protocols (Schnabel, December 2003).

Results

Results for the most widely used EMAP metrics are summarized in Table 20. Overall habitat quality is normalized to the best available reference site within the Willamette Valley monitoring by Oregon DEQ. The reference site is in the "least degraded by human activity" category and is rated as marginally acceptable as a reference site due to obvious human disturbance. The Habitat Quality Index score of 99, compared to the disturbed reference site, suggests that Mill Creek habitat is about as good as can be expected for a typical Willamette Valley stream significantly degraded by human activity.

Metrics showed good overall habitat quality, including good riparian conditions and shade.

An index of hydrologic flashiness suggested signs of hydrologic impacts. Channel metrics showed a relatively stable channel that has recommended pool area but does not meet functional criteria for riffle area, embeddeness, and large woody debris density.

Table 20: EMAP Metrics and Interpretation for Mill Creek			
Habitat Category	**Index**	**Result**	**Characterization**
Overall Habitat Quality	Habitat quality index (HQI)	99	Score s relative to a DEQ grade-C reference condition scoring 100 on a normalized scale
Overall Riparian Quality	QR1 index RCOND index	0.78 0.81	Good Good
Hydrologic Flashiness	Mean of Flashrt1, Flashrt2, and Flashrt3 indices	3.53	Signs of hydraulic impact
	Individual Metric		
Channel Morphology	Pool percentage (PCT_POOL) Riffle percentage (as PCT_FAST)	54% 16%	Meets recommended pool area Does not meet recommended riffle area
Residual Pools	Residual pool volume (TOTPVOL)	45.8m^3	n/a
Substrate Composition	Dominant substrate mean embeddedness (XEMBED) Substrate sand and fines (PCT_SAFN) D_{50} (median particle size, mm)	66% 43% 18% 21	Coarse gravel and larger (>16mm) "Not properly functioning" "At risk" (3% fines <0.6mm, 15% sand (0.6-2mm) n/a
Bed Substrate Stability	Bed stability index (LRBS_BW4)	-0.37	Streambed relatively stable
Fish Cover	Natural fish cover by area (XFC_NAT)	0.47	Fish cover relatively sparse
Large Woody Debris	Total LWD density (C1W)	433/mile	"Not properly Functioning" (good density and some large pieces, but not enough)
Riparian Vegetation Cover	Stream shading (CXDENMID)	84%	Well-shaded
Human Disturbance	Riparian human disturbance index (W1_HALL)	0.18	n/a
Invasive Plant Species	Overall invasive plant proportion (ip_score) (individual species proportion)	1.73	Invasive Plants common (English Ivy = 0, Him Black. = 0.73, Reed Canary = 1.00)

Geomorphology and Hydrology Assessment

The geomorphology and hydrology assessment was completed as a stand-alone report after the bulk of this document was finalized. When available, this report will be attached as Appendix A.

Riparian Assessment

Purpose

The riparian assessment characterizes existing conditions based on available data, to identify general riparian needs and potential areas for rehabilitation projects.

The need for riparian rehabilitation tends to be widespread and exceeds the scope and resources of the CWP mission of stormwater management. Therefore, many potential riparian projects are referred to agencies such as LCFRB, Lower Columbia Fish Enhancement Group (LCFEG), Clark Public Utilities, and the Clark Conservation District for possible implementation.

This section focuses on opportunities likely to be considered by the CWP SCIP which are primarily on publicly owned lands within high priority salmon-bearing stream reaches as defined by LCFRB salmon recovery priorities.

Method

Where possible, the assessment is based on GIS data from existing reports, primarily the 2004 Watershed Characterization and Habitat Assessment reports prepared for the Lower Columbia Fish Recovery Board (R2, 2004 and SP Cramer, 2004). These reports apply primarily to salmon-bearing stream reaches and therefore do not provide information for many smaller streams. Results are based on aerial photo interpretation using Washington Forest Practices Board methods for LWD delivery and channel shade estimates.

In streams where no data exists from the 2004 LCFRB characterization, an examination of current orthophotographs is used to make a general assessment of riparian condition.

Many riparian project opportunities are discovered through other SNAP activities, including Rapid Stream Reconnaissance feature inventories and geomorphological assessments. Potential projects discovered through these activities are discussed in the respective sections, and most are included on a final list for referral to outside agencies.

The 2004 LCFRB Habitat Assessment reports are also reviewed for specific project opportunities within each subwatershed.

Results

The Mill Creek assessment uses results of the 2004 LCFRB Habitat Assessment. The full characterization reports are available on the Clark County website at:

http://www.clark.wa.gov/water-resources/documents.html#mon

Riparian (Wood Delivery)

Figure 18 summarizes the LWD delivery potential for Mill Creek from the 2004 LCFRB assessment. LWD potential was estimated as low to moderate throughout much of the subwatershed, with moderate to high potential in the lower mainstem.

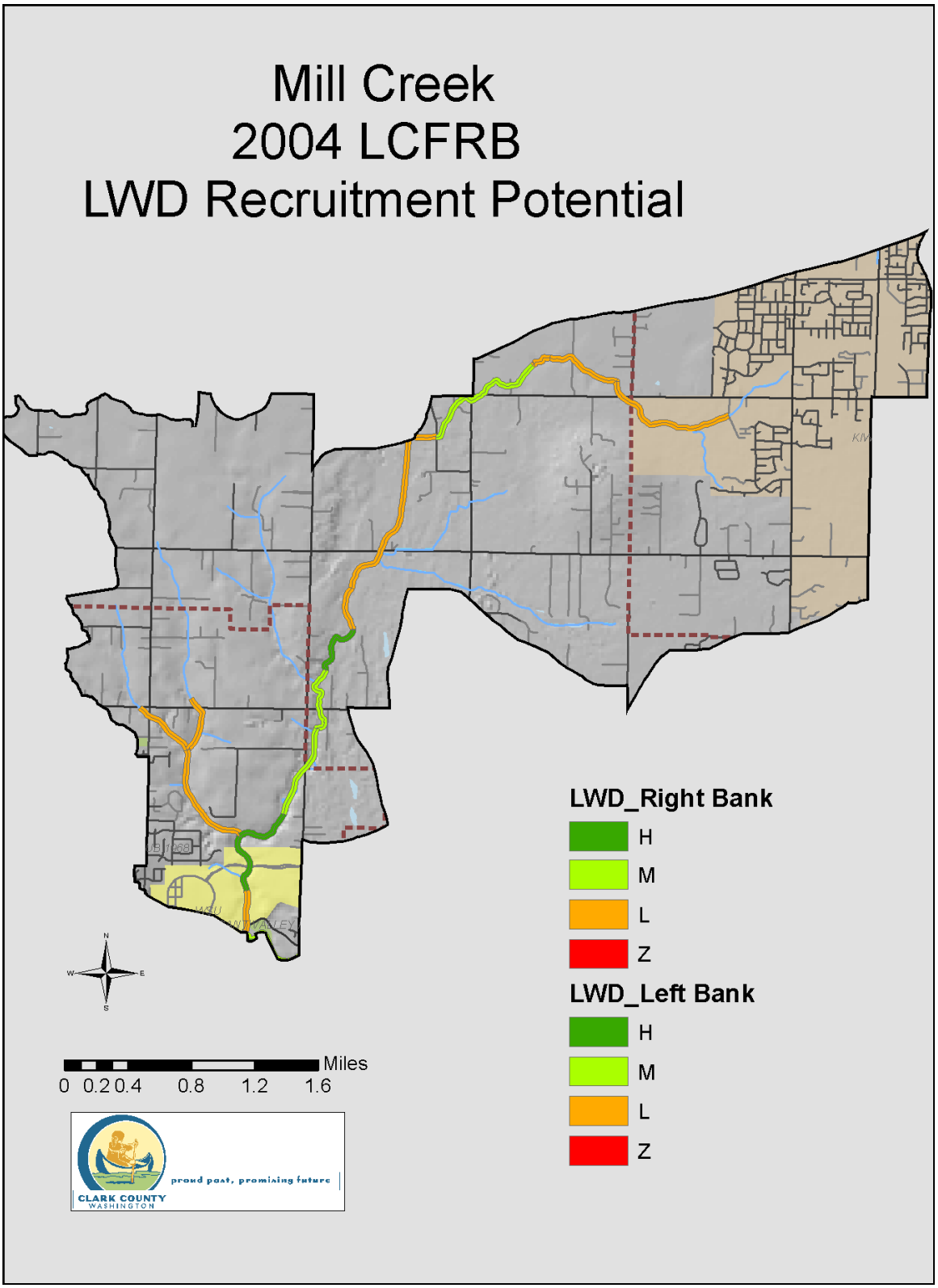


Figure 18: Mill Creek LWD Recruitment Potential (adapted from R2, 2004)

Shade

Figure 19 illustrates shade conditions for Mill Creek from the 2004 LCFRB Habitat Assessment. Throughout the Salmon Creek watershed, overall shade levels were below state targets and likely insufficient to maintain water temperature criteria (R2, 2004).

