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.

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1. Introduction

1.1 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.

1.2 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 1.

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.

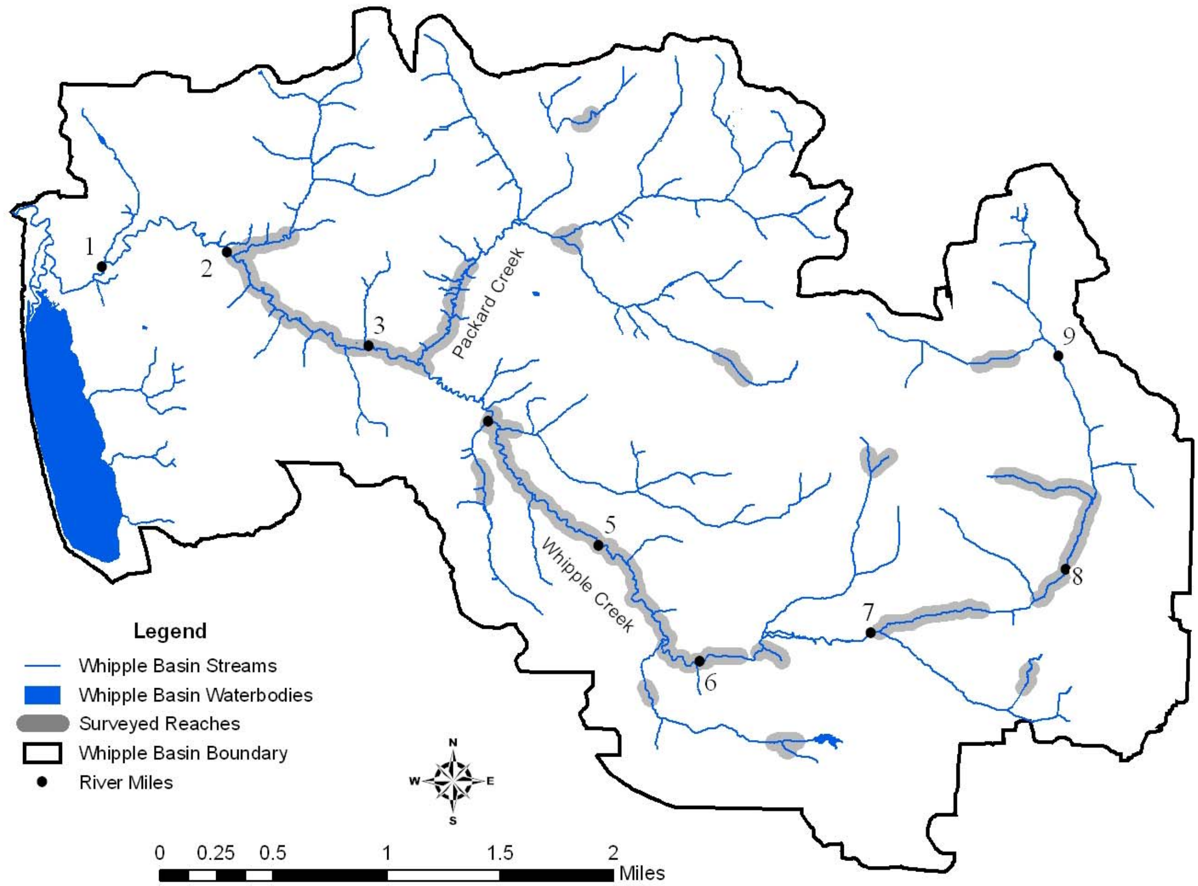

Figure 1. Stream segments surveyed by Inter-Fluve staff.

2. Watershed setting

2.1 Geology

Pleistocene outburst flood deposits (Missoula Floods) cover most of the basin (Figure 2). 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 2) 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.

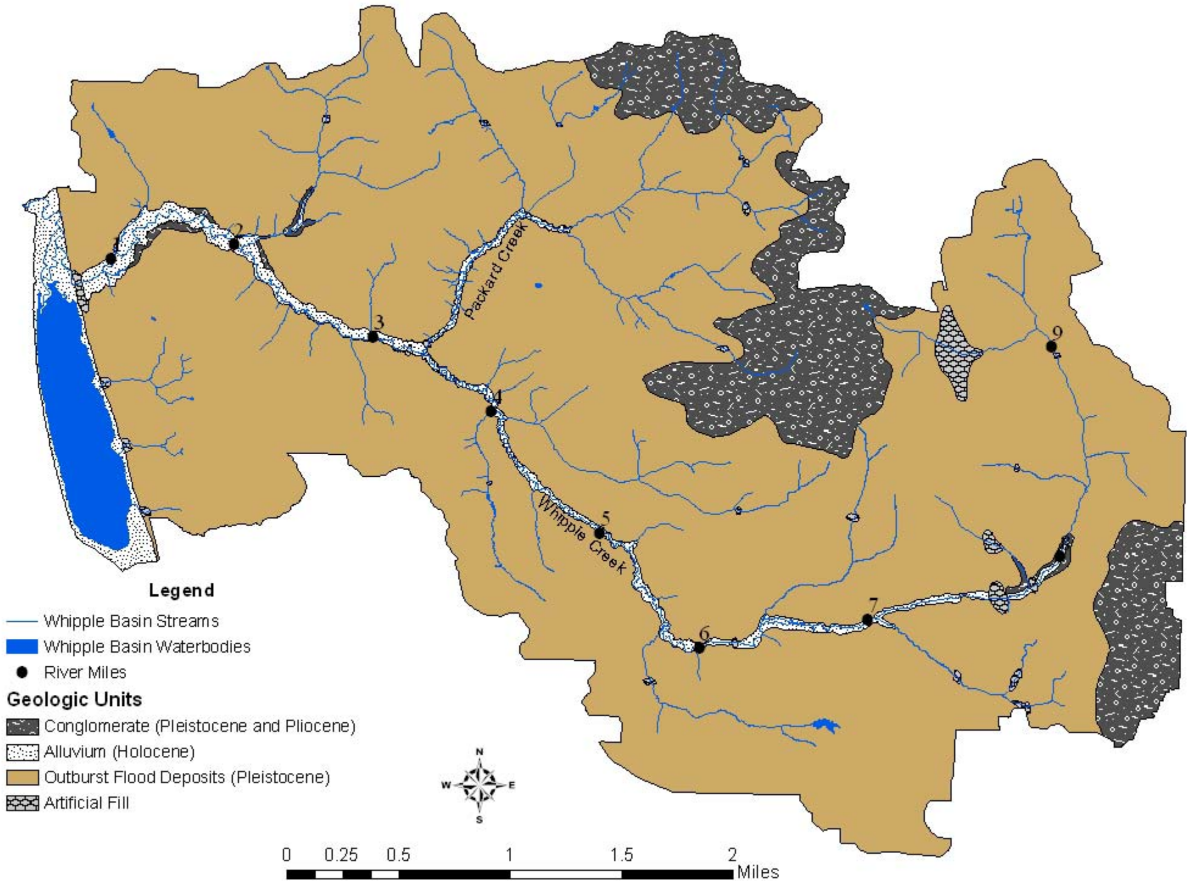

Figure 2. Geologic map of the Whipple Creek Basin (Data for this map was obtained from Clark County GIS).

2.2 Topography

The topography of the basin is characterized by rolling hills in upland areas, with steep slopes adjacent to stream channels in 1^{st} 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 3.

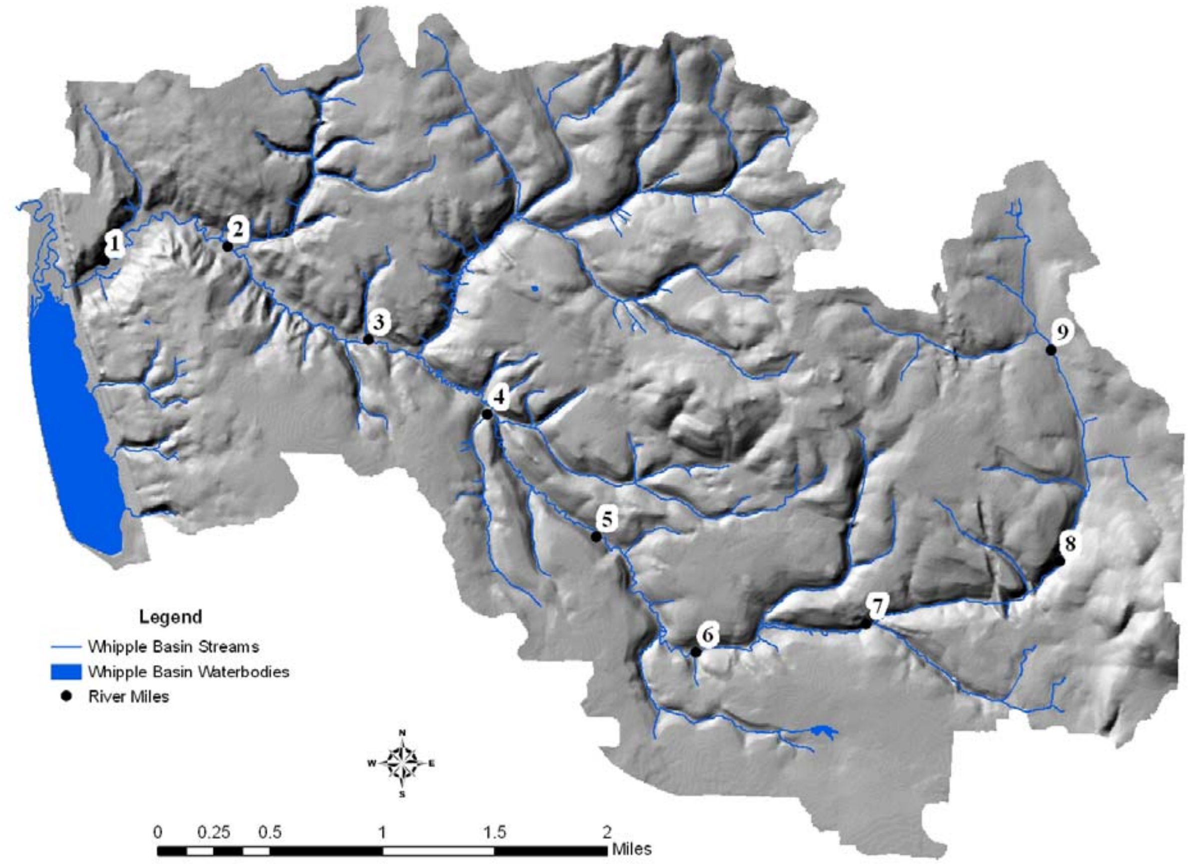

Figure 3. Hillshaded relief image of the Whipple Creek Basin.

2.3 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.

2.4 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 4). 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.

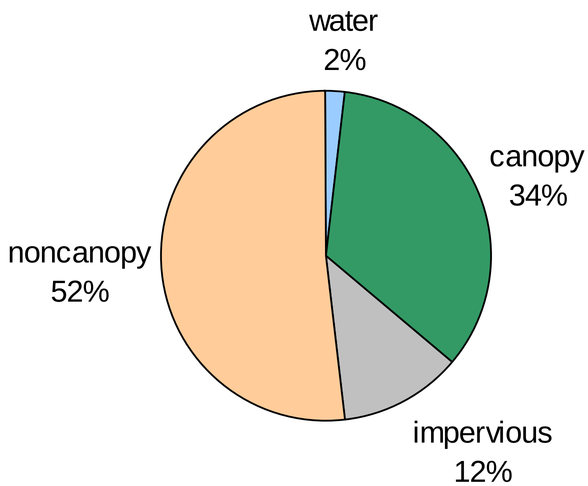

Figure 4. Pie chart of land cover characteristics in the Whipple Creek Basin. The data has been summarized from Clark County land cover GIS data. The land cover data was derived from 2002 LiDAR elevation data and 2002 infrared aerial photography.

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 redcedar (*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 redcedar, 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 redcedar, or western hemlock (*Tsuga heterophylla*), with a variety of understory species. Himalayan blackberry is often found as the dominant understory in these areas.

3. Land-use

3.1 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 redcedar, 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.

3.2 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.

4. Watershed processes

4.1 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.

4.1.1 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 5 and Figure 6). Areas of nominally pervious surfaces, which contain compacted soils, may significantly add to actual watershed imperviousness.

