

Appendix D

A Spatial Framework for Riparian Zone Management in Snohomish and Stillaguamish Lowlands

Paul Cereghino, NOAA Restoration Center

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Introduction

Riparian Zone Management encompasses both protection and restoration efforts to influence the functions of the “riparian zone” to provide public trust benefits. The National Research Council defines riparian zone as:

...transitional zones between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems. Riparian areas are found adjacent to perennial, intermittent, and ephemeral streams, lakes, estuaries, and marine shorelines. (National Research Council 2002)

The riparian “zone” is a continuum with the greatest function near channels, but which reaches deeply into the watershed—for example, landscape forest cover “influences exchanges of energy and matter with aquatic ecosystems” by modifying the timing and quantity of hydrologic flow into those systems. As with many ecological topics, lines of authority are drawn based on political arguments over the meaning of the word “significantly”.

Put more simply, the health of public trust resources like water supply and fish populations depends on how we manage the movement of water, from precipitation until discharge into the sea. We can measure the effectiveness of riparian zone management in stream hydrography, channel structure, and water quality. Water quantity and quality however are also affected by geology and climate, and impacts from development are cumulative, making individual development actions and ecosystem effects difficult to connect. Similarly the lines between watershed management and riparian zone management are legitimately blurry, as watershed condition can pressure riparian buffer functions and independently degrade in-stream conditions.

Riparian zone management as a holistic practice, whether voluntary, or by government contract, incentive or regulation, could include:

1. **Streamside Reforestation** – planting forests near streams to improve soils, shade streams, and produce large wood and leaf litter.
2. **Channel Restoration** – removing armoring, and restore the sinuosity, riffle-pool structure, and floodplain connectivity of stream channels.
3. **Floodplain Reconnection** – removing levees and causeways that prevent the flow of floodwater, or install wood structures that stabilize islands, and reactivate side channels or reverse incision.
4. **Wetland Enhancement** – retaining and infiltrating surface runoff, by holding rain high in the watershed through earthworks or beaver management.
5. **Watershed Forest Management** – protecting and managing watershed area for forest canopy.
6. **Constraint on Development** - where private and public proposals for development are prevented, limited, or modified to reduce impacts.

If our riparian zone management is robust, then we will have abundant clean cold water in streams that support fish and wildlife and agriculture, ample groundwater supplies, reduced flooding, and we will increase our resilience to changes in climate. If our riparian zone management is weak, we will damage public trust resources while wasting effort on inadequate solutions and protestation.

Actual riparian zone management requires labor, knocking on doors, sending our fliers, hosting community meetings, developing and monitoring designs and contracts, procuring materials, mobilizing and supporting crews, volunteers and contractors. Diverse actors collectively implement riparian zone management: local governments,

tribal governments, special districts, non-governmental organizations, state programs, federal programs, and most importantly private landowners. In the end we evaluate effectiveness by measuring the aquatic ecosystem, to detect a change in hydrography, channel structure, or water quality. From analysis to implementation, the opportunity for strategic incoherence is phenomenal.

Regardless, we must either increase the efficiency of our efforts or increase allocation of resources. Continued water quality violations, declines in fish populations, increasing impervious areas, and declining forest cover suggest that current efforts are insufficient. In a democratic systems, increasing resources for either regulation, incentives or restoration depends on having a large proportion of the community willing to consent to the costs because they value the benefits. In short, riparian zone management must be efficient and desirable, and broadly perceived as such.

Given the complex nature of the riparian zone, its connection to the watershed, and the need to both be and appear efficient and effective with inadequate resources, some strategic thinking is likely useful. Both our capabilities and our ability to communicate depend on strategic cohesion. The riparian landscape is complicated, patterns of degradation are complicated, and both the toolkit and the social context of management is complicated. These layers of complexity, including social and political feedbacks, are symptomatic of what Snowden and Boone (2007) label as a “complex problem” where technical analysis alone is not sufficient to develop competent solutions. Complex problems suggest an experimental and incremental approach with a high level of learning and adjustment. Our analytical tools must match this strategic posture of action, observation, and adjustment.

Recent proliferation of high resolution topographic and land cover data presents the opportunity to develop precise maps of riparian landscapes, and their ecological and social context. We can identify not only historically mapped streams, but also natural flow pathways based on topography. We can divide watersheds into an infinite variety of assessment units and given them attributes. We can feed all these data into hydrologic studies and evaluate the potential contribution of each county parcel. Analyses however does not change on-the-ground condition, and analysis must interact with field effort to remain relevant.

How can digital map tools increase the strategic cohesion and social relevance of our collective work? NOAA Restoration Center has been supporting Snohomish Conservation District in aggregating and developing a high resolution rendering of the lowland riparian landscape of the Stillaguamish and Snohomish basins (Figure ##). This effort aims to empower a conversation among riparian zone field practitioners, policy partners about how we collectively approach the biological-hydrological landscape. The lowland zone was our focus because this is where rapid population growth is in direct collision with public trust natural resources. Our goal is to use spatial tools to strengthen collective riparian zone management strategies, in order to increase both efficiency and resource allocation in both public and private sectors.

Strategic Concepts for Spatial Tools

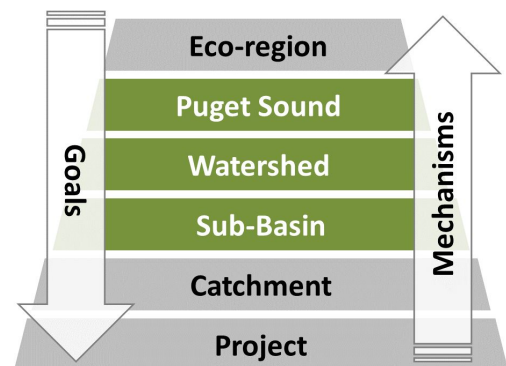
Salmon recovery, the Clean Water Act, and various initiatives in watershed planning have created an complex context from which to build a riparian zone strategy (see [literature review](#)). In addition, a new generation of digital terrain models, high resolution land cover data, and local field data allows us to better evaluate landscape conditions.

The following strategic concepts are inspired by the lessons of the [Puget Sound Nearshore Ecosystem Restoration Project](#):

- To develop landscape strategies we break complex whole systems into component parts, but these parts must be meaningful both ecologically and for management.
- A habitat management landscape is made of different types of places, with distinct processes, structures, and functions--to make these units ecologically meaningful we need to match the scale of the unit to the processes and functions of interest.
- Physical processes typically form few large units and many small units. It's how structures often evolve and trying to construct equally sized units may obscure the actual pattern of the landscape.
- Among units of a particular kind, we use attributes as surrogates for current or potential ecosystem functions, goods, and services. Attribute variation among units may be multivariate or multimodal in character, there is a high risk of correlation among attributes, and interpretation depends on our confidence in the surrogacy of each attribute.
- Patterns of degradation are also likely to vary both in both intensity and character, and analysis faces the same challenges as for unit potential services.
- An applied ecosystem management strategy will ideally be responsive to watershed context, the "type of place", the biophysical character of that place, as well as the patterns of degradation. We must decide what parts of that responsiveness should be systematized and what part should be *ad hoc*.
- The fundamental acts of strategic conversation are: 1) finding places that fit a particular high value strategic profile, or 2) defining an efficient conservation approach for given place.

