SSHIAP response to ISRP preliminary review comments pertaining to Columbia Cascade proposal: Project ID 29043

***ISRP**: The two page "Objectives, tasks and methods" section is too brief to allow review. Detailed methods should be given*

Response: Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) methods are related to role that SSHIAP plays as 1) a collector and synthesizer of existing information and 2) a developer of modeled information based on existing data. SSHIAP was designed as a data system that can provide summaries in map form (i.e., a spatial database). Core attributes (n = 13) were designed to be collected/synthesized in all WRIAs, whereas secondary attributes (n = 8) are collected/synthesized only from areas where this data has already been completed and assembled. Attribute data summaries and mapped information are assembled into a single shape files suitable for GIS use.

Table 1. Habitat Attributes used in SSHIAP

Core	Secondary[1]
1. Channel Confinement[2]	1. Estuarine-Nearshore Marine Habitat[5]
2. Channel Gradient[2]	2. Historical Habitat Conditions
3. Channel (Segment) Length[2]	3. Land Use/Land Cover
4. Channel Type (Rosgen)[2]	4. Riparian Assessment
5. Channel Width[2]	5. Water Quality
6. Elevation[2]	6. Water Temperature
7. Fish Distribution[3]	7. Water Withdrawals
8. Fish Habitat[2]	8. Wood Debris
9. Fish Passage Barriers[3]	
10. Flow[2]	
11. Habitat Type (Coarse scale)[2]	
12. Hydromodifications (Floodplain)[3]	
13. Geology/soils[4]	

[1] Potentially derivable form more than one source; may require SSHIAP refinement.
[2] Exclusively SSHIAP-generated.
[3] Derived from more than one external source (not SSHIAP-generated); often requires SSHIAP refinement.
[4] Derived from one external source.
[5] Not applicable to Columbia Cascade Province.

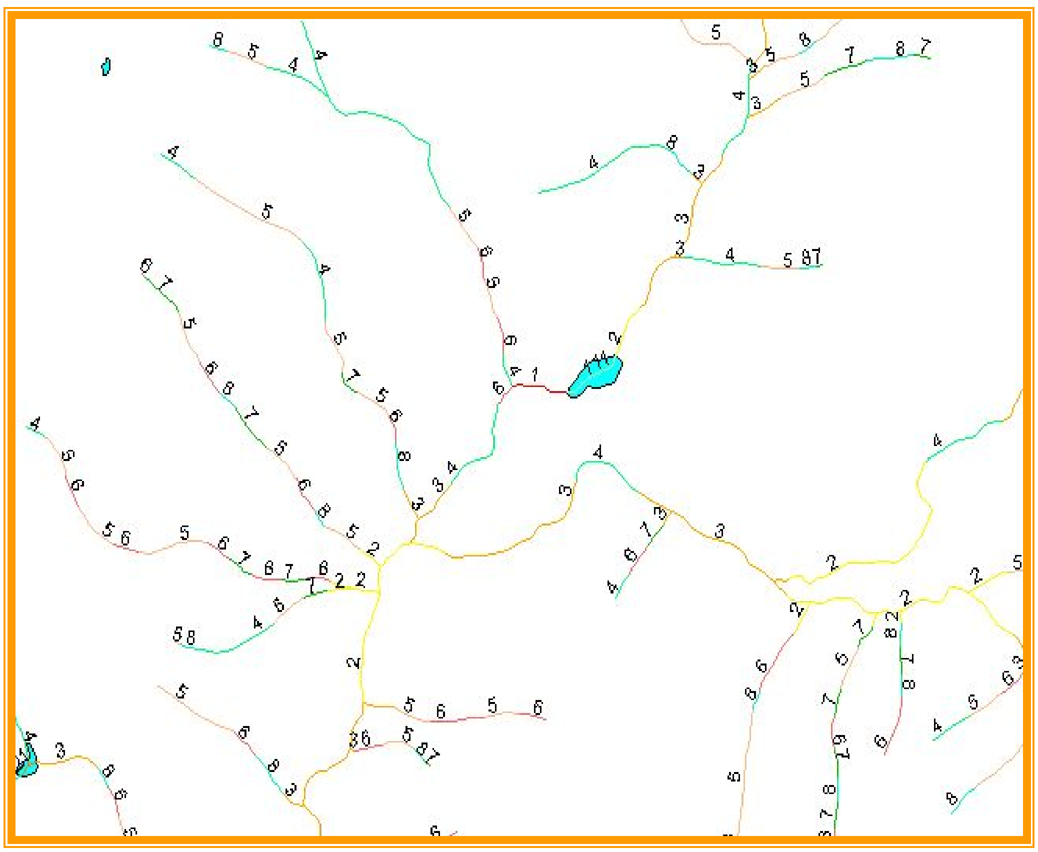
The 1:24,000 scale, cleaned and routed hydrolayer acts as the backbone upon which stream segments are defined. Attribute data are then linked to stream segments. SSHIAP uses an automated routine to segment the stream network into eight gradient classes and five Washington Department of Natural Resource (WDNR) water body types (Table 2, Figure 1). Besides gradient, SSHIAP-generated attributes include channel (segment) length, channel width, channel type (Rosgen), channel confinement, elevation, fish habitat, habitat type (coarse-scale), and flow. Elevation is derived from the WDNR 10-m Digital Elevation Model (DEM), segment lengths are obtained with an automated dynamic segmentation program inside a GIS, and stream width data are estimated from a drainage-area based model. Modeled widths are reported as point values associated with the upstream end of a segment and are based on an average value over the entire length of that segment. Rosgen channel type is determined using the confinement and gradient variables (see above) coupled to a best professional assessment of stream cross-section type

Table 2. Gradient Classes and Water Body Types used in SSHIAP

Gradient Classes	
Class Code	**Gradient Range**
1	0-1%
2	1-2%
3	2-4%
4	4-8%
5	8-12%
6	12-16%
7	16-20%
8	> 20%

Water Body Types	
USGS Water Body Type Code	**Habitat Type**
111	Marsh/Wetland
412	Double Bank Stream
101	Reservoir
421	Lake/Pond
419	Channel

Figure 1. SSHIAP segments as generated with the automated segmentation program and labeled with gradient classes and water body types (see Table 1) from a portion of WRIA 28. Two water body types are displayed in the stream network: a marsh/wetland habitat (111) near the figure center and a lake/pond habitat (421) on lower left edge.



(Figure 2). Fish habitat is predicted based on channel width and gradient derived from guidelines set by Washington Forest Practices Board (WFPB 2000) and Washington Department of Fish and Wildlife's SSHEAR Program (WDFW 2000). The coarse-scale habitat type is assessed from USGS 7.5' topographic quadrangles and aerial photographs (Table 3), and confinement is obtained through qualitative assessment of the pattern of

Figure 2. Channel types used in SSHIAP are adapted from Rosgen (1994).

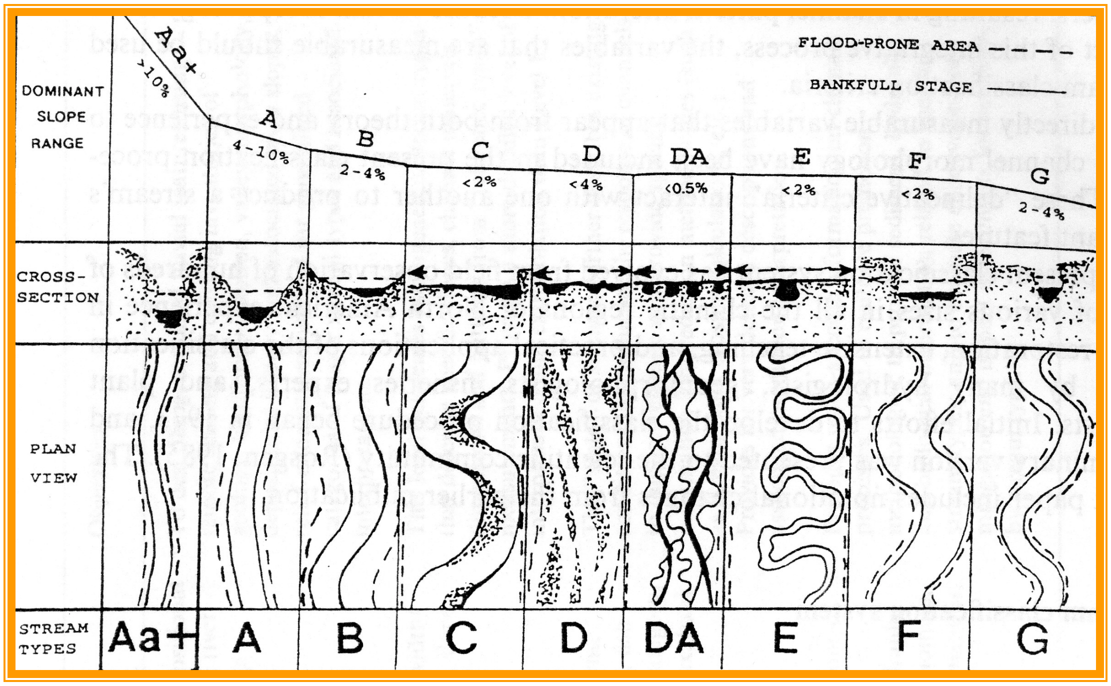


Table 3. Habitat Types (Coarse scale) used in SSHIAP

SSHIAP code	Habitat Type	Description
1	Small Tributary	Stream w/ summer low flow wetted width < 6 m ***OR*** basin area < 23 mi^2 (about half of a USGS 7.5' quad).
2	Large Tributary	Stream/river w/ summer low flow wetted width ≥ 6 m ***OR*** basin area > 23 mi^2.
3	Side Channel	Persistent secondary channel, typically w/ a vegetated island or other landform separating it from the main channel.
4	Side Channel Slough	Channel branching off the mainstem w/ > 90% pools.
5	Distributary Slough	Channel w/ > 90% pools that branch off a mainstem and flow as part of or into an estuary.
6	Lake/Pond	Habitat w/ standing water all year. Shown as unbroken blue on USGS topos; verified with aerial photographs.
7	Wetland/Pond Complex	Wetland w/ associated, perennial surface water pond(s). Blue w/ grass symbols or unbroken blue on USGS topos; verified w/ aerial photographs.

8	Seasonally Flooded Wetland	Ephemeral wetland, often w/ perennial surface water channels; identifiable w/ aerial photographs. White w/ grass symbols on USGS topos.

Based on elevation isopleths relative to the stream channel (Table 4). Flow, like stream width, is modeled using drainage area.

