ATTACHMENT 2:
HEC-RAS MODEL DEVELOPMENT

1. INTRODUCTION

The hydraulics of Thompson Creek and the potential impacts of the Thurston Highlands development were evaluated using a HEC-RAS hydraulic model. HEC-RAS is a one-dimensional hydraulic modeling program developed by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center (see http://www.hec.usace.army.mil/ for more information about the Hydraulic Engineering Center and the products it develops). The model requires two types of input: 1) geometric data consisting of cross-sections, stream reach lengths, friction factors, and bridge-culvert dimensions; and 2) flow data consisting of flow rates and boundary conditions.

The hydraulic model extends over a distance of approximately 16,000 feet along the creek from near George Road to SR 510. The section downstream of SR 510 was not included in the model because the steep slopes and high channel capacity suggest the potential for impacts is minimal.

2. GEOMETRIC DATA DEVELOPMENT

Geometric data for the hydraulic model was obtained from three sources:

1. Cross-section survey transects data points provided by KPFF Consulting Engineers. The survey data were used to develop stream bottom elevations within the banks and out to about 30 feet beyond the banks.
2. A digital elevation model (DEM) created from LiDAR (Light Detection and Ranging) data (http://pugetsoundlidar.ess.washington.edu/). The DEM contained 6-foot by 6-foot pixels. The LiDAR DEM was used to extend the stream cross-sections across the floodplain.
3. Field observations by Brown and Caldwell (December 2007- April 2008). These field observations were used to create a stream cross-section at the location of the EnviroVision gauge.

Topographic data analysis was performed using ArcGIS software. All analyses were completed using the following georeferences:

- Projection: State Plane Washington South
- Horizontal datum: North American datum of 1983 (NAD 83)
- Horizontal and vertical units: feet
- Vertical datum: North American vertical datum of 1988 (NAVD 29)

The cross-section transects were provided from KPFF in ASCII format. BC converted the data to a point shapefile in GIS and computed the distance between cross-sections using ArcGIS and orthophotography of Thompson Creek. Other data obtained from the KPFF survey include culvert inlet locations, invert elevations and crown elevations, and water surface elevations at the time of the survey.

Figure Att. 2-1 shows a schematic layout of the Thompson Creek HEC-RAS model (from George Road to SR 510). The blue line represents the location of the creek. The perpendicular green lines indicate the locations of surveyed cross-sections in the HEC-RAS model, and the grey areas represent culverts and bridges.

