2006 Stormwater Needs Assessment Program

Whipple Creek (Upper)/Whipple Creek (Lower) Subwatershed Needs Assessment Report

Clark County Public Works Clean Water Program

2006

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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
DNR	Department of Natural Resources
EDT	Ecosystem Diagnostic and Treatment model
EIA	Effective Impervious Area
EIM	Environmental Information Management
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

GPS	Geographic Positioning System
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
PFC	Properly Functioning Condition
RM	River Mile
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 Area
UIC	Underground Injection Control
USFS	U.S. Forest Service
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VBLM	Vacant Buildable Lands Model
VLWP	Vancouver Lake Watershed Partnership
WAC	Washington Administrative Code
WCC	Washington Conservation Commission
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WSDOT	Washington Department of Transportation
WSU	Washington State University

Executive Summary

Study Area

This Stormwater Needs Assessment report includes the Whipple Creek (Upper) and Whipple Creek (Lower) subwatersheds in western Clark County.

Intent

Stormwater Needs Assessment reports compile and provide 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. Assessments are conducted at a subwatershed scale, providing a greater level of detail than regional Water Resource Inventory Area (WRIA) or Endangered Species Act (ESA) plans. Stormwater Needs Assessments are not comprehensive watershed plans or stormwater basin plans.

Findings

Watershed Conditions

Table 1 summarizes conditions in the study area, including water quality, biological health, habitat, hydrology, and the stormwater system.

Table 1. Watershed conditions

Category	Status
Water Quality	
Overall	• Poor
Fecal coliform bacteria	• Whipple Creek (Upper) fails the fecal coliform standard year-round; no data in WC (Lower)
Temperature	• Whipple Creek (Upper) fails temperature standard; no data WC (Lower)
Sediment	• Turbidity values are routinely elevated
Biological	
Benthic macro-invertebrates	• Low to moderate biological integrity (WC Upper)
Anadramous fish	• Anecdotal accounts suggest possible use by cutthroat trout, steelhead, and Coho salmon (WC Lower) • Low regional recovery priority; no tier assigned
Habitat	
Reference condition NOAA Fisheries criteria	• Overall habitat score is lower than a Category C (degraded) Willamette Valley reference stream • Percent total impervious area suggests habitat is marginally functioning
Riparian	• Many reaches have intact riparian buffers due to steep valley walls • Invasive species (blackberry, reed canary grass) prevent natural forest succession
Wetland	• Primarily riverine wetlands associated with stream channels; also depressional headwater wetlands • Several intact wetlands are at risk due to channel incision • High priority should be placed on protection of existing wetlands
Hydrology and Geomorphology	
Overall hydrology	• Impacted; typical of a flashy urban or unforested rural watershed
Future condition	• Projected impervious area will cause increased rate of channel incision, bank failures, and accelerated channel migration unless adequate runoff controls are in place
Stormwater (Unincorp. areas)	
System description	• Mix of piped infrastructure (primarily south and east), and road-side ditches (north and west) • 143 public and private stormwater facilities currently mapped
Inventory status	• Complete
System adequacy	• Inadequate control and treatment • Projected impervious area indicates need for considerable investment in new and retrofit infrastructure
System condition	• Largely unknown; no inspections conducted • 311 outfalls inspected for illicit discharges; two illicit connections confirmed and removed

Opportunities

Projects listed in the SNAP report represent only a small part of those needed to protect and restore streams within the study area. Field work and review of existing information identified numerous projects and actions that can improve stream conditions, including the following:

- Focused stormwater outreach and education to streamside landowners based on assessment results
- Purchase or protection of 12 areas with intact habitat
- Construction or retrofit of several regional stormwater treatment and control facilities
- Retrofit of several public facilities
- Repair/retrofit of several stormwater outfalls to control downstream erosion
- Removal of one illicit connection of industrial wastewater to the creek
- Evaluation of several culverts for potential modifications to reduce erosion and or facilitate floodplain reconnection
- Technical assistance visits to landowners with potential source control and water quality ordinance issues
- Small or large-scale invasive plant removal and riparian restoration projects
- Exclusion of livestock from the stream in four locations
- Abatement of three erosion-control issues at ongoing developments
- Cleanup of 18 trash disposal sites

Non-project stormwater management recommendations address areas where CWP 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 study area include:

- Emphasize stormwater management that reduces runoff by dispersing it into vegetated areas on-site
- Give greater attention to the placement of outfall locations and the configuration of outfall channels
- Encourage landowners to adopt runoff reduction practices, such as disconnecting downspouts.
- Focus additional resources on inspection of stormwater outfalls and downstream channels
- Perform targeted technical assistance responding to results of field assessments

2006 Stormwater Needs Assessment Program

Introduction

May, 2009
Whipple Creek watershed was the pilot effort for the Stormwater Needs Assessment Program. Work was completed in 2005 and 2006, concurrent with the development of the overall program. Full implementation using standardized templates and techniques began in 2007. A number of separate reports and products created during the 2005 Whipple Creek SNAP have been compiled here using the standardized 2007 report format. Accordingly, the format of this report differs somewhat from later SNAP reports.

This Stormwater Needs Assessment includes the Whipple Creek (Lower) and Whipple Creek (Upper) subwatersheds. 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.

<u>Purpose</u>
The Stormwater Needs Assessment Program (SNAP) 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, floodplain 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.

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Assessment Approach

Priorities for Needs Assessment in Whipple Creek (Upper) and Whipple Creek (Lower)

The Whipple Creek subwatersheds were selected for the pilot SNAP implementation based on their location in the I-5 corridor, a significant level of projected development under the Comprehensive Plan, known stormwater-related problems, and the presence of a variety of land uses ranging from urban and commercial development to parklands and agriculture.

Assessment Tools Applied in Whipple Creek (Upper) and Whipple Creek (Lower) subwatersheds

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 follow standard protocols to provide a range of information for 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 2 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 remaining tools and chapters were completed based on pre-existing information.

Table 2. Stormwater Needs Assessment Tools

Stormwater Needs Assessment Tools	
Stakeholders	Geomorphology & Hydrology Assessment *
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 not included in the pilot implementation in this assessment area.

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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. Coordination takes the form of phone conversations, meetings, or electronic correspondence, and is 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 thought most likely to contribute materially to identifying 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 in the assessment area:

- Clark County Endangered Species Act Program
- Lower Columbia Fish Recovery Board
- Clark County Transportation Improvement Program
- Clark County Legacy Lands Program
- Vancouver/Clark Parks and Recreation

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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 Assessments
- Salmon Recovery Plan
- Clark County LISP/SCMP/Project Data
- Ecology 303D (list)
- Clark County 6-year TIP
- Clark County 2005 Subwatershed Characterization
- Clark County 2004 Stream Health Report

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Broad-Scale GIS Characterization and Metrics

Broad-scale GIS characterization is included in the Whipple Creek Technical Memo found in the Geomorphology and Hydrology chapter.

Water Quality Assessment

Purpose and Scope

This report summarizes available water quality, benthic macroinvertebrate, and physical habitat data from Whipple Creek in Clark County, Washington. It is intended to provide baseline stream health information and to better inform the process of developing the Whipple Creek Watershed Projects Plan (WCWPP). The WCWPP will utilize a variety of stream and watershed information to address existing and future stormwater management issues.

General stream health is characterized by a series of multi-metric indices as well as several individual metrics. 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. The final section includes an examination of gaps in existing monitoring data and suggests potential projects that may be considered to address those gaps.

Applicable Water Quality Criteria

In 2003, the Department of Ecology proposed numerous revisions to Washington's water quality standards. The revised standards are currently under review by US EPA and have been only partially approved. For a full explanation of current water quality standards see the Ecology website at: www.ecy.wa.gov/programs/wq/swqs/rev_rule.html.

Pending EPA approval of the proposed revisions, the existing 1997 version of the standards is to be used for temperature, dissolved oxygen, turbidity, total dissolved gas, and pH criteria. Aquatic life uses and anti-degradation policies, among other topics, are also to be interpreted based on the 1997 standards. The 2003 standards are to be applied for Recreational (includes bacteria criteria), Water Supply, and Miscellaneous uses, as well as for toxics and aesthetics, lake nutrient criteria, and various other topics.

Under the 1997 standards, Whipple Creek is a "Class A" waterbody and is expected to meet or exceed the requirements for all or substantially all uses, including: water supply; stock watering; salmonid migration, rearing, spawning, and harvesting; wildlife habitat, and; recreation, including primary contact recreation, sport fishing, boating, and aesthetic enjoyment.

Under the 2003 standards, Whipple Creek is to be protected for "primary contact recreation" as well as narrative criteria for toxics and aesthetics.

Table 3 summarizes currently applicable criteria for Whipple Creek. With the exception of toxics, these characteristics are included in or addressed by the Whipple Creek dataset.

303(d) Listing

Ecology recently finalized the 2002/2004 303(d) list of impacted waters for submittal to US EPA. Based on Clark County Water Resources data, Whipple Creek in the vicinity of Sara (intersection of NW 41st Ave and NW 179th Street) is listed as water quality impaired for fecal coliform bacteria, and as a "water of concern" for stream temperature. The 303(d) listing for bacteria places Whipple Creek on the list of waters for which Ecology is required to generate a Total Maximum Daily Load (TMDL), also known as a Water Cleanup Plan.

Table 3. Applicable water quality criteria for Whipple Creek (May 2005)

Characteristic	1997 standards	2003 standards
Temperature	18 °C (64 °F)	
Dissolved Oxygen	8.0 mg/L	
Turbidity	not to 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 values 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, radioactive, or deleterious material concentrations must be below those which have the potential…to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health

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

Clark County Stream Health Report

In 2003, Clark County Water Resources compiled available data and produced the first county-wide assessment of general water quality.

Whipple Creek was assessed in conjunction with Gee, Flume, and Allen Canyon creeks as the West Slope Watershed. 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 West Slope Watershed scored in the poor to very poor range. Though data were available for only 10% of the stream miles in the watershed, a simple land-use model predicted poor stream health in the remainder of the watershed.

The entire 2003 Stream Health Report may be viewed on the county website at http://www.clark.wa.gov/water-resources/stream.html.

Current Water Quality

The following water quality summary is based on monthly data collected between May 2002 and December 2004 at Whipple Creek station WPL050 (see Figure 1), located just downstream of the Sara intersection (NW 179th St and NW 41st Ave). The data are presented in terms of a multi-characteristic water quality index, followed by summaries of several individual characteristics. Hourly water temperature data collected from approximately May through September during 2002, 2003, and 2004 are also included.

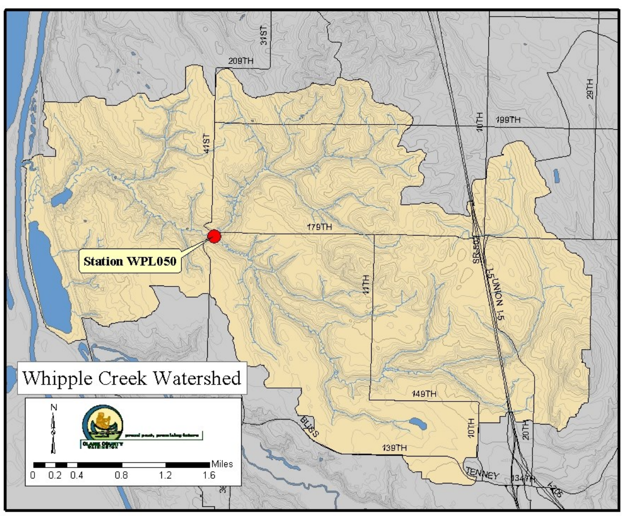

Figure 1. Whipple Creek Watershed and location of monitoring station WPL050.

<u>Oregon Water Quality Index (OWQI)</u>

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 subindex scores and an overall index score are calculated. Overall index scores are aggregated into low flow (June – September) and high flow (October – 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 2 shows seasonal mean OWQI scores for station WPL050 from 2002 to 2004. The overall average OWQI score from 2002 through 2004 is also included.

OWQI scores since 2002 rank consistently in the poor category. Individual sub-index scores for total solids, nitrogen, and total phosphorus were consistently poor, while scores for fecal coliform ranged from very poor to excellent and showed wide seasonal variations. Sub-index scores for temperature, dissolved oxygen, and pH were consistently good to excellent.

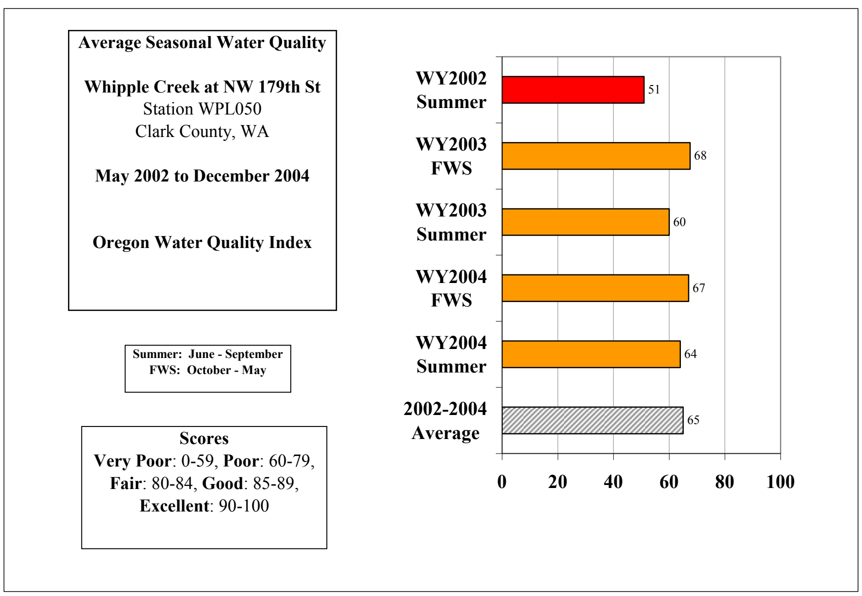

Figure 2. Average seasonal water quality, Whipple Creek station WPL050. Oregon Water Quality Index.

<u>Fecal coliform bacteria</u>
Figure 3 shows seasonal geometric mean fecal bacteria values from May 2002 through December 2004. Based on 12 sampling events, the summer (June –

September) geometric mean at station WPL050 was 688 cfu/100mL. Based on 20 sampling events, the FWS (October – May) geometric mean was 216 cfu/100mL. Geometric mean values for both seasons exceed the state criterion of 100 cfu/100mL. One hundred percent of summer samples also exceeded the single-sample criterion of 200cfu/100mL, while 60 percent of FWS samples exceeded this criterion. Individual samples ranged from 30 cfu/100mL to 1600cfu/100mL.

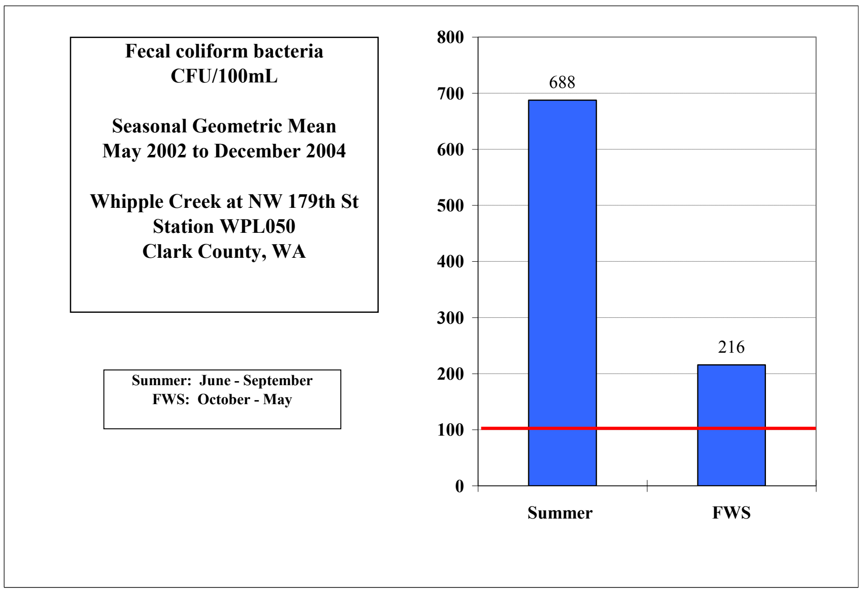

Figure 3. Seasonal geometric mean fecal coliform, Whipple Creek station WPL050, May 2002 through December 2004

<u>Nutrients</u>

Ecology has not established nutrient criteria 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 WPL050 between May 2002 and December 2004 ranged from 0.043 mg/L to 0.163 mg/L, and seventy-five percent of samples exceeded the EPA criterion. Total phosphorus concentrations typically vary seasonally in many locations; however, seasonal median values in Whipple Creek are quite similar:

- Summer median = 0.127 mg/L
- FWS median = 0.112 mg/L

Turbidity

It is difficult to establish an exact background turbidity level for Whipple Creek because no data exist from a time when Whipple Creek was not impacted by human activities. However, based on data from the least-impacted streams monitored by Water Resources, 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 Whipple Creek is between 5.5 and 7 NTU.

Since August 2001, the median of 40 turbidity samples at WPL050 is 7.7 NTU, with individual samples ranging from less than 5 NTU to 200 NTU. Turbidity varies somewhat seasonally:

- Summer median = 6.6 NTU
- FWS median = 9.8 NTU

At the WPL050 station, Whipple Creek often has a hazy, slightly milky appearance during baseflow conditions, which contributes to slightly elevated routine turbidity readings. Higher turbidity readings in the 20-40 NTU range are common during storm events. Extremely high turbidity values often indicate a specific sediment source during rainfall events. The highest recorded value in Whipple Creek was 200 NTU in November 2003. The source of this event was an overwhelmed and malfunctioning stormwater facility draining a large area of exposed soil during construction of the Whipple Creek Place subdivision, approximately one mile upstream of the monitoring station.

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, 2003, and 2004. Continuous readings provide a more complete picture of temperature dynamics than monthly grab samples.

Table 4 summarizes the continuous temperature data. The seasonal maximum temperature represents the highest recorded value during the deployment, and is the value used to compare with the 1997 criterion. Seasonal Max ΔT is the maximum daily temperature fluctuation. The 7-Day average maximum value is the maximum of the 7-day moving average of daily maximum temperatures. The 2003 standards under EPA review will utilize this metric to determine temperature compliance. The Days >64 value records the number of days on which the *daily* maximum temperature exceeded the 64° F criterion.

Table 4. Seasonal maximum temperature, temperature change, and 7-day moving average

Seasonal Maximum		Seasonal Max ΔT		7-Day averages			
Date	**Value**	**Date**	**Value**	**Date**	**Max**	**ΔT**	**Days >64 F**
7/22/02	**67.5**	7/5/02	5.4	7/23/02	66.1	3.7	23
7/30/03	**69.1**	6/25/03	5.9	7/29/03	66.9	4.6	47
7/24/04	**71.2**	6/16/04	6.0	7/22/04	69.0	4.2	61

Stream temperature at WPL050 exceeded the state criterion in each year monitored, and seasonal maximums increased each year. Due to the negative effects of chronic high temperatures on salmonids and other cold-water biota, the amount of time spent out of compliance is also of interest. Figure 4 shows the number of days on which temperatures exceeded the 64° F criterion, and the average number of hours spent above 64° F on those days.

The number of days out of compliance increased fairly dramatically each year, from 23 days in 2002 to 61 days in 2004. This increase is probably attributable to differences in ambient air temperatures and stream flow between years. Figure 4 also indicates that when exceedences occur Whipple Creek biota are subject to temperatures in excess of 64° F for a substantial part of the day.

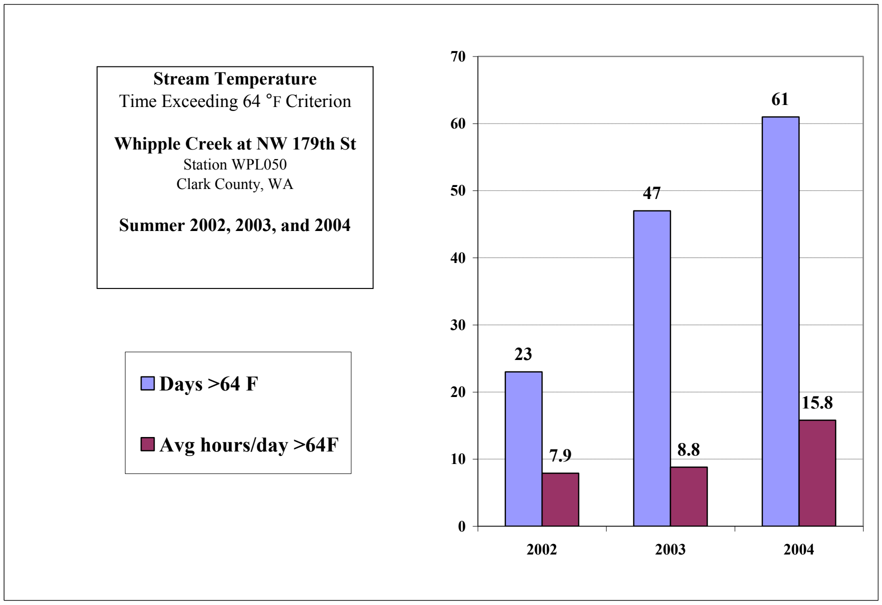

Figure 4. Time exceeding 64° F water temperature criterion, 2002 – 2004, Station WPL050.

Impacts to Beneficial Uses

General water quality in Whipple Creek is poor according to the OWQI, and listed beneficial uses are directly impacted by several water quality characteristics, including: fecal coliform bacteria, temperature, turbidity, total phosphorus, and total solids.

Observed levels of these characteristics may have negative impacts on the beneficial uses of: recreation and aesthetic enjoyment; salmonid rearing and spawning, and; wildlife habitat. Table 3 at the conclusion of this section summarizes the primary water quality impacts to beneficial uses in Whipple Creek, and probable sources of the observed impact. Beneficial use impacts and likely sources are discussed in more detail below.

<u>Recreation and aesthetic enjoyment</u>

Fecal coliform bacteria

Primary contact recreation is impacted by consistently elevated counts of fecal coliform bacteria which indicate the possible presence of pathogens. 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. Although Whipple Creek has no developed swimming or wading areas, it is likely that some local residents, particularly children, utilize the creek for recreation. If so, there is some risk of illness due to bacterial contamination.

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Water quality data suggest that fecal coliform issues in Whipple Creek stem from multiple sources. Human sources are the primary concern and represent the greatest risk of serious health impacts such as hepatitis; however, non-human sources also carry risks. For instance, beavers and other wildlife may carry the intestinal parasite *Giardia lamblia* which is spread through feces and causes a variety of intestinal symptoms in humans.

Elevated bacteria levels in summer (June-September) baseflow are likely being introduced through direct connection to sewage and animal wastes. Localized septic tank or sanitary sewer leaks enter the stream directly through shallow groundwater seeps and may also enter the storm sewer system. Past storm sewer screening activities in Whipple Creek noted several locations where baseflow being carried by storm sewers had elevated bacteria counts.

Non-human sources in summer baseflow include direct wildlife and livestock access. The 2005 Whipple Creek Stream Assessment indicated Whipple Creek supports a large amount of beaver activity. Waterfowl were also present in moderate numbers in some reaches and could be a contributing factor. In the assessed reaches, little evidence of direct livestock access was encountered and no direct access was observed. However, where evidence was found, it appeared that animals were present seasonally and primarily during the warmer months. Therefore, seasonal livestock access may be contributing to elevated summer bacteria concentrations.

Stormwater is easily overlooked as a potential source of bacteria during the summer, since rainfall is relatively infrequent. However, an examination of June through September bacteria data indicates that some of the highest dry-season bacteria concentrations have occurred during or shortly after rain events. Although dry-season bacteria concentrations are consistently elevated regardless of rainfall, the influence of stormwater should be recognized as a significant source of bacteria in Whipple Creek during the summer.

Due partly to greater dilution by higher volumes of baseflow, routine bacteria concentrations are often lower during the Fall/Winter/Spring (FWS) time period (October-May); however, total bacteria *loads* may actually be higher during this time due to the additional stream volume. Additionally, bacteria concentrations are often higher during FWS storm events as a wide range of non-point sources contribute bacteria in amounts high enough to overcome dilution effects.

FWS bacteria sources may include all of the summer sources listed above as well as increased influence from sources that require surface runoff to transport bacteria to streams. Pet waste, manure storage, livestock confinement area runoff, and wildlife waste are among sources that enter streams through the storm-sewer system or by direct overland runoff. Though limited in number, the 2005 Whipple Creek Stream Assessment noted the presence of some hobby farms with small numbers of livestock, primarily in the headwater areas of Packard Creek and Whipple Creek.

Septic and sanitary sewer leaks can be an increased problem during FWS due to increased runoff and higher groundwater levels. Studies also suggest that fecal coliform bacteria can survive and reproduce in sediments on stream bottoms and in storm sewers. During storm events, these bacteria may be re-suspended and can increase concentrations above levels that would occur due to runoff alone.

Turbidity and solids
Aesthetic enjoyment may be limited by high turbidity. Whipple Creek often exhibits a milky, hazy appearance near station WPL050, and high turbidity during rain events may result in condition resembling chocolate milk.

The primary sources of turbidity in Whipple Creek are probably erosion-related. Both off-site erosion (development, agriculture, recreational vehicle use) and in-stream erosion (bank scour, slumping, re-suspension of sediments during high flows) likely contribute significantly to the elevated turbidity during rain events. Septic or sewer leaks entering Whipple Creek through groundwater seeps may contribute to the milky or opaque appearance during baseflow conditions. Additionally, the elevated total phosphorus levels observed at station WPL050 has the potential to increase turbidity by contributing to excessive plant and algae growth, especially in ponded areas.

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. High nutrient input from Whipple Creek may be contributing to observed blue-green algal blooms in Lake River, and also in Vancouver Lake (due to tidal influence). Once the high-nutrient water enters these slow-moving water bodies, the nutrients are readily available for utilization by plants and algae. Elevated nutrient levels in Vancouver Lake have contributed to potentially toxic algal blooms during recent summers, forcing lengthy closure of swimming areas.

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

Elevated summer TP stems primarily from sources carried by groundwater seeps. Although groundwater in the Whipple Creek watershed tends to have high TP concentration (Turney, 1990), naturally elevated concentrations stemming from the underlying geology are very likely augmented by nutrients from fertilizers, leaking septic tanks and sewer infrastructure, wildlife, and direct livestock access.

Similar to bacteria, winter TP concentrations can be low or high depending on the amount of baseflow dilution and the impact of additional sources carried by storm sewers and overland runoff.

Salmonid rearing and spawning

Water temperature

Water temperature may be a significant water quality impediment to salmonid use in Whipple Creek. In particular, elevated temperatures have a detrimental impact on salmonid rearing. Migration and spawning tend to occur during cooler times of 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°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).

Although Whipple Creek is not among the warmest streams monitored by Water Resources, summer temperatures regularly exceed 64°F and suggest that temperature moderation will be a necessary component in any plan to recover fish populations.

Solar radiation is the primary driver of water temperature. The susceptibility of the stream to solar radiation is influenced by several factors including stream flow, canopy cover (shade), ponds, and the extent of groundwater influence.

Whipple Creek has relatively good riparian canopy cover throughout much of the watershed, though many areas do receive direct solar radiation and would benefit from riparian enhancement. A large number of ponds were noted during the 2005 Whipple Creek Assessment. Both beaver ponds and man-made ponds are common and likely contribute significantly to elevated temperatures. Below average summer stream flows over the past several years have made the stream more susceptible to temperature impacts.

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. While never observed directly in Whipple Creek, impacts of this type have been noted in nearby Cougar Creek, an urbanized subwatershed in Salmon Creek.

Turbidity and solids
Elevated turbidity and total solids are also a significant concern. Turbid water may limit foraging ability and indicate the presence of fine silt that clogs gills and spawning beds. Sedimentation of suspended solids loads compromises gravel spawning areas, smothers eggs, and impacts food availability by suppressing benthic macroinvertebrate populations. The available water quality data and high level of substrate embeddedness (see habitat section) suggest Whipple Creek carries a higher than desirable load of fine silt and sediment.

Total solids are composed of dissolved and suspended fractions. The dissolved fraction includes calcium, chloride, nitrate, phosphorus, iron, and other ions and particles. Suspended solids include silt, clay, algae, and other particulate organic matter.

The dissolved fraction affects the water balance in the cells of aquatic organisms; elevated concentrations make it more difficult to maintain proper cell density and function. The suspended fraction affects water clarity and sedimentation, and may serve as a carrier for toxics. High suspended solids will increase turbidity, decreasing light penetration and photosynthesis. High total solids also contributes to temperature issues by causing water to heat up more rapidly and hold more heat Primary sources of total solids include sewage, fertilizers, road runoff, and soil erosion (www.epa.gov/volunteer/stream/vms58.html).

Wildlife habitat
Water quality impacts to non-fish wildlife habitat stem primarily from the same issues noted above. Sedimentation, elevated water temperatures, and increasing total phosphorus concentrations may impact other wildlife species by modifying habitat structure and availability.

Implications for stormwater management
Table 5 lists the primary known water quality concerns and potential solutions for each. Solutions listed in bold indicate areas where Clean Water Program activities can have a positive impact. It should be noted that Clean Water Program activities, though important, are not likely to achieve water quality improvement goals on their own. Other county departments, local agencies, and the public must all contribute if water quality is to be improved.

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 5. Primary known water quality concerns and potential solutions

Characteristic	Beneficial Use Affected	Potential WC Sources	Mechanism	Solutions (bold indicates direct Clean Water Program involvement)
Fecal coliform bacteria	Primary contact recreation	failing septic systems sanitary sewer leaks livestock, pets, wildlife	groundwater seeps storm sewers groundwater seeps storm sewers overland runoff storm sewers direct access	**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
Water temperature	Salmonid rearing	vegetation removal ponds low summer flows	direct solar radiation direct solar radiation stagnation decreased resistance to thermal inputs	**Stormwater infiltration to increase baseflow** **Streamside planting/vegetation enhancement** **Education programs** Pond removal or limitation
Turbidity	Salmonid spawning and rearing; Aesthetic enjoyment	erosion *(development projects; land clearing; cropland; impervious surfaces; channel erosion)* algae	overland runoff storm sewers channel dynamics in-stream growth due to excess nutrients	Erosion control regulations **Storm sewer system cleaning and maintenance** **Storm water facility designs/retrofits to optimize settling and removal of suspended silt/clay** 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 fertilizers erosion livestock, pets, wildlife failing septic systems sanitary sewer leaks	groundwater seeps overland runoff storm sewers (see turbidity) (see bacteria) (see bacteria) (see bacteria)	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)**
Total solids	Salmonid spawning and rearing; Aesthetic enjoyment	same as turbidity, plus: failing septic systems sanitary sewer leaks fertilizers	 (see bacteria) (see bacteria) (see phosphorus)	same as turbidity, plus: **Education programs** Septic system inspections and maintenance Sanitary sewer leak identification and removal

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 viewable on the internet through the Digital Atlas located at:
http://gis.clark.wa.gov/imf/imf.jsp?site=digitalatlas&CFID=56651&CFTOKEN=98300052

Drainage system inventory is an ongoing CWP work effort focused on updating the StormwaterClk database to include all existing stormwater drainage infrastructure.

The 2005 work effort in this study area focused on identifying and mapping previously unmapped discharge points and stormwater conveyance, consisting primarily of ditch outfalls and county-road ditch conveyance.

Table 6 indicates the number of features inventoried in StormwaterClk, updated as of 2009.

The drainage system inventory for these two subwatersheds is generally completed.

Table 6. Drainage system inventory results, Whipple Creek (Upper) and Whipple Creek (Lower)

Database Feature Category	Number of mapped Features
Inlet	1621
Discharge Point (outfall)	419
Flow Control	103
Storage/Treatment	585
Manhole	834
Filter System	8
Channel	1932
Gravity Main	3701
Facilities	143

2006 Stormwater Needs Assessment Program

Stormwater Facility Inspection

Stormwater facility inspections were not conducted.

Illicit Discharge Detection and Elimination Screening

Illicit discharges are broadly defined as polluted, non-stormwater discharges entering the storm sewer system. Examples include improper cross-connections, leaking sewer lines or septic systems, and illegal dumping of materials such as waste oil or paint.

Illicit discharges may contribute to exceedences of water quality criteria in receiving waters during baseflow conditions, and may also increase pollutant levels in stormwater.

Section S5.B.8.g.ii of Clark County's 1999 NPDES permit requires an ongoing project to identify and remove illicit discharges entering the county's municipal separate storm sewer system. The IDDE Screening project fulfills the current requirement and is designed to meet future requirements of the 2007 NPDES Phase 1 municipal stormwater permit for Western Washington.

The project is based on methods described in Illicit Discharge Detection and Elimination: A guidance manual for Program Development and Technical Assessments (Center for Watershed Protection, October 2004), as required by the 2007 permit.

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

Project objectives are to:

- Identify dry-weather flows at mapped outfalls
- Conduct dry-weather field screening and analytical testing to detect illicit discharges
- Conduct and/or coordinate follow-up investigations to isolate sources when suspected illicit discharges are detected
- Refer suspected illicit discharges to appropriate staff or agencies for source removal
- Perform follow-up inspection or monitoring to confirm that source removal activities are successful

The IDDE Screening project follows several steps in each watershed, including: initial screening, follow-up investigations, referral for source removal, and effectiveness monitoring.

The initial screening step proceeds systematically through county watersheds in coordination with the Stormwater Needs Assessment Program (SNAP) and at a scope sufficient to meet NPDES permit requirements for screening implementation. Initial screening in each subwatershed is expected to require no more than one year, and multiple subwatersheds may be screened in a given year.

Subsequent follow-up investigations and source removal tasks lag behind initial screening work due to the time required to plan and carry out these activities. The timing and order of follow-up investigations depends on the number, complexity, and severity of problems discovered during initial screening. Each suspected illicit discharge is addressed as an individual case study. Summaries for each case are produced separately on completion of source removal efforts.

Overview of 2006 project activity

Needs Assessment activities and IDDE Screening were completed in the Whipple Creek watershed during 2005 and 2006 as the SNAP was being developed. Initial screening activities were completed from June-October 2006 and are summarized in this report.

Based on the county's Clarkstorm database, as of May 2006 there were 350 mapped stormwater outfalls in the Whipple Creek watershed, consisting primarily of pipe outfalls and roadside ditches. Three-hundred ten of these outfalls were screened for illicit discharges, thirty-six were eliminated from the sample set (outfalls that do not drain to surface water bodies, emergency spillways, etc), and the remaining four could not be reached due to site conditions. One additional outfall was screened based on a request by Clark County Public Works Environmental Permitting staff.

Samples were collected at 23 flowing outfalls, and follow-up investigations were performed at 6 outfalls. One serious illicit discharge was located and removed through this process. A second significant illicit discharge was discovered through SNAP field work in 2005 and removal activities are ongoing as of November 2006.

Screening Approach

Detailed methods may be found in the Quality Assurance Project Plan for the IDDE Screening project. Figure 5 outlines the general project approach.

The process begins with systematic outfall screening using a series of physical and water quality indicators. Screened outfalls may be non-flowing, flowing, or an obvious illicit discharge. Obvious illicit discharges are immediately referred for either removal or further investigation to isolate the source. Field and analytical results from flowing outfalls are interpreted using a flowchart and selected industrial discharge benchmarks (see QAPP). Non-flowing outfalls are assessed for possible intermittent discharges and may be sampled using off-hours monitoring, caulk dams, sandbags, or other methods to capture intermittent flow.

If an illicit discharge is suspected, a follow-up investigation attempts to isolate the source. Depending on the type of discharge, this may include investigations of the upstream storm drain network, the upland drainage area, a specific business or pollution-generating site, septic systems, or sanitary sewer infrastructure. These follow-up investigations may be performed by county departments or by other agencies.

When a source or source area has been isolated to the extent practicable, the case is referred to the appropriate agency or county department for removal. County technical assistance staff, code enforcement officers, or public health staff may be involved, in addition to local sewer districts and the state Department of Ecology. Effectiveness monitoring is used to confirm source removal.

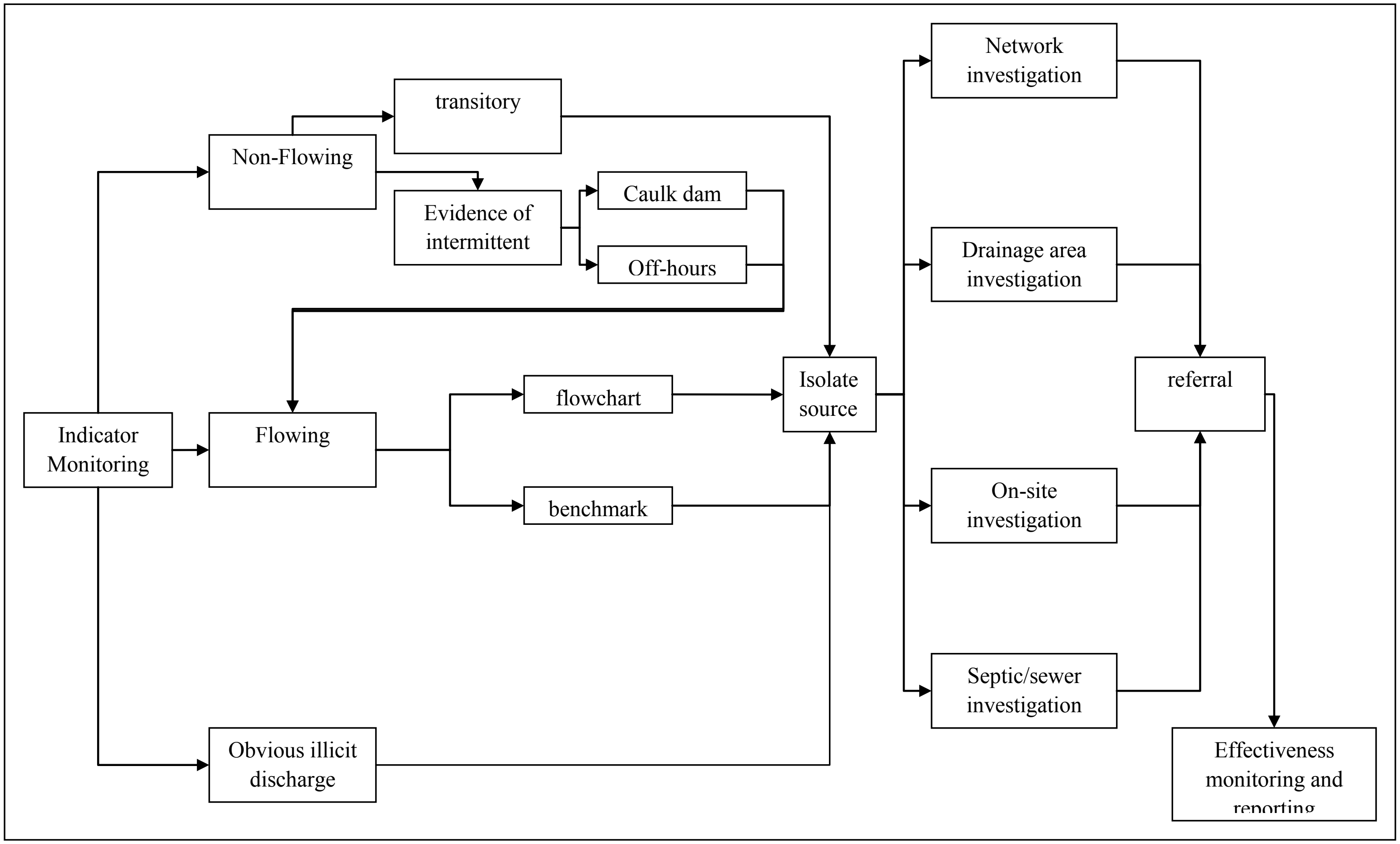


Figure 5. IDDE Screening project framework. (adapted from Center for Watershed Protection, October 2004)

Results

Project activities and results are presented in a series of maps and selected summary metrics. Case reports summarizing activities at specific illicit discharge sites (including site visits, investigations, referrals, and removal activities) are on file in the Water Resources section.

Figure 6 shows the general location of the 350 mapped stormwater outfalls in Whipple Creek, and Figure 7 summarizes notable screening activities including outfalls where water samples were collected, follow-up investigations performed, referrals made, and sources removed.

Table 7 summarizes project activities by major category, including the number of issues investigated, referred, and removed to date.

Among 311 outfalls screened, potential illicit discharges were suspected at six outfalls. Follow-up investigations were conducted for all six locations. In two cases an illicit discharge was confirmed and a source area adequately pinpointed to trigger a referral for removal. Follow-up investigation samples at the other four locations did not indicate ongoing illicit discharges. These four locations will be re-visited during 2007 screening to check for recurrence and/or the presence of intermittent discharges. No illicit discharges were reported through citizen complaints in 2006.

As of November 2006, one illicit discharge has been removed and one referral is ongoing. No cases have been closed without resolution. Details concerning these follow-up activities are included in the individual case summaries.

Table 7. 2006 project activity summary as of November 2006.