Four core attributes used in SSHIAP are derived from one or more external sources, i.e., SSHIAP personnel do not generate the primary data for these attributes. These include: Fish Distribution, Fish Passage Barriers, Hydromodifications, and Geology (Table 1). Of

Table 4. Confinement Classes used in SSHIAP

Confinement Class	Definition
Unconfined	Floodplain > 4 channel widths
Moderately Confined	Floodplain = 2 to 4 channel widths
Confined	Floodplain < 2 to 4 channel widths

these attributes, geology is the only one derived from a single source, the WDNR geology layer. The three remaining attributes are assembled from at least two external sources, and each requires some manipulation before incorporation into SSHIAP.

The Fish Distribution attribute is based on empirical fish distribution data. These data are derived from 4 sources: (1) *Limiting Factor Analysis* (LFA), a 1:24,000 scale information base from the Washington Conservation Commission that contains presence-only data on anadromous fishes and selected barrier information, both spatially variable in quality; (2) *StreamNet*, a 1:100,000 scale BPA-funded, Pacific States Marine Fisheries Commission-managed database that has barrier-related species-specific anadromous fish and bull trout presence data with spawning and rearing information, and generalized resident fish data; (3) *Area biologists*, who provide point- and reach-specific data on selected fish species; and (4) *Literature* documenting fish distribution. SSHIAP distills data from these sources to categorize distribution as *known*, *presumed*, or *potential* anadromous presence by species. A reliable source with a confirmed sighting of an anadromous fish recorded within the last 20 years tags stream from that the sighting point downstream to the mouth as ***known*** presence. A ***presumed*** assignment is based on the assessment by fish/habitat biologists that the habitat is suitable for a particular fish species according to WFPB (2000) and SSHEAR Program (WDFW 2000) guidelines (Pittman 2001; see Appendix I) and the proximity of a known presence reach. A ***potential*** assignment means that the habitat meets presumed criteria but access to fish is blocked due to human-made barriers (Pittman 2001; Appendix I). The dynamic segmentation aspect of SSHIAP allows a point- or reach-specific query to define affected areas relative to that point or reach.

The Fish Passage Barrier attribute (Figure 3) is similar to the Fish Distribution attribute in that it is assembled from multiple sources of information including: (1) SSHEAR; (2) LFA; (3) StreamNet; (4) Conservation and Public Utility Districts; and (5) SSHIAP-collected data from Area Biologists. Generally, the most substantial dataset is that of SSHEAR, to which data from other sources are appended. However, some Conservation or Public Utility Districts and county-based entities possess barrier data that has greater resolution than that of SSHEAR. However, statewide, this level of resolution is spotty, which results in substantial regional variability in barrier data.

Hydromodifications (hereafter Hydromods) addresses hydrological modifications, which are defined as human-made features that act to alter and/or degrade the natural landscape processes within a watershed, such as bank reinforcement; diking; ditching; non-barrier culverts, dams, and fishways; roads; and engineered habitat restoration projects (Figure 4). Hydromods is the most complex core SSHIAP attribute, in part because more sources are used to assemble the Hydromod data that any other core attribute. Five major sources provide data from which Hydromod data can be extracted: (1) Washington Department of Transportation; (2) WDNR; (3) Counties; (4) SSHEAR;

Figure 3. Existing fish passage barrier sources in WRIA 28 (Washougal River).

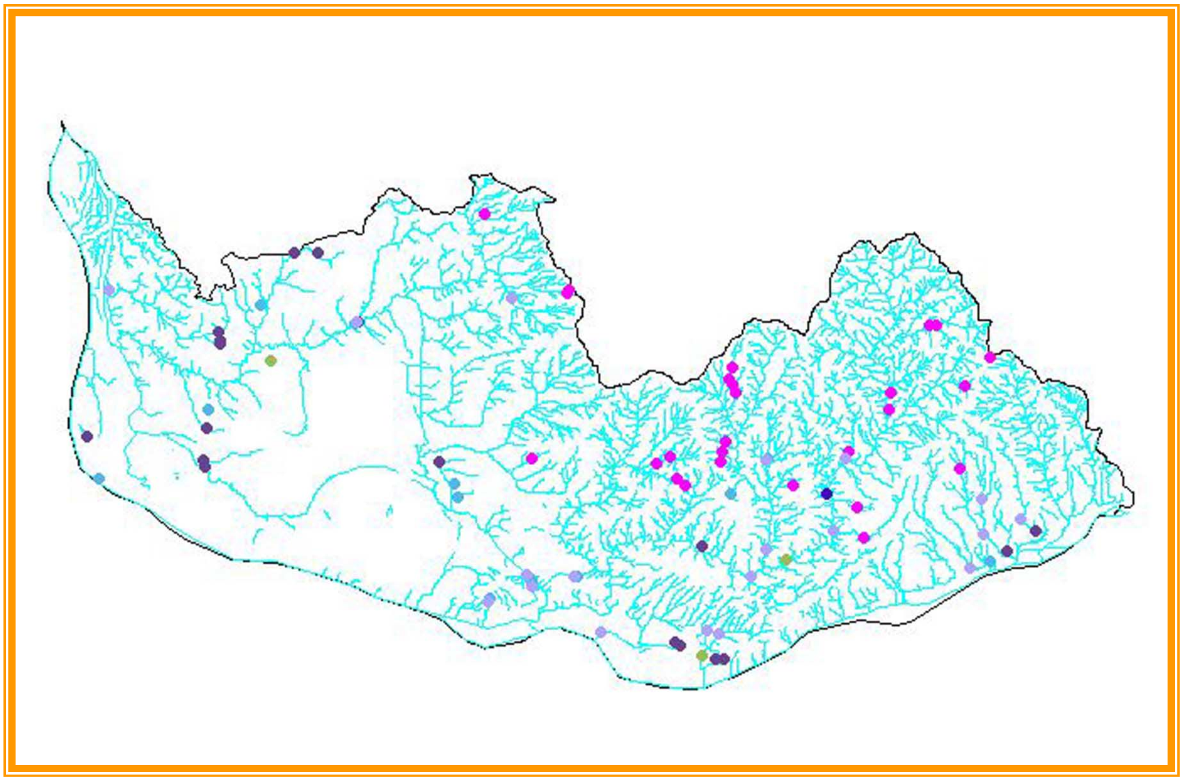
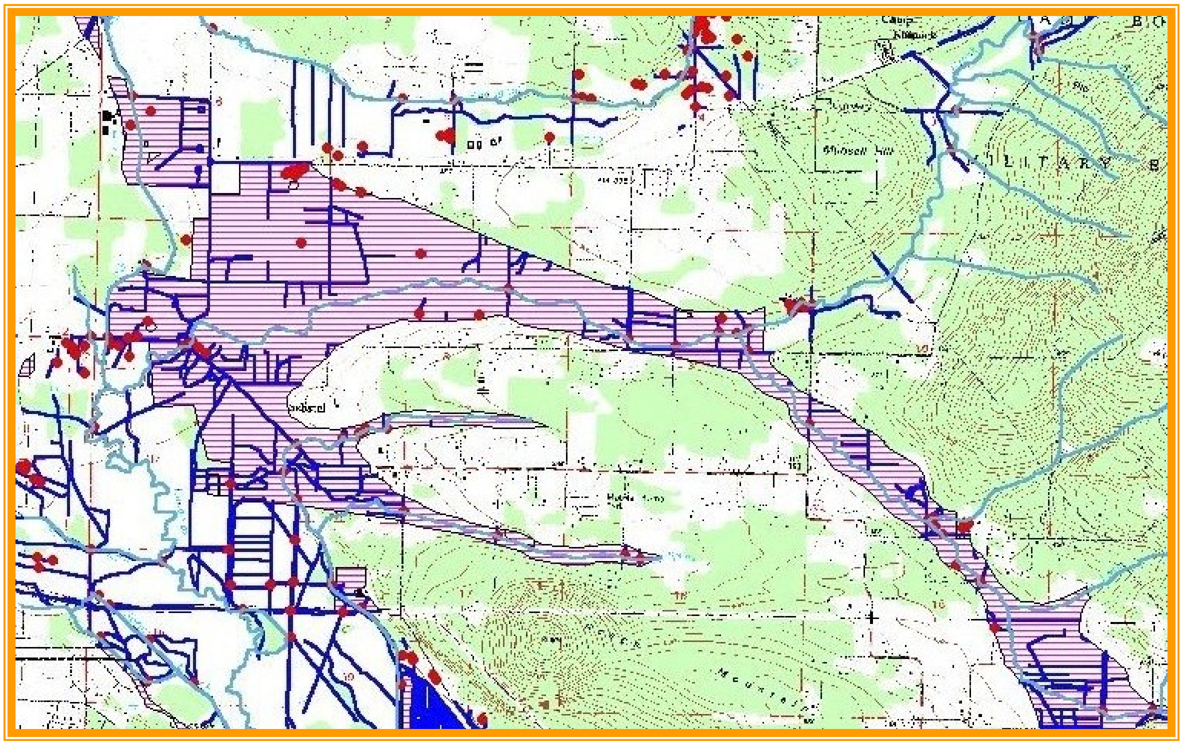


Figure 4. SSHIAP hydromodifications in the Washougal River watershed (WRIA 28). The Hydrolayer is pale blue; point hydromods (bridges, structures, etc.) are red dots; line hydromods (ditches, roads, etc.) are dark blue; and polygon hydromods (populated areas, impoundments, etc.) are purple hatched



and (5) LFA, but several other minor sources exist. Further, no sources from which Hydromod data are derived provide their data in a way that SSHIAP can use it directly. Data representing Hydromods must be individually extracted from each source to construct a Hydromod layer, a process that makes development of the data layer for this attribute more costly than any other attribute or GIS layer. A high source-extraction cost of Hydromod data is the reason development of this attribute, to date, is limited to the low-elevation part of WRIAs. Hydromod data layer is created only for the post-Pleistocene channel meander zone (N. Pittman, WDFW SSHIAP Scientific Lead, pers. comm.). In the future, identification of hydromods are likely to be limited to those requires by EDT.

SSHIAP information is depicted in 7 GIS layers (Table 5). The clean and routed Hydrolayer is the basal layer and has no core attributes directly linked to it. The segment layer has 6 core attributes that describe most features of channel segments. Remaining layers contain information on 1 - 2 attributes.

Table 5. Structure of SSHIAP GIS information system for core attributes

GIS Layer	Linked Core Attributes[1]
1. Hydrolayer (cleaned and routed)	None
2. Segment layer (dynamic segmentation)	1. Channel confinement
	2. Channel gradient
	3. Channel (segment) length
	4. Channel type (Rosgen)
	6. Elevation
	11. Habitat type (Coarse scale)
3. Flow/Width layer	5. Channel width
	10. Flow
4. Fish layer	7. Fish Distribution
	8. Fish Habitat
5. Barrier layer	9. Fish Passage Barriers
6. Hydromod layer	12. Hydromodifications
7. Geology layer	13. Geology/soils

[1] Core attribute numbering follows Table 1.