Within Mill Creek, the middle and upper reaches were shaded in the 0 to 40 percent range, while the lower reaches had 40 to 90 percent shade. There were no reaches with over 90 percent shade.

Potential Projects

No specific projects for the Mill Creek subwatershed are listed in the R2 (2004) report. Overall recommended management activities for the Salmon Creek watershed included protecting existing riparian vegetation and promoting recovery where feasible. The report also recommended limiting future human-induced encroachment in the riparian zone.

Local agencies, primarily Clark Public Utilities, have implemented riparian enhancement projects within Mill Creek and the entire Salmon Creek watershed. Field reconnaissance for the 2007 Feature Inventory in Mill Creek (see Rapid Reconnaissance chapter) and review of 2007 orthophotos indicated the presence of numerous recent planting projects, particularly in the upper watershed between approximately 179th Street and 219th Street. As these efforts continue and existing plantings mature, shade and wood recruitment potential in Mill Creek may improve considerably.

Priority project areas based on available information include:

- Public land (WSU) near the confluence with Salmon Creek has both a low shade rating and low LWD recruitment potential. Note: Parts of this area have been planted recently.
- The Mill Creek tributary NW of Washington State University is part of the Mill Creek sub-area map delineated by Clark County Community Development. This area contains priority riparian, habitat, and species buffers, but has low LWD recruitment potential.

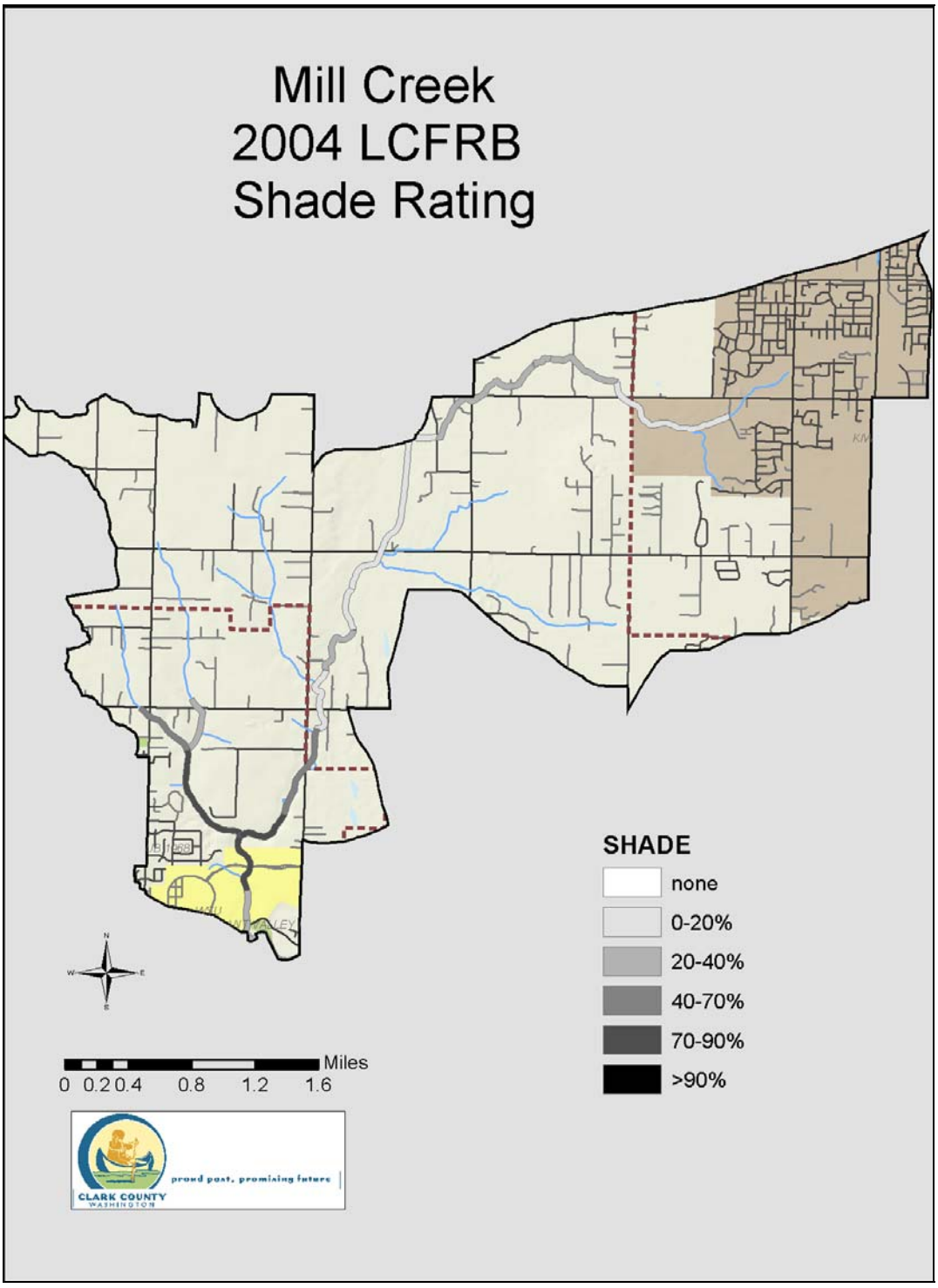


Figure 19: Mill Creek Shade Values (adapted from R2, 2004)

Floodplain Assessment

No floodplain assessment was conducted for the Mill Creek subwatershed.

Wetland Assessment

Purpose

Wetlands perform important hydrologic, water quality and habitat functions. The primary reasons for the wetlands assessments are to:

- describe wetland conditions related to how they influence hydrology, water quality and habitat;
- identify priority potential wetland projects to mitigate for stormwater impacts; and
- Make management recommendations for wetlands related to stormwater management.

The primary objective of the wetland assessment is to identify sites containing modestly sized, degraded or ditched wetlands where minor construction projects can be used to improve wetland hydrology. Improved wetland function can reduce peak storm discharges, increase groundwater recharge and improve habitat.

Methods

The assessment includes review of existing GIS data for wetlands. Primary information sources are the county wetlands atlas, Draft Watershed Characterization of Clark County Version 3 (Ecology, 2007), and personal communication with other county programs. Detailed field evaluations and extensive review of existing data were not applied in the Mill Creek watershed.

Stream Reconnaissance and Geomorphology/Hydrology assessments may also discover potential wetland-related project opportunities.

Tax-exempt parcels often indicate the presence of publicly owned land, schools, or churches where large parcel sizes and opportunities for leveraging may exist. Potential wetlands were overlaid with tax-exempt parcels and with county vacant buildable lands model (VBLM) information to identify possible wetland enhancement opportunities.

Results

Figure 20 shows potential wetland areas within the Mill Creek subwatershed based on data from the county wetlands atlas, including the Clark County wetland model, National Wetlands Inventory, and high-quality wetlands layer.

Pockets of potential wetlands are widespread in Mill Creek, with large concentrations of wetland areas in the mid-watershed and the upper watershed within the Battle Ground urban growth area.

Clark County has implemented a large-scale wetland enhancement and stormwater facility project in the headwaters of the westernmost Mill Creek tributary at the
Carrie Otter facility (NE 199th Street and NE 29th Avenue). This location was

recommended as a mitigation site opportunity in the Clark County Regional Wetland Inventory and Strategy Study.