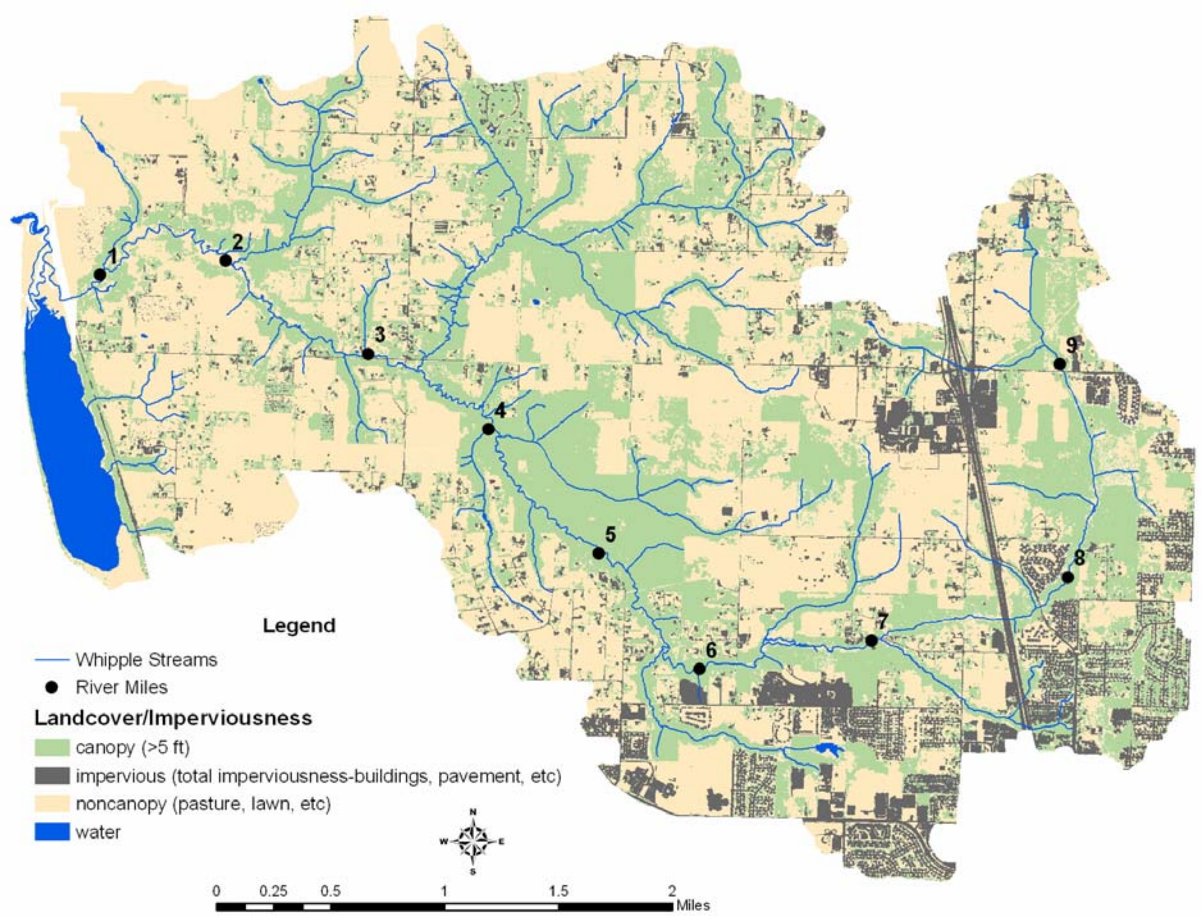

Figure 5. Land cover data/imperviousness for the Whipple Creek Basin. Source data provided by Clark County with minor edits conducted by Inter-Fluve. The land cover data was derived from 2002 LiDAR elevation data and 2002 infrared aerial photography. A significant amount of development has occurred since 2002. The current level of imperviousness therefore exceeds what is displayed.

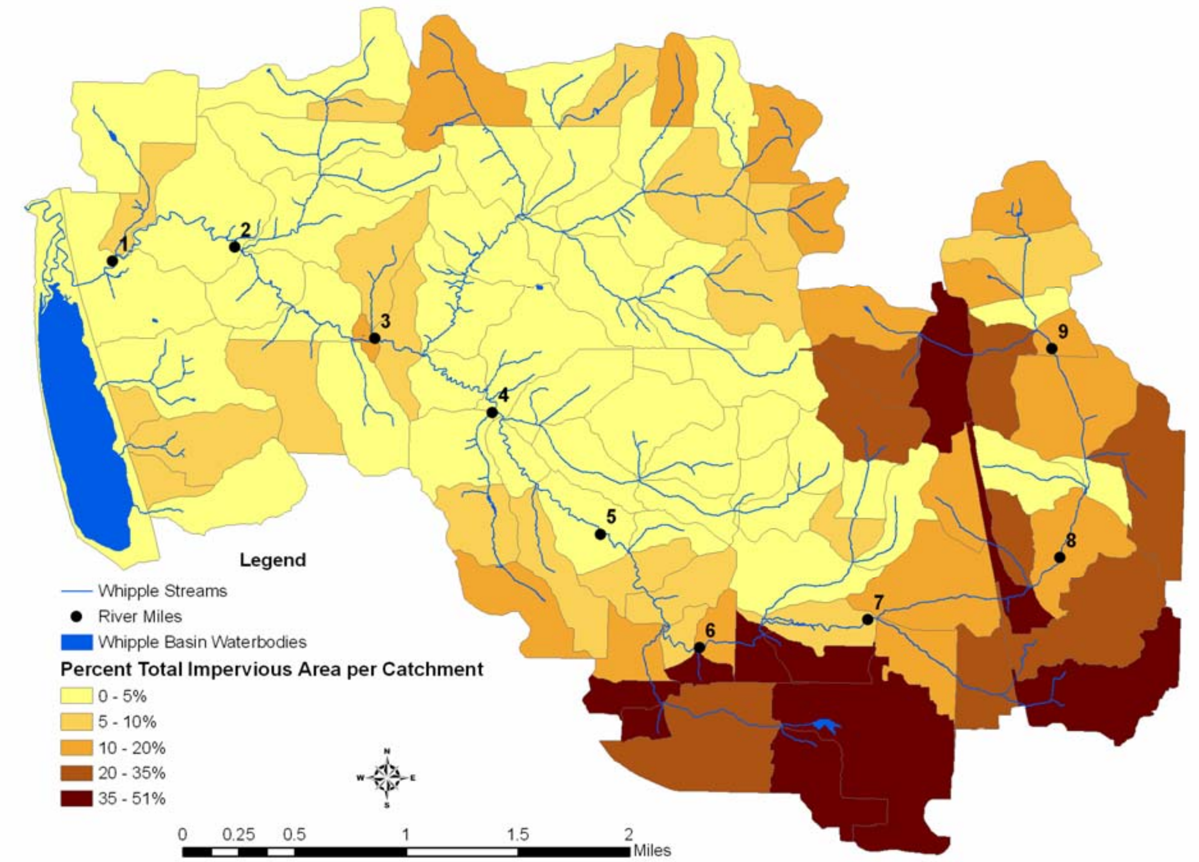

Figure 6. Percent Total Impervious Area by Catchment in the Whipple Creek Basin. Source data provided by Clark County with minor edits conducted by Inter-Fluve.

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 7. 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 8). 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.

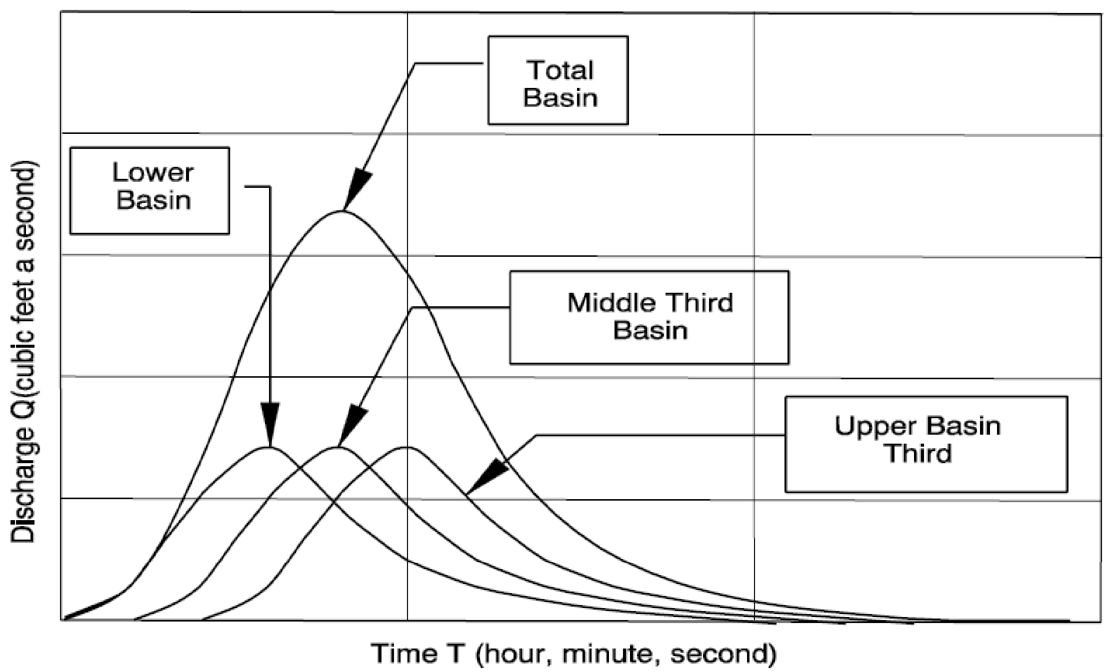

Figure 7. Hypothetical runoff hydrographs for an undeveloped basin. Reprinted from Oregon Department of Transportation (2005).

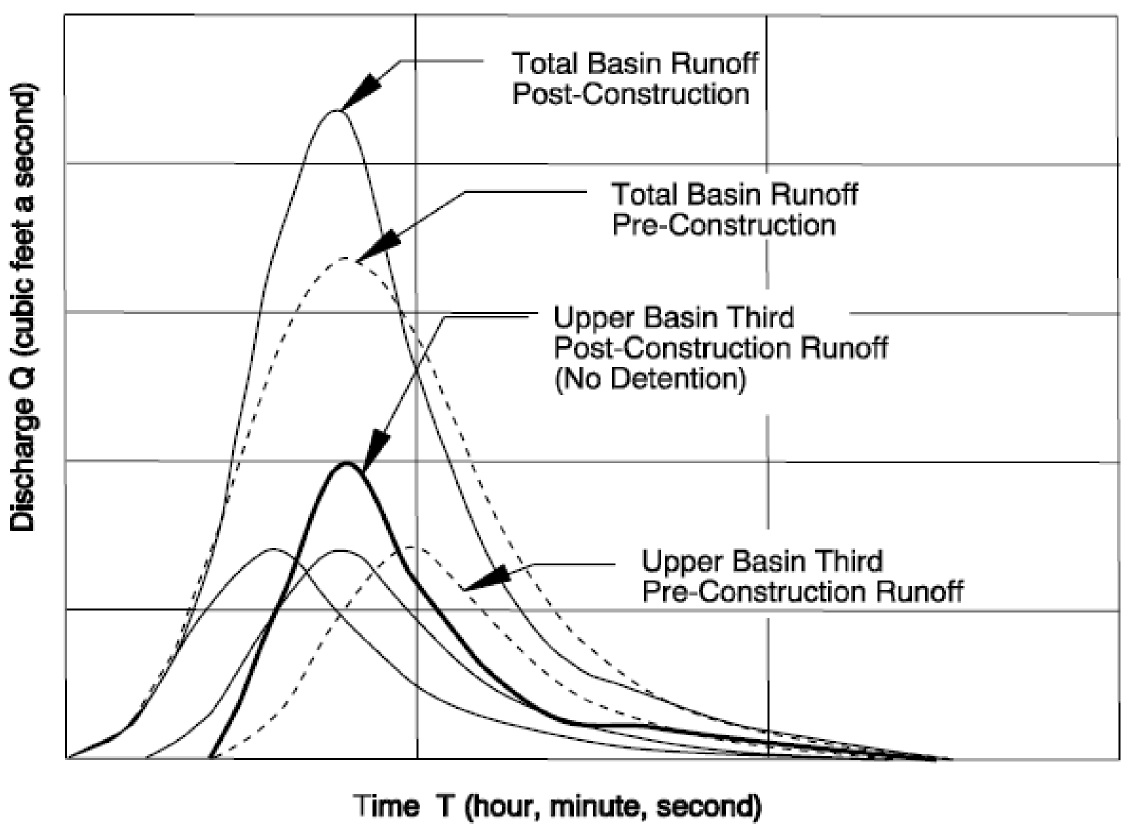

Figure 8. Hypothetical runoff hydrographs for a basin with development in the upper third of the basin. Reprinted from Oregon Department of Transportation (2005).

4.1.2 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.

4.2 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.

4.2.1 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 9.