The vision for SSHIAP is an information system that is accessible to many stakeholders, that provides a starting place (hypotheses) for planning future data collection needs. It is our intent to also provide EDT input variables by reach in the SSHIAP database. This proposal will allow development of SSHIAP for the Columbia Cascadae Province to a user-defined level, i.e., users will be able to query SSHIAP in a point or reach-specific manner. In such a query, data are appended as point- or segment-specific attributes. Refinement and updating of layers are future SSHIAP targets. The existing system assembles data for salmon, steelhead, and sea-run cutthroat; future work could address additional species. Opportunities exist for future development of the SSHIAP to address selected types of landscape changes. For example, programming could be designed to allow the fish distribution to automatically update after removal of a blocking barrier (from the database). Other opportunities exist.

The cleaned and routed hydrolayer in SSHIAP can also act as a backbone upon which users may attach other information (beyond the SSHIAP attributes) that is unique to their own programs or needs. For example, the National Marine Fisheries Service Take Reduction Team for the Lower Columbia Region has adopted the SSHIAP hydro work for use in the Washington portion of their assessment. Current SSHIAP efforts include the linkage of Ecosystem Diagnosis and Treatment (EDT) datasets (up to 43 variables) and displaying EDT model results to the SSHIAP. Results of this effort are expected to provide a clearer picture of stream segments in need of restoration or protection

SSHIAP has application as a recovery tool for anadromous fish. Identification of fish passage barriers within watersheds is among the widely recognized high priorities for the continued existence of anadromous fish species. WDFW is committed to using the best available science in recovery planning efforts for listed species in Washington State.

SSHIAP also has other potential applications. Recent efforts have identified 137 species of vertebrate wildlife with links to salmon (Cederholm et al. 2000). Since SSHIAP will provide the most refined data on landscape-scale (i.e., 1:24,000 scale) distribution for anadromous fishes in most areas of Washington State, further linking of anadromous fish stock status (as from SASSI (WDF and WDW 1993)) to wildlife distributions is expected to provide novel insights into interspecies dynamics.

***ISRP**: The proponents should discuss the quality of existing data and whether they are adequate to support the proposed work.*

***Response**:* Several aspects of SSHIAP address existing data quality and ensure that the information system is a high quality product based on the best available science.

SSHIAP is largely dependent on existing data. That is, that SSHIAP will update available landscape-scale fish data from the old stream catalogues and StreamNet, both of which resolve data at a scale no finer than 1:100,000 and which are often at least 30 years old, with current or near-current data at a 1:24,000 scale. The 1:24,000 scale coverage is a significant improvement over existing landscape-scale aquatic data sets over most of the state. Comparison of the SSHIAP data network (Figure 5a) with that available from StreamNet (Figure 5b) illustrates the improved density and accuracy of data developed in SSHIAP.

Figure 5a. SSHIAP 1:24,000 hydrolayer showing anadromous distribution (as red lines) and fish passage barriers (as red squares) in WRIA 28 (Washougal River watershed).

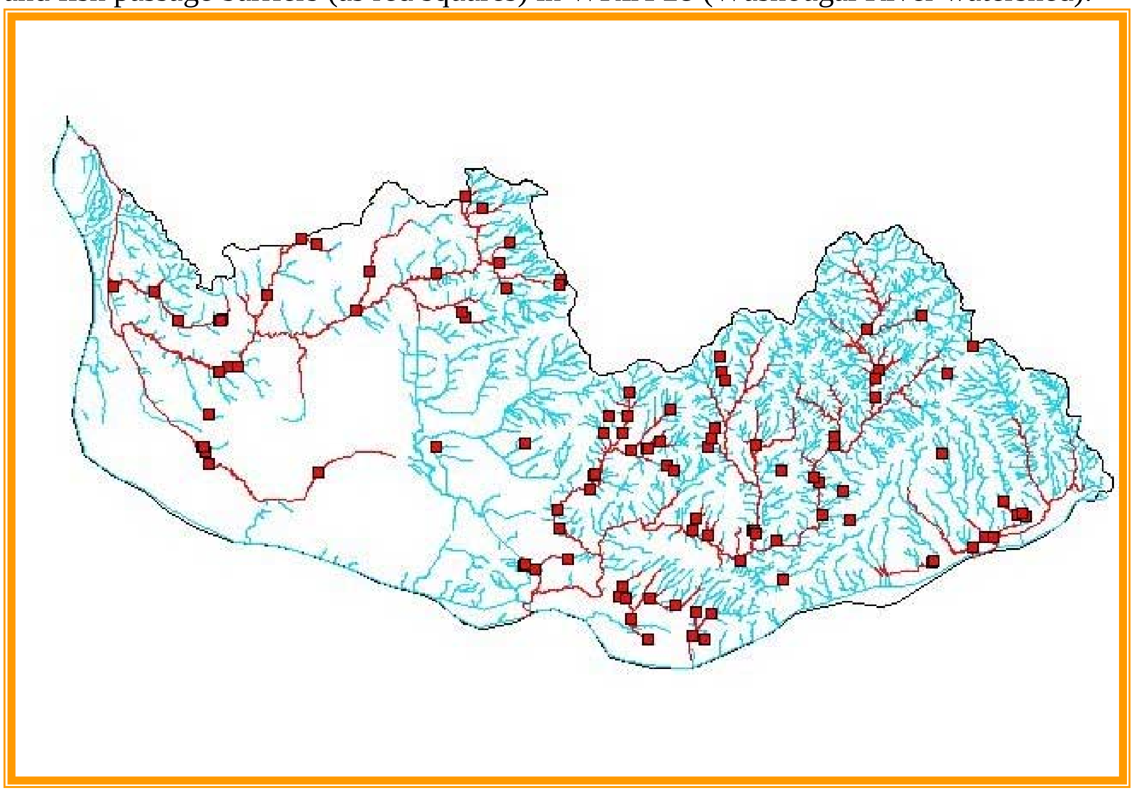
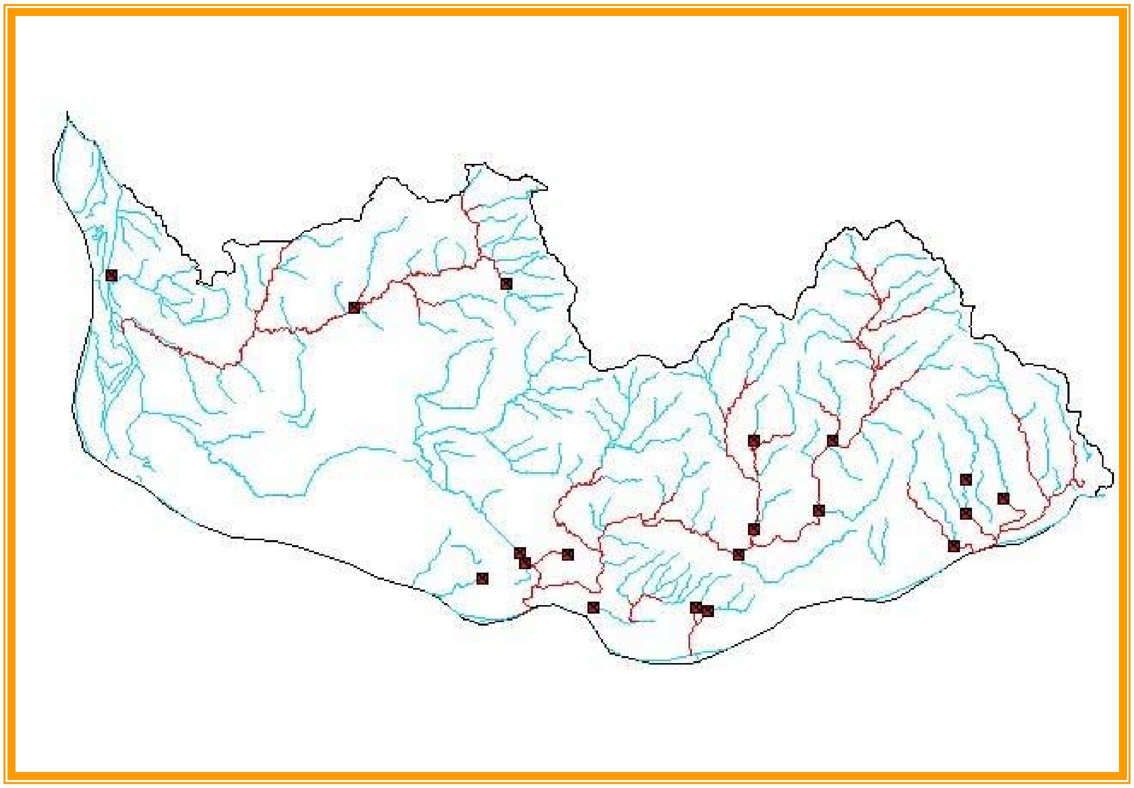


Figure 5b. StreamNet 1:100,000 hydrolayer showing anadromous distribution (as red lines) and fish passage barriers (as black squares) in WRIA 28 (Washougal River watershed).



For some core attributes, SSHIAP assembles and/or synthesizes data from a suite of disparate sources. SSHIAP can augment and refine data for selected attributes to create datasets of a quality greater than partners that contribute data to SSHIAP can provide. Attributes for which assembly and synthesis is important include Fish, Barrier, and Hydromod layers of the SSHIAP matrix (see the previous response addressing these attributes beginning on page 4).

Quality or reliability of data from assembly and synthesis attributes is ensured, in part, because SSHIAP only accepts data from partners that were collected under accepted and often stringent protocols. For example, reliability of the Fish Passage Barriers attribute data from WDFW's SSHEAR Program are based on the fact that data were collected under SSHEAR protocols (see http://www.wa.gov/wdfw/hab/engineer/fishbarr.htm) that ensure such quality.

The assembly and synthesis process can also improve data quality. For attributes in the Fish, Barrier, and Hydromod layers, editing of data errors, additions from unpublished sources, corroboration among sources are an essential part of developing SSHIAP. In some cases, SSHIAP staff has conducted additional fieldwork. For example, in the Lower Columbia Region, SSHIAP staff field assessed some 30 dams for fish passage that had no prior assessment. These were added to both the SSHIAP database and the WDFW SSHEAR database through data pipeline agreements made with that program.

