Documentation for GIS Analyses Performed During the Monitoring Location Selection Process

In connection with the Phase 3 study of toxic chemical loadings to Puget Sound, the project team will conduct surface runoff monitoring at 16 different locations: 8 in the Snohomish River Watershed (Water Resource Inventory Area [WRIA] 7), and 8 in the Puyallup River Watershed (WRIA 10). Each monitoring location will represent a drainage basin where one of the following land use categories is the dominant condition: commercial/industrial, residential, agricultural, or forest/field/other. Two separate drainage basins within each watershed will represent each land use type. For example, two drainage basins selected in the Puyallup watershed will represent agricultural land use, and two in the Snohomish watershed (a total of four).

To select specific monitoring locations in each watershed, the project team performed a series of GIS analyses to identify potential monitoring locations based on specific criteria for each of the following drainage basin characteristics:

- Land use
- Elevation
- Stream order

The following sections describe the data sources used in these analyses, the steps that were performed to identify potential monitoring locations, and the quality control measures that were taken to ensure that the data being generated was both correct and complete.

Data Sources and Limitations

The project team converted all GIS datasets used in the analyses described herein to the Washington State Plane South HARN 83 projection, with both the vertical and horizontal datum being in feet. Documentation on all datasets used in the analyses including the data source and native coordinate system can be found in Table B-1. These data sources are also described in the following subsections with any associated limitations that were imparted on the analyses.

Elevation Data

To facilitate site selection analyses, the project team obtained Digital Elevation Models (DEMs) with a pixel resolution of 10-meters from the United States Geologic Survey (USGS) through the Washington State Geospatial Data Archive (WAGDA). This was the highest resolution topographic data available with coverage extending over the entire project area. These data were subsequently used to delineate stream networks, calculate stream order, and delineate second-order drainage basins in the Snohomish River and Puyallup River watersheds.

Table B-1. Detailed information about GIS datasets used in the monitoring site selection analyses.

Data Type	Geographic Extent	Source	Coordinate System	Online Metadata (if available)
Aerial Photos	Pierce, King, and Snohomish Counties	United States Department of Agriculture National Agriculture Imagery Program	UTM Zone 10 NAD 83 (meters)	http://rocky2.ess.washington.edu/data/raster/naip2006/index.html
Elevation	Western Washington	USGS	UTM Zone 10 NAD 27 (meters)	http://gis.ess.washington.edu/data/raster/tenmeter/
Elevation	Puget Sound by quad	Puget Sound LiDAR Consortium	WA State Plane N NAD 83 (feet)	http://pugetsoundlidar.ess.washington.edu/lidardata/metadata/pslc2000/pslc2000_be_dem.htm
Elevation	King County	King County GIS Center	WA State Plane N NAD 83 (feet)	http://www.kingcounty.gov/operations/GIS/GISData/Metadata.aspx
Elevation	Pierce County	Pierce County GIS Team	WA State Plane S NAD 83 HARN (feet)	http://yakima.co.pierce.wa.us/geodataexpress/main.html
Hydrology	Puyallup and Snohomish River watersheds	USGS (NHD)	GCS_North_American_1983	http://nhd.usgs.gov/data.html
Hydrology	King County	King County GIS Center	WA State Plane N NAD 83 (feet)	http://www.kingcounty.gov/operations/GIS/GISData/Metadata.aspx
Hydrology	Pierce County	Pierce County GIS Team	WA State Plane S NAD 83 HARN (feet)	http://yakima.co.pierce.wa.us/geodataexpress/main.html
Hydrology	Snohomish County	Snohomish County Information Services	WA State Plane North NAD 83 (feet)	Not Available Online
Hydrology	Pierce, King, and Snohomish Counties	Washington State Department of Natural Resources	WA State Plane South HARN 83 (feet)	http://fortress.wa.gov/dnr/app1/dataweb/metadata/WA_Hydro_Data_Dic.htm
Hydrology	Washington State	Department of Ecology	WA State Plane S NAD 83 HARN (feet)	http://www.ecy.wa.gov/services/gis/data/hydro/rivers.htm
Land Use	Western Washington	Multi-Resolution Land Characteristics Consortium	USA Contiguous Albers Equal Area Conic NAD 83 (geographic)	http://www.mrlc.gov/nlcd.php
Roadway	King County	King County GIS Center	WA State Plane N NAD 83 (feet)	http://www.kingcounty.gov/operations/GIS/GISData/Metadata.aspx
Roadway	Pierce County	Pierce County GIS Team	WA State Plane S NAD 83 HARN (feet)	http://yakima.co.pierce.wa.us/geodataexpress/main.html
Roadway	Pierce, King, and Snohomish Counties	Washington State Department of Natural Resources	WA State Plane South HARN 83 (feet)	http://fortress.wa.gov/dnr/app1/dataweb/metadata/trans.htm
Roadway	Washington State	Washington State State Department of Transportation	WA State Plane N NAD 83 (feet)	http://www.wsdot.wa.gov/Mapsdata/geodatacatalog/