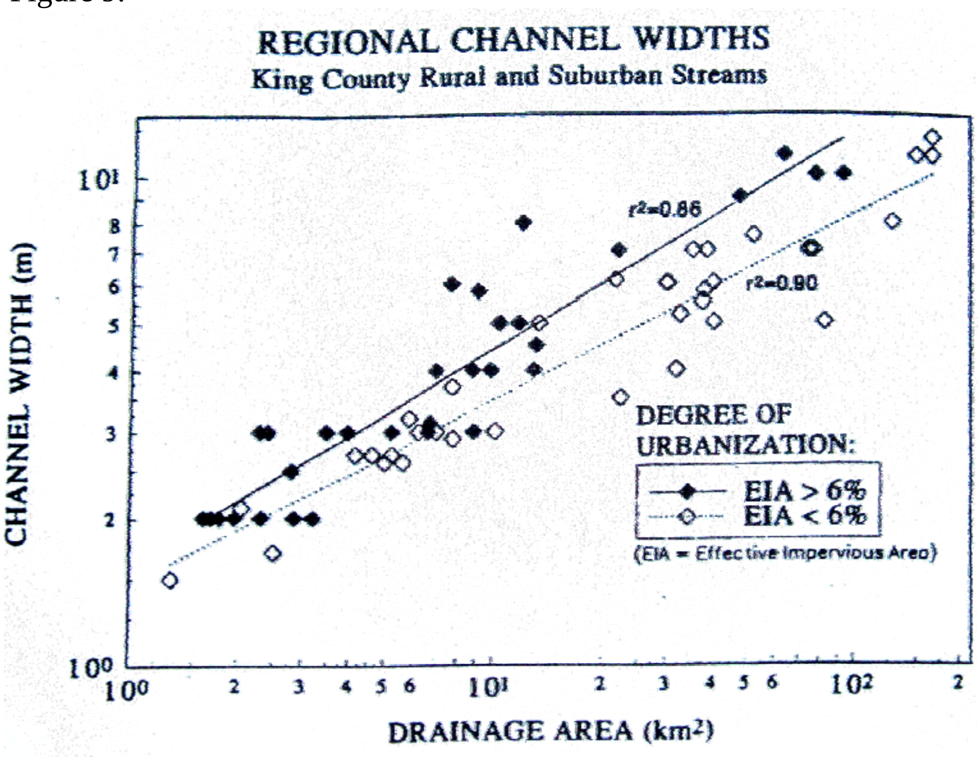

Figure 9. Channel widths as a function of imperviousness of the contributing drainage area (reprinted from Booth and Jackson 1997).

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 10).

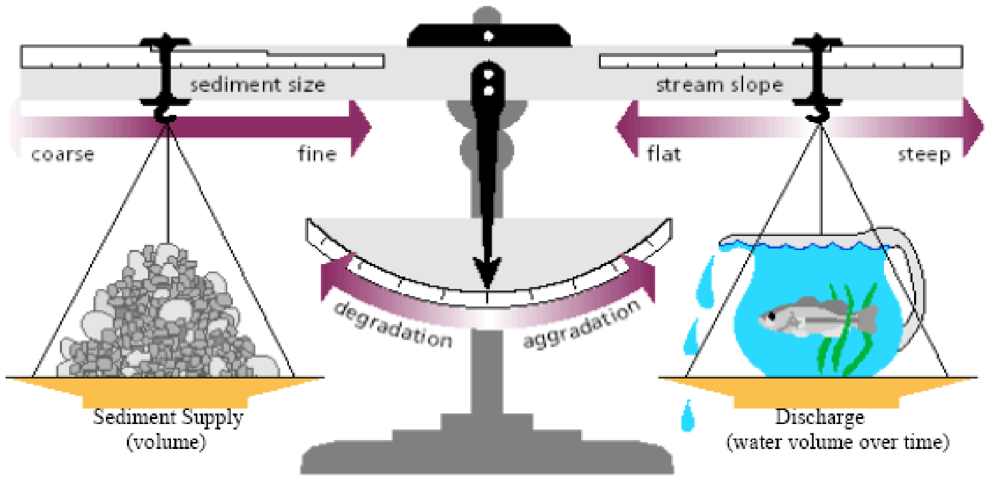

Figure 10. Lane's balance of the influence of stream slope, discharge, sediment size, and sediment supply on channel degradation and aggradation. From: Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering. In Proceedings of the American Society of Civil Engineers 81(745): 1-17.

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 11). 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.

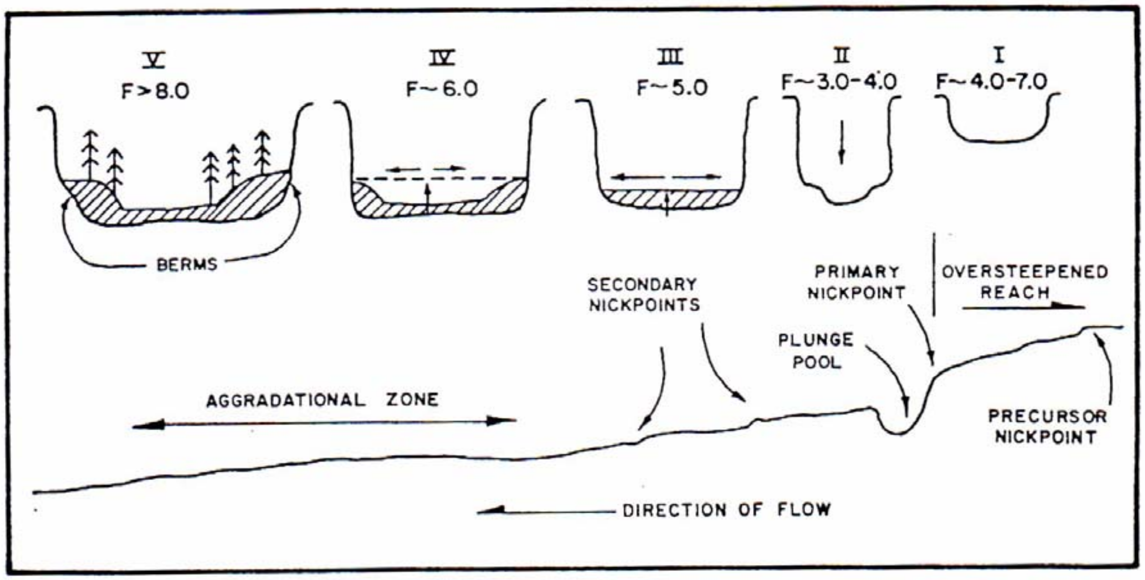

Figure 11. Stages of channel evolution in response to incision. Values of width-to-depth ratio F are included. (reprinted from Harvey and Watson 1986).

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.

4.2.2 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 12). 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.

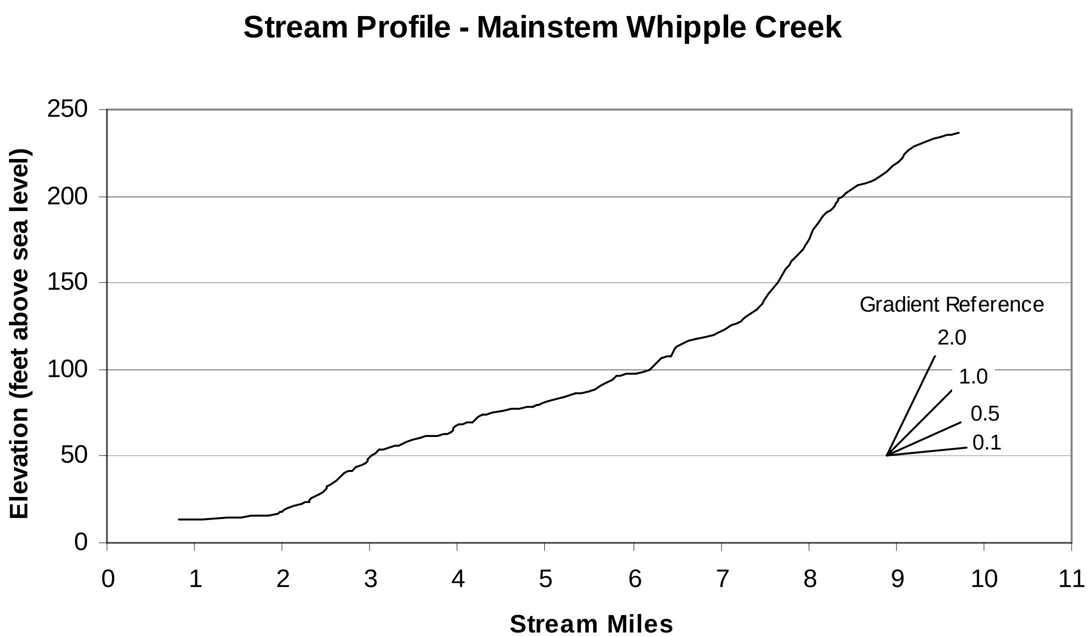

Figure 12. Stream profile for the mainstem of Whipple Creek.

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 13) 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 13. 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.

4.2.3 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 14.

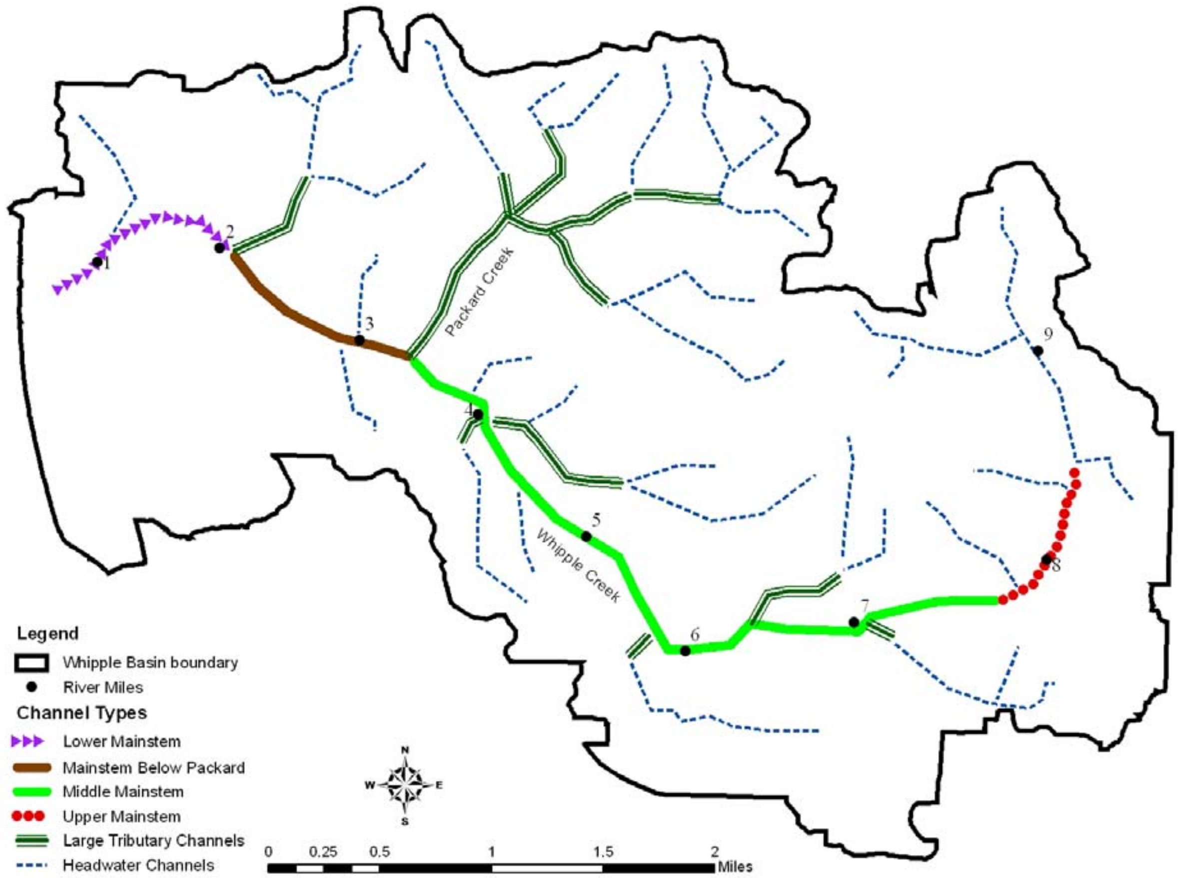

Figure 14. Map of channel type areas. This map is a generalization of the channel type areas that are discussed below. It does not reflect any formal channel typing for these streams and is only provided here as a reference for the information provided below.

4.2.3.1 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 (Section 4.5).

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 15), Whipple Creek Place (trib W6.26), on trib W5.70 T0.49S, and on trib W8.36 (see Figure 16); and outfalls at the school property (trib W5.70) and on trib P1.06 T0.49W.

Figure 15. 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 16. Photo of headcut just downstream of outlet of stormwater detention facility at headwaters of Trib W8.36. Approximate height of headcut is 6 feet.

4.2.3.2 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 17).

Figure 17. 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.

4.2.3.3 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 18 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 18. 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.

4.2.3.4 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 19). 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 19. Outcrop of Troutdale Formation in the mainstem below Packard Creek (approx. RM 2.6).

Figure 20. 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 20). 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 21). Overflow channels scour floodplains, increasing floodplain connectivity. Channel adjustments discourage invasive riparian vegetation and create soil conditions favorable to colonization by native vegetation. Figure 22 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 21. Accumulation of fine sediment as a result of backwater effects of log jam at approximately RM 2.9.

Figure 22. 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 23). The channel bed is sand and silt.

Figure 23. 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 24), 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 24. Evidence of recent over-bank flows at lawn area near RM 2.3.

4.2.3.5 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 25). 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 25. Arial photograph of lower Whipple Creek just upstream of NW Krieger Road crossing near the mouth.

4.2.3.6 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 2). 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 26). 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 26. 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 27). 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 27. Streambank erosion at lower Packard Creek just upstream of the confluence with mainstem Whipple Creek.

4.3 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.

4.3.1 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 28 for typical riparian conditions now found in the basin.

Figure 28. 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 29). Blackberries also dominate where there have been intrusions into the riparian corridor (e.g. roadways, utility corridors).

Figure 29. 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.

4.3.2 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 30).

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

4.4 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.

4.4.1 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.

4.4.2 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.

4.4.3 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.

4.4.4 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.