Quality and reliability of data for most attributes (all except fish distribution and geology attributes) is also occasionally verified through ground truthing. Ground truthing was recently begun at two sites, the East Fork Lewis River (WRIA 27) and Salmon Creek (WRIA 28) for the data collected in the Lower Columbia Region. However, it must be recognized that the ground truthing to date has been a volunteer-supported effort. As SSHIAP focus was to structure an information system that has a primary assembles existing data, the SSHIAP budget was not designed to accommodate a ground-truthing effort. The importance of ground truthing the known fish distribution information is fully recognized, but the many spatial and temporal problems of a systematic effort of this kind in which one can have confidence, as has been unequivocally demonstrated with the bull trout detection protocols (Thurow et al. 2001), exceeds the budget requested for SSHIAP.

Quality of the geology attribute is dependent on the quality of the WDNR geology layer, which is used in an unmodified form. WDNR geology represents the best available landscape assessment of geology. As the layer is periodically updated, mostly with more resolute data, the SSHIAP information system will benefit from such revision.

Quality of the core attributes that SSHIAP develops depends on a suite of expert SSHIAP and support personnel that generate data using scientifically rigorous protocols and state-of-the-art GIS computer technology. Fundamental to this enterprise is Martin Hudson (GIS specialist, Fish Program, WDFW), who cleans and routes the Hydrolayer for each WRIA into a database that has dynamic segmentation. The dynamic segmentation data structure, is widely used in the GIS community for referencing biophysical data to stream networks, provides an explicit spatial structure for storing, referencing, and analyzing data for a stream network and its watershed. Further, the dynamic segmentation specification integrates seemingly disparate data into a formal data structure. Once integrated, the data can be stored, updated, and accessed over the long term. By adhering to the segmentation specification, SSHAIP data will be well positioned to adapt to emerging GIS / database technologies (Appendix II). This feature allows identifying the location of any data types from layers that may be superimposed on that network with little effort. The cleaned-and-routed stream network (i.e., Hydrolayer) is segmented on SSHIAP-defined gradient breaks using a 10-m Digital Elevation Model (DEM) (designed by Brian Cosentino, GIS Specialist, Wildlife Management, WDFW; Appendix III). Even with setup time, segmenting the largest, most complex WRIAs requires less than a week. It needs emphasis that the cleaning, routing, and segmenting technology that WDFW uses is superior in the quality of data generated and costs much less (in both time and funding) than older methods that depend on extensive work by hand. Brian McTeague (GIS specialist, Fish Program, WDFW) has been an instrumental GIS liaison, addressing the nuances of linking the cleaned and routed Hydrolayer data that Hudson develops to the various data layers SSHIAP personnel address. Also central in the SSHIAP effort have been the innovative, unique efforts of Ned Pittman, the Scientific Lead for SSHIAP at WDFW. His modeling efforts follow recognized approaches addressing hydraulic geometry based on Dunne and Leopold (1978) and involved additions, modifications, and improvements based on Harman et al. (2001) and BC Fisheries (2001). Steven Anderson, Chris Stearns, and Eva Wilder, all SSHIAP biologists, engaged in diverse SSHIAP tasks, but Wilder was instrumental in data manipulation and organization, Hydromod development and digitizing; Anderson was also important in Hydromod tasks, which as previously note, represent the most costly data to obtain; and Stearns was crucial in researching barrier data.

We have not formally quantified the gradient segment accuracy with field observations or measured the agreement between the computerized channel segments and manual interpretation procedures. Our computerized approach, however, is objective and repeatable. We believe that the eight gradient categories derived from automated GIS techniques (Table 2) or from traditional map interpretation procedures will have varying degree of accuracy as compared against field observation data. There is considerable variation in the natural landscape that is beyond the resolution of 1:24,000-scale data. If we want high gradient accuracy (low commission and omission error) we should be aiming for about three or four gradient categories. However, SSHIAP data is adequate if the goal is to provide rapid, objective, wide-area, reconnaissance-level gradient data.

Approaches and modeling efforts noted here are elements that are part of a complete documentation of the SSHIAP methodology, which is a forthcoming SSHIAP product.

Data for two core attributes used in SSHIAP, elevation and geology, are of high quality when received, and require little or no editing and manipulation. The elevation attribute, which, as noted previously, is derived from the WDNR 10-m DEM, is appended directly to the segment layer as data that can be queried from points on the stream network for which the point-specific data appear in pull-down menus. The geology attribute uses the WDNR geology layer, which is used directly as a layer in the SSHIAP matrix.

The quality of SSHIAP data is high and reflected in the vastly improved ability to delineate stream reaches, which is important analyses, such as the EDT model. Recent comparison of EDT reaches developed using a combination of sources (Washington Stream Catalogues, USGS topographic maps, StreamNet, and input from local biologists) and those developed with SSHIAP has nearly doubled the number of unique reaches for analysis within the Chehalis basin. The basis for this differential is significantly improved barrier information (from SSHEAR, LFA, Conservation and Public Utility Districts, and other miscellaneous sources) and habitat typing (especially from WDNR). These additional reaches reflect, in a large part, important salmonid habitats such as side-channels and beaver ponds as well as other important features to consider such as fish passage barriers (natural and man-made).

ISRP*: Methods for providing meta-data for each of the data sources should be described.*

Response*:* Metadata for each of the data sources from which SSHIAP draws information on an attribute-specific basis are available at the SSHIAP website, which has the address (http://www.wa.gov/wdfw/hab/sshiap/gisdata.htm). Metadata sources are partitioned between the NWIFC, which handles SSHIAP data from drainages around the Puget Sound and the Olympic Peninsula (Bolt Decision region), and the WDFW, which addresses SSHIAP information for the remainder of the state. Systems used for data collection by NWIFC and WDFW differing is part of the reason for this partitioning.

ISRP*: How are errors quantified and what are acceptable error rates for each of the data layers?*

Response*:* Variation in the quality of fish distribution data has already been discussed; proportion of the stream network with *known* fish presence as function of *known* and *presumed* presence provides a coarse-scale (WRIA-level) estimate of data quality. The importance of ground truthing to develop error rates in the classification of fish presence has also already been acknowledged. However, precise estimates of such errors remain outside the practical scope of this project; to reiterate briefly, SSHIAP budget was not designed to accommodate an expensive ground-truthing effort on fish distribution that represents at least one, but more likely several projects. Within existing budget, SSHIAP personnel will assemble an information system that others can hang their data on. It remains for other projects and investigators to address assessment of error for fish distribution information.

Errors for some of the information layers can be addressed. Predicted stream gradient accuracy is fundamentally limited by the resolution of the DEM (elevation accuracy approximately +- 6 meters) and the position of the 1:24000-scale vector hydrography on the digital landscape. Other spatial processing errors enter into the error budget as well. As such, the most likely method to assess the accuracy of the gradient data is to compare the final computerized stream gradients (containing all accumulated error during processing) versus stream reach observations collected in the field. One approach would be to cross reference the observed verses predicted stream reaches in a table and measure the agreement with a Kappa statistic. Cosentino (Appendix III) discusses segmentation-associated error.

Important potential errors in the Flow/Width layer relate to errors in estimating flow or stream width from models developed from hydraulic geometry. Truthing of stream width data has revealed that non-estuarine model estimates of width have errors of < 1%. Flow data from model estimates at known gauge stations is targeted for comparison to gauge data. That calibration has yet to be conducted.

Ground truthing is also being used to verify channel confinement, channel gradient, Rosgen channel type, coarse-scale habitat type, and selected fish passage barriers. As ground truthing was begun this month, the data have not yet been analyzed to provide error estimates for these attributes.

Fish habitat is modeled on gradient and stream width, so is dependent on the error linked to those attributes.

Fish Barrier and Hydromod data are QA/QCed by one SSHIAP biologist verifying that all barriers and hydromods within target region (see page 4) have been digitized from available sources.

WDNR had its own verification system for the geology attribute (layer).

ISRP: *To assist in formulating a sound basin-wide monitoring program, the proponents are referred to the programmatic section of this report on Monitoring, the specific comments on Aquatic Monitoring and Evaluation, and the specific comments on Terrestrial Monitoring and Evaluation.*

The proponents most respectfully interpret that the ISRP, in making the above statement, construed SSHIAP to be a monitoring program. SSHIAP is not a monitoring program, it was designed to be a user friendly information system designed to provide landscape-scale data on anadromous fish distribution in the context of an advanced GIS system that could be queried by users, that users could potentially hang their own data on, and that could evolve or improve as new data and innovations are added to the system.

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Appendix I

11 March 2002 DRAFT

SSHIAP Method for Determining *Presumed* and *Potential* Habitat for Anadromous Salmonids

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Overview*:* Most existing fish distribution data sets reflect the 'known' distribution of salmonids (i.e., documentation of locations of where fish have been seen). It is widely accepted that existing fish distribution inventories are not complete. Examination of fish distribution in combination with related datasets (i.e., hydrology, fish barriers, gradient, channel width) has led to the need for determining and reporting additional *presumed* and *potential* anadromous salmonid habitat. This document offers methods to address the systematic determination of presumed and potential salmonid habitat.

For the purposes of this document, *presumed* and *potential* anadromous salmonid habitat will be determined based upon the following aspects:

1) *Presumed Fish Use Based on Channel Width and Gradient*
2) *Gradient as a Fish Passage Barrier*
3) *Species-specific Stream Gradient Utilization and Passability*
4) *Other Natural and Man-Made Barrier Data*

1. Presumed Fish Use Based on Channel Width and Gradient, as included in the Washington Forest Practices Board (2000). The following reflects methods to determine *presumed* and *potential* salmonid habitat:

Waters presumed to have fish use (WFPB 2000) have the following characteristics:

a. Stream segments having a defined channel of ≥ 2 ft within the bankfull width in Western Washington; or ≥ 3 ft or greater width in Eastern Washington; and having a gradient ≤ 16%.
b. Stream segments having a defined channel of ≥ 2 ft within the bankfull width in Western Washington; or ≥ 3 ft width in Eastern Washington, and having a gradient >16% and ≤ 20%, and > 50 ac in contributing basin size in Western Washington or > 175 acres contributing basin size in Eastern Washington, based on hydrographic boundaries.
c. Ponds or impoundments having a surface area of < 1 ac at seasonal low water and having an outlet to a fish stream.
d. Ponds or impoundments having a surface area > 0.5 ac at seasonal low water.

SSHIAP develops a GIS layer entitled "*presumed fish use*" based upon conditions of category (1a) above. SSHIAP stream-width modeling was based upon approaches outlined by Dunne and Leopold (1978) and Harman et al. (2001). Modeled data was regionally corrected using field data collected by SSHIAP staff during the summer of 2000.

A very strong association exists between anadromous fish distribution and the channel width category of ≥ 4 ft in bankfull width. Thought to be a conservative measure considering the Forest Practice Rules listed above, the SSHIAP methodology uses a 4-ft bankfull channel rule for tributary spawning species. Mainstem spawners (i.e., chinook) will be limited to channels ≥ 10 ft bankfull width, a value that also agrees well with previously known distributions for these species.

