Geomorphology and Hydrology Assessment
for
Upper Gee Creek

by

WEST CONSULTANTS, INC.

2601 25th Street SE, Suite 450
Salem, OR 97302

for

Clark County, Washington

Department of Public Works
Clean Water Program
1300 Franklin Street
Vancouver, WA 98666

June 3, 2008

TABLE OF CONTENTS

Figures

Tables

Appendices

1 Purpose

A geomorphology and hydrology assessment was conducted for Gee Creek to help understand the dynamic processes at work within the basin and their interrelation with human influences. This understanding is used to provide insights into the mechanisms that create real or perceived watershed and stream corridor impairments. Additionally, the assessment provides an understanding of how basin physical conditions and processes influence current and potential future hydrology, channel morphology, flooding, channel erosion, water quality and fish and wildlife habitat. Results of the assessment were used to form management recommendations and identify future capital stormwater and habitat restoration projects.

2 Methods

2.1 Watershed Conditions

Available data and documentation regarding watershed conditions were collected, including: historic and current aerial photography; soils data; geologic maps and reports; topographic data; land cover and land use data; stormwater infrastructure data; existing hydraulic models and floodplain mapping; feature inventory data; and available technical reports. A field reconnaissance was conducted on March 25, 2008 to observe current conditions with regard to channel form, stream stability, riparian vegetation, channel bed and bank material, woody debris, surrounding land use, hydraulic structures, sinuosity, hydromodifications and floodplain connectivity. The field observations are summarized in Appendix A. Field photographs are hyperlinked in the provided ArcGIS project file (SNAP_StudyArea_Basins.mxd).

The available data and documentation were reviewed and evaluated in combination with field observations to characterize the existing basin physical conditions and provide insight into the physical processes and human influences that are the controlling factors on the hydrology and geomorphology of the streams in the Upper Gee Creek basin. The details of this effort are presented in Section 3.1.

2.2 Hydrology

Upper Gee Creek basin and tributary basin areas were delineated using the provided topographic data. Available hydrologic data from the stream flow gage at Abrams Park were collected and evaluated. The period of record for the gage is from 1/26/2003 to present. The available record was too short to conduct peak or low flow frequency analyses. Therefore, peak flow statistics were estimated using regional regression equations (Sumioka et al, 1997) and low flow conditions were generalized based on the available data. A quantitative indicator of the flashiness of a basin is the value of T_{Qmean}, which is the portion of time mean daily flows exceed the mean annual flow. T_{Qmean} was determined using the available flow data from the Abrams Park gage for water years 2003-2007.

2.3 Geomorphology

The morphologic characteristics for streams in the Upper Gee Creek basin were characterized. This included evaluation of channel planform, channel profile, and valley geometry. Channel planform was characterized using current aerial photography supplemented with LiDAR derived stream centerlines (Clark County, 2004). Channel profiles were created using data from the HEC-RAS model for Gee Creek (WEST, 2005) and by extracting elevations along the stream centerlines from a digital terrain model (DTM) developed from the available 2-foot contour interval topographic mapping (Clark County, 2003). Cross sections were located along the valleys of Upper Gee Creek and its major tributaries. Cross section spacing was selected to best represent the variations in valley form and how the form transitions from upstream to downstream. Elevation data for each cross section were extracted from the DTM of the basin and aligned along a common central axis for plotting purposes.

In addition to the evaluation of morphologic characteristics of the channels, a discussion regarding the role of large woody debris in channel development is provided.

3 Results

3.1 Watershed Conditions

3.1.1 Geology

Upper Gee Creek is an 8.7 square mile drainage basin located within the Ridgefield quadrangle (USGS, 1990), which is in the northern part of the Portland Basin, a roughly 770 square mile topographic and structural depression in the central Puget-Willamette Lowland (Beeson et al, 1989; Swanson et al, 1993; Yeats et al, 1996; Evarts, 2004). The Portland Basin is approximately 40 miles long and 20 miles wide, with its long axis oriented northwest (Evarts, 2004). Previous studies (L.M. Liberty, 2003; Swanson et al, 1993; Mabey and Madin, 1995) indicate that as much as 1,800 feet of late Miocene and younger sediments have accumulated in the deepest part of the basin near Vancouver. Most of the basin-fill material was carried in from the east by the Columbia River which flows northward just west of the Ridgefield quadrangle (Evarts, 2004). A geologic map of the Upper Gee Creek basin is shown in Figure 1.

The physiography of the Ridgefield quadrangle is dominantly a nearly flat, modestly dissected surface of elevation 275 to 300 feet developed on the basin-fill sediments (Evarts, 2004). The top of the surface declines gradually westward to about 250 feet near the town of Ridgefield (Evarts, 2004). The surface is interrupted by lows hills in the south and truncated to the west and north by erosional scarps overlooking the Columbia River Floodplain and the East Fork Lewis River valley, respectively (Evarts, 2004).

The low hills in the southern portion of the quadrangle form the highest point in the Upper Gee Creek basin at elevation 450 feet and are formed by a northwest – southeast trending anticline which exposes early Pleistocene or late Pliocene age conglomerate beds of sand, gravel and cobble of Columbia River and Cascadian origin. The Plio-Pleistocene conglomerate is characterized by coarse grain size, moderate to good sorting, open and sand matrix, well developed clast imbrication, and crude stratification which suggest deposition by fluvial processes (Evarts, 2004). The Plio-Pleistocene conglomerate was previously referred to by Mundorff (1964) as the Upper Troutdale Formation.

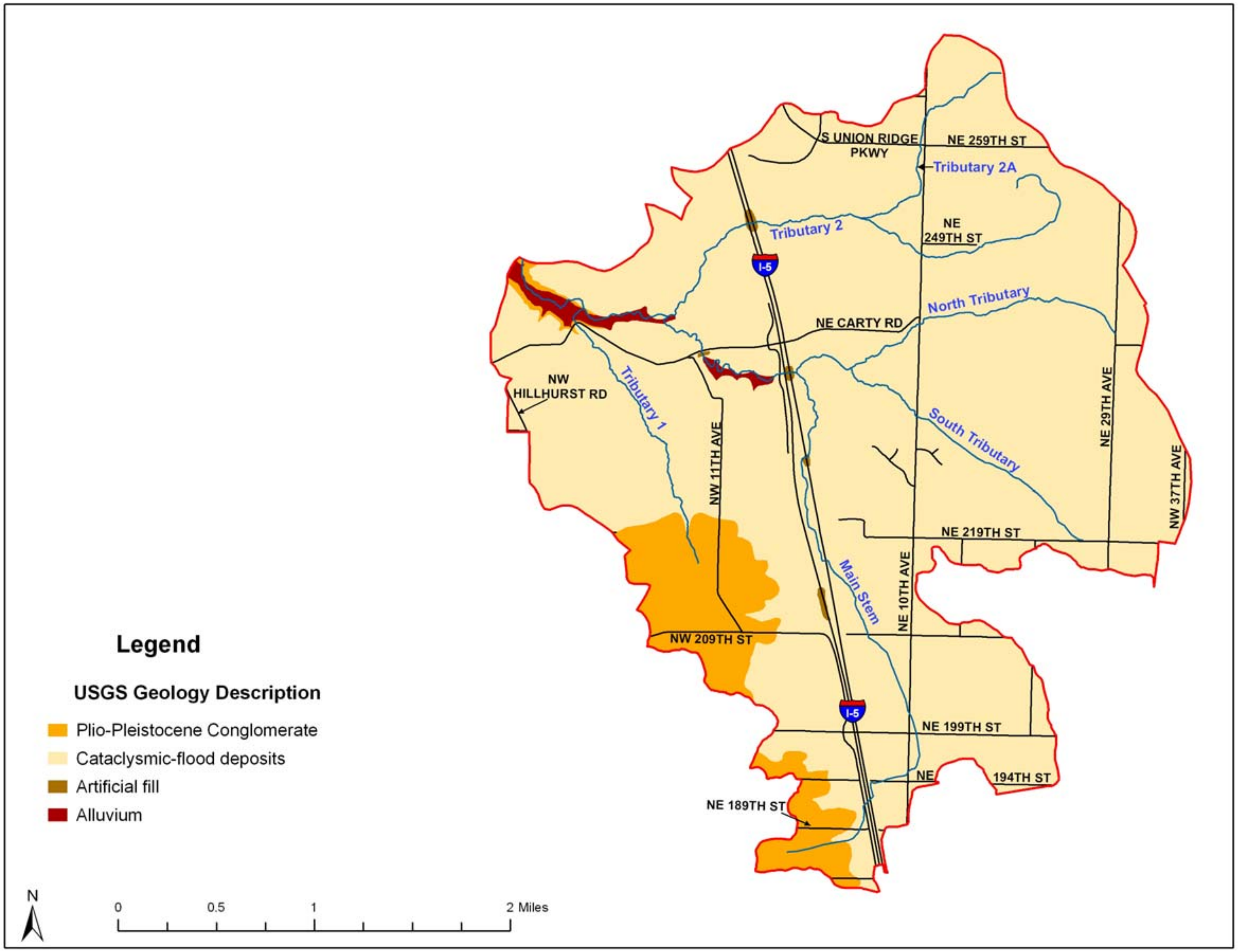

Figure 1. Geologic Map of the Upper Gee Creek basin (from Evarts, 2004).

The Plio-Pleistocene conglomerate is overlain by Pleistocene Cataclysmic Flood Deposits of clay, silt, and fine to medium sand. Late in the last glacial period, a series of glacial outburst floods from Glacial Lake Missoula flowed down the Columbia River valley and ponded in the Portland Basin. This resulted in deposition of silt and fine sand sediments as much as 100 feet thick (Waitt, 1994, 1996; Evarts, 2004). The Cataclysmic Flood Deposits form the upper surface of the majority of the Upper Gee Creek basin. Other than the exposures that form the low hills in the southern portion of the quadrangle, the Plio-Pleistocene conglomerate is exposed in locations where Gee Creek has incised through the upper layer of Cataclysmic Flood Deposits. This can be seen along the left stream bank at the 24th Ave stream crossing located north of Carty Road. Gravel and small cobble sized stream bed material is present at this location. Approximately 4,000 feet upstream of the 24th Ave crossing is the Carty Road stream crossing where the bed material is observed to be sand and small gravel. This suggests that the source of stream bed material transitions from the Pleistocene Cataclysmic Flood Deposits upstream of Carty Road to the Plio-Pleistocene conglomerate downstream of Carty Road.

The depositional zones within the valley bottoms of Upper Gee Creek and its tributaries are composed of Holocene Alluvium of silt, sand and gravel deposits which are reworked from older weakly consolidated sedimentary units.

3.1.2 Streams

Gee Creek is a 4th order tributary to the Columbia River. The mainstem extends approximately 11.5 miles, of which 4.9 miles are located within the Upper Gee Creek basin. The headwaters are located in the southern most portion of the basin just west of the Interstate 5 freeway (I-5). From its headwaters, the stream flows northeast under I-5; then north-northwest roughly paralleling I-5; then west under the north bound lanes of I-5 near the Gee Creek rest area; then in the median between the north and southbound lanes of I-5 for approximately 0.6 miles; then east under the north bound lanes of I-5; then north-northwest paralleling the freeway for approximately 0.5 miles; then west under both the north and southbound lanes of I-5; then west-northwest toward the City of Ridgefield and the Columbia River. The downstream terminus of the Upper Gee Creek basin is located just upstream of Royle Road. Major tributaries include North Tributary and South Tributary as well as several unnamed tributaries with origins located east of I-5. For discussion purposes, the unnamed tributaries were given the following names: Tributary 1, Tributary 2, and Tributary 2A. The tributaries generally flow in a westerly direction combining with Gee Creek near I-5. A drainage basin map showing the location of Gee Creek and its major tributaries is shown in Figure 2. The 8.7 square mile drainage basin is approximately 3 miles wide from east to west 4 miles long from north to south.

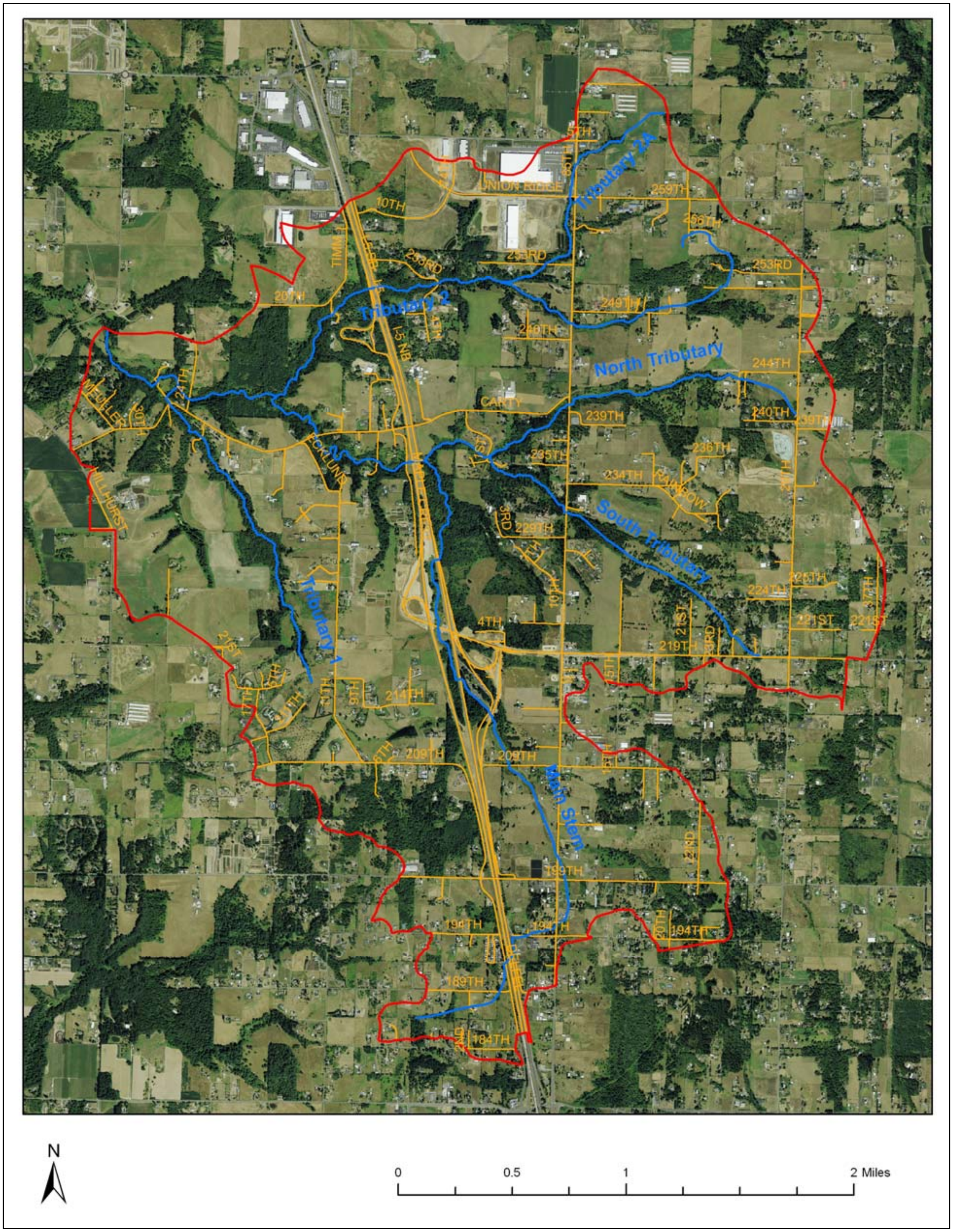

Figure 2. Upper Gee Creek drainage basin map

Upstream of Carty Road, the streams have bed and bank material consisting of clay-, silt-, and sand-sized sediment owing to the fine grained nature of the Cataclysmic Flood Deposits that formed the parent bedrock and soils that cover the majority of the basin. Bed material gradually increases in size from sand and small gravel at Carty Road to gravel and small cobble at 24th Avenue, located approximately 0.7 miles downstream. The increase in bed material size is the result of the stream's incision into the Plio-Pleistocene conglomerate bedrock which consists of consolidated sand-, gravel-, and cobble-sized material. Bank material is typically clay-, silt-, and sand-sized sediment except where the stream abuts the Plio-Pleistocene conglomerate bedrock.

3.1.3 Soils

Upper Gee Creek basin consists primarily of moderately well drained soils, 78% of basin area; with smaller portions of well drained soils, 6% of basin area; poorly drained soils, 14% of basin area; and very poorly drained soils, 2% of basin area. An NRCS hydrologic soil group map is shown in Figure 3. As seen in the figure, the majority of the basin streams are located within the well drained soils. However, the upper portions of the main stem and tributaries are located within poorly drained soils. Further, the reach of Gee Creek between 199th Street and the northbound I-5 Gee Creek Rest Area is located within very poorly drained soils.