4.5 Wetlands

4.5.1 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 1^{st} 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 30). Depressional headwater wetlands are located at the headwaters of many 1^{st} 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.

4.5.2 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 31). 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 31. 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.

4.6 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 32.

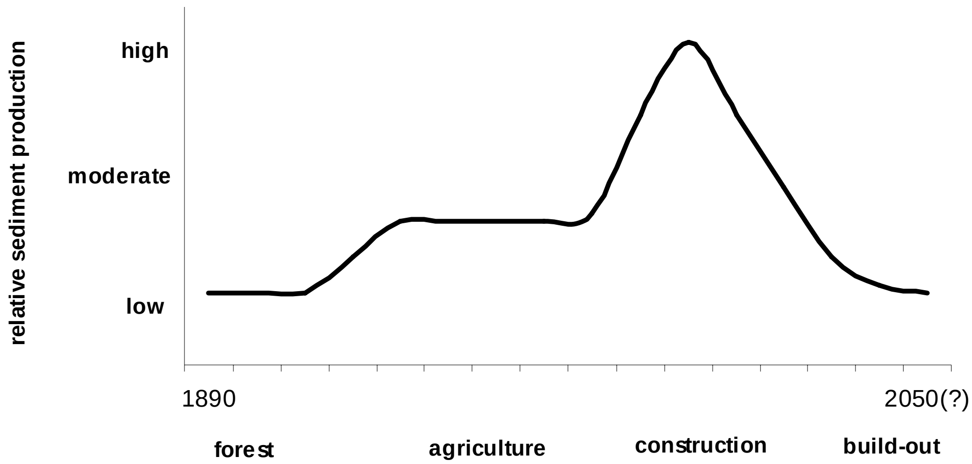

Figure 32. Conceptual diagram of estimated past, present, and future Whipple Creek Basin sediment production volumes.

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 33).

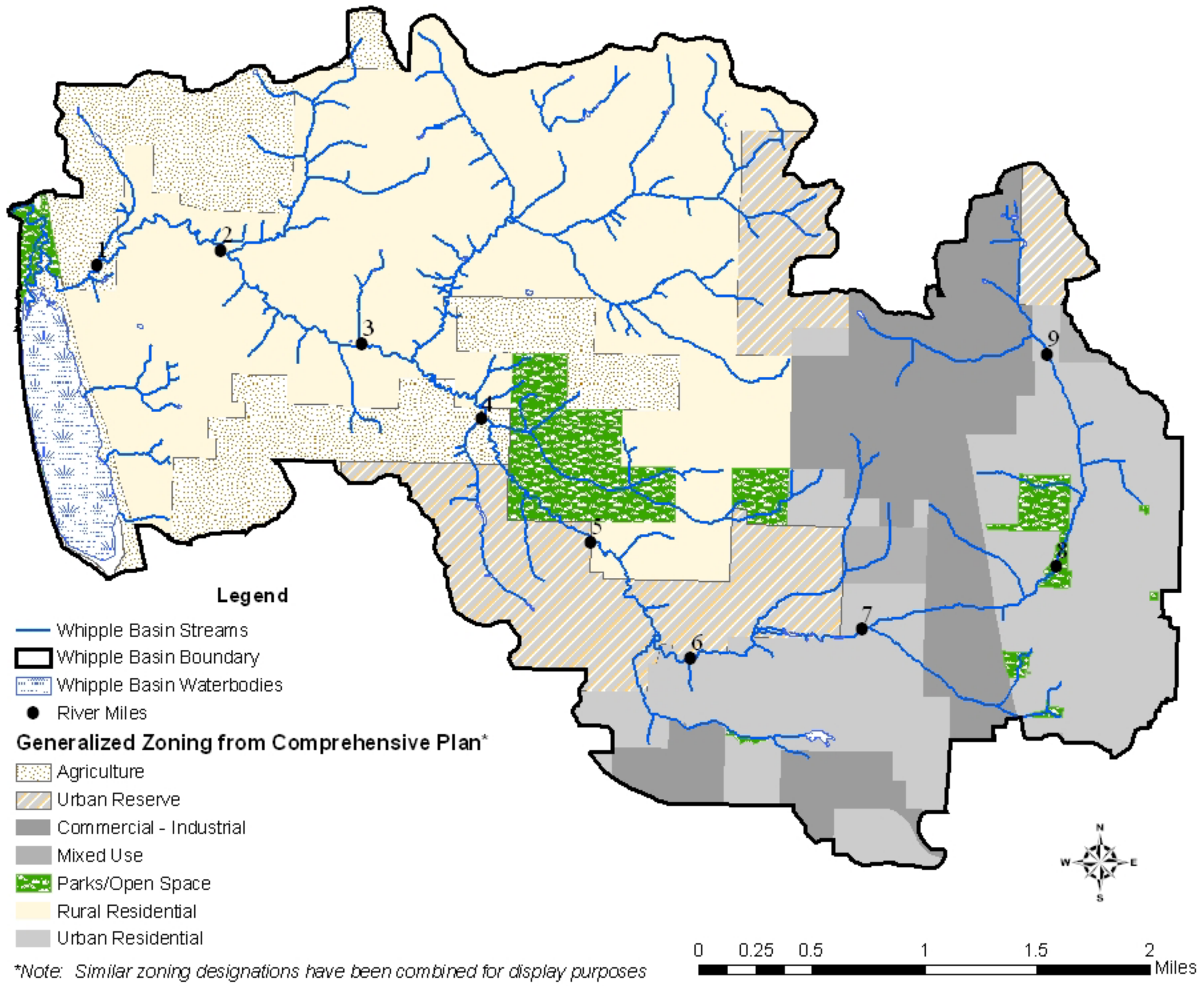

Figure 33. Generalized zoning designations from the Clark County Comprehensive Plan 2004. Original data obtained from Clark County GIS.

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 Section 4.1.1). 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).

5. 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.

5.1 Types of monitoring

5.1.1 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.

5.1.2 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.

5.1.3 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.

5.1.4 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.

5.1.5 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.

5.1.6 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.

5.2 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 1. The type of monitoring used to satisfy each objective is included.

Table 1. 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.

5.3 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).

5.4 Monitoring parameters and techniques

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

5.4.1 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 Section 5.3) 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.

5.4.2 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.

5.4.3 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.

5.4.4 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

5.4.4.1 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.

5.4.4.2 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.
- 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.

5.4.4.3 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.

5.4.5 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.

5.4.6 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.

5.4.7 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.

5.5 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 (Section 5.4.4.3), 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 1^{st} 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.

5.6 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).

6. Improvement measures

6.1 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 34. 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 2 lists potential objectives for areas of the basin. The areas are depicted in Figure 35.

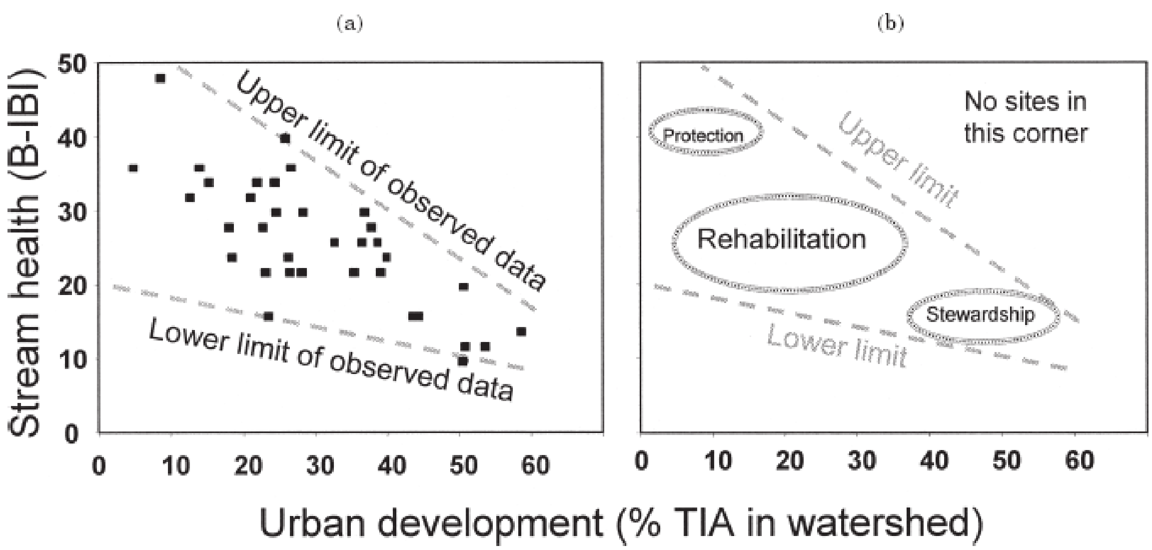

Figure 34. TIA related to stream health using B-IBI scores (a) and the objectives for management (b). Reprinted from Booth et al. (2004).

Table 2. 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
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.

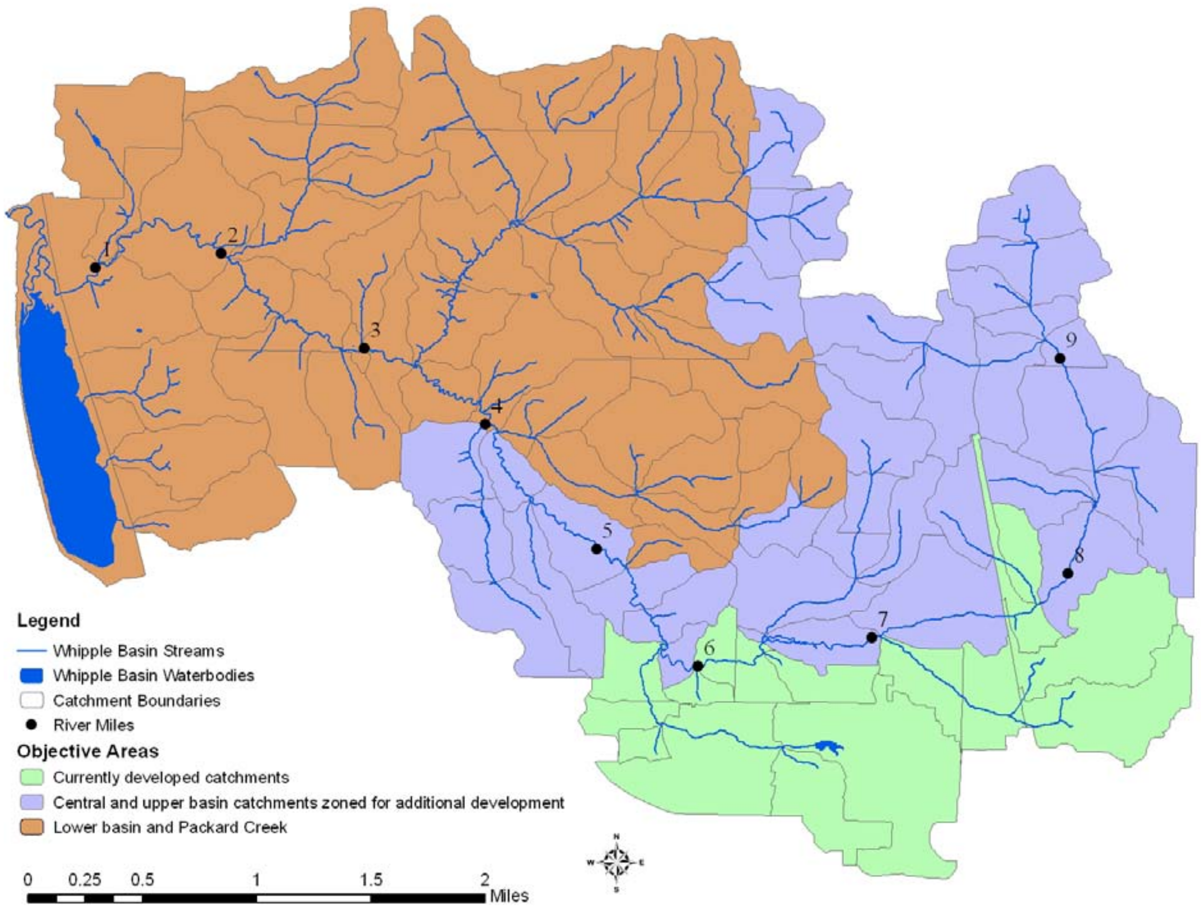

Figure 35. Map of Whipple Basin catchments highlighted according to the management objectives included in Table 2.

6.2 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.

6.3 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 Sections 4.2.3.1 and 6.4.2 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 Sections 4.5.2 and 6.4.5). 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 in Sections 4.3.1 and 6.4.9, 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.

6.4 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.

6.4.1 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 36. 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.