These principles suggest that a spatial tool for strategy development will need to be as complex as the landscape and flexible so that it can evolve over time. Freshwater hydrologic systems are exceptionally nested. Catchments lie within catchments within sub-basins within watersheds, and the semantics vary from author to author. Lyle (1984) in his treatise on multi-scale planning, suggests that the larger scale analyses of regions and watersheds provide a context for establishing goals. Our goals express our desire for large scale effects. Each decreasing scale of analysis informs and refines these goals.

By contrast our actions are inherently small efforts--to affect change we are limited to a sequence of projects (Figure ##). By this logic a strong strategic framework lets us consistently integrate layers of context into goals that can evolve. Reciprocally, a strategic framework also helps us locate and evaluate a sequence of projects to achieve those goals.



Data Evaluation

To explore riparian zone management strategies, we have developed a multi-scale geographic information system to describe the hydrologic landscape to inform an evolving riparian strategy. This tool aims to integrate context across scales, to provide a robust linkage between potential project sites and landscape goals.

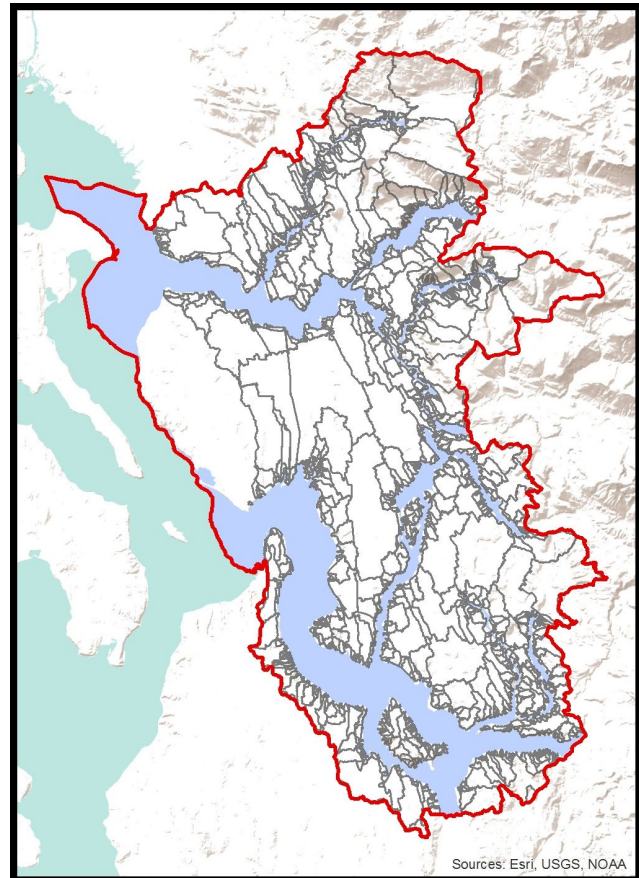
A conceptual argument is the heart of strategy. The map is a representation of the strategic logic, and so the map must be efficiently updated over time as both the data and the strategic argument evolves. A holistic effort is likely to pursue multiple strategies as we apply the hydrologic toolkit to a complex landscape, and test alternative arguments. If a map tool is framed to narrowly (to respond to a single argument), or only to answer only general questions (because we don't yet know what questions to ask) it will not contain the detail necessary to engage a conservation effort, and it will quickly become obsolete as field practitioners continue to develop their strategies in response to field conditions.

To discriminate among “kinds of places” I was inspired by Montgomery (1999) and his process domain concept, which elevates the role of geomorphic

disturbance regime in freshwater stream habitat structure. Watershed analysis under Salmon recovery and more contemporary work by the Watershed Characterization Project applies some of these process domain concepts, through the differentiation between floodplains and tributary sub-basins (SBSRF 2005), and between lowland and montane sub-basins (Stanley et al 2012). As our study area is focussed on lowland landscapes, our first differentiation of landscape units was between, 1) floodplains, where broadscale flood disturbance by large flows of water create landforms through transport and deposition, and 2) tributary streams, with structures dominated by incision into the glacial plateau. Each tributary stream is associated with a particular catchment, and enters the floodplain at a point (Figure ##). Further subdivision of the whole landscape was deferred until after examination of the landscape pattern resulting from this first differentiation.

Five types of spatial data were evaluated for the purpose of constructing the hydrologic network and this initial spatial structure:

1. **Streams (lines)** - For the purpose of representing mapped stream channels we compared, 1) Washington Department of Fish and Wildlife Fish Distribution data, 2) Northwest Indian Fisheries Commission Salmon and Steelhead Habitat Inventory and Assessment Project stream segments, 3) Snohomish County stream type lines, and 4) the National Hydrologic Dataset. The Snohomish county lines provided an significant improvement in channel position that agreed with aerial photography, and used a fish presence metric useful for management, and generally consistent with WDFW data. Reluctantly the SSHIAP data, which



includes potentially useful channel confinement and slope attributes, was discarded because of the inaccuracy of channel position compared to county data.

2. **Waterbodies (polygons)** - To represent mapped bodies of water bodies we examined water body data from 1) state ecology, and 2) Snohomish County. The county waterbody polygons were used as they identify current areas occupied by large rivers, delineated gravel bars, and also identified significant wetlands. Further the county data included water type, suggesting fish presence, and therefore management drivers.
3. **Watersheds (polygons)** - A variety of watershed polygons are available. We compared the potential use of, 1) National Hydrologic Dataset (NHD) subdivisions of Hydraulic Units, 2) SSHIAP polygons, constructed for each aforementioned SSHIAP stream segment, 3) Assessment Units (AUs) from the Puget Sound Watershed Characterization, formed by equal sized aggregation of SSHIAP units, and 4) PSNERP drainage units. The individual stream catchment has ecological and physical integrity, and so seemed like an important unit for connecting planning to practice. The SSHIAP units provided the most attractive building blocks for constructed nested, multi-scale management units, as NHD and AUs units were too large to evaluate individual catchments, and lumped floodplain and glacial plateau catchments haphazardly. PSNERP drainage units were conceptually desirable for the nearshore, but don't subdivide large river watersheds. All watersheds were based on lower resolution DEMs then currently available for the study area. We propose to construct new set of stream catchments from the point where flow accumulation intersects the floodplain boundary (please see methods).
4. **Digital elevation models (raster)** - Snohomish County Public Works has constructed a LiDAR mosaic using best available coverage. A portion of the upper Pilchuck Creek area (Stillaguamish Basin) was appended to this mosaic to complete the lowland Stillaguamish portion of the basin.
5. **Floodplains (polygon)** - floodplain delineation is a contentious topic, because of the regulatory implications of being inside or outside a floodplain. Floodplain mapping can therefore be political as much as geophysical. Using materials assembled by Puget Sound Partnership staff (Burke, pers. comm.) I compared, 1) FEMA 100 year and 500 year floodplain boundaries, 2) PSNERP delta process units (based on historical cartography), and 3) recent model based boundaries by USGS (Konrad, 2015) including both "valley bottom" and "low floodplain" units. The purpose of differentiating floodplains from other watershed surfaces was to capture how management and ecosystem services changes in flat landscapes that potentially interact with rivers. The Konrad units were constructed without political considerations, and were focussed on broadly capturing the floodplain landform (areas within 10m of bankfull river surface elevation) regardless of development or jurisdiction. They extended into major tributaries, and were the most inclusive and consistent boundary. In addition, Konrad defined a zone of "low floodplain" for those areas where river flood inundation was anticipated to be frequent (median annual maximum river stage). This nested two level floodplain delineation provided the greatest utility for this analysis.