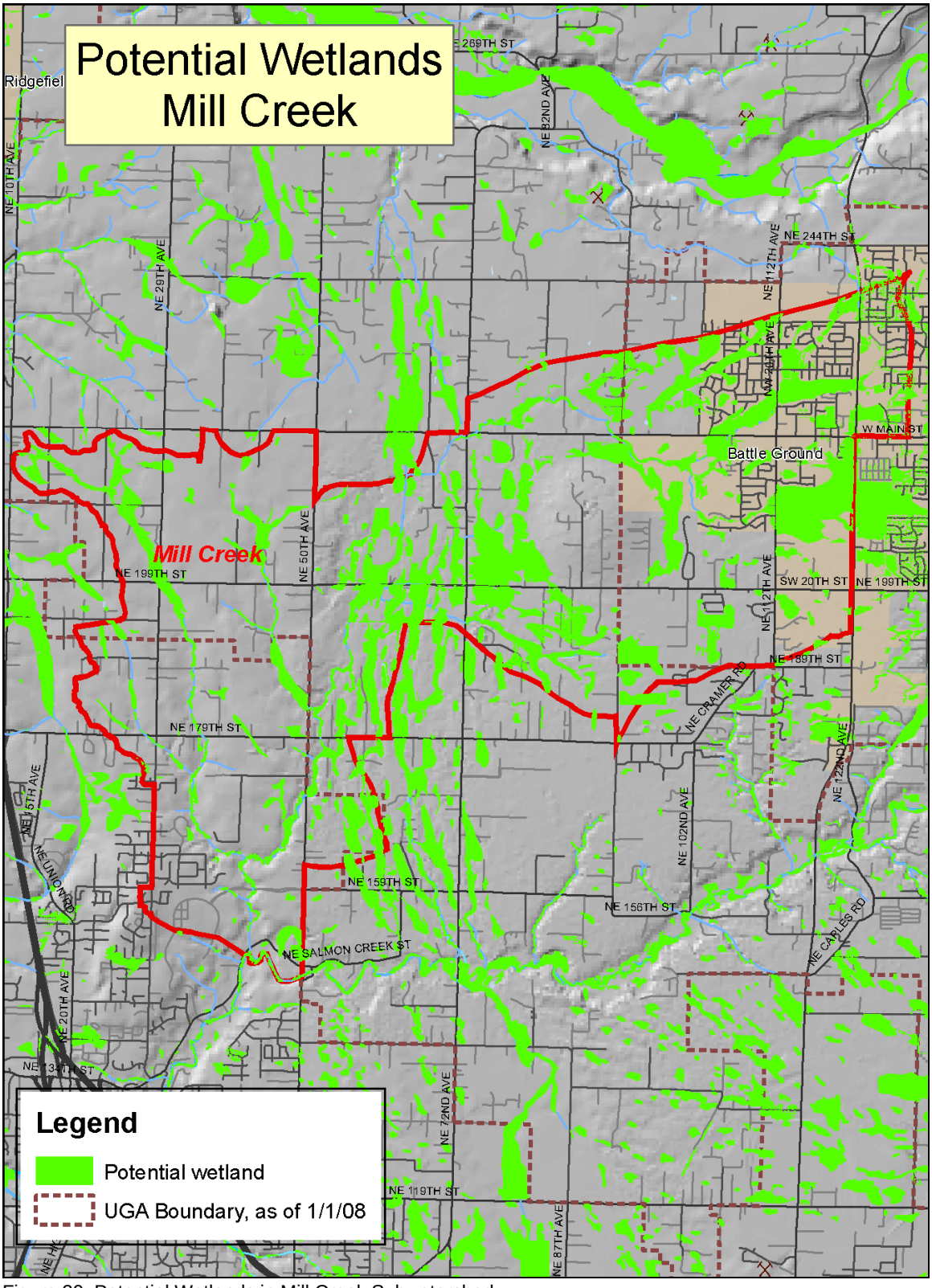


Figure 20: Potential Wetlands in Mill Creek Subwatershed

Draft Watershed Characterization

The Draft Watershed Characterization may be found on the Clark County website at http://www.clark.wa.gov/mitigation/watershed.html. Results pertaining to Mill Creek are summarized below.

Mill Creek is part of the Terrace hydrogeologic unit, characterized by rain-dominated precipitation, west to southwesterly trending groundwater flow, and a large delta (now a terrace) formed by glacial floods consisting of gravels, sand, silts and clay. Topography is relatively level to moderately steep in the foothills and slopes above the Columbia River (Ecology, 2007).

Figure 21 depicts priority areas for protection and restoration of hydrologic processes county-wide based on an analysis of the relative importance and level of alteration in each subwatershed.

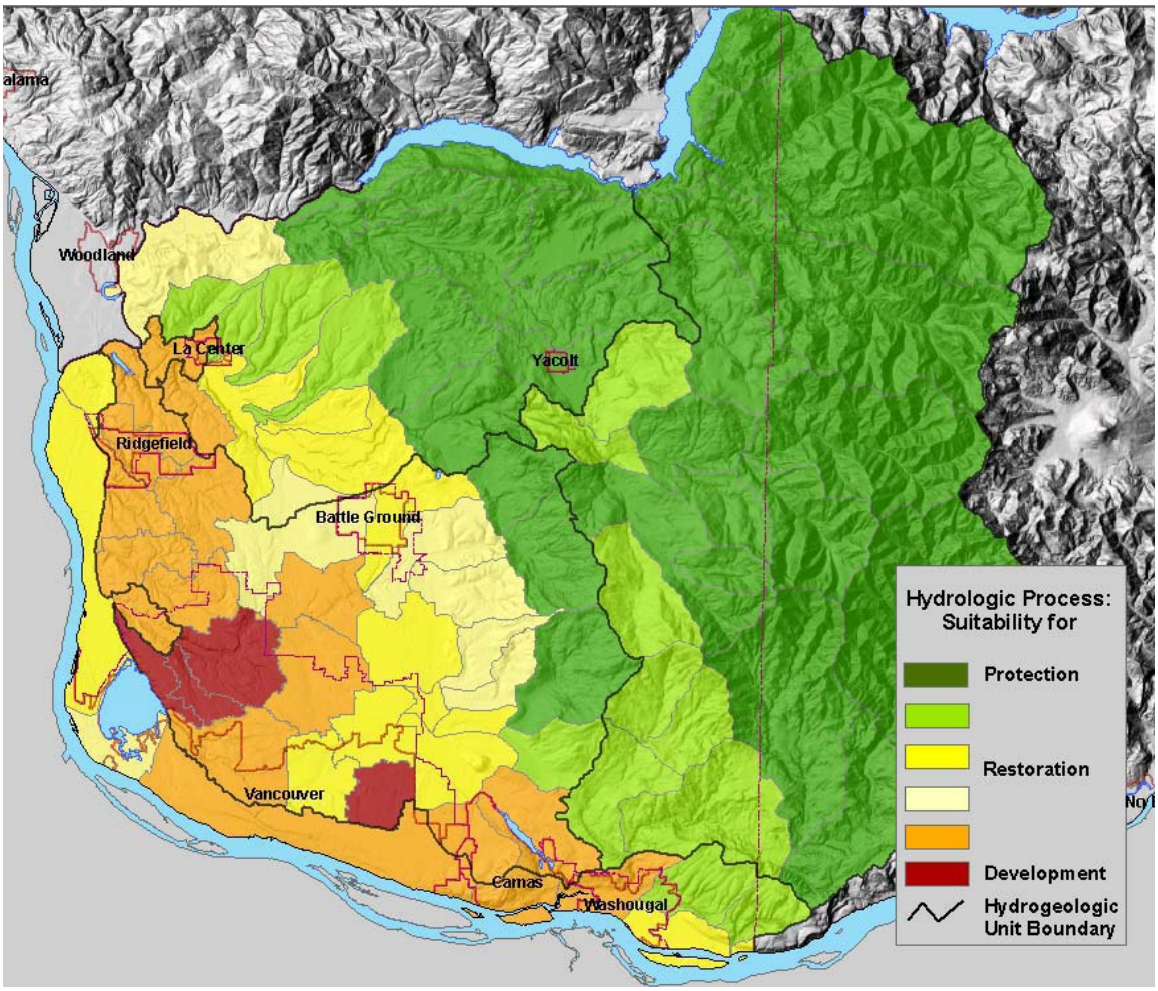


Figure 21: Priorities for suitability of areas for protection and restoration for the hydrologic process (from Draft Watershed Characterization of Clark County (Ecology, 2007)).