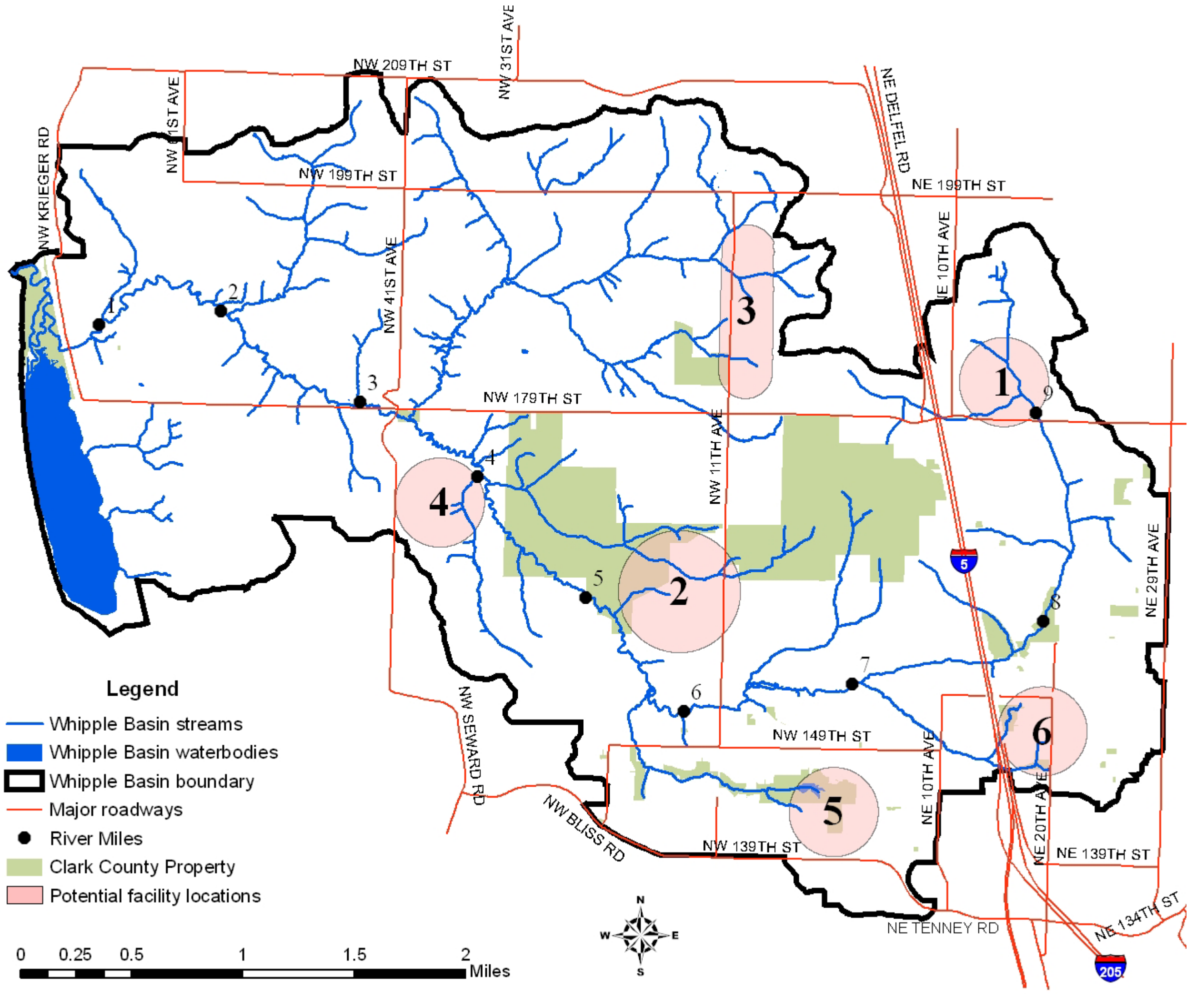

Figure 36. Potential locations for regional stormwater detention facilities. Numbers refer to the list and description of locations in Section 6.4.1.

6.4.2 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.

6.4.3 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

6.4.4 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 37 for an example photograph

Figure 37. 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 in Section 5.4.4). 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.

6.4.5 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 Section 5.4.4 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 38 for an example photograph

Figure 38. 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 in Section 6.4.2
- Other headcuts identified through Clark County surveys.

6.4.6 Large woody debris – valley jams

Considerations

- Large, floodplain-spanning jams can be used in 1st-3rd 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 1st – 3rd 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.

6.4.7 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 39


Figure 39. 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.

6.4.8 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.

6.4.9 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 40

Figure 40. Riparian revegetation 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.

6.4.10 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 41)

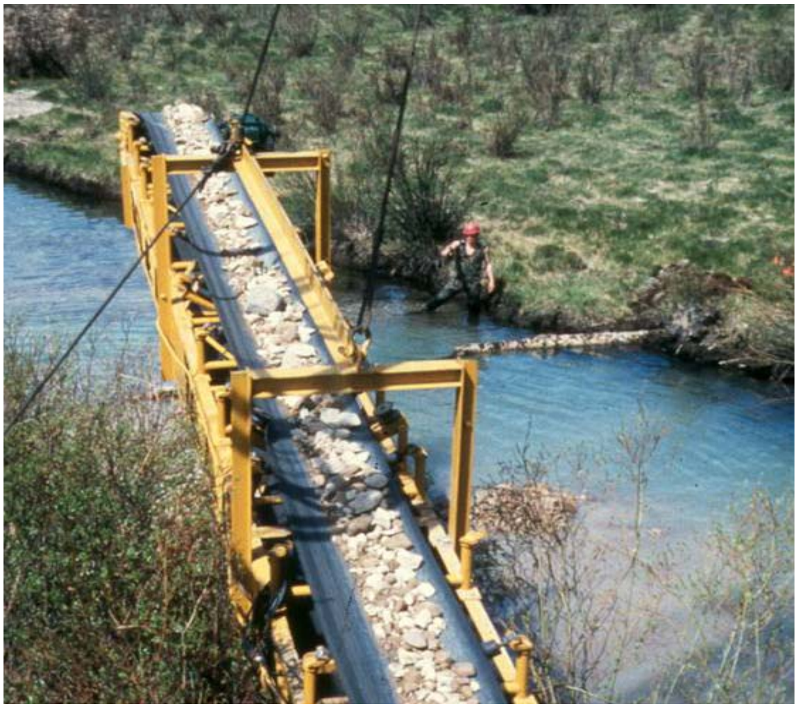

Figure 41. Conveyor placing substrate (cobbles and gravels), Ruby River, Montana.

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 doubtfull whether anadromous fish could pass through the middle mainstem, I-5 culverts, and Union Road culvert to access this area for spawning.

6.4.11 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 42)

Figure 42. 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.

6.4.12 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.

6.4.13 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.

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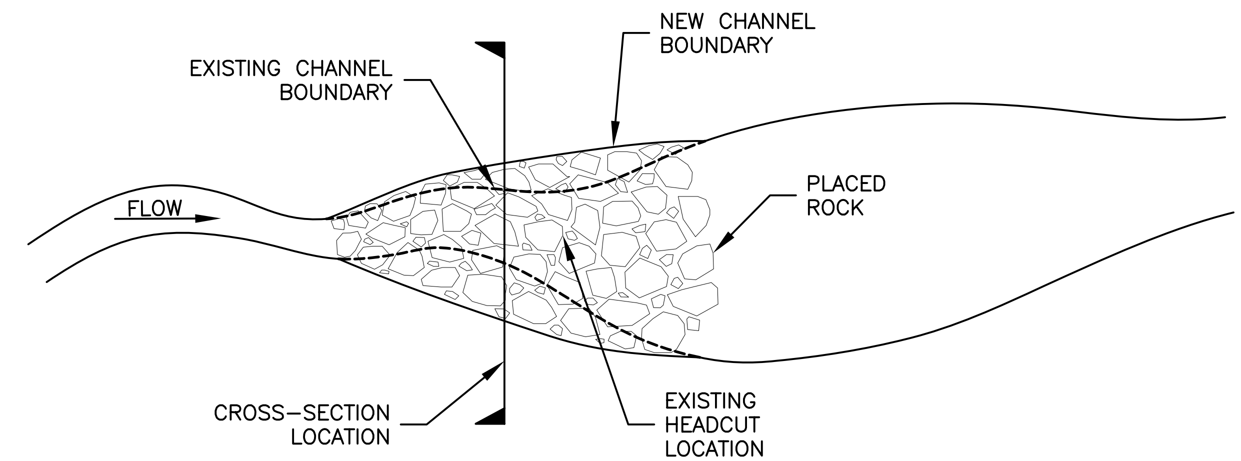
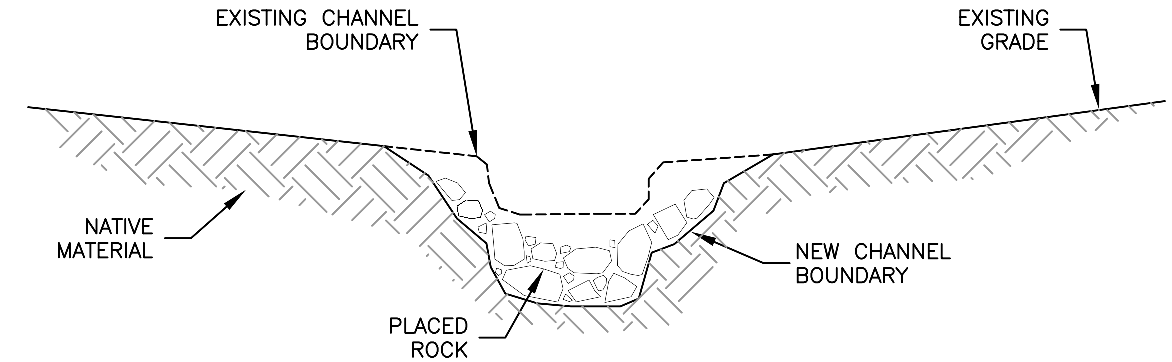
Attachment A

Conceptual Designs for Improvement Projects



PLAN VIEW:
TYPICAL LARGE HEADCUT
NOT TO SCALE



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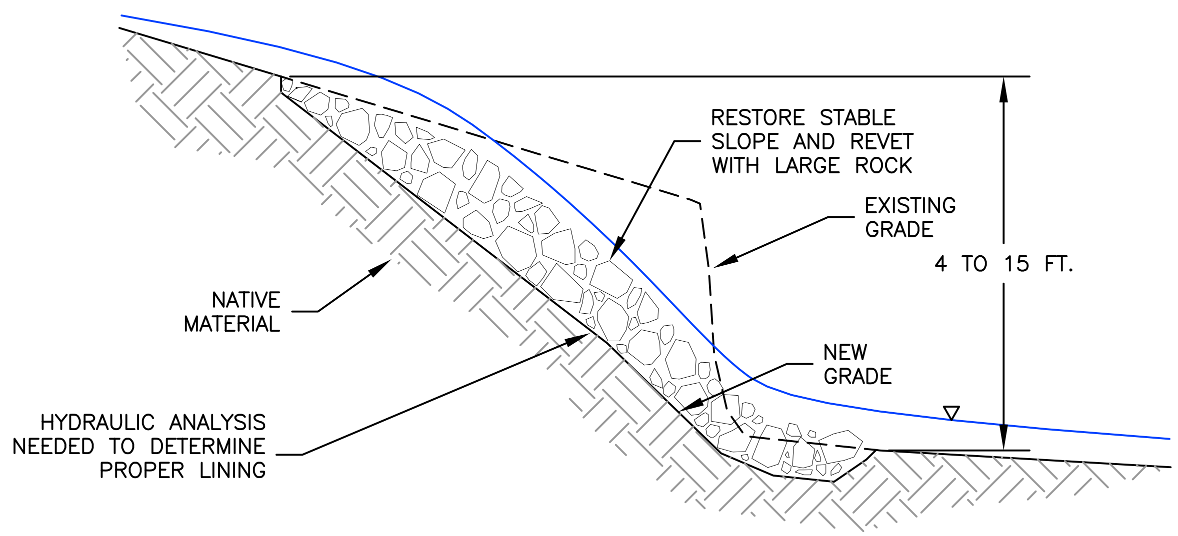

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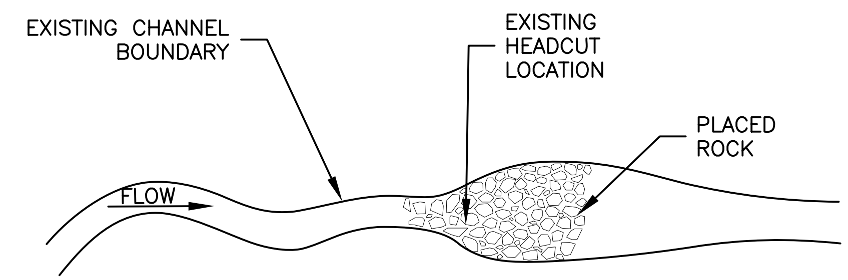

PLAN VIEW:
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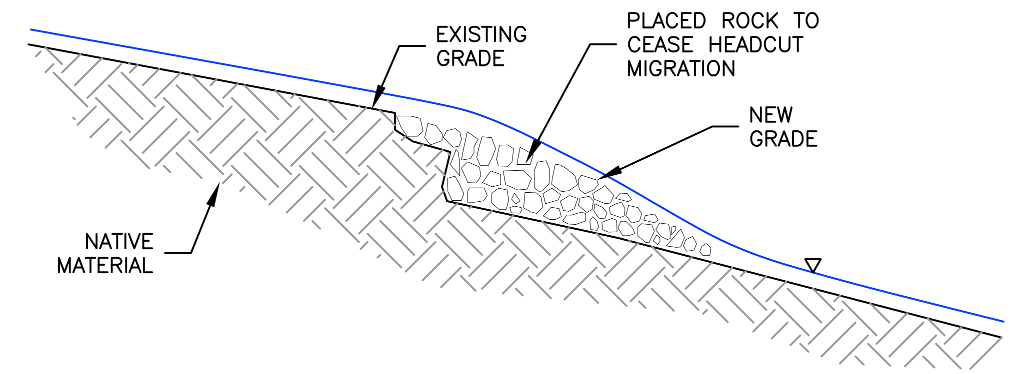

