# Memorandum

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**To**: Dennis Dixon, Pierce County Water Programs

**From**: Patty Dillon and Sam Gould

**Subject**: Pierce County DFF Floodway Mapping

**Pages**: 10

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## Introduction

Pierce County regulates development in the floodplain and enforces higher regulatory standards than the minimum National Flood Insurance Program (NFIP) rules. One of these higher standards expands the definition of floodway to include areas that are inundated in a 1% annual chance flood by deep water and/or fast flowing floodwaters. Northwest Hydraulic Consultants, Inc. (**nhc**) was contracted by Pierce County Water Programs to develop a map of the Deep and Fast Flowing (DFF) regulated Floodway in Pierce County because this area is not mapped by FEMA and it is not intuitive where this floodway is located within the floodplain. This report outlines the methodology used to map the DFF Floodway in Pierce County.

## Study Area

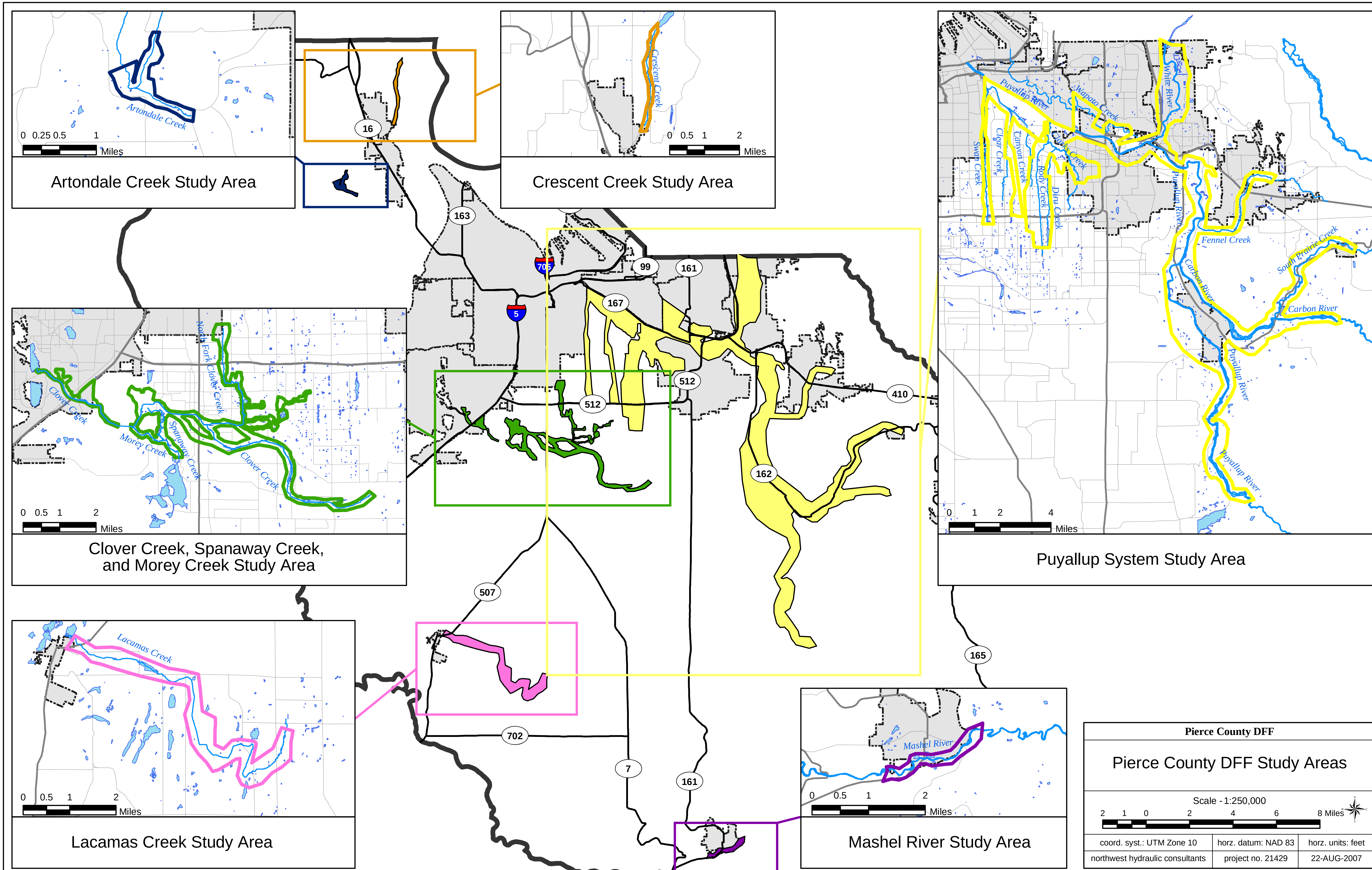
This project was limited to the reaches of rivers and creeks for which detailed study was performed in recent Pierce County Flood Insurance Studies (FIS). For convenience of analysis and display, these river reaches and creeks were separated into six different study areas shown in Table 1 and in Figure 1. The Clover Creek, Spanaway Creek, and Morey Creek study area as well as the Puyallup System study area both contain multiple rivers and/or creeks. In these areas, covering connected stream networks, DFF floodways were determined for each creek based on the individual models then combined into a single unit for mapping.