Metric	Number
# of outfalls screened	311
# of outfalls with sufficient flow to collect water samples	23
# of suspected illicit discharges	6
# of investigations initiated	6
# of illicit discharge sources located	2
# of outfalls to be re-visited in 2007	4
# of referrals	2
# of illicit discharges removed	1
# of investigations and referrals ongoing	1
# of cases closed without resolution	0

2006 Stormwater Needs Assessment Program

The 2007 Western Washington Phase I NPDES permit will require that follow-up investigations must be initiated within 21 days from the discovery of a suspected illicit discharge. The average time between discovery and initiation of follow-up investigations in 2006 was twelve days, ranging from one to 19 days. “Discovery” is defined as the date when a discharge is first suspected or when lab results are received indicating a potential discharge. “Initiation” is defined as the beginning of planning for the follow-up investigation, typically at least seven days prior to field follow up.

Field and laboratory data for all initial screening visits are included in Appendix A.

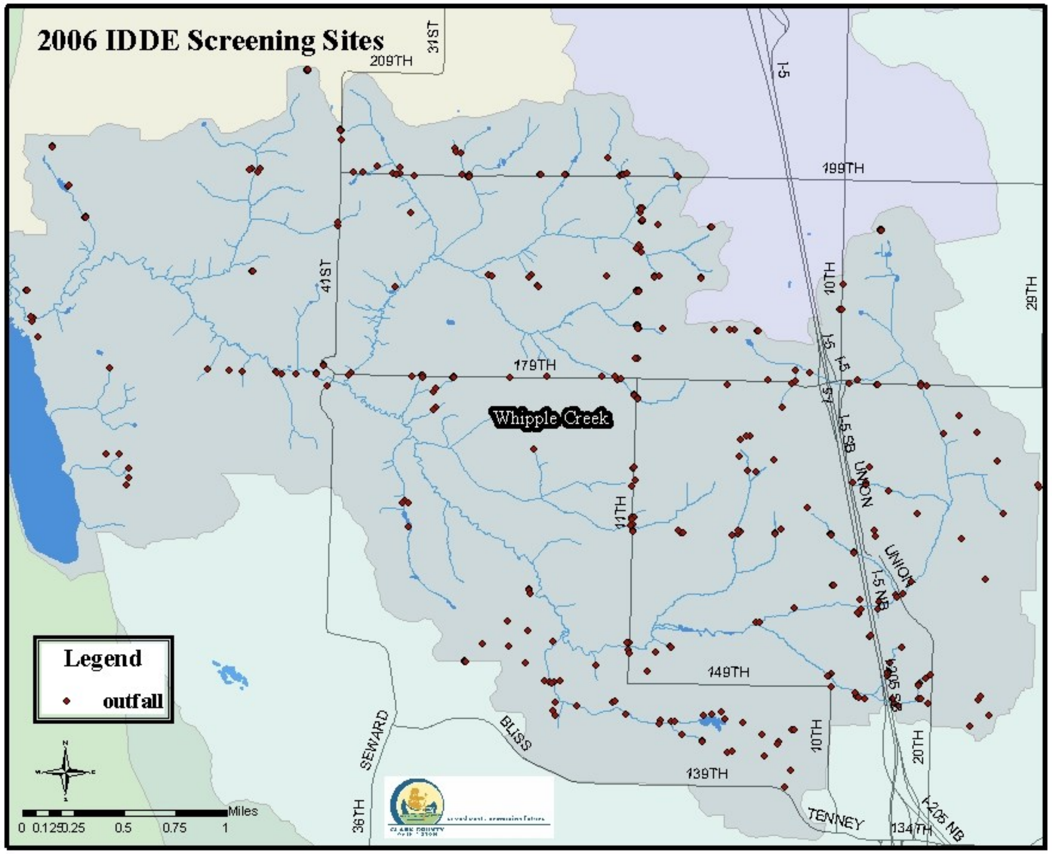


Figure 6. General location of outfalls screened in 2006.

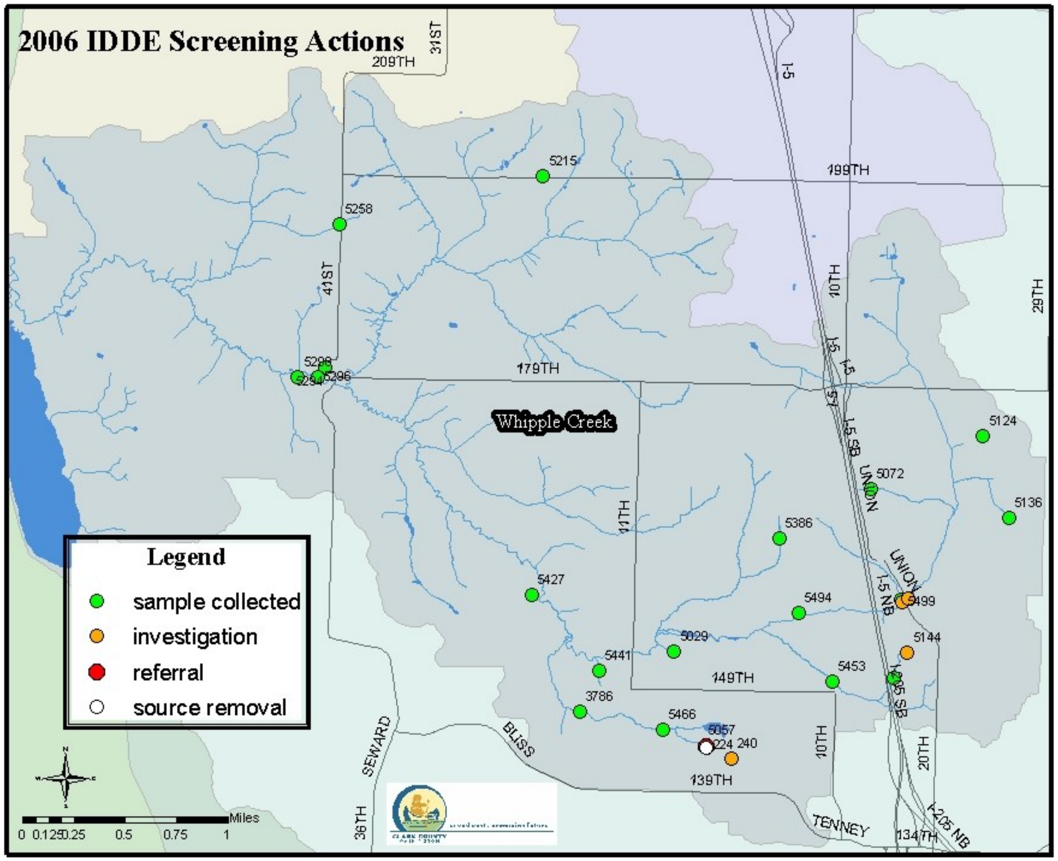


Figure 7. Summary of 2006 IDDE Screening project activities.

Adaptive Management

Project tracking metrics

Several additional metrics are calculated to enable project managers to better evaluate the project and document general patterns in screening activities. The tables below summarize the types of discharges suspected based on screening data, the screening activity responsible for discovering the discharge, and the type of follow-up investigation utilized.

Table 8. Suspected discharge types for initial outfall screening

Type of discharge suspected at screened sites	Number
dry or too little flow to sample	288
natural/clean water	17
sanitary	4
washwater	1
industrial	1
TOTAL SITES SCREENED	**311**

Table 9. Reason illicit discharge suspected

Reason suspected	Number
flowchart	5
benchmark	0
field observation	1
citizen complaint	0

Table 10. Type of follow-up investigations utilized

Investigation type	Number
Storm Network	5
Drainage area	0
On-site	2
Septic/Sewer	1

Table 8 indicates that out of 23 screened sites where flow was present, 17 appeared to consist of clean water flows. Sanitary sources were the primary suspected illicit discharge type (4), while washwater and industrial sources accounted for one suspected discharge each. Table 9 shows that the flowchart method detected the most potential illicit discharges, followed by field observations. Neither citizen complaints nor industrial flow benchmarks indicated any potential illicit discharges in 2006. The majority of follow-up investigations involved the upstream storm-drain network, though two on-site investigations and one sewer investigation were also conducted (Table 10).

The level of participation by outside agencies and departments is also of interest to project managers. Table 11 below outlines agency involvement.

Table 11. Agency and County Department involvement in investigations and referrals.

Agency or Department	Investigation	Source Removal
CC Public Works Water Resources	6	2
Clark Regional Wastewater District	2	1
Clark Public Utilities	0	0
CC Code Enforcement	0	0
WA Department of Ecology	1	1
CC Public Health	1	0

Interagency Cooperation

Interagency cooperation is a critical component of follow-up investigations and source removal activities. During 2006, project staff met with representatives from Clark County Public Health and the Clark Regional Wastewater District to establish lines of communication and a process for addressing investigations and referrals. Details of this standard process are incorporated in Version 2.0 of the Quality Assurance Project Plan.

Data management

Data management procedures were not finalized for the 2006 project due to ongoing modifications to Water Resources' overall data management structure. As this structure is finalized during 2007, IDDE Screening data will be effectively linked with other databases and tools developed to facilitate data entry. Details of these procedures will be incorporated in future versions of the Quality Assurance Project Plan.

Project Modifications

A number of modifications will be made to increase project efficiency in 2007 and may be reflected in Version 2.0 of the QAPP.

1) *Dry weather definition*: For planning purposes, "dry" means no measurable rainfall (<0.01") in the past 48 hours. If rain has fallen in the general vicinity within 48 hours, screening will typically not be conducted.

2) *Color wheel:* The color wheel will not be used for routine screening, EXCEPT in those rare cases where visual observation indicates extensive coloration.

3) *Ditch outfalls:* Ditch outfalls comprise a high percentage of the existing outfalls in many areas, but tend to have a very low occurrence of dry weather flow and illicit discharges. In future years, the IDDE Screening project will be expanded to cover several subwatersheds per year, increasing the need for efficiency. Ditch outfalls will NOT be logged with the GPS and data sheets will NOT be filled out in the field except for ditches where water samples are collected or where illicit discharges are suspected. Electronic data entry will be conducted in the office for dry ditch outfalls.

4) *Water samples from ditch outfalls*. If flow is sufficient to collect samples relatively quickly and with no contamination, samples will be collected for ALL standard parameters. However, in many cases, ditch outfalls have very low flows that are difficult to sample effectively. In these cases,

staff will attempt to collect a clean sample for Fecal Coliform ONLY. Field meter readings will be collected ONLY if there is sufficient flow to submerge the probes or if a sufficient volume can be collected in a clean container to obtain measurements.

5) *Unreachable or hidden outfalls.* If a mapped outfall cannot be located or is unreachable due to vegetation, terrain, or property access, one of several options may be pursued:

a) skip the outfall. Further steps taken by the project manager may include:
i) contact Public Works Operations and request a crew to clear vegetation and/or locate outfall.
ii) contact landowner for access permission
iii) remove the outfall from consideration under IDDE Screening

b) if the outfall is from a stormwater facility and the facility is obviously dry, assume the outfall is also dry and complete as much of the data collection as possible. In most cases, such outfalls will also be referred to Operations for vegetation clearing.

c) locate the nearest "upstream" accessible point (manhole, ditch access point, etc) and perform the screening at that location. Note the change under a comment field in the data dictionary.

6) *GPS data logger*: Use of TerraSync software and data dictionaries with the Trimble GeoXT GPS unit will be discontinued. An ArcMap software application will be developed to provide better access to stormwater infrastructure data in the field and to facilitate more efficient data collection.

7) *Field photos:* Digital photographs will only be taken for outfalls where water samples are collected and/or where an illicit discharge is suspected during initial screening. Long-term photo storage will be limited to those locations where follow-up investigations are performed or illicit discharges are discovered.

Stream Reconnaissance and Feature Inventory

Executive Summary

Background

This report summarizes the planning, implementation, and products of the Whipple Creek Stream Assessment project. Several watershed-scale characterization maps are also included, as are lists of immediate problem referrals and potential areas for preservation.

From December 2004 through May 2005, Clark County Public Works Water Resources assessed 25 stream miles in the Whipple Creek watershed for stormwater impacts and stream improvement opportunities.

Methods

The Whipple Creek Stream Assessment utilized the Unified Stream Assessment (USA) protocol designed by the Center for Watershed Protection (March 2004) for EPA's Office of Water Management. The USA is part of a larger set of protocols developed by the Center as an integrated framework for improving and rehabilitating small urban watersheds.

The USA is a systematic technique to locate and evaluate problems and restoration opportunities within the urban stream corridor. Taken in conjunction with other watershed data, results of the USA may be used to develop urban stream restoration plans.

The project focused first on the more heavily developed upper watershed, followed by the more rural Packard Creek tributary.

A letter of intent was sent to 398 property owners bordering Whipple Creek, explaining the project and notifying landowners of the county's plans to access these properties. The letter announced the county's intentions and placed the responsibility on landowners to respond if they wished to deny access. Only five landowners chose to decline access, with an additional 20 landowners calling in support of the project or to request prior notification so animals could be penned or landowners home at the time of the assessment.

A press release was also issued at the beginning of the project in an effort to increase public awareness, eventually leading to an article featuring the project in the Columbian newspaper.

Results

Figure 8 shows the location of the assessed catchments within the Whipple Creek watershed. Approximately 25 miles of stream corridor were assessed, including 56 complete catchments and 4 partial catchments.

Primary products from the assessment included:
1) a SQL database populated with complete assessment data
2) a geodatabase including location data for all assessed features, linked to the SQL database
3) an initial tally of assessed features and restoration opportunities, summarized by reach

2006 Stormwater Needs Assessment Program

In addition to these required products, the project led to a number of general impressions regarding the Whipple Creek watershed, a list of problems for immediate referral, and a list of areas where preservation of existing habitat should be considered. Several watershed characterization maps were also generated based on assessment data.

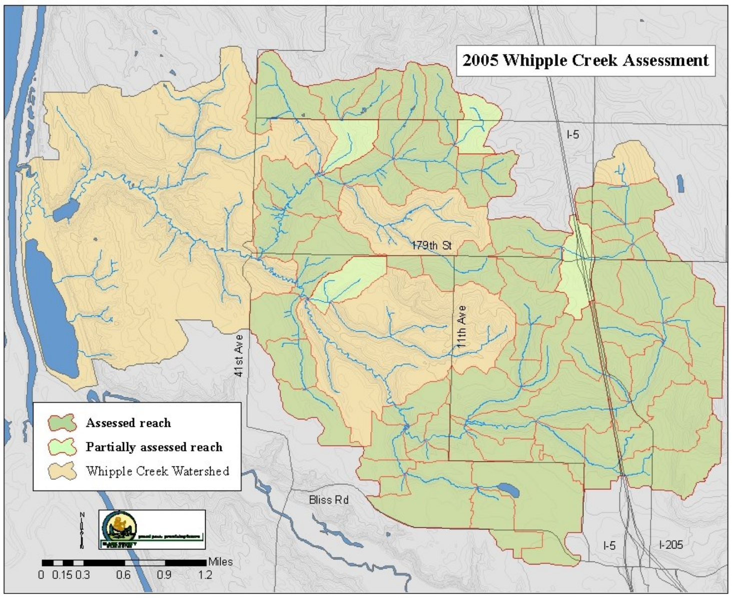


Figure 8. Whipple Creek Stream Assessment reaches, 2005.

The Whipple Creek Stream Assessment generated a large amount of information that should be an integral component of stormwater planning in the Whipple Creek watershed and other projects.

Potential projects are numerous. Out of the 544 assessed features, over 300 were ranked as possible opportunities to improve the stream. These potential projects vary widely in type, cost, and priority; however, this number provides an indication of the amount of improvement work that could be done in the assessed reaches.

Opportunities involving county stormwater infrastructure are primarily associated with stormwater outfalls and stream crossings. Forty-one outfalls and 72 stream crossings were assessed as project opportunities.

Erosional features were numerous, with long segments of stream scour and incision very common.

Impacted buffers were also very common, and 83 of 87 assessed impacts were ranked as possible projects. Buffer improvement opportunities tend to focus on invasive plant removal and streambank re-vegetation, and in many cases could be combined with erosion-related improvements. Buffer opportunities involving animal access issues were infrequent.

Channel modifications were relatively infrequent and only 10 potential projects were recorded. Eighteen trash and debris sites were located during the assessment. None of the eight utility features assessed appeared to require restoration projects.
An additional result of assessment activities was the discovery of various issues or situations in need of timely referral for corrective action. Referrals ranged from incomplete stormwater infrastructure mapping to the presence of rare species, and included several imminent or existing threats to stream health. In particular, several erosion control problems and one long-running illicit discharge were discovered and subsequently addressed.

Conclusion
In general, the assessment confirms that the Whipple Creek corridor has been heavily impacted by past and current human activities. Within the assessed reaches, degraded areas far outnumber those that remain intact. In many reaches, increased runoff from historical clearing and development has led to significant channel incision and floodplain disconnection. Streambank scour and fine sediment accumulation are common. Riparian conditions are mixed: many areas have ample vegetated buffer widths, yet a large portion of the vegetation is comprised of invasive species, particularly Himalayan blackberry.

Degradation is not limited to developed or developing areas. Impacts were clearly present in the more rural areas despite significantly lower levels of development and infrastructure. Historical clearing of forest for agriculture, road-building, and timber harvest appears to have altered hydrologic conditions sufficiently to cause channel impacts. Our observations are consistent with current knowledge regarding stream channel impacts: both forest conversion *and* increased development cause significant degradation.

In any case, Whipple Creek serves as a good example of the extent to which human activities can degrade stream function and habitat.

2005 Whipple Creek Stream Assessment
Summary Report

Project Name: Whipple Creek Stream Assessment
Project Type: Monitoring and Evaluation
Accounting Number: 4420-000-531-534-203- RC #011129
Cost: ~$65,000
Schedule: December 2004 - May 2005
Associated Documents: Whipple Creek Stream Assessment Project Plan

Introduction

Report Purpose

This report summarizes the planning, implementation, and products of the Whipple Creek Stream Assessment project. It describes project design, field methods, products, and field observations, including a general project evaluation. Because the assessment was intended to provide tools for use by other projects, data analysis is general and limited. Several watershed-scale characterization maps are included, as are lists of immediate problem referrals and potential areas for preservation. Additional detailed analysis of Whipple Creek Stream Assessment data will be performed according to the needs of the projects listed below.

Project Purpose

From December 2004 through May 2005, Clark County Public Works Water Resources assessed 25 stream miles in the Whipple Creek watershed for stormwater impacts and stream improvement opportunities. The assessment was performed in support of three projects required under Clark County's NPDES permit (WA-004211-1, July 1999):

1) <u>Whipple Creek Watershed Projects Plan</u>. Clark County is required to develop stormwater plans under special permit condition S9.E.1. Whipple Creek Stream Assessment data are to be analyzed and used in conjunction with other watershed information to identify and prioritize stream improvement activities for the Whipple Creek Watershed Projects Plan.

Components of the Whipple Creek Watershed Projects Plan require considerable analysis and mapping of Whipple Creek Stream Assessment data. The watershed-scale characterization maps and many of the other results included in this summary are intended primarily to support the watershed projects plan. Detailed analysis concerning specific project opportunities and prioritization are included in the Whipple Creek Watershed Projects Plan.

Assessment information will also be included in an ArcReader product developed for the Whipple Creek Watershed Projects Plan. ArcReader enables users who are not equipped with ArcMap GIS to view GIS information, and will enhance data usability by a variety of interested parties.

2) <u>Illicit Discharge Detection and Elimination</u>. Ongoing illicit discharge screening is required under permit section S5.B.8.g.ii. The Whipple Creek Stream Assessment documented the location

and conditions of storm sewer outfalls within assessed stream reaches, and provides a basis for future IDDE implementation in the Whipple Creek watershed.

3) Storm Sewer Mapping. Storm sewer mapping is required under special condition S5.B.6. Water Resources' storm sewer mapping activities have been ongoing for several years. The Whipple Creek Stream Assessment documented the location of previously unmapped stormwater infrastructure and provided limited ground-truthing for previously mapped areas.

The Unified Stream Assessment

The Whipple Creek Stream Assessment utilized the Unified Stream Assessment (USA) protocol designed by the Center for Watershed Protection (March 2004) for EPA's Office of Water Management. The USA is part of a larger set of protocols developed by the Center as an integrated framework for improving and rehabilitating small urban watersheds.

The USA is a systematic technique to locate and evaluate problems and restoration opportunities within the urban stream corridor. Data are collected for nine components along each assessment reach: eight impact assessments and one reach assessment. Impact assessments document storm water outfalls, severe erosion, impacted stream buffers, trash and debris, utilities in the stream corridor, stream crossings, channel modifications, and miscellaneous features. They are designed to collect basic data on the location, condition, and potential restorability of individual features present in the stream corridor. Reach assessments summarize overall stream corridor conditions within each reach.

Maps and calculated metrics provide a preliminary assessment of problems and opportunities for stream improvement or rehabilitation for each reach and the watershed as a whole. Taken in conjunction with other watershed data, results of the USA may then be used to develop urban stream restoration plans.

Project Description

Objectives

The primary objectives of the Whipple Creek Stream Assessment were to:

1) Provide USA assessment data for approximately 25 stream miles at a catchment scale.
2) Locate and map county stormwater outfalls and non-county outfalls within the assessed catchments.

Additionally, the project presented an opportunity for Water Resources to assess the overall suitability of the USA protocol for identifying potential stormwater or stream habitat improvement projects and providing information for future stormwater planning efforts.

Scope

For planning purposes, the watershed was divided into 4 general areas: 1) Upper watershed (above 157th Street), 2) Middle watershed (Packard Creek confluence to 157th St), 3) Packard Creek, and 4) Lower watershed (below Packard Creek confluence).

The project plan intended to focus first on the more heavily developed upper watershed, followed by the middle watershed, Packard Creek, and the lower watershed.

Based on LiDAR (Light Detection and Ranging) topographical mapping data, the Whipple Creek watershed includes approximately 50 miles of perennial stream channel. The project target was to assess ~25 miles of stream corridor; however, it was anticipated that the total mileage assessed would depend heavily on the accessibility of private property and on conditions encountered in the field. The project plan suggested these general priorities:

Upper watershed:

- All accessible stream reaches found on the LiDAR stream layer will be assessed.

Middle watershed:

- Mainstem and major tributary reaches (>1/2 mile in length) will be assessed. Smaller tributaries may be assessed if field conditions indicate significant impacts, or if the tributary drains an area suspected to be a source of impacts.

Packard Creek:

- Same as middle mainstem

Lower watershed:

- Only mainstem reaches will be assessed. Tributary reaches may be assessed if field conditions indicate significant impacts.

Final decisions regarding whether to assess a specific reach were made by crews in the field and by the project manager based on professional judgment.

Products

The Whipple Creek Stream Assessment was primarily a data gathering effort intended to compile tools to be used by other projects. This project provided field assessment data, GIS data showing the location of each assessed feature, and an initial tally of assessed features and stream improvement opportunities. The following specific products were produced by the Whipple Creek Stream Assessment:

1) a SQL database populated with complete assessment data
2) a Geodatabase including all assessed features, linked to the SQL database
3) an initial tally of assessed features and restoration opportunities, summarized by reach

See the Results section for further information about these products, as well as additional results, analysis, and observations.

Organization and Schedule

Project Team

Agency:	Clark County Public Works Water Resources (Water Resources)	
Project Manager:	Jeff Schnabel	
Clients:	Jim Soli and Rod Swanson	
Program Supervisor:	Earl Rowell	
Primary Team Members:	Jeff Schnabel	Bob Hutton
	Ron Wierenga	Ken Lader
	Jason Wolf	
	Mike Szwaya	

Table 12 lists project tasks and primary staff. Project planning activities began in December 2004, with field assessments conducted over a 10-week period from February 9 through April 15, 2005. Data entry, GIS editing, and quality assurance reviews were performed during April 2005. Products were delivered in May 2005.

Table 12. Project tasks and primary staff.

Task	Primary Staff
Budget issues	Rod and Jim
Stream reach delineation	Mike
Modifications to Access database	Mike
Field map generation	Ken
ArcHydro/database compatibility issues	Mike
Landowner access letter	Jeff, w/Kelli (review by PIO and Pros. Atty)
Press release	Don Strick (PIO)
GPS setup	Ken, Mike
Field work planning and logistics	Jeff
Field crew	Jeff, Ron, Jason
Data entry into Access database	Jeff, Jason, Bob
GPS data edited as GIS layer	Ron
Geodatabase development	Mike
Project summary and product compilation	Jeff, Mike

Methods

Preliminary project methods are documented in the Whipple Creek Stream Assessment Project Plan. The following describes finalized methods and reflects modifications made during the project.

Sampling Design

The Whipple Creek Stream Assessment was a census-type survey intended to gather information from a large percentage of the sample population (stream reaches), with a primary focus on urban and urbanizing areas where development activities and stormwater infrastructure are most prevalent.

Reach Delineation

Project data are organized into catchment-level reaches. Based on LiDAR topographical mapping data, the Whipple Creek watershed was divided into 102 catchments within an ArcHydro model, each consisting of a stream reach approximately ¼ to ½ mile in length with a drainage area of 100-200 acres.

Each catchment was assigned a unique reach code based on the stream mile marker at the downstream end of the catchment. Whipple Creek catchments were preceded by the label "W", and Packard Creek catchments were labeled "P". Tributary catchments were appended to the end of the mainstem code using a "T" followed by the mile marker, and split tributaries were delineated with a directional label such as "E". Some examples follow:

W8.50 = Whipple Creek mainstem reach beginning 8.50 miles upstream from the mouth.
P1.55 = Packard Creek mainstem reach beginning at 1.55 miles from Whipple Cr confluence
W5.70T0.36E = tributary reach beginning at 0.36 miles upstream from WC confluence.

Private Property Access and Public Notification

A letter of intent (Appendix A) was sent to the owners of 522 taxlots bordering Whipple Creek, explaining the project and notifying landowners of the county's plans to access these properties. Landowners were invited to contact the project manager if they did not wish to grant access privileges. Prior to distribution, the letter was reviewed and approved by the project clients, county Public Information and Outreach (PIO) office, and county Prosecuting Attorney's office. Responses were entered into Water Resources' landowner contact database and a map was maintained indicating parcels where access was not allowed and where prior contact was requested before entering a parcel.

Landowners were not required to submit a form granting permission for access, meaning that individual landowners were free to change their mind at any time. Field crews were instructed to abide by the decision of landowners at the time of contact, regardless of prior notification. If requested to leave a parcel, crews were instructed to do so immediately.

Additionally, a press release was created prior to project implementation to better inform the public and media interests about the upcoming work effort. This press release eventually led to a feature article in the Columbian newspaper.

Field Procedures

Maps

1) GPS base map: Field crews carried a GPS unit with a base map including roads, streams, waterbodies, storm sewer infrastructure, septic tanks, sanitary sewer lines, contours, and taxlots.

2) Field maps: A set of 11" x 17" field maps was produced as a backup to the GPS. Field maps included ortho-photographs covering each catchment. Field maps were produced based on an index grid, stored in a binder, and appropriate maps selected for each field day.

3) An ArcMap GIS workspace and table depicting landowner permission status was consulted regularly during field event planning.

Equipment

Waders	Cell phone	Two-way radios
Field maps	Copy of authorization letter	Extra pencils/GPS stylus
Digital camera	Laser range-finder	Spare batteries
Field forms binder	Gloves	
Pens/pencils	Parking contacts	
GPS unit	Machetes	
First aid kit	Backpacks	

Field Assessment

Field assessments were completed during a 10-week period between February 7 and April 15, 2005. Field work was limited to three days per week to allow staff time for other ongoing projects. Assessments progressed at the rate of approximately ½ stream mile to 1 stream mile per day, and varied widely depending on terrain, accessibility, and vegetation.

Field data collection was based on the protocols described in Unified Stream Assessment: A User's Manual (Center for Watershed Protection, 2004), Manual 10 in the Urban Subwatershed Restoration Manual series. The protocol included eight impact assessment forms documenting storm water outfalls, severe erosion areas, impacted stream buffers, trash and debris, utilities, stream crossings, channel modifications, and miscellaneous features. Digital photos were taken to document each assessed feature. Finally, reach assessments summarized general stream corridor conditions within each catchment.

Field assessments were performed by teams of two or three staff. In most cases, a two-person crew was sufficient; however, three-person crews were used for safety and convenience when work was performed in remote areas or in areas with difficult access.

The assessment proceeded upstream starting at the bottom of each pre-defined catchment. Impact assessments and photo documentation were performed as features were encountered along the stream corridor. Assessment forms were filled out as completely as possible in the field without greatly hampering upstream progress. Reach assessment forms were completed at the conclusion of each reach or field day with input by two staff members to promote consistent interpretation.

Field crews modified pre-delineated catchments as necessary during the course of field work. In general, modifications of this type were in response to drastically changing channel conditions within a pre-delineated reach. Necessary modifications were then made to the catchment layer in GIS.

The location of each assessed impact was recorded using a Trimble GeoExplorer XT Global Positioning System (GPS) unit. For linear features (erosional areas, impacted buffers, etc), GPS points were logged at the beginning and end of each impacted segment when possible. Distances were estimated using GPS points, laser range-finder readings, and occasional field crew approximations.

Data Management

<u>Field sheets</u>

544 individual impact assessment forms were completed during the project, in addition to 60 reach-level assessments. Data were recorded in pencil on waterproof field forms. A field binder was used to organize data sheets by type during each field day, after which completed sheets were transferred to a master data binder for safekeeping until data entry.

<u>Photos</u>

Nearly 900 digital photographs were taken over the course of field work. Photos were recorded in the field on both a photo log and on the individual impact assessment form to which they pertained. Each photo retained a unique ID number assigned by the camera. Following each field day, the camera was downloaded and photos stored in date-stamped folders. Photos were later linked to map features in the Whipple Creek geodatabase.

<u>Data entry</u>

An Access database specifically designed to store USA data was provided by the Center for Watershed Protection (March 2004). Water Resources modified this database significantly and migrated it into a SQL database format to interface more efficiently with existing Water Resources databases. Data entry forms were created in an Access project to provide a more user-friendly front-end to the SQL database. Data entry forms closely mimicked field forms to facilitate data entry.

Completed field forms were copied and compiled by catchment to facilitate data entry. Reach assessment forms for each catchment were entered first, followed by individual impact assessment forms. Upon entry into the SQL database, a unique ID number was generated for each assessed impact. This unique ID number is used as the primary key to link data in the SQL database with features in the Whipple Creek geodatabase. As each impact form was entered, staff labeled the field sheet with the auto-generated ID number, initialed the field sheet, and placed a check mark on the sheet to indicate a completed entry.

<u>GPS data</u>

GPS data points were recorded for each of the 544 features assessed during the project and linked to the SQL database using the unique ID numbers described above.

GPS data were downloaded following each field day and merged for editing into a GIS workspace containing all GPS points generated by the project. Editing consisted of confirming and reconciling the location of each GPS point with information recorded on the field sheets, linking the point to the appropriate SQL database ID number, and converting GPS points into point, line, and polygon features representing the assessed impacts. This GPS information was then incorporated as feature classes within the Whipple Creek geodatabase.

Field sheets were initialed and highlighted to indicate completed GIS editing.

Quality Assurance

Field

Because qualitative field assessments allow latitude for subjective interpretation, field assessments were conducted by a limited number of staff to promote consistency. Field staff read and familiarized themselves with USA documentation and data collection tips, and relied on continual collaboration in the field to facilitate consistent interpretation. All field work was led by professional monitoring staff with experience in a wide variety of field data collection techniques and issues.

Field sheets were organized by type in a field binder, and each completed sheet was labeled with a unique combination of reach code and feature code. Changes to field sheets were initialed by the data recorder or project manager.

Photo logs and field sheets were cross-checked with field maps at the conclusion of each field day, and any necessary modifications or additions to field sheets were performed at this time.

Data entry and GIS editing

All data were manually entered into the SQL database by project staff under the direction of the project manager. All entries from 50% of the catchments were reviewed for accuracy by the project manager and corrections made as needed. Additionally, a few key fields (e.g. the “potential restoration candidate” field) were checked for all entries. Database issues were submitted as necessary to the database manager for corrective action.

Final GPS data for approximately 10% of assessed reaches were reviewed for accuracy by the project manager.

Results

Figure 9 shows the location of the assessed catchments within the Whipple Creek watershed. Approximately 25 miles of stream corridor were assessed, including 56 complete catchments and 4 partial catchments.

The project scope was modified somewhat during implementation in response to field conditions and client priorities. Completion of the highest priority area (upper Whipple Creek and tributaries) required 6 weeks, after which project clients were presented with a series of options for the remaining 4 weeks of field work: 1) focus on assessing the middle and lower mainstem of Whipple Creek and the Packard Creek mainstem, 2) focus on assessing the majority of the Packard Creek mainstem and tributaries, or 3) select specific catchments of interest throughout the watershed.

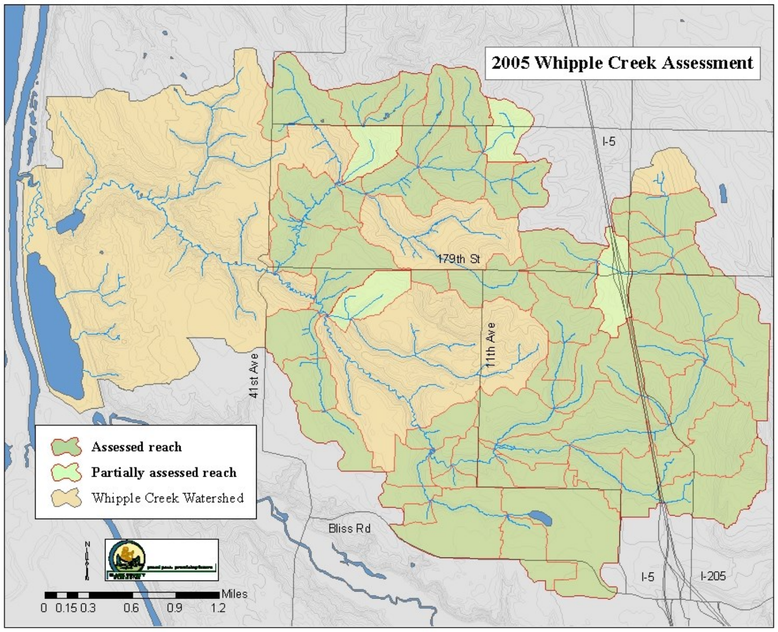


Figure 9. Whipple Creek Stream Assessment reaches, 2005.

The clients chose to focus on assessing as much of the Packard Creek subwatershed as possible. Packard Creek represented a definable area with a set of impacts indicative of a more rural landscape. Packard Creek is also situated in an area where future development is likely to occur. Additionally, the clients selected a single tributary stream in the middle section of the Whipple Creek watershed. This less-developed tributary tended to have similar underlying geology as heavily developed tributaries in the upper watershed and represented a possible opportunity for comparison.

Data limitations

There are limitations to the appropriate use of Whipple Creek Stream Assessment data, primarily in the interpretation of certain types of metrics.

Our application of the protocol focused to a greater degree on locating and documenting the presence of impacts as opposed to providing a detailed interpretation of their severity or level of restoration opportunity. Though experienced in field data collection, field staff were not engineers or stream rehabilitation specialists. Field rankings were based on initial staff impressions and when in doubt rankings tended toward the middle of the range in order to not artificially eliminate unrecognized opportunities. Additionally, field interpretation of problem severity and restoration potential evolved somewhat over the course of the project after a larger number of features were available for relative comparison.

Distance measurements were made with a variety of field and GPS methods that did not always agree. When editing GPS data into the GIS layer, lengths and widths of line and polygon features often required adjustment based on professional judgment.

Given these limitations, two general rules of interpretation should be noted by data users:

1) Severity and opportunity rankings should be interpreted as initial estimates. A ranking of three or above generally indicates staff believed a possible opportunity exists or that the impact is relatively severe. However, an impact ranking "4" may not prove to be a higher priority than one ranked "3". In some cases, further site analysis will be required to evaluate opportunities.

2) Areal and linear calculations of impacts (e.g. acres of impacted buffer, miles of eroded streambank) are initial estimates. More detailed site analysis is required to produce accurate totals for projecting rehabilitation costs.

Products

The following describes the content and location of the primary products (as of June 2005):

1) SQL database:
All project field data are stored electronically in a SQL database on the Water Resources Nt05 server at Network\Langroup\Nt05\WQ\Monitoring\Database\Admin\USA\USA.mdb. Original field sheets and copies used for data entry are also on file at Water Resources. The SQL database is linked to the geodatabase (product #2 below).

2) Geodatabase:
All assessed features are stored electronically in a Whipple Creek geodatabase at \\Nt05\wq\GIS\Data\Hydrography\Whipple\\Nt05\wq\GIS\Data\Hydrography\Whipple\WhippleWatershed.mdb. The geodatabase may be used to generate an atlas-style series of paper maps for detailed examination of project opportunities (Appendix E includes an example map of assessed features).

3) Tally of assessed features:
Appendix B contains a tally of assessed features and potential restoration opportunities, grouped by catchment and feature type. The table may also be found in electronic format at Q:\Monitoring\011129 Whipple Creek Stream Assessment\WC Assessment summary tally.mdb. The tally of assessed features provides a starting point for project selection by the Whipple Creek Watershed Projects Plan.

In addition to the required products, the project led to a number of general impressions regarding the Whipple Creek watershed, a list of problems for immediate referral, and a list of areas where preservation of existing habitat should be considered. Several watershed characterization maps were also generated based on assessment data (Appendix D). These items and the tally of assessed features are discussed below.

Tally of features and opportunities

The table in Appendix B includes a column for each feature type and a row for each assessed reach. Each row shows the number of assessed features of each type, along with the number of potential opportunities for that feature type. Summing across the row gives the total number of project opportunities in that reach.

Comment [TMK1]: Update this cross reference

Each column is also summed to indicate the total number of features and opportunities for each feature type across the entire assessment.

Potential projects are numerous. Out of the 544 assessed features, over 300 were ranked as possible opportunities to improve the stream. These potential projects vary widely in type, cost, and priority; however, this number provides an indication of the amount of improvement work that could be done in the assessed reaches.

Opportunities involving county stormwater infrastructure are primarily associated with stormwater outfalls and stream crossings. Forty-one outfalls and 72 stream crossings were assessed as project opportunities. In many cases, the county already owns the infrastructure and road rights-of-way to allow access to these features. In many cases outfall and stream crossing retrofits or maintenance would provide direct and immediate improvement to overall stream condition in the form of erosion control, flow attenuation, streambank stabilization, and trash reduction. Many stream crossings also present barriers to fish migration. Carefully selected barrier-removal projects could open up significant areas for fish usage.

Erosional features were numerous, with long segments of stream scour and incision very common. Out of 88 assessed features, 60 potential opportunities were recorded. Evaluating the potential for improvement is more complex for erosional features than for outfalls and stream crossings. In some cases, stormwater retrofits or upstream controls may help to slow or eliminate further erosion. However, rehabilitating areas with severely eroded streambanks and re-connecting the channel to its floodplain would often be contingent on the purchase of land or the cooperation of private streamside landowners. Therefore, the best opportunities for large-scale projects to stabilize streambanks may be on publicly owned parcels.

Impacted buffers were also very common, and 83 of 87 assessed impacts were ranked as possible projects. In many cases potential restoration projects would again be contingent on landowner cooperation; however, a good number of opportunities also exist on publicly owned parcels. Buffer improvement opportunities tend to focus on invasive plant removal and streambank re-vegetation and in many cases could be combined with erosion-related improvements. Buffer opportunities involving animal access issues were infrequent. Those that were discovered were included on a list for immediate referral to the Clark Conservation District.

Channel modifications were relatively infrequent and only 10 potential projects were recorded. These focus primarily on removal of canalizing materials (riprap, concrete). All channel modifications were relatively small (10 to 50 feet in length), and in most cases these opportunities would likely be pursued only in conjunction with larger multiple-benefit projects.

Eighteen trash and debris sites were located during the assessment. These vary widely in their accessibility and size, but all were recorded as potential projects. While some sites would require heavy equipment, most were of a scale appropriate for volunteer groups or county-sponsored corrections-crews. In some cases, landowners could potentially be required to perform cleanup activities through county Code Enforcement. Most or all of these opportunities should be addressed in some fashion: trash removal provides direct benefits to stream health and is a highly visible stream improvement activity.

Among the 87 miscellaneous features recorded, 30 presented a variety of potential projects. These include culvert removal projects, storm water facility maintenance, and potential storm water detention projects, among others.

None of the eight utility features assessed appeared to require restoration projects.

General watershed characterization maps

Three watershed characterization maps were generated by summarizing selected reach level metrics. These maps are included as Appendix D.

Comment [TMK2]: Update this cross reference

- **Map 1)** Reach Level Assessment score for each assessed catchment

Description: The Reach Level Assessment consists of eight sub-metrics relating to stream and riparian condition. Each sub-metric receives a score from 0 to 20. The total score (0 to 160) indicates overall condition and may be compared between reaches to prioritize high or low quality areas.

- **Map 2)** Bank Erosion and Floodplain Connectivity scores for each assessed catchment

  Description: Bank erosion severity and floodplain connection are two sub-scores within the Reach Level Assessment. These scores address important components of stream condition that are particularly prone to stormwater impacts. Low scores in these two categories often reflect low overall scores for stream condition.