PROFILE VIEW:
TYPICAL SMALL HEADCUT
NOT TO SCALE

*NOTE: HEADCUT REVETMENTS INCORPORATING WOODY DEBRIS CAN BE UTILIZED TO ENHANCE AESTHETICS

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Headcut Revetment Conceptual Design

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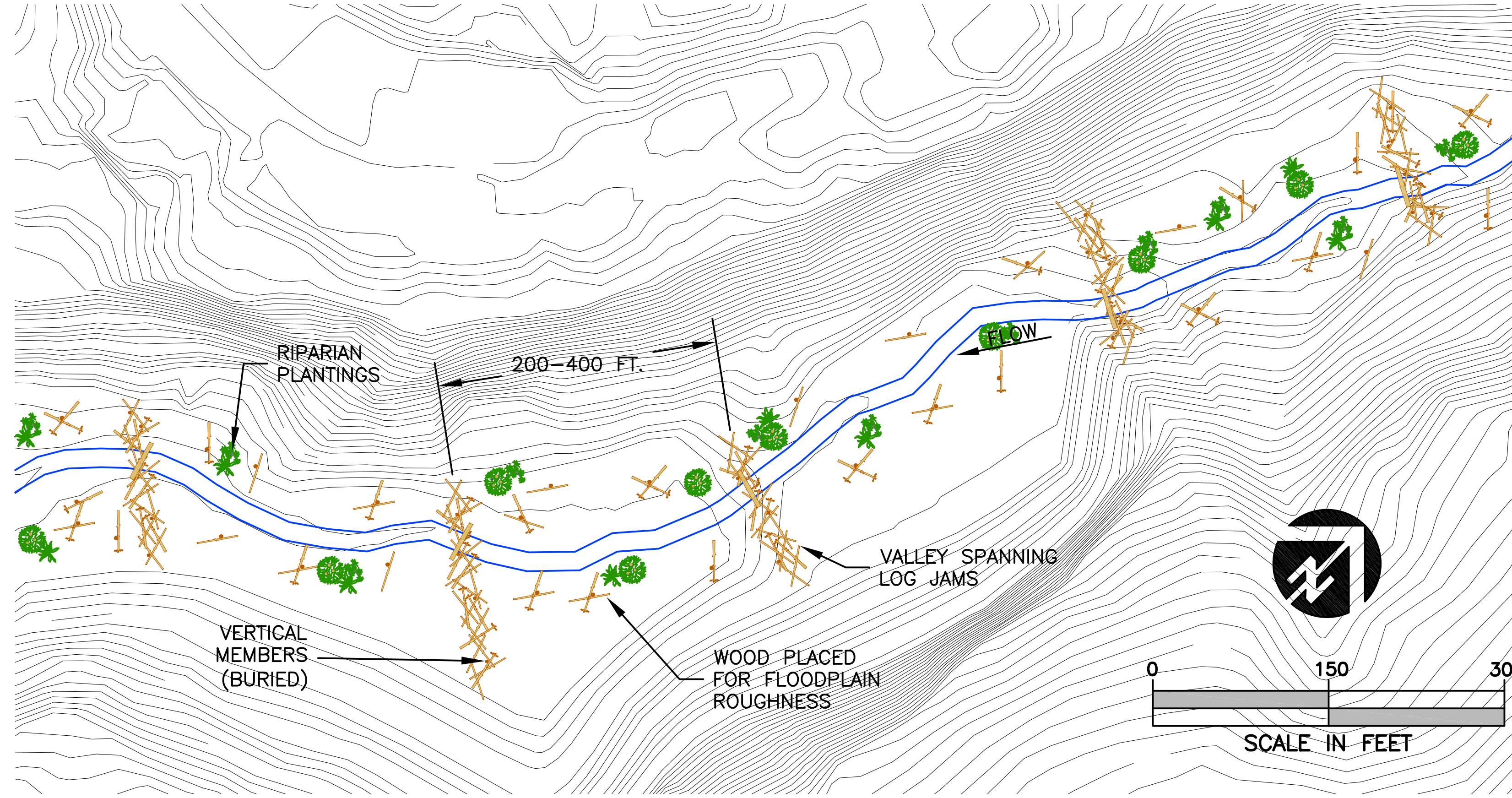
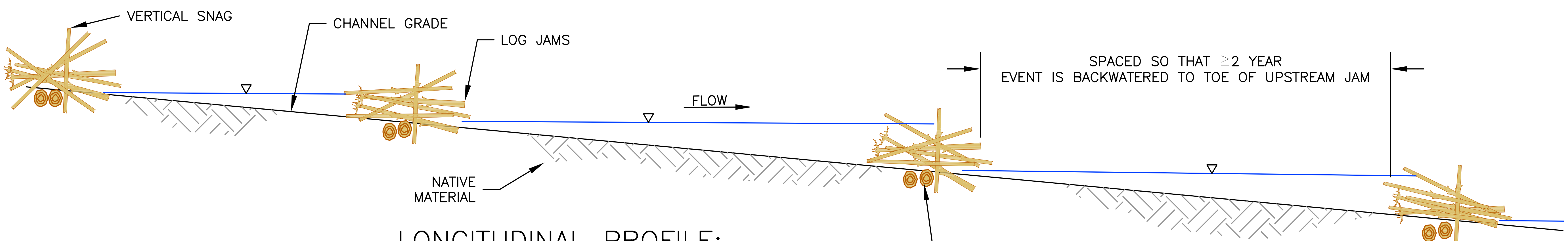
1 OF 7





LONGITUDINAL PROFILE: TYPICAL LOG JAM PLACEMENT

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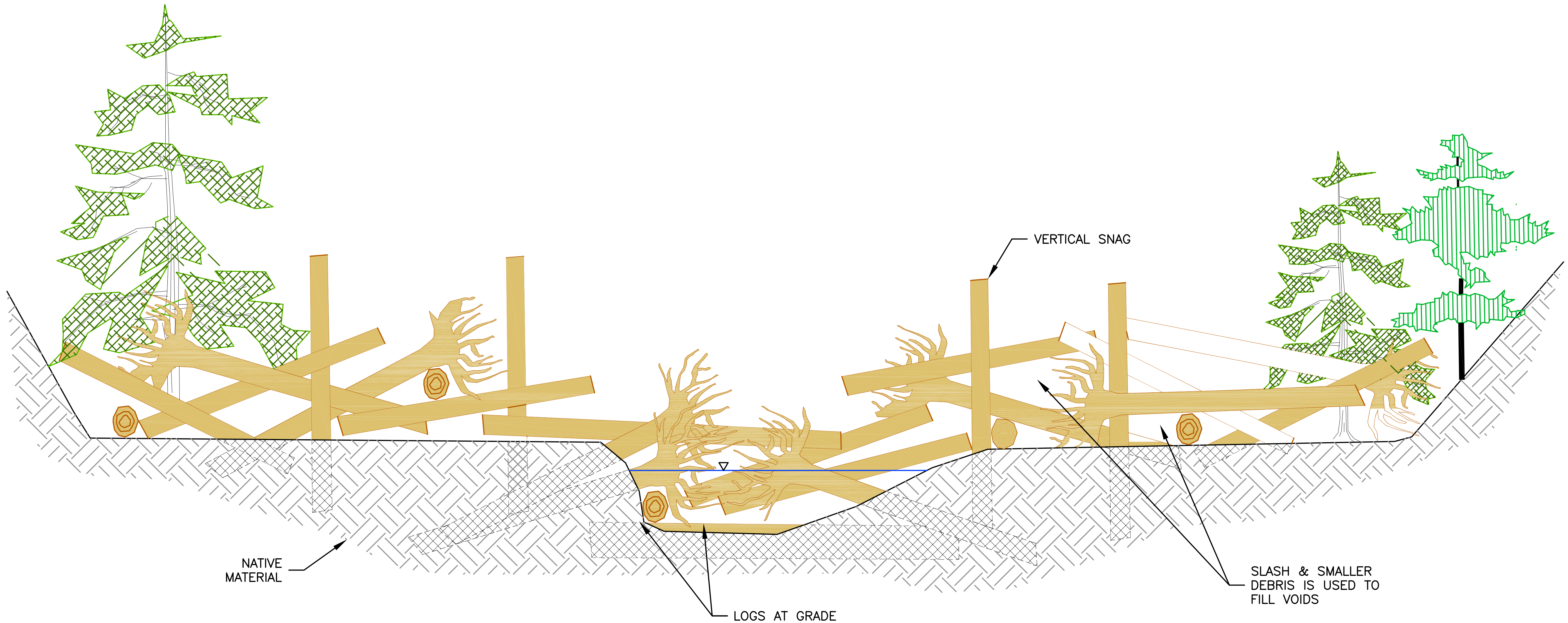
Valley Spanning Log Jams
Conceptual Design



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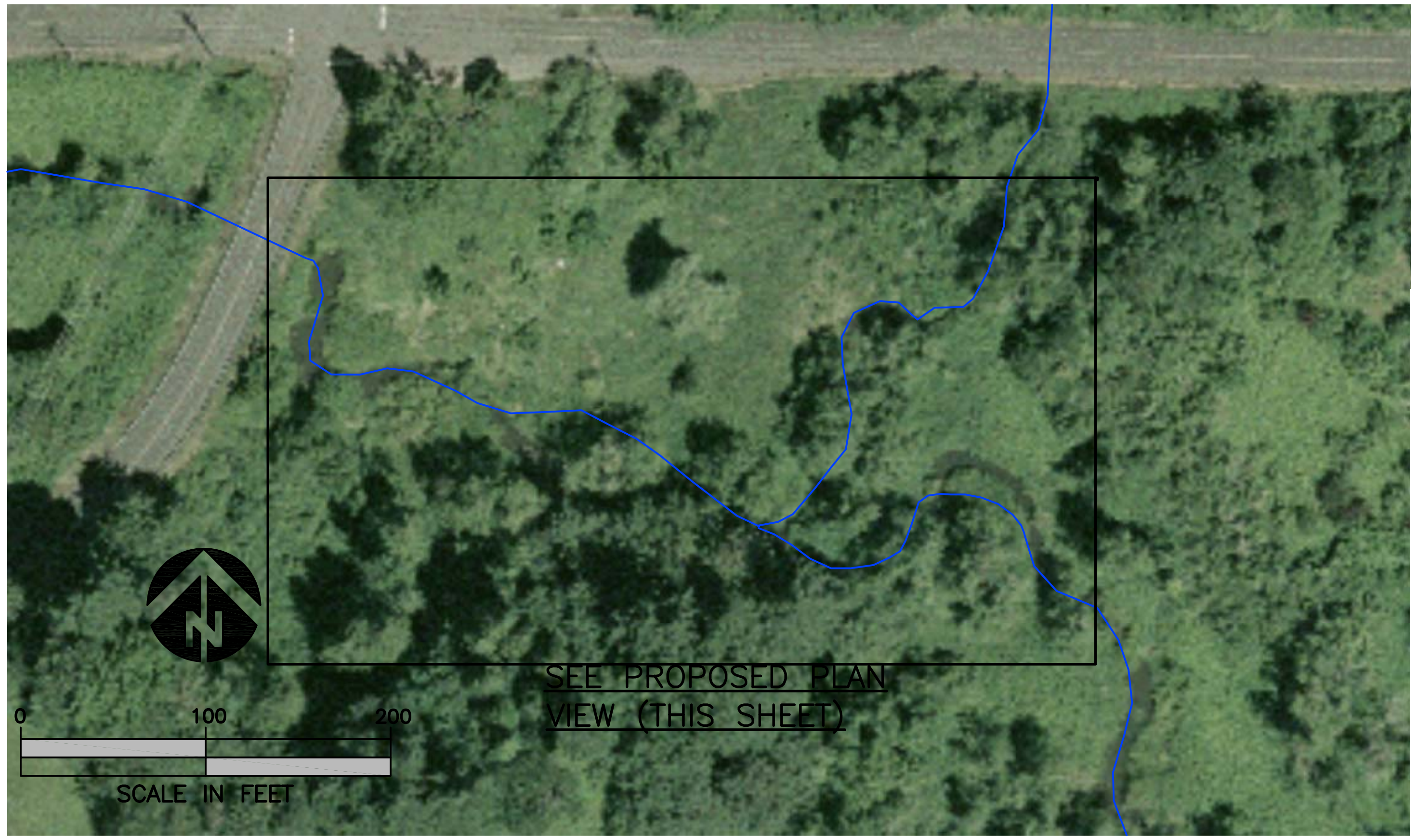