The project team also obtained higher resolution LiDAR data with a pixel resolution of 6-feet from the Puget Sound LiDAR Consortium (PSLC). These data were used to refine drainage basin delineations for the subset of basins that were selected for monitoring. These data were available for 4 of the 16 drainage basins selected for monitoring. Contour data with an elevation interval of 20-feet or better were obtained at the county-level where available, and were also used to refine drainage basin delineations.

Because the elevation data used in this project have different levels of resolution, the drainage basin delineations will vary in their accuracy. For example, a drainage basin delineated strictly from the WAGNA 10-meter DEM will inherently have more inaccuracy than a basin delineation that was refined with the high-resolution LiDAR. It should also be noted that drainage basin delineations performed for agricultural monitoring locations likely have more inaccuracy relative to those for other land use categories due to the general lack of topographic relief in these areas.

Hydrologic Data

The project team used several hydrologic datasets to verify the stream network and drainage basin delineations that were developed from the WAGNA 10-meter DEM. In particular, the project team used the National Hydrography Dataset (NHD) for this purpose. This dataset maps the surface water drainage system for the United States at a 1:24000 scale, including stream segments, water bodies, and other hydrologic features. The dataset was created by USGS in cooperation with the U.S. Environmental Protection Agency, U.S. Forest Service, and other partners.

Hydrologic data were also obtained at the county level from King, Pierce, and Snohomish counties; and at the state level from the Washington State Department of Natural Resources. Because the NHD, county, and state level hydrology datasets were much more detailed than the channel network delineated by the WAGNA 10-meter DEM, these data were helpful in determining channel accuracy, especially for agricultural monitoring locations were man-made ditches were prevalent.

Land Use Data

The project team obtained land use/land cover data from the Multi-Resolution Land Characteristics Consortium 2001 (MRLC 2001), a cooperative project that was implemented by nine federal agencies with the objective of making available Landsat 5 imagery of the conterminous United States. The National Land Cover Dataset 2001 (NLCD 2001) is a second generation raster dataset showing 21 classes of land-cover data at a resolution of 30-meter pixels. Each pixel represents a normalized land use value obtained through the combination of datasets from three time periods. Figure B-1 shows the grouped NLCD 2001 land cover in the Snohomish River and Puyallup River watersheds.

Roadway Data

The project team used GIS roadway data at the county level to evaluate monitoring locations accessibility. Portions of three counties (King, Pierce, and Snohomish) are encompassed within the Snohomish River and Puyallup River watersheds. Most of these counties had publicly available GIS roadway data; where data were not available from the jurisdiction directly, data were obtained from the Washington State Department of Natural Resources. It should be noted that not all of the roadways mapped through these sources are publicly accessible, as is often the case with some forest and private roads.