- **Map 3)** Dominant substrate and fish barrier ratings for each assessed catchment

  Description: This map provides basic information on the potential for fish spawning (areas with gravel substrate) and distribution (location of fish passage barriers) in the assessed reaches. As part of the overall characterization, this information may be used to locate particular projects to support fish-related beneficial uses.

Immediate Problem Referrals

An additional result of assessment activities was the discovery of various issues or situations in need of timely referral for corrective action. Such issues were noted by field staff, entered into a tracking spreadsheet with basic information, and referred to appropriate county and agency staff for attention or resolution. The referral list is included as Appendix C and may be found in electronic format at Q:\\Monitoring\Whipple Creek Stream Assessment\Discussion and Referrals\2005 Whipple Creek referrals.xls.

Referrals ranged from incomplete stormwater infrastructure mapping to the presence of rare species, and included several imminent or existing threats to stream health. In particular, several erosion control problems and one long-running illicit discharge were discovered and subsequently addressed.

Referred issues included:

4 areas with unmapped stormwater facilities	3 erosion control issues
1 opportunity to preserve high-quality habitat	1 stormwater facility repair
1 illicit discharge to the creek	4 wildlife-related inquiries
4 sites with livestock access to the creek	1 commercial debris pile on streambank
4 possible septic system issues	

Not all referred issues have been resolved as of June 2005; however, unresolved issues have been referred to the appropriate staff and follow up is ongoing or pending.

General impressions based on field observations

Field crews spent many hours traversing the Whipple Creek stream corridor during the assessment. In addition to the data recorded for individual stream corridor features, a number of general patterns and issues were noted over the course of the assessment. Portions of the following are compiled from a list of discussion points kept by field staff.

In general, the assessment confirms that the Whipple Creek corridor has been heavily impacted by past and current human activities. Within the assessed reaches, degraded areas far outnumber those that remain intact. In many reaches, increased runoff from historical clearing and development has led to significant channel incision and floodplain disconnection. Streambank scour and fine sediment accumulation are common. Riparian conditions are mixed: many areas have ample vegetated buffer widths, yet a large portion of the vegetation is comprised of invasive species, particularly Himalayan blackberry.

Degradation is not limited to developed or developing areas. Impacts were clearly present in the more rural areas despite significantly lower levels of development and infrastructure. Historical clearing of forest for agriculture, road-building, and timber harvest appears to have altered hydrologic conditions sufficiently to cause channel impacts. Our observations are consistent with current knowledge regarding stream channel impacts: both forest conversion *and* increased development cause significant degradation.

In any case, Whipple Creek serves as a prime example of the extent to which human activities can degrade stream function and habitat. Evidence of past and current impacts is already extensive in this moderately developed (upper watershed ~25% total impervious area, lower watershed ~19%) watershed. There is no evidence to suggest that further development can occur in Whipple Creek without increasing those impacts. On the contrary, continued development will result in ongoing degradation and further destabilization of stream channels, further disruption of habitat, and increased water quality problems.

The Independent Science Panel review of the 2001 Stormwater Management Manual for Western Washington notes that project-by-project mitigation does not address watershed-scale issues such as cumulative impact, and is not sufficient to prevent declining habitat conditions (June, 2003). The report may be viewed at http://www.governor.wa.gov/gsro/science/isprpt2003sum.pdf .

Additionally, section 1.7.5 of the February 2005 Stormwater Management Manual for Western Washington states acknowledges that:

> "… despite the application of appropriate practices and technologies identified in this manual, some degradation of urban and suburban receiving waters will continue, and some beneficial uses will continue to be impaired or lost to new development. This is because land development, as practiced today, is incompatible with the achievement of sustainable ecosystems." (February 2005)

Given the observed conditions in Whipple Creek and the current state of watershed science, staff believe that management recommendations from the Whipple Creek Watershed Projects Plan should include an acknowledgment of the fact that, under current standards, further development cannot be undertaken without continuing consequences to the health and habitat of Whipple Creek.

<u>Beaver dams</u>
Beaver dams are extensive in the Whipple Creek mainstem and some tributaries. Many have extensive sediment deposition behind them. These sediments are composed of sand, silt, or mud and are often very deep, loose, and unconsolidated. 2004 was an unusually dry winter and the infrequency of storms may have reduced sediment flushing and contributed to unusually deep sedimentation behind these structures. Both aerobic and anaerobic sediments were observed. In many areas the sediment deposition appears to be filling in deeply incised channels, and it appears that the dams are very important for storing much of the Whipple Creek sediment load.

Beavers appear to take advantage of incised streams. Building dams is easier and the stream tends to remain within its banks and not enter the floodplain. Eventually the sedimentation behind the dams will fill in the channel. Intentional beaver dam removal or floods have the potential to re-mobilize large amounts of sediment.

Water quality is relatively poor in the ponded stream sections. High nutrients, sediments, and warm temperatures lead to stagnant conditions and algal growth. Although the habitat quality in beaver pond areas is excellent in terms of complexity, water quality seems to limit utilization by aquatic organisms. Upstream stormwater control and treatment is important to limiting accumulations of pollutants in these areas.

<u>Wildlife</u>
In addition to beaver, staff observed a moderate amount of wildlife usage of the stream corridor. Evidence of deer, raccoon, song-bird, and waterfowl use was common, in addition to frogs,

salamanders, and newts. No anadromous fish, no crayfish, and few resident fish were observed. Two species of interest were noted and reported to fish and wildlife agencies:

Red-legged frog
A field crew noted the presence of a Northern Red-legged frog on March 9, 2005. The Red-legged Frog was recently split into two species -- the California Red-legged, which is on the Endangered Species List, and the Northern Red-legged which occurs in our area. A Northern Red-legged frog was seen at GPS point MI-3 in catchment W6.44T0.00. JoAnne Shute at WDFW noted that the Northern Red-legged is listed as a sensitive species in Oregon and Canada, but is not listed in Washington. However, Ms. Shute also noted the species is likely to make the sensitive list soon as it does not thrive in rapidly developing areas such as Clark County.

Freshwater mussels
Freshwater mussels have been the subject of local US Fish and Wildlife Service surveys and have been recognized as a valuable indicator of stream health for salmonids. A field crew noted the presence of an intact freshwater mussel bed on March 22, 2005. The location is logged as GPS point MI-1 in catchment W3.85. This finding was reported to Jennifer Poirier at USFWS.

Invasive blackberries
Field staff observed patterns in blackberry invasions. It is evident that development project clearing to the edge of valley walls or floodplains impact the fringe of vegetation and that non-native plants establish on this front. In some places encroachment on both sides of the creek allowed the non-native vegetation to bridge the entire floodplain and valley floor. Blackberries encroach to varying degrees from nearly every road crossing, again gaining a foothold in the disturbed soil that accompanies construction activities.

Staff also observed patterns where land was disturbed for utilities such as storm water outfalls. In many places where stormwater outfalls were run-out into the forest or buffer area, blackberries had established along the exact line of disturbed soil. If efforts were made to replant the disturbed zones blackberries had overwhelmed the plantings.

In many areas better vegetation management in the period following disturbance could prevent much larger problems once the invasive species get fully established. In many areas, invasives (particularly blackberries) appear to be the primary or secondary issue degrading the quality of the Whipple Creek riparian corridor.

Subsurface flow/gully erosion issues
Erosion issues first noted at a stormwater facility for Whipple Creek Place subdivision suggest that concentrated subsurface flow has the potential to destabilize hill slopes, leading to active erosion of the valley walls, floor, banks, and channel. The resulting sediment is available for downstream transport to mainstem creeks where sedimentation can severely limit beneficial uses and alter water and sediment dynamics.

Watersheds along the Columbia Slope, including Whipple Creek, have a structure that is different from the typical bowl or "basin". Tributaries originate on flat plateaus and run off crests and bluffs to stream channels. The steepest sections of these creeks are often mid-length where they crest the plateau edges and rapidly lose elevation to floodplain floors. Valleys and steep drainages tributary to the mainstem creeks were formed over long periods of time and under very different surface and subsurface hydrologic conditions than after development takes place. Because they are often situated in highly erodible soils and underlying geology, they are easily de-stabilized.

It appears that the upland plateau areas are important sinks of water, infiltrating large amounts of rainfall. Land development results in lost infiltration and reduced storage capacity, sending runoff rapidly to steep channels that are not capable of maintaining stability.

Stormwater facilities and outfalls are often located on the last available ground on plateau edges before gullies and valleys begin, leaving little room for energy dissipation. Drainage lines installed to de-water retaining walls, hillslopes, and other structures often provide concentrated flow to steep slopes. These practices appear to reduce the subsurface flow path and result in unstable, channelized gullies as large amounts of shallow groundwater move laterally to valley walls.

<u>Downstream assessment for development projects</u>
Observations made during the assessment led staff to consider the issue of downstream impacts from development activities and the way in which such impacts are assessed and/or mitigated. In a number of cases, downstream impacts such as incision and headcuts appear to have occurred as a result of recent development projects.

County code provides for downstream analysis of stormwater impacts, but data are usually lacking. Results from the Whipple Creek Stream Assessment provide an inventory of known channel stability problems and a basis for performing off-site impact analysis. A potential option to address the issue of unstable channels and downstream impacts would be through the state SEPA process, where assessment results could be incorporated into SEPA review for mitigation.

<u>Stormwater outfalls</u>
Many of the assessed stormwater outfalls, including some road ditches, are causing significant impacts to the stream corridor in the immediate vicinity of the outfall. Common impacts include localized erosion, invasive plant colonization, and trash accumulation. In some cases outfalls are suspected of contributing to dry-weather water quality problems and need to be sampled during future outfall screening activities.

A significant number of outfalls require some degree of maintenance, including replacement or upgrading of energy dissipation structures, clearing of vegetation and sediment clogs, installation or repair of trash grates, and stabilization of adjacent stream banks. Facilities associated with some of these outfalls appear to be undersized or in need of maintenance to address short-circuited flow paths or poorly established vegetative filters.

<u>Stormwater facility inspections</u>
Issues noted at Whipple Creek Place and other subdivisions led to suggestions that facility inspection protocols may need modification to increase examination of outfalls and potential downslope erosion issues. Current inspections tend to focus on maintenance standards such as

mowing and facility structures, with little attention paid to possible impacts on unstable slopes immediately down-gradient from the outlet area.

At Whipple Creek Place, initial attempts to fix a series of holes short-circuiting baseflow and storm flows under a level spreader were unsuccessful, highlighting the need for additional follow-up inspections especially when short-term fixes are used.

<u>Anecdotal accounts</u>
Conversations with long-time stream side landowners suggest the creek has changed over the past 50 years. Several landowners reminisced about the historical presence of steelhead and sea-run cutthroat trout on their properties. Others noted the disappearance of once-abundant crayfish populations. Recent increases in beaver activity were also reported by a number of residents.

Very few residents complained of rising water levels or increased flooding, though several noted that water backs up behind undersized culverts during storm events and they suspect increased development upstream is contributing.

A number of residents commented they had not been near the creek on their property for years, citing impenetrable blackberry thickets as the reason.

Potential areas for preservation
Though the majority of assessed reaches were moderately to severely degraded, a number of reaches still exhibit relatively intact channel conditions and/or habitat. These intact remnants provide islands of habitat that act as a buffer from surrounding impacted areas. In many cases, the presence of intact areas serves to protect downstream reaches from further damage.
Protecting or enhancing intact streams is generally considered more cost-effective than attempting to "fix" streams after they are degraded. For that reason, opportunities to purchase, set-aside, or otherwise protect intact stream reaches should be actively pursued.

Table 13 is a list of 12 relatively high-quality stream reaches that should be a priority for preservation. The table includes the Reach Level Assessment score (0 – 160) and a brief comment describing reasons the reach may be worth protecting.

Reaches were selected for various reasons, including opportunities to:

- connect or extend high-quality reaches already under county ownership
- protect intact wetland areas from encroaching development
- protect areas where sensitive habitats or rare species were encountered (e.g. Northern red-legged frog)
- contribute to ongoing efforts by the county to purchase remnant pieces of excellent habitat, and;
- preserve or enhance areas where future salmonid re-introduction could occur

In many cases multiple landowners control the property within each reach, making the purchase of large areas of contiguous habitat potentially challenging. Regardless, the county should be aware of these areas and be prepared to take advantage of opportunities that may arise. In some cases landowners could be provided with information describing options for the preservation of their creek-side properties (federal programs, The Nature Conservancy, Columbia Land Trust, and others).

One opportunity from Table 13 was included in the list of immediate referrals from the project. Large parts of reach W7.82 and reach W8.36 are included in a 40-acre parcel owned by the Van Buren family. County and state habitat biologists recognize this property as perhaps the highest quality habitat remaining within the Whipple Creek watershed. In response to issues stemming from the proposed development of this land, the county has pursued funding sources to make possible the purchase of the property. The Clean Water Program is exploring the possibility of contributing to the purchase and enhancement of this property.

Table 13. Priority reaches for preservation/protection

Reach Code	Reach ID	Reach Score	Comments
W5.70T1.08E	43	127	county-owned; large pond/marsh complex controlling stormwater for large area and protecting downstream channel; adjacent wetland recently filled for new development
W6.41	46	138	large series of beaver ponds and wetland complex in good condition
W6.44T0.00	59	115	many groundwater seeps; upper part forested; Northern red-legged frog observed
W6.44T0.75N	57	126	partially county-owned; intact forest with some large trees
W7.82	50	133	partially county-owned; part of reach lies on Van Buren property which was referred as a high priority for purchase
W8.36	51	131	likely the best remaining habitat in watershed; reach lies primarily on Van Buren property noted above; beaver pond complex throughout reach; recognized as prime habitat by county and WDFW
W8.50	60	113	property immediately north of Van Buren (Milton Brown); lower end is intact beaver ponds/wetland complex providing stormwater control; threatened by surrounding development
W8.50T0.00	52	127	intact wetland on Milton Brown property is threatened by planned developments; upland has been logged in past 10 years but stream and wetlands are high quality
W9.14	66	134	headwater stream in good condition currently, but vulnerable to futureI-5 corridor development impacts
W9.31	67	--	High quality headwater wetland; vulnerable to future I-5 corridor development impacts; high priority for preservation/protection; no score given due to lack of defined channel
P0.00*	76	110	impacted, but one of few potentially accessible reaches with gravel substrate; also storage opportunity along flat riparian area near mouth
P1.06*	80	98	impacted, but one of few potentially accessible reaches with gravel substrate

* P0.00 and P1.06 are included primarily because these reaches are among a very few areas with gravel substrate where future salmonid spawning might occur. Both reaches, and the reach that lies between them (P0.55), have significant impacts and would require fairly extensive rehabilitation.

Project Evaluation/Observations

As the first project of its kind performed by Clark County, the Whipple Creek Stream Assessment provided an opportunity to evaluate a new method for obtaining stream corridor information. The final section of this summary notes a variety of successes, challenges, limitations, and observations that may be used to refine future projects of this kind.

Overall

The Whipple Creek Stream Assessment generated a large amount of information that should be an integral component of stormwater planning in the Whipple Creek watershed and other projects. A final assessment of the applicability of the protocol to Water Resources planning needs will be made pending the outcome of the Whipple Creek Watershed Projects Plan.

Initial staff impressions suggest the protocol is most suited to assessing impacts in urban and urbanizing streams where development activities and stormwater infrastructure are most prevalent. Areas dominated by rural land uses may be better suited to a different protocol or a streamlined version of the USA.

The protocol appears to be very successful at discovering and documenting stream corridor features. Many features assessed through this project were previously unknown, and a large number of potential areas for improvement were documented. In fact, opportunities likely far outpace available funding and staff availability, suggesting that the subsequent prioritization of potential projects will be vital to the efficient allocation of funding.

The assessment produced a large body of digital photographs. Many of these photos are being used to educate the public about non-point source pollution, in addition to providing valuable information about each assessed feature.

Property access/public response

Property access issues were virtually non-existent. 398 letters were mailed to the owners of 522 tax parcels bordering Whipple Creek. Rather than requesting access permission, the letter simply announced the county's intentions and placed the responsibility on landowners to respond if they wished to deny access. Because this approach had not been previously attempted by Water Resources, the extent and tone of public response was a matter of some concern.

Twenty-five landowners responded by phone, a response rate of sixteen percent. Only 5 landowners denied access and the remainder were calling in support of the project or to request prior notification so animals could be penned or landowners home at the time of the assessment.

Numerous landowners were also contacted in the process of securing permission to park vehicles. With rare exceptions, landowners were very accommodating. This exercise also led to opportunities to discuss the project with watershed residents.

A press release was issued at the beginning of the project in an effort to increase public awareness. An unplanned benefit of the press release was the opportunity for several staff to participate in a field demonstration and interview with a local reporter, leading to the publication of an article in The Columbian newspaper discussing the influence of rapid development on Whipple Creek.

Field work

Field work proceeded more slowly than anticipated, due primarily to heavy vegetation growth (particularly Himalayan blackberry) and difficult terrain in many areas of the stream corridor. The USA protocol suggests field work progresses at a rate of 1.5 to 2.5 stream miles per day, depending on the terrain. Pre-project estimates for the Whipple Creek Stream Assessment assumed a rate of 1 to 1.5 miles per day. Actual rates averaged 0.5 to 1 mile per day, and probably represent a reasonable estimate for most urbanizing Clark County streams.

Consistent data collection was a challenge for field crews, despite the use of a limited number of staff as field personnel. A number of opportunities were noted to enhance consistency and efficiency in data collection, including:

- Distance measurements should be made carefully and cross-checked with GPS points when possible. Logging a GPS point at the beginning and end of each linear feature is preferable to a single point and distance estimate.
- A maximum width should be set for impacted buffer estimates, reflecting required habitat buffer widths where appropriate.
- Some elements of the field sheets are duplicative and/or unclear. Some of these were addressed during the project, but additional modifications would improve field and data entry efficiency.
- Based on information needs identified by project clients, limited revisions to the reach assessment or other field sheets could increase the applicability of the assessment. For instance, a standard metric for bank stability could be added to the reach assessment.
- A consistent approach to grading stream crossings as fish barriers should be applied to every crossing regardless of location within the assessment reach. For instance, a consistent grade should be applied to all beaver dams.

Weather was unseasonably warm and dry during the assessment period. Wet weather could have a significant impact on an assessment, primarily due to its effect on stream depth and field operations. Water quality issues (e.g. turbidity, storm sewer discharge impacts) may have been underestimated due to the dry weather. The extent of vegetation growth encountered between February and April suggest that such an assessment would be impossible to conduct during the summer months. An earlier start date, such as January, would improve the likelihood that crews finish the allotted work prior to the onset of extensive vegetation growth.

Safety

Stream assessment requires hard physical labor on the part of field crews. Safety concerns are numerous, including steep slopes, slippery footing, fences, extremely thick and/or hazardous vegetation (blackberry, nettle), extensive machete use, heat, cold, and unexpectedly deep water. Fortunately, the project did not result in any serious or permanent injuries to staff. However, one staff member sustained an ear injury requiring medical attention, and staff experienced numerous falls, cuts, bruises, and strained muscles.

To minimize the likelihood of injury, crews must be in good physical shape and be experienced in traversing streamside areas. Clients, project managers, and field staff need to be aware of the inherent risks and take reasonable precautions. Regardless of the level of field crew experience, staff injuries will remain a very real possibility.

Sufficient field time must be budgeted so that crews are not compelled to rush or take chances in order to complete their work. Time pressures may lead to unnecessary risks and/or the omission of important features from the assessment. If in doubt about a potential hazard (landowner, dogs, impenetrable blackberry thicket) crews should be encouraged to take time to assess the best approach, which may include turning back.

Data entry

Data entry proceeded more quickly and smoothly than anticipated. However, slight discrepancies between the design of the field sheets and the data entry form resulted in a higher number of entry errors than expected. Minor design adjustments and data validation checks embedded in the data entry forms would be helpful. Removal of certain marginally useful fields would also expedite data entry and improve accuracy.

Appendix A--- letter of intent

January 24, 2004

Name
Address

Dear xxxxxx xxxxxxx:

Clark County's Clean Water Program is planning to conduct a stream assessment in Whipple Creek and its tributary streams during February and March, 2005. The assessment will cover approximately 25 miles of stream channel, a portion of which may lie on or near your property. This includes taxlot # xxxxxxxxxxx as well as any additional taxlots under your ownership within the study area.

Information gained through the assessment is critical to improving water quality in the Whipple Creek watershed. We will use it to upgrade county storm sewer maps, locate storm sewer outfalls, find severe erosion problems, and identify potential sites to improve stream habitat or manage stormwater more effectively.

The assessment requires no removal of rocks, dirt, or plants, and no markers will be left on your property. Depending on the length of stream, we anticipate that field crews of two or three persons will need to access your property for as little as a few minutes and not more than an hour or two on one day only. Crews will confine their assessment activities to the stream and streambank areas.

Field crews are insured by Clark County and will proceed with caution to avoid common streamside hazards; however, if you are aware of an extreme hazard on your property, please notify me as soon as possible.

Your cooperation is appreciated and helps ensure the success of this project. Project results will enable the Clean Water Program to better serve you and your neighbors by addressing stormwater issues and improving water quality in Whipple Creek.

If you have questions or concerns about this project, or prefer that we do not access the stream on your property, please contact me at 360-397-6118 x4583.

Sincerely,

Jeff Schnabel
Water Resources Scientist

Appendix B – Tally of features

2005 Whipple Creek Assessment

Tally of Assessed Features and Restoration Opportunities

	Outfalls		Erosion		Impacted Buffer		Channel Modification		Stream Crossing		Miscellaneous		Utility Impact		Trash/Debris		TOTAL	
ReachCode	#	Restoration	#	Restoration	#	Restoration	#	Restoration	#	Restoration	#	Restoration	#	Restoration	#	Restoration	#	Restoration
P0.00	0	0	4	1	2	2	1	1	1	1	3	0	0	0	0	0	11	5
P0.55	1	1	3	3	1	1	1	0	4	2	4	3	0	0	0	0	14	10
P1.06	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
P1.06T0.00N	2	0	1	1	0	0	0	0	2	2	0	0	0	0	0	0	5	3
P1.06T0.49W	2	1	3	2	3	3	3	3	7	6	5	2	0	0	3	3	26	20
P1.06T0.57NE	0	0	1	1	3	3	1	1	2	2	1	0	0	0	0	0	8	7
P1.06T0.57NW	3	0	1	0	3	3	0	0	3	3	0	0	0	0	0	0	10	6
P1.23	0	0	2	2	5	5	1	0	3	2	3	1	0	0	1	1	15	11
P1.23T0.98S	0	0	1	1	2	2	1	1	1	1	0	0	0	0	0	0	5	5
P1.67	1	1	3	0	5	5	1	1	3	2	4	1	0	0	1	1	18	11
P1.67T0.00	0	0	5	2	2	2	0	0	2	2	2	0	0	0	0	0	11	6
P1.67T0.34	1	1	2	2	1	1	1	1	3	3	1	0	0	0	0	0	9	8
P2.06T0.00E	2	0	1	1	1	1	0	0	2	2	0	0	0	0	0	0	6	4
P2.06T0.00N	2	1	2	1	4	3	2	0	5	5	2	0	0	0	0	0	17	10
P2.16	1	0	1	0	1	1	0	0	3	3	0	0	0	0	0	0	6	4
P2.51	1	1	1	1	2	2	1	0	1	1	0	0	0	0	0	0	6	5
W3.85	0	0	0	0	1	1	0	0	5	1	2	0	0	0	0	0	8	2
W4.00T0.00	0	0	2	1	1	1	0	0	3	3	3	0	1	0	0	0	10	5
W4.00T0.37	1	0	1	1	3	3	2	0	3	2	2	1	1	0	1	1	14	8
W4.00T0.79	0	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0	3	1
W4.09T0.00	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
W5.50	0	0	2	1	2	2	0	0	2	0	2	0	0	0	0	0	8	3
W5.70	0	0	1	1	2	2	1	0	5	1	0	0	0	0	0	0	9	4
W5.70T0.00	1	1	3	2	3	3	1	0	4	2	0	0	0	0	0	0	12	8
W5.70T0.36	0	0	2	1	1	1	0	0	0	0	1	1	0	0	0	0	4	3
W5.70T0.49E	4	4	3	2	2	2	1	1	3	1	3	0	1	0	3	3	20	13
W5.70T0.49S	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	3
W5.70T1.08E	10	1	1	0	0	0	0	0	0	0	1	0	1	0	1	1	14	2
W5.70T1.08S	3	3	3	2	2	2	0	0	0	0	1	0	0	0	0	0	9	7
W5.99	0	0	4	4	1	1	0	0	2	1	0	0	0	0	0	0	7	6
W5.99T0.00	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	3	1

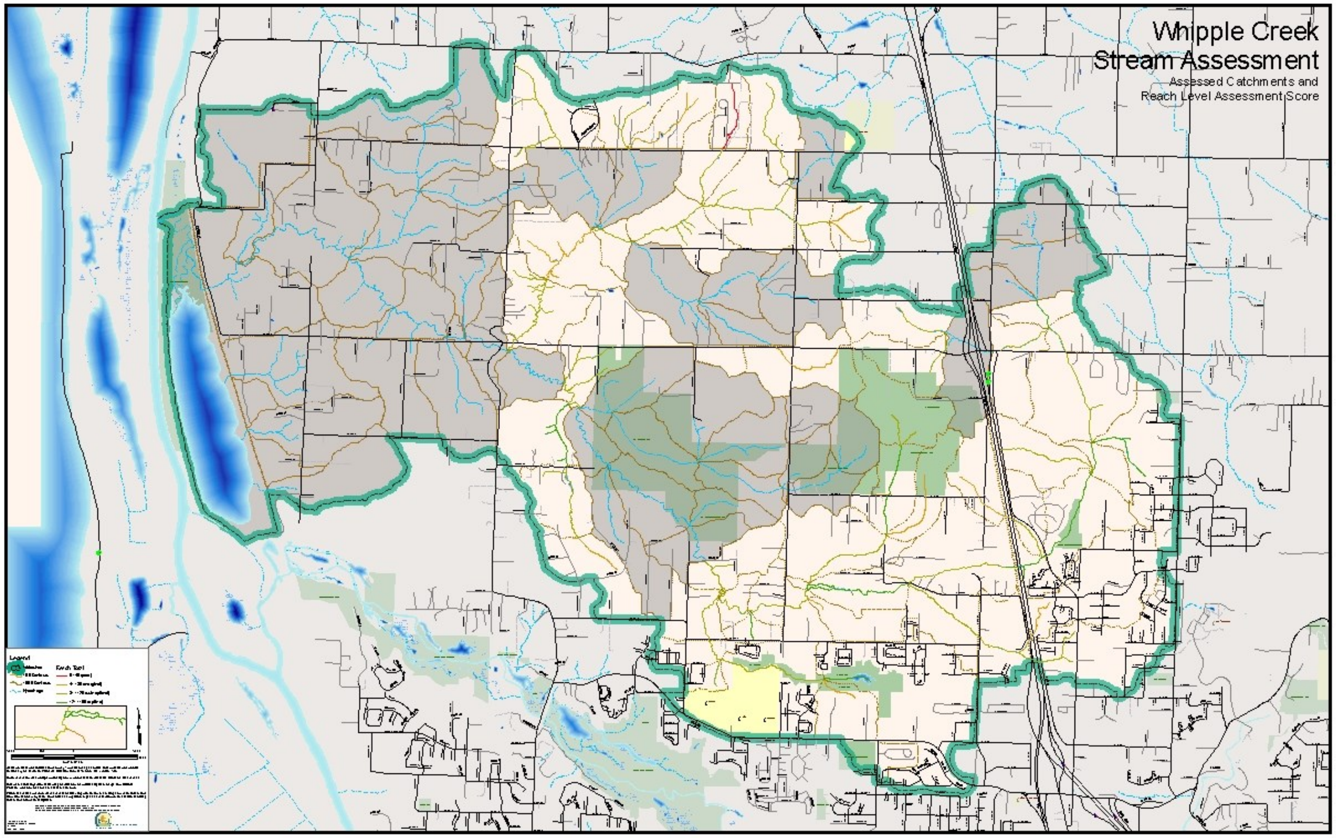
	Outfalls		Erosion		Impacted Buffer		Channel Modification		Stream Crossing		Miscellaneous		Utility Impact		Trash/Debris		TOTAL	
ReachCode	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**	**#**	**Restoration**
W6.20	1	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	5	1
W6.26T0.00	1	1	3	3	0	0	0	0	0	0	2	1	0	0	0	0	6	5
W6.41	0	0	0	0	2	1	0	0	5	0	0	0	0	0	0	0	7	1
W6.44T0.00	0	0	1	1	2	2	0	0	4	1	3	0	0	0	0	0	10	4
W6.44T0.53E	5	0	1	0	2	2	0	0	2	2	1	1	0	0	0	0	11	5
W6.44T0.53N	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	3	3
W6.44T0.75N	2	0	2	1	0	0	0	0	0	0	2	0	0	0	0	0	6	1
W6.44T1.01N	4	0	1	1	1	1	0	0	0	0	0	0	1	0	1	1	8	3
W7.06	4	3	3	3	3	3	0	0	11	1	5	1	0	0	0	0	26	11
W7.06T0.00	2	2	3	3	3	3	0	0	10	2	2	0	0	0	1	1	21	11
W7.06T0.48	1	0	2	2	1	1	0	0	8	2	2	1	0	0	1	1	15	7
W7.06T0.74N	5	3	1	1	1	1	0	0	0	0	3	3	0	0	0	0	10	8
W7.06T0.74S	5	2	0	0	1	1	0	0	0	0	1	1	0	0	1	1	8	5
W7.68	3	2	2	1	2	2	1	0	1	1	0	0	0	0	0	0	9	6
W7.82	3	2	3	1	3	2	1	0	0	0	5	1	0	0	0	0	15	6
W7.82T0.00	2	1	1	0	1	1	0	0	1	1	0	0	0	0	1	1	6	4
W7.82T0.22	6	1	2	1	3	3	0	0	3	2	3	1	0	0	1	1	18	9
W8.36	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	4	0
W8.36T0.00	2	0	2	2	0	0	0	0	2	2	0	0	0	0	1	1	7	5
W8.50	3	2	1	1	1	1	1	1	5	1	6	3	1	0	0	0	18	9
W8.50T0.00	2	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	4	3
W9.00	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
W9.14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
W9.14T0.00	1	1	2	2	1	1	0	0	2	2	1	1	1	0	1	1	9	8
W9.14T0.29	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2	2
W9.14T0.54N	0	0	0	0	1	1	0	0	4	3	4	3	0	0	0	0	9	7
W9.14T0.54S	4	1	1	0	2	2	0	0	1	1	2	1	0	0	0	0	10	5
W9.31	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
W9.31T0.00	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1
	96	**41**	**88**	**60**	**87**	**83**	**22**	**10**	**138**	**72**	**87**	**30**	**8**	**0**	**18**	**18**	**544**	**314**

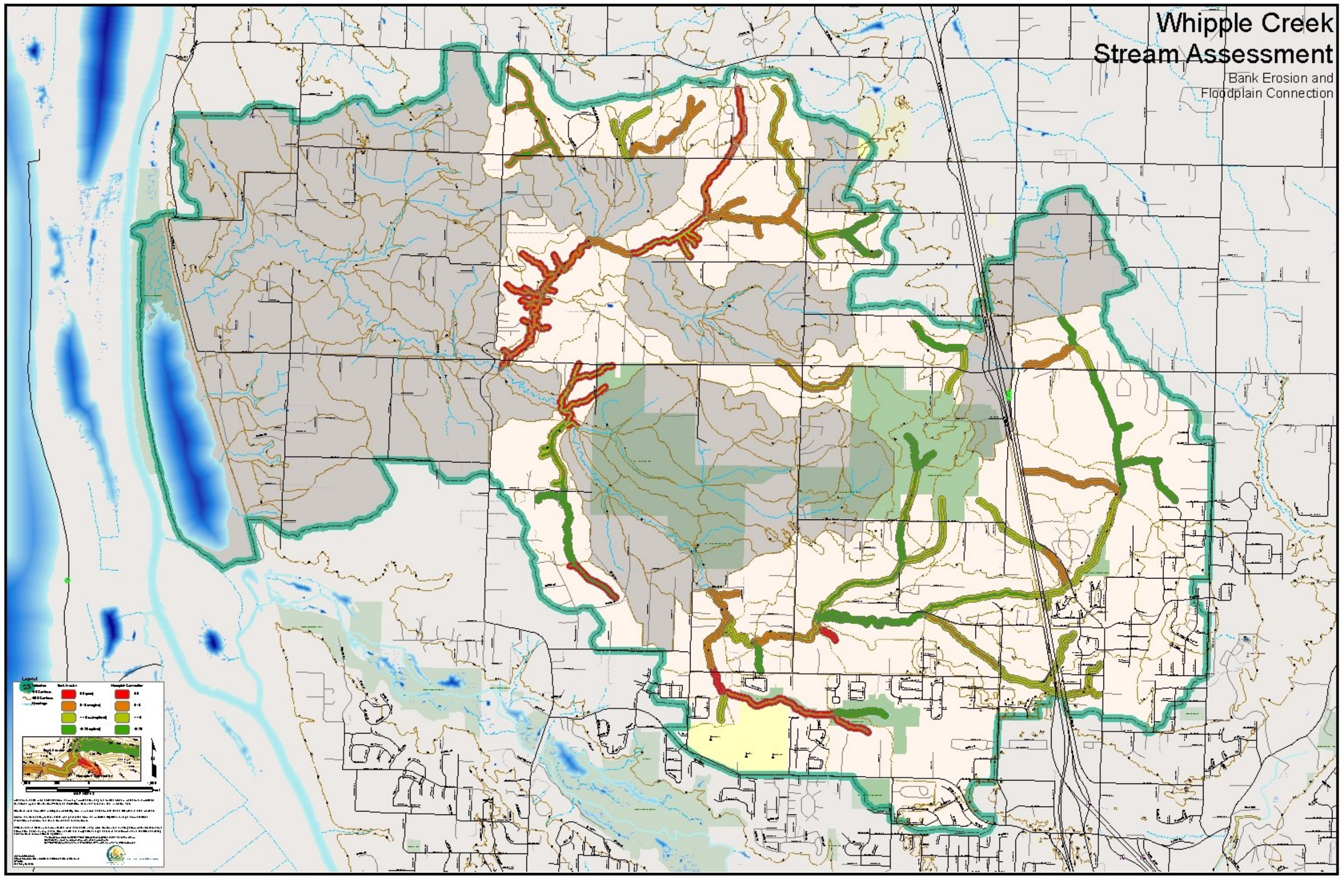
Appendix C – Referrals

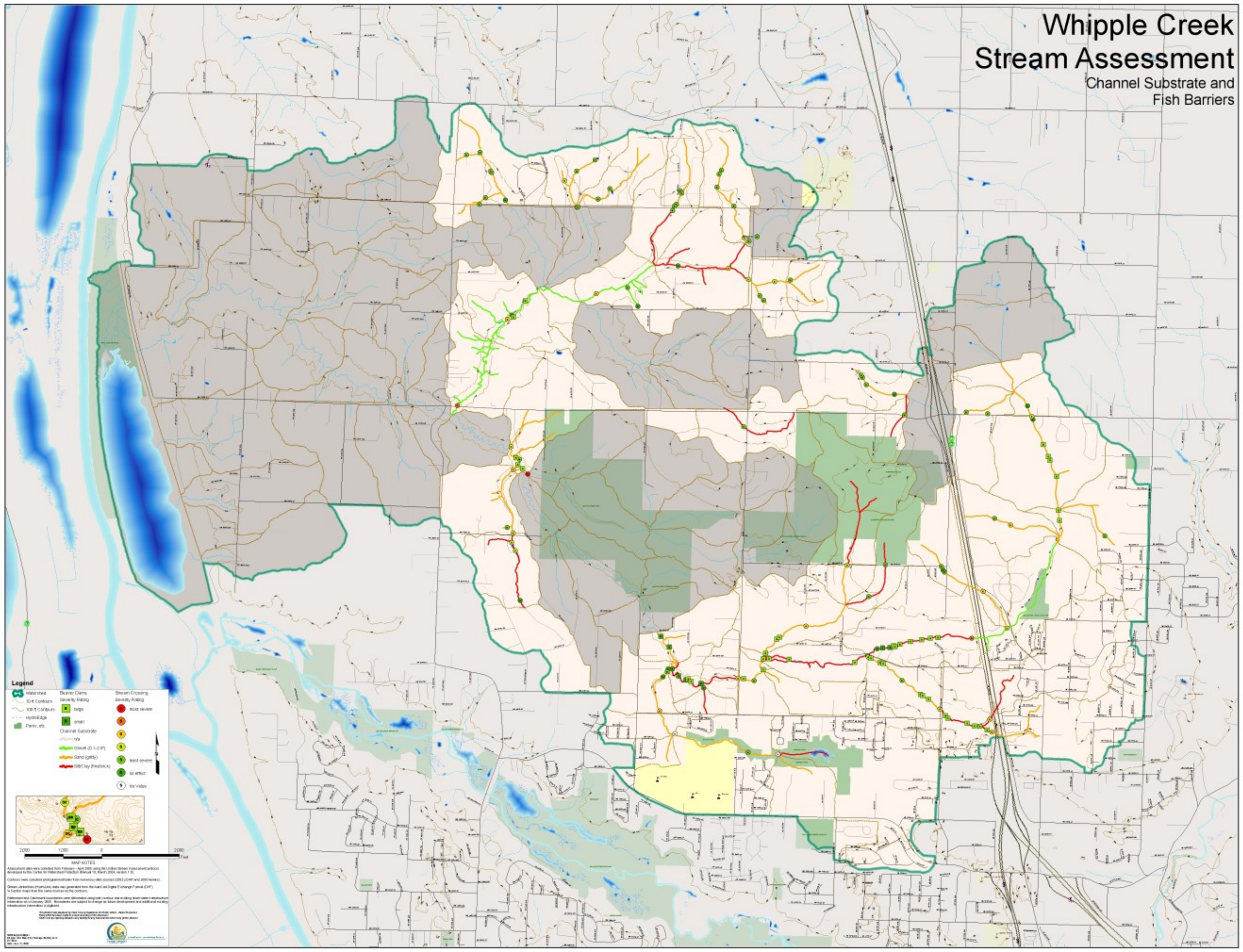
2005 Whipple Creek Assessment Referrals

ReferralDate	IssueDescr	Assessment ReachID	ParcelSN	ParcelOwner	StaffIssued	AcencyReferred	StaffReferred	DateResolved	Comment
2/22/2005	Un-mapped ponds and outfall east of 20th Ave	W7.82	117892864	SOLMONSON DONALD W & SANDRA	Szwaya	Clark County	Henry Schattenkerk	ongoing	Facility needs to be mapped
2/24/2005	Small hole in swale of facility above eroding gully	W6.26T0.00	185575168	CLARK COUNTY	Wierenga	Clark County	Ken Lader	ongoing	Ken referred to Jeff Tuttle to fix hole
2/24/2005	Strong odor of chemical (solvent?) in tributary to Whipple Creek	W5.70T1.08S	118107676	VALENTINE FAMILY LTD PTNSP	Schnabel	Ecology	Curt Piesch	2/25/2005	Site visited by Curt, Ron W., and Cary A. Solvent odor not present but potential issues noted (see below)
2/25/2005	Business has stormwater runoff issues on site	W5.70T1.08S	118107676	VALENTINE FAMILY LTD PTNSP	Wierenga	Clark County	Cary Armstrong	3/15/2005	Cary visited site with Kim Kagelaris and Marlou Pivirotto. Solvent issues found and actions pending
2/28/2005	Need to coordinate with Dave Howe about Whipple Creek property	W7.82;W8.36	181935000	VAN BUREN HELENE HIDDEN TRST	Schnabel	Clark County	Dave Howe	3/2/2005	Dave notified of WC Project, Jeff requested WR contribute CWP funding toward purchase
3/1/2005	WSDOT is doing an inventory along I-5; need to coordinate if possible	reaches on I-5 corridor	NA	NA	Schnabel	Clark County	Rod Swanson	3/3/2005	Rod contacted Erin Gardner at WSDOT. Clearing is eng. survey for upcoming I-205/I-5 interchange project
3/2/2005	Un-mapped facility near I-5	W7.06	185669000	LIES BRIAN S & LAURIE ETAL	Wierenga	Clark County	Ken Lader	3/10/2005	Facility needs to be mapped
3/2/2005	Un-mapped facility and inaccurate infrastructure mapping	W7.06T0.74N	117894650	Clark County	Schnabel	Clark County	Ken Lader	ongoing	Facility and area need mapping investigation
6/2/2005	Possible presence of threatened species (red-legged frog)	W6.44T0.00	NA	NA	Wolf	WDFW	staff biologist	6/2/2005	Frog not positively identified, but likely red-legged. May be listed as sensitive species in future
3/8/2005	Un-mapped facilities and infrastructure at fairgrounds and amphitheatre	W9.14T0.54S; WT6.41T1.01N; W7.82T0.22; W6.44T0.53E	182148000; 182213000; 182214000	Clark County	Wierenga	Clark County	Henry Schattenkerk	3/10/2005	Facilities need to be mapped
3/7/2005	County soil surplus site has site drains routed through silt fence	W9.14T0.54N	116530000; 116521000; 116520000	Tehennepe, Dubravac	Schnabel	Clark County	Cary Armstrong	3/9/2005	Cary to Sheila Pendleton. Sheila to Charlie Hord (Construction Mgmt). Drains re-routed inside fence
6/2/2005	Livestock access to stream-- impacted streambank and riparian area	W7.06	185749000; 185741000; 185747000	LIES RUDY & MARY ETAL CONT	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing
6/2/2005	Livestock access to stream-- impacted streambank and riparian area	W7.82T0.22	182139000; 182154000	GONZALES LL0YD ETAL; OLSON STEPHAN E & ALLISON L	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing
6/21/2005	Possible septic system issues	W8.50	181904000; 181936000	WOOLEY RICHARD & GLENNYS; SIMMONS CHARLES F & RUTH C	Schnabel	Clark County Health Dept	Steve Keirn		Health Department may wish to inspect these two parcels for septic issues
6/21/2005	Unidentified pipe outfall may be related to septic drainfield	W7.06T0.00	185404000	BAXTER DONALD & KAREN	Schnabel	Clark County Health Dept	Steve Keirn		Health Department may wish to inspect this parcel for septic issues
3/22/2005	Bank stabilization problem at PW county's Sara planting site	P0.00	182705000	CLARK COUNTY	Wierenga	Clark County	Heath Henderson	ongoing	Forwarded info to Phil Gaddis to address
3/22/2005	Freshwater mussel bed in lower Whipple Creek	W3.85	182659000	BENES MICHAEL & CATHY	Wierenga	USFWS	Jennifer Poirier	3/25/2005	Jennifer responded with interest in the beds; may use site in upcoming volunteer training
4/5/2005	Large animal track needing identification	P1.67	180742000	HOFFMAN SALLY R	Wierenga	USFWS	Donna Allard	4/8/2005	Steve Engel identified as very large canine track, probably not feline
4/7/2005	Large amount of debris piled up next to stream	P1.06T0.49W	179831000	MEYER KEVIN D	Wierenga	Clark County	Cary Armstrong	ongoing	
4/14/2005	Severe off road vehicle impact to stream	P2.06T0.00N	179698000	SHIPP STEVE & DEBRA CONT	Wierenga	Clark County	Cary Armstrong	ongoing	Cary referred to Scott Melville, CE officer
6/21/2005	Strong sewage odor from SW outfall	P1.06T0.49W	NA	CLARK COUNTY	Schnabel	Clark County	Steve Keirn		possible inspection, or include in Illicit Discharge project
3/31/2005	Livestock access causing stream bank erosion and riparian impact	P1.23T0.98S	182378000	NYE MARTIN & CHERIE	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing

