Informational Reference Guide:
Ecosystem Diagnosis Treatment and Life Cycle Models

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Contents

BACKGROUND AND PURPOSE

Two computer models are being developed to provide information on how habitat conditions affect salmon populations of Spring Chinook, Fall Chinook, coho, and steelhead in the Chehalis Basin, the Ecosystem Diagnosis and Treatment (EDT) Model and the Life Cycle Model (LCM). These models are intended to provide quantitative and qualitative assessments of: (1) how changes in stream environments from pre-settlement conditions have affected salmon (i.e., *"what's been broken"*); and (2) how actions under consideration for the Aquatic Species Restoration Plan (ASRP) as part of the Chehalis Basin Strategy would be expected to affect salmon in the future (i.e., *"what actions hold the most promise for fixing what's been broken"*).

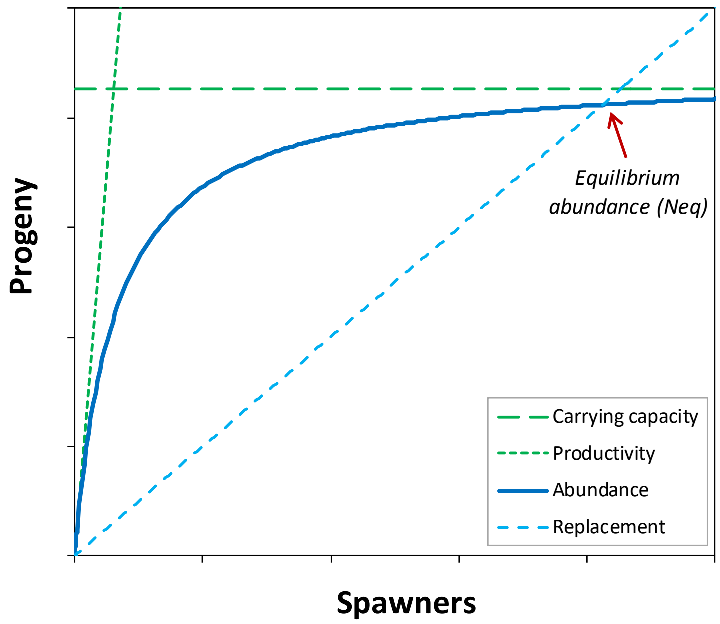
The purpose of this guide is to provide a high-level topical summary to help the Science Review Team (SRT) understand, contrast, compare, and interpret results produced by EDT and LCM.

This document was reviewed by Chip McConnaha (ICF) and Tim Beechie (NOAA Fisheries) prior to its distribution. Their comments were incorporated into this document.

FUNDAMENTALS – BEVERTON-HOLT RELATIONSHIP:

Both EDT and LCM rely heavily on the Beverton-Holt (B-H) Stock-Recruitment relationship (Figure 1), which provides a theoretical framework for describing salmon population dynamics in terms of two parameters representing productivity and capacity. The general form of B-H relationship is asymptotic with production per spawner incrementally decreasing as populations approach a limit. The shape of the relationship is determined by the quality and quantity of habitats that support a salmon population throughout its life cycle.

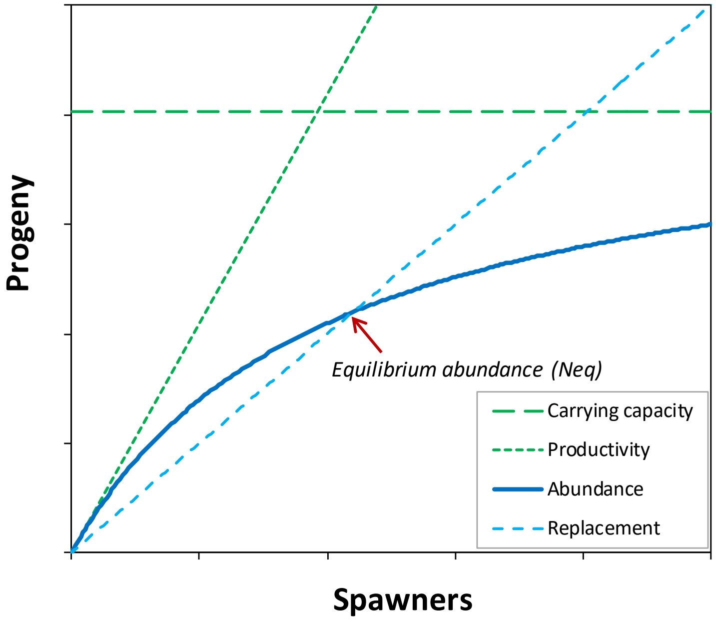
Fig. 1. Stock-Recruitment Relationship



Two parameters determine the shape of the B-H production curve. The <u>productivity</u> parameter is the slope of the relationship at low spawner density, representing the intrinsic production of the population that would occur in the absence of any competition for resources; this is an extremely important parameter that reflects the capability of the population to withstand stresses like environmental variability or harvest. Capacity is the asymptotic limit for the size of the population as a result of limited resources like food and living space. The difference between the solid blue line and the diagonal replacement line is called surplus over replacement and it represents the size of potentially sustainable harvest.