Mapped soil units in the Upper Gee Creek basin include: Cove silty clay loam, 1.6% of basin area; Gee silt loam, 70.3% of basin area; Hesson clay loam, 0.6% of basin area; Hillsboro loam, 0.1% of basin area; Hillsboro silt loam, 4.8% of basin area; Odney silt loam, 14.0% of basin area; Puyallup fine sandy loam, 0.6% of basin area; and Sara silt loam, 7.9% of basin area. An NRCS soil map is shown in Figure 4. Watershed soils generally consist of clay, silt and sand sized material derived from the underlying Cataclysmic Flood Deposits. These fine soils are the source materials that are supplied to the stream channels as a result of surface erosion.

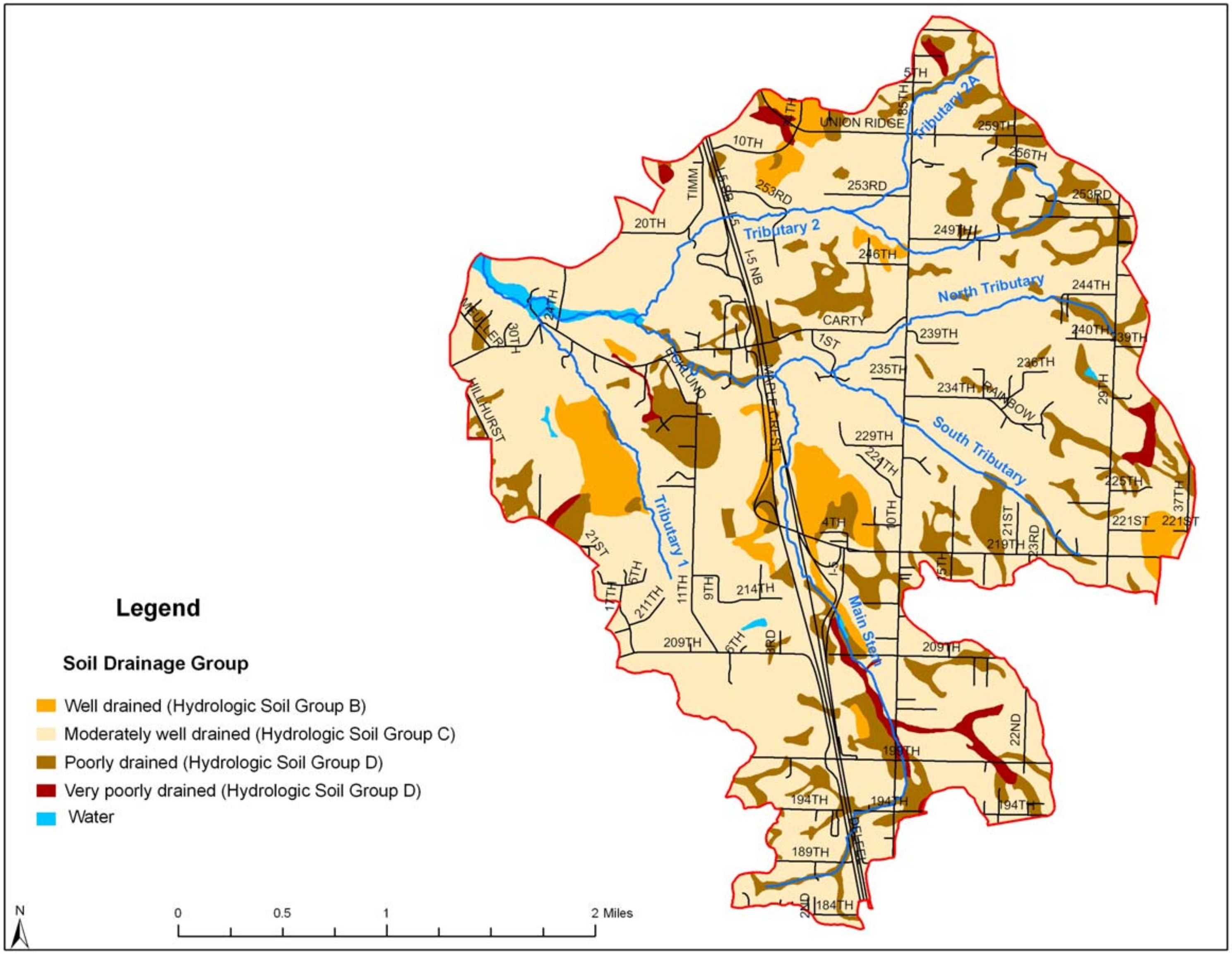

Figure 3. Hydrologic soil group classification of soils in Upper Gee Creek Basin (data from NRCS, 2004).

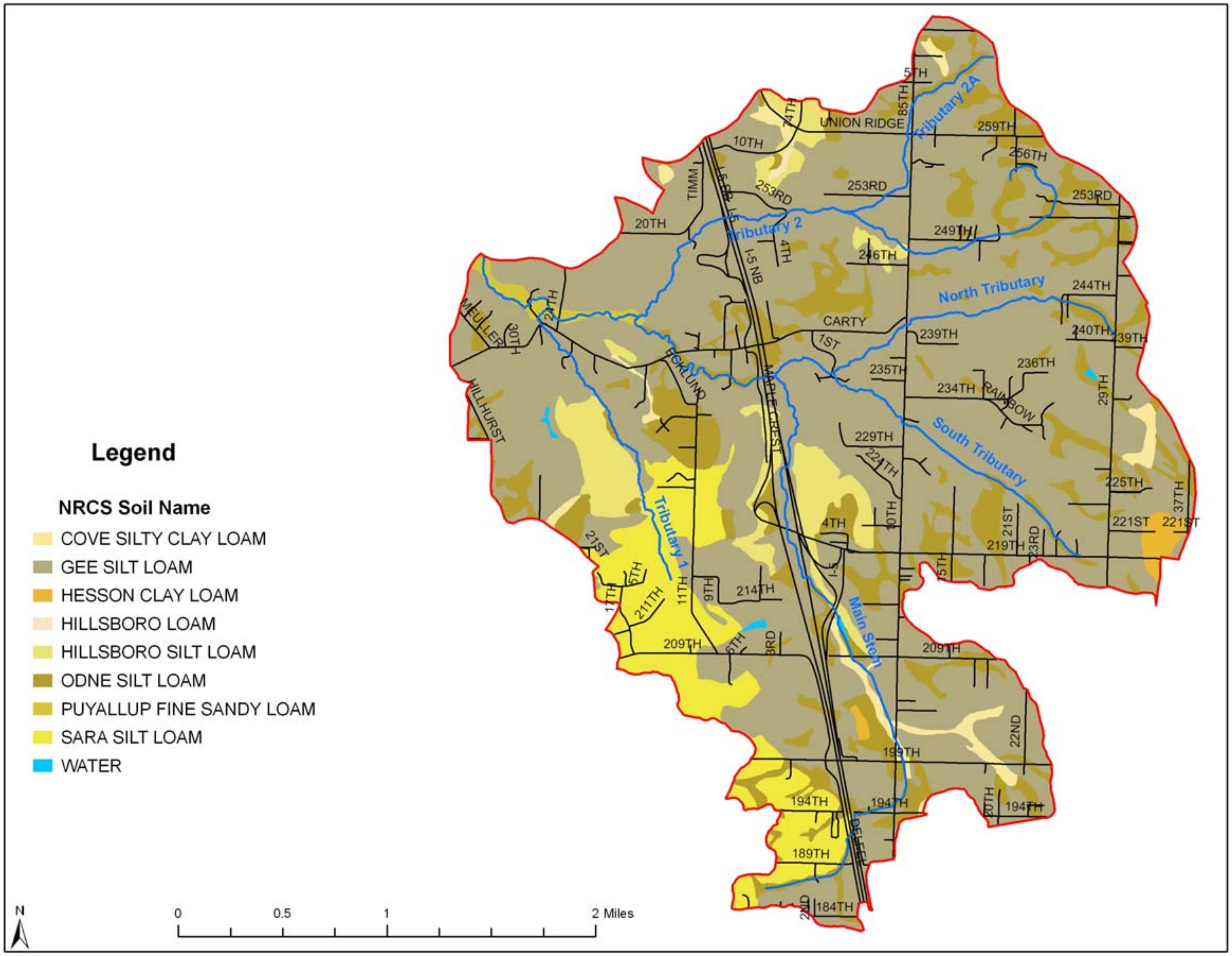

Figure 4. Soils map for the Upper Gee Creek Basin (data from NRCS, 2004).

3.1.4 Topography

The topography of Upper Gee Creek basin is characterized by nearly flat, modestly dissected surfaces with rolling hills in the southwestern portion of the basin. Elevations range from approximately 450 feet in the southwestern edge of the basin to approximately 130 feet at the western edge near Royle Road. The average basin elevation is 263 feet and the average watershed slope is 6.3 percent (Wierenga, 2005). Moderately steep slopes (erosional scarps) occur adjacent to the mainstem and tributary stream channels and associated floodplain terraces. The erosional scarps developed by incision and lateral migration of the associated stream channels within the relatively fined grained soils and parent rock of the Cataclysmic Flood Deposits. Areas in the basin with unstable slopes tend to be located where the stream channels are directly adjacent to or impinging on the base of the erosional scarps. Floodplain terraces are generally narrow or nonexistent in the upper portion of the basin but increase to between 250 feet to 300 feet in width at the downstream end of the basin near Royle Road. A shaded topographic relief map of the basin is shown in Figure 5.

3.1.5 Disturbances

There is little documentation available regarding significant historic disturbances in the Upper Gee Creek basin. Forest fires and flooding were likely the main disturbances prior to Euro-American settlement. Since much of the forest land was converted to agricultural uses in the early 20th century, forest fires have likely not been a significant source of disturbance in the basin since that time. Historic flooding along Gee Creek is not well documented; however, records of flooding along other streams in Clark County suggest that significant flooding occurred in 1964, 1977, 1996, and as described in Section 3.2, in 2005 and 2007. Flooding continues to provide periodic disturbance and may likely have increased in severity as the basin land cover was converted from forest to agriculture and more recently from agriculture to a mix of agriculture, urban housing and industry. Future flooding conditions are likely to be exacerbated by future increase in impervious surface area.

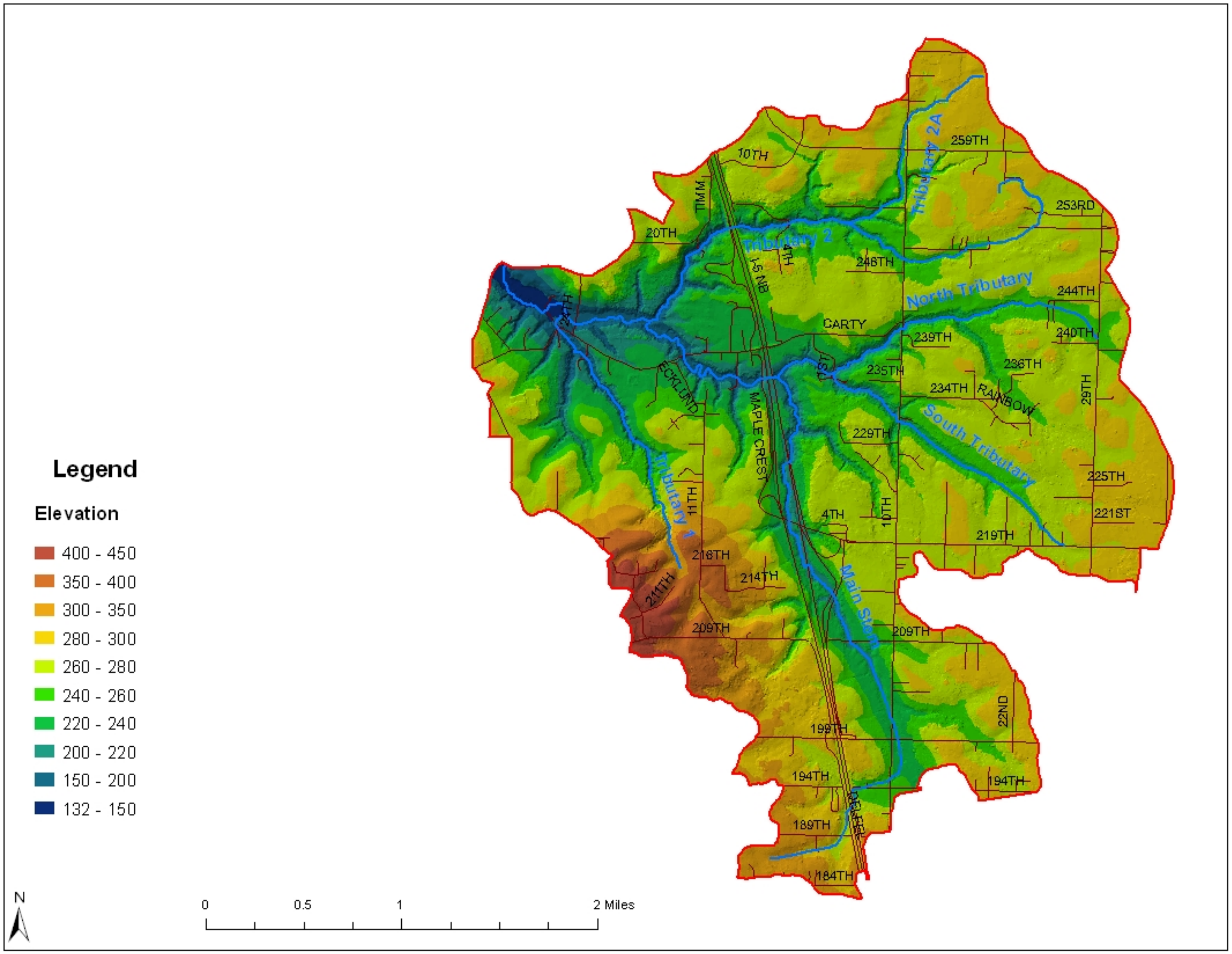

Figure 5. Topographic relief map of the Upper Gee Creek Basin.

3.1.6 Land Cover and Land Use

3.1.6.1 Historic

Historic land used conditions in the Gee Creek basin are published in a report entitled Gee Creek Watershed Restoration Background Report by Lynn Cornelius (2006). The following is a summary of this report.

The Upper Gee Creek basin was originally dominated by forest consisting of Fir, Cedar, Maple and Hemlock in varying stages of fire succession. Clearing of the forest began with the earliest settlements, and land was steadily converted to other uses, principally farming. Important farm products grown in the fertile Gee Creek basin soils include tree and berry fruit, potatoes, dairy, beef cattle, hay and grain.

With the decline of river travel for access and commerce, and the advent of land-based travel, roads were developed in the Upper Gee Creek basin connecting to the nearby cities of Vancouver and Portland. As early as 1888, many of the current primary road routes were established, presumably with early versions of stream crossings, road fill, and associated stream impacts.

The construction and maintenance of I-5 and associated stormwater runoff are the largest recent major road impacts in the watershed. The construction of I-5 occurred in the late 1950's and early 1960's. The grading and filling associated with the highway construction have resulted in significant encroachment on the Gee Creek channel and floodplain. Gee Creek crosses under I-5 four times and flows within the median of the north and southbound lanes for a distance of approximately 0.5 miles.

By the 1950's, dairy farming was recognized as the most important agricultural industry in the Ridgefield Area. In general, dominant land use eras in the watershed since Euro-American settlement have been: fishing; furbearer; timber harvest; crop, dairy, and livestock farming; rural and local industrial; rural-residential; and modern urban residential/light industrial in the City of Ridgefield and along the I-5 corridor.

3.1.6.2 Current

The current basin land use consists primarily of rural residences, agriculture, and forest land. Suburban developments are more prominent in the southern portion of the basin and industrial developments are becoming more prominent in the northern portion of the basin. In 2002, the basin land cover was 28.3% forested, 5.4% impervious, and 65.9% non-canopy (Figure 6). The forest lands that remain tend to be focused along the stream corridors in the middle and lower portions of the basin. The upper basin tributaries tend to have sparse, intermittent or no forest cover as much of this land has been cleared for agricultural uses.

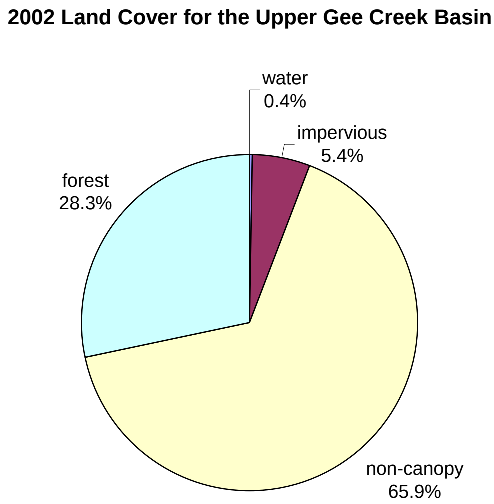

Figure 6. Land cover characteristics for the Upper Gee Creek basin (data from Clark County 2002 Land Cover shapefile)

3.1.6.3 Future

Future land use for the Upper Gee Creek basin is characterized in the document “Clark County 20-Year Comprehensive Growth Management Plan 2004-2024”. The land use zoning for the basin was extracted from the accompanying GIS coverage and is provided in Table 1.