In general, green areas have higher levels of importance for watershed processes and limited alteration and should be considered for protection. Yellow areas have a higher level of importance for watershed processes and a higher level of alteration and should be considered for restoration unless watershed processes are permanently altered by urban development. Orange to red areas have lower levels of importance for watershed processes and higher levels of alteration and should be considered as more suitable for development. Because orange areas represent a transition from restoration areas, planning measures employing both restoration and appropriately sited development should be considered. (Ecology, 2007)

The highest ranked areas for protection (dark green) do not typically occur in the Terrace unit. Overall, results for the Terrace unit suggest focusing restoration activities east of Interstate 5, with particular emphasis on "siting and designing development in a manner that protects and maintains processes (i.e., through low impact development measures including clustering, density bonuses, transfer of development rights, and mitigation banking)", and concentrating development on the west side of I-5 in upland areas while protecting aquatic resources and discharge areas, such as slope wetlands. (Ecology 2007).

The Mill Creek subwatershed is indicated as suitable for restoration of both wetlands and forest cover, due to a higher level of alteration and a higher level of importance for watershed processes.

Potential Projects

Potential project locations for further exploration based on this wetland assessment include:

- Table 21 includes tax exempt parcels that overlap with potential wetlands from the Clark County wetlands model

Table 21: Tax Exempt Parcels Overlapping Potential Wetlands				
ASSR_SN	**ASSR_AC**	**OWNER**	**PT1DESC**	**Description**
192831000	2.01	Fire District #11	Government buildings	Small area of potential wetland behind buildings
192809000	37.67	State of Washington	Unused or vacant	Small area of potential wetlands
193128000	2.2	Clark County	Unused or vacant	May be existing SW facility
193629000	50	Battle Ground School District #119	Unused or vacant	Open ground with several areas of potential wetland
181766000	5	Battle Ground School District #119	Unused or vacant	High-quality wetlands
117891125	3.11	Clark County	Unused or vacant	Parks/Open space with critical lands. Has access easement and some potential wetlands

Macroinvertebrate Assessment

Purpose

The Benthic Macroinvertebrate Index of Biological Integrity, or B-IBI (Karr, 1998), is a widely used measure of stream biological integrity or health based on macroinvertebrate populations. Macroinvertebrates spend most of their lives in the stream substrate before emerging as adults. While in the stream, they are subject to impacts from chronic and acute pollutant sources, hydrology modifications, and habitat changes.

The B-IBI score is an index of ten metrics describing characteristics of stream biology, including: tolerance and intolerance to pollution, taxonomic richness, feeding ecology, reproductive strategy, and population structure. Each metric was selected because it has a predictable response to stream degradation. For example, stonefly species are often the most sensitive and the first to disappear as human-caused disturbances increase, resulting in lower values for the metric "Number of Stonefly taxa".

In addition to the overall B-IBI scores, examining individual metric scores gives insight into stream conditions and better explains differences in the overall score.

Methods

All field and laboratory work followed Clark County's standardized protocols for macroinvertebrate sampling and analyses (Clark County Public Works Water Resources, June 2003). Samples are collected during late summer, preserved, and delivered to a contracted laboratory for organism identification, enumeration, and calculation of BIBI metrics.

Raw data values for each metric are converted to a score of one, three, or five, and the ten individual metrics are added to produce an overall B-IBI score ranging from 10 to 50. Scores from 10 to 24 indicate low biological integrity, from 25 to 39 indicate moderate integrity, and greater than 39 indicate high biological integrity.

Results are influenced by both cumulative impacts of upstream land use and reach-specific conditions at the sampling station. Thus, samples from a given reach integrate local and upstream influences. Many of the B-IBI metrics are also influenced by naturally occurring factors in a watershed; for example, the absence of gravel substrate can lower scores.

Annual macroinvertebrate samples were collected from station MIL010, just upstream from Salmon Creek Avenue on the Washington State University Vancouver Campus, between 2001 and 2007 (see Figure 22 in the Water Quality Assessment section).

Results

Based on six samples collected between 2001 and 2007 (no sample in 2003), the average Total B-IBI score was 28 (Table 22) and ranged from 26 to 30.

The average score falls at the upper limit of the low category of biological integrity. All of the yearly Total B-IBI scores were well within typical inter-annual variability of less than five points observed for Puget Sound region streams (Karr 1998 and Law 1994) and in Clark County data.

Table 22: MIL010 Average Annual Macroinvertebrate Community Metrics and Total Score from 2001 through 2007

B-IBI Metrics	MIL010 6-Year Averages		
	Value	Score	Category
Total number of taxa	36.3	3	moderate
Number of Mayfly taxa	4.7	1	low
Number of Stonefly taxa	4.3	3	moderate
Number of Caddisfly taxa	7.3	3	moderate
Number of long-lived taxa	2.7	1	low
Number of intolerant taxa	0.3	1	low
Percent tolerant taxa	36.9	3	moderate
Percent predator taxa	6.7	1	low
Number of clinger taxa	20.3	5	high
Percent dominance (3 taxa)	50.2	3	moderate
Sum of average metric scores		24	low
6-year average total B-IBI score		**28**	**moderate**

Examining average results for the ten metrics results shows four low, five moderate, and one high rating. In particular, the low average score for the intolerant taxa metric suggests degraded water and habitat quality since sensitive taxa are among the first organisms to disappear as human disturbances increase (Fore, 1999). In addition, low scores for Mayfly taxa, long-lived taxa, and percent predator taxa could reflect, respectively, the presence of certain pollutants such as heavy metals, exposure to chronic or recurring water quality or habitat impacts, and decreasing diversity of prey items.

Booth, et. al., (2004) found there is a wide, but well-defined range of B-IBI scores for most levels of development, but observed overall that B-IBI scores decline consistently with increasing watershed total impervious area (TIA). Figure 22 shows that MIL010 Total B-IBI scores fall in the middle of the range of expected scores (estimated 2000 TIA from Wierenga, 2005). By comparing Mill Creek to the likely range of conditions for watersheds with similar amounts of development, measured as impervious area, it is possible to make some general statements about the potential benefits from improving stream habitat.

Given that available Total B-IBI scores fall mostly in the middle of the expected range for a watershed with 23 percent impervious area, there is considerable room for improvement or for further degradation. There is an opportunity to increase the level of biological integrity by improving habitat and stream conditions. Management strategies that support rehabilitation are important to minimize or prevent further reductions in its already low to moderate biological health.

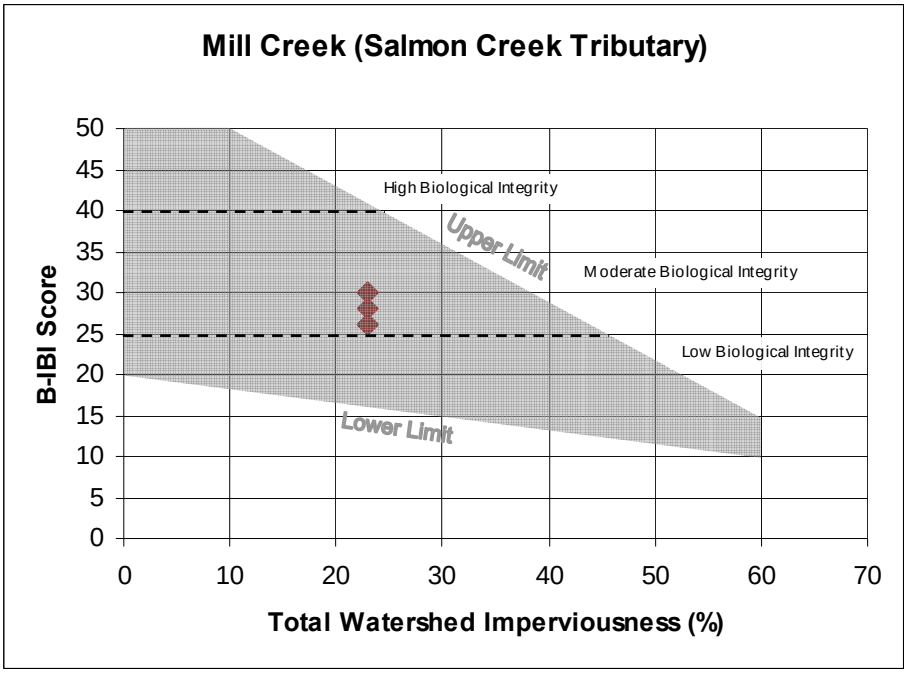


Figure 22: Approximate range of B-IBI in Puget Lowland watersheds, showing progressive decline with increasing imperviousness in the upstream watershed. Adapted from Booth et. al., 2004. Markers indicate Total BIBI scores at MIL010 for particular years, vs. estimated 2000 subwatershed TIA.