These spatial resources were used to construct a nested set of units that describe the hydrologic landscape. Floodplains were identified and divided into high and a simplified rendering of low areas. Floodplain units were further dissected by perennial channels. DEMs were used to identify flow accumulation pathways. Buffers were constructed around streams, water bodies, and flow accumulation pathways. Watersheds were constructed using DEMs, for each point where more than 10 acres of flow accumulation enters a floodplain. Catchments were further subdivided into headwaters and main stem units, based on stream order. Specific catchments were outlined where an accumulation of flow without an observed channel enters a stream buffer. All units were combined into a tessellated network of polygons.

Next Steps - Strategy Formulation and Polygon Attribution

This is an interim report on the process of developing a likely spatial framework. Future phases of work can only be advanced in collaboration with the local and regional riparian zone management community. These future phases involve evaluation of the spatial framework by the application of strategic thinking.

The proposed draft polygon set serves only to provide a flexible framework in which to ask questions. The data do not provide the question. Ecosystem restoration designers must use their knowledge of regional, watershed, and local goals to develop strategic arguments, that can then be framed as spatial questions.

The strategic arguments for organizing riparian zone management are finite. The following strategic concepts were found in watershed planning documents:

- 1) **Respond to Fish Use** – we restore riparian zone functions in areas with documented or anticipated spawning or rearing of specific species.
- 2) **Respond to Vegetation Condition** – We consider the condition of vegetation both in the near-stream zone, and in the catchment and,
 - a) **Cut Losses** - At some point we may choose to “cut our losses” and we don’t try to restore fully functioning systems, and instead focus on mitigating the impact of a severely degraded catchment on downstream systems, or focus work in other catchments where greater return on investment can be assured.
 - b) **Protect the Best** - we target systems with high functioning vegetation patterns and use measures to prevent degradation of those functions.
- 3) **Respond to Stressors** - We intensify our riparian management efforts to compensate for specific degradation of watershed units. That stressor response may be specific. For example, we may intensify wetland enhancement to intercept sediments in catchments with lots of tillage or livestock.
- 4) **Respond to Multi-benefit Opportunities** – We may chose sites based on the overlap with other public mandates, so that we co-locate riparian work with the protection of agricultural lands or flood hazard mitigation. These strategies may provide specific synergies, where management measures are mutually reinforcing.
- 5) **Respond to Water Quality Parameters** – we intensify efforts in areas with measurable water quality violations, and employ and place interventions that are most likely to address the water quality violation in question. This may be combined with the “respond to stressor” strategy.
- 6) **Respond to Cold Water Refugia** – we prioritize channel restoration in the vicinity of cold water refugia, particularly for pool formation. We intensify *wetland enhancement* in the catchments of cold water refugia to protect groundwater recharge in catchments associated with cold water refugia.
- 7) **Respond to In-channel Conditions** – we use channel restoration and jam installation to modify systems where we have observed that floodplain modification and deforestation has led to channel widening or incision.
- 8) **Respond to Landowner Willingness** - though rarely articulated in planning documents, different neighborhoods may have more or less interest among landowners. Developing the relationships necessary for riparian zone management may be a strategic driver.

- 9) **Respond to Reach Geomorphology** – we locate floodplain reconnection and in channel work based on how we expect that reach confinement, aggradation, incision, or avulsion may cause the site to evolve over time or result in greater or lesser interaction between the channel and the riparian zone.

Many of these concepts are relatively ambiguous in that they don't specify the scale at which the strategy would be applied. A strategy may also combine multiple concepts to favor action where a combination of conditions are present. That combination of factors may be sequential, such as selecting a focus area at a larger scale, and then applying strategic principles within that focus area based on the nature of the larger scale assessment. A strategy may imply a particular intervention. The resources for riparian zone management provided by state and federal programs may be preallocated by politicized budget processes. Local strategy may have to apply resources that are predefined in their use. Development of a rational local strategy can serve as an argument to increase local control of resources to maximize efficiency of agency programming.

The strategic argument, however framed, describes the scale of attribution, and the kinds of attributes necessary to locate areas of interest. Alternately, a strategic argument can be structured, so that analysis informs the kind of interventions for any given location. This is a restatement of the principle that there are two fundamental acts of strategic conversation: 1) finding places that fit a particular high value strategic profile, or 2) defining an efficient conservation approach for given place.

By defining our strategic approach, we can then determine which attributes to apply to our landscape units at what scale, or whether we even have the data to attribute landscape units reliably. Instead of obscuring data weaknesses in a opaque analytical process, we can be identified strategic interests, with no supporting data as a gap in technical knowledge, and find ad hoc methods for reflecting strategically important considerations in our field work.

The following attributes are likely to become attributes at some scale to inform analysis:

- **Polygon area** – catchment area is highly variable, and depends on complex post-glacial topography, and so may not have intrinsic value. Catchment area does describe the amount of runoff that will enter the stream buffer at the pour point. Large catchments exert a greater effect on water quality and quantity than small catchments. Polygon area is also used to calculate land cover percentage metrics.
- **Stream length** – the mapped stream density describes the degree to which a catchment tends to produce runoff. Surface soils that tend to rapidly saturate and produce overland flow will naturally form a higher channel density.
- **Concentrated flow path length** – the concentrated flow path density describes the extent to which topography conflates surface flow into confined pathways, as opposed to landscapes where flow concentration is poorly developed.

Degradation Metrics

- **Road length** – all roads are assumed to both generate runoff of perhaps 5 or 10 times forested landscapes, and through ditch systems, concentrate that runoff at low points that coincide with flow paths. In this way, roads effectively expand the drainage network within a catchment.
- **Percent Impervious** – The proportion of impervious land cover describes the degree to which development is producing Stormwater.

- **Percent Cleared** – the proportion of the polygon that is neither forest nor wetland describes the gross degree of vegetation modification.