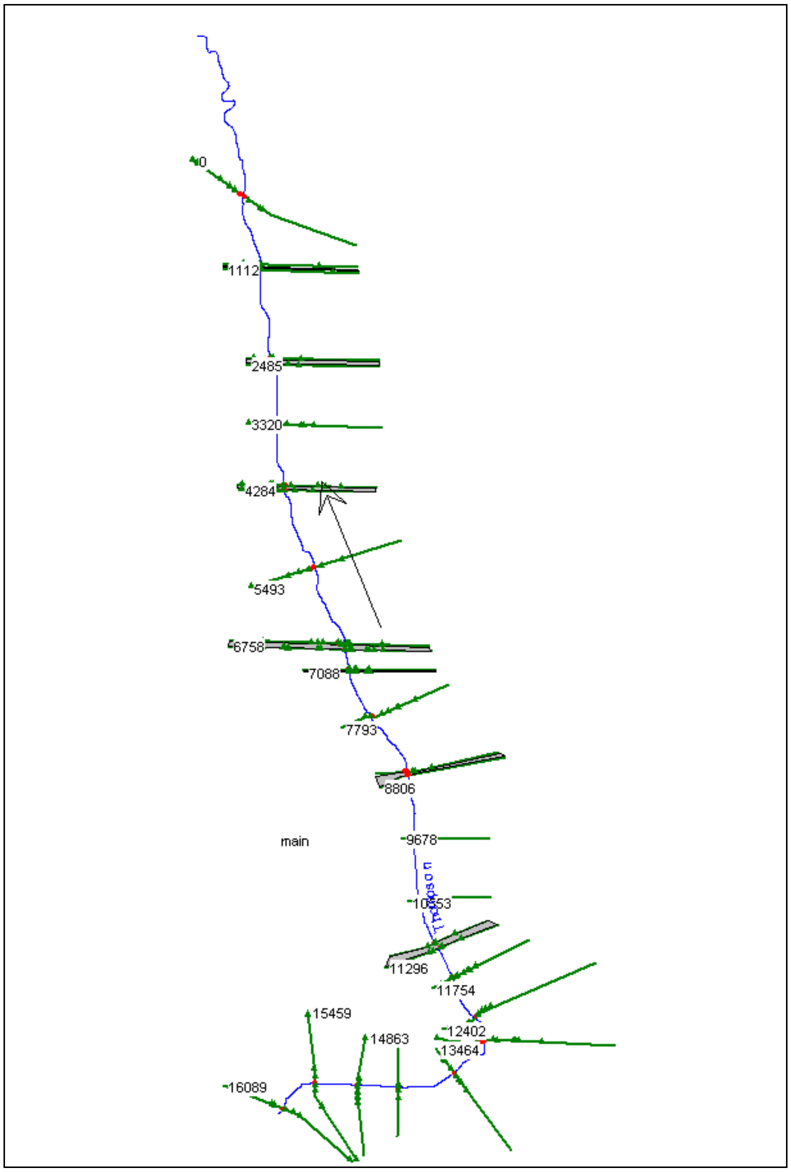

Figure Att. 2-1. HEC RAS Schematic

Thompson Creek has numerous road crossings ranging in size from a single 36-inch diameter culvert to the 15.5 feet wide by 4.5 feet high arch culvert of the Tahoma Terra Bridge. For sections of the creek that were accessible to KPFF's survey team, the physical characteristics of these structures were included in the HEC-RAS model. Table Att. 2-1 lists the culvert types, sizes, and materials that were accessible to the project team. The project team was unable to gain access to some of portions of Thompson Creek that runs through private land, notably sections upstream of the Tahoma Terra Bridge and between 93rd Avenue SE and 89th Avenue SE. Any hydraulic structures in these locations were not characterized and explicitly simulated.

Table Att. 2-1. Thompson Creek Stream Crossings				
Location	**Station**	**Type**	**Size/Diameter**	**Material**
Tahoma Terra Bridge	112+86	1 x Arch	1 x 15.5-ft x 4.5-ft	concrete
Berry Valley Road	88+06	2 x Circular	2 x 24-in	concrete
Private Road	70+88	1 x Arch; 1 x Circular	Arch: 1 x 4.5-ft x 3-ft Circular: 48-in	corrugated metal
93rd Avenue SE	67+58	3 x Circular	1 x 24-in 1 x 30-in 1 x 36-in	concrete
89th Avenue SE	42+84	1 x Circular	1 x 36-in	concrete
86th Avenue SE	24+85	1 x Circular	1 x 36-in	corrugated metal
Anderson Lane SE	11+12	1 x Circular	1 x 48-in	corrugated metal
SR 510	0+00	1 x Circular	1 x 54-in	concrete

HEC-RAS uses Manning's equation to estimate the energy and hydraulic grade lines at each model cross-section. Manning's roughness coefficient values ("n" values) were assigned to each cross-section based on field observations. The values used are given in Table Att.2-2.

Bank stations were set on each cross-section by approximating the main flow channel. Temporary ineffective areas (i.e., areas of the cross-section where flow is negligible) were set in off-channel depressions to confine conveyance to the main channel for all cross-sections unless overtopping occurs.

Table Att. 2-2. Manning's Roughness Coefficient, n			
River Station	**Left Overbank**	**Channel**	**Right Overbank**
160+89	0.055	0.05	0.055
154+59	0.055	0.05	0.055
148+63	0.08	0.06	0.06
143+01	0.12	0.08	0.12
134+64	0.12	0.08	0.12
127+82	0.065	0.07	0.065
124+02	0.065	0.07	0.065
117+54	0.065	0.07	0.065
112+96	0.06	0.045	0.06
112+03	0.06	0.07	0.06
105+53	0.075	0.06	0.07
96+78	0.06	0.06	0.06
88+06	0.065	0.045	0.065
87+45	0.045	0.045	0.045
77+93	0.055	0.055	0.075
70+88	0.055	0.055	0.055