Physical Habitat Factors

Physical habitat is discussed in more detail in the Physical Habitat Assessment section. Based on a 2002 field assessment at MIL010 (Clark County, December 2003), 'overall riparian quality' was rated 'good', and the 'overall habitat quality' rated 99 out of 100, compared to a Category C Willamette Valley reference stream site. Streams in reference Category C have some remaining habitat value but are significantly degraded.

Other generally accepted criteria suggested degradation of important macroinvertebrate habitat features, including signs of hydrologic impacts, low percentage of riffle habitat, high substrate embeddedness, and elevated levels of sand and fine particles. Bed substrate stability metric indicated a 'relatively stable' channel. In general, all of the above are indications that current habitat stability and quality may be insufficient to support healthy macroinvertebrate populations.

Hydrology

TQmean is a hydrologic statistic calculated as the annual fraction of a year that daily mean discharge exceeds annual mean discharge (USGS, 2002). Lower fractions indicate a more "flashy" system. Based on continuous flow monitoring data (2003 through 2006) from a station one quarter mile upstream from Salmon Creek Avenue, Mill Creek has a relatively low average TQmean value of 0.27, indicating a hydrologic setting more similar to urban than suburban and rural watersheds. Watersheds with similar "flashy" values experience more excessive stormwater runoff and streambank erosion that may substantially alter macroinvertebrate populations by increasing streambed disturbances and sedimentation, and diminishing overall aquatic habitat.

Stormwater Management Recommendations

Based on low to moderate biological integrity indicated by the existing dataset, stormwater management efforts should support limiting further degradation and rehabilitation of degraded areas.

Suggested stormwater management activities that may protect and improve aquatic habitats include:

- Reducing peaks and duration of stormwater flows through capital facility improvements.
- Promoting LID practices to minimize increases in impervious area.
- Riparian habitat improvement projects.

Fish Use and Distribution

Purpose

Fish distribution refers to salmon and steelhead use. This information helps to identify stream segments where land-use changes may impact fish populations, informs management decisions, and aids in identifying and prioritizing potential habitat improvement and protection projects.

Methods

Fish distribution is mapped from existing Clark County GIS information, which reflect data collected and analyzed by the Northwest Indian Fisheries Commission (NWIFC). Fish distribution data for Clark County is available on the County's website.

Several sources of barrier assessment data are available and are briefly summarized here, including:

- WDFW passage barrier database
- Salmon Scape (http://wdfw.wa.gov/mapping/salmonscape/)
- Clark County 1997 passage barrier data clarkgis\avdata\shapes\resource\fishpass.shp)
- Clark Conservation District/LCFRB passage barrier dataset

Many stream crossings have not been assessed for passage barrier potential, and the extent of public and private road crossings is a good indicator of the potential for additional barriers. Road crossings were mapped by overlaying the county road layer (roads.shp) with LiDAR-derived stream data from StrmCntr.shp.

Results/Summary

Distribution

The available evidence suggests that anadromous fish use of Mill Creek includes Fall Chinook, Coho salmon and winter steelhead (Figure 23). The LCFRB identified Mill Creek as Tier 4 in its 2004 Salmon and Steelhead Recovery Plan. It is a Group D subwatershed because it includes only Tier 4 reaches. The recovery emphasis for this subwatershed is for restoration. Mill Creek Reach 3 has a ranking of 96 percent restoration versus 4 percent preservation and Reach 5 is valued at 91 percent restoration versus 9 percent preservation.

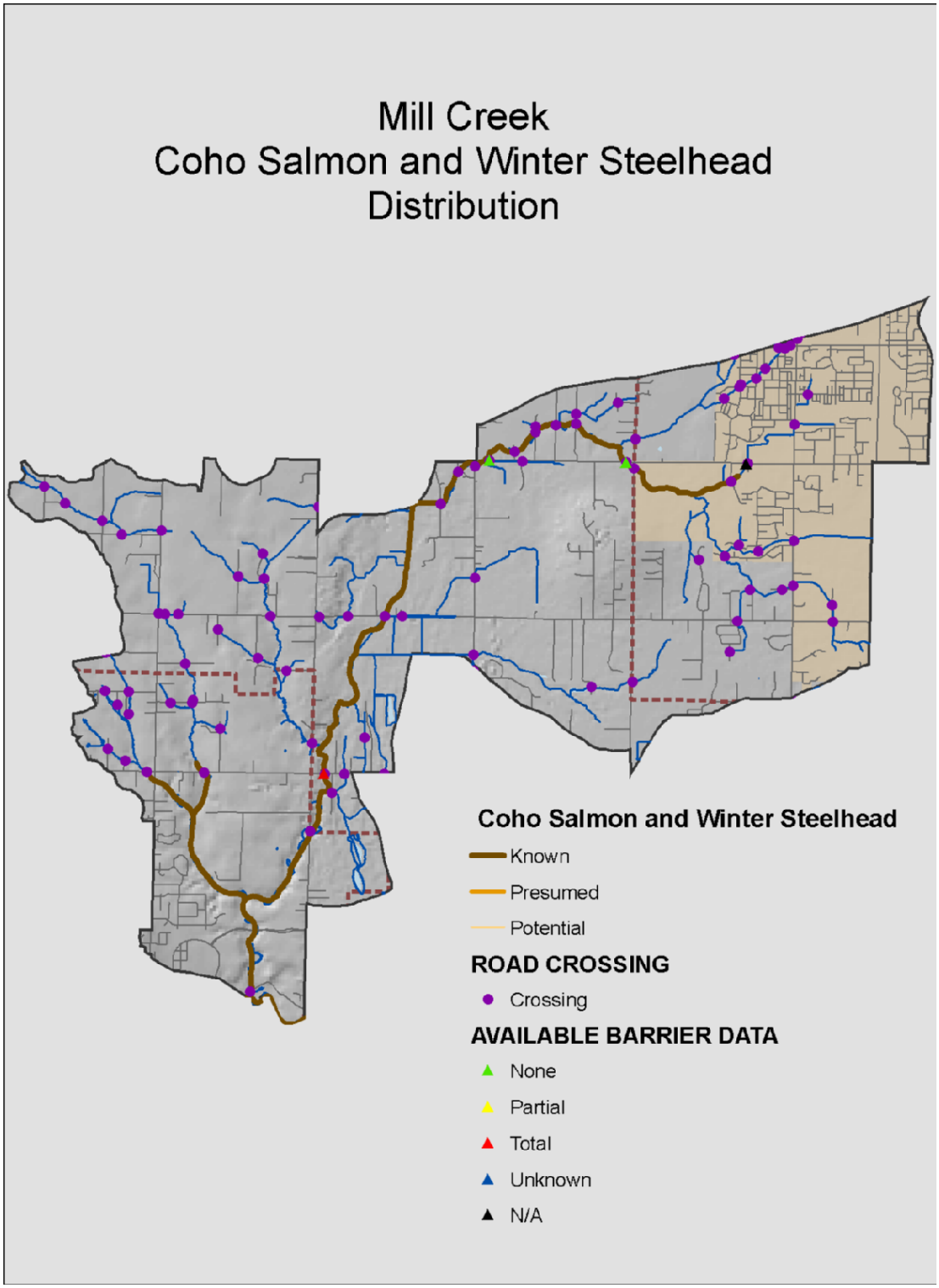


Figure 23: Fish Distribution and Barriers

Barriers

The WDFW barrier database and the 2007 LCFRB Regional Culvert Survey provide the most complete assessment of barriers in Mill Creek subwatershed (Figure 23). There is a known barrier on the mainstem of Mill Creek where NE 179th Street crosses. Although the database identifies this as a total barrier, there is known presence of Coho salmon and winter steelhead above this location.