Water Retention Metrics

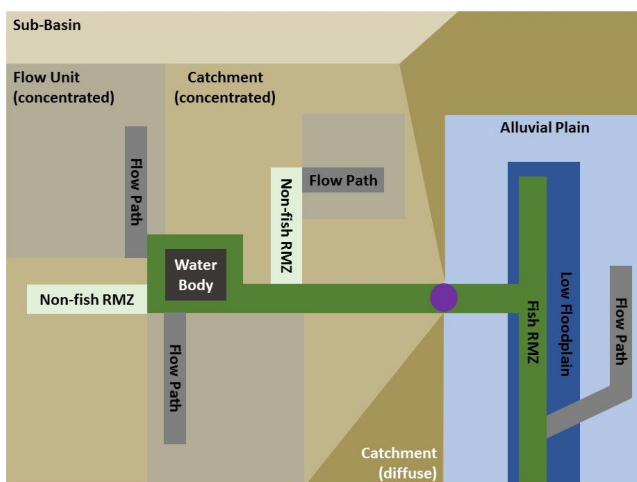
- **Depression Volume** – in processing digital elevation models for routing flow, we fill areas that drain nowhere. The volume of this fill area describes the degree to which the landscape is likely to retain surface runoff due to irregular topography. Some of this irregularity may be related to data error, and so this metric is not precise, but provides a general order of magnitude. There should be a correlation between depression volume, percent wetland, and slope.
- **Average Slope** – average slope within the catchment describes the rate
- **Percent Wetland** – The area of
- **Percent Forested** – Describes the like
- **Percent Open Water**

Social Dynamics

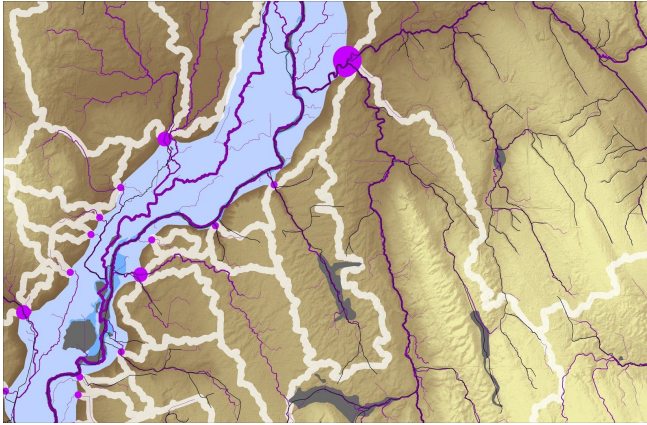
- **Average parcel size** – the average parcel size describes the intensity of community settlement in the catchment. The parcel size is an attribute of the parcel, and this attribute is averaged for all parcels in each polygon. (There is some complexity here, as the analysis
- Mean potential parcel size (zoning)
- Percent forest cover loss

Description of Landscape Model

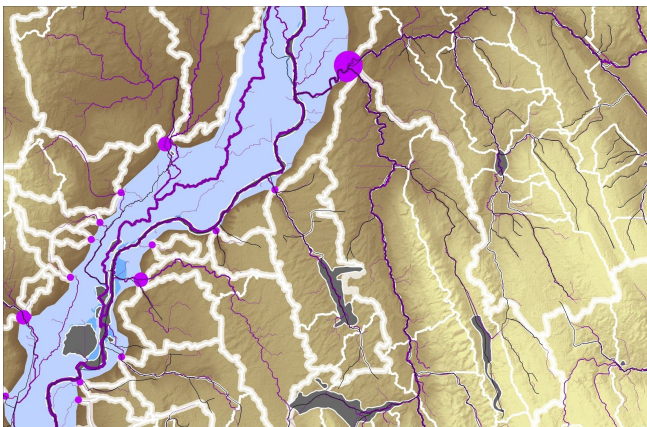
The following sequence of images describes the conceptualization of the tessellated polygon network anticipated to support multi-scale adaptive riparian zone strategy development.



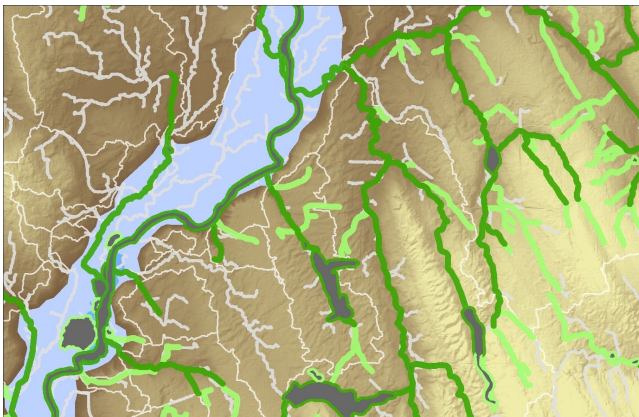
Conceptual diagram of nested polygons. The sub-basin (whole diagram) contains alluvial plain (blue) and two kinds of catchments draining to the alluvial plain: concentrated (light brown; where flow enters the plain through a concentrated flow (purple dot)) and a much small area of diffuse catchments (dark brown; essentially portions of the valley wall between concentrated catchments). Within the alluvial plain (light green) is an area of low floodplain (dark green). Across this landscape there are three kinds of riparian management zone: fish zones, no fish zones, and flow path zones, based on the attributes of the line used to create the zone. A concentrated catchment is further subdivided



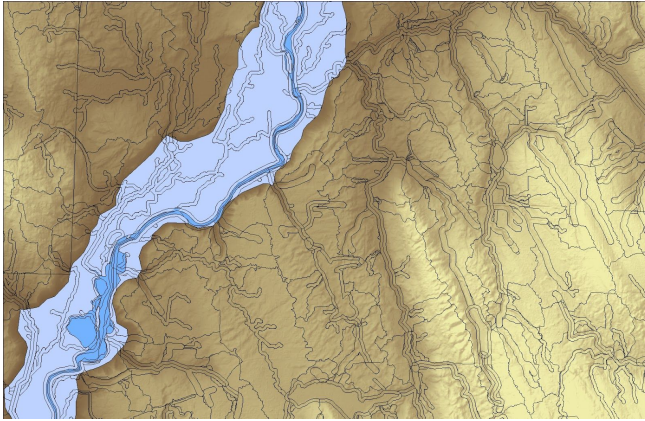
Catchment Construction - Floodplains (blue) were differentiated from the glacial lowlands (brown). Floodplains are divided into high (light blue) and low (dark blue) zones. Both observed stream channels (black), flow accumulation derived from DEMs (purple) and water bodies (grey) were used to define the hydrologic landscape. Catchments (white) were identified where flow accumulation lines enter into the valley bottom (purple dots, with dot size relative to catchment size).