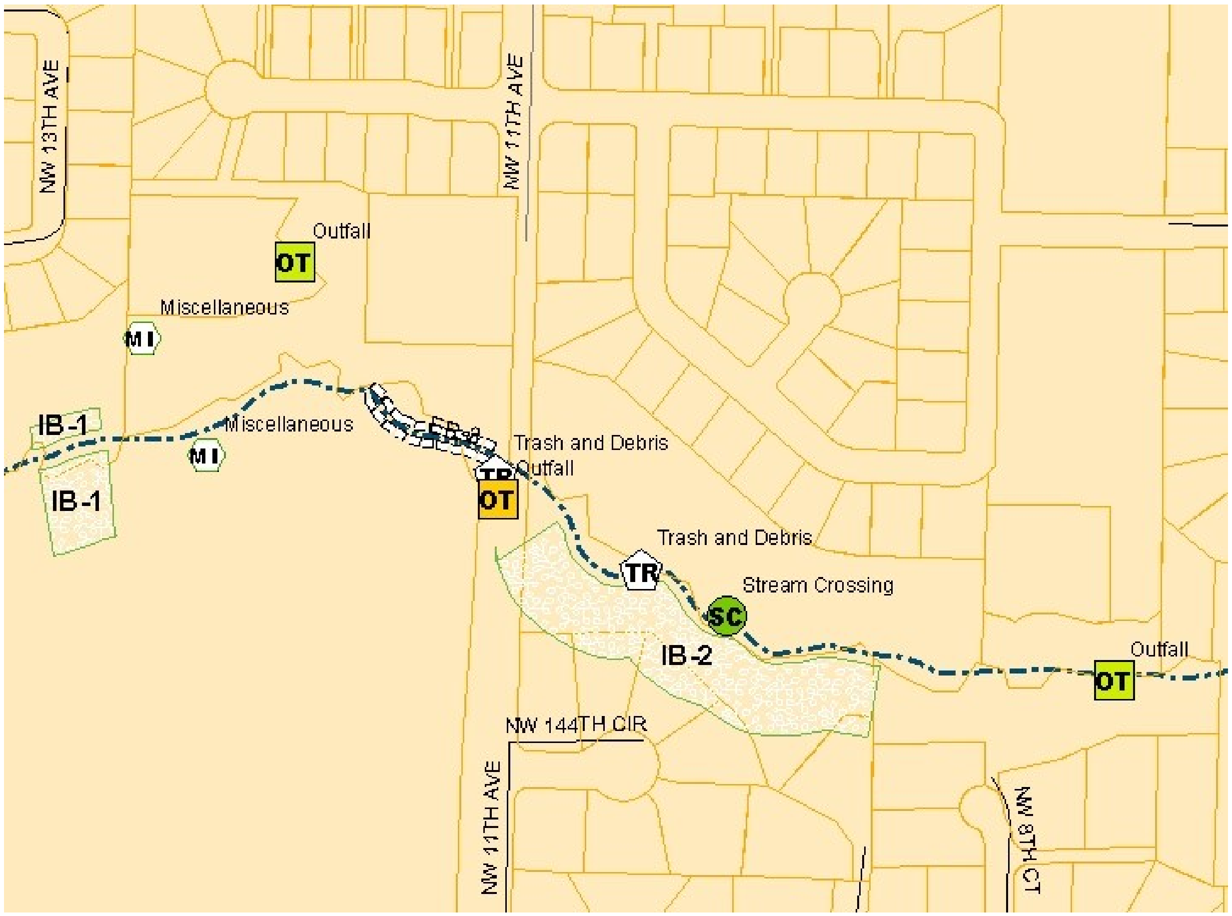
Appendix D – Watershed Characterization Maps




Whipple Creek
Stream Assessment
Bank Erosion and
Floodplain Connection


Whipple Creek
Stream Assessment
Channel Substrate and
Fish Barriers
Legend

Appendix E – Example map of assessed features



Physical Habitat Assessment

Water Resources collected quantitative habitat measurements for a 500-ft reach immediately upstream of the Sara intersection (NW179th Street and NW 41st Ave) during 2002. The assessment utilized methods described in the USEPA Environmental Monitoring and Assessment Program (EMAP) Western Pilot Study: Field Operations Manual for Wadeable Streams (Peck et al., eds. 2001) and was performed as part of Water Resources' Long-term Index Site Project (LISP). For additional detail, see the Long-term Index Site Monitoring Project: 2002 Physical Habitat Characterization report (Schnabel, 2003) on the county website at http://www.clark.wa.gov/water-resources/documents.html.

EMAP physical habitat protocols are designed for monitoring applications where robust, quantitative descriptions of reach-scale habitat are desired, such as site classification, trend interpretation, and analysis of possible causes of biotic impairment (Peck et al., 2001). They are designed to collect quantifiable measurements about general physical habitat attributes important in influencing stream ecology. Table 14 summarizes a number of indices and metrics derived from the EMAP data and provides a brief characterization of the site based on each metric.

Based on a habitat quality index that includes metrics for channel complexity, substrate composition, fish cover, and canopy density, Whipple Creek scored considerably below an Oregon DEQ grade-C reference stream. Grade "C" sites are the lowest grade of sites that qualify for use as a reference site, and are only used when a less impacted site is not available (Drake, 2003 draft). They exhibit marginally functional watershed and stream conditions, with obvious human disturbance. Given this criterion, the Whipple Creek index score indicates a highly disturbed system.

Table 14. Summary of Habitat Metrics in Whipple Creek EMAP reach near Sara.

Habitat category	Index or metric	Result	Characterization
Overall habitat quality	Habitat quality index (HQI)[1]	71	Score is relative to a DEQ grade-C reference condition scoring 100 on a normalized scale[2]
Overall riparian quality	QR1 index[3]	0.70	Good
	RCOND index[4]	0.68	Good
Hydrologic flashiness	Mean of 3 indices[4]	4.13	Obvious hydrologic impact
Channel morphology	Pool percentage (PCT_POOL)	27%	Does not meet recommended pool area[5]
	Riffle percentage (as PCT_FAST)	19%	Does not meet recommended riffle area[5]
Substrate composition	Dominant substrate	61%	Fine gravel and smaller (<=16mm)
	Mean embeddedness (XEMBED)	86%	"Not properly functioning"[6]
	Substrate sand and fines (PCT_SAFN)	46%	"Not properly functioning"[6] (22% fines <0.6mm, 25% sand (0.6-2mm)
	D_{50} (median particle size, mm)	1.2	n/a
Bed substrate stability	Bed stability (LRBS_BW4)	-1.63	Streambed relatively unstable[7]
Fish cover	Natural fish cover by area (XFC_NAT)	0.52	Fish cover relatively abundant
Large woody debris	Total LWD density (C1W)	401/mile	"Not properly functioning"[6] (good density but not large enough)
Riparian vegetation cover	Stream shading (XCDENMID)	73%	Moderately shaded
Invasive plant species	Overall invasive plant proportion (individual species proportion)	1.27	Invasive plants common (English Ivy = 0.09, Him Black = 0.55, Reed Canary = 0.64)

[1]developed by Glen Merritt, Washington Department of Ecology
[2]Drake, 2003 draft, Oregon Department of Environmental Quality
[3]Dr. Philip Kaufmann,USEPA; Butkus, 2002
[4]Dr. Philip Kaufmann, USEPA
[5]Peterson et al., 1992; WDFW and Western Washington Treaty Tribes 1997; WDNR 1997
[6]National Marine Fisheries Service (NMFS) Matrix of Pathways and Indicators, 1996
[7]Kaufmann, et al., 1999

There were a few bright spots in the assessment. Overall riparian quality was good based on two multi-metric indices, fish cover was relatively abundant, and riparian shading was relatively good at 73%. However, these metrics are site-specific and do not necessarily integrate or reflect watershed-wide conditions.

For most other metrics, including those that integrate impacts from the upstream watershed, Whipple Creek fell short of desired conditions. Whipple Creek was among the most "flashy" of 10 streams assessed in Clark County during 2002. "Hydrologic flashiness" is an indication of the tendency of a stream to exhibit extremes in flow regime. Storm hydrographs from a "flashy" stream are often much steeper and of shorter duration than normal. Flashiness is often associated with streams in watersheds having large amounts of impervious surface area or cleared land, as stormwater volumes tend to increase and runoff reaches the stream more quickly.

Conversely, a flashy stream may exhibit very low flows during dry weather due to lack of groundwater recharge during wet weather. Because flashy streams often have wide channels that have been scoured by storm flows, summer baseflow may only fill a fraction of the channel.

Channel morphology was dominated by glide habitat, with far fewer pools and riffles than recommended. Substrate was dominated by sand, silt, and fine gravels, with a high level of embeddedness and a very small median particle size. As a result, the streambed is relatively unstable in the assessed reach. The bed stability metric compares the size range of streambed material with the stream's erosive capability. If most of the streambed sediments are finer than the size the stream is capable of moving, then the streambed is relatively unstable.

Total Large Woody Debris (LWD) density was relatively high at a frequency of 401 pieces/mile in the assessed reach. However, most pieces were not large enough to qualify as high quality wood. Invasive plants were dominant throughout the reach, particularly Himalayan blackberry and Reed Canary grass.

Implications for stormwater management

The EMAP assessment was performed on a single 500-foot reach toward the lower end of the 10-mile Whipple Creek mainstem. Results may not be indicative of the entire stream. However, the cumulative result of upstream land use and management is a highly disrupted and unstable stream channel at the assessment site.

From a stormwater perspective, the unstable streambed, high level of "flashiness", fine-grained and highly embedded substrate, and modified channel morphology indicate significant challenges. These metrics indicate that Whipple Creek is subject to higher flows than it can handle effectively, and carries a significant amount of silt and sediment.

Overall, the EMAP metrics suggest that stormwater projects and watershed activities that help stabilize flow regime and control channel erosion could lead to localized improvements in stream habitat. However, due to the complexity and extent of influences on hydrologic condition, it is difficult to predict whether stormwater projects alone can have a substantial impact on watershed-wide habitat quality.

Geomorphology and Hydrology Assessment

This section was taken from the following technical memo.

TECHNICAL MEMO

To: Clark County Public Works

From: Inter-Fluve, Inc.

Date: May 18, 2006

Subject: Technical assessment of the Whipple Creek Basin to support stormwater basin planning efforts in Clark County, WA. – Working Draft.

2006 Stormwater Needs Assessment Program

Introduction

Purpose

This memorandum is intended to provide Clark County (County) with technical information regarding stream geomorphology, aquatic habitat, and wetland conditions in the Whipple Creek Basin with respect to the effects of the stormwater system. The information is based on field visits to the watershed, review of existing data and reports, and consultation with County staff. The report includes:

- A review of relevant technical information
- Descriptions of watershed process conditions
- Anticipated future trends
- Recommended actions, and
- Suggestions for planning, assessment, and monitoring.

The information is intended to support and inform efforts by Clark County to: 1) conduct stormwater planning, 2) identify ecological impacts related to growth and development, 3) implement stormwater improvement/mitigation projects, and 4) conduct monitoring to inform management. This evaluation is also intended to support future efforts in other Clark County watersheds.

Approach

An understanding of stormwater runoff processes and habitat conditions related to stormwater was obtained through a combination of approaches. Existing material was first reviewed, including a draft watershed assessment report, Whipple Creek Stream Assessment Summary and related maps, a hydrology and hydraulics modeling report, interim project identification and prioritization information, water quality and benthic macro-invertebrate data, GIS layers of watershed conditions and land-uses, and aerial photography. A total of 5 field trips were performed, including 2 outings with County staff to communicate their knowledge of the basin and the location of notable features identified during previous County surveys. The field visits included a subset of the sites previously surveyed by County staff in addition to several unsurveyed sites. Field notes and photos were taken during field visits. Stream reaches surveyed by Inter-Fluve staff are identified in Figure 10.

Field observations, existing reports, and the experience of the investigators were used to provide the qualitative discussions and recommendations contained in this memorandum. The report contains a brief overview of the basin and its land-use history, followed by more specific discussions of stream channel geomorphology, riparian conditions, aquatic habitat, and wetlands. Following this are descriptions of potential monitoring activities and recommendations for how the County might prioritize monitoring efforts. The final section includes descriptions of recommended mitigation/improvement efforts. Sample design concepts and photos are provided for a few of the recommended improvement strategies.

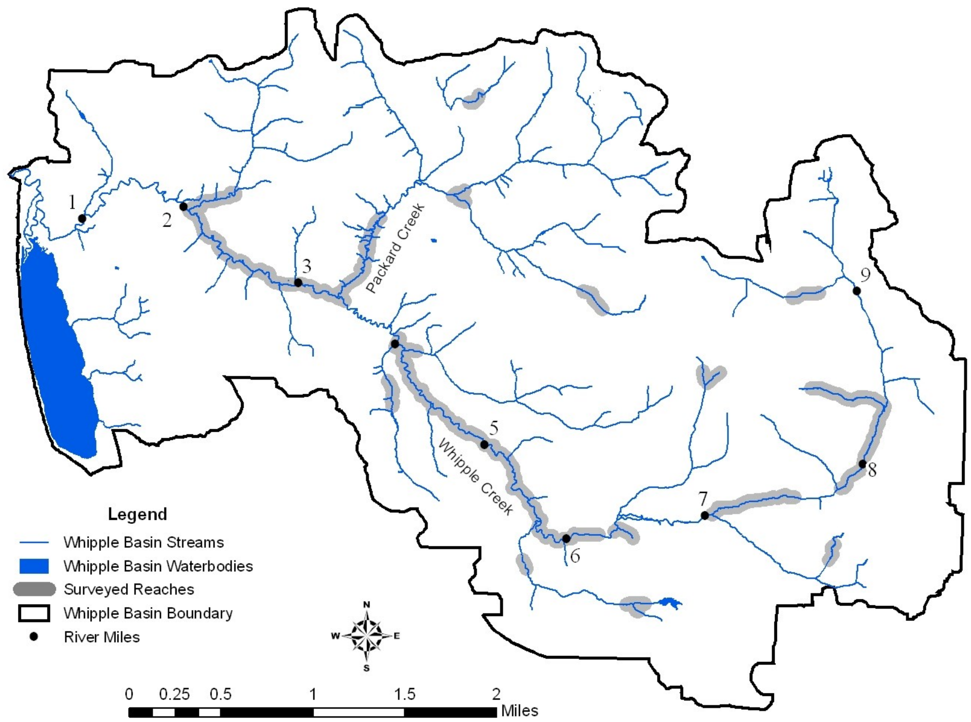


Figure 10. Stream segments surveyed by Inter-Fluve staff.

Watershed setting

Geology

Pleistocene outburst flood deposits (Missoula Floods) cover most of the basin (Figure 11). Outburst flood deposits are sands and silts, are moderately drained, and have moderate-to-high erodibility. K Factor (used in the Revised Universal Soil Loss Equation) is 0.32, which is considered moderately to highly susceptible to water erosion. Older sedimentary rocks (listed as “conglomerate” in Figure 11) underlie these outburst flood deposits and surface in higher elevation areas in the eastern portion of the basin. A few outcrops also exist in river valleys. The older sedimentary rocks are often referred to as the Troutdale Formation, remnants of an ancient lake or an historical Columbia River. This material is composed of sands and gravels and is generally coarser-grained than the outburst flood deposits. Coarse sediments, which are relatively uncommon in Whipple Creek, originate from these sedimentary deposits.

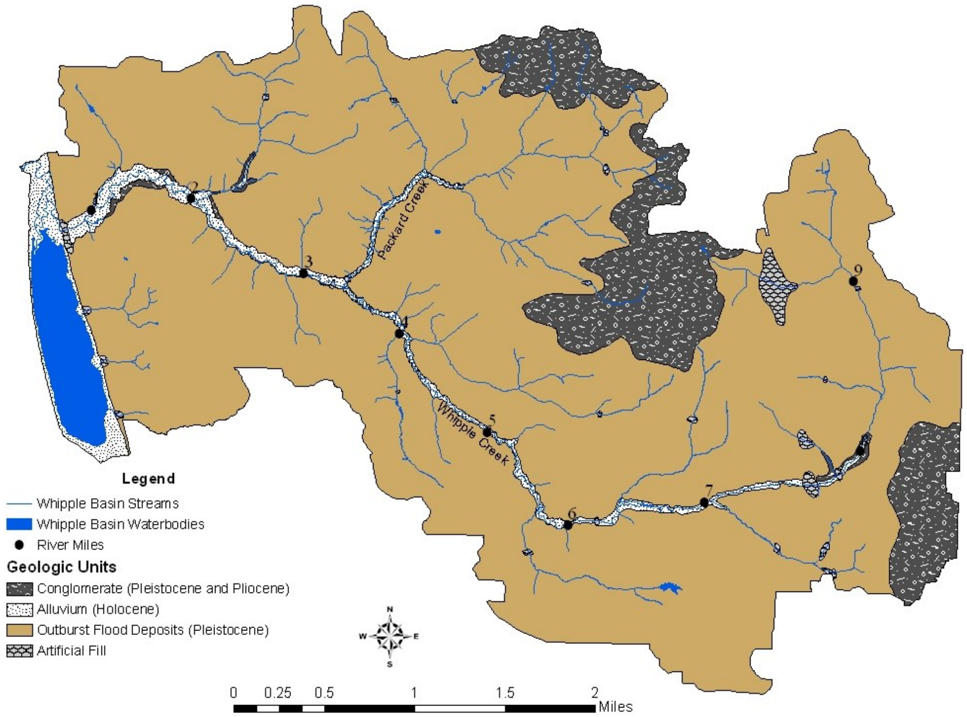


Figure 11. Geologic map of the Whipple Creek Basin (Data for this map was obtained from Clark County GIS).

Topography

The topography of the basin is characterized by rolling hills in upland areas, with steep slopes adjacent to stream channels in 1st order stream valleys. Floodplains are broad along the lower mainstem (~800 ft wide near the mouth just upstream of Kreiger Rd) and are present at varying degrees along the remainder of the mainstem. There are not extensive floodplains along tributaries, except for Packard Creek, which has a floodplain terrace along the lower several thousand feet. Where significant floodplains exist, they are typically bounded by steep valley hillslopes. A hillshaded map is provided in Figure 12.

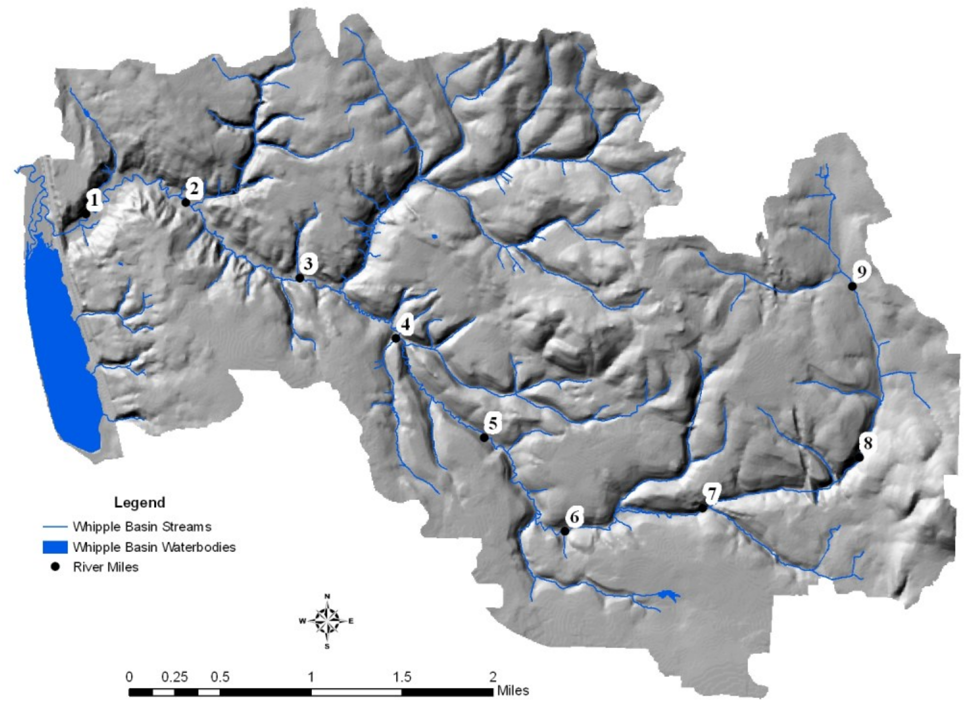


Figure 12. Hillshaded relief image of the Whipple Creek Basin.

Streams

Whipple Creek is a 4th order tributary to Lake River, which flows into the Columbia approximately 6 miles downstream of the Whipple confluence. The mainstem extends approximately 10 miles, with its headwaters near I-5 just north of Salmon Creek, WA. The primary tributary is Packard Creek, which enters from the north between river miles (RM) 3 & 4.

The majority of stream channels are dominated by highly erodible fine sediments. Coarse sediments are located in some areas, including in the mainstem upstream of I-5 for approximately 0.5 mile, in the mainstem between RM 2.3 and Packard Creek, in Packard Creek, and in the north-side tributary entering the mainstem at RM 2 (W2.04 T0.00). Coarse substrates are not particularly abundant in any of these areas except for the mainstem between RM 2.3 and Packard Creek. Coarse-grained streambanks can be found along this section. Erosion resistant clay lenses can be seen in portions of the upper mainstem and in upper basin tributaries. Channel-spanning beaver dams can be found throughout the mainstem and major tributaries. Many of these dams are substantial structures that store large amounts of material and likely withstand large flow events.

Land cover

The basin consists primarily of rural residences, agriculture, and forest land. Suburban development dominates the southeastern portion of the basin. The basin is 34% forested, 12% impervious (Total

Imperviousness), and 51% non-canopy (fields or meadows) (see Figure 13). Large tracts of intact upland forests are uncommon, but do exist in the Packard Creek Basin, north of the mainstem between river mile (RM) 4 and 5 (Clark County land), and on the east and west side of the upper mainstem between RMs 8 and 9.

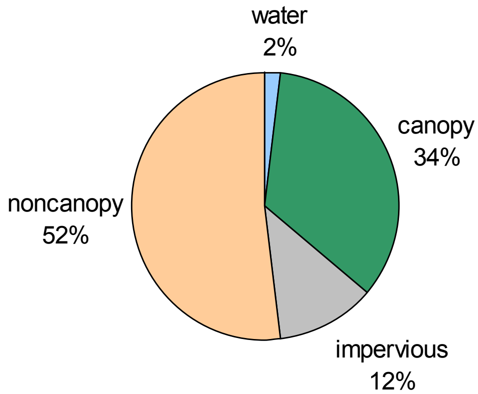


Figure 13. Pie chart of land cover characteristics in the Whipple Creek Basin. The data has been summarized from Clark County land cover GIS data. The land cover data was derived from 2002 LiDAR elevation data and 2002 infrared aerial photography.

Riparian vegetation consists of a mix of native and non-native species. Species compositions depend on a number of factors, including valley type, proximity to disturbed areas, and moisture levels. In frequently inundated floodplain wetlands, the overstory is typically Oregon ash (*Fraxinus latifolia*) or western red cedar (*Thuja plicata*), with the understory dominated by reed canary grass (*Phalaris arundinacea*), an invasive species that is pervasive throughout the basin. Less frequently inundated floodplain terraces tend toward an overstory of western red cedar, bigleaf maple (*Acer macrophyllum*), and alder (*Alnus rubra*), with an understory of salmonberry (*Rubus spectabilis*), ferns, and horsetails (*Equisetum spp.*). In many areas, especially near disturbed sites (e.g. roadways, lawns, utility corridors), the understory is dominated by Himalayan blackberry (*Rubus discolor*) and in some cases English ivy (*Hedera helix)*. Riparian vegetation along smaller channels lacking developed floodplains is typically Douglas fir (*Pseudotsuga menziesii*), western red cedar, or western hemlock (*Tsuga heterophylla*), with a variety of understory species. Himalayan blackberry is often found as the dominant understory in these areas.

Land-use

Historical changes

Consistent with practices throughout the region, forests were harvested shortly after initial settlement in order to provide firewood, building materials, and to clear land for agriculture. Observations of cut tree stumps indicate that many riparian areas were cleared of large conifers (western red cedar, hemlock, Douglas fir) in the early 1900s. Agriculture and forestry practices have persisted until the present. In the last 30 years, residential development has rapidly expanded into the southern and eastern portions of the basin.

Current and future conditions

The Whipple Creek Basin is most accurately characterized as a rural watershed that is rapidly suburbanizing. Older farms and rural parcels between 5 and 40 acres are being converted to suburban communities with town-size lots between 0.1 to 0.3 acres. Construction of roads, housing developments, and commercial infrastructure is widespread. The greatest land-use changes are in the south and eastern portions of the basin. This area lies within the Urban Growth Boundary (UGB) and is zoned primarily Urban Low Density Residential, Mixed Use, or Light Industrial. A significant number of parcels adjacent to the UGB are zoned Urban Reserve, where future build-out is expected. The bulk of the remainder of the basin is zoned rural, agriculture, or open space and it currently retains much of its rural character.

Future development patterns in the Whipple Creek Basin will be governed by the outcome of current growth management planning being conducted by the County. A Comprehensive Growth Management Plan adopted by the Board of Commissioners in September 2004 is currently under revision. An Environmental Impact Statement (EIS) is being prepared that will evaluate alternatives with respect to the location of the UGB. The outcome of these planning efforts will affect the degree of urban development that will be allowed in the Whipple Basin.

Watershed processes

Uplands

For the purposes of this evaluation, upland processes are considered to be the hydrologic and sediment processes operating in areas of the basin that are not part of the stream channel, riparian, floodplain, or channel migration zone areas. Uplands may also be referred to as “hillslopes” throughout this document. Even though upland processes may occur some distance from stream corridors, they have a fundamental impact on stream channel conditions and are readily impacted by changes in land-use and cover.

Runoff

In its natural state, dense coniferous forests in the basin would have provided hydrologic control of runoff. During and following rain events, a significant proportion of precipitation would have been lost as evapo-transpiration. Forest litter and tree roots would have maximized soil infiltration and streamflow would have originated from groundwater and shallow subsurface flow. Surface runoff on the uplands would have been rare. Infiltration and deep storage of rainfall would have maintained summer base flows.

Hydrologic conditions have been altered by forest harvest, agriculture, road building, and development. Urbanization, in particular, can have large impacts on hydrologic response as runoff volumes and rates increase. Soil infiltration and storage is reduced through wetland filling/draining and an increase in impervious surfaces. Runoff is transmitted more efficiently to stream channels due to hardened surfaces and the increase of surface flow paths (e.g. pipes, drainage ditches, and roadside ditches). Research has shown that urbanization can have the following impacts on watershed hydrology (Hollis 1975, Konrad and Booth 2005).

- Increase in the frequency and magnitude of peak flows, particularly those of shorter return intervals.
- Increases in the rates of increase and decrease of flows during individual storms (increased flashiness).
- Redistribution of water from base flow to storm flow due to reduced subsurface storage
- Increased daily variation in streamflow
- Reduction in low wet-season flows due to reduced shallow sub-surface flow

Watershed imperviousness if often used as an indicator of hydrologic impairment. Imperviousness is typically measured as Total Impervious Area (TIA) or Effective Impervious Area (EIA). TIA represents the proportion of the watershed covered with impervious surfaces, including pavement, rooftops, and other hardened surfaces. EIA is the area of impervious surfaces that are hydraulically connected with stream channels. Any part of the TIA that drains onto pervious areas is excluded from the EIA (Booth and Jackson 1997). EIA is generally considered a more accurate indicator of impairment. The EIA, however, does not reflect areas of nominally "pervious" surfaces, such as lawns, grazed pasture land, ball fields and other surfaces that have compacted soils and in reality are largely impervious.

Past studies have shown that significant impacts to runoff are typically seen as watershed imperviousness exceeds 10-20% (Hollis 1975, Schueler 1994). The Whipple Creek Basin currently has in excess of 10% of its total area in impervious surfaces (i.e. pavement and rooftops). Some individual catchments contain considerably higher rates of total imperviousness, while others contain less (see Figure 14 and Figure 15). Areas of nominally pervious surfaces, which contain compacted soils, may significantly add to actual watershed imperviousness.

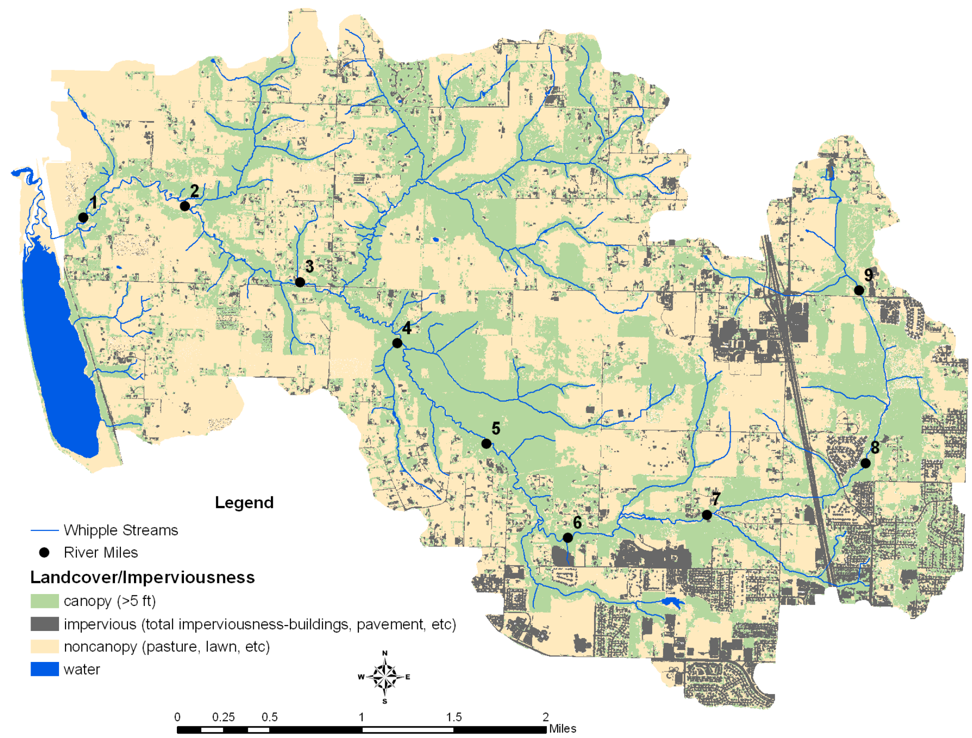


Figure 14. Land cover data/imperviousness for the Whipple Creek Basin. Source data provided by Clark County with minor edits conducted by Inter-Fluve. The land cover data was derived from 2002 LiDAR elevation data and 2002 infrared aerial photography. A significant amount of development has occurred since 2002. The current level of imperviousness therefore exceeds what is displayed.

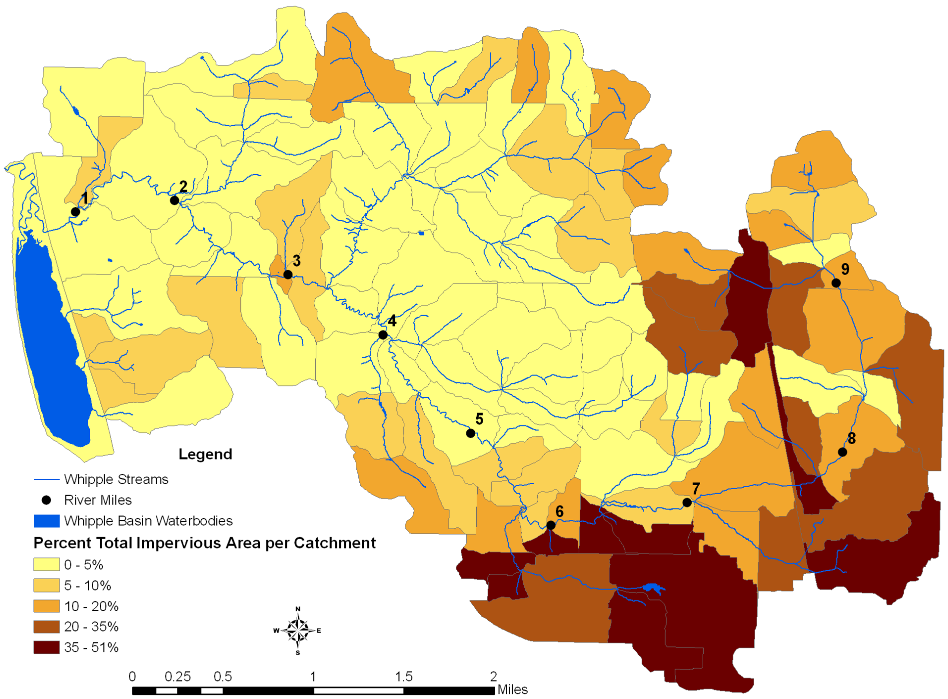


Figure 15. Percent Total Impervious Area by Catchment in the Whipple Creek Basin. Source data provided by Clark County with minor edits conducted by Inter-Fluve.

Development in certain parts of a watershed may have a greater detrimental effect on watershed hydrology than others because of the timing of flow concentration. In an undeveloped basin, flow originating from the lower, middle, and upper third of the watershed will arrive at the basin outlet in sequence, and will create hydrographs like those depicted in Figure 16. If development occurs in the upper third of the basin, flow from that area arrives sooner, and the total basin peak flow is increased (Figure 17). In contrast, if the lower third of the basin is developed, then the peak flow from that area arrives at the outlet sooner, and total peak flow at the outlet would be reduced. In the Whipple Creek Basin, development is largely occurring in the upper third of the basin, suggesting that peak flows in the lower mainstem could be dramatically increased unless adequate controls are put in place.

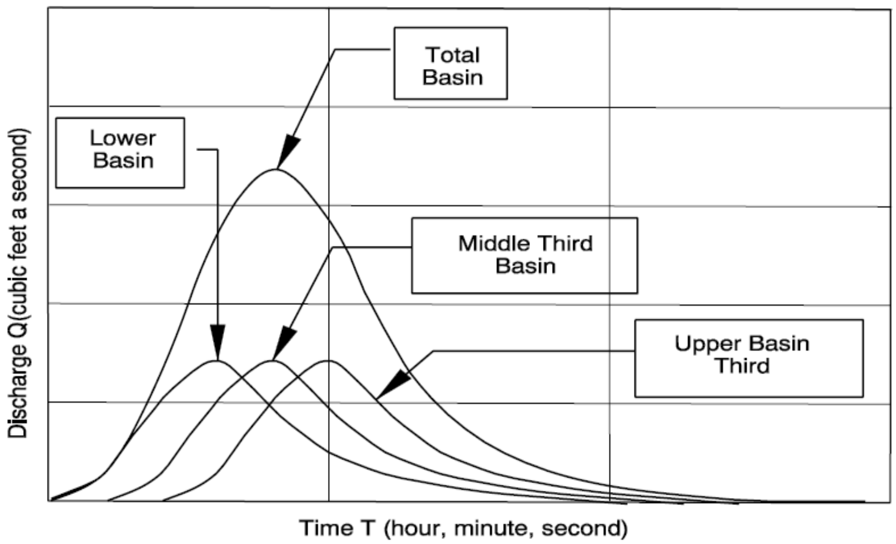


Figure 16. Hypothetical runoff hydrographs for an undeveloped basin. Reprinted from Oregon Department of Transportation (2005).

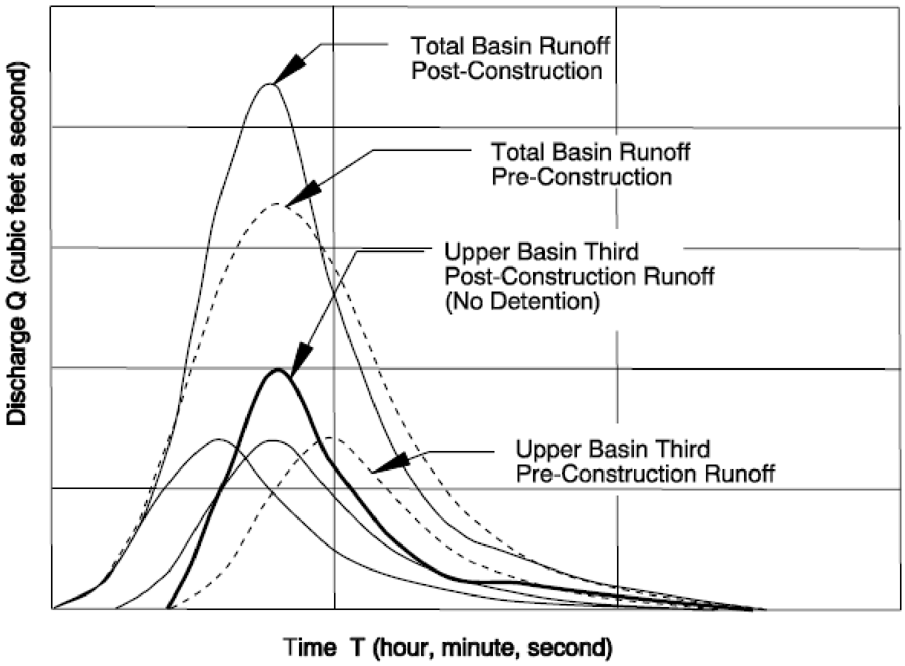


Figure 17. Hypothetical runoff hydrographs for a basin with development in the upper third of the basin. Reprinted from Oregon Department of Transportation (2005).

Fine sediment

In the natural state of the basin, modest amounts of fine sediment would have been contributed to streams from upland areas. Sediment contributions would have been limited due to less overland runoff and the protection of soils provided by forest vegetation. Episodic fire, flood, and landslide disturbances would have contributed pulses of sediment to stream channels.

In the current state of the basin, upland sediment processes are impacted by urbanization. Erosion of fine sediment increases during build-out due to soil destabilization during construction. The increase in flow paths (road ditches, storm sewer system) and direct ditchline connections to streams increases sediment delivery to channels. Erosion risk is exacerbated by the high silt content of native soils. Fine sediment delivery may be reduced in the long-term as the basin becomes hardened through development.

Urbanization can be viewed as a “press” as opposed to a “pulse” disturbance. Pulse disturbances are those with a limited temporal phase, such as flooding, fire, insect outbreaks, and landslides. Press disturbances, on the other hand, are alterations of permanent or indefinite duration that are typically imposed by human alterations to the landscape. Pacific Northwest watersheds are adapted to pulse type disturbances and in many cases rely on these processes for creation or maintenance of critical habitat. At any given time, watersheds in their natural state are within various stages of adjustment to pulse disturbances, a process termed dynamic equilibrium. A press disturbance, such as urbanization, exerts a persistent stressor that creates a new, more static equilibrium, with an associated loss of physical processes needed to support key habitats.