Aerial Photography

The project team used color aerial photography for mapping and quality control purpose. These data were obtained at the county level (King, Pierce, and Snohomish) for the Snohomish River and Puyallup River watersheds through the U.S. Department of Agriculture National Agriculture Imagery Program (USDA NAIP). The aerial photography was flown in 2006 and has a pixel resolution of 1-meter.

Methods

This section describes the GIS methods used by the project team to delineate and classify the stream channel networks in Snohomish River and Puyallup River watersheds, delineate second-order stream subbasins, and identify the 16 required monitoring locations for this study. An example process-flow diagram showing the analysis steps for the Snohomish River and Puyallup River watersheds is provided in Figure B-2.

Stream Network Delineation and Classification

To facilitate using an automated DEM-based approach for delineating subbasins in the Snohomish River and Puyallup River watersheds, the project team used the ArcGIS Hydrology Toolbox and the WAGNA 10-meter DEM to define a channel network in each watershed. In general, the level of channel network detail that can be extracted from an elevation dataset is limited both by the resolution of the elevation dataset itself, as well as by the landscape topography. Due to this consideration, DEM-derived channel networks often do not reflect the physical characteristics of the associated drainage basin when they are delineated at a finer resolution than the data supports. In this analysis, the project team determined that a contributing drainage area of 0.25 square kilometers produced stream networks in both watersheds that were suitably representative of on-the-ground conditions.

After the channel networks were delineated, the project team compared the resulting stream layers to publicly available high-resolution hydrology data as a quality control measure. Stream order was classified in ArcGIS using the Strahler method, which is the most commonly used algorithm for determining relative stream size. In this method, channel segments with no