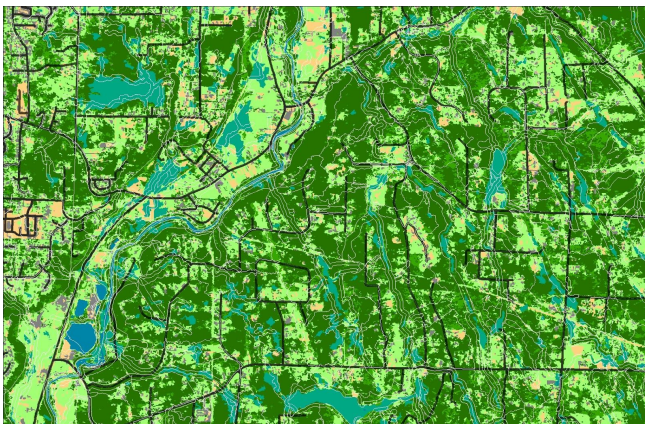
Catchment Subdivision - Catchments (thick white) are further subdivided into sub-catchments (thin white) based on stream order and divided by stream channels (into left bank and right bank.) Water bodies are excluded as a unique unit.



Riparian Zone Construction - A riparian management zone was constructed by buffering streams, water bodies, and flow accumulation paths. Buffers are coded to reflect their associated hydrologic feature and fish-bearing (dark green), non-fish-bearing (light green), and concentrated flow paths not mapped as channels (grey).



Polygon Integration - The combination of these polygons creates a tessellated set of polygons describing the relative function within a hydrologic landscape. Units are either in a riparian zone, or a watershed. Units are positioned within a catchment. Some units contain concentrated flow pathways that enter stream buffers.



Polygon Attribution - These polygons can be attributed with land use data like vegetative cover, road density or other indicators of degradation. In addition they can be further described in terms of slope, soils, or factors that may affect ecosystem service provision. The scale of attribution should be related to the scale at which ecological effects are anticipated.

Notes on Spatial Analysis Methods

Polygon Attributes

The following table describes polygon attributes of the integrated polygon unit set. The attributes provide a methods for selecting a scale or unit type, for the purpose of creating a query to identify a set of attributes with specific qualities, or for classifying a set of units based on similarities and differences among attributes.

Table 1 – Integrated Hydrologic System Polygons

Attribute	Values	Function	Origin
Analysis Units			
UnitID	##		Feature ID generated through union of all polygons sets. Combines catchment with final ID as decimal
Component - DONE	Floodplain, Watershed	Differentiate between physiographic regions	Alluvial plain follows Konrad 2015, and inclusively describes a landform rather than a particular predicted flood regime.
Municipal	Urban/GrowthArea, Non-urban	Identifies zones where modification of hydrology is pervasive, and should be excluded for analysis	State Ecology UGA
Basin - DONE	Stillguamish, Snohomish	Defined by aggregation of Sub-Basins	Defined by the manual aggregation of sub-basins.
Sub-Basin - DONE	Snohomish Estuary, Marshlands, French Slough,	Division of study area in the major components.	Defined by the manual aggregation of AlluvPlainID units into sub-basins, and then

	Lower Pilchuck River, Middle Pilchuck River, Lower Snohomish, Lower Skykomish, Woods Creek, Lower Stillaguamish, Stillaguamish River, North Fork Stillaguamish River, South Fork Stillaguamish River, Pilchuck Creek, Jim Creek		association of Catchments based on spatial join with Alluvial Plain units.
Watershed Units			
CatchmentID	##	Includes both concentrated and dispersed flows to floodplains. For concentrated catchments, it links to the FlowToFloodplain point.	Derived from FlowToFloodplain Polygons merged with floodplains with no gaps, thus Dispersed catchments were created. Handwork was required to simplify. 0=Floodplain 1-2000 = concentrated 2000-4000 = dispersed
CatchType	Concentrated, Dispersed, Floodplain	Discriminates between different catchments, based on whether they contain a flow path.	Floodplain areas include many small high spots, slightly more than an acre.
CatchmentArea	### acres	Area in acres. This is not particularly useful in floodplains, as it just describes individual elevation zones.	Calculated after the merger of catchments and floodplains. In floodplains, area is equal to the individual units within a high/complex
CatchOrder	1-6	Maximum Strahler stream order	
Floodplain Units			
PlainID	##	Designates management units in floodplain, between major channels.	0 = Watershed 1-800 = Floodplain
PlainType	High, Low, Null		
PlainArea	### acres		
Riparian Management Zone			
RMZ	Yes, No, Water	Differentiates area in or out of RMZ, and excludes waterbody area from the RMZ buffer.	See analytical methods. Integrates stream line buffer, water body buffers, and flow path buffers.
RMZtype	Stream, Waterbody, Flow, Null	Indicates the feature that was used to produce the buffer.	
RMZfish	Fish, No Fish, Null	Indicates whether stream is fish bearing based on county data.	Based on DNR stream type of original feature, using 2016 county data.
SubUnitArea	### acres		
SubCatchment Units			
SubCatchmentID	##	Units used to divide large catchments into subunits based on flow path confluences.	Generated by watershed analysis using flow path vertices. All catchment areas are divided into SubCatchments. Floodplain areas do not have catchment ID
WaterBody	Yes/No	Waterbodies that are not part of the catchment system.	
WBType	Fish/NoFish/Null	Indicates whether the waterbody is within 100 feet of a fishbearing waterbody or stream.	The water type of the water body based on the association of the water body with fish bearing stream lines.
SubCatchArea	##		
UnitID	##, Null	A unit within a catchment and sub-catchment, which either flows to a stream buffer by way of a flow path (concentrated) or without a flow path (dispersed).	For dispersed catchment types, Flow Unit, SubCatchment, and CatchmentID are the same.
UnitType	Waterbody Floodplain (356) Waterbody Watershed (315) Floodplain High (419) Floodplain Low (476) Watershed Dispersed (968) Wtrshd Catch Disp. (3,937) Watershd Catch Con. (3,759) Nearshore (27) Tulalip (8)	This summarizes landform units prior to identification of Riparian Management Zone.	Manual selection and attribution was used based on other field values.

FlowUnitType	Concentrated, Dispersed, Riparian, Floodplain, Waterbody	Describes the character of the smallest polygon units.	FlowUnits generated by a FlowToBuffer point
UnitStreamOrder	1-6	Number describing the maximum stream order attribute within the polygon. This describes the relative position of the polygon within the watershed.	This value is derived from the maximum flow path segment value within the FlowUnit, by creating a spatial join between flow path line segments and the polygons set.
UnitArea	### acres		

Spatial Datum and Projection

A State Plan geographic system was used to align with the native format of extensive raster data acquired from Snohomish County. All data were re-projected to match the Snohomish County standard.