Surplus over replacement also has important meaning for conservation and restoration planning. The greater the surplus over replacement, the more capability the population has to respond to short-term disturbances to the system, such as floods, droughts, heat waves, and downturns in marine survival. The amount of surplus over replacement is affected by both productivity and capacity, but productivity determines how "flat" the curve is, that is, how close the curve gets to the replacement line on its ascending limb. Figure 2 shows the B-H curve with a much reduced productivity value, which flattens the curve. The flatter the curve is to the replacement line, the more likely the population will be adversely affected by floods, climate change trends, and overharvest. In other words, the amount of surplus over replacement, and how flat the curve is relative to the replacement line, is an indicator of resilience in the population to stressors.

Fig. 2. Relationship with reduced productivity



Populations with low productivity are at higher risk of extinction than populations with higher productivity. And populations with high productivity will rebound more quickly following a major disturbance, such as a flood.

Both parameters can be defined by the habitat characteristics of the river system. The productivity parameter is determined by the quality of habitat, i.e., those aspects of habitat that the population does not compete for; for example, water temperature, fine sediment within spawning gravels, and the distribution and occurrence of refugia habitats (affecting the ability of individuals to find these habitats). The capacity parameter is determined by the quantity of habitat in combination with the quality of those habitats. Living space and food, and their quality, are the determinants of capacity.

Considering how habitat characteristics affect the two parameters begs the question: What is habitat? Most simply, it is the environment from the perspective of a specific species. It is a subset of all environmental conditions that provide for occupancy, survival, and at the appropriate time, reproduction by a given species. It is the sum of all of the resources needed by that species, which include food, cover, space, and any special factors needed for survival and reproduction. These factors include chemical properties (e.g., oxygen) and temperature, among others. From the eyes of the focal species, it includes other interacting species, notably predators and competitors. All of these factors comprise the habitat of a given species.

The B-H curve indicates where the population would tend to stabilize numerically in the absence of harvest, i.e., where the curve crosses the replacement line. This point, called the equilibrium spawner abundance (Neq), is the result of both the productivity and capacity parameters. Both the EDT and LCM models produce estimates of Neq for each population being modeled under different habitat scenarios. Both models also estimate productivity and capacity for each population and scenario being modeled. These model outputs (Neq abundance, productivity, and capacity) are metrics by which we describe what we call population performance.

The models are used to evaluate the performance of salmon and steelhead spawner aggregations within each subbasin of the Chehalis River basin. We refer to these spawner aggregations as “populations” for the sake of the modeling, though we do not mean they are distinct populations genetically.

NOAA relies upon the concept of a viable salmonid population to guide assessment and recovery under the Endangered Species Act (ESA). A viable salmonid population (VSP) is defined as an independent population[1] “of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100- year time frame.“ NOAA employs a VSP framework consisting of four parameters: abundance, intrinsic productivity[2], population spatial structure, and diversity. These four parameters are often referred to as the VSP parameters.

The models provide information for all four of these parameters, and therefore, are helpful for evaluating VSP characteristics for populations, or groups of populations, at different scales within the river basin. (It is noted that neither model makes any assumptions about what constitutes truly independent populations in the Chehalis basin consistent with the NOAA definition; in fact, no analysis has been done by anyone to draw these distinctions within the river basin.) It would be more accurate to refer to these populations as “spawning aggregations”—we use “population” here for convenience and simplicity.

The terms “Neq abundance”[3] and “productivity” as applied in the models are consistent with their application in the VSP framework. Neither EDT nor LCM incorporate concepts of minimum viable population sizes or the smallest number of individuals capable of persisting at a specific statistical probability level for a selected amount of time, see also the Allee Effect https://conservationbytes.com/2008/12/22/classics-the-allee-effect/. A population viability analysis, requiring specific types of models, is used to assess extinction risks of small populations.

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[1] / An independent population is defined as a collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period are not substantially altered by exchanges of individuals with other populations.

[2] / Intrinsic productivity is equal to the productivity parameter as defined in this document (see McElhaney et al. 2000). NOAA also uses another parameter called “population growth rate”, often calling it productivity, instead of intrinsic productivity, to define VSPs. The terms intrinsic productivity and population growth rate are closely related (McElhany et al. 2000).

[3] / Neq is roughly equivalent to abundance as used in the VSP framework—it differs in that it is a modeled estimate of a steady-state equilibrium abundance as opposed to a time series of empirical abundance values.