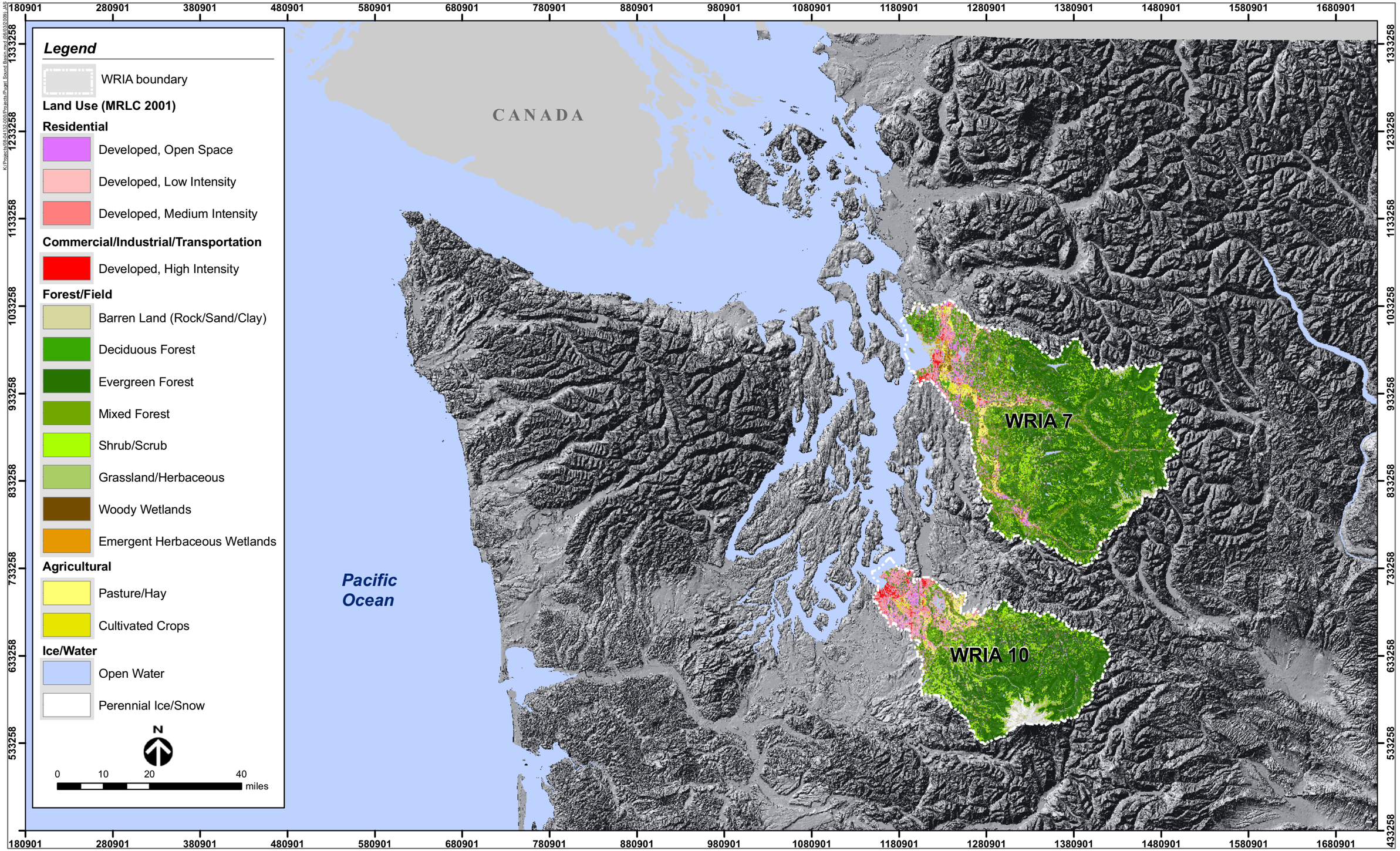

Figure B-1. Land use shown by the National Land Cover Dataset 2001 (NLCD 2001) in the Puyallup and Snohomish River watersheds.

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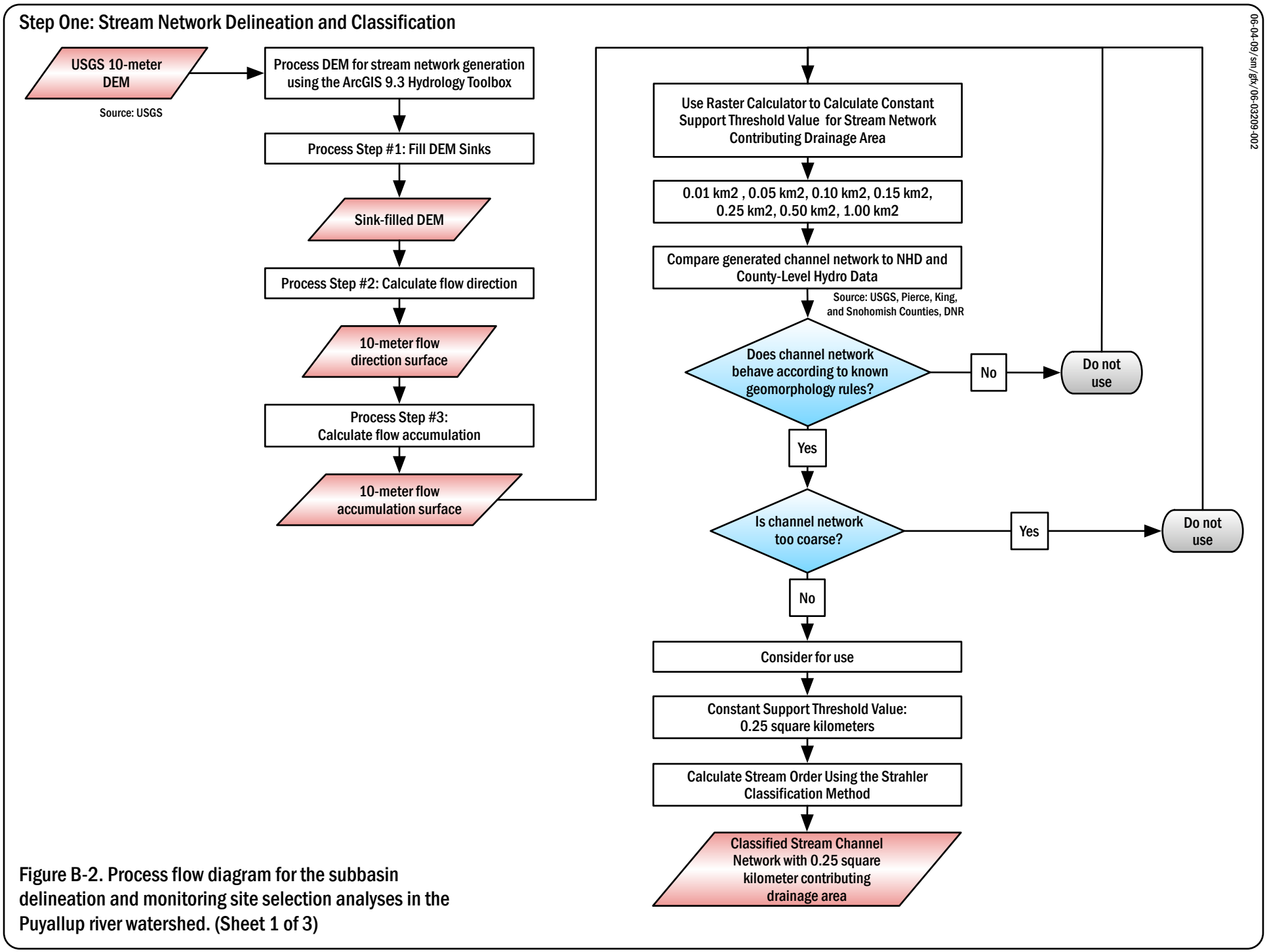