NAD_1983_StatePlane_Washington_North_FIPS_4601_Feet
WKID: 2285 Authority: EPSG

Projection: Lambert_Conformal_Conic
False_Easting: 1640416.666666667
False_Northing: 0.0
Central_Meridian: -120.83333333333333
Standard_Parallel_1: 47.5
Standard_Parallel_2: 48.73333333333333
Latitude_Of_Origin: 47.0
Linear Unit: Foot_US (0.3048006096012192)

Geographic Coordinate System: GCS_North_American_1983
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

Analytical Methods

The following methods were used to develop the draft polygon set.

- **Define Study Area** to include
 - **Snohomish** – The lowland Snohomish Basin was defined as AUs downstream of the Skykomish-Elwell confluence, and not including Snoqualmie valley in King County. Mountain AUs were only included for the purpose of capturing tributary catchments, including Woods Creek, and local headwaters to the Skykomish Floodplain described above.
 - **Stillaguamish** - Intended to represent lowland watersheds including Pilchuck and Jim creeks, and portions of the north and south fork mainstem. Initially a lowland AUs were included. An arbitrary cutoff was selected in the north fork to exclude the Deer Creek

catchment, and mountain AUs were then included for all tributaries of the mainstem segments included.

- **Should have included a larger area, so that ultimately the definition of high resolution watersheds could be used to ultimately define a final study area.** Also should have included nearshore watersheds to include areas of interest to the Tulalip Tribes, and include floodplain units upstream of the catchment unit limits, and the full extent of SLS reach-scale planning areas.
- **Create Stream Riparian Management Zone (RMZ)**
 - County streams are better fit to the digital elevation model and are improvement on NWIFC SSHIAP and WDFW FishDist stream line work, which is coarser in resolution and older in provenance.
 - CLIP stream features to the study area
 - DISSOLVE stream lines on WTRTY_CD which uses DNR water type
 - BUFFER to create full rounded 100' foot buffers dissolved on water type.
 - SEPARATE BY ATTRIBUTE to create a unique feature class for each value in WTRTY_CD
 - UNION of all buffer types and EXPORT TO EXCEL, where we recode to define a single water type for each polygon, selecting the more regulated type at areas of overlap.
 - ADD DATA to bring the new table back into ArcGIS, and JOIN the streamtype value.
 - DISSOLVE polygons by the joined streamtype value.
- **Waterbody Riparian Management Zone (RMZ)**
 - SELECT BY LOCATION all waterbodies, that intersect the stream RMZ, with a 200' tolerance. EXPORT to a new layer of "connected waterbodies."
 - SELECT BY LOCATION all of these connected waterbodies that intersect a stream buffer coded 'Fish', and EXPORT these waterbodies, to be used as fish bearing waterbodies, because of their proximity. DISSOLVE as a new layer of "fish waterbodies."
 - DISSOLVE all "connected waterbodies", and then ERASE using the new "fish waterbodies" leaving only "no fish" waterbody feature.
 - MERGE "fish" and "no fish" feature classes, and create a new attribute to define their fishiness.
 - Prior to creation of buffers, the Nearshore Floodplain polygon (see below) was used to delete all waterbodies located within the historical delta. The existing polygon structure in these areas was not useful for management of the historical delta landscape.
 - **GRAVEL BARS** - gravel bars and included in the waterbody inventory, but are given a water type of X, even though they are associated with waters of the state. We wanted to include gravel bars in mainstem streams and rivers as part of the mainstem polygon.
 - SELECT BY ATTRIBUTE water bodies coded X, and from those, SELECT BY LOCATION those that are within 100 feet of a waterbody coded S (waters of the state). Visual inspection to insure no outliers were captured. EXPORT these waterbodies into a new feature class.
 - BUFFER, 100 foot, full rounded, on all water bodies, and gravel bars. With separate buffers dissolved on water type code.
- **Integrate Buffers and Interpret Water Type**

- o Within river basins our “riparian management zone” is a polygon made up of buffers on county stream lines, buffers on connected waterbody polygons (including gravel bars), and buffers on flow paths.
- o Created a UNION of all four buffer feature classes.
- o Exported TABLE TO EXCEL, and created final field values for RMZType and RMZfish using logic statements.
 - “Water body” was used over “stream” which was used over “flow”.
 - Fish was identified where indicated by water type. Gravel bars were included in the fish category, and all flows were assumed to be non-fish bearing.
- **Create Alluvial Plain Polygons Set**
 - o Attempts to use watershed formation tools to define alluvial polygons results in very complex structures, that didn’t have management value. The discrepancy between channel position, and hydrologic flow path further reduced the value of using automated watershed definitions in floodplains. By contrast, dividing the landscape by stream lines reflects cultural divisions of the landscape, like “what side of the river are you on”. However, without additional manual splitting and lumping, the stream division method results in small fragments and amoeboid shapes connected by narrow isthmuses.
 - o Analysis by Konrad produced a very inclusive and broad “alluvial plain” area. The related low floodplain analysis shows areas frequently inundated by flood waters. These two polygon sets provide a nested pair of alluvial plain boundaries.
 - o The USGS low floodplain polygons were generated using a 10m raster, and resulted in complex polygons with intricate boundaries, not useful for management.
 - EXPORT the low elevation component.
 - AGGREGATE POLYGON Polygon, with 40 foot distance, and with any polygon smaller than 10 acres discarded.
 - SMOOTH POLYGON using a PAEK algorithm, with 200 foot tolerance to reduce residual blockiness. 200 feet was selected by increasing tolerance (50’ 100’, etc.) until the edges of the 10m raster was obscured.
 - o IDENTITY was used to attribute the Split floodplain polygon with the low elevation polygons.
 - o MULTIPART TO SINGLEPART was used, revealing 2123 units
 - o ELIMINATE was used to combine all sliver polygons of less than 1 acre area with their neighbors with the longest shared border, leaving 634 floodplain units.
 - o SELECT BY ATTRIBUTE polygons from the PSNERP GSU where Z=2 and associated with the STL or SNH deltas, or located between these two. These polygons were dissolved to form a single nearshore polygon, based on historical mapping.
 - o IDENTITY to apply low zones within larger alluvial plain polygon.
 - o SELECT BY ATTRIBUTE perennial streams with a water type of S, F, or Np, and then SPLIT the alluvial plain by those perennial stream lines
 - SELECT BY ATTRIBUTE any polygon less than 10 acres. These units were manually MERGED with an adjacent polygon, with a preference for joining across the smaller stream, and creating units with a low perimeter to area ratio.