The other two terms used in the VSP framework, “spatial structure” and “diversity”, are very closely related and address how a population adapts and distributes among the many diverse habitats across a large geographic area such as a watershed. At the scale of the entire Chehalis basin, or the eleven Ecological Regions (ERs) within the basin, both spatial structure and diversity are important to population performance. To simplify the discussion here, we refer to both of these concepts together simply as “diversity.”

Although the term diversity in biology can have different definitions and uses (e.g., life history diversity and genetic diversity), here it refers to the number, or percentage, of populations within the basin or an ER that we would consider to be robust, that is, having both sufficient productivity and Neq abundance to be resilient to existing and future stressors. At a minimum then, diversity represents the proportion of the populations represented by a reported group with productivities >1 and with some minimum Neq abundance.[4] An objective of the ASRP is to have high diversity within the aggregate population structure for a species at the basin and ER scales, meaning here that a relatively high percentage of the populations are robust. In this sense, overall resilience and sustainability are increased with high diversity. (The term diversity also considers how the EDT model uses it later in this document.)

For Viable Salmonid Populations, NOAA identifies diversity within and between populations as being important because “In a spatially and temporally varying environment, there are three general reasons why diversity is important for species and population viability. First, diversity allows a species to use a wider array of environments than they could without it. Second, diversity protects a species against short-term spatial and temporal changes in the environment. Third, genetic diversity provides the raw material for surviving long-term environmental change.”

EDT AND LCM DO NOT INCLUDE:

EDT and LCM are designed to focus on certain relationships between naturally-produced salmon and freshwater habitats. Consequently, the models only partially consider or entirely do not consider the following in how they are currently configured:

- Harvest by marine or freshwater fisheries.

  Both models can incorporate a constant harvest rate but neither has been configured to do so for their analyses of baseline conditions and restoration scenarios. The LCM is also capable of incorporating a variable harvest rate. It should be recognized that harvest has an important effect on population productivity when measured using spawners returning to the spawning grounds.

- Hatchery-wild interactions within a given species.

  The EDT model partially takes into account interactions with hatchery released fish through some competition and potential for increased disease effects due to hatchery releases. The LCM does not incorporate these effects. Neither model addresses possible loss of genetic fitness due to interbreeding with hatchery fish.

- Inter species interactions

  The EDT model partially takes into account assumed adverse competition with other fish species as a function of species richness in the stream system and introduction of exotic fish species, though

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[4] / We note that application of the Chehalis EDT model uses both spatial structure and diversity terms. Spatial structure is identified as the number of subbasin populations with Neq >50. Diversity refers to within a population (i.e., within a subbasin) the percentage of life history trajectories with productivity >1.

this is done using a very generalized relationship. The model assumes an increase in predation due to invasive species as a function of the number of invasive fish species present; this also is done in a very generalized manner. The LCM does not incorporate these effects.

- Stochasticity or trends in freshwater environmental conditions

  Neither model as currently configured considers stochasticity (random environmental effects) in freshwater conditions or trends in conditions. Both models assume constant, or steady-state, conditions over a period of years to estimate Neq abundance. The LCM has the capability of incorporating stochasticity for marine survival, and for certain freshwater conditions such as annual variation in peak flow. For the LCM analysis in their Phase 1 report, steady-state conditions were used for simplicity, so that the effect of various habitat relationships on population performance was more obvious.

- Effects of estuarine conditions and variability in estuarine/marine survival

  Neither model considers the significant alterations that have occurred to the estuarine system of the Chehalis basin as a result urbanization, industrialization, and dredging and filling of the harbor and shorelines. Also, neither model considers the effects of variability in estuarine/marine survival or possible trends in that survival rate, although as mentioned above, the LCM has the capability of incorporating variable marine survival rates. It is noted that the amount of variability that can occur in marine survival rates can overwhelm the portion of the life cycle that occurs in freshwater—driving overall life cycle productivity to extremely low levels, potentially threatening population viability.

MODEL COMPARISONS:

Documentation

Documentation

	EDT	LCM
General description	Blair, Greg & Mobrand, Lars & Lestelle, Lawrence. (2009). The Ecosystem Diagnosis and Treatment Model: A Tool for Assessing Salmonid Performance Potential Based on Habitat Conditions.	NA
Chehalis Configuration	McConnaha, W., et al. 2017. Analysis of Salmonid Habitat Potential to Support the Chehalis Basin Programmatic Environmental Impact Statement.	Beechie, T. et. al. 2020. Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-cycle Model. Phase I Project Report. February 2020.