**Table 1. Streams / Rivers and Study Area Definitions** (study miles in brackets)

| | | | | | |
|---|---|---|---|---|---|
| Artondale Creek (2.3) | AR | Diru Creek (3.0) | PS | South Prairie Creek (6.2) | PS |
| Carbon River (8.4) | PS | Fennel Creek (5.4) | PS | Spanaway Creek (2) | CL |
| Canyon Creek (6.0) | PS | Lacamas Creek (8.2) | LA | Swan Creek (3.5) | PS |
| Clarks Creek (2.4) | PS | Mashell River (2.4) | MA | Wapato Creek (6) | PS |
| Clear Creek (2.2) | PS | Morey Creek (2) | CL | White River (5.5) | PS |
| Clover Creek (23.1) | CL | Puyallup River (30) | PS | Woodland Creek (3.5)[a] | PS |
| Crescent Creek (3.3) | CR | Rody Creek (3.5) | PS | | |

[a]Woodland Creek not included in this report due to model/map discrepancies identified during the DFF analysis. DFF analysis will be performed when model issues have been addressed.

AR Artondale Creek Study Area
PS Puyallup System Study Area
CL Clover Creek, Spanaway Creek, and Morey Creek Study Area
CR Crescent Creek Study Area
LA Lacamas Creek Study Area
MA Mashel River Study Area



Artondale Creek
0 0.25 0.5 1
Miles
Artondale Creek Study Area
Crescent Creek
0 0.5 1 2
Miles
Crescent Creek Study Area
Puyallup River
Wapato Creek
White River
Swan Creek
Clear Creek
Canyon Creek
Rody Creek
Diru Creek
Fennel Creek
South Prairie Creek
Carbon River
Puyallup River
0 1 2 4
Miles
Puyallup System Study Area
North Fork Clover Creek
Clover Creek
Morey Creek
Spanaway Creek
0 0.5 1 2
Miles
Clover Creek, Spanaway Creek, and Morey Creek Study Area
Lacamas Creek
0 0.5 1 2
Miles
Lacamas Creek Study Area
Mashel River
0 0.5 1 2
Miles
Mashel River Study Area
16
163
705
5
99
161
167
512
410
162
507
702
7
165
Pierce County DFF
Pierce County DFF Study Areas
Scale - 1:250,000
2 1 0 2 4 6 8 Miles
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: feet
northwest hydraulic consultants
project no. 21429
22-AUG-2007


Figure 1

## DFF Methodology

The DFF floodway consists of areas that are greater than three feet deep, have a velocity greater than three feet per second, or have some combination of depth and velocity lying above Pierce County's DFF threshold (Figure 7) for the 1% annual chance flood. In addition, active channel areas were assumed to be included in the DFF floodway. The following sections outline the methodology developed by **nhc** to identify and map DFF floodway areas using GIS techniques. All analysis was performed in ArcGIS Version 9.x.