Recommendations

Mill Creek is a Tier 4, Group D subwatershed. Conditions at the watershed level are impaired for hydrology and moderately impaired for sediment. Even at this level of functionality this subwatershed is buffering downstream conditions to some degree. This demonstrates the relative importance of this subwatershed to fish use and distribution. Recommendations for projects include the barrier at 179th Street identified in the 2007 LCFRB Regional Culvert Survey.

Hydrologic and Hydraulic Modeling

Hydrologic and hydraulic modeling was completed as a stand-alone report after the bulk of this document was finalized. When available, this report will be attached as Appendix B.

Analysis of Potential Projects

This section provides a brief summary of stormwater problems and opportunities, notes recently completed, or current projects within the study area that may be relevant to SNAP project selection, describes the analytical approach, and lists recommended projects and activities for further evaluation. Projects or activities are placed in one of six categories.

Summary of Conditions, Problems, and Opportunities

Conditions and Problems

This section briefly summarizes important results from the assessment and identifies overall stormwater-related problems.

Coordination with Other Programs

Mill Creek lies within a rapidly urbanizing area of the county where stormwater-related implementation is already significant. Clark County Public Works recently built a large stormwater project in a tributary headwater at the Carrie Otter wetlands (NW 199th Street and NW 29th Avenue). Clark Public Utilities has been very active in this subwatershed through its riparian enhancement projects. Mill Creek is also included in Ecology's Salmon Creek fecal coliform TMDL implementation. Future planned work by WSDOT to widen SR502 between I-5 and Battle Ground, may provide leveraging opportunities.

Broad-Scale Characterization

Mill Creek is a major tributary to Salmon Creek and has a multi-jurisdictional drainage area including the City of Battle Ground, Clark County, and areas within the City of Vancouver UGA. Mill Creek soils tend to be fine-grained and have high clay content with low permeability. Much of the subwatershed is classified as Hydrologic Soil Group D, which is often associated with wetland conditions.

Hydrologic conditions are typical of a relatively flashy urban or unforested rural subwatershed, with TQmean between 25 percent and 30 percent. Modeling in 2003 suggested Mill Creek may be in a transition period from stable to unstable channels.

Standard metrics based on NOAA fisheries standards indicates significant human alteration and suggest Mill Creek stream habitat is significantly degraded. These metrics include forest cover, TIA and EIA, road density, and stream crossing density.

A future estimated EIA of 23 percent based on the 2008 Comprehensive Plan suggests that a significant amount of new stormwater infrastructure will be needed to control impacts. Based on current and predicted EIA and forest cover, it is likely that stream channels will remain predominantly unstable.

Water Quality Assessment
Mill Creek is 303(d) listed for fecal coliform under Category 4a, and for dissolved oxygen and pH under Category 2.

A relatively large water quality dataset is available for Mill Creek as Clark County maintains long-term monitoring and hydrologic stations.

Based on 2002 through 2006 data, water quality index scores are poor. Significant temporal trends for fecal coliform and turbidity both indicate degrading water quality. Compared to other monitored Clark County streams, Mill Creek appears to be at increased risk of near-term water quality degradation.

Mill Creek is one of the cooler monitored streams in Clark County. However, stream temperatures are elevated during summer, exceeding state criteria by 6-8 degrees F and remaining elevated for extended periods.

Overall, fecal coliform bacteria and stream temperature are the primary parameters of concern in this subwatershed. The apparent increasing trend in turbidity is also cause for concern.

Drainage System Inventory
Drainage mapping is incomplete; however, most discharge points and stormwater facility polygons were mapped in 2007. Additional inventory will be completed in 2008 and 2009.

Public Stormwater Facility Inspection
As of December 2007, there were 19 mapped public stormwater facilities in the Mill Creek subwatershed. Ninety-five percent of the facility objects within these facilities were in compliance with standards in the 2005 SWMMWW Volume 5. Three facilities generated referrals; two for routine maintenance activities and one as a potential retrofit opportunity.

Off-site assessments conducted for 105 public stormwater outfalls discharging to critical areas identified one case of serious erosion and slope instability. The facility responsible for this issue was released from warranty in non-compliant condition. Repairs will be addressed by the CWP under the 2008 SCIP.

Illicit Discharge Screening
Screening conducted at 231 known stormwater outfalls identified one potential illicit discharge. Follow-up investigation was unable to confirm an ongoing illicit discharge. The location will be re-screened in 2008.

Stream Reconnaissance Feature Inventory
Significant stream impairments, potential environmental and safety hazards, and stormwater project opportunities were recorded for approximately six miles of stream corridor. A total of 71 significant features were identified, primarily

stream crossings and impacted stream buffers. Forty-five potential projects were identified in six categories, with the majority being projects outside the scope of CWP activities and subsequently recommended for referral to outside groups or agencies.

General observations from the feature inventory in Mill Creek included:

- Predominant source of stormwater is road surfaces, with a smaller contribution attributed to residential development.
- Impacted buffers are prevalent, with a wide range of riparian vegetation conditions.
- Extensive streambank areas have been replanted in recent years.
- Stream channels appeared to be relatively stable but exhibit somewhat simplified geometry, with little diversity in bedforms or habitat.
- Features of interest were often discovered along small first-order tributaries, many of which were not included in the survey scope. Thus, it is likely that additional features of interest exist in areas not assessed.
- Numerous fences cross the stream corridor, fragmenting habitat and causing unfavorable hydraulic conditions by accumulating debris at higher flows.

Physical Habitat

Physical habitat data is limited. Based on results from an assessed reach on the WSU campus in 2002, habitat quality was similar to a Category C (marginally acceptable due to obvious human disturbance) reference stream in the Willamette Valley.

Geomorphology and Hydrology

See Appendix A for results of these assessments.

Riparian Assessment

In the 2004 LCFRB Habitat Assessment, LWD delivery potential was estimated as low to moderate in much of the subwatershed, with moderate to high potential in some areas of the lower mainstem.

Overall shade levels were below state targets and likely insufficient to maintain water temperature criteria.

Clark Public Utilities has been very active in implementing riparian enhancement projects in the Mill Creek subwatershed. As these projects mature, both shade and LWD recruitment potential may improve considerably.

Wetland Assessment

Pockets of potential wetlands are widespread in Mill Creek, with large concentrations in the mid- and upper-watershed. Clark County has implemented a large-scale wetland enhancement and stormwater facility project at the Carrie

Otter wetlands, a mitigation-site location recommended in the Clark County Regional Wetland Inventory and Strategy Study.

Ecology's draft wetland characterization of Clark County places Mill Creek in a category suitable for restoration due to a higher relative level of importance for watershed processes and a higher level of current alteration from historical conditions.

There are six tax-exempt parcels which overlap with potential wetlands and were evaluated for restoration potential.

Macroinvertebrate Assessment
Based on samples collected from 2001 to 2007, Mill Creek exhibits low biological integrity. Scores are mid-range compared to the predicted range of B-IBI scores for areas with similar levels of TIA, suggesting that factors other than TIA are contributing to low observed scores. Thus, it is likely that biological integrity could be improved somewhat through improvements to habitat and stream conditions.

Fish Use and Distribution
The available evidence suggests that anadromous fish use of Mill Creek includes Fall Chinook, Coho salmon and winter steelhead. The LCFRB identified Mill Creek as Tier 4 in its 2004 Salmon and Steelhead Recovery Plan. It is a Group D subwatershed because it includes only Tier 4 reaches. The recovery emphasis for this subwatershed is for restoration.

There is one known barrier on the mainstem, at NE 179th Street, which is recommended for removal. Conditions at the watershed level are impaired for hydrology and moderately impaired for sediment. However, even at this level of functionality, this subwatershed is buffering downstream conditions to some degree, indicating its relative importance to fish use and distribution.

Hydrologic and Hydraulic Modeling:
See Appendix B for results of these assessments.

Recently Completed or Current Projects

There are no stormwater projects in Mill Creek under the 2007 through 2012 SCIP. Clark County recently completed construction (2006) of the Carrie Otter Wetlands facility at 199th Street and 29th Avenue. WSDOT is in the planning phase of a major project to widen SR502 from I-5 to Battle Ground. This project will cross Mill Creek and tributaries multiple times, and traverses numerous wetland areas. Potential leveraged projects could be explored with WSDOT during project development (construction date ~2012).