Populations Represented

Populations Represented	
EDT	**LCM**
Populations in EDT are geographically defined spawning aggregations represented by groups of life history trajectories. EDT populations in the ASRP are delineated by subbasins within the Chehalis basin. Subbasins are independent watersheds that flow to the mainstem Chehalis River or to Grays Harbor. The mainstem Chehalis River is also segmented into several subbasins. The populations are then defined as the spawner aggregations that spawn in each of those subbasins.	Populations are defined in the same manner as in the EDT model. Subbasins are also delineated in the same way as in EDT.

Stream Reach Delineation & Geometry

Stream reach delineation and geometry	
EDT	**LCM**
EDT employs geospatial data in the National Hydrography Dataset (NHD, maintained by USGS) for configuring the stream reach system for the model; Stream reaches used by salmon and steelhead are delineated based on a combination of tributary confluences and geomorphic characteristics; reach lengths are derived in GIS from the NHD coverage; wetted channel widths in the tributaries are based on recent and older data sets collected through various studies; channel width in the mainstem Chehalis River is derived from a HEC-RAS model.	LCM employs the same geospatial data as used in EDT; the overall stream system configuration is the same as in EDT. The entirety of the stream system is delineated into 200 m reaches for the sake of GIS analysis of attributes used in the model. Current wetted channel widths are from ICF and are the same as in EDT.

Life Stages

Life Stages Modeled

Fall Chinook		Spring Chinook	
EDT	**LCM**	**EDT**	**LCM**
Spawning	Spawning	Spawning	Spawning
Egg incubation	Egg incubation	Egg incubation	Egg incubation
Fry colonization	Fry colonization	Fry colonization	Fry colonization
0-age transient rearing	Fry migration	0-age transient rearing	Fry migration
0-age resident rearing	0-age natal basin rearing	0-age resident rearing	0-age natal basin rearing
0-age migrant	0-age mainstem rearing	0-age migrant	0-age mainstem rearing
0-age inactive	Delta-bay rearing	0-age inactive	Delta-bay rearing
1-age resident rearing	Ocean rearing (age 2-5)	1-age resident rearing	Ocean rearing (age 2-5)
1-age migrant	Prespawner	1-age migrant	Prespawner
Ocean rearing (age 1-5)		Ocean rearing (age 1-5)	
Migrant prespawner		Migrant prespawner	
Holding prespawner		Holding prespawner	

Coho		Steelhead	
EDT	**LCM**	**EDT**	**LCM**
Spawning	Spawning	Spawning	Spawners/eggs
Egg incubation	Egg incubation	Egg incubation	Emergent Fry
Fry colonization	Fry colonization	Fry colonization	Fry
0-age resident rearing	0-age summer rearing in natal basin	0-age resident rearing	Age 0+ summer rearing
0-age migrant	0-age summer rearing in mainstem	0-age migrant	Age 1 winter rearing in natal basin
0-age inactive	1-age winter rearing in natal basin	0-age inactive	Age 1 winter rearing in mainstem
1-age inactive	1-age winter rearing in mainstem	1-age resident rearing	Age 1+ summer rearing in natal basin
1-age resident rearing	Delta-bay rearing	1-age migrant	Age 1+ summer rearing in mainstem
1-age migrant	Ocean rearing (age 2-3)	1-age inactive	Age 2 winter rearing in natal basin
Ocean rearing (age 1-2)	Prespawner	2+-age resident rearing	Age 2 winter rearing in mainstem
Migrant prespawner		2+-age migrant	Age 2+ summer rearing in natal basin
Holding prespawner		2+-age inactive	Age 2+ summer rearing in mainstem
		Migrant prespawner	Age 3 winter rearing in natal basin
		Holding prespawner	Age 3 winter rearing in mainstem
			Delta-bay rearing
			Ocean rearing (Age 3-7 Adults)
			Kelt ocean rearing

How B-H Parameters Are Estimated

How Population B-H Parameters are Estimated	
EDT	**LCM**
The basic approach is that population performance parameters are calculated directly from Moussalli-Hilborn disaggregated B-H equations. Stream-reach and life stage specific capacity (as densities) and productivities are assessed based on habitat relationships and habitat characterizations (see below). Life history trajectories (pathways in space and time that simulate how a species utilizes the stream system during its life cycle) are randomly generated (many thousands) to "sample" the environment consistent with known	The basic approach steps through the sequence of life stages for the species, beginning with the spawner to egg life stage, advancing surviving progeny through all life stages in the life cycle to produce the number of surviving adult spawners returning to the subbasin of origin. This is done for each subbasin's population. Stream-reach and life-stage specific capacity (area x densities) and productivities are assessed based on habitat relationships and habitat characterizations (see below). These life-stage