Figure B-2. Process flow diagram for the subbasin delineation and monitoring site selection analyses in the Puyallup river watershed. (Sheet 1 of 3)

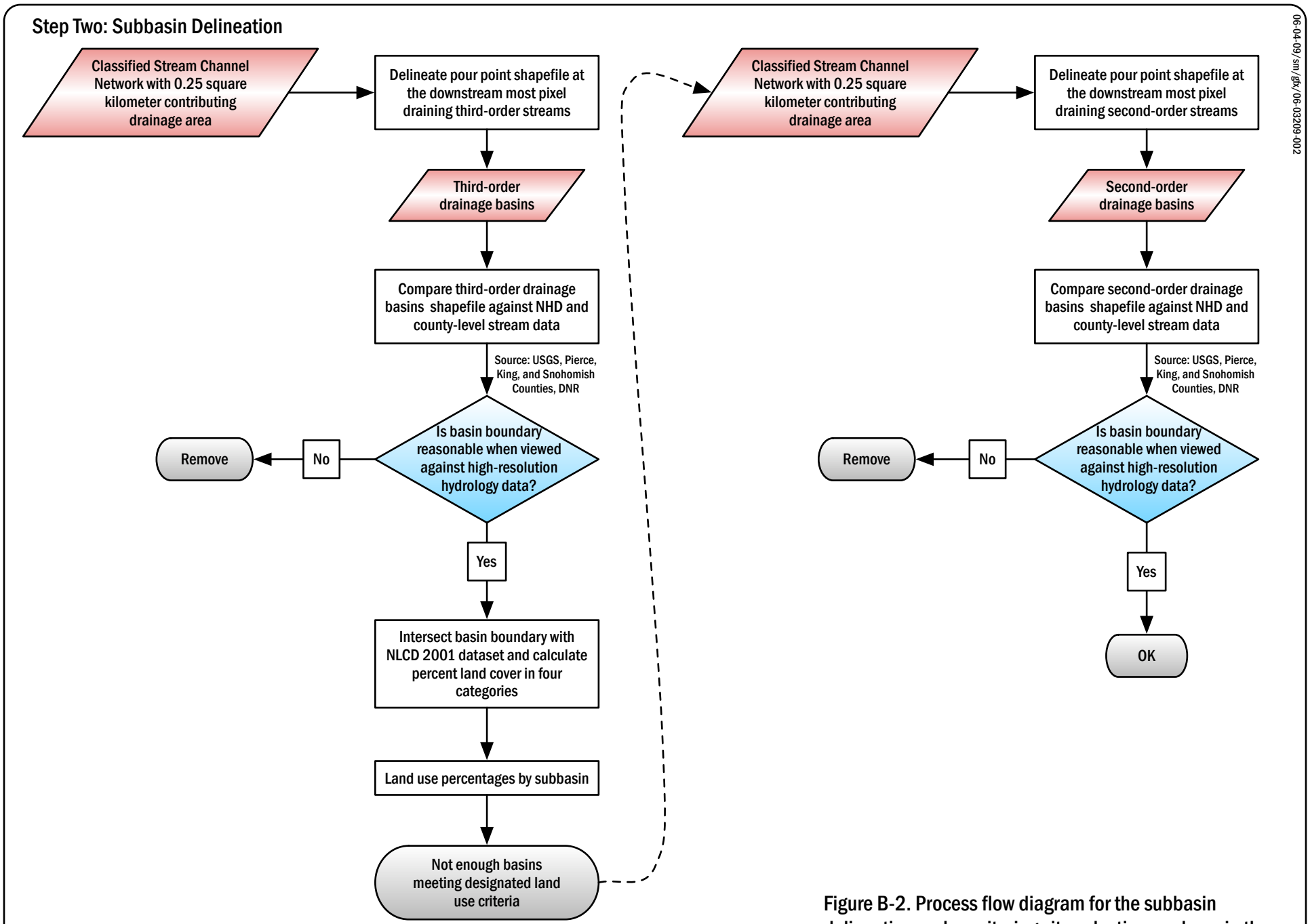

Figure B-2. Process flow diagram for the subbasin delineation