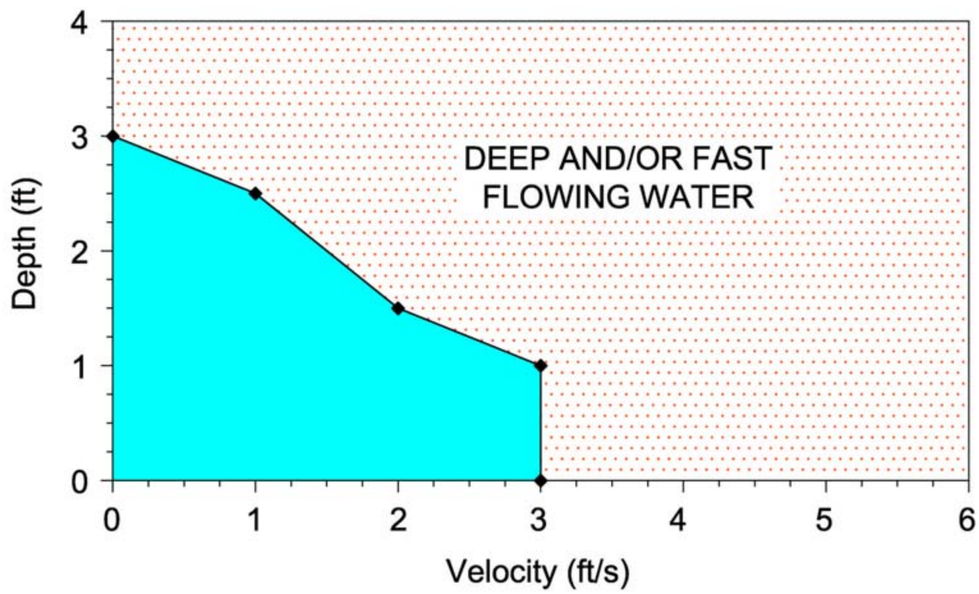



**Figure 2. DFF graph**

### *Active Channel*

The active channel was defined using infrared (IR) aerial photos, bank stations from the HEC-RAS models, and/or depth grid information. If the active channel was visible in the IR photos, it was delineated based on the photos. For smaller creeks where the active channel was not visible, the active channel was defined based on the bank stations defined in the HEC-RAS models and the depth grid. Inclusion of active channel areas in the DFF floodway by definition eliminates the need to modify topographic data that does not reflect channel bathymetry; this significantly simplifies the analysis required to perform DFF mapping, particularly for smaller streams.

### *Depth Grid*

Depth grids were created by subtracting the ground topography (LiDAR data) from the 1 percent annual chance (100-year) water surface, as determined from modeling results.

Water surface grids were created using the base flood elevations (BFE) and cross section water surface elevations from the Pierce County Digital Flood Insurance Rate Map (DFIRM). At the request of Pierce County, the BFEs and cross sections were extended beyond the 1 percent annual chance floodplain to provide a buffer to account for discrepancies in floodplain topography between the LiDAR data used for DFF mapping and the photogrammetric contours used in the model development. In order to better define channel and flow directions, **nhc** created breaklines roughly parallel to the direction of flow by connecting BFE and cross section end points. Using the BFEs, cross sections, and breaklines, a water surface TIN was created. These TINs were then converted to raster format to create the water surface grids. Finally, the LiDAR data was subtracted from the water surface grid to generate the depth grid. All rasters (grids) used in this analysis were defined as having 2 m by 2 m grid cells.

### *Velocity Grid*

To determine velocities for mapping, **nhc** added velocity tubes to the HEC-RAS models for each stream. The velocity tube approach breaks down each cross section into zones (or tubes), partitions the flow based on cross sectional area, and calculates a flow velocity for each tube, creating pseudo-2D velocity profiles. The cross-section velocity profiles were exported from the model as points for import into GIS.

In order to generate the velocity grid, velocity contours then had to be defined between cross sections. First, the outer boundary of the velocity contours was defined using the 1 percent annual chance floodplain boundary as a zero velocity contour. Then, using the velocity points, depth grid, and aerial photos, velocity contours were drawn to provide an approximation of the velocities and flow paths in between the HEC-RAS model cross sections. Velocity contour delineation is the most complex step in the DFF methodology and requires substantial knowledge of system hydraulics and engineering judgment. Once the contours were created, they were converted to a velocity TIN, which was converted to a raster to create the velocity grid.

### *Grid Analysis*

The DFF determination is based on the depth and velocity as shown in Figure 2. To allow the DFF analysis to be carried out efficiently ArcGIS ModelBuilder (Version 9.2) was used to construct a tool that would automate the various steps in the grid analysis. Figure3 shows a simplified flow chart of the DFF calculation. A short explanation of steps shown in the flowchart is given below. A complete flow chart of this model can be found in the appendix along with a complete listing of the analysis steps.