Stream channels

Stream channel processes are the dynamic elements that govern channel morphology. They include the inputs, outputs, and storage of wood, water, and sediment. Prior to European settlement, stream channels were adjusted to the natural hydrologic, sediment, and wood supply regimes. Frequent flood flows, occurring once every one to two years, would have governed channel size and shape. The magnitude of these flows is often termed the dominant discharge. Larger, more infrequent floods would be accompanied by more intense scour and fill events, which would be followed by a period of adjustment to the dominant discharge. Sediment conditions would be governed by channel scour and fill patterns, hillslope sources, and the underlying geology. Coarse sediment in the Whipple Basin would have been naturally limited because of the fine-grained geology. Coarse substrates would exist only where the underlying geology provided a source, such as several areas where the Troutdale Formation surfaces in the basin, and where channel and flow conditions were adequate to distribute and maintain coarse bed material.

Field evidence suggests that the large diameter of native conifers in the riparian zone would have provided fallen wood of sufficient size to remain in the channel until decay. These pieces of woody debris would have been a dominant factor in shaping stream channels. Woody debris would have provided stable grade control and trapping of sediments, and the increased roughness would have reduced the erosivity of flows, thus limiting channel incision and allowing for stable channels at gradients that would otherwise result in bed degradation (incision).

Channel geomorphic processes have been altered by changes to the watershed runoff regime, changes to the watershed sediment regime, past riparian timber harvest, hydromodifications, and invasive plant species. The effects of these changes are discussed in the following sections.

Technical background

Some general principles of stream channel geomorphology and the effects of urbanization are useful for evaluating current and future conditions of Whipple Basin stream channels. A considerable amount can be learned from the large volume of research related to the response of stream channels to land use, and urbanization in particular. The discussion below focuses on a few of the key geomorphic processes that are useful to consider when evaluating conditions in Whipple Creek and other nearby watersheds that are experiencing rapid land use changes.

Channel erosion processes

Stream channel changes occur through complex interactions of flow, sediment supply, riparian condition, wood supply, and human alterations. A primary response of channels to urbanization-induced flow alterations is channel enlargement. This phenomenon has been studied extensively in urbanizing basins in the US (Hammer 1972, Booth and Jackson 1997). See Figure 18.

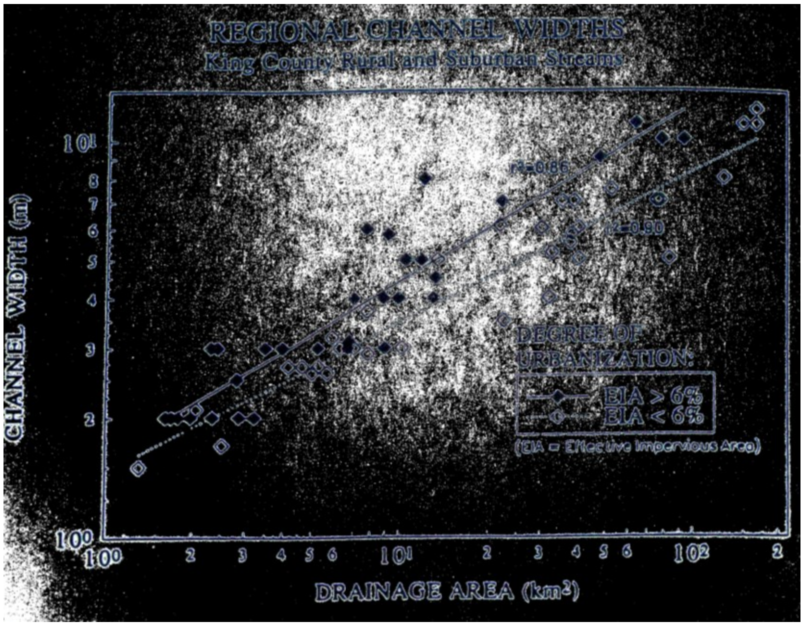


Figure 18. Channel widths as a function of imperviousness of the contributing drainage area (reprinted from Booth and Jackson 1997).

Enlargement occurs in response to changes in the dominant discharge to which stream channels are adjusted. Booth (1990) describes enlargement as either incision or quasi-equilibrium expansion. Quasi-equilibrium expansion is an increase in channel width and depth in rough proportion to the increase in discharge created by land use change. Incision, on the other hand, is an exaggerated deepening and subsequent expansion of the channel out of proportion with the increase in discharge. Thus, channels expand to beyond what is needed to convey the new flood flows.

The potential for stream channel erosion can be thought of in the context of average boundary shear stress (τ_0), which represents the ability of the flow to erode the channel boundary:

$$\tau_0 = \gamma RS$$

where γ is the specific weight of water, R is the hydraulic radius of the flow (area/perimeter), and S is the channel slope. Because γ is constant and R approximates flow depth in most natural channels, the shear stress can be thought of as the product of the flow depth and the channel slope. A similar relationship is that of stream power, which is simply a function of the product of discharge (Q) and channel slope. All other factors being equal, areas that exhibit higher rates of shear stress or stream power would be expected to have greater risk of channel erosion. In urbanizing basins, erosion increases due to the increase in discharge and therefore depth. Slope may also increase, especially in areas where streams have been straightened or where headcuts have formed, creating dramatic increases in slope. Headcuts result in exaggerated local shear stresses that cause continued erosion, serving to propagate the headcut upstream until the entire channel segment has been reduced to a lower slope with greater vertical stability (lateral instability may persist because of over-steepened banks and channel adjustment dynamics discussed below). This process creates over-enlarged channels with capacities that exceed what is needed to carry the dominant discharge. Whether a channel gradually widens or deepens to accommodate higher discharges, or whether it exhibits catastrophic incision, depends on a number of factors beyond the parameters included in the shear stress or stream power functions. These include geologic characteristics, sediment transport conditions, wood loading, and streambank integrity provided by vegetation.

Channel erosion and deposition processes are depicted well in a cartoon by Lane (1955), which shows how sediment supply, sediment size, channel slope, and stream discharge interact to favor either sediment degradation (erosion) or aggradation (deposition) (Figure 19).

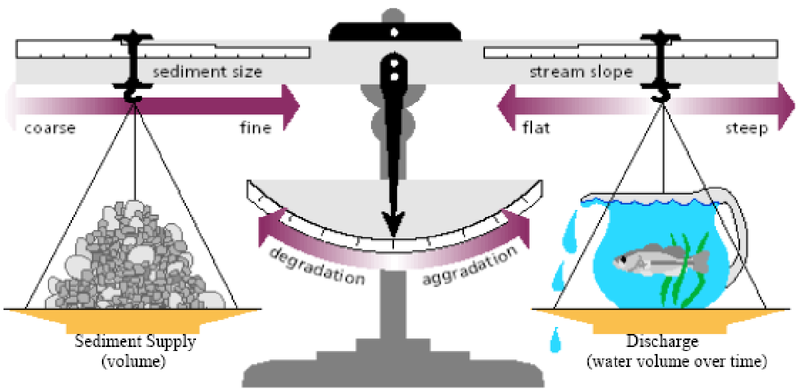


Figure 19. Lane's balance of the influence of stream slope, discharge, sediment size, and sediment supply on channel degradation and aggradation. From: Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering. In Proceedings of the American Society of Civil Engineers 81(745): 1-17.

Influence of channel type

With respect to sediment transport conditions, stream channels can be generally categorized into source, transport, and response reaches (Montgomery and Buffington 1998). Source reaches are steep colluvial headwater channels where sediment supply is dominated by hillslope sources and typically exceeds the transport capacity. Transport reaches are of moderate gradient and contain step-pool, cascade, or bedrock channels where transport exceeds supply. Response reaches are low gradient alluvial channels (pool-riffle, dune-ripple) with high rates of sediment deposition. Erosion patterns differ depending on channel type and their location within the basin. Source channels, with their higher gradients, are more likely to incise because of high shear stresses on the channel bed. Incision occurs when there is insufficient grade control from bed geology, wood, or root masses, and if transport capacity exceeds supply, which can occur with increases in discharge and channel over-steepening (e.g. headcuts). Transport reaches are also susceptible to channel incision because they contain slopes great enough to create high shear stress on the bed. Incision is exacerbated in these reaches if the sediment supply coming into the reach is not able to keep up with the high transport rate.

Response reaches will tend to favor widening over deepening because of the high rates of sediment deposition and low rates of transport. These channels will increase their capacity through erosion of the channel banks as opposed to erosion of the bed. In meandering reaches, this can create excessive erosion on the outside of meander bends, leading to more sinuous channel planforms with less gradient and more potential to collect sediment. As sediment collects, overbank flows between meanders become more common. The steeper gradient of overbank flowpaths that shortcut meanders can initiate headcutting of a new channel between meander bends that can 'capture' the main stream (avulsion) and lead to a straighter, more incised channel. Headcutting can propagate upstream from the avulsion site, thus incising upstream channels within their existing planform.

Influence of geology
Geology also plays a dominant role in channel enlargement. If the local geology supplies coarse material to the channel, then channels may be more resistant to enlargement. Coarse bed material in combination with finer bank material may favor widening. Cohesive soils with high clay content can maintain steep, resistant banks that may favor the formation of channelized segments with low width-to-depth ratios.

Influence of large woody debris
Large woody debris plays an important role in west-side Pacific Northwest stream channels. Channels the size of those found in the Whipple Basin are not large enough to transport much of the wood that is contributed. If not removed, wood remains in the channel until decay, serving as a powerful geomorphic agent in the shaping and stability of stream channels. Fallen logs provide roughness (energy dissipation), bed and bank protection, and grade control. The presence of wood allows stream reaches to maintain steeper gradients while remaining stable. This is accomplished through the creation of channel steps that are stabilized with logs. Stream types governed by the presence of wood in this manner have been referred to as having "forced" channel morphologies (Montgomery and Buffington 1998). Without the presence of wood, these channels would exhibit alternative channel patterns and forms, with higher channel scour and sediment transport rates.

Influence of riparian vegetation
The presence or absence of riparian vegetation also has an important influence on channel erosion. This is especially true in low gradient reaches where decreased root strength may cause dramatic channel widening. In smaller, first order channels, root strength may provide stability to the channel bed itself, helping to halt incision. Removal of streamside vegetation may exacerbate the process of channel incision and widening.

Influence of beavers
Beaver dams provide an important geomorphic control on stream channels. Similar to the influence of large wood, beaver dams provide grade control that slows water velocities, reduces gradients between dams, and reduces overall channel erosion. Beavers are most active in low gradient, alluvial channels, sometimes creating sequences of long pools within the channel and at other times transforming fluvial segments into broad wetland complexes that store a tremendous amount of sediment. Removal of beaver dams increases local gradients, channel erosion, and sediment transport to downstream reaches.

Re-stabilization of channels

Once channels incise in response to land-use alterations, they may eventually re-stabilize to a predictable form after a period of adjustment. Re-stabilization does not imply a return to post-development conditions. It simply signifies a reduction in actively expanding channels. Hammer (1972) was one of the first investigators to recognize that channels tend to re-stabilize a few decades following urbanization. Schumm et al. (1984) produced a conceptual model of channel evolution that demonstrates how channel form adjusts and re-stabilizes in response to incision (Figure 20). In this scenario, which is typical of many urbanized streams, the stream adjusts to its new gradient and size by creating a new floodplain made up of material that continues to be eroded from upstream locations.

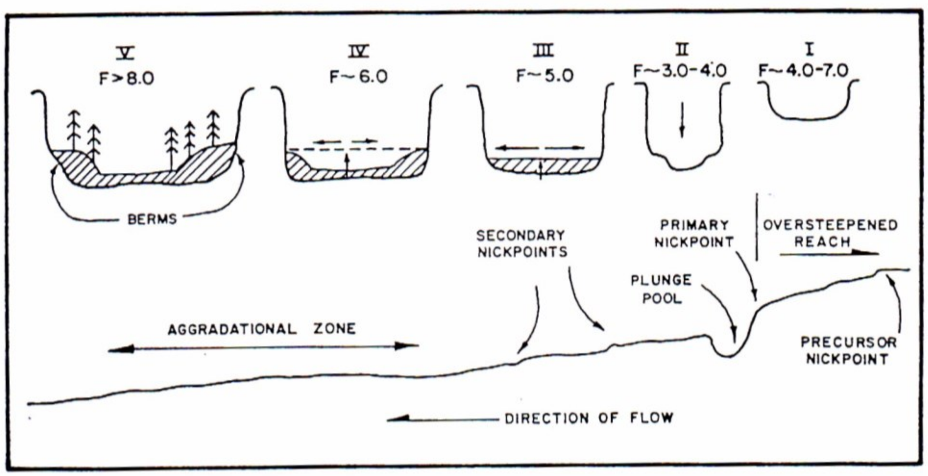


Figure 20. Stages of channel evolution in response to incision. Values of width-to-depth ratio F are included. (reprinted from Harvey and Watson 1986).

Finkenbine et al. (2001) found that urban streams near Vancouver, BC tended to re-stabilize after approximately 20 years. In the Puget Sound region, Henshaw and Booth (2000) found that most streams restabilize after 10 to 20 years yet some streams appear to remain unstable. This instability is attributed to the interplay of changes to the flow and sediment regimes. Conversion to a more flashy flow regime, with greater and more frequent flow events of shorter duration, may result in mobilization of bed material without full sorting of the material. Smaller, inter-storm flows are incapable of moving the coarse sediment mobilized during the larger events and only serve to embed the material with fines. In this sense, the channel is neither adjusted to the high, channel forming flows, or the more frequent flow events, and it remains persistently unstable.

A basin with a slow rate of development is more likely to experience gradual channel expansion that may go unnoticed. High rates of urbanization are more likely to cause catastrophic channel incision, with large headcuts and deeply entrenched channels.

Stream re-stabilization does not imply a return to healthy conditions. Although some studies have shown an increase in bed coarsening and a reduction in fine sediment that may benefit aquatic organisms, other changes limit overall stream health (Finkenbine et al. 2001). Potential negative outcomes include incised channels with disconnected floodplains, higher stream velocities, decreased base flows, and decreased channel shifting dynamics important for riparian vegetation establishment and wood recruitment.

Whipple Basin channel geomorphology

Many Whipple Basin stream channels are experiencing active channel enlargement. Enlargement takes the form of incision or widening depending on channel type and location within the basin. In general, field observations indicate that incision, through the process of headcutting, heavily affects the steeper 1st order tributaries. Channel widening is the dominant form of enlargement in 2nd and 3rd order response reaches. The mode of channel response generally follows the gradient pattern in the basin (Figure 21). Field investigations indicate that higher gradients favor incision, while lower gradients favor widening. Many incidences of channel widening, however, represent adjustment to past incision, where avulsions have straightened and incised channels. These patterns are generalizations, with variations depending on flow volume and local soil and bank stability conditions.

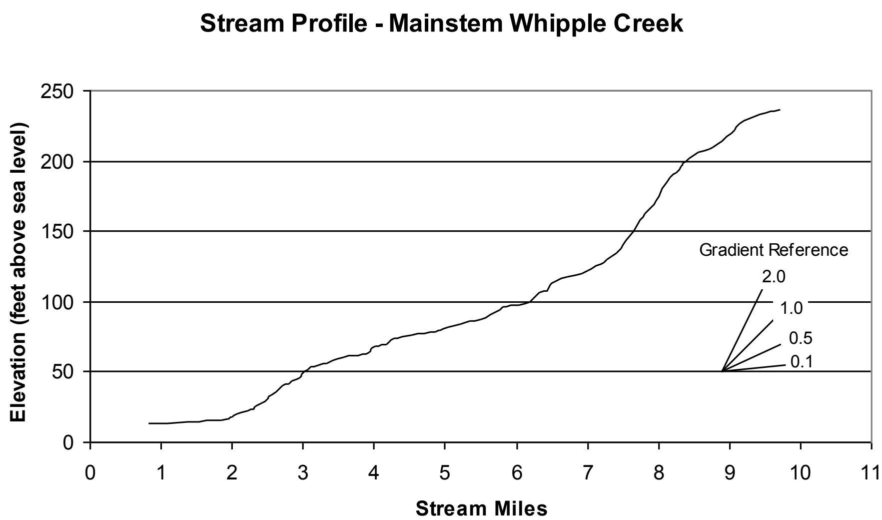


Figure 21. Stream profile for the mainstem of Whipple Creek.

Severe streambank erosion is prevalent along many stream reaches, especially those experiencing channel widening. Whipple Basin channels are particularly susceptible to erosion because of silt and sand banks. A lack of coarse substrate reduces resistance to erosion and contributes to incision. Coarse substrate is only found in significant amounts in the mainstem above I-5, the mainstem between river mile 2 and 3, the river mile 2.04 trib, and in Packard Creek. The lack of coarse material is due to the underlying geology that provides little in the way of material larger than sand sized particles.

Although riparian corridors are mostly intact throughout the basin, intrusions have occurred over the years for various purposes, including utility corridors, transportation corridors, logging access, livestock access, and residential uses (e.g. lawns). Large trees that historically would have fallen into stream channels were removed years ago. Conifers on the order of several feet in diameter (see Figure 22) have been replaced by smaller hardwood species or invasive species. The removal of large wood that historically provided natural grade control has served to destabilize channels.

Figure 22. Old-growth fir snag in riparian area of Trib W8.36.

Intrusions into riparian corridors have opened the door for colonization by invasive species, which out-compete native trees and shrubs. A lack of bank vegetation exacerbates bank erosion in many places. The reduction in vegetated banks and large wood has contributed to transient states of channel stability.

Road crossings provide hardened control points that are halting head cutting in places. However, road crossings and other hydromodifications lock the stream in place. This prevents dynamic channel changes that could add needed coarse sediment to channels and could help control invasive plants.

Characteristics by channel type and location

Field reconnaissance suggests that certain areas and channel types within the basin are having distinctive responses to land-use changes. The characteristics of specific locations within the basin are discussed below under their respective headings. A map of these locations is presented in Figure 23.

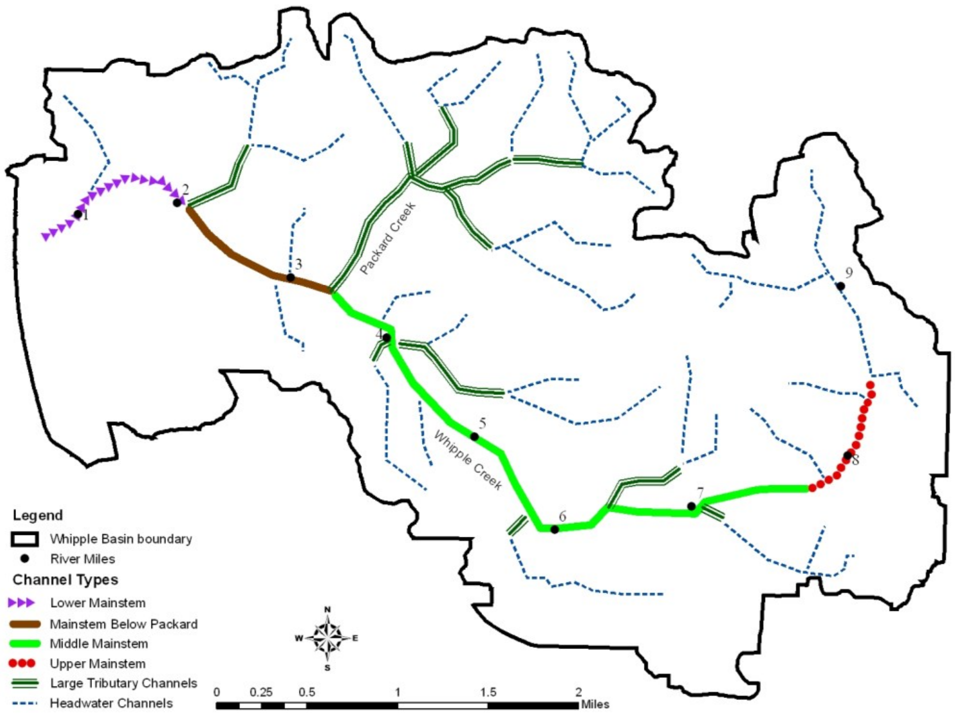


Figure 23. Map of channel type areas. This map is a generalization of the channel type areas that are discussed below. It does not reflect any formal channel typing for these streams and is only provided here as a reference for the information provided below.

Headwater channels

Headwater channels consist of the small, 1st and 2nd order channels located throughout the basin. These streams consist primarily of source and transport reaches with gradients up to 5 percent. Many of these tributaries have their sources in depressional wetland areas, while others head in small, steep valleys. Channel bed and bank sediment is typically sand and silt. Root masses and wood provide structure.

A common response of these channels to increases in imperviousness is headcutting due to the higher gradients and therefore greater shear stress. Headcutting at the upper end of small channels essentially serves to move the channel initiation point further upslope in order to accommodate for a greater storm runoff volume per unit area of contributing catchment. This process is made worse because intermittent and ephemeral headwater swales are frequently located in cleared areas (agriculture or past agriculture) with little soil stability provided by vegetation. They are particularly susceptible to channel formation if the contributing basin imperviousness increases. This process has put several wetland source areas at potential risk of being drained. Specific areas noted during field surveys are described in the wetlands section (page 137).

Some of the most severe erosion has occurred near the outlets of stormwater detention facilities or other stormwater outfall locations, where large (up to 15 ft) headcuts have formed in small channels or on valley hillslopes leading to channels. These features are the result of improperly designed or maintained facilities that have failed to control for the effects of flow concentration at discharge locations. Example locations include detention facilities at the fairgrounds site (trib W6.44, Figure 24), Whipple Creek Place (trib W6.26), on trib W5.70 T0.49S, and on trib W8.36 (see Figure 25); and outfalls at the school property (trib W5.70) and on trib P1.06 T0.49W.

Figure 24. Photo of headcut just downstream of outlet of stormwater detention facility at headwaters of Trib W6.44 (Clark County Fairgrounds site). Approximate height of headcut is 12 feet.

Figure 25. Photo of headcut just downstream of outlet of stormwater detention facility at headwaters of Trib W8.36. Approximate height of headcut is 6 feet.

Upper mainstem (RM 7.8 – RM 8.4)

The upper mainstem is defined here as the reach extending from Union Road upstream to approximately RM 8.4. This reach is a 3rd order channel with moderate gradient (approx. 1.5%). The reach contains a moderate amount of coarse material (gravels and small cobbles) and segments with pool-riffle sequences. In places, channel steps are formed by small woody debris. Banks are fairly stable throughout with both native and non-native vegetation (blackberries) and root masses providing stability. Large patches of dense blackberry thickets are located beneath openings in the riparian forest canopy. These patches are interspersed with healthier forest patches with native vegetation. A medium (approx. 4 ft) headcut is located at the top of this reach at approximately RM 8.3. Upstream of this location the stream is a slightly entrenched (high valley width to bankfull width ratio) channel with a low width/depth ratio. The stream is well connected with its floodplain and courses through floodplain wetlands thick with reed canary grass and beaver activity. Below this location, the stream is incised and appears to have drained former floodplain wetlands. Further downstream, the channel appears to be in a moderate-to-good condition. Several small headcuts (less than 3 feet in height) are located along the length of the lower reach with evidence of moderate channel expansion in places (see Figure 26).

Figure 26. Photo of exposed root mass of Western Red Cedar (covered in moss) adjacent to Whipple Creek upstream of Union Road. Exposure of root mass suggests channel expansion (deepening) has occurred in this area.

Channel degradation has been limited here for a number of reasons. First, there are large areas of the contributing basin that remain in a forested condition and most of this is located along the stream corridor. Furthermore, fine sediment has been retained upstream in the system of floodplain wetlands/beaver dams. There is also a source of coarse material and flow competency to maintain it. This segment, however, is susceptible to further channel enlargement and potential severe incision. This is due to the anticipated intensive development in the upper basin, gradients with sufficient shear stress potential, lack of wood recruitment potential, and lack of hydraulic controls to limit headcut progression.

Middle mainstem (RM 3.2 – RM 7.8)

The middle mainstem is defined here as mainstem Whipple Creek extending from the Packard Creek confluence upstream to Union Road. This segment consists of 3rd and 4th order reaches with very low gradient (<0.35%). These channels are primarily response reaches, with channel beds and banks made up of sands and silts. Figure 27 depicts a channel that is characteristic of the middle mainstem. Coarse material is scarce, with isolated pockets of gravels located at areas of high scour (i.e. culvert outlets) or at tributary confluences. The upper portion of this segment (upstream of 11th Ave.) alternates at times between a defined channel and long beaver dam complexes where standing water extends across the floodplain. The lower portion of this segment also contains beaver activity, but channels are more defined, with beaver dams and small log jams creating sequences of steps separating long, slow moving pools.

Figure 27. Characteristic middle mainstem reach at approximately RM 7.2.

The entire segment contains broad floodplains, most of which appear to be moderately-well connected with the stream channel. During field visits following 2-year or greater flow events in winter 2005-06, there was evidence that flows were at or near top of banks, although substantial inundation of floodplains had not occurred. In some locations, it is probable that flows that would have historically been over-bank flows may now be contained within the channel.

Field evidence suggests channel widening has been the primary form of channel adjustment, although deepening has also occurred in some locations. Fine sediment contributions from construction in upland areas and from incision in the steeper, upper basin channels have probably limited incision in favor of widening. The majority of channel banks are steep and bare, with signs of active erosion. Accumulations of sand on the channel bed are evident in many locations. There is little bank integrity provided from roots, and in many places, dense reed canary grass or blackberries dominate the floodplain and channel margins. Stream-adjacent hillslope slumps are evident in many areas where the channel abuts the valley hillslope. Slumps primarily contribute fine material. There occurrence may be exacerbated by stream erosion of the bank toe.

Small wood debris jams, often associated with beaver activity, are located throughout, but there is little large wood present in the channel or floodplain. Where large pieces of wood do exist, they often span above the channel, without providing much geomorphic influence. Most of the large wood was likely removed from the system years ago, which was followed by alder establishment, and now invasive species prevent the growth of a new coniferous forest.

Mainstem below Packard (RM 2 – RM 3.2)

The mainstem below Packard is a 4th order channel with low gradient (0.7%). However, with a slightly greater slope than the middle mainstem, and a greater amount of coarse bed material, this reach has a dramatically different character than its upstream neighbor. There is also considerably more flow in this reach, owing to the contribution from Packard Creek.

This reach contains a significant quantity of coarse bed material in the form of gravels and cobbles up to 12cm median diameter. Coarse material is sourced from the underlying Troutdale Formation, which can be seen in channel banks as coarse gravels and cobbles in a sandy matrix (see Figure 28). The gradient and flow volume through this reach is sufficient to mobilize this sediment, maintaining good sorting and cleaning of the substrate. Consequently, this reach contains the greatest quality salmonid habitat in the basin.

Figure 28. Outcrop of Troutdale Formation in the mainstem below Packard Creek (approx. RM 2.6).

Figure 29. Log jam with large key piece at approximately RM 2.8.

There is evidence of channel expansion, primarily through widening. The stream is eroding the hillslope toe in some locations, especially in areas where the floodplain width narrows. Unlike other areas in the basin, bank erosion here provides coarse material and causes adjustments of channel form that adds to habitat complexity. Channel adjustment is also created by in-channel wood debris. Wood jams are present here to a greater extent than in other areas of the basin. Some jams are composed of large key members with smaller racked pieces (see Figure 29). Some of the wood spans above the channel but much of it lies within the active channel.

Log jams in this reach are providing important channel functions. Field observations following flood events indicate that jams are trapping fine sediments downstream, within, and upstream of the jams (Figure 30). Overflow channels scour floodplains, increasing floodplain connectivity. Channel adjustments discourage invasive riparian vegetation and create soil conditions favorable to colonization by native vegetation. Figure 31 depicts an area where backwater effects from an upstream log jam created floodplain overflow and subsequent scour and fill of material, allowing for young alders to colonize the site. This is the only location observed in the entire basin where there is any significant new growth of young riparian trees.

Figure 30. Accumulation of fine sediment as a result of backwater effects of log jam at approximately RM 2.9.

Figure 31. Young alders colonizing fine sediments recently deposited as a result of channel adjustment due to an upstream log jam (approx. RM 2.4).

Below approximately river mile 2.4, conditions change dramatically. The gradient lowers and the stream enters a disturbed area. The upstream portion is within a maintained residential lawn, where lack of riparian vegetation and mowing up to the stream edge has caused severe bank instability. Below this, the stream enters a large pasture that extends to the stream edge, with cattle access to the stream channel. The channel here is severely incised and over-widened, with no woody riparian vegetation, and blackberry thickets along the channel (Figure 32). The channel bed is sand and silt.

Figure 32. Whipple Creek in pasture area (near RM 2.2). Removal of riparian vegetation, colonization by invasive plants, and cattle access to the stream has resulted in a severely eroding and incised channel.

During field surveys following 2-year plus flood events in winter 2005-6, overbank flows were evident at the lawn at the upper end of this disturbed reach (Figure 33), but did not occur in the incised channels in the pasture. These channels have over-enlarged beyond what is needed to convey the dominant discharge and have therefore lost their connection with floodplains. It is probable that meander patterns and channel geometries have changed dramatically in this area. Sinuous channels were likely straightened either through avulsions or direct human alteration. Incision then followed, lowering gradients and simplifying channels. There is currently very little suitable habitat in this area. Channel restoration at the upper end of this pasture area could potentially create sufficient gradient and channel structure to maintain suitable spawning gravels.

Figure 33. Evidence of recent over-bank flows at lawn area near RM 2.3.

Lower mainstem (RM 0 – RM 2)

The lower mainstem below river mile 2 was not surveyed. Given the gradient profile and field observations from the road crossing near the mouth, it is assumed this reach would be similar to the middle mainstem, only with broader floodplain wetlands with less woody riparian vegetation (Figure 34). Channels near the mouth are very low gradient response channels with bed and banks comprised of silty material. Tidal backwater effects appear to extend some distance upstream. Floodplains are wide (approx. 800 feet), have high water tables, and are dominated by reed canary grass. The only trees are sparsely distributed Oregon Ash.

Figure 34. Arial photograph of lower Whipple Creek just upstream of NW Krieger Road crossing near the mouth.

Large tributary channels

Large tributary channels consist of the 3rd order tributary channels in the three largest tributaries to Whipple Creek. These include Packard Creek, trib W2.04, and trib W4.09. Field reconnaissance was conducted in the lower half-mile of Packard Creek, the lower one-third mile of trib W2.04, and in only a few locations in lower trib W4.09.

These channels are mostly transport and response reaches with gradients ranging from 1-4%. Coarse material is present in these reaches to varying degrees. Trib W2.04 contains the greatest amount of coarse material, owing to the incision of its valley into the Troutdale Formation (See geologic map Figure 11). Packard Creek and trib W4.09 have modest amounts of coarse material, likely sourced from Troutdale Formation outcrops in headwater areas.

Packard Creek is the largest and most significant of the tributaries. It is in fairly good condition overall. It appears to have incised following land clearing activities in the early-mid 1900s but has re-adjusted through sediment aggradation and widening. Pool-riffle sequences are interspersed with channelized areas where the stream is continuing to adjust through bank erosion. Steps and pools are created by woody debris, although much of the fallen wood spans above channels (Figure 35). Root masses, sometimes from mature cedars, provide bank stability in many areas. Packard Creek is the only one of these streams that contains significant floodplains, which appear to be moderately disconnected from the stream channel. Floodplain width near the mouth is approximately 150 feet.

Figure 35. Photo of wood spanning above channel in Packard Creek. This is a common occurrence in Packard Creek and other incised channels.

Where Packard Creek courses through the floodplain of mainstem Whipple Creek, significant bank erosion has developed (Figure 36). An actively eroding 8 foot cut-bank has been caused by downcutting of Packard Creek to meet the grade of mainstem Whipple, which is incised into its floodplain at this location. The large amount of material contributed from bank slumping has further directed flow to the eroding bank. This process will continue until either channel roughness increases to slow velocity, the slope is reduced sufficiently to reduce shear stress, or bank resistance is increased.

Figure 36. Streambank erosion at lower Packard Creek just upstream of the confluence with mainstem Whipple Creek.

Riparian areas and floodplains

Many stream reaches have vegetated floodplains and riparian buffers that are protected by steep hillslopes bordering stream valleys. This condition bodes well for Whipple Basin stream channels. If invasive species can be controlled, intact riparian areas have the potential to support the restoration of channel processes, aquatic habitat, and water quality.

Riparian forest vegetation

Probably the most ubiquitous condition observed in riparian areas is the lack of natural succession to mature native forest vegetation. In a healthy system, following clearing of timber through natural or anthropogenic disturbance, a natural succession of riparian forest vegetation will occur (Naiman et al. 1998). In non-wetland riparian areas, this includes initial colonization by 'invader' species such as willow, cottonwood, and alder. An alder overstory then persists for a few decades, allowing for undergrowth of shade-tolerant conifers. Conifers eventually replace the alder, completing the cycle to a new mature coniferous forest that provides stream shading, a source for instream woody debris, and bank stability.

In contrast to the pattern described above, we see a different process of succession that has followed the harvest of riparian timber in the early-to-mid 1900s. Essentially, natural forest succession has been interrupted by invasive species. Alders were able to re-colonize following harvest, but invasive species have prevented subsequent conifer growth. As a result, most riparian areas now contain sparse collections of alders at the tail end of their lifespan, with no young recruits of conifers or deciduous tree species. Blackberries or English Ivy have prevented the re-establishment of new seedlings and invasive species now form dense mats on the forest floor. Reed canary grass takes over in moister areas where vegetation such as bull rushes and Oregon Ash would have dominated. See Figure 37 for typical riparian conditions now found in the basin.

Figure 37. Typical riparian conditions now found in the basin (Left photo: blackberry dominated; Right photo: reed canary grass dominated).

The interruption of natural forest succession is exacerbated by channel incision. Incision reduces overbank flooding and channel migration; processes that are necessary to scour new surfaces for native seed germination. Incision also drains floodplain soils, which may allow blackberries to take over in place of wetland vegetation. Wetland vegetation, however, is dominated by reed canary grass in most areas. There are several examples where floodplain wetlands dominated by reed canary grass have been drained due to channel incision and are now dominated by blackberries (Figure 38). Blackberries also dominate where there have been intrusions into the riparian corridor (e.g. roadways, utility corridors).

Figure 38. Reed Canary Grass (in foreground) dominates this riverine wetland area. Himalayan blackberry becomes the dominant vegetation as one moves downstream as a result of incision that has drained the floodplain terrace. A headcut is located near the transition from Reed Canary Grass to blackberry.

Floodplain function

Floodplain function is limited throughout the basin by hydromodifications and channel incision. In several locations, abandoned stream crossings and remnant floodplain fill structures are limiting floodplain connections, limiting lateral channel movement, and are contributing to incision. These structures are located at a few locations along the mainstem, including near RM 4.2, RM 5.2, and RM 7.3 (Figure 39).

Actively used crossings are also limiting floodplain function in many locations, but these also provide artificial grade control that may limit additional channel incision. In many places, beaver dam complexes are enhancing floodplain function by aggrading sediments and providing connection of channels with floodplains.

Figure 39. Remnant floodplain fill spanning the floodplain near RM 7.3. The creek currently flows through a break in the fill.

Aquatic habitat

Aquatic habitat conditions would historically have been good in Whipple Creek, especially for fish that utilize small streams like coho, steelhead, and cutthroat trout. Habitat has been affected by a century of land-use and has probably improved considerably since the original phase of timber harvest and land clearing for agriculture. Land clearing would have altered flow regimes and increased fine sediment delivery. Riparian timber harvest would have reduced streambank integrity, reduced shading, and reduced large wood recruitment. As with many streams in the region, direct removal of wood from channels would have altered channel morphology and removed important fish habitat including pools and cover.

In the years following initial land clearing, conditions would have improved due to channel adjustment to the new sediment and flow regime and re-growth of riparian forests. In the 1970s, however, urbanization impacts began to create a new press disturbance on the landscape, and aquatic habitat is again at risk, with the potential for long-lasting effects. Aquatic habitat integrity generally declines with urbanization (Schueler 1994, May et al. 1997). The hydrologic, channel geomorphic, riparian, and floodplain processes discussed previously tend to reduce and simplify the habitats that are available for aquatic organisms. The presence of suitable substrates, pools and riffles, cover, cool temperatures, dissolved oxygen, and access to channel habitats can all become impaired.

Fish species presence

The specific extent of fish distribution in the basin is unknown. According to accounts from local biologists, cutthroat have been observed in the mainstem upstream of I-5 and steelhead have been observed in the mainstem near the Packard Creek confluence and in Packard Creek itself. A field visit on Dec 14, 2005 noted a potential coho redd in lower Packard Creek. The mainstem up to I-5, Packard Creek, and the lower quarter mile of trib W2.04 are all accessible to anadromous fish. However, given the lack of quality habitat in the mainstem above Packard Creek, anadromous use probably does not extend much beyond this point.

The species most likely to be present are coho, steelhead, and cutthroat trout. The stream is too small for any significant use by Chinook and although chum may have historically been present in low numbers in the lower mainstem, their poor status in the region suggests they are currently absent from the system. The numbers of all species are likely to be low because of lack of quality habitat.

Passage barriers

The I-5 and Union Road crossings likely obstruct fish passage on the mainstem. Passage through this area needs further evaluation. There are also barriers on several mainstem tributaries. One of the most significant is a perched culvert at an abandoned stream crossing about a quarter mile up trib W2.04. This stream contains good gravels and the basin is relatively intact, suggesting that opening up this barrier could provide access to quality habitat. Additional investigation into the extent of upstream habitat should be conducted. A damaged culvert at trib W4.09 may also be blocking access to suitable habitats. The extent and quality of habitat above this blockage also warrants further investigation.

There are many large, channel-spanning beaver dams on the mainstem and Packard Creek that could potentially limit fish passage. Some large beaver dams that remain in place year after year may warrant investigation for fish passage. The potential benefits of removing beaver dams to increase passage should be weighed against the potential impacts on channel and floodplain function.

Physical habitat availability

Field observations suggest spawning habitat is the greatest limiting factor for salmonids in the basin. Habitat is naturally limited due to stream sizes, topography, and substrate conditions. Human alterations have further limited available habitat through impacts to the sediment and flow regime, fish passage conditions, and channel degradation.

Rearing habitat in the form of beaver ponds is abundant. These areas provide important winter refuge for young coho. Studies on the Oregon coast have shown that winter rearing habitat is typically limiting for coho (Nickelson 1998). Whipple Creek, in contrast, contains scarce spawning habitat and abundant beaver pond habitat, suggesting that spawning is limiting. Compared to coho, steelhead rearing habitat is less abundant. Steelhead prefer to rear in higher gradient channels, where they can seek flow refuge behind structures (wood, substrate) while having quick access to adjacent high flow areas for drift feeding. Age-0 steelhead are likely to rear in their natal stream. Age-1 steelhead, due to their larger size and feeding requirements, are more likely to rear in the mainstem.

A quick gage of available habitat can be conducted by looking at stream gradient and channel type. Suitable spawning habitat for anadromous salmonids is typically located in pool-riffle or plane-bed channels with gradients less than 3% (Montgomery et al. 1999). In the Whipple Basin, channels below approximately 0.5% slope contain sand and silt substrate that is unsuitable for spawning. This leaves a few isolated areas where conditions are suitable. These include the mainstem between river mile 2 and 3, lower Packard Creek, and the lower end of trib W2.04. Other potentially suitable areas, such as trib

W4.09 and the mainstem above I-5 are isolated by passage barriers, but may contain suitable habitat for resident cutthroat.

The best habitat is located on the mainstem between river mile 2.4 and 3.2. This is a pool-riffle and plane-bed reach with suitable gradient and spawning gravels. Wood accumulations create pools, cover, and habitat complexity. Moderate-to-high shading is provided by relatively intact riparian canopies and by topography in some areas. The pasture reach downstream of RM 2.2 may have provided suitable habitat historically, but incision has lowered the gradient and simplified the channel.

The lower portion of Packard Creek also contains suitable habitat, although gravels are less abundant than in the mainstem. Pool-riffle sequences are interspersed with segments of lesser quality, where channel incision has degraded habitat complexity.

Trib 2.04, while small, contains abundant gravels that would be suitable for coho, steelhead and resident trout spawning. The lower few hundred feet, which courses through the low gradient floodplain of mainstem Whipple Creek, is deeply entrenched and would have to be evaluated for fish passage.

Water quality

Water quality data has been collected by Clark County at the Sara monitoring site on a monthly basis since May of 2002. This site is located on mainstem Whipple Creek just downstream of the intersection of NW 179th Street and NW 41st Ave. This dataset is the most comprehensive water quality data available for the basin. Clark County has used the Oregon Water Quality Index (OWQI), which incorporates temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia + nitrate nitrogen, total phosphorous, total solids, and fecal coliform bacteria. According to the OWQI, seasonal water quality has been either poor or very poor for the sampling period.