life history patterns. Trajectories are initiated across the entirety of spawning distribution assumed to have occurred historically (or expanded to account for where passage has been created past waterfalls). Each trajectory spans the entire life cycle of the species. Calculations are made of cumulative capacity and cumulative productivity at important life stage changes (such as smolt and return from the ocean) based on disaggregation B-H methods. Steady-state end of life productivity, capacity, and Neq values are then calculated directly for each trajectory based on Moussalli & Hilborn equations. All trajectory parameter estimates are then "rolled-up" (grouped) to compute population specific values using a procedure of weighting individual trajectory results. Trajectories are grouped for each subbasin to produce the population-level parameter values.	specific values for all stream reaches in a subbasin are averaged to produce estimates of average life-stage capacities and productivities for each subbasin. Moussalli-Hilborn disaggregated B-H concepts are employed to incorporate effects of habitat quality on life stage specific capacities. Modeling of a species' life cycle is done by stepping through the life cycle for each life stage beginning with eggs deposited within the each subbasin. Fish are moved downstream from the subbasin consistent with a set of rules for the progression of how fish are expected to move into the mainstem Chehalis River, then into the estuary, the ocean, and back. Populations are modeled independently over successive generations as progeny produced by spawners experience habitat conditions in different environments, undergoing different life stages until they return as spawners. Productivities are estimated from the number of returning spawners produced at very low parent spawner levels (recruits per spawner). Returning spawners are estimated for each generation over 100 generations. The spawners produced after 100 generations represent the Neq value. Capacity is estimated from B-H formulas using the estimates of productivity and Neq.

Relationships Between Habitat Conditions and B-H Parameters

Relationships Between Habitat Conditions and B-H Parameters	
EDT	**LCM**
Survival factors are computed in the model from a set of defined environmental attributes (approximately 45 attributes) that affect these factors by species and life stage. The relationships between these attributes and the survival factors are defined in the model by rules, which are based on scientific literature and relevant studies. The EDT rules are configured to adjust a set of species lifestage-specific productivity and density (capacity) benchmarks to reflect the modeled scenario in a stream. The represent hypotheses about the relative sensitivities of lifestages to underlying habitat characteristics that are applied in all streams. Benchmarks are assumed optimal or ideal environmental conditions for the species	Life stage maximum densities (capacities) and productivity survival values by species are defined in the model based on available information from rivers in the Pacific Northwest where relevant studies have been done. Habitat attributes are assumed to affect these density and productivity values, and functional relationships between habitat conditions and density or productivity are used in the model to modify life-stage parameters, based on available scientific literature and relevant studies (Beechie, T. et. al. Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-cycle Model. Phase I Project Report. February 2020).

and life stage. (Lestelle, L., Mobrand, L. & McConnaha, W. 2004. Information Structure of Ecosystem Diagnosis and Treatment (EDT) and Habitat Rating Rules for Chinook Salmon, Coho Salmon, and Steelhead Trout.) Reach-specific or subbasin-specific survival factor results are available on request.	Reach-specific habitat attributes, and subbasin-specific life-stage parameters and model outputs (Neq, productivity, and capacity), are available on request.
Survival factors • Channel stability • Chemicals (toxicants) • Competition with hatchery fish • Competition with other species • Flow • Food • Habitat diversity • Harassment (poaching) • Key habitat (physical habitat quantity) • Obstructions (barriers) • Oxygen • Pathogens • Predation • Sediment load • Temperature • Water withdrawals (entrainment) The EDT survival factors are computed from rules for individual attributes. For example, Habitat Diversity is computed from relationships for gradient, riparian function, large wood and natural and artificial confinement. These component relationships provide a precise definition of the Survival Factors.	Habitat attributes • Migration barriers • Fine sediment in spawning gravels • Wood abundance change in small streams and large rivers • Shade (temperature) changes in small streams and large rivers • Bank armor in large rivers • Large river channel straightening • Beaver pond changes in small streams • Floodplain habitat change (including side channels, ponds, marshes, and lakes) • Wood abundance and floodplain habitat change combined • Peak flow effect (feature turned off currently) • Impervious surface area (for current and future condition) • Change in low flow (for future condition)
Note about EDT survival factors: The names of some factors differ somewhat among EDT documents over the years.	

Data Sources

Data Sources		
	EDT	**LCM**
Historical Conditions	Inferences from historical maps and notes; aerial imagery of landforms, stream channels, and relict channels; available information on historical land cover; see Mobrand Biometrics	Historical maps and notes for floodplain habitats (see Beechie et al. 2020) Contemporary reference site data for riparian condition, effects of