Analysis Approach

Purpose

The Analysis of Potential Projects narrows the initial list of possible projects to a manageable subset of higher priority opportunities. Listed opportunities in sections of the SNAP report include sites requiring immediate follow-up, possible stormwater capital improvement projects, referrals to ongoing programs, and potential projects for referral to other county departments or outside agencies.

Stormwater capital improvement project opportunities are recommended for further evaluation by engineering staff, and potential development into projects for consideration through the SCIP process. Referrals to ongoing programs such as IDDE screening, operations and maintenance, and source control outreach receive follow-up within the context and schedules of the individual program areas. Referrals to other county departments, such as Public Health, or to outside agencies such as Clark Conservation District and Clark Public Utilities, may lead to additional activities outside the CWP scope.

Methods

An initial review is conducted for all potential projects identified during the stormwater needs assessment. Field notes, descriptions, field photos, and other associated information are reviewed. In some cases, additional field reconnaissance is performed.

In general, potential capital projects are evaluated by CWP staff on the basis of problem severity, estimated cost and benefits, land availability, access, proximity and potential for grouping with other projects, and potential for leveraging resources. Staff considers supporting data and information from throughout the SNAP report to assist in the initial project review.

Based on this review, lower priority opportunities are removed and higher priority projects are recommended for further consideration by the CWP.

Emergency/Immediate Actions

Emergency/Immediate actions may be pursued by Clark County staff or referred to other appropriate agencies. These cases represent a potential or immediate threat to public health, safety, or the environment, and require timely follow-up.

Identifier	Issue	Project	Action
UT-3	Exposed sewer manhole appears to be leaking; water and algae on trail immediately downslope	Site visit	Refer to CWP Technical Assistance and CRWWD
MB-4	18’ high earthen dam with 700’ backwater. Outlet works in disrepair and piping through dam is evident	Site visit	Refer to CWP engineering
TR-5	Car battery dumped in stream	Remove	Refer to CWP staff

Potential Stormwater Capital Projects

Stormwater Capital Facility Improvement Projects

Identifier	Issue	Project	Action
OT-1	Roadside ditch with untreated runoff to stream	Detain and/or treat ditch runoff	Evaluate for 2008 SCIP
6-yr CIP	Potential leveraged project	NE 179th Street	None- CIP project on hold
geomorphology	No major facility to detain current flows and/or serve future development	Construct large facility primarily to serve future headwater development	Evaluate for 2008 SCIP

There are several significant TIP projects on the County's 20-year CIP list, including NE 72nd Avenue, NE 50th Avenue, NE 29th Avenue, and Salmon Creek Avenue. Potential cooperative projects should be explored as these CIPs enter the planning phase.

Stormwater Infrastructure Maintenance CIPs

Identifier	Issue	Project	Action
PSFI Project Facility #995	Biofiltration swale with non-compliant water depth	Re-design or repair swale	Evaluate for 2008 SCIP
Outfall #227	Erosion problem	Re-design or repair outfall	Evaluate for 2008 SCIP

Stormwater Class V Underground Injection Control projects:
No projects found in the Mill Creek subwatershed.

Habitat Rehabilitation/Enhancement Projects

Identifier	Issue	Project	Action
ER-1	Small headcut with incision downstream. May eventually impact NE 50th Ave culvert (200')	Arrest headcut with riprap or woody debris	Evaluate for 2008 SCIP
wetlands	Existing wetland buffer on Fire District #11 property	Wetland enhancement /invasives removal	Evaluate for 2008 SCIP
geomorphology	Probable wetland mitigation for CIP 179th Street project	Construct floodplain bench / channel enhancement	Evaluate for 2008 SCIP

There are 11 conservation covenants registered in Mill Creek, primarily in headwater areas. These locations may provide future opportunities for enhancement or stormwater-related projects.

Property Acquisition for Stormwater Mitigation

Identifier	Issue	Project	Action
MI-17	Three parcels (100 ac total), forest and wetland within WDFW Priority Habitat Buffer; adjacent to 160 ac BGSD property and contiguous with WSU Vancouver campus. Within Mill Creek Subarea planning area	Pursue options to protect this property, including purchase/conservation easements/etc. Possible leverage with BGSD.	Evaluate for 2008 SCIP and refer to CC Conservation Lands Program

Follow-up Activities for Referral within CWP

Private Stormwater Facilities Maintenance

Identifier	Issue	Project	Action
OT-28	Private outfall with staining; facility (swale) needs inspection and possible modification	Site inspection	Refer to PW private facility inspector

Public Works stormwater infrastructure maintenance

The Public Facility Inspection section describes routine stormwater infrastructure maintenance needs referred to Public Works Operations during ongoing inspections. No additional stormwater infrastructure maintenance needs were discovered.

CWP Outreach/Technical Assistance

Identifier	Issue	Action
WQ-16	agricultural runoff ditch from horse pasture	Refer to CWP Outreach; contact landowner about BMPs and CCD assistance
MI-2	multiple hay bales on slope above wetland, unknown reason	refer to CWP Outreach for technical assistance visit

CWP Infrastructure Inventory

No features to add to inventory

Projects for Referral to Other Departments/Agencies/Groups

Identifier	Issue	Action
SC-73	Outlet of NE 29th Avenue culvert severely damaged and embankment eroding	Refer to PW Operations
IW-2/AP-5	Vehicle access impacting wetland/floodplain. CPU project in area	Refer to CPU
CM-1	4,000' headwater tributary reach straightened as drainage ditch. Excellent location for large-scale restoration project. Developer-owned, 425 acres Existing CPU project on mainstem, same parcel.	Explore LID/stream restoration as part of future development mitigation
SC-15, SC-16, SC-18, SC-12,	Perched outlets or culvert hydraulics may limit fish passage; extreme expansion scour.	Refer to WDFW for potential barrier analysis
SC-10	known barrier at 179th Street mainstem just east of 50th Avenue	Refer to MOP; barrier removal possible mitigation opportunity for future 179th Street widening. Potential 3 miles of Coho habitat.
IB-1-6, 55-59, 41-45, 47	Widespread invasive plant species, primarily reed canary grass and blackberry	Refer to CPU for riparian project evaluations
TR-1	Numerous tires and wheels in creek, private property	Refer to Health Department complaint line for removal
CM-2	Tires and fencing placed to slow erosion around large cedar tree	Refer to CPU for riparian/streambank stabilization

Non-Project Management Recommendations

Non-project stormwater management recommendations address areas where county programs or activities could be modified to better address NPDES permit components or promote more effective mitigation of stormwater problems. Information of this type contributes to adaptive management strategies and more effective stormwater management during the permit term.

Management and programmatic recommendations in the Mill Creek subwatershed, by permit component, include:

Storm Sewer Mapping and Inventory

- A complete drainage system inventory is critical to effective maintenance and inspection activities. Sufficient resources should be allocated to complete the stormwater inventory both in Mill Creek and countywide.

Coordination of Stormwater Activities

- Promote protection of first-order tributary streams. Consider the use of habitat buffers, establishment of conservation easements, and increased control of existing stormwater and agricultural runoff.
- Mill Creek restoration and protection has active support and involvement through the Salmon Creek Watershed Council and ongoing Salmon Creek TMDL implementation. Support for and coordination with these efforts should be continued and enhanced whenever feasible.
- Pursue future collaborative stormwater activities between Clark County, City of Battle Ground, and Vancouver-Clark County Parks and Recreation in the upper watershed.

Mechanisms for public involvement

- Publish SNAP reports on CWP web page

Development Regulations for Stormwater and Erosion Control

- EIA is expected to increase to approximately 23 percent in the Mill Creek subwatershed under the current Comprehensive Plan. At this level, adverse changes to stream hydrology and stability will occur unless development standards effectively control the duration of erosive flows. Clark County is currently working to adopt standards equivalent to the 2005 Ecology stormwater manual.
- In developing areas, emphasize stormwater management that focuses on reduction of runoff and diffuse infiltration close to the source rather than in centralized facilities. LID practices should be encouraged.
- Consider stormwater basin planning as a tool to better manage stormwater impacts due to future growth in the entire Mill Creek subwatershed.