Consistently high fecal coliform levels (as much as 688 cfu/100mL compared to the state standard of 100 cfu/100mL) have been measured (Schnabel 2005). High fecal coliform is most likely related to failing septic systems, livestock waste, and storm sewer runoff. Septic drain fields for houses that sit atop stream valley hillslopes could readily transport bacteria to stream channels. Cattle and horse grazing occur throughout the watershed. Animal wastes enter headwater channels and road ditches during runoff events.

Nutrient levels (phosphorous and nitrogen) are also high. As with bacterial contamination, septic and livestock wastes can increase nutrients. Other potential sources include soil erosion and fertilizers.

Turbidity has been consistently high, with a median of 7.7 NTU and max values as high as 200 NTUs. The stream has also been observed to have a "hazy, slightly milky" appearance during baseflow conditions (Schnabel 2005). High turbidity during runoff events is expected, especially considering the amount of construction activities where bare soil is exposed and easily delivered to stream channels through the road drainage network. Turbidity during base flow periods has potential negative impacts on aesthetics, stream productivity, and salmonid feeding. Baseflow turbidity is most likely related to the high level of fine material in the streambed. Even during low flows, the stream is capable of mobilizing accumulated silts. Turbid conditions may be especially apparent at the sampling location due to the location downstream of the sand and silt-bedded middle mainstem reach.

Temperature at Sara far exceeds the state standard of 64°F; with 61 days exceeding the limit in 2004. Temperature impairment is most likely due to enlarged width-to-depth ratios and reduced baseflows. Beaver ponds are also likely contributing to heating. Impairment of riparian shade probably has a moderate effect, since most riparian zones have relatively good canopy cover.

Clark County has collected macroinvertebrate data to apply to the Benthic Index of Biological Integrity (B-IBI). Scores in 2001 and 2002 indicated low biological integrity and 2004 scores indicated moderate integrity. These scores are not surprising given basin conditions. Additional B-IBI measures in other parts of the basin, especially in less impacted catchments such as Packard Creek, and in different channel types, would provide good additional information for comparison.

Wetlands

Wetland types and function

Wetlands in the Whipple Creek Basin consist of riverine wetlands located within stream corridors and depressional headwater wetlands that are the source of 1st order channels. In some areas, slope wetlands may exist where hillside seeps empty into river valleys.

Wetlands are performing important roles in the basin. These include: 1) providing flood flow dampening, 2) collecting fine sediments, 3) providing storage of water to supply streams during dry periods, and 4) nutrient cycling and water quality filtering. These functions are critically important in the Whipple Basin, where degradation from land-use impacts is increasing.

A large portion of the mainstem floodplain is wetlands, especially where beaver dams increase the frequency of floodplain inundation. Riverine wetlands are also located on floodplain terraces supplied by hillslope seeps. In some areas, riverine wetlands are associated with remnant floodplain fill at old crossings or dam sites (see Figure 39). Depressional headwater wetlands are located at the headwaters of many 1st order stream channels. Historically, the majority of these channels may have originated at depressional wetland areas that have been drained and are now in agriculture or residential uses.

Current wetland mapping does not include all of the wetland areas in the basin. Mapped wetland areas include only those in the National Wetlands Inventory and those that have been mapped as part of permitting processes. A recent remote sensing study that models wetlands throughout the County (Clark County Public Works 2005) is a good start at identifying where previously unmapped wetlands may exist. Field mapping of wetlands would need to be conducted to develop an accurate inventory.

Wetlands at risk

Stream channel incision has put several wetland areas at potential risk of being drained from migrating headcuts that can deepen and widen channels, reduce groundwater levels, and favor invasive upland vegetation. One of the most susceptible of these areas is the mainstem headwaters upstream of RM 8.3, especially considering the additional development expected along I-5 in the northeast portion of the basin. This is an important groundwater recharge and storage area that helps moderate flows in downstream channels. Additional imperviousness here could result in loss of wetland function. A headcut just downstream of this reach, at RM 8.3, is currently moving upstream, incising through and draining adjacent floodplain wetlands (see Figure 40). There are a few other examples where headcuts pose a potential short-term risk of wetland draining. These include the headwaters of trib W7.06, trib W5.70, trib P1.06T O.49W, and trib P1.06T O.57NE.

Figure 40. View of incised channel downstream of headcut near RM 8.3.

A very high priority should be placed on protecting existing wetlands and efforts should be made to restore degraded ones. Off-site mitigation for development in wetland areas should be discouraged, as it is difficult to create functioning wetlands in areas that historically did not support them. Furthermore, stream channels and aquatic biota have adjusted to the hydrologic and water quality benefits of wetlands in their individual catchments; if new wetlands are created in other catchments to mitigate for filled ones, then stream habitat quality may degrade.

Anticipated trends

Insight into the future condition of Whipple Basin stream channels can be gained through past studies of channel evolution in response to land-use. The story in the Whipple Creek Basin is probably similar to the chronology that has been observed for other urbanizing streams. This includes a low level of sediment production during pre-settlement forested conditions, an increase to moderate levels during the period of agriculture, a dramatic increase during the construction phase, and a reduction to low levels once the watershed is built-out. A conceptual diagram of this process, which has been adapted from information in other reports (Wolman 1967, Booth and Henshaw 2001) is presented in Figure 41.

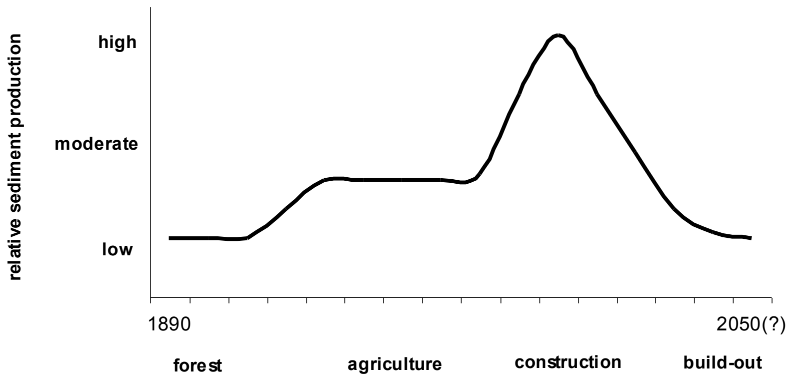


Figure 41. Conceptual diagram of estimated past, present, and future Whipple Creek Basin sediment production volumes.

Whipple Basin stream channels would have underwent adjustment to the initial forest harvest and land clearing for agriculture that occurred throughout the region in the early 1900s. It is probable that re-stabilization occurred following these initial impacts (some headcuts may date back to these initial impacts). Channels are now beginning a subsequent phase of adjustment to urbanization, which includes additional channel enlargement and sediment supply from construction activities. Most of this activity has occurred in the southeast portion of the basin. Based on zoning patterns, additional suburbanization is expected to continue to extend into much of the remainder of the basin (Figure 42).

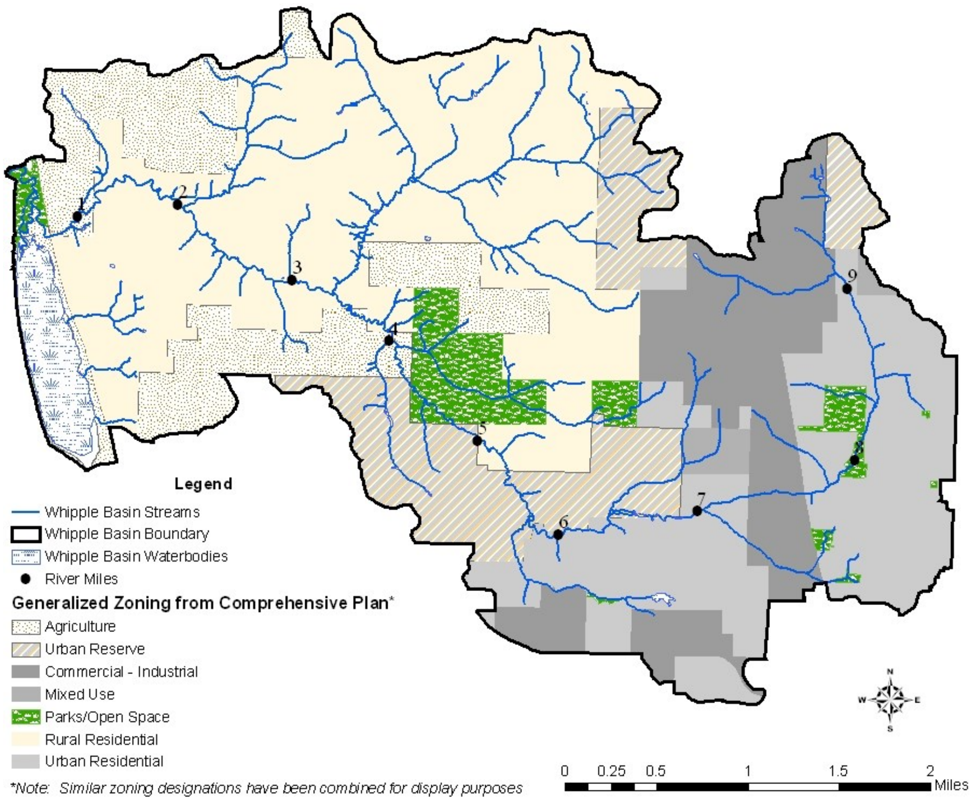


Figure 42. Generalized zoning designations from the Clark County Comprehensive Plan 2004. Original data obtained from Clark County GIS.

As a result, some of the largest impacts to channels may be yet to come. As has been seen already, the higher gradient, low order channels are most susceptible to rapid adjustment. Stream channel initiation points will continue to migrate up-valley (via headcuts) in headwater channels in order to adjust to greater runoff. Headcuts will eventually self-stabilize once their contributing basins are small enough. Lower gradient mainstem channels (response reaches) are more likely to widen because of sediment aggradation and lack of bed shear potential. Mainstem channels with sufficient gradient, lack of woody bank protection, and no natural or manmade hydraulic controls may be susceptible to incision through headcutting. Incision may more readily occur in higher gradient areas between RM 2 & 3 and above RM 7. Incision will be limited by stream crossings that provide hydraulic controls that will stop migrating headcuts. Incision may be accompanied by a coarsening of the bed, which can occur during the later stages of urbanization when fine material inputs from construction are reduced but there remain the higher transport capacities generated by the higher peak flows (Finkenbine et al. 2001).

As a result of future development focused in the upper third of the basin, impacts on downstream hydrographs may be particularly pronounced. A quicker time of concentration for flows from the upper basin may compound peak flows in the lower mainstem (see Runoff section, page 106). This may increase channel degradation unless adequate runoff controls are put in place.

Current floodplain function along the mainstem and Packard Creek appears to be only slightly-to-moderately impaired. The current level of impairment is a result of past land clearing and has been limited by beavers and by an influx of sediment from land-use activities. In mainstem and Packard Creek channels, if the stream undergoes additional incision it may no longer be able to access its floodplain during frequent flood events (1-5 yr events)

If wood is not recruited to channels and if there continues to be a shortage of coarse sediment, then instability will persist throughout the basin. Even though most reaches have riparian buffers, invasive species will likely prevent the establishment of coniferous riparian vegetation that is needed to provide long-term wood recruitment.

Once development in the basin slows, stream channels may continue to respond to the impacts of development for many years. This is due to a lag time for incision, where channel response to flow increases is masked by increases in sediment supply from construction. Once construction eases and the basin becomes built-out, sediment-starved channels may then begin to incise. This may occur a decade or more following build-out. Response reaches are likely to experience the greatest lag-times for incision. During construction, sediment is provided from hillslope runoff. Once development slows, sediment continues to be supplied from adjusting source reaches. Only after source reaches re-stabilize do response reaches begin to incise. Based on other studies in the Pacific Northwest, stream channels would be expected to re-stabilize to the new hydrologic regime within 10-20 years following build-out, but with reduced habitat quality characteristics (Henshaw and Booth 2000).

Monitoring and data collection

This section provides input to the County regarding monitoring efforts. The section begins with an overview of the different types of monitoring, potential monitoring objectives, and considerations for devising a sampling strategy. Following this are in-depth discussions of potential monitoring parameters organized into categories. It is recognized that the suite of parameters that is discussed is likely beyond the scope of the County monitoring program, especially for Whipple Creek. A subsequent section is therefore included that describes the subset of monitoring elements that should be considered greatest priority.

Types of monitoring

Baseline monitoring

Baseline monitoring typically occurs over a given period at the beginning of a monitoring program in order to identify existing conditions. Baseline monitoring can also assist with establishing cause and effect relationships between land-uses and stream conditions. Baseline monitoring is used as a comparison point for trend monitoring. Baseline monitoring will often encompass a broad suite of parameters at multiple locations in order to get a good handle on existing conditions. Follow-up trend monitoring is generally less intensive.

Trend monitoring

Trend monitoring is intended to characterize trends in watershed conditions over time. Trend monitoring is typically conducted at set intervals over a long period of time. Trend monitoring is often used to fulfill objectives of other types of monitoring. Trend monitoring in the Whipple Basin can be used to measure the effect of continued development on stream attributes.

Implementation monitoring

Implementation monitoring is designed to determine if activities are completed as planned. Activities may include development, erosion control or other activities that are intended to adhere to certain design and construction specifications. Monitoring can occur during and following implementation. Implementation monitoring in the Whipple Basin should be applied to residential construction activities, detention facility construction, facility retrofits, and ecological improvement activities. Implementation monitoring may also be applied to gauge progress with implementing the Stormwater Basin Plan. Periodic reviews can be conducted (at least annually) to ensure that tasks are being completed as specified.

Effectiveness monitoring

Effectiveness monitoring is intended to evaluate whether improvement projects, and potentially management activities, are having their desired effect. Effectiveness monitoring can occur at a variety of spatial scales, from evaluating reach effects from a single project to evaluating watershed effects from a suite of efforts across the basin. Effectiveness monitoring should be used in the Whipple Basin to gauge the success of stormwater controls as well as stream channel, water quality, and riparian improvement efforts.

Validation monitoring

Validation monitoring is used to test whether a particular model is accurately predicting stream or watershed characteristics. In the Whipple Basin, remote sensing evaluations of imperviousness and riparian cover should be “ground-truthed” through validation monitoring. The accuracy of erosion risk indices established through HSPF, HEC-HMS, or HEC-RAS should be evaluated through field validation monitoring.

Compliance monitoring

Compliance monitoring is aimed at determining if standards, such as Washington State water quality standards, are being met. Compliance monitoring can typically occur in combination with trend monitoring. Compliance monitoring is important in the Whipple Basin to ensure that streams are meeting established criteria.

Monitoring objectives

It is important to establish specific monitoring objectives. These help to frame the questions one wishes to answer with the monitoring program. Objectives will determine the type and extent of monitoring that is conducted. Potential monitoring objectives for the Whipple Basin and other Clark County watersheds are included in Table 15. The type of monitoring used to satisfy each objective is included.

Table 15. Potential monitoring objectives for the Whipple Creek Basin and the types of monitoring necessary to accomplish them.

Monitoring Objective	Monitoring Type
Establish the current status of water quality, flow conditions, and aquatic habitat	Baseline
Establish causal relationships between land-uses and monitoring parameters	Baseline and Trend
Monitor the impact of continuing but mitigated development on water quality, flow, and habitat	Trend
Ensure projects are completed to standards	Implementation
Determine the effect of improvement measures	Effectiveness
Determine if water quality and physical habitat standards are being met	Compliance
Determine if modeling efforts are accurate	Validation

As much as possible, objectives should be redefined as testable hypotheses. A discussion of potential hypotheses and other considerations for each monitoring type are included below.

Hypotheses for baseline monitoring might reflect assumptions regarding the current status of conditions and their causal effects. An example hypothesis might be "summertime water temperatures are elevated due to low riparian canopy cover". This hypothesis would lead to a particular suite of monitoring parameters and locations. Summer stream temperatures as well as canopy cover data would need to be collected. Sample sites would need to span reaches with a variety of canopy cover characteristics in order to establish canopy cover vs. stream temperature relationships.

Hypotheses for trend monitoring might reflect assumptions as to the impact of on-going development. An example might be "the frequency and magnitude of peak flows will increase as drainage area imperviousness increases". Sampling might include continuous stream gauging and periodic measures of watershed imperviousness. Because of the temporal variability in stream flows, a basin where imperviousness is not expected to increase could be used as a control.

Implementation monitoring may include monitoring of construction activities, monitoring of stormwater improvement projects, and monitoring the implementation of the Stormwater Basin Plan. Monitoring should make sure that appropriate tasks have been completed and that standards have been met. Short-term monitoring during the course of project implementation may be necessary to minimize adverse impacts on water quality and habitat. Formal hypothesis testing is not necessary as monitoring is simply intended to determine whether or not certain conditions are met.

Effectiveness monitoring hypotheses refer to the anticipated effects of single or multiple improvement efforts on watershed attributes. An example is "erosion control projects implemented in catchment A will decrease fine sediment concentrations in reach B". Sampling might include bed sediment sampling and turbidity measures both before and after the erosion control projects are implemented. Using the appropriate scale is very important for this type of monitoring. An erosion control project at the headwaters would not be expected to create measurable results at the mouth, but it may create measurable results in the reach immediately downstream of the project site.

Hypotheses for validation and compliance monitoring are somewhat implicit in the monitoring type. These types of monitoring are focused on determining whether or not a particular standard is being met or whether a modeling tool is accurately predicting stream characteristics.

Sampling strategy

The sampling strategy includes the spatial and temporal distribution of sampling. The sampling strategy will vary depending on the type of monitoring and the objectives. Considerations for sampling strategies in the Whipple Basin are included below under headings of monitoring type:

1. *Baseline monitoring*. Baseline monitoring occurs at a high frequency but over a short duration on the order of 1 to 3 years. Baseline monitoring should include water quality, physical habitat, and land-use monitoring. Baseline monitoring should be conducted at representative sites throughout the basin. Specific sites will be determined by the parameters being sampled. For instance, baseline water quality monitoring might occur at multiple locations throughout the basin, whereas stream habitat mapping might only be needed where fish use is expected. Sites may include those for trend monitoring plus others in order to make sure any major problems are detected at the outset. Results of baseline monitoring can be used to refine where longer term trend monitoring occurs. For instance, if a particular tributary basin shows a characteristic impairment, long-term trend sampling at this tributary may be desired.

   A stratified sampling strategy may be used to reduce the quantity of sites while still enabling measures to be extrapolated to other, similar areas for assessment and modeling purposes. Sites can be stratified according to physical characteristics (e.g. gradient, elevation, basin area, channel type, geology) and/or land-use characteristics (e.g. developed, rural, forested). Relatively non-impacted monitoring sites should be established as experimental controls; one at a minimum. A potential site in the Whipple Basin might be on trib W2.04, which has rural and agricultural impacts but is unlikely to experience urban development for some time. If no other suitable sites are available in the Whipple Basin, then other nearby watersheds could be used as controls.

   The water quality, flow, and macro-invertebrate monitoring conducted over the past 3 years at the Sara site has provided a good baseline at this location. The frequency of sampling here could now be reduced and baseline water quality and physical habitat conditions could be established at a few other locations in the basin. Potential additional sites include the mainstem mouth, mainstem at 11th Ave, mainstem above I-5, Packard mouth, and trib W2.04. A highly developed upper basin tributary could also be selected, such as trib W5.70.

2. *Trend monitoring*. Trend monitoring occurs at a low frequency but over a long duration. Trend monitoring should include water quality, physical habitat, and land-use monitoring. A good spatial distribution is needed to identify cause-effect relationships. Trend monitoring will occur at all or a subset of the baseline monitoring sites. Trend monitoring occurs over a long time period but sampling can be relatively infrequent, especially for physical habitat parameters that are not expected to change readily. Water quality monitoring might occur more frequently, potentially a few times a year.

   Monitoring should continue as trend monitoring at the Sara site, but water quality sampling frequency can be reduced. Three water quality sampling periods could be established, including a summer low flow sampling, a winter high flow sampling, and a flush flow sampling. The flush flow sampling would be timed to correspond to the first freshet of the season in the fall. This is typically when water quality is poorest due to suspension of surface contaminants that have accumulated during the dry period. Flow monitoring should be continuous at the Sara site and would ideally be conducted at one or two other locations. Flow monitoring will provide important information regarding the effects of development on watershed hydrology. Packard Creek may serve as a good control basin for measuring effects on flow. Physical habitat monitoring could occur once every few years in areas of potential fish use. Individual benchmark cross-sections could be established at other locations to monitor changes in channel form related to incision or aggradation. Macro-invertebrate monitoring could be conducted annually. An appropriate indicator season could be selected through review of existing data.

3. *Effectiveness monitoring*. Effectiveness monitoring occurs at a variable frequency over a moderate-to-long duration. The spatial scale will vary depending on the project or projects being evaluated. Monitoring for watershed-scale effects can be combined with trend monitoring. More localized effects of specific projects (i.e. reach-scale) will be monitored separately. The chosen parameters will depend on the parameters that are expected to change as a result of improvement measures or management activities. Statistical considerations include the establishment of a control reach or basin of similar conditions where restoration will not occur. Pre- and post implementation monitoring can also be conducted in order to evaluate project effects. See Roni (2005) for a comprehensive discussion of statistical considerations.

   Some of the current baseline and trend monitoring being conducted at the Sara site can serve as a baseline for monitoring the effectiveness of stormwater improvement measures at the subbasin scale. These include flow, macro-invertebrates, nutrients, and bacteria. Other metrics collected at the Sara site, such as temperature, dissolved oxygen, sediment, and physical habitat conditions, respond strongly to local drivers and therefore may not be appropriate indicators of changes at the subbasin-scale.

4. *Implementation monitoring*. Implementation monitoring is conducted at or near the project location over a short duration during and immediately following project implementation. A select number of parameters are collected, depending on standards that are intended to be met. Monitoring might also take the simple form of inspecting project elements to be sure they are conducted to standards. Out-year implementation monitoring may be important for projects that are designed to perform under a particular flow scenario, such as detention facilities that are designed according to a 2-year, 10-year, or other duration return interval.

   Implementation monitoring for the Stormwater Basin Plan should occur at least annually and could take the form of a status report that describes the tasks that have been completed and how progress relates to what was set forth in the plan.

5. *Validation monitoring*. Validation monitoring occurs infrequently in response to the need to validate particular assessment tools. The amount and spatial distribution of sampling will be determined by the tool being evaluated and statistical considerations. The accuracy of erosion risk modeling conducted in the Whipple Basin should be validated by measuring channel erosion at select sites in the field and comparing it to model outputs. Similar validation monitoring should

occur for impervious surface estimates, riparian canopy measures, wetlands, and other attributes that have been determined through remote sensing methods.

6. *Compliance monitoring*. Compliance monitoring is conducted as part of baseline, trend, and implementation monitoring. Monitored parameters can be compared to established criteria such as Washington State water quality standards. This monitoring is useful for determining whether stream reaches should be added or removed from the state 303(d) list of impaired water bodies. Parameters can also be compared to established thresholds for stream habitat quality, such as those identified in the NOAA Matrix of Pathways & Indicators (NMFS 1996).

Monitoring parameters and techniques

This section describes potential monitoring parameters and techniques to consider in the Whipple Creek Basin.

Water Quality

A comprehensive background on water quality parameters is not included here. There are many great sources for this information, including MacDonald et al. (1991) and OPSW (1999). Clark County has been conducting water quality monitoring at sites throughout the county for the past several years. The Whipple Creek Water Quality and Stream Health
Data Summary (Schnabel 2005) reports on the monitoring results for the past 3 years. Parameters collected at the Sara site on Whipple Creek (near the intersection of NW 179th Street and NW 41st Ave) include the following:

- Fecal coliform bacteria
- Ammonia + nitrate nitrogen
- Total solids
- pH
- Biochemical oxygen demand
- Total phosphorous
- Turbidity
- Stream temperature
- Dissolved oxygen

Water quality conditions have generally rated as poor for most parameters. Contaminant sources are discussed in the county report but a considerable amount of uncertainty exists regarding specific sources and their spatial location. While monitoring at the Sara site will be useful for long-term trend monitoring, additional monitoring sites will be necessary to identify sources. The monthly monitoring conducted at the Sara site could be reduced to less frequent sampling (see Sampling Strategy section, page 144) and additional sites could be added.

A site at the mouth would capture watershed-wide conditions. One or more sites along the mainstem (11^{th} Ave and/or Union Road) would provide good source identification. A site at the mouth of Packard Creek would allow characterization of the largest tributary basin and would be easy to conduct due to proximity to the Sara site. Sites on other tributaries might include trib W2.04, which would provide a control basin not likely to receive intensive urbanization; and trib W5.70, which is a highly developed basin with suspected sources of contamination.

Temperature data is especially important to evaluate suitability for salmonids. Continuously recording thermographs are easy to install in multiple locations and can be left throughout the summer. Sites for temperature monitoring could include those mentioned above as well as other sites potentially used by fish such as higher on Packard Creek and on the mainstem just above the pasture (near RM 2.4). Thermographs could be placed upstream and downstream of beaver pond complexes in order to evaluate the effects of beaver dams on stream heating.

The County identifies toxic/metal sampling as a potential data gap. Sampling for chemical contaminants is recommended in this basin due to stormwater runoff and agricultural practices (pesticides, herbicides). Because chemical contaminants are often transitory in the water column, soil sampling or sampling of tissues from resident fish is recommended. Many contaminants may be undetectable in soil or water samples but may bio-accumulate in fish tissue. Surface water sampling on the rising limb of the hydrograph during the first flush flow event of the season may capture contaminated runoff.

Hydrology

Stream gauging in the Whipple Basin is conducted at the Sara site. Continuous flow monitoring is important at this location in order to assess trends in watershed hydrology due to changing land-use. Continuous monitoring is achieved through a continuously recording gage with a stage-discharge relationship. A control basin for hydrology trend monitoring would enhance the ability to identify changes due to land-use. Packard Creek may be a reasonable control because its basin is poised to receive less development than the mainstem in the near-term. Flow monitoring here would also be logistically easy given the culvert near the mouth, easy access, and proximity to the Sara sampling site. Flows in the mainstem above the Packard confluence could be derived by subtracting out Packard flows. Runoff per unit watershed area of the mainstem and Packard could be compared over time to evaluate hydrologic changes from watershed development in the upper mainstem.

The upstream extent of perennial flow in the upper mainstem and many tributary streams is largely unknown. This information could be useful for tracking sources of water quality impairments or for identifying potential fish use. Surveys during summer baseflow could establish the extent of perennial channels. These could be monitored periodically over time to determine the effect of flow changes on baseflows.

The Whipple Basin is dominated by agricultural practices. Water withdrawals for irrigation or stock watering may affect flow conditions. It may be useful to conduct an inventory of withdrawal locations and a review of water rights status.

Physical Habitat

The County collected physical habitat data using EMAP protocols (Peck et al. 2001) at a reach just upstream of the Sara intersection in 2002. The EMAP protocol is similar to many others used by a number of agencies in the region and involves the measure of habitat types, large woody debris, sediment conditions, and riparian conditions. These are then compared to established thresholds to determine habitat quality. Conditions at the Sara reach were generally poor, except for fish cover and the overall quality of the riparian area (except for the abundance of invasive species).

Surveys of this type should ideally be conducted across a number of samples in order to obtain results that are representative of a variety of channel sizes and types in the basin. Information from a single reach can give spurious results if it is used to characterize general conditions throughout the basin. For instance, if this survey was conducted just downstream at the reach below the NW 179th St. crossing, conditions would likely appear more favorable for fish because of a greater quantity of coarse sediment and higher quality pool and riffle habitat. The different characteristics of these adjacent reaches are largely due to gradient, channel type, and gravel sources as opposed to impacts to the stream channel. It is therefore best to have habitat surveys conducted in representative reaches across a broader spatial scale.

Because of the low amount of suitable salmonid habitat in the basin, it may be reasonable to conduct surveys along the entire sections of suitable habitat. This would consist of the mainstem between RM 2.4 and 4 (the mainstem above RM 4 is a low-gradient sand and silt-bedded E-type channel that is not suited to typical habitat mapping surveys), the lower mile or so of Packard, the lower quarter mile of trib W2.04 and possibly the lower portion of trib W4.09. Rapid quantification of channel types (i.e. Montgomery and Buffington 1998) and habitat types (e.g. pool, riffle, glide, beaver pond) could be conducted along most of the length with more intensive sampling (pebble counts, riparian conditions, cover, etc) conducted at specified intervals. Less intensive protocols than the EMAP protocol include the Washington Timber Fish & Wildlife method (Pleus et al. 1999), the Oregon Department of Fish & Wildlife protocol (Moore et al. 2002), and the USFS Level II habitat inventory protocol (USFS 1999). Because each of these methods vary slightly in the way they measure habitat attributes, care should be taken to ensure that appropriate data is collected to fulfill the objectives of the survey. The more intensive EMAP method could be continued at its current site, with additional sites potentially added.

Habitat typing throughout the areas of potential anadromous use allows for a comprehensive understanding of the extent and quality of available habitat and can also be applied to evaluation tools such as fish capacity and population models. It is important that a measure of flow is recorded on the day of the survey because the size of channel dimensions and habitat units can change dramatically depending on flow levels.

Data should be collected in a format compatible with analytical tools. Many tools have slightly different data format criteria or metrics. A level of detail should be collected that is sufficient to serve many applications, allowing aggregation of data where necessary.

Instream flow evaluation may be informative because of the potential effects of land-use on baseflow levels. Summer rearing of stream-type salmonids (steelhead, coho) is often the life history bottleneck because of the lack of available habitat as a result of low flows. The degree to which low summer flows limit the size of available habitat (i.e. pools) can be an indicator of hydrologic affects on fish. Habitat measures at low flows over multiple years are needed to evaluate this impact.

Sediment/Erosion Risk

Substrate and channel erosion conditions have been pretty well quantified through County surveys. There is less information, however, on the future potential risk of channel erosion. Booth and Henshaw (2001) report that susceptible channels share the following characteristics:

1. Erosion-susceptible geologic substrate
2. Moderate to high gradient
3. Absence of natural or artificial grade controls
4. Water inputs via predominantly subsurface discharge, likely to be converted to surface (point) discharge in the post-development condition

County erosion prediction efforts

The County has conducted erosion risk modeling using HEC-RAS and HEC-HMS (White et al. 2005). HECRAS data was available for the mainstem. The HECRAS approach used flow rates from HECHMS and stream channel data to model flow velocities in HECRAS. Velocities were compared to thresholds for erosion obtained from the permissible velocities of soil types found in the basin. Soil types were obtained from the NRCS soils GIS layer. Based on dimensionless indices of erosion potential, high, medium, and low erosion risk areas were identified. The HECHMS approach used flow rate, channel slope, and soil velocity thresholds to develop erosion risk indices, also breaking out the risk into high, medium, and low. Each approach modeled natural, existing, and future conditions assuming full build-out of the watershed.

The HECRAS approach is more physically-based since it uses flow velocity, which is a function of discharge, slope, and channel dimensions. HECHMS, on the other hand, only uses flow rate and slope to develop the erosion function. The high, medium, and low ratings were developed independently for each approach depending on the range of index values obtained for the existing condition model. The ratings were not calibrated to each other or calibrated using field data. This may explain differences in the magnitude of the ratings between the approaches, especially considering that the HECHMS approach encompassed channels throughout the basin whereas the HECRAS approach only modeled the mainstem.

Potential enhancements to erosion prediction efforts

The County's modeling efforts represent a good start at assessing future erosion risk in the basin. Additional efforts are underway by the County to enhance erosion risk assessment using continuous hydrology modeling (HSPF) and calibration with field data. Other considerations include the following:

- Collect additional cross-section data to expand HECRAS-based erosion modeling to the remainder of the basin. Use flow data from HSPF.
- Incorporate field-measured substrate conditions into erosion risk modeling. GIS-based soil types are not in themselves sufficient to use in modeling stream channel substrate conditions. These need to be validated or ideally replaced with field-based substrate sampling. Bledsoe and Watson (2001) present a "bed mobility index" that incorporates substrate size into stability assessment. The index is defined as:

  $$S\sqrt{\frac{Q}{d_{50}}}$$

  where S is stream channel slope, Q is discharge, and d_{50} is the median bed material size.
- A comprehensive review of potential qualitative and quantitative approaches to predicting instability can be found in Doyle et al. (2000). Quantitative measures, while more data intensive, have more predictive power than qualitative measures. Quantitative measures include shear stress, excess shear stress (shear stress/critical shear stress), stream power, stream power per unit width, Qbf (bankfull recurrence interval), Qc (recurrence interval of Q required to mobilize sediment), and bankfull

flow per watershed area (compared to stable systems). Qc is considered the best indicator because it takes into account erosive forces (shear stress), resisting forces (substrate conditions), and hydrologic conditions (flood recurrence interval). Although it is data intensive, using this index in combination with a continuous hydrologic model could be instrumental in assessing the impact of urbanization-induced flow changes on channel erosion. The EMAP bed stability protocol used by the County at the Sara site may incorporate some of the parameters discussed above.

- Current modeling looks at the change in velocity of the 2 yr event (Q2yr). Using a more frequent flow, such as the half-year event (Q0.5yr) may be more appropriate because the Q2yr is close to (or possibly above) bankfull. If future condition modeling shows an increase in the Q2yr then velocities may actually level off because of bank overtopping. This is especially a concern since the future flows are modeled using the existing condition channel dimensions (i.e. they don't account for channel expansion). Using a lower magnitude flow might give a more accurate picture of the increase in erosion that results from an increase in flow magnitude.
- It may be informative to look at the change in flow pattern as an indicator of instability. Investigators doing work in the Puget Sound region have had success with TQmean, which is the fraction of time the mean annual flow is exceeded. Because of a reduction in stormflow durations, the TQmean is less in urbanized systems than in rural systems (Konrad et al. 2005). A lower TQmean has been shown to correlate with poor stream health (measured by B-IBI) and bed instability.
- Use sediment budgeting and transport analysis to look at the effect of increased or decreased sediment supply on the type of channel erosion at different locations (e.g. catastrophic incision vs. proportional widening).
- Calibrate and validate models with field data.
- The response of channels in undeveloped catchments can be compared to degraded channels to predict potential future channel form if the catchment were to become developed. Relationships would first need to be established between channel dimensions (e.g. width) and predictor variables such as drainage area, slope, imperviousness, soils/geology, and vegetation conditions. These relationships could then be applied to undeveloped catchments to inform management decisions (e.g. zoning) and improvement measures (e.g. grade control). Harvey and Watson (1986) established one such relationship termed the Area-Gradient Index (AGI). AGI is the product of drainage area and slope at a cross section. It has been found to correlate with channel width in channels that have already proceeded through the process of channel adjustment following incision. Such techniques could also be used to predict the potential future upward migration of channel initiation points that may threaten wetlands and cause severe erosion.

Tracking erosion conditions

Trends in channel incision should be recorded. Control points could be set up in various locations, ideally in a mix of representative channel types. These points could be as elaborate as cross-section surveys tied into a stable benchmark, or could be as simple as a single measure of thalweg elevation in relation to a stable benchmark. In many locations, existing culverts could be used as a stable benchmark from which to measure the elevation of a downstream thalweg point over time. This would be a quick and easy method of tracking incision or aggradation across the watershed.

Trends in headcut movement should be recorded. Many existing headcuts in the Whipple Basin have already been recorded as part of County surveys. GPS locations in combination with follow-up surveys could be used to determine their rate of movement. Site indicators can also be used to estimate headcut migration rates. For instance, the age of a tree growing near the elevation of the channel bed downstream of the headcut can be combined with the distance to the headcut scarp to estimate the maximum average-annual rate of headcut movement. Thus, an old tree located close to the scarp suggests a slow moving or potentially inactive headcut. It should be noted, however, that aggressive headcut migration may occur only during large storm events with no activity for intervening years.

Headcut risk should also be evaluated in consideration of the distance to an upstream hydraulic control that would halt headcut migration. Potential controls include culverts, bridges, grade control structures, or hardened channel beds. There are many hydraulic controls on Whipple Basin stream channels, primarily in the form of road crossings with culverts.

Riparian Conditions

As discussed previously, one of the greatest impacts to riparian areas is the effect of invasive species on riparian forest succession. Although conditions may appear relatively healthy with respect to canopy cover and tree density, a lack of young recruits of native trees is a concern for the future of riparian forests in the Whipple Creek Basin. Monitoring in riparian areas should be designed to capture this problem in addition to standard measures of riparian condition recorded during stream habitat surveys. Riparian forest surveys using vegetation plots or transect surveys could be used to identify stem densities, tree ages, and species composition. Both ground cover and canopy surveys could be conducted. Vegetation conditions can then be evaluated with respect to their ability to provide long-term riparian functions.

When evaluating riparian conditions and potential restoration strategies, a look at historical conditions can be helpful. The original General Land Office (GLO) surveys that date back to the late 1800s can provide information on historical conditions of riparian vegetation. GLO surveyors walked section and quarter-section boundaries, taking periodic measurements of trees to establish reference points for boundary and corner markers. The surveys are akin to the point-center-quarter method of vegetation surveying. The species, density, and size of trees are either directly recorded or can be inferred from the surveys. These data provide a glimpse into the historical condition of riparian areas. If desired, the surveys can be replicated to evaluate changes in riparian forest vegetation. GLO surveys also provide useful information on stream channel locations, especially for larger streams. GLO surveys can be found at the BLM regional office in Portland, OR, at regional university libraries, and will soon be available on the BLM website at www.blm.gov/or/landrecords/index.htm.

Fish and Macroinvertebrates

The extent of fish use of the basin is largely unknown. Presence/absence surveys would help to define species and extent. These could be conducted as redd surveys in spring (trout) and fall (salmon), and snorkel surveys, electrofishing, or seining for juveniles at various times throughout the year. Preliminary efforts could focus on late summer and mid winter surveys for coho and steelhead. Electrofishing or seining may be most appropriate because of water clarity issues.

Macroinvertebrate sampling has been conducted by the County at the Sara site and the B-IBI and other multimetric indices have been used to evaluate stream health (Schnabel 2005). To create an accurate picture of conditions throughout the basin, additional macroinvertebrate sampling sites could be established, ideally corresponding to sites where water quality and/or physical habitat surveys are conducted. Invertebrate sampling covering a variety of substrate conditions would provide an interesting comparison to conditions found at the Sara site.

Land-use monitoring

Land-use monitoring can be used to identify trends in land-uses, which can be correlated with physical and biological monitoring. Most land-use monitoring can be accomplished in an office setting, using remote sensing technologies that incorporate aerial photography, satellite data, and available GIS data. The following are potential parameters of interest, some of which have already been recorded by Clark County:

- Total impervious area (TIA) and effective impervious area (EIA) by catchment. These metrics can be compared to thresholds of degradation identified in other studies (e.g. Booth and Jackson 1997). Measures should be ground-truthed to ensure accuracy.
- Forest cover by catchment. This can be compared to thresholds of degradation (Booth and Jackson 1997).
- Road densities and drainage network densities.
- Population patterns and trends.
- Zoning patterns and expected future build-out.

Priority monitoring efforts

The entire suite of monitoring elements presented above is likely beyond the resources available to Clark County, especially for the Whipple Creek Basin. It is therefore important to select the subset of monitoring activities that will answer the most critical questions facing the county as they plan for future growth. A few of those questions are presented below. Following each question is a description of the monitoring parameters or techniques that can be applied to the question. These are organized in decreasing priority order:

1. Are current regulations and enforcement procedures protecting stream channels, wetlands, and riparian habitat?

   Current regulations are intended to be based on Best Available Science in order to protect key public resources. If the regulations or their enforcement are inadequate, then their intended objectives will not be accomplished. Based on observations in the Whipple Creek Basin, there are concerns with regulations/enforcement with respect to design, construction, and maintenance of stormwater detention facilities and storm system outfalls. Following inspection and approval, and sometimes following transfer of facility ownership to the County, erosion and sedimentation problems have occurred near and downslope of outlet/outfall locations, sometimes causing severe erosion in downstream stream channels. These observations suggest that more adequate implementation/compliance monitoring be conducted following construction and maintenance of facilities. This may include a detailed inspection protocol, additional training of inspectors, and measurements of hydraulic conditions extending into downstream receiving channels, which may include establishing elevation benchmarks from which channel bed elevations can be compared to over time.

2. What is the trend direction and rate of change in channel conditions throughout the basin?

   As discussed previously (page 150), trends in channel headcutting and incision can be tracked in a number of ways. A quick and easy method of tracking channel incision is to use existing stable benchmarks (i.e. culverts) to measure the change in channel bed elevation at a number of nearby points over time. Two surveyors, using even just a rod and a hand level, can record bed elevation at specified points (i.e. thalweg at a hydraulic control) downstream of culverts. The culvert invert could be used as the stable benchmark. This rapid and inexpensive monitoring technique can be conducted over time to track changes in channel bed elevation.

   Movement of headcuts, especially large ones at the upper end of 1st order channels, can be tracked using GPS or through reference to benchmarks. This may be more difficult in channels that are eroding via multiple small headcuts that are harder to identify and track over time. Photo-documentation can be used to improve field identification of headcuts for tracking over time.

3. Which channels are likely to continue to degrade given anticipated development patterns? What are the thresholds for degradation?