	(2003) and McConnaha et al. (2017).	wood on habitat conditions, and main-channel and side-channel length (see Beechie et al. 2020). Models for fine sediment, beaver pond area, and stream temperature change (see Beechie et al. 2020).
Current Conditions	A variety of information sources described in Mobrand Biometrics (2003) and McConnaha et al. (2017). Agreed-on culvert database used by co-managers applied. Culvert database, fine sediment data, current water temperatures, and mainstem Chehalis channel geometry are the same as in the LCM.	A variety of information sources described in Beechie et al. (2020). Agreed-on culvert database used by co-managers applied. Culvert database, fine sediment data, current water temperatures, and mainstem Chehalis channel geometry are the same as in EDT.
Restoration Conditions	Restoration action or future conditions in the Chehalis basin were incorporated into EDT by adjusting current reach-level conditions using a combination of scientific effectiveness of types of actions and intensity of implementation of the specific actions. Effectiveness is a scientifically based hypothesis describing the relationship between types of restoration action (e.g placement of engineered log jams) and EDT attributes that describe the maximum theoretical control of the action type on the attribute. Effectiveness hypotheses for the Chehalis process have been developed by expert panels convened under the SRT. To evaluate a specific proposed action (including climate change), effectiveness was adjusted by the Intensity of a proposed action applied at a specific location. Intensity incorporates feasibility, cost, extent and location of a specific action.	Distribution and intensity of restoration actions derived in SRT discussions applied; effectiveness of actions based on assumptions made by SRT as part of ASRP planning. Future shade and temperature based on modeled tree growth from current condition into the future. Climate change futures based on Isaak et al. 2017 (temperature) and Mauger et al. 2016 (flows).
Major uncertainties	• Historical conditions, particularly regarding water temperature,	• Historical conditions, particularly regarding water temperature,

	meso-habitat composition, fine sediment load, spawning distribution of spring Chinook, fall Chinook, and chum. • Bed scour in all model reaches—it is incorporated in the model based on aggregate hypotheses of other EDT attributes (e.g. gradient, confinement, riparian) but has not been systematically measured in the Chehalis basin. • Fine sediment conditions in all model reaches. • Differences in estuarine survival conditions between historical and current condition and effects of estuarine habitat degradation. • Upstream migration and holding patterns (timing and distribution) of adult spring Chinook. • Effects of hybridization of spring and fall Chinook on population productivity of both run-types (this is not included in the model). • Effects of exotic fishes (e.g., bass) on juvenile salmon in the mainstem Chehalis River. • Effects of hatchery fish outplanting practices on natural population productivity. • Uncertainties exist to varying degrees for the various habitat relationships and rules applied in EDT—many of these relationships are based on theoretical considerations and inferences from studies around the Pacific Northwest. The rules have been reviewed in various ways over the past 20 years and they are still regarded as appropriate and relevant.	meso-habitat composition, fine sediment load, spawning distribution of spring Chinook, fall Chinook, and chum. • Bed scour effects—not included Phase 1 model. Redd scour as a function of peak flow is evaluated separately with the model for Phase 2. • Differences in estuarine survival conditions between historical and current condition and effects of estuarine habitat degradation. • Upstream migration and holding patterns (timing and distribution) of adult spring Chinook. • Effects of hybridization of spring and fall Chinook on population productivity of both run-types (this is not included in the model). • Effects of exotic fishes (e.g., bass) on juvenile salmon in the mainstem Chehalis River (this is not included in the model) • Effects of hatchery fish outplanting practices on natural population productivity (this is not included in the model). • Effects of wood abundance on bed scour have not been included in the model due to a lack of empirical data in the river basin. • All of the fish density and survival data used to parameterize the model are from other studies in the Pacific Northwest, and some of these studies were on ESA-listed species in rivers that have been altered to various degrees. The modelers have tried to account for this in how the parameter values were selected. The

		modeling subgroup did review most of these parameter values and they are generally regarded as being reasonable when compared to the available scientific literature.

Assumptions and Relationships

Assumptions and Relationships		
	EDT	**LCM**
Species and Life Stage	McConnaha, W., et al. 2017. Analysis of Salmonid Habitat Potential to Support the Chehalis Basin Programmatic Environmental Impact Statement.	Beechie, T. et. al. Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-cycle Model. Phase I Project Report. February 2020.
Climate Change	Climate change hypotheses were developed for EDT by the SRT. They describe expected change in a number of EDT attributes but primarily summer water temperature and winter and summer flow and channel width. Future water temperature in the mainstem Chehalis River reaches was derived from the PSU model developed for DOE. Tributary temperatures came from WDFW Thermalscape estimates adjusted for the future using the NorWeST climate change predictions. Future flow and channel width were derived from HEC-RAS. Other attributes were adjusted as described in the SRT hypothesis.	Stream temperature increase based on Isaak et al. 2017. Low flow decrease based on Mauger et al. 2016. Peak flow increase based on Mauger et al. 2016.