and monitoring site selection analyses in the Puyallup river watershed. (Sheet 2 of 3)

Step Three: Monitoring Site Selection and Subbasin Refinement

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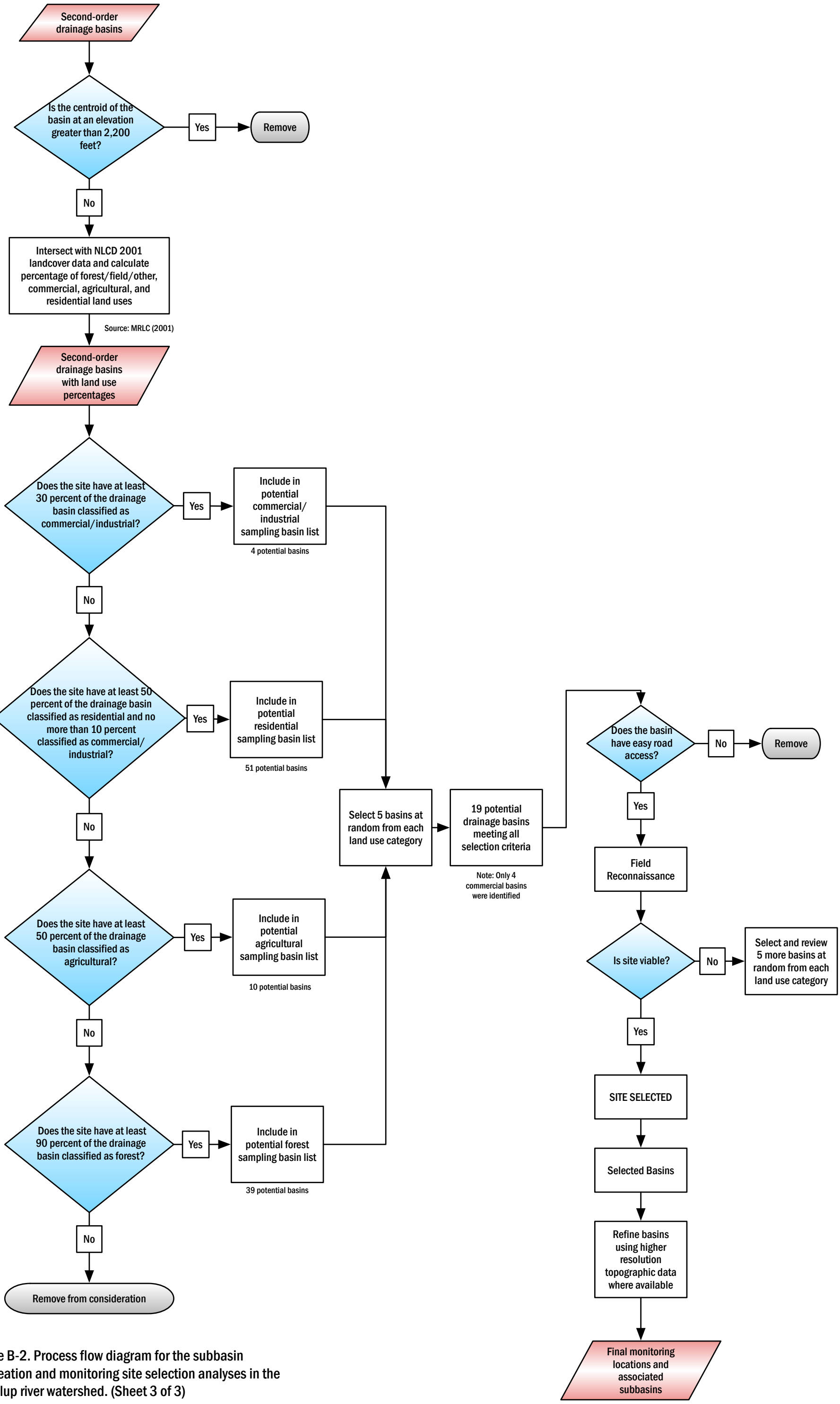