Three input files are required for the DFF calculation: the active channel shapefile, the depth grid, and the velocity grid. The active channel shapefile is converted to a grid and the area designated as active channel is classified as in the DFF floodway. Areas that are deep or have high velocity are classified as in the DFF floodway if either the depth exceeds 3 feet or the velocity exceeds 3 feet per second. Next, the areas that are in the DFF floodway due to a combination of depth and velocity are determined. This is done by first isolating the three curve ranges shown in Figure 2: 0-1 ft/s, 1-2 ft/s, and 2-3 ft/s. The portions of the depth grid in each of these ranges are isolated so that comparisons will be made only where each portion of the curve is applicable. Next the equivalent depths—i.e. the depth corresponding to the DFF threshold curve for a given velocity—for the areas in each curve range are calculated. If the flood depth for a given cell is greater than the equivalent depth, then that cell is classified as in the DFF floodway. The final step is to combine the DFF floodway areas based on active channel, depth only, velocity only, and combinations of depth/velocity into a single DFF floodway grid.

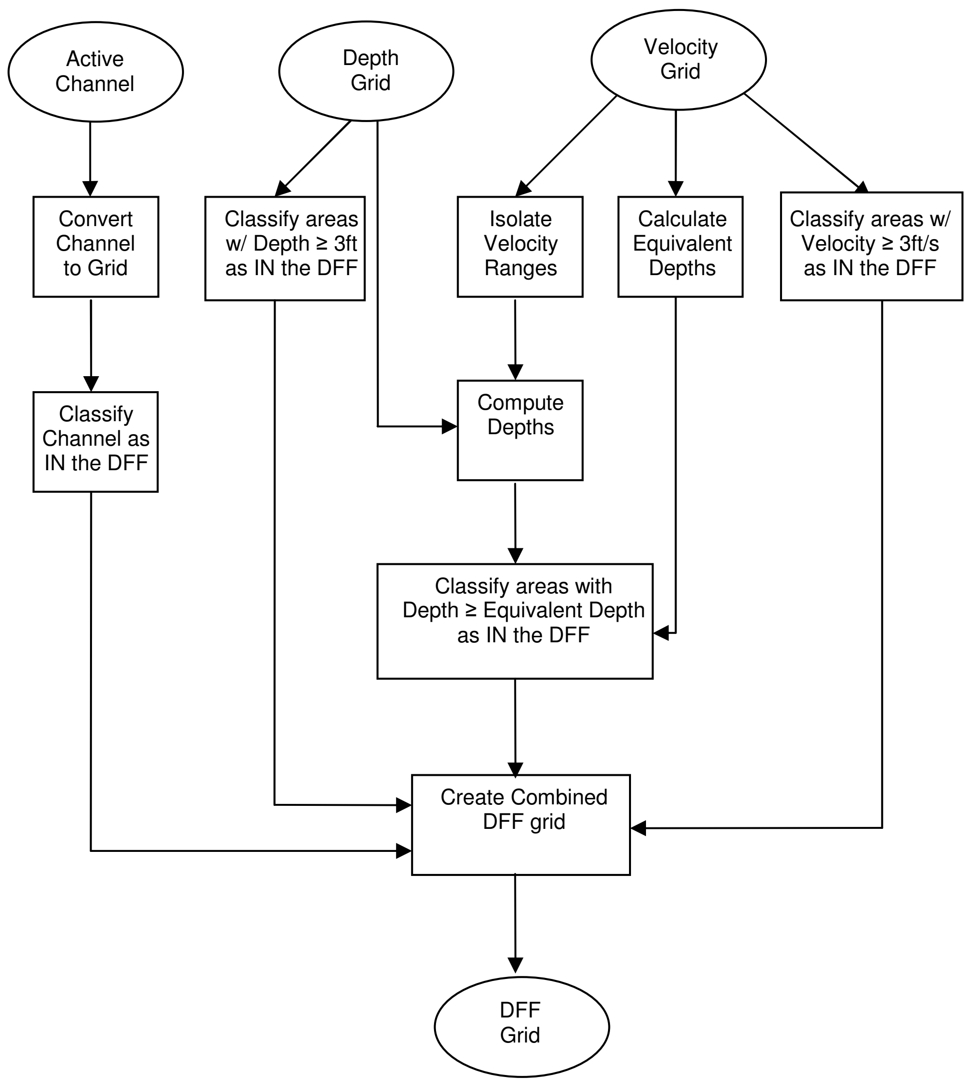



**Figure 3. Simplified DFF Flow Chart**

## *Post-Processing*

Post-processing requirements for the raw DFF grids are minimal. The post-processing involved converting the DFF grids to polygons, removing small islands and filling in gaps, and adding previously defined water bodies.

The first step in post-processing was to mosaic the DFF grids determined for individual study streams into a single DFF grid for each study area. Where DFF grids of individual river reaches and creeks overlapped at confluences, the maximum value of the overlapping cells was used in the DFF grid for the overall study area, ensuring that any area that was identified as in the DFF floodway based on a single study remained in the DFF floodway for the combined study area.