Calibration and Validation

Calibration & Validation	
EDT	**LCM**
EDT models the effect of freshwater habitat on salmon populations along numerous life-history	All parameters are from relevant empirical studies, except delta-bay productivity which is back-

trajectories. We apply a set of multipliers (marine survival multipliers) to the freshwater performance to complete the estuarine and marine life stages of the trajectories. The multipliers account for survival from juveniles leaving the system to adult return (SAR) as well as calibration of the model. The marine survival multipliers for the Chehalis are based on SAR values developed by DFW and comparison of the EDT projected abundance to DFW estimates of adult returns to the basin. Marine survival multipliers ("Juvenile to Adult Survival") used in EDT for All Populations are as follows: Spring Chinook: 5.4% Fall Chinook: 2.7% Coho: 14.5% Steelhead: 29.5% Note that these values are <u>not</u> SARs but are multipliers that incorporate both SARs and calibration to DFW abundance estimates. These values are in need of re-examination in EDT. The values for Coho and steelhead in particularly are likely too high and should be examined. A step in this is to ensure that the Juvenile to Adult Survival reported in EDT is comparable to the DFW SAR estimates.	calculated as SAR (estimate from WDFW) divided by ocean survival (values from literature) There is no calibration, but model outputs are compared to recent run size estimates to gage accuracy. Smolt to adult survival rate (SAR) values being used by species: Spring Chinook: • Fry migrants: 0.033% • Parr migrants: 2.05% • Weighted combined: 0.43% Fall Chinook: • Fry migrants: 0.19% • Parr migrants: 1.96% • Weighted combined: 0.43% Coho: 4.0% Steelhead: 8.0%
Note from Lestelle and Morishima: It appears that the calibration being referred to above is meant to achieve an outcome for run sizes returning to the Chehalis basin from the ocean or to the spawning grounds, at least for some species. It is unclear how fish intercepted by fisheries, particularly ocean fisheries, are accounted for in this since the model does not account for harvest, either in the ocean or freshwater. For example, no estimates exist for marine catch of Chehalis spring Chinook, though it is expected to be substantial.	Note from Lestelle and Morishima: It is not clear what is meant in the above text that states "model outputs are compared to recent run size estimates to gage accuracy". It would seem that this is referring to estimates of run sizes returning to either the Chehalis basin or to the spawning grounds since that is the data that was provided to the modelers by WDFW. It is unclear how fish intercepted by fisheries, particularly ocean fisheries, are accounted for in this since the model does not account for harvest. For example, no estimates exist for marine catch of Chehalis spring Chinook, though it is expected to be substantial.

Results

Results		
	EDT	**LCM**
B-H productivity and capacity parameters for Chehalis Basin	Neq abundance values for the Chehalis basin are available in the ASRP Phase 1 report (ASRP Steering Committee, November 2019). Estimates of productivity, capacity, and EDT diversity values for the basin are available upon request (contact Laura McMullen, ICF)	Estimates of Neq abundance, productivity, and capacity are provided in the Phase 1 completion report. Beechie, T. et. al. Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-cycle Model. Phase I Project Report. February 2020.
Subbasin	Estimates of productivity, capacity, and EDT diversity values for the subbasins and Ecological Regions are available upon request (contact Laura McMullen)____	Estimates of Neq abundance, productivity, and capacity are available on request from detailed output.
Resolution	The modeling approach using life cycle trajectories as explained above allows for a hierarchical examination of modeling results for all of the population performance parameters, from the entire river basin at the largest scale, then to ecological regions, geospatial units (GSUs), and finally to the individual reach scale. (GSUs are a smaller scale than subbasin and consist of collections of connected reaches.)	The modeling approach employed produces population performance parameters for three scales: entire river basin, ecological region, and subbasin.

Restoration Response

EDT and LCM produce different results in terms of the magnitude of population response to environmental change. Basin-wide results are summarized below. There are significant differences among populations; detailed information for each subbasin and Ecological Region is available by examination of output files (available from each model's lead person).

EDT results are evaluated through what EDT calls "survival factors." These factors encompass one or more environmental attributes in the model and are essentially synonymous with limiting factors. The analysis was done by replacing the environmental attributes that comprise the survival factor with the historical condition values, leaving all other factors set to the current condition, and then assessing the percentage increase in population performance through the model. The result serves as a quantitative limiting factors analysis and provides a way of answering the question "*what's broken in the river basin*."

EDT basin-wide restoration potential results. Percentage Change in Neq. Ranking in (1=largest change)				
Survival Factor	Spring Chinook	Fall Chinook	Coho	Steelhead
All factors combined (basin restored to historical condition)	2400%	127%	400%	223%
Obstructions	0% (12)	2% (8)	10% (4)	12% (3)
Sediment	10% (8)	8% (5)	10% (4)	5% (7)
Habitat Diversity	56% (3)	10% (3)	47% (1)	28% (1)
Temperature	200% (1)	3% (7)	24% (3)	18% (2)
Channel form	9% (10)	4% (6)	8% (6)	4% (9)
Predation	10% (8)	2% (8)	8% (6)	7% (6)
Flow	13% (7)	2% (8)	8% (6)	8% (4)
Hatcheries	3% (11)	1% (12)	1% (12)	0% (12)
Pathogens	31% (4)	2% (8)	3% (10)	4% (9)
Length	17% (5)	9% (4)	3% (10)	1% (11)
Width	16% (6)	13% (2)	7% (9)	5% (7)
Key Habitat	77% (2)	49% (1)	27% (2)	8% (4)
Note: Percentage change with all factors combined includes several other factors besides those listed that have small effects on overall Neq.				