Figure B-2. Process flow diagram for the subbasin delineation and monitoring site selection analyses in the Puyallup river watershed. (Sheet 3 of 3)

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tributaries are assigned an order of one, and the total number of stream orders is entirely dependent on the resolution of the channel network.

Drainage Basin Delineations

After stream orders were assigned to the channel networks for both watersheds, the project team delineated drainage basins based on the classified stream segments. The project team initially performed an analysis to delineate drainage basins for all third-order stream segments; however, the average basin size delineated using these channels was too large and did not generate enough viable basins with 50 percent or more commercial, residential, agricultural, or forest land use types. Due to this consideration, the project team performed a second analysis to delineate drainage basins for all second-order streams. Because the drainage basins delineated at this scale provided substantially more options for identifying basins with the requisite land use characteristics for this study, they were used for all subsequent analyses. For reference, Table°B–2 compares the average basin size and number of viable basins meeting the land use criteria (i.e., 50 percent or more commercial, residential, agricultural, or forest land use) for both second and third order streams in the Snohomish River watershed.

Drainage basin delineation was automated by digitizing a "pour point" at the most downstream pixel of each DEM-derived stream segment. The project team then determined the total area draining to that location. Because the DEMs only take surface flow into account, pipes and manmade drainage structures (e.g., ditch networks in agricultural areas) were often not represented in the delineated drainage basins. Due to this consideration, the project team used publicly available high-resolution hydrology data to verify and correct delineated drainage basins based on these features. Where major discrepancies were identified through this process, the associated drainage basin was eliminated from all further consideration in the analyses.

Monitoring Site Selection and Subbasin Refinement

In order to ensure the land use in the drainage basins is sufficiently representative of a particular category, the project team used a stratified random sampling process to identify the individual monitoring locations. The specific goal of this process was to eliminate bias in the monitoring location selection process to the extent possible. The general steps that were used in this process are summarized below:

1. The project team screened all the drainage basins in the Snohomish River and Puyallup River watershed to identify a subset of drainage basins for which their entire land area was below 2,200 feet in elevation. Drainage basins above this threshold were eliminated from further consideration. (This step was performed to ensure the drainage basins selected for monitoring would not be rendered inaccessible because of winter snow conditions.)