The DFF grid for each study area was then converted to a polygon shapefile, and polygons for all study areas were then merged into a single DFF polygon layer.  Next, the gaps and islands smaller then ¼ acre were removed, being careful not to remove areas of active channel areas in the smaller creeks.  The ¼ acre threshold was selected by Pierce County Water Programs.  Finally, all water bodies (from Pierce County GIS's water bodies layer) within the DFF analysis area were added to the DFF polygon layer. Addition of the mapped water bodies ensures that significant water features are included in the DFF floodway.  Because LiDAR generally does not handle water surfaces well, these areas may or may not be captured as deep water in the analysis.

### *Pilot Study*

The DFF methodology described in the previous sections was initially tested and refined by **nhc** in a pilot study of two reaches on the Upper Puyallup River and Upper Swan Creek.  The primary purposes of this pilot study were: 1) to develop and test a GIS analysis methodology to identify potential deep and/or fast-flowing areas and 2) to test whether the 1D velocity approach (described above) was sufficiently accurate for DFF mapping.

**nhc** created two-dimensional models of the pilot study reaches and compared the resultant velocity grids and DFF floodway boundaries with those generated using the methods described above.  Agreement was generally very good (approximately 85 percent or better for the DFF floodways) and Pierce County elected to move forward with the DFF mapping for the full study area using **nhc**'s methodology.  While 2D modeling can produce much more accurate spatial distributions of velocity, it would be cost prohibitive for a mapping effort of this scale.  It should be noted that there is still a considerable amount of uncertainty associated with the velocities used in this analysis, and considerable system knowledge and hydraulic judgment went into developing the velocity contours between cross sections for the 1D method.

## Appendix: Pierce County DFF Grid Analysis

This section outlines the environment settings, DFF Toolbox inputs, and analysis steps used during the Pierce County DFF Grid Analysis. Inputs were derived from aerial photography and from HEC-RAS model results as described in the report.

<u>Environment Settings:</u>
Set Current Workspace:
    Workspace for calculations
Set Scratch Workspace:
    Workspace for intermediate files
Set Raster Analysis Environment:
    To `Water Surface Boundary` polygon as analysis mask
    Output grid cell = 2m

<u>DFF Toolbox Inputs:</u>
*Depth* grid (2m grid cell)
*Velocity* grid (2m grid cell)
`Active Channel` polygon
`Output` (the workspace for the final output files)

**Analysis Steps**

1. Convert `Active Channel` to grid ⇨ *in_actchn*
2. Reclassify high *Depth*
    a. Reclassify *Depth*: ≥3 = 1, others = 0 ⇨ *in_depth*
3. Reclassify high *Velocity*
    a. Reclassify *Velocity*: ≥3 = 1, others = 0 ⇨ *in_velocity*
4. Determine combination portions of curve
    a. Isolate curve velocity ranges
        i. Reclassify *Velocity*: 2-3 = 1, others = NoData ⇨ *velocity2*
        ii. Reclassify *Velocity*: 1-2 = 1, others = NoData ⇨ *velocity1*
        iii. Reclassify *Velocity*: 0-1 = 1, others = NoData ⇨ *velocity0*
    b. Isolate depths in each curve range
        i. Multiply *Depth* by *Velocity2* ⇨ *depth2_3*
        ii. Multiply *Depth* by *Velocity1* ⇨ *depth1_2*
        iii. Multiply *Depth* by *Velocity0* ⇨ *depth0_1*
    c. Compute velocity equivalent depths for each curve range (equations determined from Figure 2)
        i. -0.5**Velocity* + 2.5 ⇨ *vel2_3*
        ii. -1**Velocity* + 3.5 ⇨ *vel11_2*
        iii. -0.5**Velocity* + 3 ⇨ *vel0_1*
    d. Compare depths and velocities (as equivalent depths) for each curve range
        i. *depth2_3 - vel2_3* ⇨ *combo1*
        ii. *depth1_2 - vel1_2* ⇨ *combo2*
        iii. *depth0_1 - vel0_1* ⇨ *combo3*
    e. Reclassify *combo**

i. Reclassify *combo1*: $\geq 0 = 1$, others = 0 (including NoData) ⇨ *in_combo1*
ii. Reclassify *combo2*: $\geq 0 = 1$, others = 0 (including NoData) ⇨ *in_combo2*
iii. Reclassify *combo3*: $\geq 0 = 1$, others = 0 (including NoData) ⇨ *in_combo3*

5. Create combined DFF grid
   a. *in_actchn* + *in_depth* + *in_velocity* + *in_combo1* + *in_combo2* + *in_combo3* ⇨ *dff_all*
   b. Classify *dff_all*: $>0 = 1$, others = NoData
   c. Convert *dff_all* to polygon `dff_poly`

The following page shows a schematic of the DFF Analysis tool developed in ArcGIS ModelBuilder (Version 9.2).