Stormwater Source Control Program for Existing Development

- Encourage landowners to adopt runoff reduction practices, such as disconnecting downspouts.

Operation and Maintenance Actions to Reduce Pollutants

- Confirm that county ditch maintenance practices minimize vegetation removal whenever possible.

Education and Outreach to Reduce Behaviors that Contribute Stormwater Pollution

Areas where increased outreach could improve stream conditions include:

- Perform targeted technical assistance responding to results of field assessments.
- Continue to encourage and support riparian planting efforts by Clark Public Utilities and private landowners.
- Replace missing or deteriorated stream name signs.
- Develop a process to provide education about appropriate ditch maintenance practices to rural landowners.
- Discourage building of private, ornamental ponds that may impact streams. This practice appears to be common in Mill Creek.
- Encourage removal of fences across the stream corridor. Numerous fences across Mill Creek fragment habitat and accumulate debris causing unfavorable hydraulic conditions.

TMDL Compliance

- There are no specific actions noted to increase TMDL compliance. Encourage continued involvement and implementation of coordinated improvement activities under Ecology's ongoing TMDL adaptive management process.

Monitoring Stormwater Program Effectiveness

- Problems caused by stormwater are common and most severe on small tributary streams. Assessment of all streams is beyond the scope of SNAP work. Future SNAP reports may benefit by focusing more assessment resources on smaller tributary streams rather than mainstem reaches.

References

Booth, D.B., Hartley, D., and Jackson, R. (June 2002). Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts: Journal of the American Water Resources Association Vol. 38, no. 3. p. 835-845.

Booth, D. B., et al. (October 2004). Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior: Journal of the American Water Resources Association, pp. 1351-1364.

Center for Watershed Protection (March 2003). Impacts of Impervious Cover on Aquatic Systems: Watershed Protection Monograph No. 1.

Clark County Public Works Water Resources (June 2003). Standard Procedures for Monitoring Activities, pp. 46-48.

Clark County Public Works Water Resources (December 2003). Long-Term Index Site Monitoring Project: 2002 Physical Habitat Characterization, pp. 35.

Clark County Public Works Water Resources (2004). Clark County Stream Health, A comprehensive overview of the condition of Clark County's streams, rivers, and lakes, pp 46.

Clark County (2004). Regional wetland inventory and strategy: 51 pages.

Cornelius, L. (July 2006). Gee Creek Watershed Restoration Background Report: WSU Clark County Extension.

Cornelius, L. and J. Finley (January, 2008). Gee Creek Watershed Restoration Project 2007 Annual Report: WSU Clark County Extension.

Cude, C. (2001). Oregon Water Quality Index: A Tool for Evaluating Water Quality Management Effectiveness. Journal of the American Water Resources Association. Vol. 37, No.1.

Everts, Russel C. (2004). Geologic map of the Ridgefield 7.5' quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map 2834, scale 1:24,000. (http://pubs.usgs.gov/sim/2004/2844).

Fore, L.S., City of Bellevue (March 1999). Measuring the Effects of Urbanization on Bellevue Streams, pp. 24.

Hill, K., and M.C. Bidwell (January 2003). A Rapid Land Cover Classification for Clark County: Washington: Department of Landscape Architecture and Urban Ecology Lab, College of Architecture and planning, University of Washington, Seattle, Washington.

Hutton, R., and C. Hoxeng (April 2007). Clark County Long-term Index Site and Salmon Creek Monitoring Projects' Status and Trends Based on Oregon Water Quality Indices and Turbidity: Clark County Water Resources Program, Vancouver, Washington.

Karr, J.R. (1998). Rivers as Sentinels: Using the Biology of Rivers to Guide Landscape Management, River Ecology and Management: Lessons from the Pacific Coastal Ecosystems. Springer, NY, pp. 502-528.

Law, A.W. (1994). The effects of watershed urbanization on stream ecosystem integrity. Masters Thesis. University of Washington, Seattle Washington.

Montgomery, David R. and John M Buffington (1997). Channel-reach morphology in mountain drainage basins: GSA Bulletin; May 1997; v. 109; no. 5; p. 596–611.

National Marine Fisheries Service (NMFS) (1996). Making Endangered Species Act determinations of effect for individual or grouped actions at the watershed scale: National Marine Fisheries Service, Environmental Technical Services Division, Habitat Conservation Branch.

National Marines Fisheries Service (August 1996). Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale: Environmental and Technical Services Division, Habitat Conservation Branch.

National Marines Fisheries Service (March 2003). ESA Guidance for Analyzing Stormwater Effects: NOAA Fisheries Service, Northwest Region.

R2 Resource Consultants, Inc. (December 2004). Kalama, Washougal, Salmon, and Lewis River Habitat Assessments Chapter 1: Introduction and Methods, report prepared for the Lower Columbia Fish Recovery Board under contract to Clark County Water Resources.

R2 Resource Consultants, Inc. (December 2004). Kalama, Washougal, Salmon, and Lewis River Habitat Assessments Chapter 3: The North Fork Lewis River Basin, report prepared for the Lower Columbia Fish Recovery Board under contract to Clark County Water Resources.

R2 Resource Consultants, Inc. (December 2004). Kalama, Washougal, Salmon, and Lewis River Habitat Assessments Chapter 5: The Salmon Creek Basin, report prepared for the Lower Columbia Fish Recovery Board under contract to Clark County Water Resources

R2 Resource Consultants, Inc. (December 2004). Kalama, Washougal, Salmon, and Lewis River Habitat Assessments Chapter 6: The Washougal River Basin,

report prepared for the Lower Columbia Fish Recovery Board under contract to Clark County Water Resources.

Schnabel, J. (December 2003). Long-Term Index Site Monitoring Project: 2002 Physical Habitat Data Summary: Clark County Public Works Department, Water Resources Program, Vancouver, Washington.

Schueler, T. (1999). Microbes and Urban Watersheds: Ways to Kill 'em. Watershed Protection Techniques. 3(1): 566-574.

SP Cramer & Associates, Inc. (January 2005). Chapter 4: East Fork Lewis River Basin – Habitat Assessment, report prepared for the Lower Columbia Fish Recovery Board under contract to Clark County Water Resources.

State of Oregon Department of Environmental Quality (July 2004). Draft Lower Willamette Subbasin TMDL.

Swanson, R.D. (July 2006). Prioritizing Areas for Stormwater Basin Planning: Clark County Public Works, Water Resources Program.

Turney, G.L. (1990). Quality of Groundwater in Clark County, Washington: US Geological Survey Water Resource Investigation Report 90-4149, 97 p.

United States Environmental Protection Agency (1986). Quality Criteria for Water 1986: EPA 440/5-86-011, Office of Water Regulations and standards, Washington, DC.

U.S.G.S. (2002). Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin: Western Washington (Water-Resources Investigations Report 02-4040), Tacoma, WA, pp. 40.

Washington State Department of Ecology website: http://www.ecy.wa.gov/programs/wq/303d/2002/2004_documents/wq_assessment_cats2004.html

Washington Department of Ecology (November 2006). Water Quality Standards for Surface Waters of the State of Washington: Chapter 173-201A WAC. Publication # 06-10-091.

Washington Department of Ecology (April 2005). O'Brien, Ed. 2005 Stormwater Management Manual for Western Washington: Volume I -- Minimum Technical Requirements and Site Planning, Report 05-10-029, Olympia, WA.

Washington Department of Ecology (April 2005). O'Brien, Ed. 2005 Stormwater Management Manual for Western Washington: Volume I -- Minimum Technical Requirements and Site Planning, Report 05-10-029, Olympia, WA.

Washington Department of Ecology (April 2006). Draft Watershed Characterization of Clark County, Version 3: Shorelines and Environmental Assistance Program.

Wierenga, R. (January 2005). Subwatershed Characterization and Classification: Clark County Water Resources Program, Vancouver, Washington.

Wierenga, R., Clark County Water Resources, (January 2005). Technical Report: Subwatershed Characterization and Classification: Clark County Washington, pp. 17.

Appendices

Appendix A — Geomorphology and Hydrology Assessment

Appendix B — Hydrologic and Hydraulic Modeling