Table B-2. Comparison of second and third order drainage basins meeting the land use selection criteria in the Puyallup and Snohomish River watersheds.

Watershed Name	WRIA Number	Stream Order	Average Basin Size (hectares)	Total Number of Basins Meeting Land Use Selection Criteria By Type [a]			
				Agricultural	Residential	Commercial	Forest/Field/Other
Puyallup River Watershed	10	2nd	250.4	10	51	4	39
Snohomish River Watershed	7	2nd	253.6	18	59	5	251
Snohomish River Watershed	7	3rd	926.2	2	13	0	183

[a] Indicates the total number of drainage basins with at least 50 percent of the total land area represented by the indicated land use.

2. Using the most recent version of the National Land Cover Dataset (MRLC 2001), the project team screened the subset of drainage basins obtained to identify representative drainage basins for each land use category based on the following criteria:

   - Commercial/Industrial: At least 30 percent of the drainage basin must be classified as commercial/industrial land use. (Initially a minimum of 50 percent was targeted for this land use category. However, this limited available drainage basins to a few that largely represented only one commercial or industrial facility, which did not meet the intent of the study.)

   - Residential: At least 50 percent of the drainage basin must be classified as residential land use; and no more than 10 percent may be classified as commercial/industrial land use.

   - Agricultural: At least 50 percent of the drainage basin must be classified as agricultural land use.

   - Forest/Field/Other: At least 90 percent of the drainage basin must be classified as forest/field/other land use.

3. Using the subset of drainage basins that met these criteria, the project team randomly selected five drainage basins for each land use category within each of the two watersheds. The project team then performed field reconnaissance on these randomly selected drainage basins to evaluate their suitability for actual monitoring relative to the following criteria:

   - Traffic and water safety
   - Ease of access
   - Property access restrictions
   - Representativeness for the targeted land use
   - Suitability for gauging (channel morphology, diversions, dams, etc.)

4. Drainage basins that were not considered suitable for monitoring based on observations from the field reconnaissance were eliminated from further consideration. If fewer than two drainage basins for any given land use were identified as being suitable for monitoring through this process, the project team randomly selected five additional drainage basins for that land use. The project team then performed field reconnaissance on these additional drainage basins as described in Step 5. This process continued until at least two drainage basins for each land use were identified as being suitable for monitoring in each of the two watersheds.

This method was used to identify 12 of the 16 monitoring locations and associated drainage basins in the Puyallup and Snohomish River watersheds. However, after all the potential drainage basins were evaluated through the process described above, suitable monitoring locations could not be found for the following land use and watershed combinations:

- One monitoring location for agricultural land use in the Snohomish River watershed
- Two monitoring locations for commercial/industrial land use in the Puyallup River watershed
- One monitoring location for commercial/industrial land use in the Snohomish River watershed

Therefore, the project team performed a more detailed GIS analysis to identify drainage basins within each watershed with the requisite land use that had not been identified through the stratified random sampling process described above. This involved manually identifying concentrated areas of commercial and agricultural land use and searching for potential streams to monitor that were not identified using the LiDAR or the DEM. After these basin boundaries had been delineated, the project team then performed field reconnaissance on these drainage basins to evaluate their suitability for actual monitoring relative to the criteria defined in Step 3 above. Once suitable drainage basins were found through this process, they were identified using a letter designation to differentiate them from drainage basins selected using the random stratified approach (see Table 4 in QAPP main text).

After 16 subbasins meeting the selection criteria had been identified in the two watersheds, the project team performed a verified the subbasin boundaries using higher-resolution topographic data, including LiDAR and county-level contour data where available. These data were used to confirm the accuracy of the delineated boundaries and to identify any possible topographic variations that might not be identifiable at the 10-meter DEM scale. In general, the precision of the basin boundaries is dependent on the resolution of the data used to refine them; therefore, all basin boundaries are approximate.