Table Att. 2-2. Manning's Roughness Coefficient, n			
River Station	**Left Overbank**	**Channel**	**Right Overbank**
70+50	0.055	0.055	0.055
67+58	0.055	0.045	0.055
66+84	0.075	0.055	0.075
54+93	0.065	0.055	0.065
42+84	0.055	0.055	0.055
42+03	0.065	0.065	0.065
33+20	0.045	0.045	0.045
24+85	0.045	0.045	0.045
23+90	0.035	0.035	0.035
11+12	0.045	0.035	0.045
10+28	0.045	0.035	0.045
0+00	0.045	0.035	0.045
Average	**0.062**	**0.054**	**0.062**

3. FLOW DATA

Flow data for Thompson Creek was obtained from EnviroVision, who under contract to Thurston Highlands, LLC., installed a monitoring station in mid-December 2007. Flows were monitored continuously using a water depth sensor located 100 feet to the north (i.e., downstream) of the Tahoma Terra Bridge. EnviroVision converted the measured depths to flows by applying a rating curve that was developed from instantaneous stream transect flow measurements conducted on several days across a range of flow conditions.

For the "low flow" HEC-RAS modeling scenario, the flow rate at Tahoma Terra was set to 2.1 cfs, which equaled the lowest flow recorded during the winter (up the time the modeling effort was started). For the "high flow" HEC-RAS modeling scenario, the flow rate at Tahoma Terra was set to 4.5 cfs, which was the highest recorded flow during winter 2008.

Thompson Creek flows are not constant along its length. According to the Infiltration Effects Report (PGG 2008) the upper reaches of the Creek gain water from the groundwater while the lower reaches lose water to the groundwater. This means that the flows in the vicinity of the EnviroVision gauge are generally higher than flows in the downstream reaches of the creek, such as near Anderson Lane. Flow observations suggest perennial flow in headwaters and ephemeral flow in lower reaches below the Tahoma Terra development.

Observed flow data was only available at the EnviroVision gage. Input flows to the HEC-RAS model for upstream and downstream reaches were adjusted to account for gaining and losing reaches, based on input from PGG staff and Brown and Caldwell staff's field observations. Table Att. 2-3 shows the HEC-RAS model input flow rates for the "base case" during low and high flow conditions. The groundwater fluxes computed by PGG for various Thurston Highlands development phases (e.g., Scenario 2 – 4) were added to these "base case" flows to estimate the water rise. For the 1996 flood simulation, we assumed the groundwater saturation would have resulted in near-steady flows downstream of the Tahoma Terra Bridge, and the groundwater fluxes were added to a uniform 47 cfs flow rate in the HEC-RAS model.

Table Att. 2-3. Flow Changes		
Station	Low Flow Conditions (cfs)	High Flow Conditions (cfs)
160+89	1.5	3.4
127+82	2.1	4.5
77+93	1.8	4.1
42+84	0.01	1.5
24+85	0.01	0.5

4. HYDRAULIC COMPUTATIONS

Steady state simulations were run for all 15 hydraulic profiles- the normal low and high flow conditions, bankfull flow, as well as scenarios 2a, 2b, 3a, 3b, 4a, and 4b run at low and high flow conditions. All profiles were run as a mixed profile regime (i.e., sub-critical and super-critical flow velocities could be computed).

The downstream boundary condition at SR 510 assumed water would be flowing at normal depth (i.e., non-accelerating flow) for all simulations.

5. CALIBRATION

The HEC-RAS model was calibrated by adjusting the Manning's roughness coefficient to better match the EnviroVision gage flow depths and periodic field depth measurements (usually collected near Berry Valley Road) from January through April. The model calibration was sufficient to address two concerns of this study: (1) the approximate water rise during normal (non-flood) conditions and (2) the potential water rise and inundation expansion during flood events. If Thurston Highlands LLC intends to pursue an off-channel storage mitigation scenario, the model calibration in the upper reaches of the creek should be improved through additional field data collection.

References:

1. Pacific Groundwater Group 2008. Infiltration Effects Analysis. Prepared for Thurston Highlands LLC, Lacey, WA.