Table 1. Land Use Zoning in Upper Gee Creek Basin

Zone	Percentage of Upper Gee Creek Basin
Urban	34
Rural Residential	42
Agricultural	24
Forest	0

As seen in the table, approximately 24 percent of the basin is zoned for agricultural use and 42 percent is zoned for rural residential development. These areas would be expected to have minimal increases in impervious surface area and therefore the least impact on future hydrologic conditions resulting from build out of the current comprehensive plan and zoning. The zoning for the remaining 34 percent of the basin is a mix of urban industrial, commercial and residential development which would be expected to have the highest proportion of impervious area and therefore the largest impact on future hydrologic conditions resulting from build out of the current comprehensive plan and zoning.

A land use zoning map is provided in Figure 7. As seen in the figure, the areas that are expected to have the greatest increase in impervious surface area and therefore the greatest impact on future hydrologic conditions are located in both the northern and southern portions of the basin. The central portion of the basin is expected to have only minimal increases in impervious areas and therefore the least impact on future hydrologic conditions.

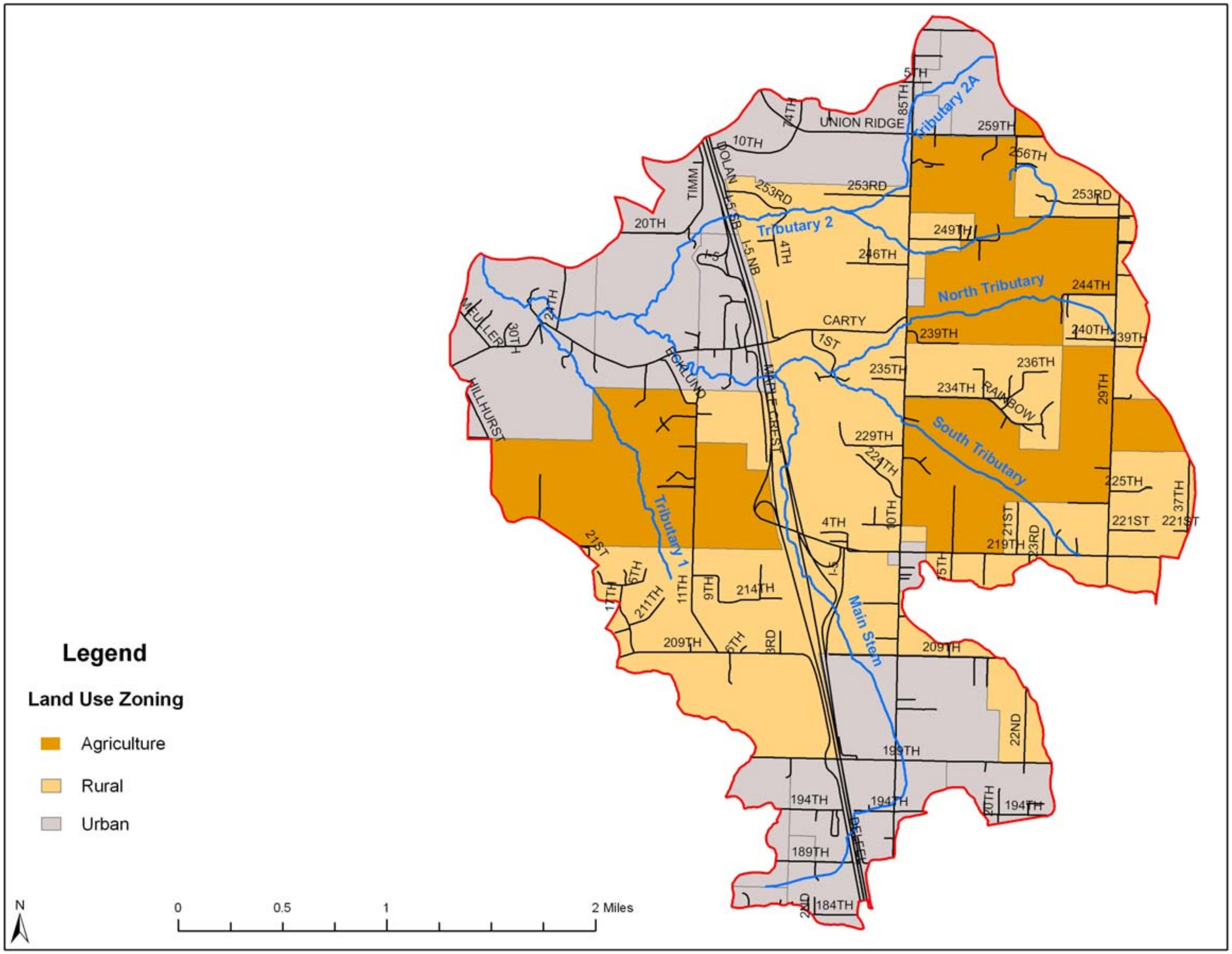

Figure 7. Land use zoning (from Clark County Comprehensive Growth Management Plan).

3.1.7 Hydromodifications

Hydromodifications that have occurred in the Upper Gee Creek basin include the following: private dams and associated ponds; stormwater detention ponds; stormwater piping, culvert and bridge stream crossings; and drainage ditches in fields and along roadways. Direct water withdrawal from streams for irrigation purposes may also be occurring, but identification of their location and extent was beyond the scope of this investigation.

3.1.7.1 Dams and Ponds

Private dams and associated ponds have been observed along both the main stem and tributary reaches of Upper Gee Creek. However, these types of modification are not prevalent in the basin. The ponds appear to be either for aesthetic/recreational purposes, or for irrigation/livestock use. Direct observation of the outlet works of the dams and downstream channel could not be made. Therefore, the extent to which these dams have altered the channel morphology and/or are considered barriers to fish passage is unknown. The associated ponds are likely trapping fine sediment; but are disrupting the transport of bed material. The ponds may also be responsible for incremental increases in water temperature during parts of the year resulting from increased atmospheric exposure to solar radiation. Fecal coliform contamination from waterfowl is an additional concern.

3.1.7.2 Stormwater Facilities

Stormwater detention basins are associated with more recent residential and commercial development in the Upper Gee Creek basin. Stormwater detention ponds temporarily store excess runoff that results from the construction of impervious surfaces. The detention ponds are typically designed to control peak flows and are likely increasing the duration of moderate flows that over time may result in the incision and subsequent instability of downstream channels. Stormwater piping is present within the basin; however, it is limited in extent and is mostly found along NE 10th Ave and in several higher density residential neighborhoods.

3.1.7.3 Drainage Ditches

Drainage ditches in farm fields and along roadways result in a greater drainage density than would otherwise occur. The increased drainage density results in a reduction in the time of concentration and therefore quicker runoff response to precipitation and increased peak flows. Drainage ditches also reduce the amount of water that would otherwise infiltrate into the surrounding soils and later be released to the streams as base flow during dry periods. In locations where treatment facilities have not been developed, roadway drainage ditches may convey pollutants that are washed from the road surface and conveyed directly to stream channels.

3.1.7.4 Hydraulic Structures

Culvert and bridge stream crossings locally modify the hydraulic conditions upstream and downstream of the structure. This effect usually results in a disruption in the natural sediment transport characteristics of the involved stream channel. In locations where the size of the hydraulic opening is restricted, backwater conditions will occur during moderate and high flows. Reduced stream velocities and shear stresses due to backwater often result in increased sediment deposition upstream of the hydraulic structure and decreased sediment supply to downstream reaches.

If significant floodplain storage is available upstream of the structure, temporary storage of flood waters can occur and result in a reduction in downstream peak flows. In contrast to upstream hydraulic conditions, downstream of the structure, stream velocities and shear stresses are increased by the restricted hydraulic opening. If not mitigated by an energy dissipation device, this usually results in scour of the channel bed material that often leaves the culvert outlet invert perched above the downstream water surface during moderate and low flows. If the disruption in sediment transport by the hydraulic structure is significant, degradation of downstream reaches may occur. Similarly, culverts and bridges affect the ability of the stream channels to migrate. This impact may alter sediment transport and the form of the upstream and downstream channel.

Figure 8 shows a channel shear stress profile of Upper Gee Creek developed from the existing HEC-RAS hydraulic model (WEST, 2005). As seen in the figure, the channel shear stress for the 10-year recurrence interval flood is significantly reduced upstream of and significantly increased downstream of several road crossings, most notably South Royle Road and Carty Road. Significant scour of the channel downstream of the Carty Road culvert was observed to be occurring. South Royle Road was not observed as it is just outside of the Upper Gee Creek basin boundary and therefore not included in this analysis.

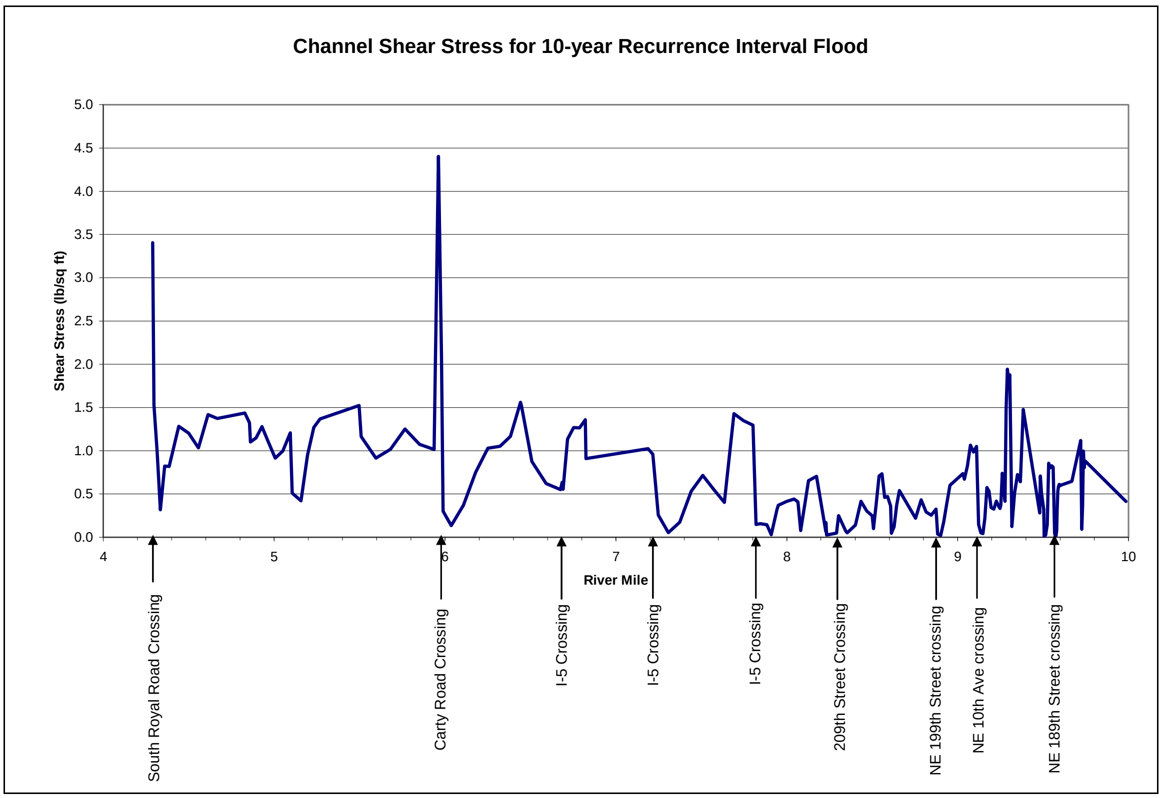

Figure 8. Channel shear stress profile for 10-year flood along Upper Gee Creek (WEST, 2005).

As seen in Figure 9, the relative percentage of the total 10-year peak flood discharge conveyed in the floodplain is significantly influenced by the existing road crossings. Backwater conditions upstream from the existing road culverts result in a greater portion of the total discharge being conveyed within the floodplain. Downstream of the culverts the discharge is mostly confined to the channel.

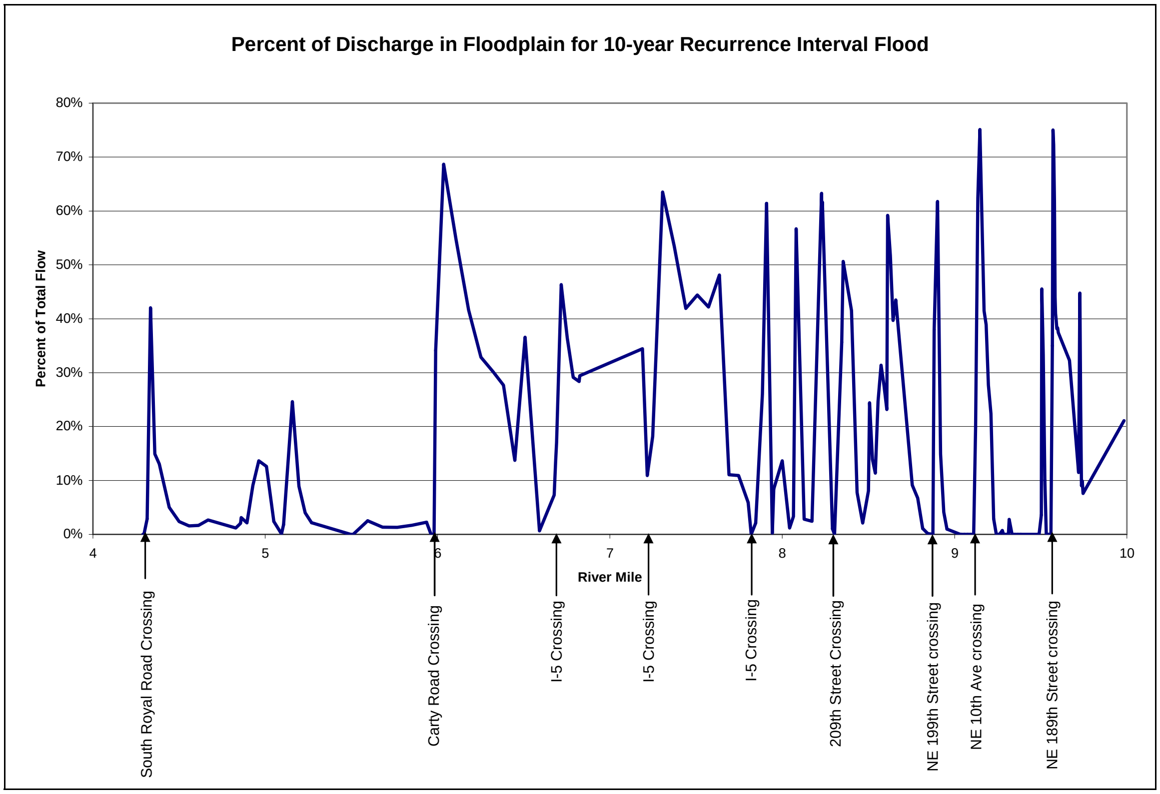

Figure 9. Percentage of total 10-year peak discharge conveyed in the Upper Gee Creek floodplain (WEST, 2005)

3.1.8 Conclusions

- Streams within the central portion of the Upper Gee Creek basin are expected to experience minimal impacts to future hydrologic conditions and therefore minimal changes to the geomorphic characteristics. These include North Tributary, South Tributary, the portion of Tributary 2 upstream of NE 10th Ave, and Tributary 1. Unless mitigated, the remaining stream reaches in the basin are likely to undergo significant morphologic change as peak flows and/or flow durations increase.

- Hydromodifications have resulted in alterations to the natural hydrologic, geomorphic and water quality conditions of Upper Gee Creek. Dams and associated ponds are altering sediment transport conditions, elevating water temperatures, and contributing to increased contamination from waterfowl.

- Stormwater detention facilities will need to be designed to manage peak flows and flow durations of erosive discharges. Otherwise, channel incision, headcutting and subsequent bank failures will occur. Degradation of the channel will be especially pronounced in the steeper gradient streams located within the fine grained Cataclysmic Flood Deposits.

- Drainage ditches have increased drainage density resulting in increased peak flows and reductions in groundwater recharge. Where treatment facilities are not installed, drainage ditches convey pollutants directly to stream channels.

- Culverts are altering sediment transport conditions and locally preventing channel migration. Where alterations are significant, such as at Carty Road (and possibly Royle Rd), considerable impacts to channel morphology have occurred. Excessive sediment deposition is occurring upstream of the Carty Road culvert and excessive scour is occurring downstream of the Carty Road culvert.

- Culvert crossings significantly influence the amount of floodwaters that are conveyed and/or stored in the floodplain. Replacement of culverts with structures having greater hydraulic efficiency and therefore less backwater, will result in greater concentration of flows in the channel and less floodplain connectivity immediately upstream of the structure. Culvert replacement may also result in increased flows downstream of the structure as a result of lost floodplain storage. Unless mitigated, localized impacts to the stream channel in the form incision and bank failures will occur. Mitigation could be in the form of woody debris jams and grade control structures. The installation of woody debris jams will result in increased channel roughness, reduced stream velocities and shear stresses, higher water surface elevations, and greater connectivity between the channel and floodplain. Grade control structures would help prevent channel incision.