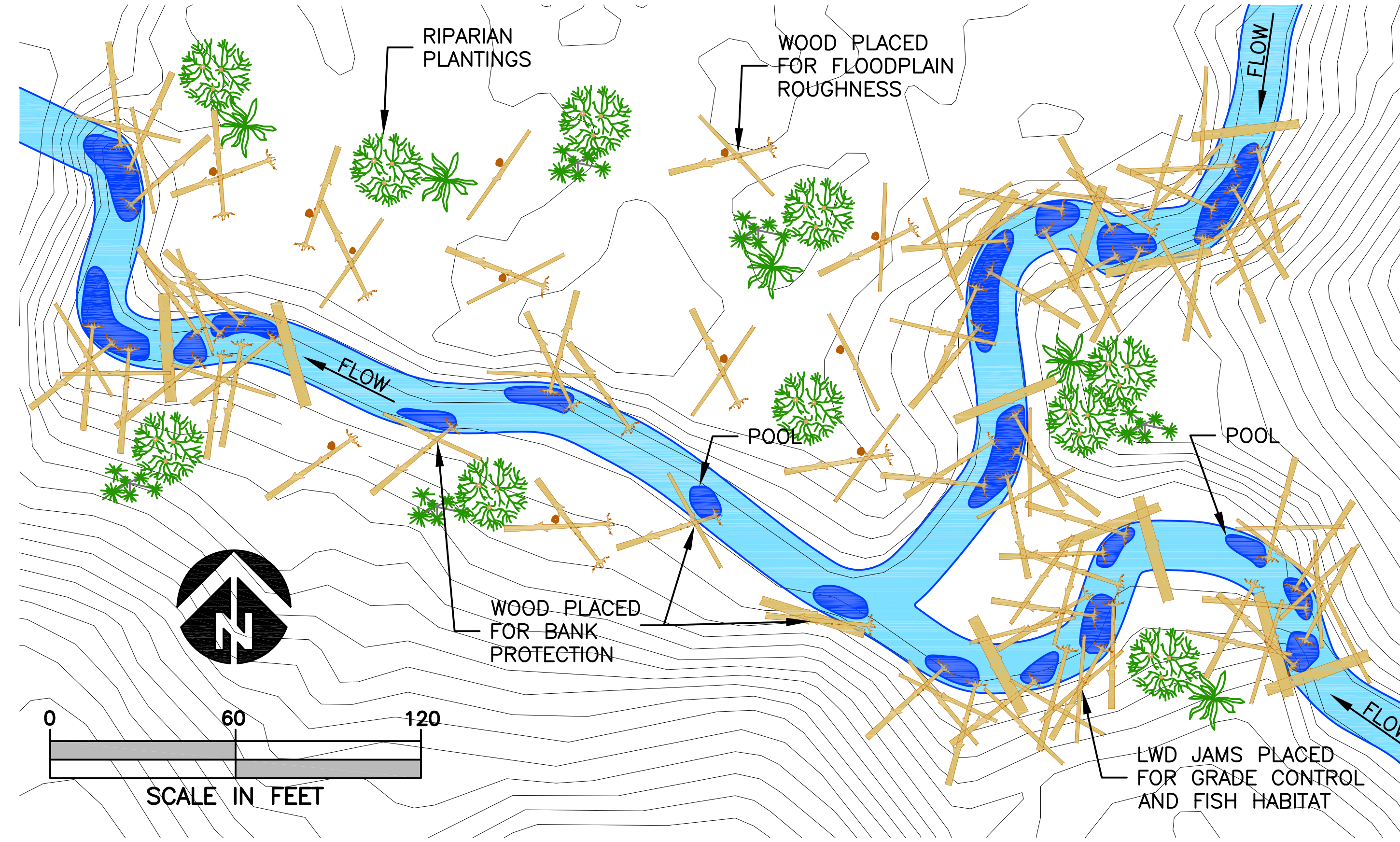

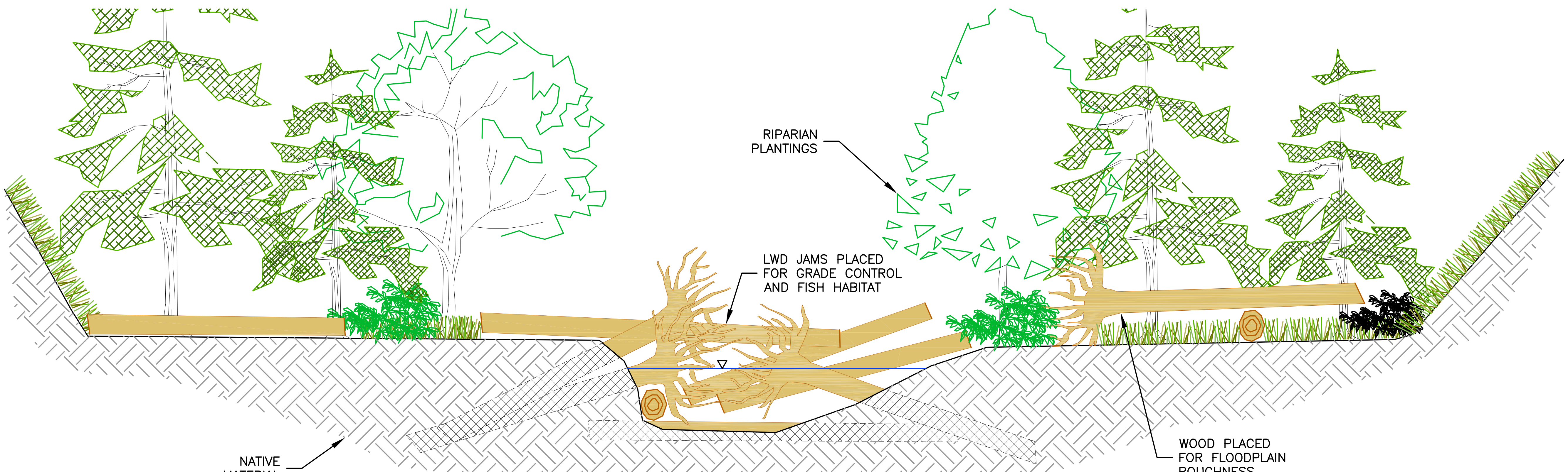

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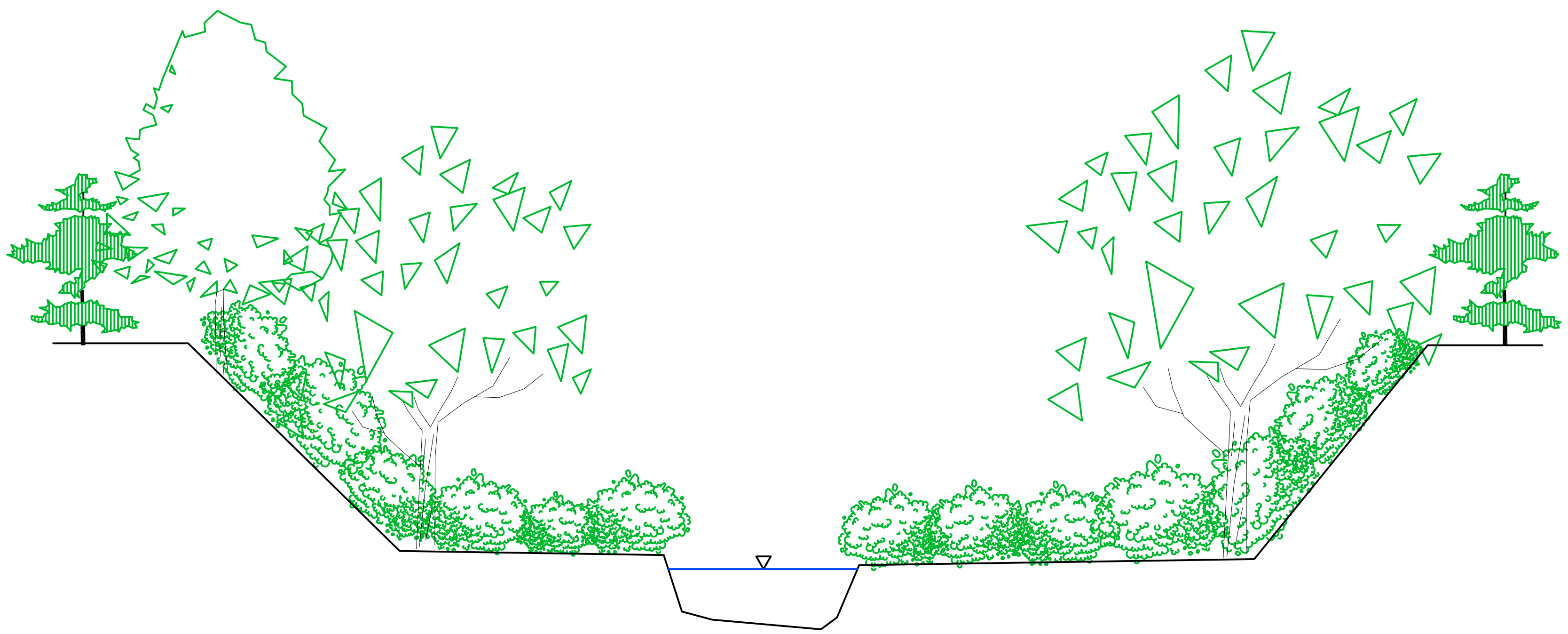
Woody Debris Supplementation
Conceptual Design

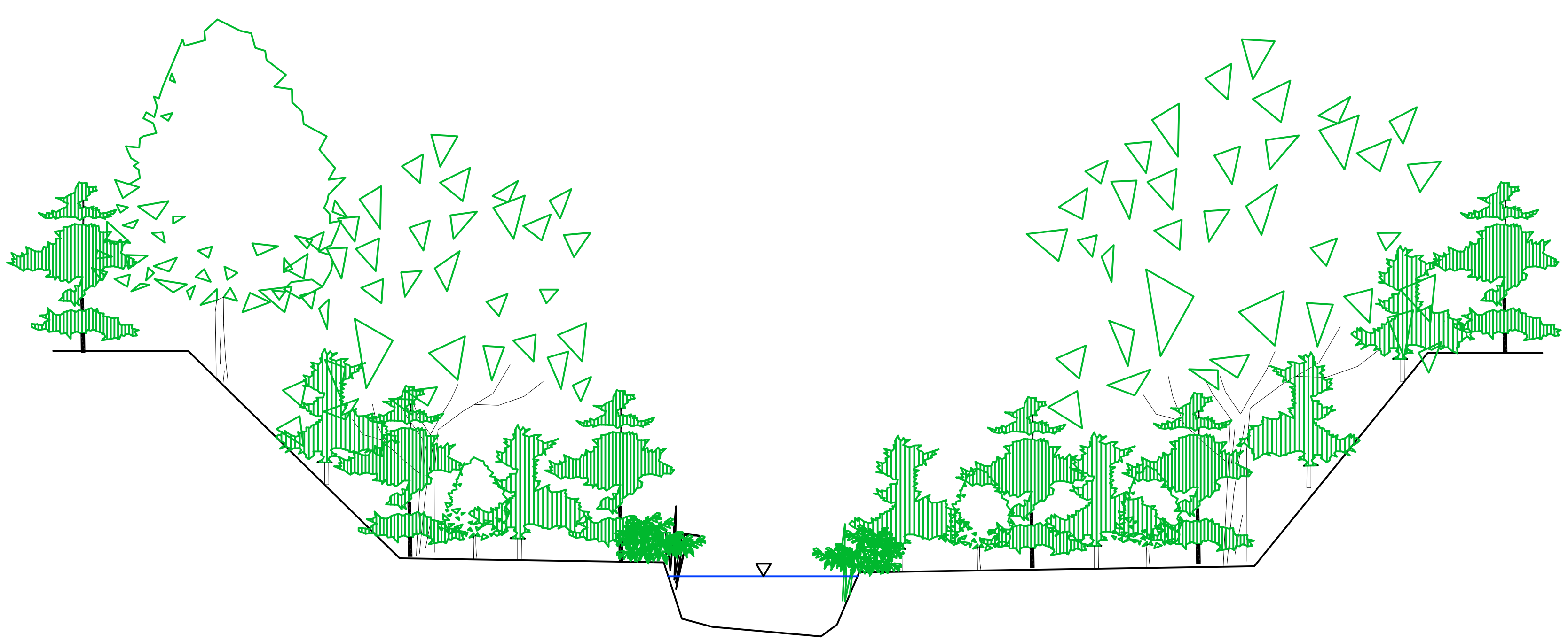
INFREQUENTLY INUNDATED FLOODPLAIN



TYPICAL CROSS–SECTION: EXISTING CONDITIONS

NOT TO SCALE

- OVERSTORY: MATURE ALDERS AND BIG LEAF MAPLE WITH NO YOUNG RECRUITS
- UNDERSTORY: BLACK BERRY THICKETS



TYPICAL CROSS–SECTION: PROPOSED CONDITIONS

NOT TO SCALE

- SELECTIVELY REMOVE BLACKBERRY THICKETS
- PLANT RIPARIAN SPECIES NEAR STREAM (E.G. WILLOWS, DOGWOOD)
- PLANT LARGE CEDAR, ALDER, BIG LEAF MAPLE (5–10 FEET TALL)