- Polygons were manually inspected, and 1) long skinny polygons bordered more than one stream system were split, 2) polygons that were much smaller than typical for a reach, or where the stream did not indicate any observable change in land management, were merged with an adjacent polygon, and 3) Where Polygons along a valley wall were excessively long, they were split, typically opposite a major tributary confluence.
- **Create Flow Accumulation Pathways and Buffers**
 - Dissolved watersheds within the SNOHOMISH and STILLAGUAMISH STUDY AREA, and used to clip LIDAR DEM
 - In the case of Stilly, created a mosaic of 1) the Snohomish County DEM and 2) the Finlayson 2006 Puget Sound Supermosaic, for Selected AUs where coverage extends outside of the county DEM coverage.
 - The Snohomish DEM was clipped with a 500 foot overlap with the selected AUs to facilitate blending at the transition. Spot checks suggested that the difference between the the DEMs at the edge was on the order of 0.5 feet plus or minus.
 - Used [Mosaic to New Raster] tool with 1 band, 32 bit float values, and blend option for overlapping cells to create a unified mosaic for the study area.
 - FILL the DEM to remove depressions in preparation for flow direction calculation
 - Used FLOW DIRECTION tool to code filled raster, and FLOW ACCUMULATION tool to define flow pathways. No force edge cells, no drop raster.
 - Created a raster of all accumulation pathways that drain more than 10 acres of land. The DEM has 6' square cells. An arbitrary cutoff was used such that all retained flow accumulation pathways were retained that received flow from a 10 acres or greater catchment (12,100 pixels)
 - Map Algebra, Raster Calculator, Code: OutRas = Raster("DEM_accum") > 12100
 - STREAM ORDER to recode the resulting raster pathways using the Strahler method
 - STREAM TO FEATURE, simplify polylines, while retaining stream order metrics.
 - Dissolve and Create 50' full buffers on resulting line work, round ends, dissolve all.
- **Identify depressions and low slope areas.**
 - CUT FILL to show area and depth of depressional features identified using Fill tool
- **Create CATCHMENTS where flow pathways discharge to the alluvial plain.**
 - INTERSECT Flow Path with Alluvial Plain polygon, to identify pour points, with no XY tolerance. [FlowToFloodplain_points]
 - MULTIPART TO SINGLE PART to divide multipoint features. 1652 features. [FlowToFloodplain_points_Multi]
 - SNAP POUR POINT within 6 foot radius of selected points using the Flow Accumulation Raster, to insure position of point on flow accumulation path. This may have the effect of placing the raster pour point slightly within the floodplain polygon. [FlowToFlood_pour]
 - WATERSHED creation, using Snapped Pour Point, and Clipped Raster using FID as raster value.
 - RASTER TO POLYGON, simplifying polygon boundary

- o ERASE portions of catchments within the floodplain. In some cases, this results in creating a multipart feature where the floodplain dissects a catchment.
- o MULTIPART TO SINGLEPART was used to reduce features to individual catchments.
- o A field for acreage was added to the feature, and CALCULATE GEOMETRY to define polygon acreage using map projection.
- o Created a test feature by adding a 100 foot BUFFER to the Full Floodplain, erasing flow path lines within this zone.
- o SELECT BY LOCATION where polygons intersect the test feature (1394/2666), SELECT BY ATTRIBUTE to remove selections smaller than 10 acres, and EXPORT remaining 1131 features.
- o JOIN polygon area data to FlowToFloodplain points, SELECT those points where the joined attributes are present, and EXPORT to final FlowToFloodplain point layer, that includes catchment acre attribute. 1131 points were selected.
- **Divide Catchments into SubCatchments at significant stream confluences.**
 - o ERASE Flow Path using floodplain extent, leaving only flow lines within Catchments.
 - o DEFINITION QUERY to exclude lines with stream order equal to one, then DISSOLVE on the stream order attribute, all remaining lines of stream order two or greater using the stream order field
 - o EDIT the resulting layer, SELECT all and then, PLANARIZE lines to divide stream segments at confluences.
 - o MULTIPART TO SINGLEPART to insure that each line segment is its own feature, and TRIM LINES to remove all dangles less than 500 feet in length to reduce the number of small arbitrary segments, and small watersheds.
 - o FEATURE VERTICES TO POINTS creating points at the beginning and end vertices of each remaining feature. This creates a duplicate points at each junction, but also a point at the end of a stream network.
 - o DELETE DUPLICATE, selecting the feature type field to delete co-located points, using a 500 foot XY Tolerance, to reduce the incidence of close points resulting in small sub-catchments, or where two points are created at the same vertex. The point with the lowest stream order value was retained, so that each point references the upstream line segment in preparation for watershed creation.
 - o SNAP TO POURPOINT with a 6 foot tolerance to match raster resolution, using feature ID to create distinct raster cells for each remaining point.
 - o WATERSHED to create sub-catchments on those pour points.
 - o RASTER TO POLYGON, with simplification of lines to create sub-basin boundaries, creating 2049 polygons. 527 of these polygons are less than 10 acres, with many very small features due to processing methods.
- **Create Concentrated Flow Units within Catchments.**
 - o SELECT integrated buffers that are not flow paths and EXPORT to [AllBuffers_StreamBodyOnly]
 - o INTERSECT flow paths with the reduced buffer feature class creating points [FlowToBuffer_rawpts], and then ERASE all points in the alluvial plain.

- o MULTIPART TO SINGLEPART [FlowToBuffer_ptsSingle] to insure each point is its own feature, and then SNAP TO POUR POINT using a 6 foot radius to identify raster points for watershed modelling [FlowToBuffer_pour]
 - o Create WATERSHED, and convert RASTER TO POLYGON [FlowUnits_raw], using simplified boundaries.
 - o ERASE integrated buffer polygon area from resulting flow unit polygons [FlowUnits_rawNoBuff], thereby cutting polygons that cross back over the stream corridor.
 - o MULTIPART TO SINGLE PART [FlowUnits_rawMulti] to insure that all resulting polygons are independent and discrete.
 - o Create a new attribute, Acres, and CALCULATE GEOMETRY to restore accuracy of the shape area attribute
 - o BUFFER the stream buffer polygon by 50 feet, and then ERASE flow pathways within this expanded buffer to create a line feature class that can be used to test whether the created and cut polygons do in fact contain a significant flow pathway (greater than 50' removed from the stream corridor).
 - o SELECT BY LOCATION all those catchments which intersect the test line (4543 of 13739). Refine by removing all polygons using SELECT BY ATTRIBUTE where shape area < 10 acres (3301), and EXPORT to a new feature class.
 - o JOIN FlowToBuffer points to the retained Catchments, SELECT where joined attributes are not null, and EXPORT to a final feature class, 3301, where polygons greater than 10 acres, are associated with a flow path greater than 50', and associated with a point where the flow path intersects the stream buffer.
 - o KNOWN ERROR. In some cases, the Flow To Buffer points are poorly associated with the resulting Buffer Catchment. Two circumstances were discovered: 1) the watershed boundary is very narrow as the flow path approaches the buffer, so that when the watershed raster is formed it is only one cell wide, and so when the watershed raster is converted to a simplified polygon, the intersection between the point and the watershed polygon is lost. 2) When the flow path moves in and out of the stream RMZ, typically in an unconfined channel where topography doesn't necessarily align with channel position. This is likely not a problem as it identifies areas where small alluvial plains result in strong interaction between the channel and the surrounding physio-hydrographic landscape. Using the method of association by attribute join, rather than spatial join resulted in clear correspondence between point and watershed.
- **Sub-Catchment Development**
 - o Divide all catchments into sub-catchments split by Streams, and Remove Waterbodies
 - UNION catchments and sub-catchments, all catchments are then defined by unique sub-catchments. Dispersed flow catchments were excluded to avoid problems created by the flowpath-streamline discrepancy. FID only.