3.1.9 Recommendations

- It is noted that the land use zoning map provides a broad level of detail regarding land use for a 20-year period (2004-2024). Those portions of the basin that are expected to experience the least amount of development over this time period should not be ignored. Reestablishment of riparian corridors in these areas while development pressure is low will allow a greater time period for the riparian vegetation to mature and therefore provide greater protection to the streams as development pressure increases in the future.

- Dams and associated ponds should be individually evaluated to determine the impact each is having on the hydrology, water quality and geomorphology of the involved stream. This could be used to prioritize both modifications to and/or removal of existing structures.

- Existing and future stormwater detention facilities should be evaluated through the use of continuous simulation hydrologic modeling to understand the magnitude of modifications to the duration of flows compared to predevelopment conditions.

- Ensure appropriate BMPs are being implemented with regard to maintenance of drainage ditches and discourage the development of new drainage ditches that have a direct connection to natural channels.

- Use geomorphically based performance standards when designing and constructing new or replacement hydraulic structures at road crossings. Designs should allow for lateral and longitudinal continuity and connectivity of both the channel and functional floodplain in addition to hydraulic design considerations.

- Replace the culvert at Carty Road with a hydraulic structure that accommodates natural fluvial processes and does not significantly alter the hydraulic and sediment transport characteristics of Gee Creek. Potential upstream and downstream impacts resulting from the replacement structure and mitigation for these impacts must be considered during design. Mitigation in the form of woody debris jams and grade control or other appropriate measures should be installed to offset the loss of floodplain connectivity and channel incision that would likely occur as a result of the culvert replacement.

3.2 Hydrology

3.2.1 Drainage Basin

The Upper Gee Creek basin is approximately 8.7 square miles in total area. A summary of tributary drainage basin areas is provided in Table 2. Average annual precipitation over the basin is 45.5 inches (NRCS, 1998). Eighty-three percent of the stream channels in the Upper Gee Creek basin are considered head water streams (1st or 2nd order) (Wierenga, 2005). Approximately 2.2 percent of the basin is mapped as wetland and 0.8 percent is mapped as floodplain (Wierenga, 2005). The relatively small percentage of wetland and floodplain areas suggests that there is minimal area available for storage and attenuation of flood waters.

Table 2. Upper Gee Creek drainage basin areas.

Stream	Drainage Area (sq. mi.)	Percent of Total
Upper Gee Creek	8.7	100
Tributary 1	0.92	10.6
Tributary 2	2.1	24.2
Tributary 2A	0.53	6.1
North Tributary	1.1	12.5
South Tributary	0.98	11.2
North + South Tributary	2.2	24.8

Six percent of the basin soils are type B (well drained) while the remaining 94 percent of the basin soils are type C/D (moderate to poorly drained). This indicates that there is a greater tendency for precipitation over the basin to contribute to surface runoff rather than infiltrate for high intensity and/or longer duration storm events that exceed soil infiltration rates. For short duration and/or low intensity storm events, a greater portion of the precipitation is likely infiltrated. Runoff rates increase in the mid and late winter months after the soil moisture levels in the basin have been replenished by late fall and early winter storm events.

3.2.2 Stream Flow Conditions

There are no stream gages available in the Upper Gee Creek basin. However, a stream gage has been in operation further downstream at Abrams Park since 2003 which is approximately 2 miles downstream of the Upper Gee Creek basin. The gage at Abrams Park has a drainage area of 11.6 square miles, which is approximately 2.9 square miles larger than the Upper Gee Creek Basin (8.7 square miles).

The maximum mean daily discharge for water years 2003 through 2007 was 360 cfs, which occurred on December 28, 2005. Within an 11.5 hour time period the stream discharge increased from 62 cfs to 770 cfs, indicating that the basin has a relatively flashy response to precipitation. The 24-hour precipitation total that created this event totaled 1.3 inches (based on the nearest precipitation gage located in Ridgefield). In contrast, a 24-hour total precipitation event of 1.9 inches occurred on November 6, 2006, producing a much lower peak discharge of 154 cfs. The relatively dry soil conditions in the fall of 2006 caused a significant portion of the precipitation to be infiltrated into the soil rather than runoff into the stream channels as occurred in late December 2005 when soil moisture levels were likely significantly greater.

A quantitative indicator of the flashiness of a basin is the value of T_{Qmean}, which is the portion of time mean daily flows exceed the mean annual flow. Low values of T_{Qmean} are often associated with urbanized watersheds. The redistribution of water from base flow to surface runoff will decrease the fraction of time that daily discharges exceed the mean discharge. Therefore, the higher the T_{Qmean} value, the more stable or less flashy the stream. The T_{Qmean} for Gee Creek is 0.25, which is a relatively low value that is more typical of an urbanized watershed. An investigation of urban and rural streams in the Puget Sound (Booth, et al, 2001) found that urban streams tended to have T_{Qmean} values of less than 0.3 while suburban streams have values greater than 0.3. It is noted that the period of record for the Gee Creek stream flow gage is a relatively short 5 years; therefore, the value of T_{Qmean} for Gee Creek is considered an approximation and the determination of other statistical indicators (e.g. $T_{0.5}$ and CV_{AMF}) was not attempted. Further, the location of the gage, several miles downstream from the Upper Gee Creek basin, results in additional drainage area and associated land use conditions which may not be representative of the Upper Gee Creek basin. This has an influence on stream flows measured at the gage and the resulting value of T_{Qmean}.

The period of record for the Gee Creek gage at Abrams Park is not sufficient to conduct a flood frequency analysis. Therefore, peak discharges and associated recurrence intervals for Gee Creek were estimated from USGS flood frequency regional regression equations (Sumioka et al, 1997) and are shown in Table 3.

Table 3. Estimated peak discharges for Gee Creek

Location	Drainage Area (mi^2)	Recurrence Interval (yrs)	Discharge (cfs)
Upper Gee Creek basin outlet upstream of Royle Road	8.7	2	270
		10	435
		25	525
		50	585
		100	650
		500	795
Gee Creek at Abrams Park	11.6	2	345
		10	560
		25	675
		50	750
		100	830
		500	1,020

Available stream flow records indicate that peak discharges for December 2005 and December 2007 were 770 cfs and 950 cfs respectively. In the last two years, floods with recurrence intervals in excess of 50- and 100-years have occurred. However, other than localized impacts associated with culvert crossings, no significant problems resulting from these recent flood events were observed.

The available period of record for the Gee Creek gage at Abrams Park is not sufficient for developing low flow statistics. However, a general characterization is provided based on the available data. The minimum mean daily flow of 0.3 cfs occurred on September 4, 2003. Discharges of less than 1 cfs are seen to occur during the months of June through September. Flows of less than 10 cfs can occur at any time of year given sufficient time between precipitation events. Mean monthly discharges for water years 2003 through 2007 are shown in Figure 10. As seen in the figure, the highest flows occur during the winter and spring months with lows flows occurring during the summer and early fall months.

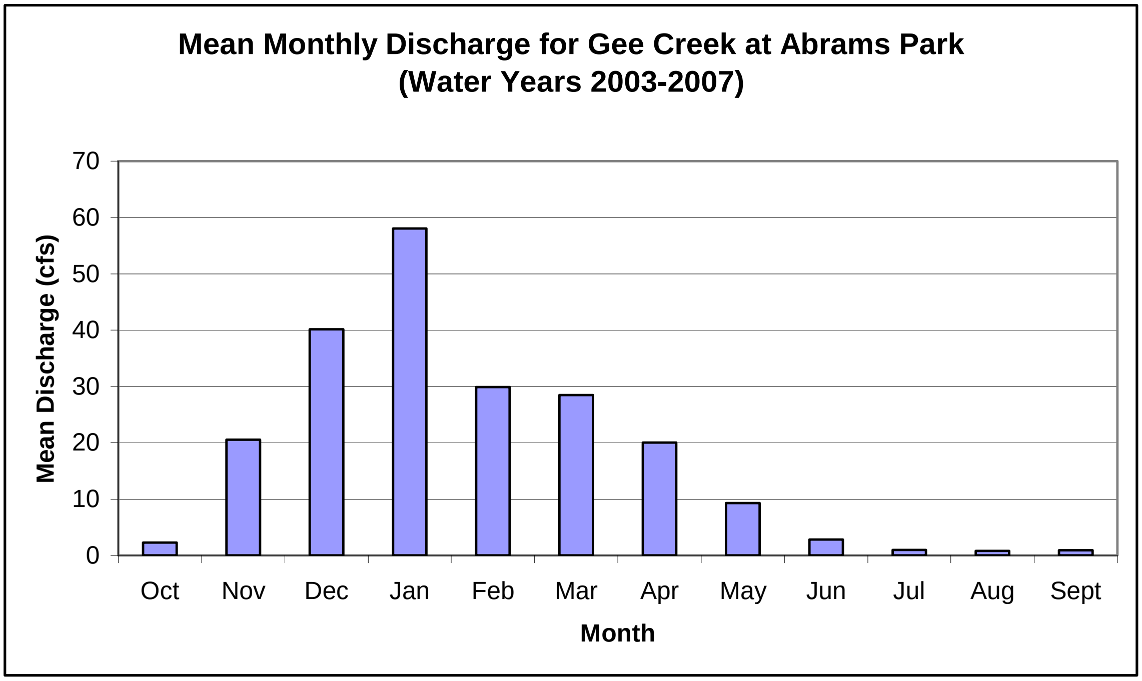

Figure 10. Mean Monthly Discharge for Gee Creek at Abrams Park

The relatively low magnitude of flows that occur during the summer and early fall months is a result of multiple contributing factors. The largest contributing factor is the temperate marine climate which tends to favor wet winters and dry summers. Additionally, the majority of the basin soils have relatively low infiltration capacities, causing much of the wintertime precipitation to run off rather than be stored in the soils and bedrock for later release to the streams. Also, the well drained topography and general absence of upland wetlands limits groundwater recharge. Further, the dominantly flat topography combined with relatively shallow incision of the stream channels into the surrounding soils and bedrock of the Upper Gee Creek basin result in surface water connections to only the upper portion of the aquifer where ground water storage volumes are limited. This may be exacerbated by surface water withdrawals for irrigation during the summer growing season. Lastly, continued increases in the amount of impervious surfaces has further reduced infiltration and increased wintertime runoff volumes. As of 2002, the total impervious area represented approximately 5.4 percent of the basin.

3.2.3 Conclusions

- The relatively small percentage of wetland and floodplain areas suggests that there is minimal area available for storage and attenuation of flood waters. Therefore, opportunities for enhancement of existing wetlands and floodplains for the purpose of increasing available storage for floodwaters are limited.

- The T_{Qmean},a measurement of “flashiness”, for Gee Creek at Abrams Park is 0.25, which is a relatively low value that is more typical of an urbanized watershed. However, the current value is not considered to be reliable given the relatively short record of stream flows and because of the downstream location of gage it may not be representative of the Upper Gee Creek basin.

- Basin soil conditions limit infiltration rates for high intensity and/or longer duration storm events. Therefore, benefits from the installation of infiltration facilities may not be realized during these types of storms. However, during low intensity and/or short duration storm events the benefits would be more pronounced.

- Recent major floods resulted in minimal erosion problems along streams in the Upper Gee Creek basin. This suggests that these streams, in their current condition, are relatively stable and not susceptible to significant degradation during large flood events. However, future changes in basin conditions that increase the duration of erosive flows, reduce riparian vegetation along channel banks, adversely alter hydraulic conditions, or impact sediment supply and transport will result in increased susceptibility to channel and bank erosion during large floods.

3.2.4 Recommendations

- Encourage the use of Low Impact Development (LID) measures for newly developing areas in the basin. LID focuses on minimizing the amount of runoff generated from the site by minimizing to the extent practical the amount of increased impervious surface area and by infiltrating and treating stormwater runoff near the source in order to best mimic the predeveloped hydrologic conditions. Where soil conditions are a limiting factor, combine LID practices with traditional stormwater detention/retention facilities.

- Continue monitoring stream flows at the Abrams Park gage and consider the installation of an additional stream gage in the Upper Gee Creek Basin. T_{Qmean} and other streamflows statistics can be used to help evaluate the effectiveness of stormwater management practices as future development occurs in the basin. An additional stream flow gage would allow for results that are representative of the Upper Gee Creek basin and thus exclude impacts to stream flows associated with development conditions downstream of the Upper Gee Creek basin.

- Develop a calibrated continuous simulation hydrologic model of the Upper Gee Creek basin to help evaluate changes in basin hydrology associated with future development. The model will help determine the magnitude and location of expected hydrologic changes and be useful to evaluate the effectiveness of stormwater facilities and potential mitigation projects.

- Develop more stringent stormwater flow control regulations that better mimic predevelopment conditions both from the peak flow and flow duration standpoint.

- Discourage surface water withdrawals for irrigation to help promote sufficient summer low flow conditions.

3.3 Geomorphology

3.3.1 Channel Planform

The planform of the stream channels within the Upper Gee Creek basin range from nearly straight to moderately meandering single thread channels. In the upper portion of the basin (east of I-5), the channels are fairly straight as they are either confined by the valley topography or have been altered by agricultural practices. The bed material in these stream reaches is composed of sand and silt sized sediment derived from the underlying Cataclysmic Flood Deposits. The channel reaches in the upper basin are generally supply limited in that for most flow conditions the channel has the ability to transport more sediment than is supplied to it. As a result, sediment deposition and resulting migration are limited in these reaches. Further, because the fine grained bed material is readily transportable, it provided little resistance to channel incision. This incision has confined the channel and further reduced its potential for migration.

Sinuosity increases along the middle and lower portions of the basin (west of I-5) as the streams increase in size and transition to transport reaches. For transport reaches, the sediment supply from upstream is in quasi-equilibrium with the sediment transport capacity. Temporary storage of sediment occurs within these reaches resulting in increased sinuosity compared to the upstream supply reaches. Additionally, the valley bottoms become wider and thus the adjacent hill slopes have less influence on channel migration.

The channel reach with the greatest sinuosity is located between I-5 and Carty Road (see Figure 11). This is a transport limited reach, in that sediment supply generally exceeds sediment transport capacity. As seen in Figure 1, the underlying bedrock exposed by Gee Creek transitions from the finer grained Cataclysmic Flood Deposits to the coarse grained Plio-Pleistocene conglomerate downstream of Carty Road. The coarser sediment is less transportable and provides greater resistance to channel incision. The culvert at Carty Road is also restricting the flows of Gee Creek causing backwater conditions that reduce stream velocities and induce sediment deposition. The combination of the underlying geology and the hydraulic conditions associated with Carty Road culvert crossing are influencing sediment transport conditions resulting in greater channel migration within this reach. Available historic aerial photography were not of sufficient resolution to determine historic channel locations or channel migration rates; however, the current channel planform and unconfined valley form imply that the channel has migrated within the confines of the valley in the past.

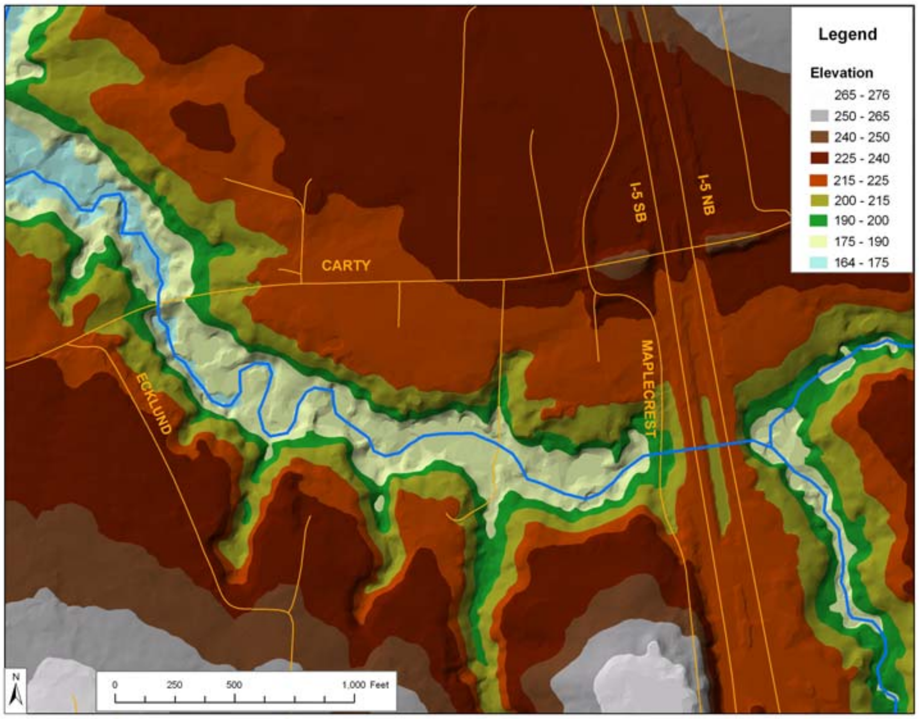

Figure 11. Plan view of Gee Creek between I-5 and Carty Road.