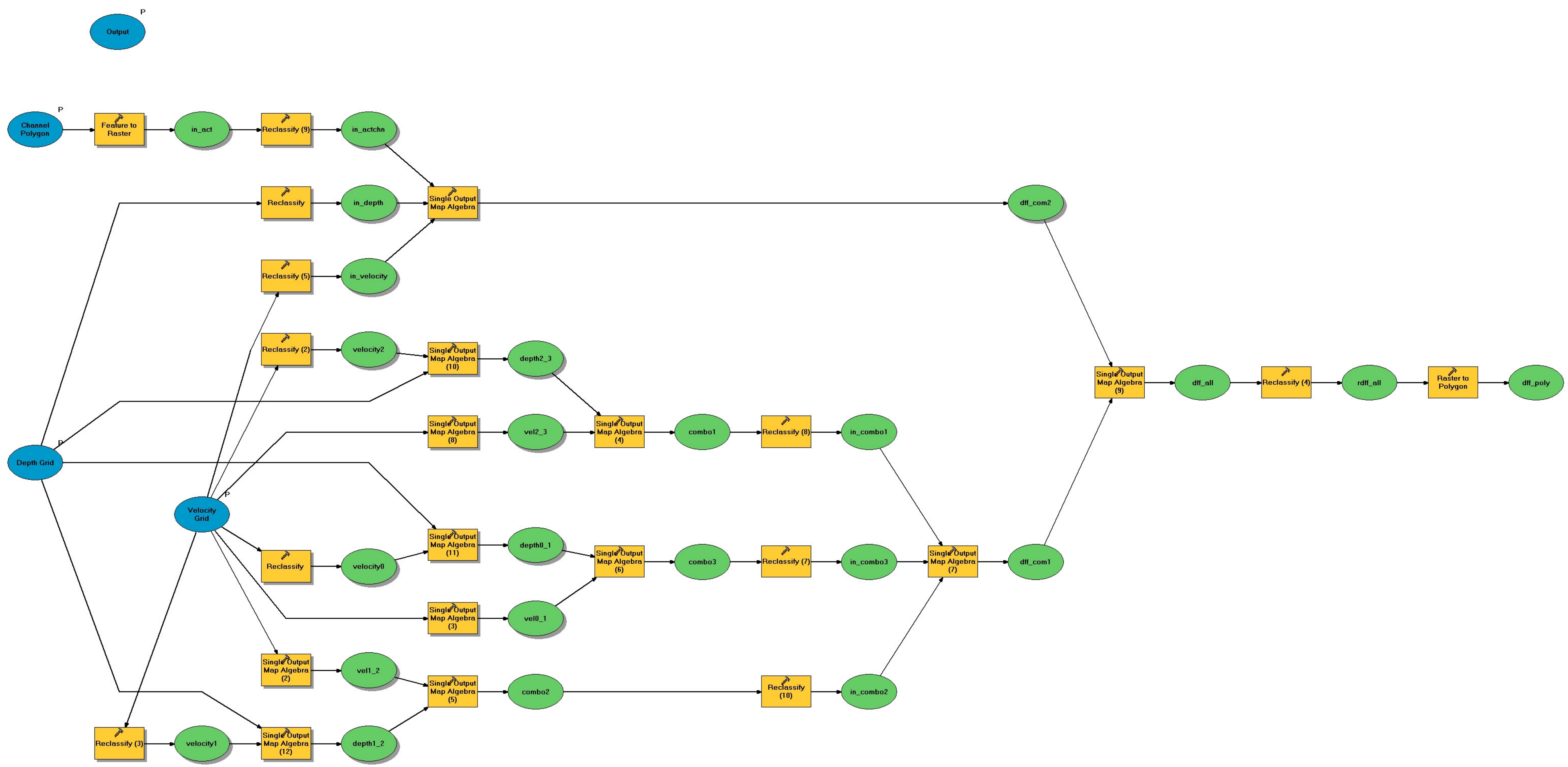



**Figure A1. DFF Toolbox Model Schematic**