2. *Gradient as a Fish Passage Barrier.* SSHIAP will use the following criteria for gradient-based barriers for all fish species throughout eastern Washington watersheds. Gradient Barrier (WDFW 2000):
   a. A sustained gradient > 20% for a distance ≥ 525 feet, or when the channel has a sustained gradient > 16% for a distance ≥ 525 feet *and* a channel width < 2 feet in Western Washington or < 3 feet in Eastern Washington, as measured at the ordinary high water width (i.e., bankfull width as described above).

3. *Species-specific Stream Gradient Utilization and Passability.* SSHIAP will utilize the information in the table below to determine species-specific gradient breaks.

   Expected species utilization (shaded) and passability (vertical lines) for each gradient stratum (WDFW 2000).

Species	Gradient Strata (%)						
	0-1	1-3	3-5	5-7	7-12	12-16	16-20
Chum							
Pink							
Coho							
Sockeye							
Chinook							
Steelhead							
Cutthroat (anadromous)							
Bull Trout[1]							
Trout[2]							

[1] Includes resident and anadromous bull trout/Dolly Varden.
[2] Includes resident rainbow and cutthroat trout.

4. *Other Natural and Man-Made Barrier Data.* SSHIAP will use information from the Salmonid Screening, Habitat Enhancement, and Restoration program (SSHEAR) database and other existing datasets pertaining to culverts to help determine presumed and potential habitat. Existing information such as known fish distribution will also be considered when determining the species-specific passability of fish barriers. When existing datasets do not contain species-specific information to assist the SSHIAP biologist, all habitat above the barrier will be qualified as *potential* for all species until better information can be collected about the specific barrier.

   Details on other natural and man-made barriers:

   a. Natural point barrier (WDFW 2000) – A waterfall > 12.14 ft in vertical height.

b. Culvert barrier (WDFW 2000) – Under this protocol a fish barrier culvert is classified as that which does not pass the lowest common salmonid denominator of either a 6 inch trout or adult chum salmon.
c. Fishway Barrier (WDFW 2000) – similar to approach listed in (b).
d. Dam Barrier (WDFW 2000) – similar to approach listed in (b).

Glossary

Presumed – Habitat appears suitable and accessible for fish use following the methods outlined in this document.

Potential – Habitat that meets the ***presumed*** criteria but is blocked to fish access due to man-made barriers.

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Appendix II

DYNAMIC SEGMENTATION IN GIS DATABASE: MANAGEMENT AND ANALYSIS

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Introduction

During 1995, the Washington Department of Fish & Wildlife (WDFW) explored a possible alternative to fish and wildlife management called Integrated Landscape Management (ILM). The concept was to investigate management resources from an integrated or ecosystem approach rather than by the more traditional individual species approach. In other words, each species is an integrated part of an ecosystem rather than an entity unto its own. It was planned that this concept could be tested for resource management across agency jurisdictions. The test area was in WDFW Region 5, Watershed Resource Inventory Area (WRIA) 27 located in Southwestern Washington State.

To support this initiative from a data perspective, a comprehensive set of Geographic Information System (GIS) layers and database files were compiled for WRIA 27, ranging from the agency's terrestrial Priority Habitat Species (PHS) polygon database to satellite imagery information to salmonid fish distribution. Additional GIS data were acquired from other land management and private agencies. The concept was to support management plan decisions with best available data for WRIA 27. The data were compiled and managed using ArcInfo, GIS software developed by Environmental Systems Research Institute (ESRI). In addition to existing GIS data layers, two pilot projects were conceived using the relatively new approach to linear GIS data management and analysis, the ArcInfo Dynamic Segmentation model for managing linear information in GIS.

The two projects were planned using this technology: a riparian habitat definition database on five Watershed Analysis Units (WAU) within WRIA 27 using Washington Department of Natural Resources (DNR) 1:24,000 scale hydrography (24K) and a WRIA-wide anadromous fish presence project using the Environmental Protection Agency (EPA) 1:100,000 scale river reach layer. Products from the two projects included maps from both, and analysis from the habitat project using the event tables with outside tables containing statistical weighting factors.

This paper will briefly describe three types of GIS methodology currently used for linear features with advantages and disadvantages of each and the 1995 ILM Project and results. Also included is a discussion on dynamic segmentation applications that will be in use at WDFW today and their analytical potential for present and future needs in fish and stream resource and habitat GIS data management and analysis at WDFW.

GIS For Linear Features

Three general approaches exist to linear feature GIS: 1) digitizing separate layers for each theme;

2) a reach-based or line segment relational database with digitized layers such as streams or roads; and 3) a dynamically segmented relational database to line layers such as streams and roads, otherwise known as dynamic segmentation.

The digitized layer approach offers only a means for thematic mapping. This methodology was developed during the early 1980's and is considered the first generation of GIS, referred to during that time as computer mapping. This approach requires that a separate layer be digitized for each theme and was used in very limited situations where permanent data storage and management was not a concern. In a large GIS covering fish presence and habitat for Washington, for example, the number of layers would range in the thousands, one for each species, requiring a very complex tracking system for management and updates. The costs would be high and benefits would be limited to mapping. One digitized layer for each species of fish would be necessary and additional layers would be required for spawning or rearing for each of the fish species. Updates and management would be too cumbersome at this level to be feasible and such a digitized layer system offers no true analytical capabilities.

The early relational database methodology offered a higher level of database management in GIS by allowing attribute information to be stored in a relational database. This added the capability for more advanced management and easier updating, but with only limited analytical capabilities. For mapping, it is less accurate than the digitized layer method because an assigned event such as anadromous fish presence attribute would often appear to extend beyond its actual location. This method was used for the 1:100,000 scale Washington Rivers Information System (WARIS), the first large-scale fish resource GIS for Washington rivers and streams. Its only real advantage over the digitized layer is the significant cost savings in management and update.

Dynamic segmentation offers the mapping advantages of the digitized layer method for fish presence by including the ability to accurately define events such as fish spawning along rivers and streams while adding the benefits of a relational database management environment with versatile analytical capabilities. The ArcInfo dynamic segmentation model is built upon route systems comprising multiple line segments that define a given linear feature such as a highway in a transportation system or a river in a layer of rivers and streams. The dynamic segmentation model can store, display, query and analyze information associated with linear features without modifying the underlying data coordinates, thus, allowing the placement of events independent of the constraints imposed by an individual line segment.

Event tables are the key attribute-information-storage-media for dynamic segmentation. They are related to the layer via a key link and using measures for which the information on an event is desired. A table may contain as few as three records (relate variable, begin measure and end measure) with the table name defining the data type. A more modern construct includes additional records for defining various species and categories of events along with support information such as event length, fish species codes, species names, use type information, stream names and data update dates and sources. The prototype model with event tables compiled at WDFW for ILM and StreamNet contained this additional information and was constructed using a one-to-many relate capability. The tables were also designed so they can be used in outside UNIX or MicroSoft Windows based DBMS software packages.

The Integrated Landscape Management Project

The stream route models developed for ILM were based on a routing hierarchy defined by the pilot project for the Washington Surface Water Information System (WASWIS). This project was developed and completed by Washington Department of Ecology (DOE). In the pilot, named rivers and streams defined the base routes, followed by sets of reaches defining unnamed streams, then by shorter single reach streams. The stream arc direction points downstream while the route measures begin at the mouth and extend up to the headwater point, thus, providing the ability for defining a location in measures that extend up from a river or stream mouth.

After the routes were completed, the problem arose concerning how to create large, complex linear event tables that were to define stream habitat information on the 24K layer and to do this efficiently due to pressing time constraints imposed by the ILM Project. The events could range from less than 100 feet in length to over 500 feet in length, thus, requiring as many as 1000 or more events within each Water Analysis Unit (WAU). The fish component of the project was not as large or complex, consisting only of migration and known rearing and spawning for anadromous species.

The standard ArcInfo method for building event tables within the Arcplot environment was explored as the primary means for completing these tasks. This involved using Arcplot to define locations on a route system and return measures to a global variable, which would then be written to a record in an open event table. A user tool could have been completed to assist in facilitating the effort, but it was decided that this technique would be to tedious due to the cumbersome nature of this approach and that the projects could never be completed within the time constraints. An alternative had to be developed if the deadline was to be met.

Within the Dynamic Segmentation data model, an automated ArcInfo application was available for transferring point layer information to point events. This procedure provided a possible solution, so a decision was made to digitize the habitat change locations as coded points defining each event's upper limits per each given habitat type. Above each point, there would begin a new upstream habitat type defined by the next point. In database or event table terms, these point events would serve as the end measure of the linear event. At that time, no means existed of converting these point data to a linear event table with begin and end measures, only the concept had been defined.

After digitizing one WAU, the task of converting point events to linear events was started. Digitizing on the other four WAUs continued with the assumption that a solution could be developed in the near future using the first WAU as a test model. After building the point event table from the coded point layer, an event table conversion to linear events was necessary. This problem was solved by developing an AML program that added an empty begin measure field to the table then transferred the point measure (ENDMEAS) of downstream event to the upstream event begin measure field (BEGMEAS). This procedure was repeated until the last upstream event measure was complete. The event table was then used for mapping and analysis.

The second or fish presence project added an additional technical twist to compiling linear event tables from point events. For the habitat project, the beginning measure of the downstream most event was assumed to be zero since data were created for all streams in the layer. This assumption would serve as well for anadromous migration since it is assumed that migration includes the entire stream up to an anadromous upper extent. This current technique, however, would not work for spawning and rearing linear events, which more often than not, included only portions of the stream below the upper extent of a given species. This problem was solved by digitizing both down stream and up stream locations of an event with point begin/end codes, along with codes defining event type. Routines developed for the habitat information were modified to meet these additional criteria.

Project Results

Relative to the data provided, a roughly 94% accuracy rate was achieved for the habitat/24K project and near 100% accuracy rate for the anadromous/100K project. This was based on comparing plots of the results to the source maps. Since event table creation was not attempted using the conventional ArcInfo method, a time comparison is not available. However, based on the conclusion of the GIS programmers involved, it was determined that the projects could not have been completed within the two-month time frame if this new methodology had not been developed.

Current Applications at WDFW (1999)

At WDFW, three applications using this methodology have been developed: 1) new database compilation; 2) an update procedure for existing databases; and 3) transfer of event data from one hydro layer to another of a different scale. All fish information for rivers and streams at WDFW is created and updated using applications one and two. A similar application (3) has been tested for transfer of existing data from the 1:100,000 scale reach system to a test model of the new 1:24,000 hydrography layer that is scheduled to be completed during the next two years (2001) by the DNR led Framework hydrography initiative. The applications (1, 2 & 3) also have been integrated into a location independent set of menus and AML programs which allow Arc Users as, well as nonusers, to create and update complex event table information using digitized points.