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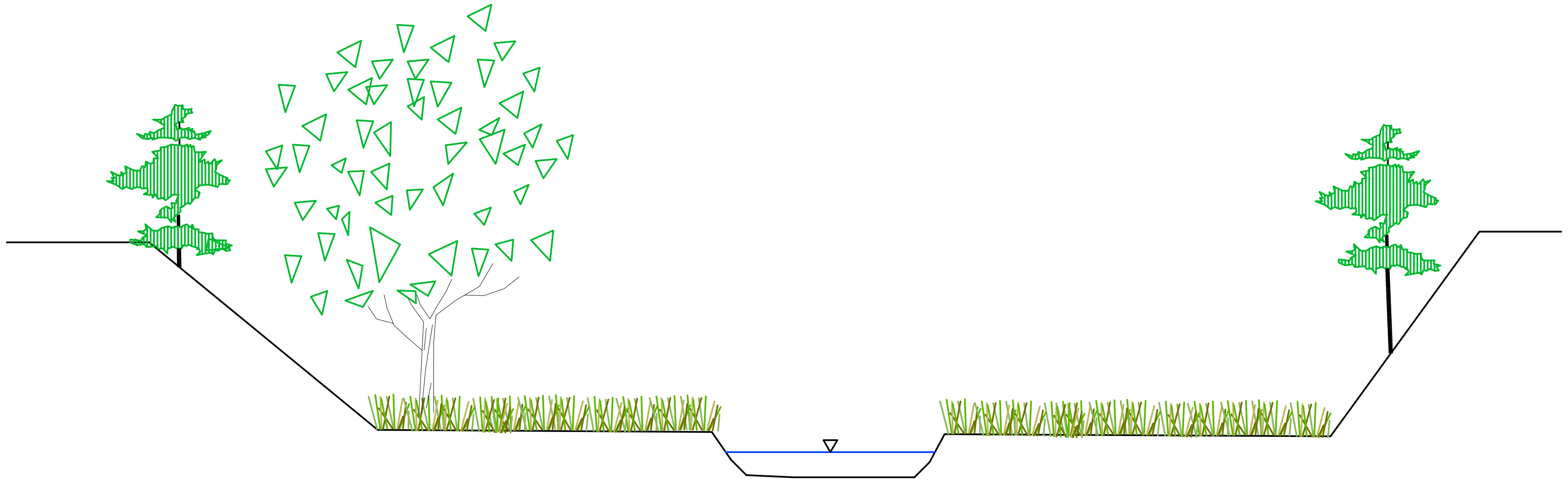
Floodplain Riparian Prescription
Blackberry Understory

FREQUENTLY INUNDATED FLOODPLAIN



TYPICAL CROSS–SECTION: EXISTING CONDITIONS

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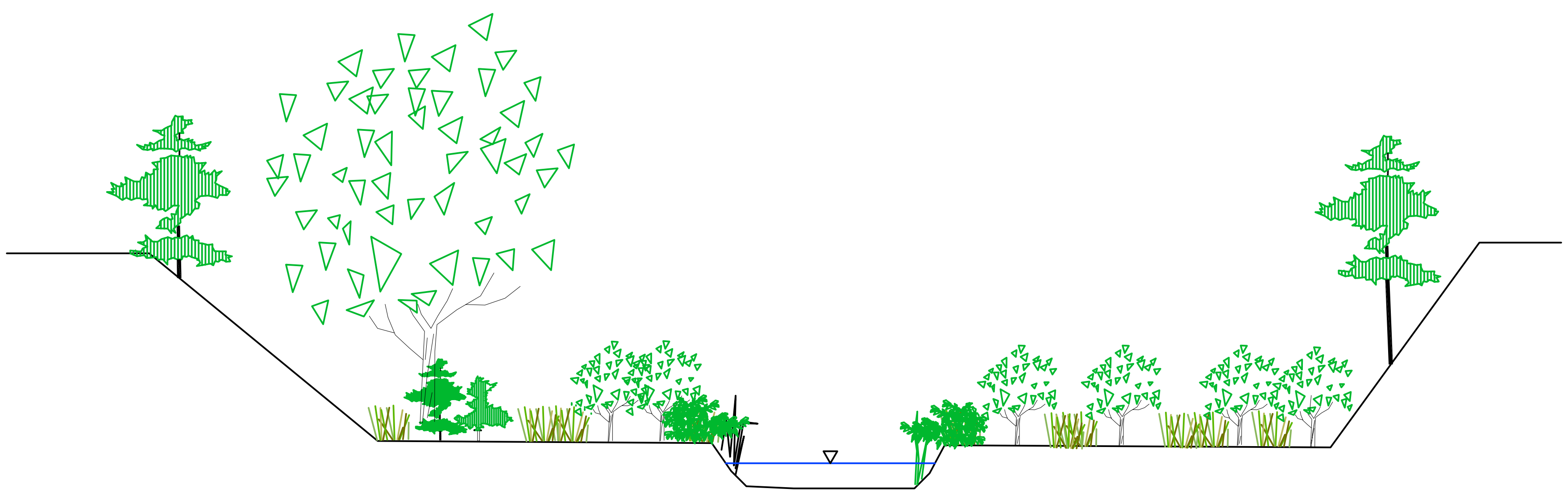
- OVERSTORY: SPARSE ALDERS AND BIG LEAF MAPLE WITH NO YOUNG RECRUITS
- UNDERSTORY: REED CANARY GRASS



TYPICAL CROSS–SECTION: PROPOSED CONDITIONS

NOT TO SCALE

- SELECTIVELY REMOVE REED CANARY GRASS
- PLANT ASH AND ALDER IN MOIST PLACES
- PLANT CEDAR IN DRIER SITES WITH SHADE
- PROVIDE BRUSH AND BEAVER CONTROL FOR NEW PLANTINGS.

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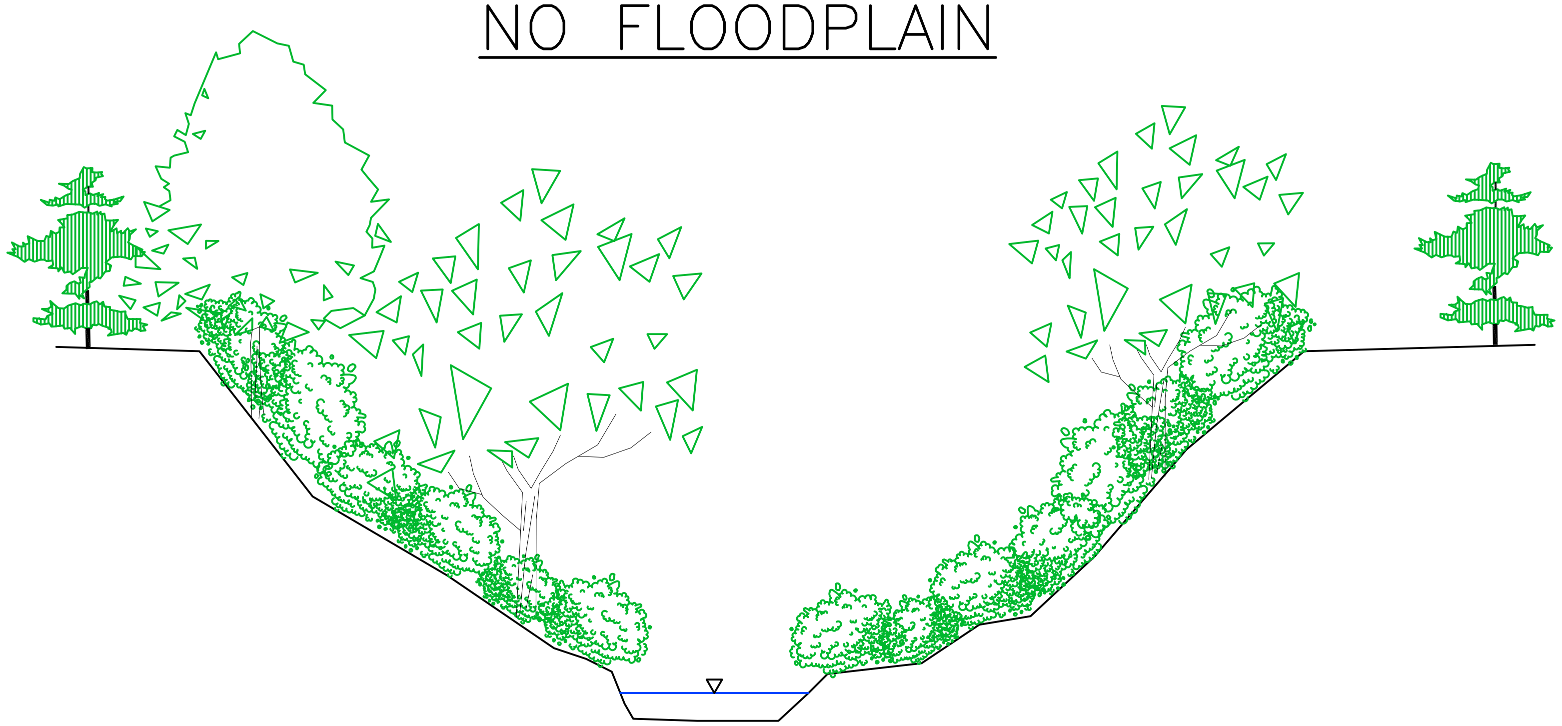
Floodplain Riparian Prescription
Reed Canary Grass Understory

NO FLOODPLAIN



TYPICAL CROSS–SECTION: EXISTING CONDITIONS
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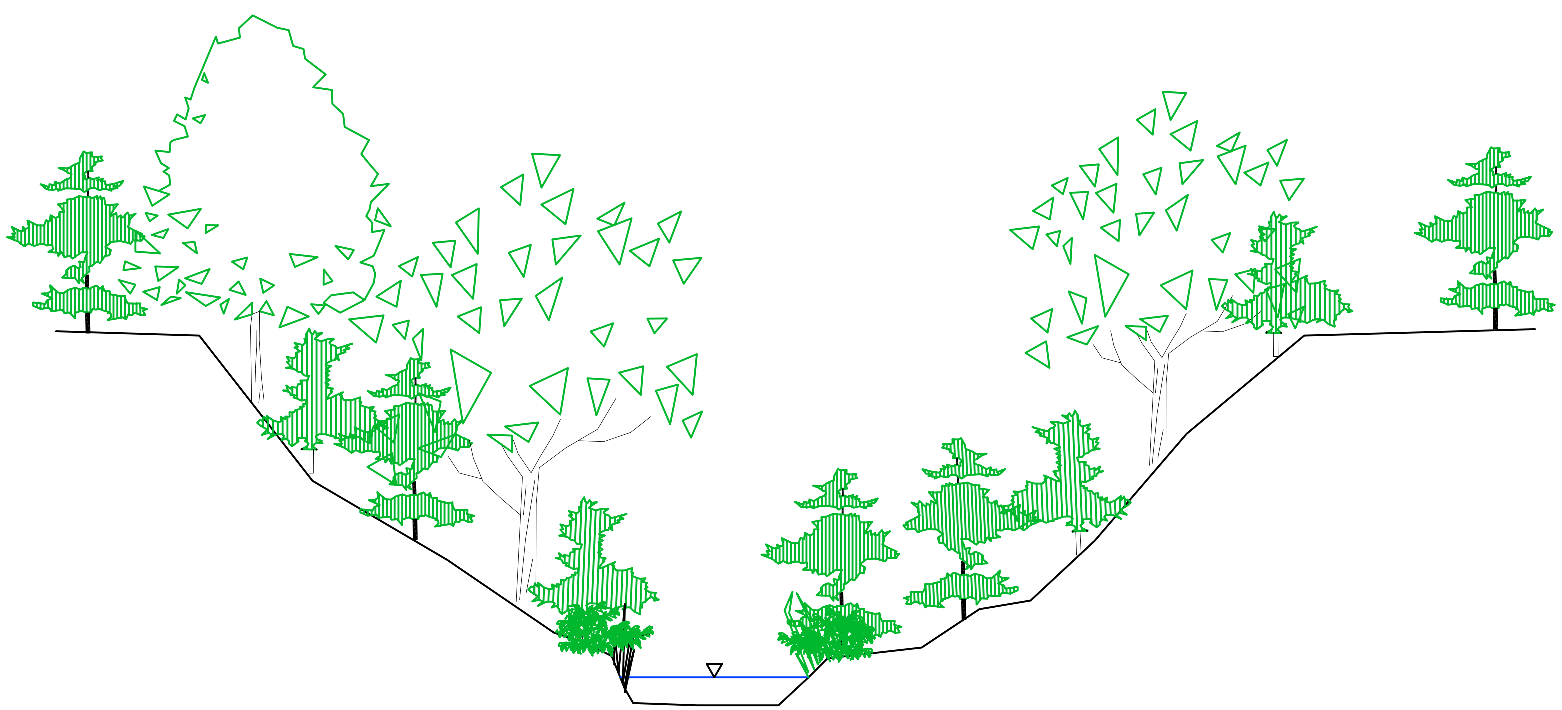
- UNDERSTORY: BLACK BERRY THICKETS



TYPICAL CROSS–SECTION: PROPOSED CONDITIONS
NOT TO SCALE

- SELECTIVELY REMOVE BLACKBERRY THICKETS
- PLANT RIPARIAN SPECIES NEAR STREAM (E.G. WILLOWS, DOGWOOD)
- PLANT LARGE CEDAR, FIR, AND HEMLOCK (5 – 10 FT. TALL)

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Narrow Valley Riparian Prescrip.
Blackberry Understory

SHEET 7 OF 7