3.3.2 Channel Profiles

A stream channel profile for Upper Gee Creek (Figure 12) was developed from the existing HEC-RAS model (WEST, 2005) developed for the preliminary FEMA Flood Insurance Study (FEMA, 2006). The channel slope, sinuosity, and bed material size were used to divide the channel into 5 separate reaches of similar geomorphic characteristics which are summarized in Table 4. As seen in the table, channel sinuosity is inversely correlated with channel slope. As the channel slope decreases, channel sinuosity increases. However, as seen in the table, Reach 1 has a slightly steeper slope than Reach 3, yet Reach 1 has greater sinuosity than Reach 3. This is the result of the difference in bed material characteristics between these two reaches. Reach 1, with it larger sized bed material, has greater resistance to channel incision compared to than Reach 3. Therefore, bank erosion and point bar deposition (and resulting channel migration) are the primary means of sediment transport in Reach 1.

Table 4. Summary of reach characteristics

Reach	Extents	Average Slope	Sinuosity[1]		Bed Material
1	S. Royle Rd to Carty Road	0.005	1.4	high	gravel/cobble
2	Carty Road to I-5	0.003	1.5	high	sand/silt
3	I-5 to 199th St	0.004	1.1	low	sand/silt
4	199th St to I-5	0.011	1.0	low	sand/gravel
5	I-5 to approximately 2,000 feet above NE 189th Street	0.019	1.0	low	--[2]

1. Sinuosity is the ratio of the channel length to the valley length. The classification of sinuosity is based on Rosgen's Stream Classification System (1996)
2. The stream bed along Reach 5 was not observed; however, given the steepness of the channel and the underlying coarse grained Plio-Pleistocene conglomerate bedrock, the bed is likely composed of gravel and cobble size material.

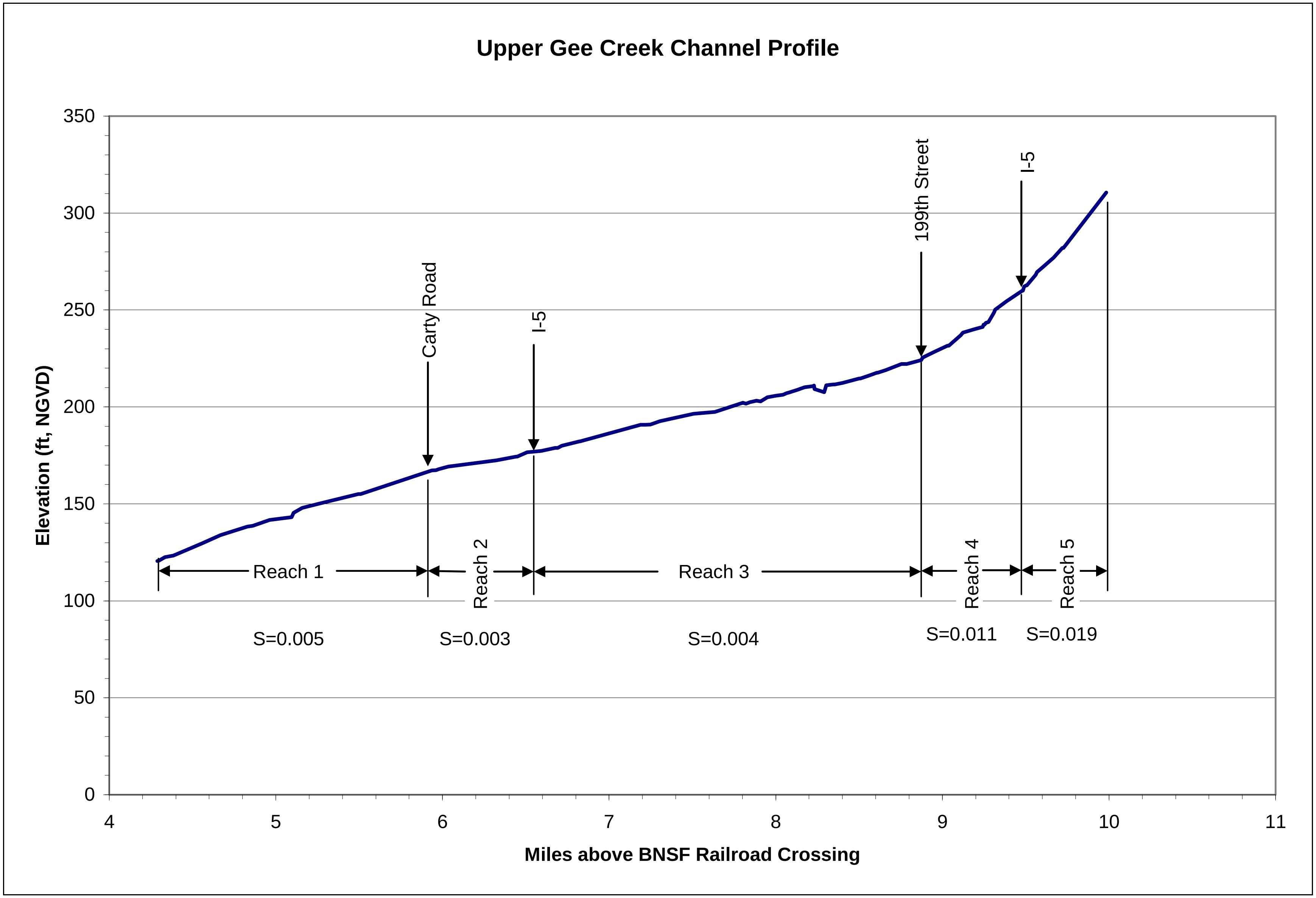

Figure 12. Stream channel profile of Upper Gee Creek (data from WEST, 2005).

Hydraulic models were not available for the tributary streams to Upper Gee Creek. However, available topographic data was used to develop a DTM of the basin and extract ground profiles along the stream centerlines. The extracted ground profiles are shown in Figure 13 through Figure 15. The ground profile along Upper Gee Creek was added to each figure for reference. As seen in figures, North Tributary, South Tributary, and Tributary 2 have similar average channel slopes of approximately 35 to 45 feet/mile (0.007 to 0.009). Tributary 2A has an average slope of approximately 70 feet/mile (0.013). The upper half of Tributary 1 has an average slope of approximately 245 feet/mile (0.046) while the lower half has an average slope of approximately 80 feet/mile (0.015). The upper third of Gee Creek has an average slope of approximately 55 feet/mile (0.01) while the lower two-thirds of the channel has a slope of approximately 22 feet/mile (0.004).

As seen in Figure 15, Tributary 1 has a significantly steeper slope compared to the rest of the basin streams. This is likely the result of the underling geology which is the coarse grained Plio-Pleistocene conglomerate. The stream does not have the ability to transport significant quantities of gravel and cobble that are found within this geologic formation. Therefore, the channel is maintained at a much steeper slope than the remainder of the basin streams which have sand and silt sized bed material reflecting the nature of the underlying fine grained Cataclysmic Flood Deposits.

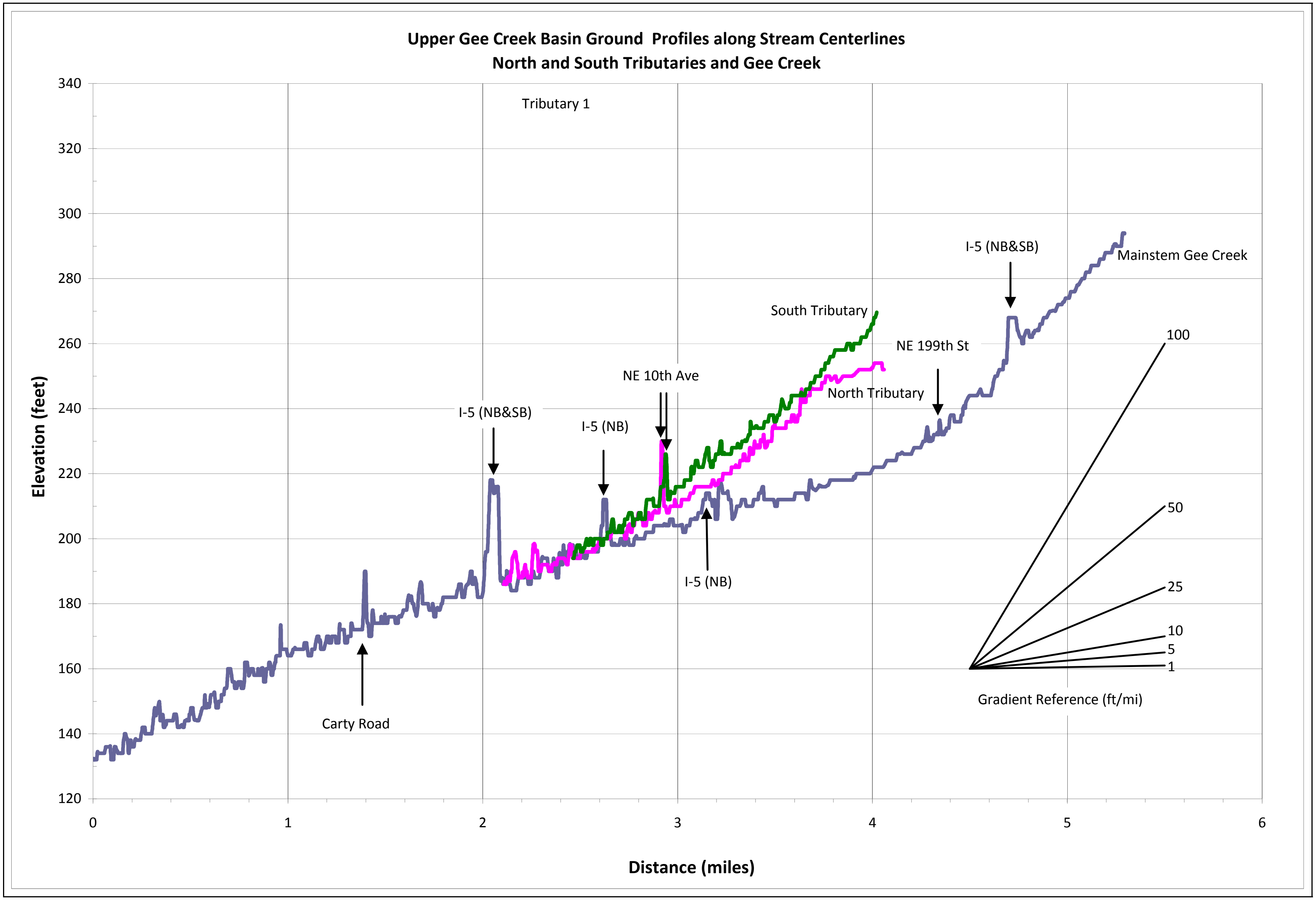

Figure 13. Ground profiles along stream channel centerlines for North Tributary, South Tributary, and Gee Creek.

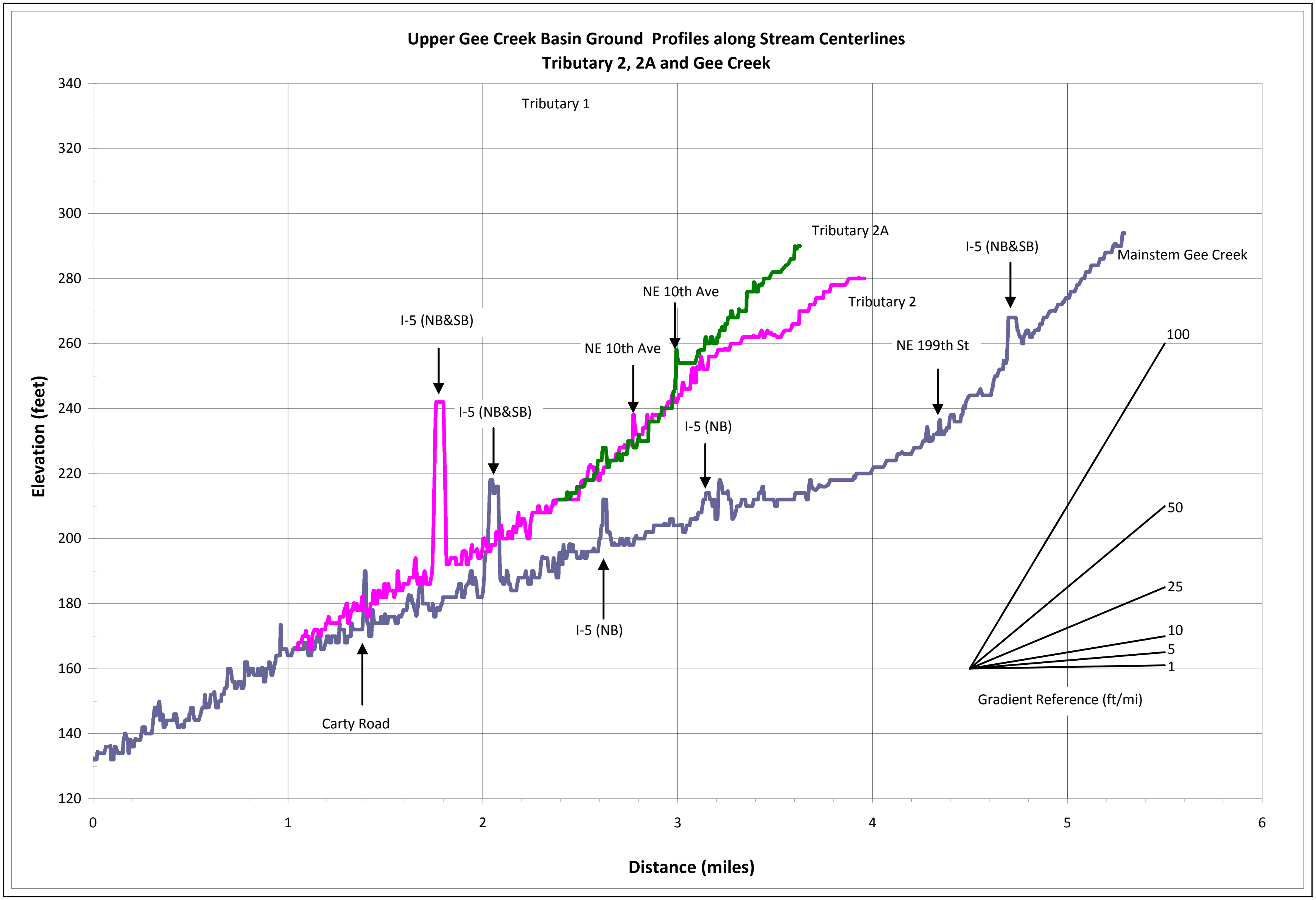

Figure 14. Ground profiles along stream channel centerlines for Tributary 2, 2A and Gee Creek.

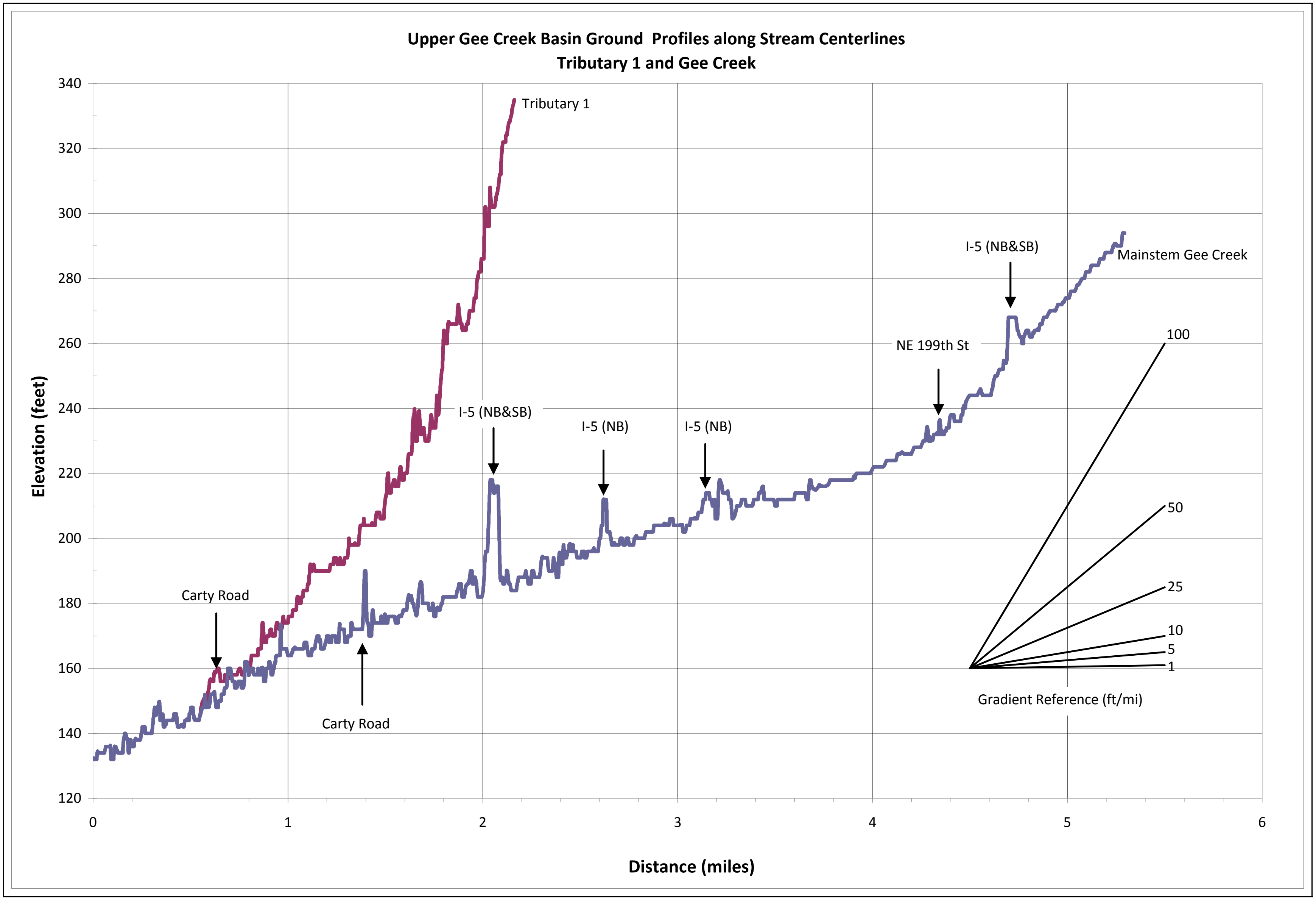

Figure 15. Ground profiles along stream channel centerlines for Tributary 1 and Gee Creek.