1. New Database Creation: During 1996-1997, the first dynamic segmentation version of StreamNet was created using these applications developed for the prototype during 1995. Several problems were encountered during prototype development. The first was that defects in the route system were readily detected when the data stream was interrupted by faulty routes. This was corrected by fixing problem routes. The 1:100,000 scale hydrography digital line graphs (DLG) from the United States Geological Survey (USGS) was plagued by stream naming errors, which included misnamed streams and missing names on many short reaches within a named stream such as the Skagit River. Several modifications of the data have been made since and were completed easily once the DLGs and route system was corrected.

One major deficiency in the 1:100,000 scale for routing was that numerous short reaches, often less than 100 feet, were difficult to visually detect and were causing the route disconnect problems. Further, due to the requirement of maintaining the EPA-defined River Reach Code or RRN, an un-split of the reach system was not allowed. Other problems were data streams that tended to travel upstream above the upper most point rather than down, causing difficulty and delays on data entry. This was the result of flipped arcs within the route. The use of these procedures underscored the importance of a clean, error free route system to lay data over. The current status of the DNR 1:24,000 scale layer includes many of the above deficiencies along with additional problems along section and township lines. Routines have been developed to resolve these problems.

When a route system is clean and reliable, the data entry routines are very robust and reliable. Included are quick on-screen check maps that allow the user to monitor progress against the source map without plotting, and quickly return to the procedures if point digitizing contained errors or, more often, omissions due to the inability to "see" the route system at the data entry level. It is a closed loop system that requires the initiation of an exit option by the user. A user can also end work at anytime and restart the system where work had ended, thus, allowing complete user flexibility.

Database creation is used for WDFW fish information, including anadromous fish migration, spawning and rearing, bull trout status, SaSI (Salmonid Stock Inventory) and resident fish presence. During data entry or update, records are continuously pulled and written to the event table containing migration, spawning and rearing during compilation or updates. The final tables include all available information on anadromous species or resident, whichever the case may be. The tables are also designed for use in outside DBMS software such as MicroSoft Access, dBASE, and Paradox.

2. Updates: Procedures for updates are the same as for database creation. The only significant difference is that a tracking variable exists in each record that allows tracking of changes since creation or the last update. When new tables are transferred to the agency database, the tracking variables are set so that later revisions do not required entire database recompilation. All that is required during update procedures is the addition, deletion or movement of points, then re-creation of the temporary table, followed by an append to or a replacement of existing records, depending up on the situation. The new software is designed to make a distinction between a change in a record or records, or an append of new records to the table.

3. Data Transfer: Since WDFW will be eventually transferring the 100K fish resource data to a new 1:24,000 hydrography layer, methodology has been developed to do this with minor effort once the new layer is in place. Tests have been completed on routed prototype 24K layers in the Skagit River basin. Points have a unique distinction of being scale-independent because each is a point on a spatial plane rather than a line described at a given scale. For example, a reach on the upper Skagit River defined at 1:100,000 (100K) scale may be significantly different in length and/or shape (sinuosity) than at the 24K. The point does not change with the exception that the location relative to a linear feature may change. In the majority of cases, this will not affect event table creation due to snap distance defined by the user for the software. What is significant is the linear distance along a stream of a described event. At the 24K scale, the distance may be 50% or more than that of the 100K distance due to sinuosity. The rebuild of event tables, therefore, is enhanced across scales because of the scalability of points.

An additional advantage of points is that data created by outside agencies using conventional event table compilation in Arcplot can also be transferred to WDFW databases if desired. The linear event table can be collapsed to point events that can then be converted to points using commands included with the ArcInfo software. The points are then converted back to linear events using the above procedures. If event tables are from a 100K layer and are to be transferred to 24K, the source layer must be used to create the points to be transferred to the higher 24K scale. Again, the scale-independent advantage of points is used to overcome scale differences. This can also work from 24K to 100K. Points allow freedom in flexibility in the data management of linear events.

The above methodologies for transferring event data have proven to work at WDFW. But there was another methodology considered in IRICC and regional Framework to transfer event tables from layer to layer and across scales. In brief, this method ties the events to an index which would serve as the transfer medium. This index would be similar to an address system used along streets. In use, the address would remain constant on the spatial plane as one transverses up stream from the begin and end address, regardless of scale. This index or address would serve as the scale-independent means of transfer, thus, in theory this would allow WDFW to take a US Forest Service table of the same stream that includes the index and transfer directly to the WDFW layer, regardless of scale. If proven to work with minimal error, this would enhance data transfer between layers.

Questions remained concerning this method of transfer. How does an index that is a measure actually account for the continuous linear differences of the measures between scales as one moves upstream? No constant exists between scales in river measures due to differences in sinuosity, which are constantly inconsistent. It is a technical challenge. At the time, this answer had not been clarified and tests of this theory were planned at WDFW. During the interim, the point method offered the only reliable method for transfer of data between scales and had the added advantage of continuous updates (For data creation and updates, the index or address method will not enhance data updates outside of the point method, a separate concept completely.) This event table transfer would have been valuable for data transfer between agencies.

Note: It has since been proven that this methodology would be too inefficient and unreliable for the reasons stated above. Use of this methodology was dropped from the latest Hydro Framework technical plan (January 2002).

Analytical Capabilities

Analytical capabilities in dynamic segmentation are quite extensive. Numerous event tables could be combined using ArcInfo tools to answer questions on subjects pertaining to fish presence and habitat availability. Relationships could be developed between a number of parameters from permanent event tables storing fish information, in-stream fluvial information and riparian habitat data. Other than the ILM project of 1995, analytical capabilities of dynamic segmentation have not be utilized that extensively to date. Reasons for this primarily revolve around the lack of data concerning fish other than known presence or migration, spawning and rearing in conjunction with funding limits. StreamNet currently is 100% funded by the Bonneville Power Authority and the priorities are data acquisition to fulfill the requirements of the StreamNet work plan.

However, even with this limited information, several questions could be answered. For example where do Coho and Winter Steelhead spawning overlap. Dynamic segmentation provides routines to merge event tables in order to answer the above question. The results can include locations where both Coho and Winter Steelhead spawn, and areas where each spawn outside of the overlap, thus, one has a new event table that defines all Coho and Steelhead spawning and where they overlap. These tables are created using routines provided by ArcInfo, which can be called from AML programs. A well-designed mapping system can then illustrate these findings on a map or the tables can be dumped to an outside DBMS table for statistical analysis with other data concerning these species. Other questions could be as follows:

1. What relationship is there between Steelhead spawning and in-stream substrate, water temperatures and riparian habitat?
2. Where do warm water resident species overlap with Chinook spawning and/or

rearing?

3. Where does anadromous migration by species run through lakes and what species are in those lakes that could affect out migration to the ocean?

Recently, a more comprehensive fish and habitat database known as SSHIAP is being constructed using 24K or greater hydro, but it is still in its early stages of development. Analytical capabilities will be much more significant, for example, presumed and potential anadromous fish presence can be defined using barrier and habitat information provided by the database. With the introduction of SSHIAP data into event tables, perhaps many questions could be answered concerning the interaction of these habitat information with anadromous and resident species using dynamic segmentation and event tables. For the SSHIAP GIS project, the base feature layer will be the 1:24,000 scale DNR hydrography layer called HYDRO.

Database Structure

The Segmentation Data Model has a unique GIS data structure consisting of a three-way internal software *relate* among the line layer arc attribute table (AAT), a route attribute table (RAT), and a section table (SEC). An additional *relate* is assigned by the user when an event table of information, such as fish presence, is compiled or used for mapping and analysis. An event table is structured similar to a DBMS table, but with beginning and ending measures, or positional measures along a routed feature. The route attribute table and section tables take on the name of the layer along with the name of the route system.

The arc attribute table or AAT defines the topological relationships and basic information for a linear feature layer such as one consisting of rivers and streams. This table is the means for the software to track individual features on the spatial plane. For example, this table provides information so that the location of the Skagit River and its individual reach segments can be defined on the spatial plane relative to its tributaries and their reach segments.

One or more records define a river or stream, depending upon the number of reaches required. The Skagit River may have one hundred or more reaches, while several others may have less than ten or may have only one. This table also includes information such as stream name, water type designation and the route key or relate variable. For all Washington river- and stream-based layers, this key variable is LLID. The LLID is a unique 13-character string, based on the Latitude and Longitude of the stream's confluence or mouth. In the case of the Skagit River, the LLID (1223661483874) is identical in both 100K and 24K layers.

The route attribute table or RAT defines the route system in relationship to the layer via internal relates to the SEC and the AAT tables. Each river or stream has one record in the RAT table regardless of the number of reaches defining a given stream. Each record will carry the LLID variable to relate back to the AAT and SEC. The RAT version for SSHIAP contains additional information above the default versions built by the software. For database management purposes, additional external relate variables are included along with basic information pertaining to a stream. This approach provides external management of the database outside of the ArcInfo environment to facilitate processing and reduce run time. A compiled program will run several times faster than accessing the database via the typical GIS graphic management tools, often reducing several minutes of run time to several seconds.

The section table or SEC provides the link between the RAT and the AAT and an even table. This SEC table contains information about the linear layer that provides the means for an event table to define an event along the line feature layer. The SEC contains the key variable (LLID) along with length and positional information about each route constructed on the feature layer. One record exists for each reach in a given route. This information, along with the measures for events defined in an event table, provide the end results such as maps and analytical options. Additional information has also been added to the standard SEC to provide external database management capabilities.

The event table is the keeper of the information about events such as fish presence and/or spawning and rearing. Other information could include in-stream and riparian habitat information. Events are in the form of point occurrences, such as barriers to anadromous fish, or linear, such as known spawning locations. At minimum, the event table must contain the key variable (LLID) and a measure for a point event, or begin and end measures for a linear event. The measures zero position is the beginning of the stream or route. The event table may carry a name that defines its purpose, such as COHOPRES.EVT for coho salmon presence. The event tables for StreamNet and SSHIAP are and will be much more complex, containing a multitude of one to many relates.