   Identifying channels susceptible to erosion can guide land-use planning and in-stream activities (i.e. placement of grade control). Current physically-based modeling efforts using HSPF, HECHMS, and HECRAS are expected to provide good estimates of current and potential channel stability throughout the basin. To support and help verify these modeling efforts, statistical relationships could also be established that predict channel response to land use. These relationships would rely on local empirical data from stream channels that have already undergone a response to urbanization. The observed response can be applied to non-urbanized basins to determine the potential for channel change given various levels of potential future imperviousness.

   Selection of predictor variables begins with consideration of the fundamental drivers of erosion, notably slope and some measure of flow condition (either depth – as in shear stress, or Q – as in stream power). Measures of slope are readily available through remote sensing procedures or through rapid field measures. Flow metrics are more difficult to obtain; however, drainage area and percent imperviousness can serve as surrogate measures of flow, especially when making relative comparisons among streams within similar climatic and geologic conditions. These metrics are easily obtained (and may exist already) through GIS analysis.

   Using space-for-time substitution, regression relationships are established between channel conditions (width and depth) and predictor variables (slope, drainage area, percent imperviousness) at sites covering a range of imperviousness. These relationships can then be applied to non-developed catchments to predict: 1) anticipated changes to stream channels as a result of changes in watershed imperviousness, and 2) threshold limits of imperviousness that should be avoided to prevent severe channel degradation.

Although several other factors should be at least qualitatively considered (e.g. channel boundary conditions, "effective" imperviousness, site conditions), such an analysis could be conducted with relatively little expense and would have the benefit of providing a channel stability prediction tool developed from local conditions. This tool could be developed from and applied to basins throughout the County.

4. What is the status and extent of salmonid use of the basin?

   Much of the emphasis on protecting stream channels stems from the need to protect habitat of sensitive aquatic species; most notably salmon and steelhead that are listed as 'threatened' under the Endangered Species Act. While salmon have been reported to use Whipple Basin streams, there is currently a paucity of information regarding their specific use and extent. Getting a better handle on fish use would help to inform management decisions. This could be accomplished through presence/absence surveys using seining or electro-fishing (Whipple Basin streams may be too turbid or too small to successfully conduct snorkel or redd surveys). Conducting a baseline stream habitat survey is also recommended in order to quantify the current quality and extent of useable habitat.

Monitoring reporting

An annual monitoring report should be a clear, concise, and consistent progress report. These reports should be kept to a minimum length to ensure that they are accomplished in a timely manner. After an initial template is established, subsequent years' data can quickly be added. Each report should have the same format as the previous year and should report past years' data as well as new data. Sections should be organized according to type of monitoring or the hypothesis being tested. Implementation or validation monitoring for specific projects do not need to be contained in the annual monitoring report. The annual report should be considered a source of data and information for basin planning efforts, other researchers, and for the interested public. Good examples of annual reports are the Oregon Department of Fish & Wildlife research reports (http://oregonstate.edu/Dept/ODFW/progress-reports/index.html).

Improvement measures

Objectives

Objectives for conducting improvement/mitigation measures should be explicitly stated; and realistic in the context of development trends. Recent reports by researchers and practitioners acknowledge the importance of project planning in a watershed context, with emphasis placed on maintaining or re-establishing physical, chemical, and biological processes in a holistic context, as opposed to focusing solely on opportunistic improvements of stream corridor structure at individual sites (Wohl et. al. 2005, Beechie and Bolton 1999). In support of this approach, Roni et al. (2002) present a hierarchical framework for selecting improvement measures. These measures are focused primarily on maintaining and re-establishing physical processes that support aquatic biota:

Hierarchy of restoration (from Roni et al. 2002)

1) protect functioning habitat
2) reconnect isolated habitats
3) Restore sediment and flow processes
4) Restore riparian areas
5) Stream channel enhancement

*increasing nutrients is also recommended where nutrient availability has been shown to be limiting.

Taking an urban stream-centric approach, which includes a dose of reality for what can truly be accomplished in urban streams, Schueler and Brown (2004) propose 9 watershed improvement objectives. They range in order of difficulty from things like stream clean-ups to recovering biological diversity and function. Limitations for each are given based on levels of watershed imperviousness. The objectives are included below, presented in order from easiest to hardest to accomplish. As watershed imperviousness increases, the potential for accomplishing elements toward the end of the list becomes more and more difficult.

1) Clean up stream corridor
2) Naturalize stream corridor
3) Protect threatened infrastructure
4) Prevent additional streambank erosion
5) Expand/reconnect stream network
6) Increase fish passage
7) Improve fishery habitat
8) Achieve natural channel design
9) Recover aquatic diversity and function

By combining the process-based objectives outlined by Roni et al. (2002) and the realistic urban stream objectives outlined by Schueler and Brown (2004), reasonable objectives for Whipple Creek can be developed. Objectives will vary by location in the basin, with an emphasis on protecting the best habitat, restoring recoverable habitat, supporting critical functions, and controlling for risks. This strategy is displayed well in Figure 43. This strategy ensures that resources will not be wasted on attempting to completely recover the natural function of highly developed streams, which can be an uphill battle. Instead, improvement measures will target basins with high potential. The only measures conducted in highly developed basins would be those that reduce risk to infrastructure or reduce risk to higher quality downstream channels. Table 16 lists potential objectives for areas of the basin. The areas are depicted in Figure 44.

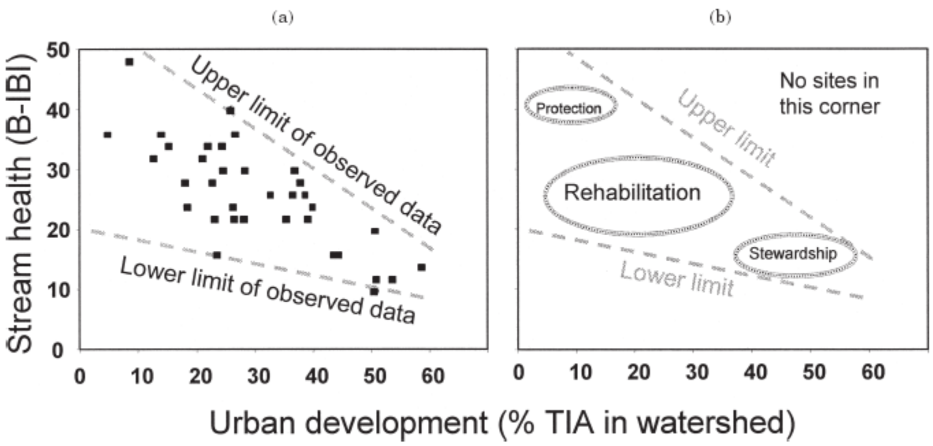


Figure 43. TIA related to stream health using B-IBI scores (a) and the objectives for management (b). Reprinted from Booth et al. (2004).

Table 16. This table lists potential management objectives for Whipple Basin Catchments based on past and anticipated land-uses as well as stream conditions.

Location	Objectives	Description
Currently developed catchments	• Address eminent risks of channel degradation	Prevent incision at high risk areas, such as where headcutting threatens wetlands or infrastructure
	• Retrofit facilities to adhere to performance standards	Ensure existing facilities are functioning properly and not causing channel degradation
	• Protect local recreation and aesthetics	Conduct stream cleanups and riparian and channel restoration to the extent necessary to facilitate public use, education, and appreciation
Central and upper basin catchments slated for additional development	• Address eminent risks of channel degradation	Prevent incision at high risk areas, such as where headcutting threatens wetlands or infrastructure
	• Implement development regulations/LID	Ensure that new development and associated facilities sufficiently protect watershed processes
	• Protect land through acquisitions/easements	Acquire land or development rights in sensitive areas, including stream corridors, wetlands, and aquifer recharge areas.
	• Retrofit facilities to adhere to performance standards	Ensure existing facilities are functioning properly and not causing channel degradation
	• Provide regional and stream valley flow detention	Assess the potential for use of regional facilities and provide flow detention and grade control in stream valleys in anticipation of increased imperviousness
	• Restore riparian function	Restore mature riparian vegetation through planting and control of invasive species in order to benefit stream temperatures, LWD, and bank stability. Controlling invasive species at this stage will be easier than after development.
	• Protect local recreation and aesthetics	Conduct stream cleanups and other measures to facilitate public use, education, and appreciation

Location	Objectives	Description
Lower Basin and Packard Creek	• Address eminent risks of channel degradation	Prevent incision at high risk areas, such as where headcutting threatens wetlands or infrastructure
	• Implement development regulations/LID	Ensure that new development and associated facilities sufficiently protect watershed processes
	• Conduct growth planning to protect watershed resources	Plan future growth and development to ensure adequate protection of natural resources. Packard Creek is relatively healthy and undeveloped and offers a great opportunity for watershed protection.
	• Protect land through acquisitions/easements	Acquire land or development rights in sensitive areas, including stream corridors, wetlands, and aquifer recharge areas.
	• Retrofit facilities to adhere to performance standards	Ensure existing facilities are functioning properly and not causing channel degradation
	• Improve fish passage at barriers	Assess and restore passage at barriers. Addressing fish barriers is low on the list because of the low severity of the problem in the Whipple Creek Basin.
	• Restore riparian function	Restore mature riparian vegetation through planting and control of invasive species in order to benefit stream temperatures, LWD, and bank stability. Fence cattle from riparian areas.
	• Enhance instream aquatic habitat	Restore channel structure and habitat through placement of woody debris, grade control, and streambank stabilization. Add spawning gravels in select areas in Packard Creek.

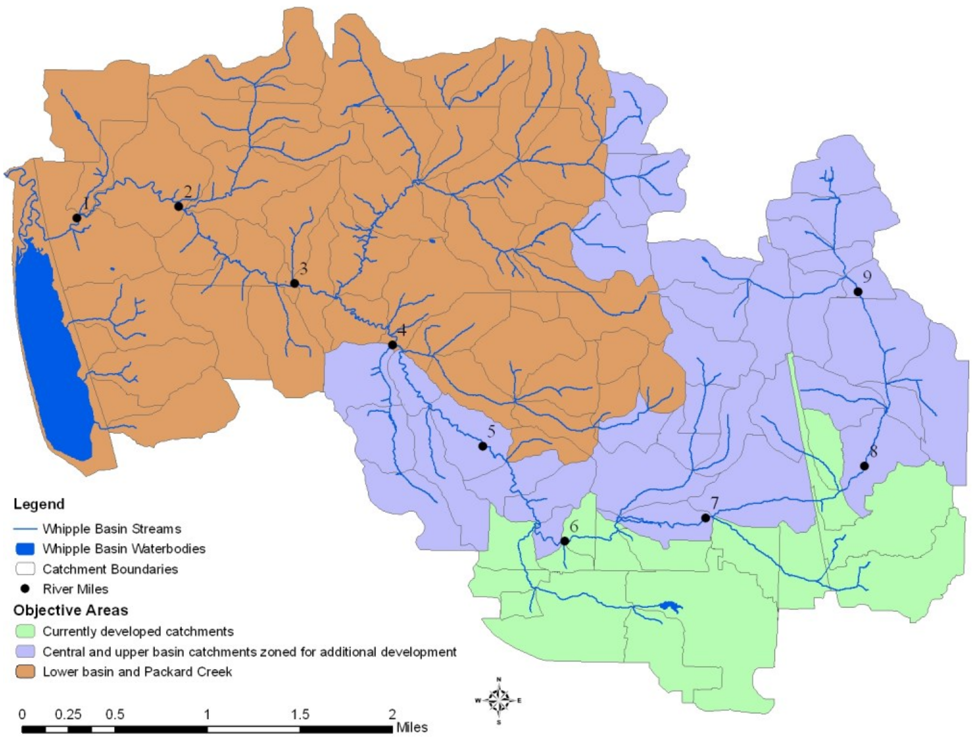


Figure 44. Map of Whipple Basin catchments highlighted according to the management objectives included in Table 16.

Potential preservation areas

An ounce of prevention is worth a pound of cure. Preventing degradation before it occurs is the most effective and cheapest method of managing for watershed impacts. Preservation occurs through a number of means, including land-use regulations, set-asides, and easements. Protecting intact areas that are providing important benefits is the best approach.

Potential preservation areas include the following, with a brief discussion of each:

- Mainstem above Union Road – this area is slated to receive intensive development because of its proximity to I-5. The uppermost portion of this area contains headwater wetlands that provide important wetland habitat and infiltration storage.
- Packard Basin – the basin is largely agricultural but the headwaters lie within the Urban Reserve. Limiting future development here will help protect basin-wide watershed processes that affect important salmon habitat in lower Packard Creek.
- Trib W2.04 – this relatively intact and forested basin has very little intensive development. Protecting basin-wide watershed functions will support quality habitat for salmonids in the lower reaches and in lower mainstem Whipple Creek. This basin

could serve as a potential experimental control with which to compare to basins with greater development.

- Stream corridors – current regulations are likely adequate to protect stream corridors from intensive development, but intrusions for roads or utility corridors may still occur. These intrusions favor invasive species and should be avoided or conducted to adequately control for invasive species colonization.
- Wetlands – adequate protections should be provided for all existing wetlands because of their important hydrologic and habitat attributes. Mitigation for their removal often does not adequately replace their function.

Adequacy of existing regulations

Several interrelated County ordinances and programs protect natural resources and habitat. Most of the applicable ordinances are in Title 40 of the Clark County Code. Ordinances and programs include the Stormwater and Erosion Control Ordinance, the Wetlands Protection Ordinance, the Habitat Conservation Ordinance, the Floodplain Management Ordinance, the Geologic Hazard Areas Ordinance, the Critical Aquifer Recharge Area Ordinance, the Water Quality Ordinance, the Shoreline Master Plan, SEPA, ESA, and others. In general, the programs provide important protection of natural resources and habitat conditions in the Whipple Creek Basin. However, field observations suggest that in some cases the regulations may not be fully accomplishing their intended objectives.

The Stormwater and Erosion Control Ordinance (Clark County Code Chapter 40.380) is intended to minimize erosion from land development. This ordinance specifies stormwater-controls, such as detention facilities, for land-use development activities. Standards set forth in the ordinance ensure that the County's stormwater requirements are compatible with the WA State Dept. of Ecology Stormwater Management Manual for Western Washington (2001). Compatibility with this manual is a requirement of the County's NPDES permit. Two of the 10 stated purposes of the ordinance are to: 1) "prevent surface and groundwater quality degradation and prevent erosion and sedimentation of creeks, streams, ponds, lakes, wetlands and other water bodies", and 2) "minimize erosion and control sediment from land development and land-disturbing activities". Despite the intent of the ordinance, several detention facilities and stormwater outfalls are contributing to erosion, in a few cases as severe as 10 foot headcuts in headwater stream channels (see pages 119 and 163 for location information). Erosion is due to either a lack of proper location of outlet, lack of proper flow control to the outlet, a lack of proper lining of the outfall location, or some combination thereof. Current facility construction standards or their review/enforcement appear to be unable to provide adequate protections necessary to fulfill the intent of the regulations.

Implementation of a more stringent review/inspection process would help ensure that facilities are constructed properly and that detrimental impacts to receiving waters will be avoided. Greater attention should be given to the placement of outfall locations and the configuration of outfall channels and lining. Proper lining using rock or geotextile is often necessary to prevent erosion. At some facilities observed in the Whipple Basin, protection of the outfall location ends at the riparian buffer boundary, presumably because of stringent riparian protections. Severe erosion of riparian soils has occurred as a result. To prevent erosion, outfall channel protections should extend at least down to existing stream channels in areas of potentially unstable geology and erosion hazard. An exemption from riparian/shoreline protections may be needed to allow for erosion control features.

A potential means of ensuring proper facility function is to establish long-term agreements with developers responsible for facility construction. Such agreements would be of sufficient duration (minimum 10 years) to allow for the evaluation of facility performance under a variety of storm conditions. During this period, if the facility fails to function properly, upgrades or maintenance would be the responsibility of the developer. An alternative option would be to require a reserve of funds to be placed in escrow for a number of years. These funds would be used for upgrades or maintenance as needed. The funds would be returned to the developer if the facility functions properly over a given timeframe.

In addition to erosion features at discrete outfall/facility locations, erosion throughout the stream network suggests that stormwater controls may not be sufficiently offsetting development impacts. This may be due to a number of reasons, including: 1) accumulation of impacts from small-scale activities that do not trigger stormwater controls, 2) impacts from development that occurred prior to stormwater regulations, or 3) inadequate standards, regulations, or enforcement. Another contributing factor to channel erosion may be the lack of infiltration and deep storage of stormwater. This process has the effect of re-distributing flow from the dry period (base flow) to the wet season. This has the effect of increasing the erosive capacity of wet-season flows. Providing stormwater retention (infiltration) is recommended where feasible. Infiltration is most successful as a source control.

As discussed in previous sections, some wetland areas throughout the basin are at risk from migrating headcuts that can incise channels and drain wetland complexes (see page 137 and 165). Although one of the stated purposes of the Wetland Conservation Ordinance (Clark County Code Chapter 40.450) is to “further the goal of no net loss of wetland acreage and functions”, there are currently no standards that specifically address the problem of wetland draining via channel incision. Furthermore, small and lesser quality wetlands are exempted from protections of the WCO. The cumulative effect of exempt wetlands may have a significant effect on hydrologic, water quality, and habitat conditions.

The abundance of invasive plant species is a major concern with respect to recovery of healthy riparian zones. Addressing this issue through the Habitat Conservation Ordinance (Clark County Code Chapter 40.440) may provide some benefit. As discussed on pages 131 and 169, invasive species tend to establish as a result of disturbance to riparian forests, including relatively minor perturbations such as clearing for utility corridors and lawns. In some cases, providing a foothold for invasive species to establish may be more harmful than direct removal of native vegetation. This is because invasive species can prevent the re-growth of native species for long periods and can also readily colonize adjacent areas. To address this issue, the HCO could require those conducting riparian vegetation clearing to ensure they do not favor invasive species or to control for them if they do become established.

In addition to the specific observations listed above, it should be noted that existing regulations do not require improvement measures except as mitigation for a potentially degrading activity. Thus, requirements are not expected to improve conditions beyond their current status, but instead are geared towards preventing additional degradation. In most cases, conditions will not improve unless proactive restoration measures are implemented.

Specific applications and design considerations

This section describes potential improvement strategies and locations. These strategies represent applied approaches to accomplish watershed improvement objectives. Conceptual designs and example photos are provided for some of the approaches.

Stormwater facility type and location

Considerations

- Local facilities (as opposed to regional facilities) require the least amount of infrastructure and are better suited as infiltration facilities because of spatially distributed groundwater recharge
- Local facilities should be sited such that outflows return to stable channels ideally at the downstream end of the drainage area being developed
- Regional facilities have the benefit of better oversight for design, construction, and maintenance compared to local facilities
- Regional facilities can be designed to accommodate stormwater from small developments that are not required to provide detention
- Must be cautious with regional facilities because of re-distribution of water from one portion of the basin to another. Discharges from facilities may overwhelm channels and alter basin hydrographs. Facilities should be located and configured to avoid inter-basin transfers of water. Even inter-catchment (tributary basin) transfers should be minimized to avoid overwhelming channels with extended flow durations that channels may not be able to withstand.
- Regional facilities should be sited such that outflows are received in stable channels, ideally in the mainstem or large tributary channels. If necessary, conveyance to stable channels may be best accomplished through piping.

Locations

- Locations for local facilities will depend on local development patterns
- Five potential locations for regional facilities are listed below. Their general locations are displayed in Figure 45. The first four sites are located in areas that are currently rural residential or agriculture but where future intensive development is expected based on proposed zoning. If regional facilities are utilized, these four sites should be considered high priority in order to protect existing conditions in catchments that are currently relatively undeveloped. The remaining two sites (5 and 6) are located in areas that are currently densely developed but that are showing signs of continued channel erosion from storm flows. Placement of regional facilities in these locations would augment existing local detention facilities in order to further protect stream channels from degradation. The following list can be regarded as being in rough priority order based on professional judgment in consideration of the indicated factors:
    1. West side of the upper mainstem near RM 9 (NE 179th Street). This location would accommodate the future anticipated commercial and residential development in the mainstem headwaters and protect important headwater wetland storage. The outfall would ideally be located in the mainstem downstream of the confluence with Trib W9.14.

2. North of the middle mainstem between RM 5.5 – 7. This location could receive stormwater from areas of greatest anticipated development in the upper third of the basin. Public land in the area could potentially be utilized. Outflow could be routed to the mainstem to reduce tributary impacts, or ideally, could be disbursed to the mainstem and Trib W4.09 according to area serviced by the facility.
3. Headwaters of Packard Creek. A portion of the eastern headwaters of Packard Creek is located in the Urban Reserve. Packard channels have recovered well from historical land-use impacts and the basin remains largely unaffected by recent development. New development without adequate stormwater detention will re-initiate channel erosion.
4. South side of middle mainstem near RM 4. This location could serve development expected in the Urban Reserve in the Trib W4.00 drainage. Outflow could potentially be routed to the mainstem below the confluence with Trib W4.00.
5. Headwaters of Trib W5.70. This area is nearly built-out, with the exception of areas along the stream corridor of Trib W5.70 up to the headwaters. Channel erosion is occurring through headcutting. Erosion and flooding from future runoff events could be minimized through placement of a regional facility in this area.
6. Headwaters of Trib W7.06. This area is nearly built-out, with the exception of isolated undeveloped areas that are likely to be built-out soon. The northern fork (W7.06 T0.74N) contains an old facility that could potentially be retrofitted as a regional detention facility.

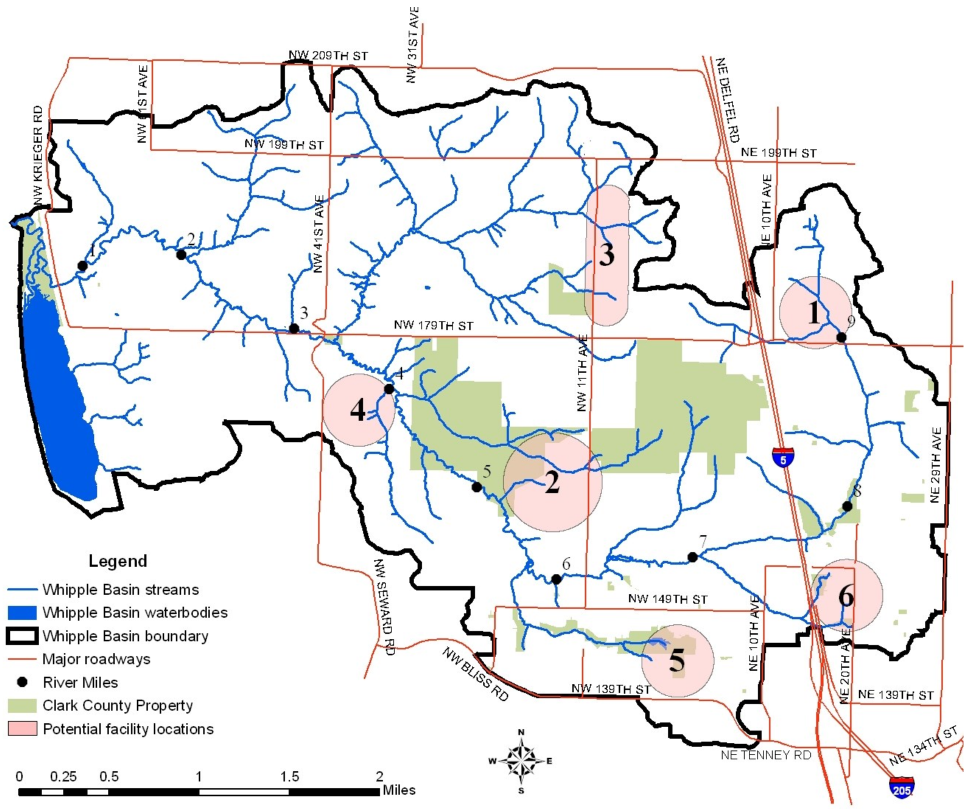


Figure 45. Potential locations for regional stormwater detention facilities. Numbers refer to the list and description of locations in the Stormwater facility type and location on page 161.

Stormwater facility design and retrofit

Considerations

- Erosion is caused by improperly designed and located detention facility outflows and other outfalls.
- All existing or new outfalls should be designed to prevent erosion on receiving hillslopes and in downstream channels.
- Outfalls should ideally be routed to stable channel locations
- Parallel piping can be used to route outfalls to downstream, stable channels.
- Rock can be used to stabilize outfall locations. Incidences of erosion even with use of rock indicate that proper lining is necessary to ensure stability.
- Riparian buffer protections should not preclude routing outfalls to channels where potentially unstable geology and erosion hazards exist.
- Use site infiltration where possible (recharge basins, retention facilities)
- Maintenance agreements or monetary set-asides can be utilized to ensure performance of stormwater facilities over a range of storm conditions.

Locations

- Retrofit facility at Whipple Place subdivision on trib W6.26. Concentrated flow on hillslope near facility outfall is causing severe erosion. Consider routing flow to the nearby mainstem. Stabilize eroded area.
- Retrofit facility at Fairgrounds to ensure that parking lot runoff enters facility properly and that outfalls are not continuing to erode channels. Stabilize existing two headcuts located in valley below facility (headwaters of trib W6.44).
- Retrofit facility at headwaters of trib W8.36 to ensure that channel erosion does not continue. Stabilize exiting headcuts.
- Other facilities and outfalls with similar problems have been identified by Clark County but were not surveyed as part of this effort.

Low impact development

Considerations

- Low impact development (LID) is an approach that manages rainfall at its source through distributed micro-scale controls. Controls are implemented at the lot-scale as opposed to at the sub-division or regional-scale.
- LID techniques include: bioretention ponds, infiltration of roof runoff, infiltration trenches, conversion of ditches to swales, ditchline disconnect from stream channels, pervious pavement, and others.
- LID techniques should be required or encouraged at new developments.
- See http://www.epa.gov/owow/nps/lid for more information

Locations

- entire basin, especially in areas of high density development

Channel grade control

Considerations

- Potential applicability to many Whipple Basin stream channels
- Grade control via headcut revetment is described in a separate section below
- Restoring channel incision once it has occurred is very difficult
- Grade control structures can be placed in incising channels to halt incision or in channels where incision is anticipated.
- A variety of weir-type structures exist that use combinations of logs, rocks, or other materials. Typical terms to describe configurations include weirs, sills, vanes, drop structures, step-pools, and boulder clusters. See Saldi-Caromile et al. (2004) and Schueler and Brown (2004) for comprehensive reviews and design concepts.
- Depending on stream size and type, hydraulic and geomorphic investigations should be conducted to ensure that structures do not limit natural channel dynamics.
- In small channels, sequences of sediment check dams may be used to trap sediment and raise the elevation of the channel bed. These are best in small, flat streams with high sediment loads. There may be a few potential locations in 1st order headwater channels, especially those impacted by agricultural practices.

Example

- See Figure 46 for an example photograph

Figure 46. Series of rock steps installed for channel grade control, Tower Brook, Chesterfield, MA.

Locations

- Mainstem upstream of Union Road (RM 7.82) (could be addressed through valley-spanning log jams – discussed below)
- Mainstem near the Packard Creek confluence (can be combined with LWD installation – discussed below)
- Mainstem near RM 2.4 (upper pasture – could be combined with LWD installation – discussed below)
- Other incision-prone areas (see methods for determining incision-prone areas on page 148). These may include streams in basins slated for new development, including tribs W4.00, W4.09, W6.44, W7.06, W7.82, W8.36, W8.5, W9.14, W9.31, and the mainstem headwaters.

Headcut revetment

Considerations

- Headcuts may represent an eminent risk of channel degradation that could threaten floodplain connections and wetland function.
- The likelihood, rate, and extent of continued headcut progression can be evaluated through consideration of basin conditions, stream energy, and location of hydraulic controls (see page 148 for methods of determining risk).
- The risk of continued headcutting and a determination of what’s at risk (i.e. wetlands, floodplains, infrastructure) should be used to prioritize locations.
- Headcuts in low order channels can be stabilized readily through rock and/or log revetments. Rock is cheapest alternative.

- Placement of a distribution of rock sizes (well-graded), ranging from an armor layer to readily transportable sizes, can increase stability of headcuts while providing a source of coarse sediment to be transported by the stream to downstream areas over time. Channel type and processes must be considered.
- An appropriate lining should be used to ensure erosion does not undermine structure.
- Headcuts greater than 4 or 5 feet should be pulled back to a stable grade to reduce the amount of required revetment material. Smaller cuts can be treated with a wedge of rock placed at the structure.
- In areas where a more natural look is desired, logs could be incorporated into revetment structures.

Design concepts

- See Attachment A – Sheet 1
- See Figure 47 for an example photograph

Figure 47. Series of rock grade control/headcut revetment structures placed in Oak Creek, Portland, OR

Locations

- Headwaters of trib P1.06 T0.57NE (potential risk to wetland)
- Headwaters of trib W5.70 (potential risk to wetland)
- Headwaters of south fork of trib W7.06 (potential risk to wetland)
- Mainstem at RM 8.3 (potential risk to floodplain/wetlands)
- Headcuts associated with detention facilities mentioned on page 163
- Other headcuts identified through Clark County surveys.

Large woody debris – valley jams

Considerations

- Large, floodplain-spanning jams can be used in 1^{st}-3^{rd} order channels to detain flood waters and provide valley-wide grade control in anticipation of increased runoff from developing areas.
- Structures can provide stormwater detention in excess of that provided by detention facilities at sub-divisions.
- Structures can be placed sequentially to backwater entire channel segments during large runoff events, thus reducing channel erosion.
- Structure porosity can maintain fluvial segments between structures at the majority of flow levels where channel erosion is unlikely.
- Structures can make use of existing geology or existing hydromodifications to construct structures.
- Structures would be most effective in 1^{st} – 3^{rd} order channels. The necessary size would be prohibitive in the mainstem below RM 6 or 7.

Design concepts

- See Attachment A – Sheets 2 & 3

Locations

- Upper mainstem above Union Road – good location for a sequence of jams (see example drawing in Attachment A – Sheets 2 & 3).
- Mainstem below I-5 (approx. RM 7.3). Existing floodplain fill from an old crossing here could be utilized
- Trib W9.14 – good location in anticipation of greater development in the upper mainstem.
- Trib W6.44 – good location in anticipation of greater development in this catchment. According to County survey, may be some existing fill from an old road crossing that could be utilized.

Large woody debris – channel and habitat enhancement

Considerations

- Large woody debris structures can provide grade control, increase floodplain function, provide gravel retention, create pools, and enhance aquatic habitat structure.
- Focus on re-creating 'forced' channel morphologies that historically existed. Goal is to provide roughness, create pool-riffle or step-pool morphologies, and enhance cover and habitat complexity. Structures may increase overbank flows where existing channel incision is not severe.
- Wood should be placed in floodplains in combination with stream channel LWD projects. Wood in floodplains can accomplish the following: 1) increases floodplain roughness, which can reduce frequent channel avulsions, 2) increase localized scour of floodplain depressions and overflow channels, increasing complexity, 3) provide a source of in-channel LWD in the event of stream channel re-location, and 4) provide slow water refuge sites for fish during large flood events.
- Gravel supplementation could be included as a component of large wood projects where there is potential fish use and where the channel hydraulics are appropriate.

Design concepts

- See Attachment A – Sheet 4
- See example photos in Figure 48

Figure 48. Large wood complexes installed for streambank protection (left, Kelley Creek, Portland, OR) and for habitat enhancement (right, side-channel of Clackamas River, OR).

Locations

- Mainstem near Packard Creek – This area is incised and simplified. Wood structures that build grade, protect banks, and add complexity could provide benefits to fish and water quality (see example for this area in Attachment A – Sheet 4).
- Mainstem below NW 179th Street crossing – this area has a low floodplain terrace (large residential yard) that could be reconnected to the stream with log structures providing grade control. Protection of roadway embankment could be included.
- Lower mainstem in upper pasture area (near RM 2.3) – this area is highly incised and unstable and is completely devoid of large wood. Wood is necessary to speed channel adjustment, build grade, and provide habitat complexity for fish.
- Lower Packard Creek – much of the wood now spans above the channel. Wood placement would enhance channel adjustment processes and create habitat complexity for fish.
- Trib W2.04 – the lower portion is entrenched into mainstem floodplain deposits. Channel reconstruction and wood installation could enhance its use by fish. A good gravel supply is available.

Fish passage

Considerations

- Fish passage is potentially limited by road crossings at a number of locations.
- Fish passage barriers at some crossings may not be worth restoring because of poor habitat quantity or quality above the barrier.
- Beaver dams may limit passage at some flows, but dam removal may not outweigh the geomorphic benefits of dams.

Locations

- An abandoned crossing with a perched culvert approximately 1,000 ft up trib W2.04 may be the highest priority barrier. Additional investigation is needed to evaluate flow conditions for passage in downstream areas as well as the extent and quality of potential habitat upstream of the barrier.
- There are a few potential passage issues on the mainstem including NW 11th Ave crossing, I-5 crossing, and Union Road crossing. These crossings should be evaluated together because suitable spawning habitat is unavailable until the I-5 crossing. Thus, passage improvement at only one site may not open up any additional habitat.
- Trib W4.09 – damaged culvert at mouth. The quality of upstream habitat should be investigated.
- Passage at Packard Creek at NW 179th crossing appeared to be suitable during Dec 05 – Jan 06 surveys. However, other investigators have noted passage issues here. Year-round passage conditions warrant further investigation.

Riparian restoration

Considerations

- Control invasive species and promote establishment of riparian conifers (Douglas fir, western hemlock, western red cedar) throughout the basin. Conifers will provide long-term wood recruitment, shade, and bank stability.
- Invasive species are preventing the natural succession to a coniferous riparian forest in many locations. Invasive species are also preventing the growth of new deciduous species such as Oregon ash, bigleaf maple, and alder.
- Plant conifers of sufficient size and provide follow-up management to control for impacts of invasive species and beavers. Planting fewer, large conifers that can extend above the blackberries may be the best approach for long-term success.
- Moist areas with frequently inundated soils tend to be overrun with reed canary grass. Restoration of tree species can be attempted in these areas by selectively removing the reed canary grass and planting ash, alder, and maple, with western red cedar in drier, shadier spots.
- Eradication of reed canary grass is difficult, and for large patches, requires aggressive long-term treatments (see http://tncweeds.ucdavis.edu/moredocs/phaaru01.pdf for more information).
- Drier sites are often dominated by blackberries. Restoration in these areas can be accomplished by selectively removing patches of blackberries and planting trees of sufficient size (6-8 feet) to get above the blackberries.
- In floodplain areas that are infrequently inundated and currently have an open deciduous canopy, alder, big leaf maple, and Douglas fir can be planted, with western red cedar in shaded spots.
- In dry sites with no floodplains and moderate canopy cover, cedar, fir, and hemlock can be planted.
- Willows, dogwoods, spirea, and other ‘invader’ species that rapidly propagate from cuttings can be planted directly on eroding streambanks.
- Restoration of riparian vegetation will require continued annual maintenance to ensure success.

- Fencing cattle from streambanks could significantly improve riparian and channel conditions in a few locations.
- In a few locations, residents could be approached for restoration of riparian areas where lawns have been maintained up to the channel boundary.

Design concepts

- See Attachment A – Sheets 5, 6, & 7
- See example photos in Figure 49


Figure 49. Riparian re-vegetation on Salmon Creek, WA. Photo taken 6 months after planting (left) and 10 years after planting (right).

Locations

- Entire basin.
- Riparian restoration should be conducted following any restoration actions that involve riparian disturbance.
- Focus should be placed on mainstem reaches and major tributaries that have perennial flow in order to control summertime stream temperatures important for juvenile salmonid rearing.
- Cattle fencing could be conducted on the mainstem at the pasture area near RM 2 and on Packard Creek (P1.23).
- Maintained lawns that extend to the channel are located on the mainstem near RM 2.4, downstream of NW 179th St., near RM 5.7, near RM 7.1, and at other mainstem and tributary locations.

Gravel augmentation

Considerations

- Gravel supplementation and retention projects could increase spawning habitat.
- Gravel supplementation should only occur where hydraulic and geomorphic conditions can maintain clean gravels on the channel bed.

Example

- See example photo of gravel installation (Figure 50)

Figure 50. Conveyor placing substrate (cobbles and gravels), Ruby River, Montana.

Locations

- Gravel supplementation could be beneficial in Packard Creek, where there is sufficient stream power to periodically move and sort coarse material and wash out fines. There is also enough woody debris to trap and sort material. There is currently a low source of gravel.
- Whipple Creek above Union Road also has geomorphic conditions that would support gravel augmentation, but it is doubtful whether anadromous fish could pass through the middle mainstem, I-5 culverts, and Union Road culvert to access this area for spawning.

Hydromodification removal

Considerations

- In some areas, remnant floodplain fill from old or abandoned crossings may be inhibiting floodplain function. Removal of these hydromodifications can increase stability and function of channels/floodplains.
- Other potential hydromodifications that should be considered for removal include hardened bank protection features (e.g. rip-rap, rock spurs) and large inorganic debris in channels (i.e. concrete blocks).
- Some of the sites listed below are also included as potential locations for fish barrier removals.

Example

- See example of hydromodification removal (Figure 51)

Figure 51. Removal of concrete weir in Johnson Creek, Portland, OR.

Locations

- Mainstem at approx. RM 7.3 – remnant floodplain fill. If this feature is not incorporated into a restoration project (i.e. valley log jam), then it should be removed.
- Mainstem near RM 5.2 – an abandoned crossing constricts the channel just upstream of trail crossing. May be a low priority because of constriction from trail crossing just downstream.
- Mainstem near RM 4.2 – old (approx. 100 years) valley fill keeping channel in current location and increasing grade. Unknown origin. Could be removed to restore natural channel dynamics. Additional hydraulic investigation is needed.
- Other sites noted on Clark County surveys include an abandoned crossing at the mouth of trib W4.09 (also a fish barrier), an old crossing on trib W6.44, an old crossing and earthen berm on Packard (P0.55 & P1.67, respectively), and a culvert crossing on trib W5.70 T0.49E.

Combined approaches

- Restoration activities are most effective if multiple attributes are addressed, including channel processes, floodplain function, and riparian conditions.
- Re-establishing native riparian forest vegetation should be a component of nearly every project since: 1) most projects are likely to have some impact to riparian areas, and 2) restoring native vegetation is key to providing long-term stability.
- Upland sediment and runoff conditions must be addressed for stream corridor enhancements to be successful.

Things to avoid

This document has focused primarily on recommended measures. Sometimes it is useful to also know what to avoid. In light of this, the following is a brief list of things that should be avoided throughout the course of stormwater basin planning:

- Avoid major manipulations to stream channel geology that would limit natural channel dynamics. Channels are meant to change as necessary to adjust to altered conditions. Adding hardened control points to dynamic channel types interferes with this process and can be detrimental to channel habitat in the long run, despite the short-term benefits. Elements that use wood debris are often more appropriate for this reason.
- Do not spend lots of time on channel enhancements if contributing processes are not also dealt with.
- Do not spend lots of money removing or improving barriers where very little beneficial habitat is made accessible.
- Be cautious with applying short-term habitat “fixes” that do not address long-term management issues. Focus on long-term solutions with long-term commitments by policy-makers and managers. Protection through policy change or land acquisition is one of the best long-term solutions.
- Do not let a lack of information prevent the application of solutions based on current knowledge.

2006 Stormwater Needs Assessment Program

Riparian Assessment

A general riparian assessment is included in the Whipple Creek Technical Memo found in the Geomorphology and Hydrology chapter.

2006 Stormwater Needs Assessment Program

Floodplain Assessment

A general floodplain assessment is included in the Whipple Creek Technical Memo found in the Geomorphology and Hydrology chapter.

2006 Stormwater Needs Assessment Program

Wetland Assessment

A general wetland assessment is included in the Whipple Creek Technical Memo found in the Geomorphology and Hydrology chapter.

Macroinvertebrate Assessment

Water Resources collects benthic macroinvertebrates annually at station WPL050. The bugs are preserved and submitted to a professional laboratory for taxonomic identification and enumeration. Data are available at station WPL050 (see Water Quality section) for 2001, 2002, and 2004.

Benthic Index of Biological Integrity

Water Resources utilizes the widely applied Benthic Macroinvertebrate Index of Biological Integrity, or B-IBI (Karr, 1998), to measure the health of streams based on the macroinvertebrate population.

Karr's B-IBI score is the sum of ten metric scores that measure various aspects 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 to disruption and will be the first to disappear from a stream as human disturbance increases.

The raw data value for each metric are converted to a score of 1, 3, or 5, and the ten individual metrics are added to produce an overall B-IBI score ranging from 10 to 50. Scores from 10-24 indicate low biological integrity, from 25-39 indicate moderate integrity, and greater than 39 indicate high biological integrity.

Figure 52 includes the overall B-IBI scores from WPL050 in 2001, 2002, and 2004.