3.3.3 Valley Cross Section Geometry

Selected cross sections located along the valleys of Upper Gee Creek and its major tributaries were extracted from the DTM of the basin to help understand the valley geometry and how its form transitions from upstream to downstream. The locations of the extracted cross sections are shown in Figure 16. Valley cross section geometries for Gee Creek and its major tributaries are shown in Figure 17 through Figure 22.

3.3.3.1 Gee Creek Upstream of 199th Street and Tributary Reaches East of NE 10th Ave

Gee Creek upstream of 199th Street (Reaches 4 and 5 in Figure 12) and the tributary stream reaches located east of NE 10th Ave are generally confined within a "V" shaped valley form. The confined valley form in the upper watershed is further evidence that these stream reaches are supply limited "source" reaches in that, over the long-term, sediment transport capacity generally exceeds sediment supply. These reaches will tend to incise over time and are considered to be the most susceptible to increases in peak flows and/or increases in the duration of flows that exceed the critical shear stress of the bed material. Gradual incision is expected to continue to occur with time unless there is sufficient grade control from vegetation, woody debris, or the underlying geology. Culvert crossings will continue to provide a form of grade control, although this is not typically their primary function. Further, significant discontinuities in grade at culvert outlets can have undesirable impacts on fish passage.

3.3.3.2 Gee Creek between I-5 and 199th Street and Tributary Reaches between NE 10th Ave and I-5

The reach of Gee Creek between I-5 and 199th Street (Reach 3 in Figure 12) and the tributary streams between NE 10th Ave and I-5 progressively become less confined as the valley bottoms flatten and widen becoming more trapezoidal in shape. These reaches are considered "transport" reaches in that, over the long-term, sediment transport capacity generally equals sediment supply. Temporary storage of sediment occurs within these reaches resulting in increased sinuosity compared to the upstream supply reaches.

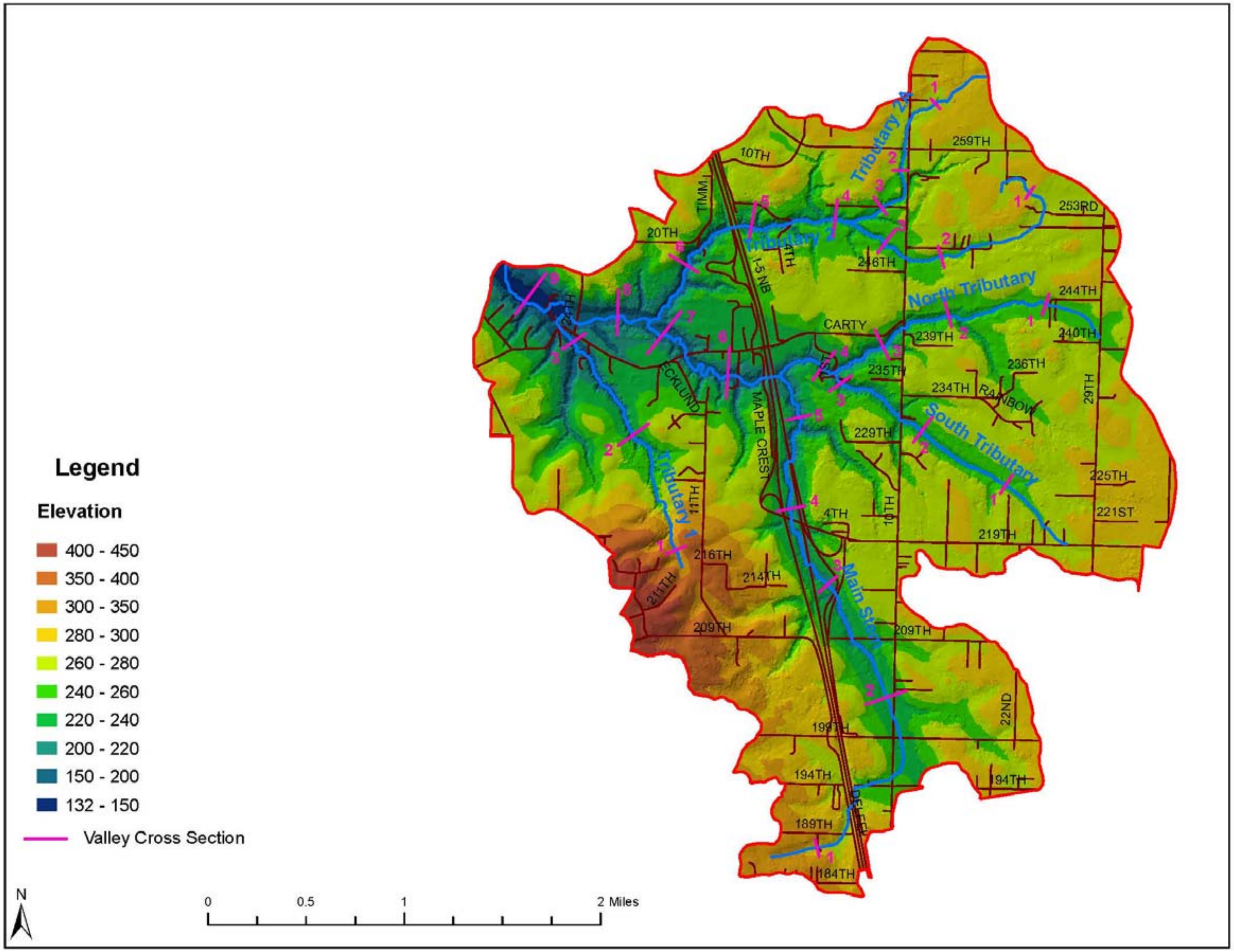

Figure 16. Location of valley cross section extracted from DTM.

3.3.3.3 Gee Creek between I-5 and Carty Road

The reach of Upper Gee Creek between I-5 and Carty Road (Reach 2 in Figure 12) is a transport limited "response" reach in that, over the long-term, sediment supply generally exceeds sediment transport capacity. The channel slope is controlled at the downstream end by hydraulic conditions associated with the Carty Road culvert crossing and the intersection of the stream bed with the underlying coarse grained Plio-Pleistocene conglomerate bedrock. The combination of these two features reduces the sediment transport capacity of the channel below the sediment supplied from upstream reaches resulting in long-term sediment deposition.

3.3.3.4 Gee Creek between Carty Road and Upper Gee Creek Basin Outlet

The reach of Upper Gee Creek downstream of Carty Road (Reach 1 in Figure 12) is considered to be a supply limited "source" reach in that, over the long-term, sediment transport capacity generally exceeds sediment supply. The underlying coarse grained Plio-Pleistocene conglomerate is more resistant to transport except during larger flows and is therefore limiting the supply of sediment to the stream. Any input of fine sediment from upstream will be transported through this reach except where local hydraulic conditions reduce the velocities and shear stresses sufficiently to encourage deposition. This condition would be typical of floodplain areas with sufficient hydraulic roughness or in backwater areas upstream of hydraulic constrictions. Temporary storage of fine sediment occurs within overbank areas of this reach resulting in greater sinuosity compared to the supply reaches further upstream.

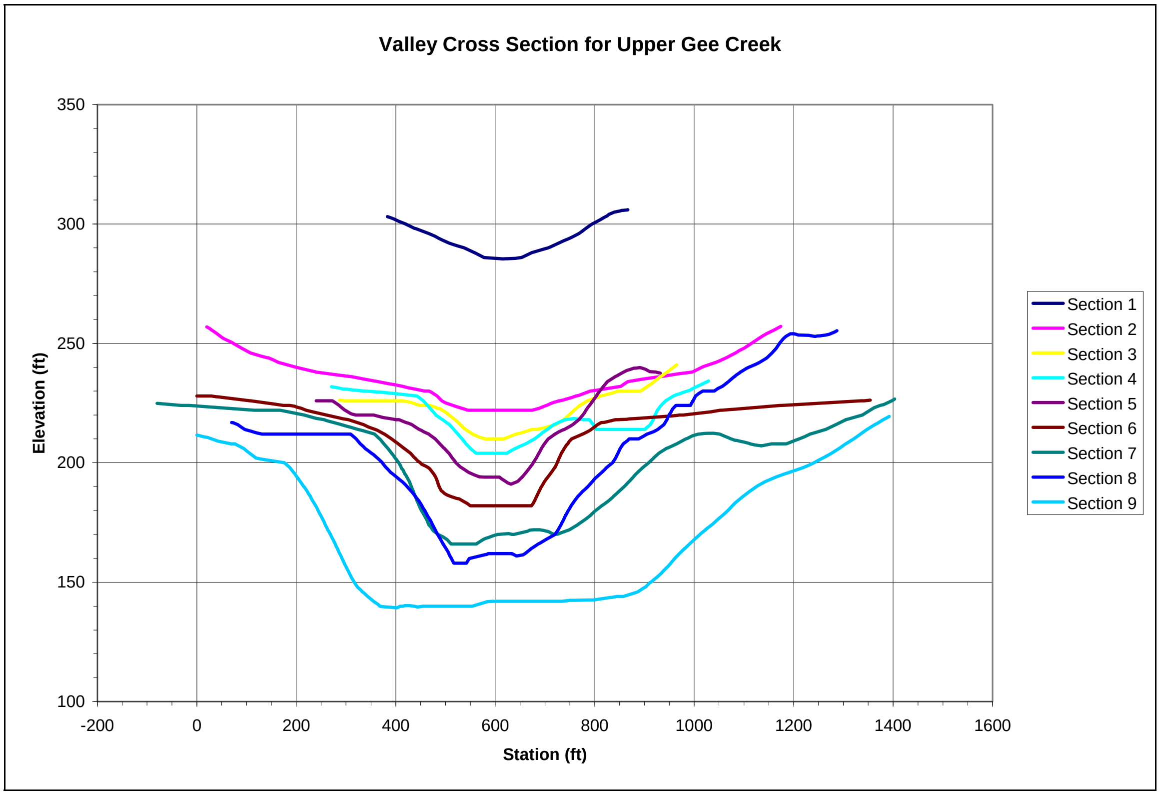

Figure 17. Valley cross sections for Upper Gee Creek.

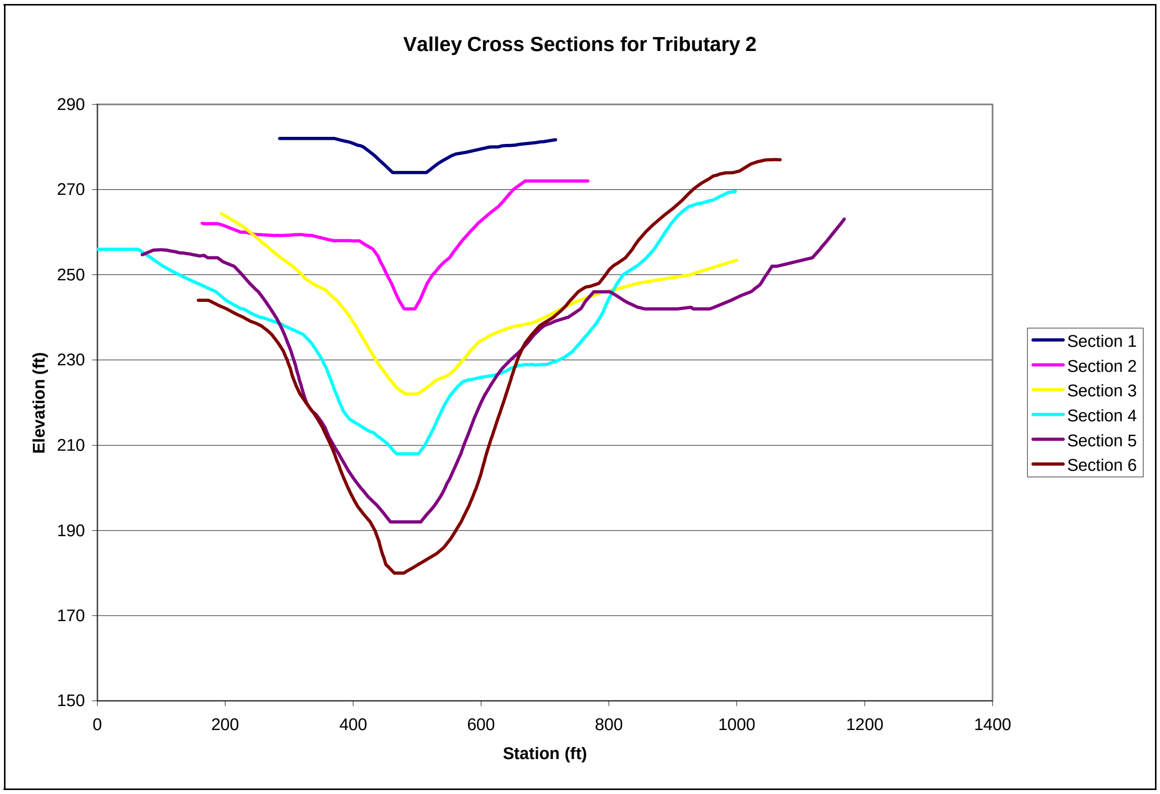

Figure 18. Valley cross sections for Tributary 2.

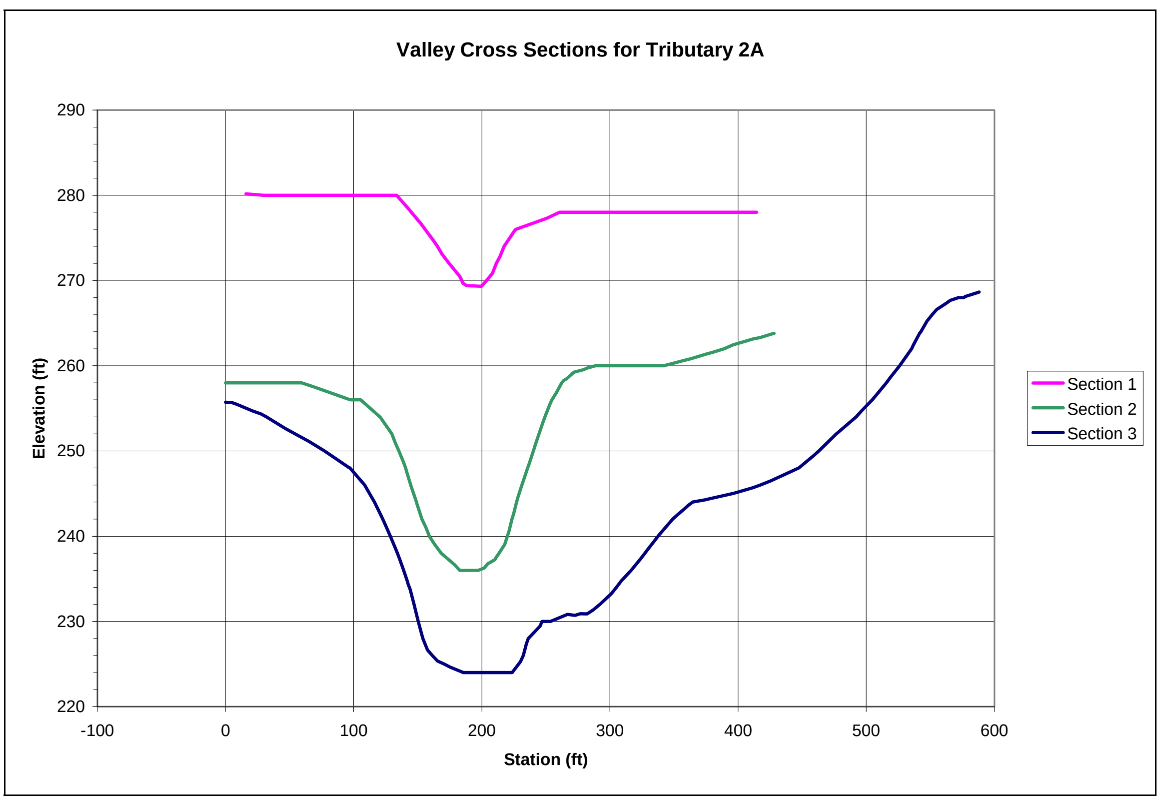

Figure 19. Valley cross sections for Tributary 2A.