Example: In StreamNet, the table that defines or stores anadromous fish contains all species and use-type information. The information is mapped from the table using a multi-level select procedure to bypass the one to many relate situation that ArcInfo has difficulty working with. The table in StreamNet is called ANADROMOUSFISH.EVT. The table also contains other information, such as stream name, and is designed for both GIS and outside DBMS use. A simplified structure of an event table defining anadromous fish information for Fall Chinook (CHFA) and Winter Steelhead (STWI) in the Skagit River could be as follows:

LLID	BEGMEAS	ENDMEAS	SPPCODE	USETYPE
1223661483874	0.00	1897.67	CHFA	3
1223551483874	1897.67	8231.54	CHFA	2
1223551483874	8231.54	12450.95	CHFA	1
1223551483874	12450.95	45899.05	CHFA	2
1223551483874	45899.05	78010.56	CHFA	3
1223551483874	0.00	10887.07	STWI	3
1223551483874	10887.07	12587.87	STWI	2
1223551483874	12578.87	35098.00	STWI	3
1223551483974	35098.00	67009.62	STWI	2
1223551483974	67009.62	89786.55	STWI	1

The above table does not represent real data, but is for illustration purposes only. The most notable aspect of this table is the measures. For an anadromous fish species, the measures run from zero to the maximum distance up stream that fish have been observed. Often a barrier to anadromous fish is encountered at this end measure. When one event ends the next begins, as noted if one follows Fall Chinook up stream. Use-type 1 defines spawning; 2 defines rearing; and 3 defines migration. In reality, the tables are more complex with significantly more information and with events over lapping one another. An event table for StreamNet also includes all streams with anadromous presence within a basin. However, this example serves well for illustrative purposes.

Appendix III

28 September 2001 DRAFT

Automated Segmenting of 1:24,000-Scale Hydrography: A GIS Data Set to Assist Fish Habitat Analysis

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OVERVIEW

Background

The Salmon and Steelhead Habitat Inventory and Analysis Project (SSHIAP) funded the production of this data set. The original extent of this project included Water Resource Inventory Areas (WRIAs) 22 through 62. Additional WRIAs have been added to the project area. As of 25 June 2001, 36 WRIAs have been processed (Table 1).

Purpose

Stream gradient is an important physical element defining fish habitat. The very large project area and limited resources available to this SSHIAP effort precluded field mapping of channel gradient or interpretation of gradient from paper map sources. Therefore, we developed a geographic information system (GIS) methodology capable of rapidly producing stream gradient data over a large area that is consistent with existing manual segmentation techniques used in the Pacific Northwest. As such, the core GIS procedures and algorithms are based on elevation contour interpretation methods.

Stream Segmenting Terminology

Stream "segmenting" implies a different mix of activities (integration of ancillary data, types of interpretation procedures, output map product form, etc.) depending on the organization performing the work. As applied in this project, stream segmenting is the partitioning of streams, as depicted in the digital GIS environment, into sub units based strictly on gradient, water body type, and junction of significant tributaries. Ancillary data such as aerial photography and field observations are not included in the process.

Data Scale and Source

The primary data used in this project were 1:24,000-scale hydrography lines and polygons and DEM. WDNR provided the DEM and raw 1:24,000-scale hydrography data. The GIS processing utilized 10-meter DEM data where available; 30-meter DEMs were integrated in areas without 10-meter DEM coverage.

Error Sources

Manual and automated gradient interpretation methods are subject to similar spatial error sources[1]. Error sources unique to automated gradient processing include:

1) Elevation errors intrinsic to 10-meter and 30-meter DEM,
2) Extraction of elevation grid cell values from DEM grid, and
3) Interpolation of elevation between vertex pairs.

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[1] Washington Department of Fish & Wildlife (WDFW), 2001. *SSHIAP Hydro Preparation Procedures*.

Appropriate Use of the Gradient and Associated Data

The data from this effort are intended to assist the initial classification of stream gradient and to enable the user to quickly stratify broad gradient breaks for a WRIA. Basically, it is expected that the data products will accelerate the laborious and costly manual interpretation process currently employed. While lacking the interpretive nuances that the human interpreter can provide, the final data provide a uniform and objective computation of gradient across all SSHIAP WRIAs.

Data Products

Several spatial and tabular products exist, including ArcInfo vector covers, INFO data tables, and tabular data in text format. All data are organized by WRIA. The spatial data contain attributes for elevation, gradient, water body type, significant tributary, and other descriptors. The spatial data are compatible with the UNIX Arc Version 8.1 Dynamic Segmentation data model. The tabular data mirror the attributes of the ArcInfo vector covers. In addition, data tables are provided which index the connectivity between stream segments. While not fully tested, the index tables should enable the user to analyze the data outside of a GIS environment using a non-spatial database.

Gradient Classes

The user can group raw gradients into their own gradient categories if desired. SSHIAP specified particular gradient classes (see Table 2).

Data Accuracy

Formal measures of accuracy of the output data have not performed as yet. It is anticipated that accuracy will be tested against field data. In addition, the agreement between manual and automated gradient processing may be of interest.

Future Work

As funding permits, the current work may be extended for the tasks below:

1) Complete hydro processing for SSHIAP WRIAs
2) Reprocess WRIA gradients generated from 30-meter DEM using 10-meter DEM
3) Perform accuracy/agreement analysis
4) Develop valley confinement attributes
5) Improve elevation/gradient interpretation algorithm
6) Improve data input/output efficiency

Table 1: Gradient Processing Status June 2001

WRIA	DEM SOURCE	PROCESSED
1	10	NO
2	10	Y
3	10	NO
4	10	NO
5	10	NO
6	10	Y
7	10	NO
8	10	NO
9	10	NO
10	10	NO
11	10	NO
12	10	NO
13	10	Y
14	10	NO
15	10	NO
16	10	NO
17	10	NO
18	10	NO
19	10	NO
20	10	Y
21	10	NO
22	10	Y
23	10	Y
24	10	Y
25	10	Y
26	10	Y
27	10	Y
28	10	Y
29	10/30	Y
30	10/30	Y
31	30	Y
32	10/30	Y
33	30	Y
34	30	Y
35	10/30	NO
36	30	NO
37	10/30	NO
38	10	Y
39	10/30	Y
40	30	NO
41	30	NO
42	30	NO
43	30	NO
44	10/30	NO
45	10	Y
46	10	Y
47	10	NO
48	10	Y
49	10/30	Y
50	10/30	Y
51	10/30	Y
52	10/30	Y
53	30	Y
54	30	Y
55	10/30	Y
56	30	Y
57	30	Y
58	10/30	Y
59	10/30	Y
60	10	Y
61	10	Y
62	10	Y

SPATIAL DATA PROCESSING

Technical Approach

The automated gradient computation and segmentation methods developed from this project capture the rudiments of map-based manual stream typing typically performed in the Pacific Northwest. Manual techniques require the visual interpretation of contour lines, water bodies, and other features on 1:24,000-scale hard copy maps. One of the first steps the interpreter performs is the counting of elevation contour lines along a stream as depicted on the map. Moving upstream, the interpreter "breaks" the stream into gradient class segments based on prescribed gradient categories. Automation of segment "lumping" and "splitting" rules – secondary procedures that generalize channel segments based on criteria such as minimum segment length and number of contour intervals[2] – was not included as a formal data product.

Technical Implementation

The automation of manual segmenting methods may appear straightforward, however, one quickly finds the data volume requirements are substantial (e.g., 2.9 million data points, 480,000 lines) and that considerable cross indexing and measurement are required between the base data types (i.e., hydro line, vertex-elevation, and water body type). Arc AML was used primarily for data preparation and generation of the final Dynamic Segmentation covers and tables. Gradient/segment processing was developed using C programming. C provides tools for building highly flexible data structures and functions that can be linked efficiently using pointers. Likewise, the dynamic memory allocation functionality of the compiled C code enabled all work to run in very fast computer memory. The programs were developed and tested in Microsoft C. An open source (GNU) C compiler was used to generate executable C code on a Solaris operating system. Production was accomplished in the UNIX environment.

Automated Segmenting Overview

Description of Primary Data. The primary input data are 1:24,000-scale hydro lines, selected water body features (see Table 2), and 1:24,000-scale DEMs in Arc/Info/Grid format. All input and output data are in the State Plane South coordinate system and are cast on the North American Datum of 1927 (NAD27).

Base Data Processing. Prior to automated segmenting, several critical procedures are required to prepare the input hydro data[1]. The raw 1:24,000-scale hydro line and polygon coverage for each WRIA is extracted from the spatial database. The hydro cover arcs are edited where necessary. Arcs are set to point down stream. Interior centerlines within water body features are added when needed to complete connectivity of the line layer. Each stream receives a unique route ID number. C code was developed to scan a routed hydro cover and detect breaks. After the breaks are fixed, another C program is used to

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[2] For manual stream segmentation concepts and methods see:
Pleus, A.E. and D. Shuett-Hames. 1998. *TFW Monitoring Program methods manual for stream segment identification*. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-98-011. DNR #103. May.

Washington Department of Fish & Wildllife, 2000. *Salmon and Steelhead Habitat Inventory and Assessment Project, Standard Approach and Methodology*.

rapidly generate Arc/Info-compatible route and section table data. Once these procedures are complete, the final routed hydro cover and associated Dynamic Segmentation data are ready for the segmenting process.

Extraction of Elevation Data. Elevation data were extracted from GRID Fill-processed 10-meter DEM grid cell data for each vertex in the hydro line cover. Vertices are spaced approximately 10 meters or less, therefore, channel elevation is nominally sampled every 10 meters. Thirty-meter DEM data were used for WRIAs with incomplete 10-meter DEM coverage. The elevation extraction step is a point-on-grid cell procedure using ARC GRID SAMPLE functionality.

Contour/Gradient Computation. Contour/gradient computation is accomplished in two passes. The first pass partitions the input hydro lines into pseudo 40-foot contour-based segments. For each route, the vertex elevation is scanned going up the route. If the upper vertex elevation equals or passes through one standard 40-foot contour interval, a segment break is initiated. The location of the break (i.e., the estimated standard 40-foot contour interval) is dependent on a simple interpolation between the lower vertex and the upper vertex. The second pass breaks the contour segments based on water body type or junction with a significant tributary.

Water Body Processing. Water body feature segment breaks are defined at the start and end of a water body type. All arcs falling within a water body type are attributed with the appropriate WDNR polygon feature code. Water body types 101,111,421, and 419 are forced to a flat gradient (class C1). The user may note a possible mismatch between gradient class and the computed gradient.

Tributary Status. Additional processing breaks segments at locations where a significant tributary joins a segment. A significant tributary must have at least one of the following attributes to force a segment break:

- Stream name present
- Stream present in 1:100,000-scale hydro
- Stream has a WDNR Water Type code 1,2,3,4,or 5

The output data contain an attribute (TRIBSTAT) listing tributary status (0,1). Significant tributary breaks are not applied to Lake/Pond and Reservoir water body types.