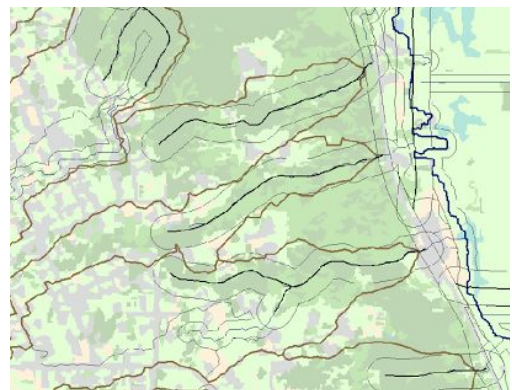


- Select all stream lines, and then SPLIT POLYGONS in the advanced editing window, dividing polygons split by a stream, into stream-left and stream-right.
- ERASE using final waterbodies [SubCatchment_NoWtbdy]
- MULTIPART TO SINGLEPART creates unique polygons [SubCatchment_single]
- CALCULATE GEOMETRY to update acre attribute, and SELECT BY ATTRIBUTE all polygons less than 10 acres. 11728 of 115482 (11068 less than 1 acre)
- ELIMINATE by combining small selected polygons with the adjacent polygon with the longest shared border.
- UNION waterbodies with the divided catchments
- SELECT BY ATTRIBUTE where the polygon is not a water body, and has an acreage of less than 1.
- **Integrated Polygon Network**
 - UNION floodplain units and catchments, with no gaps. This produces 3537 units including a large number of small dispersed catchments. 866 are less than 1 acre, and 1255 less than 10 acres
 - Create fields for target attributes (see table above)
 - SELECT by ATTRIBUTE all Watershed component features. These includes all dispersed watershed units, as well as small units located in floodplains.
 - Create attributes and use calculator to develop final polygon values.
 - Manually select and attribute [Basin]
 - Manually select and attribute [SubBasin] for floodplain units, and then CREATE LAYER of those units and complete a SPATIAL JOIN to attribute watershed units using the adjacent floodplain unit.
 - [CatchmentID] is based on the original Catchment layer with value from 0-1623, while dispersed units were created from 2000+ based on a calculation using the new FID. Alluvial units remain 0
 - CatchmentType is assigned either “Concentrated” or “Dispersed” following union. CatchOrder follows catchment attributes.
 - Plain attributes are based on Floodplain attributes.
 - IDENTITY was used to bring in [SubCatchments_final] along with the “WaterBody” and “WaterBodyType” attributes, to further divide catchments. [Union_FloodCatchSub_raw]
 - IDENTITY to integrate flow to buffer catchments
 - SINGLE PART TO MULTIPART yields 207,767 objects.
 - ELIMINATE as selectively used to remove small polygons
 - Component = ‘Watershed’ and Area < 1 acre.
 - [Union_FloodCatchSub_1] and Waterbody <> “Yes”
 - Results in elimination of 195,746 objects in [Union_FloodCatchSubFlow_elim]
 - 2053 floodplain polygons are less than 1 acre covering 266 acres over the county. This appears to be primarily small pieces of LOW elevation floodplain, very similar to, but not located within adjacent Waterbody polygons. 1864 <0.5 acres covering 130 acres countywide, and 1453 are less than 0.1 acres covering an area of 30 acres countywide.

- Component = 'Floodplain' and Area < 0.5 acres (Eliminating an additional 1864 polygons) [Union_FloodCatchSubFlow_elim2]
 - o Clean up fields
 - Unit Type developed by SELECT BY ATTRIBUTE for each criteria
 - SPATIAL JOIN was used to attribute each polygon with the maximum FlowPath Stream Order value intersecting the polygon.
[Union_FloodCatchSubFlow_StrOrder]
 - o IDENTITY was used to bring in [AllBuffers_final] to form [Union_FloodCatchSubFlowBuff_raw]
 - o ELIMINATE was used to correct slivers. The IDENTITY function produced 26322 polygons. 7403 are less than 1 acre. 5266 are less than 0.5 acres, and 2405 are less than 0.1 acres. I chose to not remove slivers. There seemed like no rational method for aggregating slivers, because it either reduces or increases a buffer arbitrarily. One strategy might be to extract all buffers, eliminate small slivers, and then erase the footprint and merge.
 - o DISSOLVE city UGA polygons on UGA name to form [CityUGA_diss]
 - o IDENTITY to bring in UGA polygon boundaries.
 - o MULTIPART TO SINGLEPART turned 25568 polygons into
- **Attribute Polygons**
 - o TABULATE AREA was used to summarize each land cover within each SubZone
 - o TABLE TO EXCEL was used to move the final data into a more fluid setting for analysis.
 - o SLOPE attribution?
 - o Salmon use attributes?

Observation of Analytical Weaknesses

1. In some cases where the flow path or stream runs along the edge of a catchment, the 100' RMZ extends beyond the catchment for which the RMZ was calculated. This creates an RMZ associated with a stream, that is then attributed to the adjacent catchment. This could be avoided by having a unique code identified for all RMZ based on the line used in buffer creation, associated with the catchment.
2. I made a mistake while keeping track of ID numbers for all the nested scales. I lost unique identifiers for the flow to buffer units. The points should be useful for reconstructing those relationships, except the point to catchment creation process did produce errors, due to the discrepancy between the county stream lines, and the DEM derived flow lines. A forcing process where the DEM is reconstructed to force flow to the stream may be useful to reduce this error, but risks failing to identify where stream



channels are perched! I could not identify a solution that resolves this issue. Additional care should be applied to identifying and preserving the associative relationships of all unique identifiers.

3. There are many ways to simplify the complex patterns of land cover that describe each unit. We can now characterize land cover and multiple nested scales. We can identify attributes that simplify slope and depressions to further describe the natural character of a catchment. Now what do we do with this potential? We need to stop and describe the functions we want to achieve, and then consider how those functions are affected by the attributes we have available. This is the importance of completing an initial conversation on strategy before attribution.
4. In some significant cases, the mapped channel enters the floodplain in a position that is significantly different than the flow accumulation pathway suggested by the DEM. In these cases there is a disconnection between the watershed boundary (created from the DEM) and the channel position, where a large channel from a large watershed enters the floodplain at the point associated with a smaller catchment.
5. Existing county “land cover” data merge vegetative characteristics and wetlands, which creates ambiguity around whether a wetland represents mature vegetation or “natural conditions” or if such areas should be a subject of riparian zone management. Hydrologic context should be separated from development extent.

Citations

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