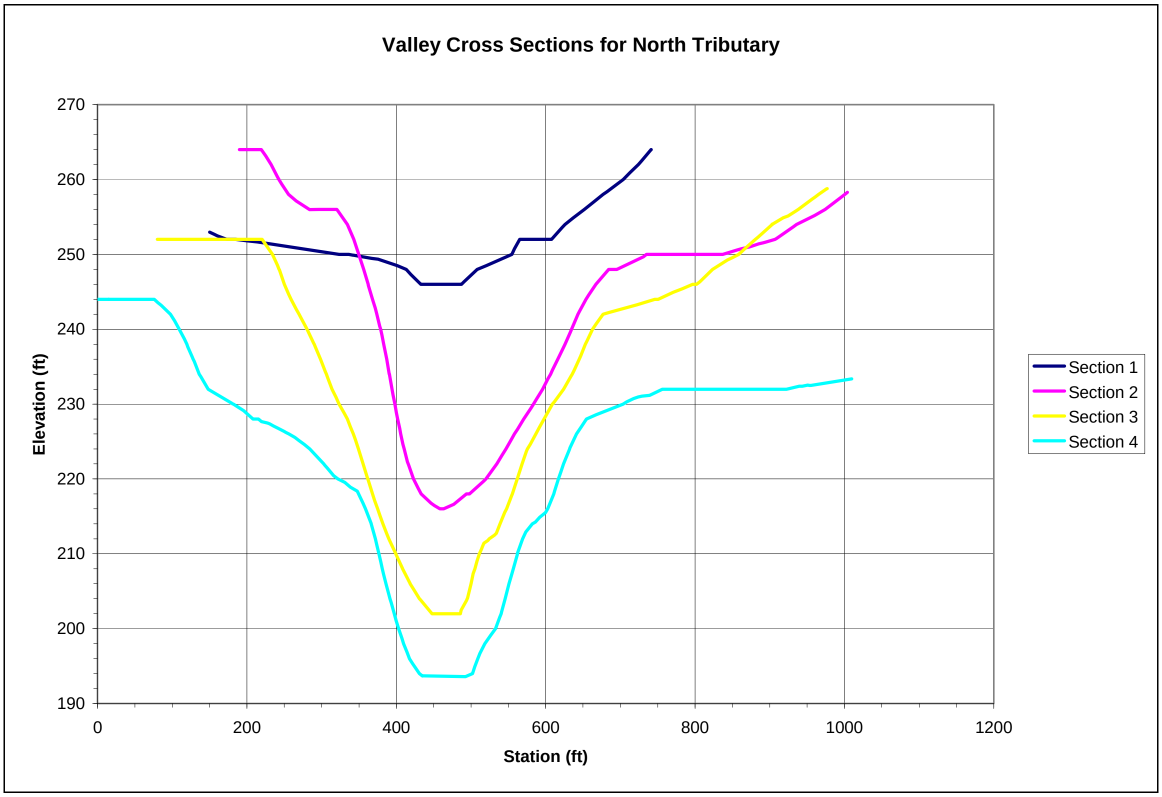

Figure 20. Valley cross sections for North Tributary.

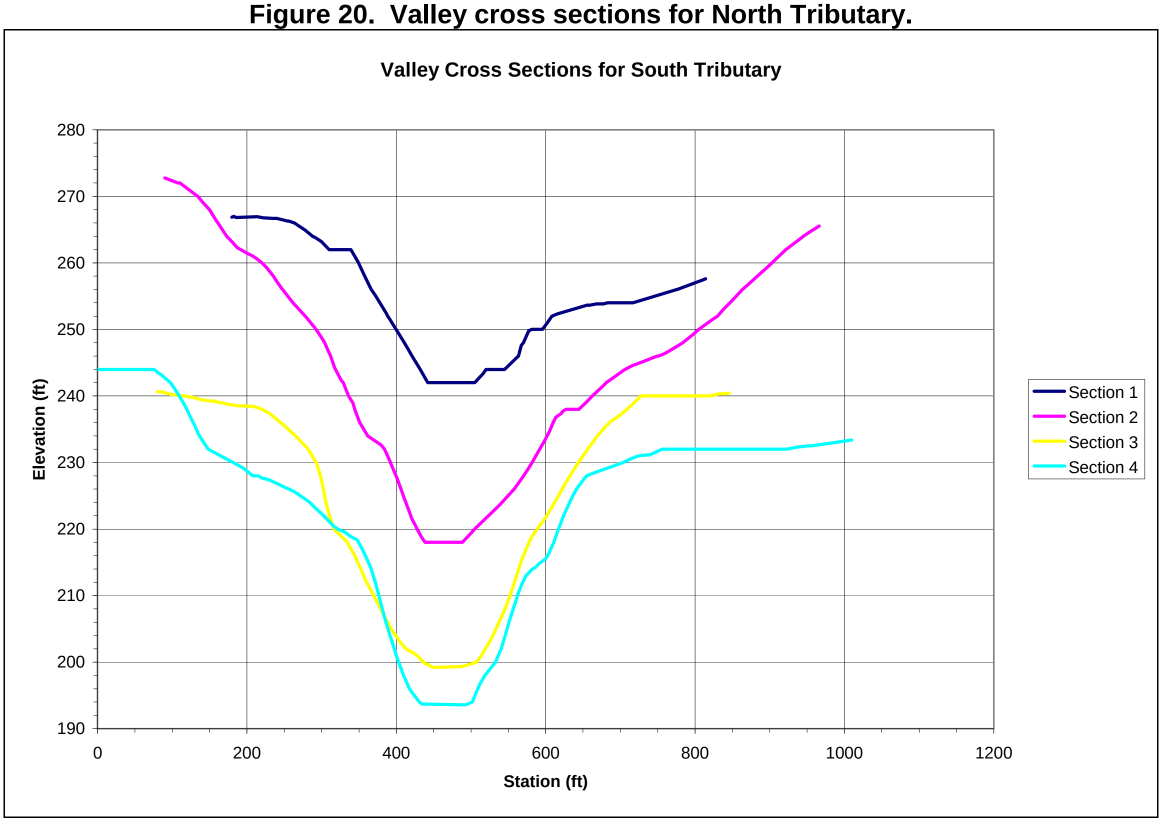

Figure 21. Valley cross sections for South Tributary.

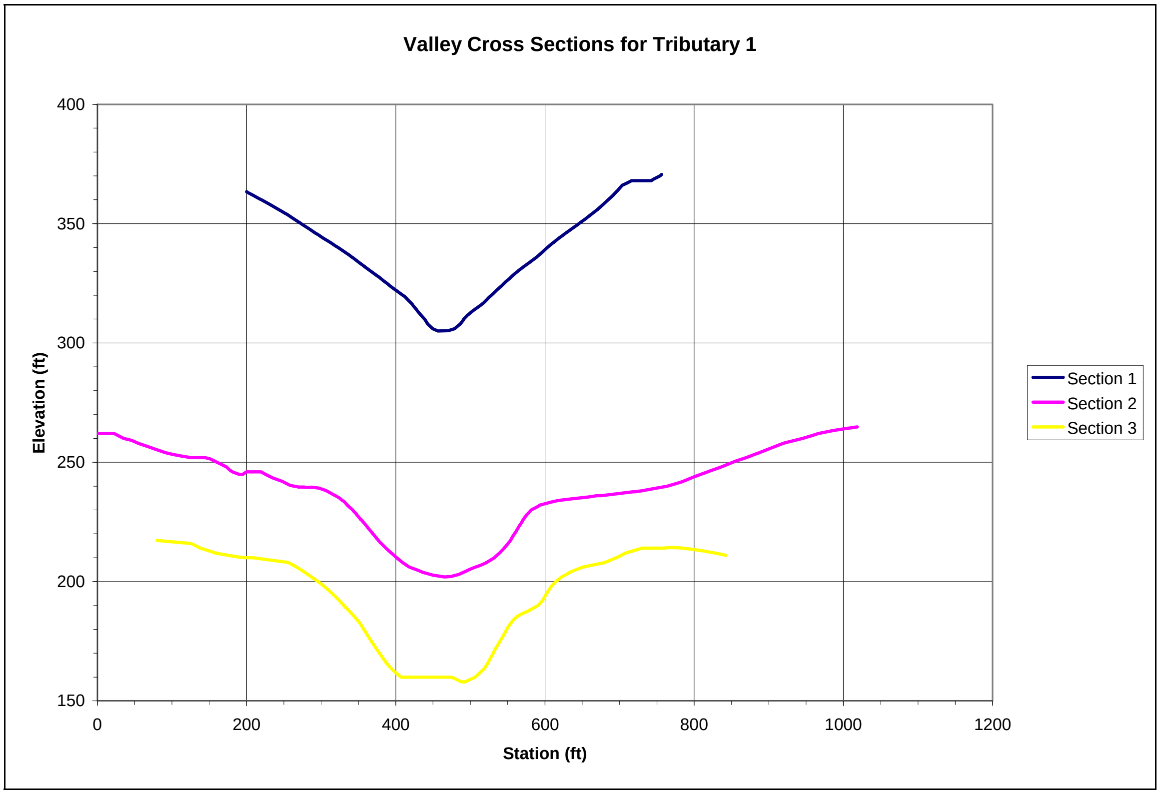

Figure 22. Valley cross sections for Tributary 1.

3.3.4 Large Woody Debris

Prior to removal, large diameter trees would have provided a supply of large woody debris to the stream channels. Large woody debris likely played a significant role in the form and function of streams in the Upper Gee Creek basin. The sizes of the channels found in the basin are too small to transport the majority of the wood that was contributed by the riparian forests that were once present along the stream corridors. Therefore, if not removed, the large woody debris likely remained in the channels until decay.

Large woody debris provides roughness, helping to dissipate energy and reduces the ability of the stream to transport sediment. Woody debris can also provide a protective cover, essentially shielding the bed and banks from erosive flow conditions. Further, large woody debris can act as grade control locally reducing the channel slope, trapping sediment and preventing channel incision. Woody debris can also control local hydraulic conditions that provide complexity and a variety of habitat conditions.

The majority of the remaining forest land in the Upper Gee Creek basin is found on steeper slopes adjacent to the mainstem and tributary stream channels and associated floodplain terraces in the middle and lower portions of the basin where the land is not conducive to farming. The extent to which the remaining forest lands have been altered from their conditions prior to Euro-American settlement is unknown. However, field observations indicate that the remaining forest lands do not contain a significant amount of large diameter trees suggesting that much of the original timber was likely harvested in the late 1800's and early 1900's.

3.3.5 Conclusions

The geomorphology of the streams in the Upper Gee Creek basin result from a combination of natural and human related controlling factors. The underlying geologic formations in the basin have the greatest control over channel planform, channel slope, and cross section geometry. The stream reaches located within the easily transported fined grained Cataclysmic Flood Deposits are the most susceptible to channel incision and have been incising into the surrounding landscape since the last glacial period. The stream reaches located within the less transportable coarse grained Plio-Pleistocene conglomerate are less susceptible to incision but more susceptible to channel widening.

Existing culverts provide local grade control; however, the culverts that are located in the lower stream reaches inhibit natural channel migration. As seen in Figure 9, culverts have significant impacts on channel hydraulics and floodplain connectivity. The culverts are providing a benefit by increasing floodplain connectivity within the system of naturally incised channels. However, floodplain connectivity would have historically been provided by backwater caused by large woody debris jams. Further, several culverts are creating additional impacts such as excessive upstream sedimentation, excessive downstream channel scour, limiting channel migration and potentially creating barriers to fish passage. These negative impacts may outweigh the floodplain connectivity benefit. Replacement structures that include proper mitigation could minimize the negative impacts and continue to provide floodplain connectivity.

Channel reaches that contain sufficient functional large woody debris are less susceptible to degradation by future increases in peak flows and flow durations. Enhancement and/or restoration of native riparian forests will provide a future source of large woody debris to the streams. The following sections list specific conclusions regarding the geomorphology of channel reaches located within the Upper Gee Creek basin.

3.3.5.1 Gee Creek Upstream of 199th Street and Tributary Reaches East of NE 10th Ave

- Unless properly managed, future increases in impervious surface area within the upper portion of the basin will result in increased peak flows and/or flow durations. These changes will likely cause channel incision in the “source” reaches within the upper basin to accelerate beyond current rates. However, either man-made or natural (such as large woody debris) grade controls would help to minimize the increased rate of incision.

- If grade controls are nonexistent, the resulting channel degradation and headcutting will move the channel initiation point further upslope, increasing the drainage density and efficiency with which the surrounding soils are drained. Channel degradation and headcutting will destabilize channel banks causing bank failures and an overall widening of the stream valley. Unless controlled the upper watershed stream reaches will transition, through both erosion and bank failures, from their current narrow “V” shaped valley form toward a deeper and broader trapezoidal shaped valley form as seen in downstream reaches.

- Existing culvert crossings will continue to provide some measure of grade control with these reaches but may eventually become barriers to fish passage.

- For those stream reaches that are draining portions of the watershed that are likely to experience a slow rate of development and therefore minimal changes to the existing hydrologic conditions, the above described channel changes may go unnoticed. Whereas stream reaches that drain portions of the watershed that are likely to experience higher rates of development and if not properly mitigated, significant changes to the existing hydrologic conditions, significant channel incision, headcutting, and bank failures will be readily evident.

3.3.5.2 Gee Creek between I-5 and 199th Street and Tributary Reaches between NE 10th Ave and I-5

- Future increases in peak flows and flow durations originating in the upper basin may have only minimal impacts on channel morphology within these “transport” reaches if there is a proportional increase in upstream sediment supply. However, if increases in peak flows or flow durations originate locally, such as from a new stormwater outfall, there will not be a proportional increase is sediment supply. This would initiate channel incision causing the reach to transition from a “transport” reach to a “source” reach.

- Existing culvert crossings will continue to provide some measure of grade control and will limit channel migration within these reaches.

3.3.5.3 Gee Creek between I-5 and Carty Road

- The “response” reach between I-5 and Carty Road could react in different ways to future increase in flow magnitude and/or duration. If the increased flows originate in the upper basin and if there is a proportional increase in upstream sediment supply, the additional sediment supplied to the reach will result in greater deposition rates, increased channel migration, and accelerated bank erosion. However, if the increased flows originate locally, such as from a new stormwater outfall, there will not be a proportional increase is sediment supply. In this case, the downstream hydraulic and bed controls will likely minimize significant morphologic changes.

3.3.5.4 Gee Creek between Carty Road and Upper Gee Creek Basin Outlet

- If future increases in flow magnitudes and/or durations occur, the reach located downstream of Carty Road which is underlain by the coarse grained Plio-Pleistocene conglomerate will initially resist channel incision. Since bank material within this reach is generally composed of easily transported sand and silt sized material, increased erosion will occur along the outside of meander bends resulting in channel widening. Where the outside of the meander bend abuts the valley walls, erosion at the toe of the slope may result in slope failures. If future flows become sufficient to erode and transport the underlying coarse grained Plio-Pleistocene conglomerate bedrock, incision and bank failures will occur.

3.3.6 Recommendations

- Restore and/or enhance riparian vegetation to provide a future source of large woody debris to the channel. Priority should be given to those reaches downstream of areas that are zoned for urban development. Emphasis should also be given to those reaches underlain by the fine grained Cataclysmic Flood Deposits.

- Although a lower priority, stream reaches that are expected to experience the least amount of development should not be ignored. Reestablishment of riparian corridors in these areas while development pressure is low will allow a greater time period for the riparian vegetation to mature and therefore provide greater protection to the streams as development pressure increases in the future.

- Develop monetary incentives that encourage land owners to enhance or restore riparian corridors.

- Develop education and outreach programs that promote the benefits of healthy riparian corridors. Encourage farm and ranch owners to participate in the NRCS Conservation Reserve Program http://www.nrcs.usda.gov/programs/crp/ which is administered through the Clark Conservation District http://www.clarkcd.org/

4 Summary and Conclusions

The mainstem and tributary channels in the Upper Gee Creek basin are currently not experiencing significant geomorphic changes. Their current geomorphic character results from a combination of natural and human related controlling factors. The underlying geologic formations in the basin have the greatest control over stream morphology as the size of the sediment supplied by the underlying bedrock determines the channels relative resistance to erosion. The stream reaches located within the easily transported fined grained Cataclysmic Flood Deposits are the most susceptible to channel incision and have been incising into the surrounding landscape since the last glacial period. The stream reaches located within the less transportable coarse grained Plio-Pleistocene conglomerate are the least susceptible to incision.

Conversion of the basin from its preEuro-American settlement forested condition to primarily agriculture land use in the late 1800's to early 1900's along with removal of riparian vegetation and woody debris likely resulted in an increased rate of channel incision. Since much of the road system was likely established at the same time the forests were being cleared for agriculture, the culvert stream crossings likely acted as grade control and helped resist the resulting incision just as the current stream crossing culverts are currently helping resist incision.