Delete Status. A delete status (DELSTAT) attribute (0,1) is generated based on the following criteria:

- Tributary status is false
- Channel length is less than 2000 feet
- Channel does not have a tributary
- Channel is dominated by segments exceeding 20% gradient

Arcs are not deleted from the output data during segment processing. The DELSTAT attribute is provided so that users can delete arcs at their discretion.

Down Route Gradient. Each route is checked to determine if it has a connecting route down stream. If a down route exist, then the initial segment gradient class is modified if two conditions are satisfied:

- The connecting down route segment has a lower gradient class
- The connecting down route segment has a gradient <= 12%

If the conditions are both true, then the bottom segment of the route gets the down route gradient class (GCLASS0)

Grouped Gradient Class. An additional procedure is applied to the final segment data in which identical adjacent gradient class (GCLASS0) or water body type (WB) are grouped into one segment. These data are provided in a separate Dynamic Segmentation data table and Arc/Info cover.

Connectivity Index Tables. Two tables index connectivity between routes and individual segments. A route-level table lists the down and up routes (if they exist) for each route within a WRIA. A segment-level table lists up-routes (if they exists) for each segment along a route. The segment-level tables list up-route ID numbers and distance-to-junction (arc distance in feet) above the base of a stream. Connectivity data can be related with the segment covers/data tables using route number, reach number, and other keys.

DATABASE FILES, TEXT FILES, AND ARC COVERS
An informal listing and description is provided below addressing data output file types and attributes, raw text file data, and AML/C processing.

INFO Data Files
Two INFO event table data files are provided: GEOSEG.EVT and GEOSEG2.EVT.
GEOSEG.EVT contains non-grouped segments.
GEOSEG2.EVT contains the grouped segments.

Event table columns:
ROUTENUM = SSHIAP defined unique route ID number
REACHNUM = sequentially numbered segment number relative to the base of the route
FROM = from length (feet)
TO = to length (feet)
FELEV = from elevation (integer feet)
TELEV = to elevation (integer feet)
GRAD = gradient percent
SN = stream name flag (0,1)
WB = WNDR Waterbody type
GCLASS0 = SSHIAP gradient class
GCLASS2 = grouped SSHIAP gradient class
DELSTAT = delete status flag (0,1)
STS = tributary status internal segment break flag
TRIBSTAT = tributary status flag (0,1)

Text Format Data Files
Two connectivity index tables are provided: routeconnect.txt and reachconnect.txt.
reachconnect.txt columns:
route number
reach number
up route number 1
up route number 2
measure from route base

routeconnect.txt columns:
route number
number of segments
tributary status
up route 1
up route 2
up route 3
down route 1
down route 2
down route 3

ARC/INFO Covers
Two Arc/Info line covers are provided: GRADHYDRO and GRADHYDRO2. These covers were generated using EVENTARC, therefore the attributes are identical to their respective event tables. GRADHYDRO contains the primary segments. GRADHYDRO2 contains the "grouped" segments. Arc shape files are not generated as part of this project.

UNIX Processing Specific to WDFW
Processing AMLs are located at /data*

AML processing in order:
1. prepdem.aml
2. getlines.aml
3. genpoints.aml
4. gensegments.aml
5. buildevent.aml
6. buildindex.aml
7. zipfiles.aml
8. killgisdata.aml

The initial master routed hydro cover used at the start of processing is
/data*.

WRIA gradient processing files and final output data located at the current WRIA work area = /data*.

C programs are located on /data*
hydseg.h
addfeature.c
convertformat.c
linklist.c
buildrteindex.c
dhead.c
pointprocess2.c
classifysegs.c
genlinearevt.c
hydrogradient.c
lineprocess.c

Input/Output Files Generated During AML/C Processing
linedata.txt
sample0.txt
sample1.txt
pointdata0.txt
pointdata.txt
elevation.txt
hydrogradient.txt
arcroutedata.txt
contour_evttab.txt
group_contour_evttab.txt
reachconnect.txt
routeconnect.txt

AML Descriptions

prepdem.aml:
Extracts a grid bounded by the current WRIA boundary, plus an extra buffer, from the WDNR statewide elevation grid. Initial grid is WDEM. This grid is resampled to a 33-foot cell size. The GRID program FILL is used to fill sinks in the initial DEM.
Final output grid=FILLDEM.

getlines.aml:
Generates primary line data and line attributes used in subsequent C programs for building line and point data structures. Arc line data provide topology (fnode, tnode), route identifier, line identifier, water body type, and other attributes. Subsequent C programs link stream vertex data (x, y, elevation) using route and line identifiers.

Final output file dumped from hydro-water body IDENTITY = linedata.txt
Input file contains arc attributes for:
MARSHLAND=111,
STREAM=412,
RESERVOIR=101,
LAKEPOND=421,
CHANNEL=419

Notes:
-Copies SSHIAP final routed hydro.
-Creates constant ARC ID attribute called ORGID.
-Selects WATERBODY TYPES in {101,111,412,419,421}
-Performs ARC IDENTITY between hydro.aat and selected waterbodies.
-Generates basin area and assigns to each arc. Basin area is not accumulated downstream. Basin area is currently not used in any processing, but can be integrated if need arises.
-ARC RENODE performed
-ARC DENSIFY performed to 33 feet
-hydro.aat arcs are AE FLIPPED to point upstream
-unloads to linedata.txt:
ROUTENUM: SSHIAP route number
ORGID: constant arc ID value after ARC IDENTITY
COV#:
FNODE#:
TNODE#:
LENGTH:
BODYTYPE: selected WDNR water body types.
BACRES: estimated basin area acres (not accumulated)
WATERTYPE: WDNR Water Type Codes (1-9)
STRNFLG: 100k stream name flag (0,1)
SRCFLG: 100k hydro presence flag (0,1)

genpoints.aml:
Uses ARC UNGENERATE to build the primary list of line lengths and vertices for the hydro coverage. Initial line cover arcs point upstream. The C program convertformat.c is called to reformat the UNGENERATE text file hydroidx.ung into a point file format acceptable to GRID SAMPLE. GRID SAMPLE provided with input file pointdata0.txt.

Output file sample1.txt from SAMPLE modified using dehead.c. Output files are pointdata0.txt, pointdata.txt, and elevation.txt.

Notes:
-performs IDEDIT
-performs UNGENERATE on hydro-waterbody IDENTITY cover
-performs GRID SAMPLE using vertex data and the grid FILLDEM.
-calls C program CONVERTFORMAT
-calls C program DHEAD
-reads hydroidx.ung (convertformat.c)
-reads pointdata0.txt (convertformat.c)
-final coordinate file columns in pointdata.txt are ORGID XCOORD YCOORD
-final elevation file = elevation.txt = ELEVATION

gensegments.aml:
This is where segmenting is performed. Compiles and runs the primary driver C program **hydrogradient.c**. Two command line arguments are required for hydrogradient.c. The args are WRIA number and tribstatus option.

Notes:
One header file and five C source code files are compiled with the driver program.
hydseg.h: contains the primary point, line, event structure, and enumeration declarations.

lineprocess.c: builds line data structure, arranges route arcs in upstream order, builds pointers between routes and segments; unloads data to hydgradient.txt; prints log file.

pointprocess.c: reads pointdata.txt, elevation.txt; builds point data structure, links vertex coordinates/elevation with route/segment and direction; generates raw 40-foot contour breaks.

addfeature.c: inserts selected water body breaks into the initial contour break segments. Inserts segment breaks at significant tributary junctions. Elevations recalculated at new breaks. Sets Boolean tributary status attribute. Tributary breaks can be forced at nearly all stream junctions or at selected junctions based on conditional criteria. Tributary status is selected on hydrogradient.c command line.

linklist.c: very limited linked list utilities for point data structure generation**.**

classifysegs.c: sets SSHIAP gradient class breaks**;** sets Boolean attribute for delete status

buildevent.aml:
This is where the ARC-compatible final event tables and line covers are generated.
Compiles and runs genlinearevent.c
Reads hydrogradient.txt.

Final event tables are GEOSEG.EVT and GEOSEG2.EVT.
Final output text files = contour_evttab.txt, groupcontour_evttab.txt
The contour_evttab.txt file is an event table format containing measures for all segments. The group_contour_evttab.txt is an event table format containing measures for grouped segments. If adjacent segments along a route have the same SSHIAP gradient class or WB, then the segments are combined into one segment. Measures and elevations are updated accordingly. GCLASS2 contains grouped gradient class or WB.

Notes:

EVENTARC is run on geoseg1.evt (GCLASS0) to generate the line cover gradhydro1.
EVENTARC is run on geoseg2.evt (GCLASS2) to generate the line cover gradhydro2.

Event table columns:
ROUTENUM = SSHIAP routenum
REACHNUM = sequential segment number from route base to end
FROM: from measure
TO: to measure
FELEV: from elevation (integer feet)
TELEV: to elevation (integer feet)
GRAD: gradient percent
SN = stream name flag (0,1)
WB = WDNR Waterbody type
GCLASS0 = SSHIAP gradient class
GCLASS2 = grouped SSHIAP gradient class
DELSTAT = delete status flag (0,1)
STS = tributary status segment break flag
TRIBSTAT = tributary status flag (0,1)

Output text columns for contour_evttab.txt are
RTE# SEG# LEN NUMSEGS FELEV TELEV WB SN GRAD GCLASS0 GCLASS2 DS STS TS
Output text columns for contour_evttab.txt are the same.

RTE# = Routenum#
SEG# = Segment# = ORGID from HYDROIDX(hydro-waterbody ARC IDENTITY)
LEN = Length
NUMSEGS = Number of gradient segments
FELEV = from elevation (integer feet)
TELEV = to elevation (integer feet)
WB = WDNR waterbody type
SN = stream name flag
GRAD = percent gradient
GCLASS0 = SSHIAP gradient class
GCLASS2 = grouped SSHIAP gradient class
DS = delete status flag
STS = significant junction break processing attribute
TS = tributary status flag

buildindex.aml
Produces two tables that can be used to determine connectivity between interior line arcs and other routes and connectivity between routes. *Grouped segments are not used in this processing*. This AML compiles and calls the buildrouteindex.c.

buildrouteindex.c: reads arcroutedata.txt and contour_evttable.txt; builds route/segment pointers; measures distances for all stream junctions above base of current route. Output files = reachconnect.txt and routeconnect.txt

Notes:
Routed hydro AE FLIPPED to point upstream.
Performs Arc UNGENERATE on SSHIAP routed hydro cover to create arcroutedata.txt.

Output file columns: reachconnect.txt
route number
reach number
up route number 1
up route number 2
measure from route base

routeconnect.txt columns:
route number
number of segments
tributary status
up route 1
up route 2
up route 3
down route 1
down route 2
down route 3

zipfiles.aml
gzips all textfiles in ../ws/wria

killgisdata.aml
Kills intermediate grids and covers.