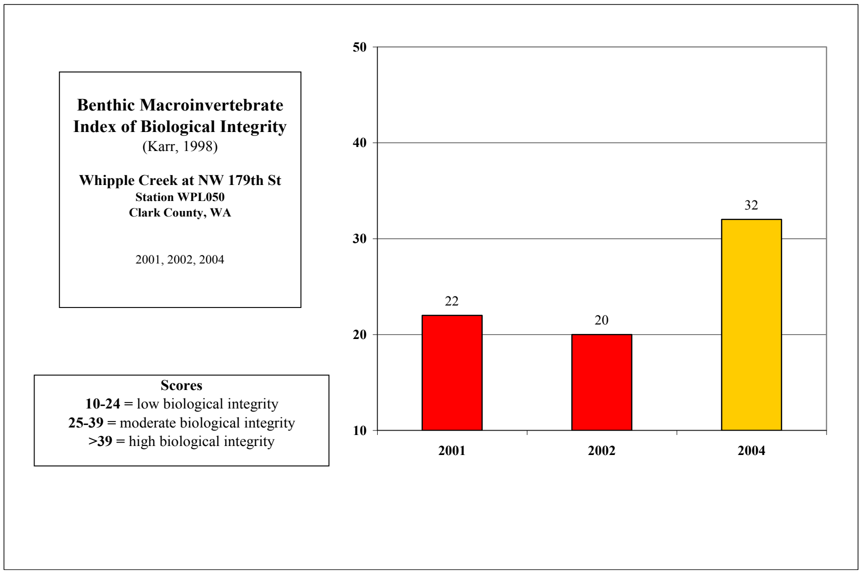


Figure 52. B-IBI scores for Whipple Creek station WPL050, 2001, 2002, and 2004.

B-IBI scores in 2001 and 2002 indicated low biological integrity. In 2004, the score improved into the moderate range. Given only three years of data, it is unknown whether the improvement in 2004 is indicative of a larger trend or simply the result of short-term variations in weather or local conditions. Regardless, the available data suggest that biological integrity in Whipple Creek is substantially degraded.

In addition to the overall B-IBI scores, individual metric scores may give insight into stream conditions and better explain differences in the overall score. King County provides a basic description of each B-IBI metric and these are paraphrased below. For a full description see http://dnr.metrokc.gov/wlr/waterres/Bugs/metrics_desc.htm.

Total taxa richness: The total number of taxa collected. Stream biodiversity declines as flow regimes are altered, habitat is lost, chemicals are introduced, energy cycles are disrupted, and alien taxa invade.

Mayfly (Ephemeroptera) taxa richness: The total number of mayfly species collected. Mayfly diversity declines in response to human influence. Many graze on algae. They are sensitive to chemical pollution that interferes with algae growth, but may increase in diversity over stoneflies and caddisflies in cases of high nutrient enrichment.

<u>Stonefly (Plecoptera) taxa richness</u>: The total number of stonefly species collected. Stoneflies are the first to disappear as human disturbance increases. Many are predators that depend on hiding between rocks- these types are very sensitive to sediment pollution. Others are shredders that rely on leaf litter from overhead tree canopies. Most require cool water and high dissolved oxygen levels.

<u>Caddisfly (Trichoptera) taxa richness</u>: The total number of caddisfly species collected. Caddisflies are a diverse group including some sensitive and some tolerant taxa representing many functional feeding groups (scrapers, collectors, predators). Taxa richness tends to decline as stream habitat becomes less varied and complex.

<u>Intolerant taxa richness</u>: These are the most sensitive taxa, representing approximately 5-10% of the taxa present in a region. They are the first to disappear as disturbance increases.

<u>Clinger taxa richness</u>: These taxa are adapted to hold onto smooth substrates in fast water. Because they occupy the open area between rocks, they are particularly sensitive to fine sediment.

<u>Long-lived taxa:</u> These taxa require more than one year to complete their life cycles, thus they are exposed to all the human activities that might influence the stream over a lengthy period. These taxa may disappear from streams that run dry during part of the year or experience on-going cyclical problems that interfere with their life cycles.

<u>Percent tolerant:</u> Tolerant taxa are present at most stream sites, but as disturbance increases they will represent an increasingly large percentage of the population. Tolerant species represent the 5-10% most tolerant taxa in a region. They are the opposite end of the spectrum from intolerant taxa.

<u>Percent predator</u>: Predators are the peak of the food web and depend on a reliable source of other invertebrates they prey on. The percentage of predator taxa provides a measure of the trophic complexity supported by a site.

<u>Percent dominance (3 taxa):</u> As diversity declines, a few taxa will begin to dominate the population. More tolerant or opportunistic species will replace sensitive or specialized species as habitat becomes more limited. This metric is calculated by adding the individuals in the three most common taxa and dividing by the total number of individuals in the sample. Figure 53 shows the individual metric scores for each year.

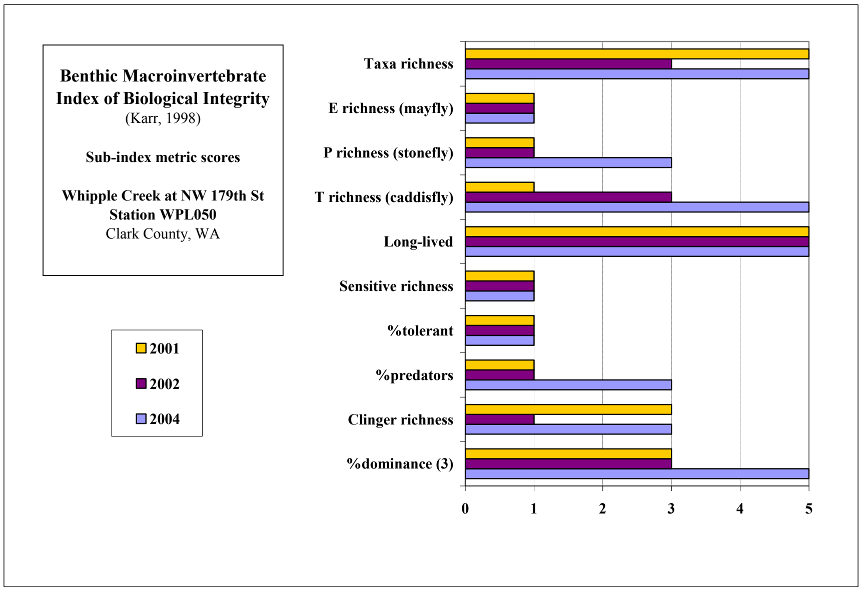


Figure 53. B-IBI metric scores for station WPL050, 2001, 2002, and 2004.

Overall taxa richness has remained moderate to good, as has the number of long-lived species. Beyond these two metrics, there is less good news. Although a substantial increase in caddisfly richness (6 taxa) and a slight increase in stonefly richness (2 taxa) is encouraging, we do not see a similar increase in some other critical metrics. Notably, the scores for sensitive richness and percent tolerant species are uniformly low, indicating few sensitive species and a dominance by pollution tolerant taxa. The percent dominance score in 2004 reflects a slight increase in diversity.

Predator species increased in 2004, in keeping with the increases in stonefly and caddisfly species, as well as the overall increase in diversity. Clinger species richness varied widely in the past several years. As a measure of sediment pollution, the variability in clinger richness likely reflects the unstable nature of the stream substrate. In some years sediment may be washed away to expose increased gravel substrate, while in other years these habitats are covered up.

It should be noted that many of the metric scores for Whipple Creek are very near B-IBI category thresholds and could readily rise or fall to another category. Differences as little as a single taxon would be enough to change a metric score in some cases.

Hilsenhoff Biotic Index

The Hilsenhoff Biotic Index (Hilsenhoff, 1988) summarizes the overall pollution tolerances of the taxa collected. Although it was originally developed to detect organic pollution, this index has also been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. A family level HBI is calculated for each sample. Samples with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. (BLM/USU National Aquatic Monitoring Center (http://www.usu.edu/buglab).

For 2002 and 2004, HBI scores for WPL050 were 4.31 and 4.55, respectively, indicating slight to moderate nutrient enrichment. These results are consistent with the elevated nutrient levels routinely detected in water quality samples.

Implications for stormwater management

Macroinvertebrate sampling is conducted on riffle habitat within a single 500-foot reach toward the lower end of the 10-mile Whipple Creek mainstem. Results may not be indicative of the entire stream. However, the cumulative result of upstream land use and management has an impact on conditions at the sampling station. The low to moderate biological integrity indicated by samples from WPL050 suggests that human influence on Whipple Creek has been substantial.

The B-IBI scores reflect impacts to habitat complexity and stability. Based on metric scores and our existing knowledge of water quality conditions, the impacts to benthic macroinvertebrate populations are likely attributable largely to altered flow regimes and sediment accumulation. Elevated stream temperatures are a known problem and may also be impacting some of the more sensitive taxa. The potential presence of toxins in the sediment or water column could also have an impact, particularly on sensitive taxa and overall taxa richness.

In addition to stabilization of flow regimes, stormwater projects that focus on controlling turbidity, total solids, and temperature are likely to have the most positive impact on biological integrity in Whipple Creek. Should toxins prove to be an issue, projects or management activities designed to reduce pesticides and other toxins would be appropriate

Fish Use and Distribution

Fish use, distribution, and barriers are discussed in the Whipple Creek Tech Memo found in the Geomorphology and Hydrology chapter.

2006 Stormwater Needs Assessment Program

Hydrologic and Hydraulic Models

Hydrologic and hydraulic modeling reports are included in Appendix A.

2006 Stormwater Needs Assessment Program

Analysis of Potential Projects

The analysis of potential projects:

- Briefly summarizes stormwater conditions, 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
- Lists recommended projects and activities for further evaluation

Projects or activities are placed in one of several 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

Clark County and Vancouver-Clark Parks have significant land holdings in this assessment area. There are several programmed county Transportation Improvement Program projects, including

- NE 179th St - NE 10th Ave to NE 29th Ave
- NE 179th St/I-5 Interchange Roundabouts - NW Delfel Rd to NE 13th Ave
- NE 10th Ave - NE 141st St to NE 149th St
- NE 10th Ave - NE 149th St to NE 164th St

Whipple Creek does not have an active watershed council or grass-roots watershed group. Ecology TMDL development has not yet been scheduled.

Water Quality Assessment

Whipple Creek is 303(d) listed for fecal coliform bacteria under Category 5 (polluted waters requiring a TMDL), and for temperature under Category 2 (waters of concern).
A relatively large water quality dataset is available for Whipple Creek. Clark County maintains long-term monitoring and hydrologic stations.

Based on 2002 - 2004 data, water quality index scores are poor. Overall stream health was rated as poor to very poor in the 2004 Stream Health Report. Fecal coliform bacteria, stream temperature, turbidity, and nutrient levels are known parameters of concern in this assessment area.

Drainage System Inventory

Drainage mapping is complete for this assessment area.

Public Stormwater Facility Inspection

Stormwater facility inspections were not conducted.

Illicit Discharge Screening
Screening conducted at 311 known stormwater outfalls confirmed and removed two illicit connections to the storm sewer.

Stream Reconnaissance Feature Inventory
Significant stream impairments, potential environmental and safety hazards, and stormwater project opportunities were recorded for approximately twenty miles of the Whipple Creek stream corridor. A total of 544 features were identified, including large numbers of stream crossings, stormwater outfalls, severe bank erosion, and impacted stream buffers. Over 300 potential project opportunities were initially identified, ranging from large stormwater retrofits or facility construction to small channel improvements, barrier removals, and trash cleanup. A much smaller list of high priority projects was developed and submitted for consideration under the 2007-2012 Stormwater Capital Improvement Program.

General observations from the feature inventory include:

- Within the assessed reaches, degraded areas far outnumber those that remain intact; however, a number of high quality areas were noted and should be protected
- Impacted buffers are prevalent, with a wide range of riparian vegetation conditions.
- Beaver dams are extensive and are likely providing sediment storage and grade control
- Invasive blackberries tend to invade where land-disturbing activities occur, including the areas along stormwater outfall installations
- Stormwater facilities and outfalls are often located on plateau edges near gullies and valleys; concentrated flows from these locations has resulted in unstable, channelized gullies in a number of areas
- Numerous stormwater outfalls are causing localized erosion, invasive plant colonization, and trash accumulation
- Issues noted at outfalls suggest that facility inspection protocols may need modification to increase examination of outfalls and potential downslope erosion

Physical Habitat
Physical habitat measurements were made in 2002 on a portion of Whipple Creek (Upper) just upstream from the Packard Creek tributary mouth. Based on EPA protocols, habitat in this reach scored considerably below an Oregon DEQ grade-C reference stream. Grade C streams are the lowest grade of reference sites and typically exhibit marginally functional watershed and stream conditions with obvious human disturbance.

Tech Memo Sections (included in report under the Geomorphology chapter)

Broad-Scale Characterization

Both subwatersheds are located in rural unincorporated Clark County along the I-5 corridor north of Vancouver. Missoula flood deposits of sand and silt cover most of the basin. Soils are moderately drained and moderately to highly erodible. Coarse sediments (gravels) are relatively uncommon, with most stream channels dominated by highly erodible fine sediments. Topography is rolling, with steep slopes adjacent to stream channels. The basin is most accurately characterized as a rural watershed that is rapidly suburbanizing. Based on the Clark County Comprehensive Plan, impervious area is projected to increase significantly, particularly in the headwater areas near the I-5 corridor. Hydrologic regime is typical of a flashy urban or unforested rural stream.

Geomorphology and Hydrology

Many stream channels are experiencing active channel enlargement in the form of incision and/or widening. Incision tends to be prevalent in the steeper 1st order tributaries, while widening is the dominant form in the 2nd and 3rd order (mainstem) reaches. Whipple Creek channels are particularly susceptible to erosion. Substrate is primarily composed of silts and sands, with a lack of coarse substrate in most reaches. Most large trees have been removed and woody debris no longer provides the grade control and channel stabilization that it did historically. Road crossings often provide hardened control points and are acting as grade control in many places.

Riparian Assessment

Many reaches have intact riparian buffers due to steep valley walls. However, the quality of these riparian areas is degraded. Invasive species, particularly blackberry and reed canary grass, have prevented the normal succession to mature conifer forest in many areas. Channel incision has exacerbated this problem by reducing overbank flooding and channel migration.

Wetland Assessment

Wetlands are primarily associated with stream channels, although some depressional headwater wetlands are also present. A number of intact wetlands are at risk of draining due to migrating headcuts and channel incision. In general, a high priority should be placed on protecting the remaining intact wetlands, and efforts should be made to restore degraded areas. Off-site mitigation for development in wetland areas should be discouraged.

Fish Use and Distribution

Fish distribution data is very limited. The available evidence, largely from anecdotal accounts, suggests that anadromous fish use may include cutthroat trout, steelhead, and Coho salmon. Regional recovery priority is low. The LCFRB (2004) did not assign a priority tier to Whipple Creek. Barriers appear to be common but are not well-evaluated. Opportunities may exist to open up high quality habitat areas in tributaries along the lower mainstem

Macroinvertebrate Assessment

Macroinvertebrate data from three years on Whipple Creek (Upper) indicate low to moderate biological integrity. Scores for sensitive species and tolerant species are uniformly low, indicating few sensitive species and a dominance by pollution tolerant taxa.

Hydrologic and Hydraulic Modeling
Complete hydrologic and hydraulic modeling reports including HEC-HMS, HSPF, and HEC-RAS are in Appendix A.

In August 2005, Clark County staff completed a Hydrology and Hydraulic model using HEC-HMS and HEC-RAS computer programs for Whipple Creek Watershed. This was Part-1 of a larger plan which aimed to reasonably represent hydrologic and stream flow conditions within Whipple Creek Watershed. The Part-1 modeling also had the goals of simulating changing land use conditions and identifying needed capital improvement projects. The following is a brief highlight of the models result:

- HEC-HMS and HEC-RAS models appeared to produce reasonable results to predict where erosion would occur and stream channels would transition from stable to unstable.

- HEC-RAS model produced more reasonable results since it uses complete channel geometry as instead of stream channel slope and velocity to predict areas susceptible to erosion.

- Storage routing upstream of roadway embankments significantly attenuated peak flows along downstream reaches, indicating less potential erosion problems.

As part of HEC-HMS modeling, the following “design storm” runs were completed:

- 2-year (dominant erosion/stream-channel forming storm event)
- 10-year (design storm for roadway drainage)
- 100-year (design storm for flooding of homes)

At the completion of the Part-1 study, the County staff revised the goals of the Part-2 hydrologic and hydraulic analysis. The county identified a need to compare the simulated stream erosion conditions to the field data collected during the Stream Assessment. Part-2 of the Whipple Creek Watershed Projects Plan was completed by Otak in March 23, 2007. This part focused on studying additional land use scenarios and further advancing CIP.

The Part-2 hydrologic modeling showed that future developments in the Whipple Creek watershed will likely increase stream flows in most areas of the watershed. However, the increase in peak flows and flow durations will most likely be evident in the upper areas of the watershed, near I-5 and other areas zoned for high density development. Mitigation measures are needed to prevent future flow increases, and, where possible to reduce existing flow levels allowing the stream to better accommodate the current flow regime.

The following table shows a comparison of estimated peak flows during a 2-year rainfall event, using HEC-HMS and HSPF hydrologic modeling along Whipple Creek.

	2-year Existing Flow			**2-year Future Flow**		
River Mile	HSPF	HEC HMS	Percent Change	HSPF	HEC HMS	Percent Change
9.369	23.4	66.1	35%	51.0	84.5	60%
6.598/6.874	87.0	196.3	44%	154.7	238.2	65%
5.257/5.031	140.3	274.2	51%	224.9	327.2	69%
3.132/3.204	217.7	354.9	61%	314.8	427.7	74%
2.037/1.874	247.8	392.9	63%	341.7	469.7	73%

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 illicit discharge 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 considering 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.

Potential Stormwater Capital Projects

Potential projects include those listed below. In addition, see pages 157-173 for example locations where various improvement measures could be implemented.

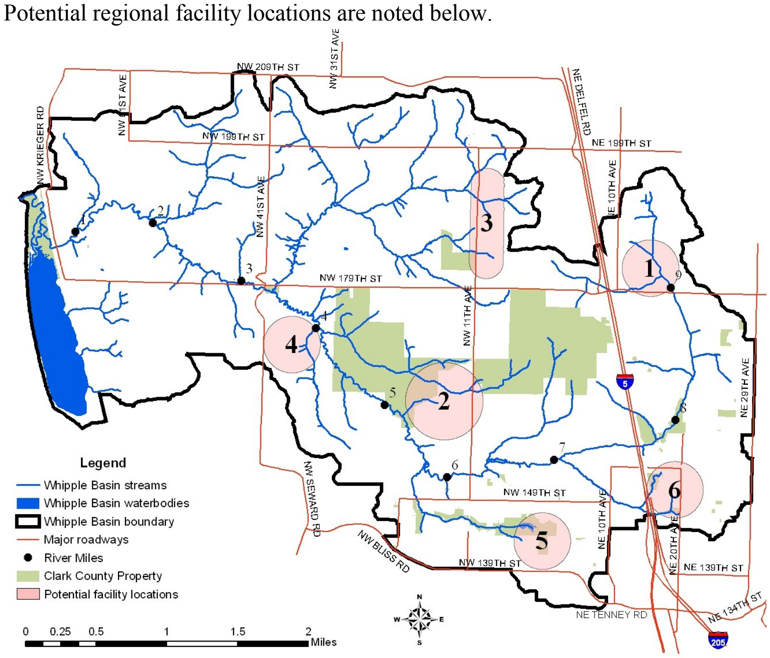
Catchment	ID	Photo	Issue	Potential project
W5.99	er-4	31-33	channel instability and pinch point d/s of 11th Ave	unknown
W5.70T0.00	sc-4	50	undersized culvert and sediment deposition	combination with proposed pedestrian bridge?
W5.70T0.49E	ot-1	67-71	outfall w/associated erosion and trash/flow issues	possible facility development on ridge—school district property. Or, retrofit and maintenance at existing OT
W5.70T0.49E	ot-3	79	outfall, ports clogged and lid popped	possible retrofit. Maintenance also needed
W5.70T1.08E	er-1	86-89	outfall likely causing headcut and incision	possible retrofit
W5.70T1.08S	ot-3	112	outfall/stream daylights d/s of NW 3rd Ct. trash and high flows/downstre am impacts	possible upstream detention?
W7.82	ot-1	138	previously unmapped facility, has design flaws, maintenance issues	maintenance and/or facility redesign
W8.36T0.00	er-1	148-149	6' headcut	unknown
W6.20	mi-1	206-209	existing ponded area	off-channel storage
W6.26T0.00	er-2	212-217	Whipple Creek Place facility issues	retrofit/redesign/maintenanc e
W7.06T0.74N	man y	279-291	problem outfalls,	major reach renovation—primarily pond fix and

			sediment-filled pond, riparian issues. This is a "re-do" reach	outfall retrofit/maintenance
W9.14T0.54N	mi-1	335-336	broken culvert in ditch	could be fixed, storage added as part of larger 179th/I-5 interchange projects
W9.14T0.54S	mi-2	354-355	previously unmapped fairgrounds facility. Sediment issues/clogged pipes	maintenance, evaluation for other work
W7.82T0.22	ot-6	371	downstream channel erosion	facility flow path could be lengthened
W6.44T0.53E	er-1	383	large headcut	unknown
W6.44T0.53N	er-1	392-393	road culvert issues. Culvert damage, bank failure	repair/stabilization
W6.41T1.01N	er-1	411	large headcut	unknown
W8.50	ot-3	460-463	facility sedimented/flow path short-circuit	eval/redesign/maintenance
W9.14T0.00	mi-1	487-488	ditch eroding may start to undermine roadway. Also d/s culvert has sediment issues	ditch eval/stabilization. Culvert maintenance
W4.09T0.00	sc-1	528-530	culvert for unused road is complete passage barrier. This cuts off ~2 miles of habitat through Whipple Creek Park	removal
W4.00T0.00	sc-1	531	culvert for farm road is complete	removal/retrofit

			passage barrier. Cuts off ~ 0.3 mile of habitat	
P0.00	er-1	587-592	county riparian planting is eroding, significant sediment source	stabilization
P1.06T0.49W	ot-1	762-768	culvert issues and LID opportunity	eval/retrofit outfall. Eval for LID demo project
P1.06T0.00N	sc-1, 2	804-811	channel instability associated with crossings	eval/stabilization
P1.06T0.57NE	er-1	831-835	heacuts	unknown

<u>Regional stormwater facilities</u>

Potential regional facility locations are noted below.



Property acquisition or protection

Reach Code	Reach ID	Reach Score	Comments
W5.70T1.08E	43	127	county-owned; large pond/marsh complex controlling stormwater for large area and protecting downstream channel; adjacent wetland recently filled for new development
W6.41	46	138	large series of beaver ponds and wetland complex in good condition
W6.44T0.00	59	115	many groundwater seeps; upper part forested; Northern red-legged frog observed
W6.44T0.75N	57	126	partially county-owned; intact forest with some large trees
W7.82	50	133	partially county-owned; part of reach lies on Van Buren property which was referred as a high priority for purchase
W8.36	51	131	likely the best remaining habitat in watershed; reach lies primarily on Van Buren property noted above; beaver pond complex throughout reach; recognized as prime habitat by county and WDFW
W8.50	60	113	property immediately north of Van Buren (Milton Brown); lower end is intact beaver ponds/wetland complex providing stormwater control; threatened by surrounding development
W8.50T0.00	52	127	intact wetland on Milton Brown property is threatened by planned developments; upland has been logged in past 10 years but stream and wetlands are high quality
W9.14	66	134	headwater stream in good condition currently, but vulnerable to futureI-5 corridor development impacts
W9.31	67	--	High quality headwater wetland; vulnerable to future I-5 corridor development impacts; high priority for preservation/protection; no score given due to lack of defined channel
P0.00*	76	110	impacted, but one of few potentially accessible reaches with gravel substrate; also storage opportunity along flat riparian area near mouth
P1.06*	80	98	impacted, but one of few potentially accessible reaches with gravel substrate

Referrals

2005 Whipple Creek Assessment Referrals

ReferralDate	IssueDescr	Assessment ReachID	ParcelSN	ParcelOwner	StaffIssued	AcencyReferred	StaffReferred	DateResolved	Comment
2/22/2005	Un-mapped ponds and outfall east of 20th Ave	W7.82	117892864	SOLMONSON DONALD W & SANDRA	Szwaya	Clark County	Henry Schattenkerk	ongoing	Facility needs to be mapped
2/24/2005	Small hole in swale of facility above eroding gully	W6.26T0.00	185575168	CLARK COUNTY	Wierenga	Clark County	Ken Lader	ongoing	Ken referred to Jeff Tuttle to fix hole
2/24/2005	Strong odor of chemical (solvent?) in tributary to Whipple Creek	W5.70T1.08S	118107676	VALENTINE FAMILY LTD PTNSP	Schnabel	Ecology	Curt Piesch	2/25/2005	Site visited by Curt, Ron W., and Cary A. Solvent odor not present but potential issues noted (see below)
2/25/2005	Business has stormwater runoff issues on site	W5.70T1.08S	118107676	VALENTINE FAMILY LTD PTNSP	Wierenga	Clark County	Cary Armstrong	3/15/2005	Cary visited site with Kim Kagelaris and Marlou Pivirotto. Solvent issues found and actions pending
2/28/2005	Need to coordinate with Dave Howe about Whipple Creek property	W7.82;W8.36	181935000	VAN BUREN HELENE HIDDEN TRST	Schnabel	Clark County	Dave Howe	3/2/2005	Dave notified of WC Project, Jeff requested WR contribute CWP funding toward purchase
3/1/2005	WSDOT is doing an inventory along I-5; need to coordinate if possible	reaches on I-5 corridor	NA	NA	Schnabel	Clark County	Rod Swanson	3/3/2005	Rod contacted Erin Gardner at WSDOT. Clearing is eng. survey for upcoming I-205/I-5 interchange project
3/2/2005	Un-mapped facility near I-5	W7.06	185669000	LIES BRIAN S & LAURIE ETAL	Wierenga	Clark County	Ken Lader	3/10/2005	Facility needs to be mapped
3/2/2005	Un-mapped facility and inaccurate infrastructure mapping	W7.06T0.74N	117894650	Clark County	Schnabel	Clark County	Ken Lader	ongoing	Facility and area need mapping investigation
6/2/2005	Possible presence of threatened species (red-legged frog)	W6.44T0.00	NA	NA	Wolf	WDFW	staff biologist	6/2/2005	Frog not positively identified, but likely red-legged. May be listed as sensitive species in future
3/8/2005	Un-mapped facilities and infrastructure at fairgrounds and amphitheatre	W9.14T0.54S; WT6.41T1.01N; W7.82T0.22; W6.44T0.53E	182148000; 182213000; 182214000	Clark County	Wierenga	Clark County	Henry Schattenkerk	3/10/2005	Facilities need to be mapped
3/7/2005	County soil surplus site has site drains routed through silt fence	W9.14T0.54N	116530000; 116521000; 116520000	Tehennepe, Dubravac	Schnabel	Clark County	Cary Armstrong	3/9/2005	Cary to Sheila Pendleton. Sheila to Charlie Hord (Construction Mgmt). Drains re-routed inside fence
6/2/2005	Livestock access to stream-- impacted streambank and riparian area	W7.06	185749000; 185741000; 185747000	LIES RUDY & MARY ETAL CONT	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing
6/2/2005	Livestock access to stream-- impacted streambank and riparian area	W7.82T0.22	182139000; 182154000	GONZALES LL0YD ETAL; OLSON STEPHAN E & ALLISON L	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing
6/21/2005	Possible septic system issues	W8.50	181904000; 181936000	WOOLEY RICHARD & GLENNYS; SIMMONS CHARLES F & RUTH C	Schnabel	Clark County Health Dept	Steve Keirn		Health Department may wish to inspect these two parcels for septic issues
6/21/2005	Unidentified pipe outfall may be related to septic drainfield	W7.06T0.00	185404000	BAXTER DONALD & KAREN	Schnabel	Clark County Health Dept	Steve Keirn		Health Department may wish to inspect this parcel for septic issues
3/22/2005	Bank stabilization problem at PW county's Sara planting site	P0.00	182705000	CLARK COUNTY	Wierenga	Clark County	Heath Henderson	ongoing	Forwarded info to Phil Gaddis to address
3/22/2005	Freshwater mussel bed in lower Whipple Creek	W3.85	182659000	BENES MICHAEL & CATHY	Wierenga	USFWS	Jennifer Poirier	3/25/2005	Jennifer responded with interest in the beds; may use site in upcoming volunteer training
4/5/2005	Large animal track needing identification	P1.67	180742000	HOFFMAN SALLY R	Wierenga	USFWS	Donna Allard	4/8/2005	Steve Engel identified as very large canine track, probably not feline
4/7/2005	Large amount of debris piled up next to stream	P1.06T0.49W	179831000	MEYER KEVIN D	Wierenga	Clark County	Cary Armstrong	ongoing	
4/14/2005	Severe off road vehicle impact to stream	P2.06T0.00N	179698000	SHIPP STEVE & DEBRA CONT	Wierenga	Clark County	Cary Armstrong	ongoing	Cary referred to Scott Melville, CE officer
6/21/2005	Strong sewage odor from SW outfall	P1.06T0.49W	NA	CLARK COUNTY	Schnabel	Clark County	Steve Keirn		possible inspection, or include in Illicit Discharge project
3/31/2005	Livestock access causing stream bank erosion and riparian impact	P1.23T0.98S	182378000	NYE MARTIN & CHERIE	Schnabel	Clark Conservation District	Denise Smee	ongoing	Conservation District may wish to contact landowners regarding livestock fencing

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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 NPDES permit term.

Management and programmatic recommendations in the assessment area, by permit component, include:

<u>Storm Sewer Mapping and Inventory</u>
None.

<u>Coordination of Stormwater Activities</u>
None.

<u>Mechanisms for public involvement</u>
- Publish SNAP reports on CWP web page

<u>Development Regulations for Stormwater and Erosion Control</u>
- Emphasize stormwater management that reduces runoff by dispersing it into vegetated areas on-site
- Give greater attention to the placement of outfall locations and the configuration of outfall channels

<u>Stormwater Source Control Program for Existing Development</u>
- Encourage landowners to adopt runoff reduction practices, such as disconnecting downspouts.

<u>Operation and Maintenance Actions to Reduce Pollutants</u>
- Focus additional resources on inspection of stormwater outfalls and downstream channels

<u>Education and Outreach to Reduce Behaviors that Contribute Stormwater Pollution</u>
- Perform targeted technical assistance responding to results of field assessments
- Continue to encourage and support riparian planting efforts by private landowners
- Replace missing or deteriorated stream name signs

<u>TMDL Compliance</u>
- There are no approved TMDLs in the assessment area

References

Booth, D.B. and C.R. Jackson. (1997). Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation: Journal of the American Water Resources Association, vol. 33, no. 5, p. 1077-1090.

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.

City of Vancouver – Surface Water Management (May 2007). Burnt Bridge Creek Watershed Program. Vancouver, WA

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.

Cramer, S.P. & 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.

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.

Lower Columbia Fish Recovery Board. (Dec. 2004). Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. Volume II, Subbasin Plan Chapter G, North Fork and East Fork Lewis River.

Lower Columbia Fish Recovery Board. (Dec. 2004). Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. Volume II, Subbasin Plan Chapter H, Lower Columbia Tributaries Bonneville and Salmon.

Lower Columbia Fish Recovery Board. (Dec. 2004). Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan. Volume II, Subbasin Plan Chapter I, Washougal.

Lower Columbia Fish Recovery Board. (2007). Regional Culvert Inventory, Project #02-1658N, Final Report.

Lower Columbia Fish Recovery Board. (2008). East Fork Lewis River Community Habitat Restoration Plan and Project Design – Draft Technical Memorandum 1 and 2.

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 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.

Parametrix, Inc. (2002). Burnt Bridge Creek Riparian Habitat Assessment. Prepared for the City of Vancouver, 37 pp.

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.

Schnabel, J. (September 2004). Salmon Creek Watershed: Summer 2003 Stream Temperature. 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.

S.P. 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.

Vancouver Lake Watershed Partnership Technical Group. Technical Foundation for Future Management of Vancouver Lake (November 2008).

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.

US Army Corps of Engineers (November 2007). Review of Biological Research on Juvenile and Adult Salmonid use of Vancouver Lake. Portland District.

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 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 State Department of Ecology. Stormwater Management Manual for Western Washington (February 2005). Publication Numbers 05-10-029 through 05-10-033.

Washington Department of Ecology (April 2007). Draft Watershed Characterization of Clark County, Version 3: Shorelines and Environmental Assistance Program.

Washington Forest Practices Board Manual (March 2000).

Washington State University Vancouver (2009). Bollens, Stephen and Gretchen Rollwagen-Bollens. Year One Annual Report: Biological Assessment of the Plankton in Vancouver Lake, WA.

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

Wierenga, R. (2005.) Benthic Macroinvertebrate and Water Temperature Monitoring for Clark County Watershed Assessments in 2004. Clark County Public Works Department – Water Resources Program. Washington Department of Ecology Grant number G0300020 and Clark County Clean Water Program.

FROM WQ REPORT

Butkus, S. (June 2002). *Washington State Water Quality Assessment: Year 2002 Section 305(b) Report*. Publication No. 02-03-026. Washington State Department of Ecology, Environmental Assessment Program, Olympia WA.

Clark County Water Resources. (2004). *2003 Clark County Stream Health Report*.

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.

Drake, D. (November, 2003, unpublished draft). *Selecting Reference Condition Sites: An Approach for Biological Criteria and Watershed Assessment.* Watershed Assessment Section, Oregon Department of Environmental Quality.

Hilsenhoff, W. L. (1988). *Rapid field assessment of organic pollution with a family level biotic index.*. The Journal of the North American Benthological Society. 7:65-68.

Karr, J.R. (1998). *Rivers as sentinels: Using the biology of rivers to guide landscape management*. Pages 502-528 In: R.J. Naiman and R.E. Bilby, eds. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer, New York, New York.

Kaufmann, P.R., P. Levine, E.G. Robison, C. Seeliger, and D.V. Peck. (1999). *Quantifying Physical Habitat in Wadeable Streams*. EPA 620/R-99/003. U.S. Environmental Protection Agency, Washington, D.C. 102p + App.

Kaufmann, P.R. and D.P. Larson. (2003, personal communication, manuscript in review*). Sedimentation in Pacific Northwest Coastal Streams: Evidence from Regional Surveys of Bed Substrate Size and Stability.*

Kaufmann, P.R. (2003) Personal communication. Stream Flashiness Index calculations.

Merritt, G.D., B. Dickes, and J.S. White. (January 1999). *Biological Assessment of Small Streams in the Coast Range Ecoregion and the Yakima River Basin.* Publication No. 99-302.
Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA.

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.

Peck, D.V., J. Lazorchak, and D. Klemm, eds. (April 2001). Environmental Monitoring and Assessment Program-Surface Waters: Western Pilot Study Field Operations Manual for Wadeable Streams (draft). U.S. Environmental Protection Agency.

Peterson, N.P., A Hendry, and T.P. Quinn. (1992). *Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions.* TFW-F3-92-001. Washington Timber, Fish, and Wildlife. Olympia, WA.

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.

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

Turney, G. (1990). *Quality of Groundwater in Clark County, Washington*, *1988*. 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 an standards, Washington, DC.

Washington Department of Natural Resources (WDNR). (1997). *Board Manual: Standard methodology for conducting watershed analysis.* Washington Department of Natural Resources, Washington Forest Practices Board, Olympia, WA.

Washington Department of Fish and Wildlife (WDFW) and Western Washington Treaty Tribes. (1997). *Wild Salmon Policy.* Washington Department of Natural Resources, Washington Forest Practices Board, Olympia, WA.

FROM TECH MEMO

Bledsoe, B.P., and C.C. Watson. 2001. Effects of urbanization on channel instability. Journal of the American Water Resources Association. Vol. 37, No. 2.

Booth, D.B. 1990. Stream-channel incision following drainage-basin urbanization. Water Resources Bulletin Vol 25, No 3.

Booth, D.B. and C.R. Jackson. 1997. Urbanization of Aquatic Systems-- Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation. Journal of the American Water Resources Association. Vol. 22 No. 5.

Booth, D.B. and P.C. Henshaw, 2001. Rates of Channel Erosion in Small Urban Streams. In: Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas, M. Wigmosta and S. Burges (Editors). AGU Monograph Series, Water Science and Application Volume 2, pp. 17-38. Washington, D.C.

Booth, D.B. J.R. Karr, S. Schauman, C.P. Konrad, S.A. Morley, M.G. Larson, and S.J. Burges. 2004. Reviving urban streams: land use, hydrology, biology, and human behavior. Journal of the American Water Resources Assoc. (JAWRA) 40(5):1351-1364.

Clark County Public Works and contributing agencies and consultants. 2005. Clark County, Washington – Regional Wetland Inventory and Strategy. Clark County Department of Public Works, Vancouver, WA.

Doyle, M.W., J.M. Harbor, C.F. Rich, and A. Spacie. 2000. Examining the effects of urbanization on streams using indicators of geomorphic stability. Physical Geography, Vol. 21, No. 2, pp. 155-181.

Finkenbine, J.K., J.W. Atwater, and D.S. Mavinic. 2001. Stream health after urbanization. Journal of the American Water Resources Association. Vol. 36, No. 5.

Hammer, T.R. 1972. Stream channel enlargement due to urbanization. Water Resources Research. Vol. 8, No. 6.

Harvey, M.D. and C.C. Watson. 1986. Fluvial processes and morphological thresholds in incised channel restoration. Water Resources Bulletin. Vol. 22, No. 3: pp 359-368.

Henshaw, P. and D. Booth. 2000. Natural restabilization of stream channels in urban watersheds. Journal of the American Water Resources Association. 36(6): 1219-1236.

Hollis, G.E. 1975. The effect of urbanization on floods of different recurrence interval. Water Resources Research 11:431-435.

Hollis, G.E. and J.K. Luckett. 1976. The response of natural river channels to urbanization: two case studies from Southeast England. Journal of Hydrology; 30; p. 351-363.

Konrad, C.P. and D.B. Booth. 2005. Hydrologic changes in urban streams and their ecological significance. American Fisheries Society Symposium 47:157-177.

Konrad, C.P., D.B. Booth, and S.J. Burges. 2005. Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: Consequences for channel form and streambed disturbance. Water Resources Research, 41, W07009, doi:10.1029/2005WR004097.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, and E.B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques. Vol. 2, No. 4.

Montgomery, D. R., E.M. Beamer, G.R. Pess, and T.P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Sciences. 56:377-387.

Montgomery, D.R. and J.M. Buffington. 1998. Channel processes, classification, and response. Chapter 2 *in* River Ecology and Management – Lessons from the Pacific Coastal Ecoregion. R.J. Naiman and R.E. Bilby eds. Springer-Verlag, New York.

Moore, K., K. Jones, and J. Dambacher. 2002. Methods for stream habitat surveys. Aquatic Inventories Project – ODFW Natural Production Program. Corvallis, OR.

Naiman, R.J., K.L. Fetherston, S.J. McKay, and J. Chen. 1998. Riparian Forests. Chapter 12 in: River Ecology and Management – Lessons from the Pacific Coastal Ecoregion. R.J. Naiman and R.E. Bilby eds. Springer-Verlag, New York.

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

Nickelson, T. E. 1998. A Habitat-Based Assessment of Coho Salmon Production Potential and Spawner Escapement Needs for Oregon Coastal Streams. Oreg. Dep. Fish and Wildl., Fish Div., Fish. Info. Rep. 98-4 Portland, OR.

Oregon Department of Transportation (ODOT). 2005. ODOT Hydraulics Manual – Preliminary Draft. Prepared by: Engineering and Asset Management Unit – Geo-Environmental Section.

Oregon Plan for Salmon and Watersheds (OPSW). 1999. Water Quality Monitoring – Technical Guidebook. Interagency Water Quality Monitoring Team, Salem, OR.

Peck, D.V., J. Lazorchak, and D. Klemm, eds. (April 2001). Environmental Monitoring and Assessment Program-Surface Waters: Western Pilot Study Field Operations Manual for Wadeable Streams (draft). U.S. Environmental Protection Agency.

Pleus, A.E., D. Schuett-Hames, and L. Bullchild. 1999. TFW monitoring program method manual for the habitat unit survey. Prepared for the WA Dept. of Natural Resources under the Timber, Fish & Wildlife Agreement. TFW-AM9-99-003. DNR #105.

Roni, P. 2005. Monitoring Stream and Watershed Restoration. American Fisheries Society publication. Edited by P. Roni, Northwest Fisheries Science Center, Seattle, USA.

Saldi-Caromile, K. K, Bates, P. Skidmore, J. Barenti, D. Pineo. 2004. Stream Habitat Restoration Guidelines: Final Draft. Co-published by Washington Departments of Fish and Wildlife and Ecology and United States Fish and Wildlife Service. Olympia, WA.

Schnabel, J. 2005. 2005 Whipple Creek Stream Assessment Summary. Clark County Public Works – Water Resources Section. Clark County, Vancouver, WA.

Schueler, T. 1994. The importance of imperviousness. Watershed Protection Techniques. Vol. 1, No. 3.

Schueler, T. and K. Brown. 2004. Urban Stream Repair Practices – Version 1.0. Manual 4 of Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicot City, MD.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. Incised channels: morphology, dynamics and control. Water Resources Publications. Littleton, CO.

USFS. 1999. Stream Inventory Handbook Level I and II – Version 9.9. US Forest Service Pacific Northwest Region 6.

Wolman, M.G. 1967. A cycle of sedimentation and erosion in urban river channels. Geografiska Annaler: 49a; 2-4.