As the amount of impervious surface area in the basin increase with time, runoff volumes and peak flows will increase. Unless controlled, the sand and silt bed stream reaches in the middle and upper portion of the basin will incise at a faster rate. The channel incision will cause bank failures that will result in greater valley widths and increase the supply of sediment derived from the fine grained Cataclysmic Flood Deposits to downstream reaches. The reach between I-5 and Carty Road will likely respond to the increased sediment load through acceleration of channel migration as this reach has historically been prone to sediment deposition. Bank erosion along the outside of meander bends would become more severe and could potentially accelerate erosion of the adjacent terrace slopes. The gravel and cobble bed reach of Gee Creek below Carty Road is more resistant to incision and will likely exhibit increased bank erosion resulting from greater shear forces associated with higher discharges. However, if the duration of flows that equal or exceed the threshold of transport for the gravel and cobble size bed material is increased, channel incision would likely occur within this reach as well.

Various alternatives exist to help protect the streams in the Upper Gee Creek basin from human-caused degradation. The most effective alternatives are to protect and restore riparian forest cover, limit the increase in effective impervious area, and properly manage runoff associated with development. Current land use zoning maps indicate that 65 percent of the basin can be used for either agriculture or rural residential development. These areas will likely to produce the least impact to streams compared to the current conditions. The remaining 35 percent is zoned for a mix of low and medium density residential, light industrial, employment center and commercial use, which would be expected to have greater proportion of impervious area and therefore a greater impact on associated basin streams.

Additional alternatives to limit human-caused degradation of streams in the Upper Gee Creek basin include specific project and management recommendations which are presented in the following sections. Implementation of these projects and management recommendations would help reduce the magnitude of current human caused impairments that have resulted from historic and current land use and minimize future impacts resulting from expected future development within the Upper Gee Creek basin.

5 Project Recommendations

Various potential projects could be developed to help recover existing impairments and help reduce future degradation of streams in the Upper Gee Creek basin. Table 5 summarizes the location and types of projects recommended.

Table 5. Recommended Stormwater Capital Improvement Projects.

Stream	Location/Reach	Impairment	Project
Gee Creek	Upstream terminus to I-5 rest stop	Lacks sufficient riparian vegetation and in many locations has extensive invasive plant species	Riparian plantings and invasive species removal
Gee Creek	Between I-5 and 194th St.	Channelized and extensive blackberry	Stream restoration
Gee Creek	At 199th Street	Undersized Culvert	Replace culvert
Gee Creek	At Carty Road	Undersized Culvert	Replace culvert and mitigate for potential channel and floodplain connectivity impacts associated with the replacement structure
Tributary 2A	Between Union Ridge (259th St.) and NE 10th Ave	Failure of grade control along stream restoration site	Replace grade control and repair damaged stream banks
Tributary 2A	Upstream of Union Ridge (259th Street) to terminus	Generally lacks sufficient riparian vegetation	Riparian plantings
Tributary 2	Upstream of NE 10th Ave to terminus	Generally lacks sufficient riparian vegetation	Riparian plantings
North Tributary	Between I-5 to 1st Ave and upstream of NE 10th Ave to terminus	Generally lacks sufficient riparian vegetation	Riparian plantings
South Tributary	Upstream of imaginary intersection of 15th Ave to terminus	Generally lacks sufficient riparian vegetation	Riparian plantings
Tributary 1	Ustream of imaginary intersection of 225th Street to terminus	Generally lacks sufficient riparian vegetation	Riparian plantings

As seen in Table 5, the culverts at 199th Street and Carty Road should be replaced. The culvert at 199th Street is undersized resulting in roadway overtopping in 2007. Further, the culvert is damaged and is suffering significant corrosion. The culvert at Carty Road is significantly undersized and should be replaced with a hydraulic structure that accommodates natural fluvial processes and does not significantly alter the hydraulic and sediment transport characteristics of Gee Creek. Potential upstream and downstream impacts resulting from the replacement structure and mitigation for these impacts must be considered during design.

The remaining recommended projects are either enhancement or establishment of a healthy riparian corridor through invasive species removal and new riparian plantings. These types of projects are considered to provide the greatest benefit to the streams in the Upper Gee Creek basin. From a geomorphic standpoint, an established riparian corridor will help create hydraulic roughness that reduces stream velocities and erosion potential and help reduce bank erosion. More importantly it allows for the recruitment of large woody debris which is generally lacking in the basin streams. An established functional riparian corridor will help minimize impacts associated with future increases in flow magnitudes and/or durations.

Private dams and associated ponds have been observed along both the main stem and tributary reaches of Upper Gee Creek. The benefit of removing or modifying dams would have to be carefully considered and evaluated on a case by case basis. Therefore, alteration or removal of individual dams was not included in the above list of recommended projects.

6 Management Recommendation

Various management alternatives exist to help recover existing impairments and reduce future degradation of streams in the Upper Gee Creek basin:

- Restore and/or enhance riparian vegetation to provide a future source of large woody debris to the channel. Priority should be given to those reaches downstream of areas that are zoned for urban development. Emphasis should also be given to those reaches underlain by the fine grained Cataclysmic Flood Deposits.

- Although a lower priority, stream reaches that are expected to experience the least amount of development should not be ignored. Reestablishment of riparian corridors in these areas while development pressure is low will allow a greater time period for the riparian vegetation to mature and therefore provide greater protection to the streams as development pressure increases in the future.

- Dams and associated ponds should be individually evaluated to determine the impact each is having on the hydrology, water quality and geomorphology of the involved stream. This could be used to prioritize both modifications to and/or removal of existing structures.

- Existing and future stormwater detention facilities should be evaluated through the use of continuous simulation hydrologic modeling to understand the magnitude of modifications to the duration of flows compared to predevelopment conditions.

- Ensure appropriate BMPs are being implemented with regard to maintenance of drainage ditches and discourage the development of new drainage ditches that have a direct connection to natural channels.

- Use geomorphically based performance standards when designing and constructing new or replacement hydraulic structures at road crossings. Designs should allow for lateral and longitudinal continuity and connectivity of both the channel and functional floodplain in addition to hydraulic design considerations.

- Encourage the use of Low Impact Development (LID) measures for newly developing areas in the basin. LID focuses on minimizing the amount of runoff generated from the site by minimizing to the extent practical the amount of increased impervious surface area and by infiltrating and treating stormwater runoff near the source in order to best mimic the predeveloped hydrologic conditions. Where soil conditions are a limiting factor, combine LID practices with traditional stormwater detention/retention facilities.

- Continue monitoring stream flows at the Abrams Park gage and consider the installation of an additional stream gage in the Upper Gee Creek Basin. T_{Qmean} and other streamflows statistics can be used to help evaluate the effectiveness stormwater management practices as future development occurs in the basin. An additional stream flow gage would allow for results that are representative of the Upper Gee Creek basin and thus exclude impacts to stream flows associated with development conditions downstream of the Upper Gee Creek basin.

- Develop a calibrated continuous simulation hydrologic model of the Upper Gee Creek basin to help evaluate changes in basin hydrology associated with future development. The model will help determine the magnitude and location of expected hydrologic changes and be useful to evaluate the effectiveness of stormwater facilities and potential mitigation projects. The model could also be used to revise Clark County and City of Ridgefield development regulations via a Stormwater Basin Plan

- Develop more stringent stormwater flow control regulations that better mimic predevelopment conditions both from the peak flow and flow duration standpoint.

- Discourage surface water withdrawals for irrigation to help promote sufficient summer low flow conditions.

- Develop monetary or tax incentives that encourage land owners to enhance or restore riparian corridors.

- Develop education and outreach programs that promote the benefits of healthy riparian corridors. Encourage farm and ranch owners to participate in the NRCS Conservation Reserve Program http://www.nrcs.usda.gov/programs/crp/ which is administered through the Clark Conservation District http://www.clarkcd.org/

7 Bibliography and References

Beeson, M.H., Tolan, T.L., and Anderson, J.L., 1989, The Columbia River Basalt Group in Western Oregon; Geologic Structures and other Factors that Controlled Flow Emplacement Patterns, in Reidel, S.P. and Hooper, P.R., eds., *Volcanism and tectonism in the Columbia River flood-basalt province*, Geologic Society of America Special Paper 239, p223-246

Clark County Department of Assessment and GIS, MrSID aerial photography mosaics, years 1955, 1968, 1984, 2002, and 2007

Clark County, September 2007, 20-Year Comprehensive Growth Management Plan 2004-2024

Clark County Department of Assessment and GIS, December 2003, LiDAR derived 2-foot contour interval topographic mapping, NAD 1983 Washington State Plane South Zone (FIPS 4602 Feet), NGVD 1929 (1947 adjustment).

Clark County, December 2003, Long-Term Index Site Monitoring Project: 2002 Physical Habitat Characterization, Public Work Department, Water Resources Section

Cornelius, Lynn, July 2006, Gee Creek Watershed Restoration Background Report, WSU Clark County Extension

Evarts, Russell C., 2004, Geologic Map of the Ridgefield Quadrangle, Clark and Cowlitz Counties, Washington, U.S. Geological Survey

Federal Emergency Management Agency, September 29, 2006, Preliminary Flood Insurance Study for Clark County Washington and Incorporated Areas, Department of Homeland Security

Herrera Environmental Consultants, April 2008, Draft - Feature Inventory GIS database

Liberty, L.M., Hemphill-Haley, M.A., and Madin, I.P., 2003, The Portland Hills Fault –uncovering a hidden fault in Portland, Oregon using high-resolution geophysical methods, Tectonphysics, v. 368. p. 89-103

Mabey, M.A. and Madin, I.P., 1995, Downhole and Seismic Cone Penotrometer Shear-Wave Velocity Measurements for the Portland Metropolitan Area, 1993 and 1994, Oregon Department of Geology and mineral Industries, Open File Report O-95-7

McGee, Dale A., November 1972, Soil Survey of Clark County, Washington, National Resource Conservation Service (NRCS) (formerly SCS)

Mundorf, M.J., 1964, Geology and Groundwater Conditions of Clark County, Washington, U.S. Geological Survey Water-Supply Paper 1600

National Resource Conservation Service (NRCS), 2004, GIS data from NRCS website: http://www.ncgs.nrcs.usda.gov/branch/ssb/products/ssurgo/fact-sheet.html

National Resource Conservation Service (NRCS), April 1998, U.S. Department of Agriculture, Annual Precipitation Map of Washington

Rosgen, D.L., H.L. Silvey, 1996, Applied River Morphology, Wildland Hydrology Books, Fort Collins, CO.

Swanson, R.D., McFarland, W.D., Gonthier, J.B.,and Wilkinson, J.M., 1993, A Description of Geologic Units in the Portland Basin, Oregon and Washington, U.S. Geological Survey Water-Resources Investigation Report 90-4196

Sumioka, S.S., Kresch, D.L., and Kasnick, K.D., 1997, Magnitude and Frequency of Floods in Washington, U.S. Geologic Survey Water-Resources Investigation Report 97-4277

U.S. Geological Survey, 1990, 1:24,000 topographic map of the Ridgefield Quadrangle

Waitt, R.B. Jr., 1994, Scores of Gigantic , Successively Smaller Lake Missoula Floods Through Channeled Scabland and Columbia Valley, in Swanson, D.A., Haugerud, R.A., eds., *Geologic Field Trips in the Pacific Northwest*, Seattle, University of Washington Department of Geological Sciences, p.1K-1-1K-88

Washington Department of Ecology (WDOE), April 4, 2007, Watershed Characterization of Clark County, Version 3

WEST Consultants, Inc. (WEST), July 2005, HEC-RAS hydraulic model of Gee Creek, Developed for Preliminary FEMA Flood Insurance Study of Clark County Washington and Incorporated Areas, September 2006

Wierenga, Ron, January 2005, Subwatershed Characterization and Classification, Clark County, Washington, Clark County Water Resources Program

Yeats, R.S., Graven, E.P., Werner, K.S., Goldfingerm, Chris, and Popowski, T.A., 1996, Tectonics of the Willamette Valley, Oregon, in Rogers, A.M., Walsh, T.J., Kockelman, W.J., and Priest, G.R., eds., *Assessing Earthquake Hazards and Reducing Risk in the Pacific Northwest*, U.S. Geological Survey Professional Paper 1650, v. 1, p. 183-222

Appendix A
Summary of Field Observations

Stream	Location	Hydraulic Structure	Upstream of Road Crossing									Downstream of Road Crossing									Additional Comments
			Floodplain Connectivity	Sinuosity	Riparian Cover	Bed Material	Bank Material	Woody Debris	Land Use	Active Erosion	Potential SCIP	Floodplain Connectivity	Sinuosity	Riparian Cover	Bed Material	Bank Material	Woody Debris	Land Use	Active Erosion	Potential SCIP	
Gee Creek	194th Street	Culvert	poor	none	poor	silt/sand	silt/clay	none	industrial	No	Channel Restoration/ Riparian Plantings	moderate	none	poor	silt/sand/grass	silt/clay	none	Residential	No	Riparian Plantings	Riparian cover improves downstream toward 10th Ave, Upstream the Creek appears to have been relocated along the property boundaries and is essentially a ditch lined with blackberry
Gee Creek	199th Street east of NE 10th Ave	Culvert	good	slight	poor	silt/clay with minor small gravel	silt/clay	none	undeveloped	no	Culvert Replacement / Riparian Plantings	moderate	slight	none	silt/clay with minor small gravel	silt/clay	none	agriculture	minor	Culvert Replacement / Riparian Plantings	Downstream the banks are near vertical between 12" and 18" tall with some undercutting. Culvert outlet is damaged which is reducing its capacity. Culvert inlet is corroded, causing a scour hole to form which is undermining the roadway fill. Recent high flows overtopped the road resulting in erosion of the downstream side of the roadway fill (no armored with rock).
Gee Creek	209th Street	Culvert	good	moderate	none	silt/clay	silt/clay	none	agriculture	no	Riparian Plantings	good	n/a	poor	silt/clay	silt/clay	none	pasture	no	Riparian Plantings	Downstream is a shallow pond that is likely causing sedimentation to occur.
Unnamed Tributary to Gee Creek	10th Ave north of 224th Street	Culvert	no floodplain	slight	moderate	unknown - likely silt/clay	unknown likely silt/clay	minor	residential	no	Invasive Plant Species Removal	no floodplain	slight	moderate	unknown - likely silt/clay	unknown - likely silt/clay	minor	residential	no	Invasive Plant Species Removal	Dense blackberry invading riparian zone both u/s and d/s
South Tributary to Gee Creek	NE 10th Ave south of 234th Street	Culvert	good	slight	moderate	silt/clay with minor small gravel	silt/clay	yes	residential/ agriculture	no		good	slight	very good	silt/clay with minor small gravel	silt/clay	yes	undeveloped	no		Upstream has stormwater detention facility along right bank that appears to encroach on the floodplain
North Tributary to Gee Creek	NE 10th Ave north of 240th Street	Culvert	good	moderate	moderate	silt/clay with minor small gravel	silt/clay	minor	agriculture/ silvaculture	no		good	moderate	good	silt/clay with minor small gravel	silt/clay	yes	undeveloped	no	Invasive Plant Species Removal	Blackberry encroaching on downstream right bank riparian zone
Confluence of North and South Tributaries to Gee Creek	NW 1st Ave south of Carty Road	Culvert	good	moderate	moderate	sand/silt	sand/silt	no	residential	no	Invasive Plant Species Removal	good	moderate	moderate along left bank, poor along right bank	sand/silt	sand/silt	minor	residential	no	Riparian Plantings	Blackberry encroach on both banks upstream. Sedimentation upstream of culvert has created a wetland margin along channel.
Unnamed Tributary to Gee Creek	NE 10th Ave south of 249th Street	Box Culvert	good	moderate	poor	silt/clay	silt/clay	minor	agriculture/ residential	no	Riparian Plantings	good	moderate	poor	silt/clay	silt/clay	none	agriculture/ residential	no	Riparian Plantings	Downstream appears to be an inline stormwater detention facility. Upstream has significant blackberry encroachment along both banks.
Unnamed Tributary to Gee Creek	259th Street (Union Ridge) west of NE 10th Ave	Box Culvert	poor	slight	extensive new plantings	silt/sand	silt/clay	yes	Industrial/ commercial	yes	Repair/replace grade control and channel banks	good	modeate	moderate	silt/sand with minor small gravel	silt/clay	minor	Industrial/ commercial/ residential	no		Upstream is sight of stream restoration project which has been affected by recent high flows. Installed log grade controls have been flanked by the stream resulting in headcutting of the channel and bank failures.
Gee Creek	Carty Road east of NW Ecklund Road	Culvert	good	high	moderate	silt/clay	silt/clay	yes	residential	no	Culvert Replacement (bridge?)	good	moderate	good	sand/gravel	silt/sand	minor	residential	yes	Culvert Replacement (bridge?)	There is a large scour hole d/s of culvert
Gee Creek	NW 24th Ave	Culverts	yes	moderate	good	gravel/ cobble	sand/silt	minor	residential	minor		good	moderate	moderate	gravel/ cobble	sand/gravel on right bank, silt/sand on left bank	minor	residential	yes		active erosion along toe of slope downstream of culvert along left bank