LCM results are evaluated through what are referred to as diagnostic scenarios. Nine diagnostic scenarios were defined to determine which types of habitat changes most limit rebuilding salmon populations within the Chehalis Basin, and how those limitations vary by subbasin. This intent of this analysis was to help identify types of key restoration actions for the populations. The diagnostic scenarios were analyzed by setting one habitat component at a time to historical conditions and leaving the other components set to current conditions. The result is a type of quantitative limiting factors analysis. The table below shows the percentage increase in population Neq by changing the habitat component listed.

There are significant differences in modeling results among populations; detailed information for each subbasin and Ecological Region is available by examination of output files.

LCM basin-wide restoration potential results Percentage Change in Neq (Rank 1=highest)				
Diagnostic scenario	Spring Chinook	Fall Chinook	Coho	Steelhead
All scenarios combined	243%	113%	337%	86%
No barriers	0% (9)	2% (7)	9% (7)	3% (7)
Fine Sediment	56% (2)	33% (2)	15% (6)	13% (4)
Wood Loading	32% (5)	23% (3)	25% (4)	30% (2)
Shade	40% (3)	2% (7)	20% (5)	8% (5)
Large river Bank Conditions	3% (7)	2% (7)	0% (8)	1% (8)
Large River Length	7% (6)	4% (5)	0% (8)	4% (6)
Beaver Ponds	1% (8)	3% (6)	100% (1)	0% (9)
Flood Plain Habitat	35% (4)	15% (4)	61% (3)	17% (3)
Floodplain & Wood	74% (1)	41% (1)	90% (2)	51% (1)

Case Study

COMPARISON OF MODELED ESTIMATES OF POPULATION PERFORMANCE: Projections of Spring Chinook historical, current, No-Action late century, and ASRP Scenario 3 late century.

Projections of Spring Chinook Response to ASRP Scenario 3

	EDT	LCM
Historical Productivity	8.8	4.8
Historical Capacity	30,750	4,488
Historical Neq	27,270	3,551
Historical Diversity	98.0%	
Current Productivity	3.2	2.0
Current Capacity	2,619	2,021
Current Neq	1,811	1,035
Current Diversity	7.2%	
2080 productivity No Action	3.1	1.68
2080 capacity No Action	835	1,543
2080 Neq No Action	568	627
2080 Diversity No Action	1.8%	
2080 productivity ASRP 3	3.6	1.92
2080 capacity ASRP 3	3,011	1,885
2080 Neq ASRP 3	2,180	901
2080 Diversity ASRP 3	8.6%	

EXPLANATION FOR CAUSES OF DIFFERENCES:

Response from Chip McConnaha on EDT:

There are at least three differences between EDT and LCM that contribute to the differences in results. First, EDT includes a greater number of habitat attributes than LCM, effectively breaking survival into more, possibly finer-scale changes than LCM. The effect of this on performance of the models has not been evaluated but should be noted. A second and probably more significant factor is a difference in assumed temperature with climate change (McConnaha 2020 memo). Late century temperature in EDT is based on the PSU temperature model projections. These projections show not only an increase in summer water temperature in late century but an extension of the warm period into spring and fall. Warm temperature is projected to remain into October, which overlaps with Chinook salmon spawning and resulted in a large decrease in projected abundance in late century. I don't think this was the assumption in the LCM and so they show a lesser effect of late century conditions on Chinook salmon. A third difference is in how the two models predict the effect of ASRP restoration actions. EDT relied on hypotheses regarding expected change in the future as a result of different types of restoration actions. NOAA developed separate physical models for shade, tree growth and other factors that were used in the LCM. The differences between these methods of capturing the ASRP restoration actions are potentially interesting and should be examined more thoroughly.

Response from Tim Beechie on LCM:

- For the current and 2080 no-action scenarios, roughly similar abundance estimates between EDT and LCM for spring Chinook suggest that the models behave similarly when differences in habitat data inputs are similar.
- However, the 2080 ASRP III results differ substantially. This appears to result from differences in modeled shade in late century. EDT assumes continued shade increase and temperature decrease based on agreed upon assumptions from the SRT, resulting in 2080 abundance similar to current abundance. LCM uses modeled tree growth to estimate shade and temperature change in the future, and the model indicates that most of the potential temperature reduction is achieved by 2045, and increasing future temperature from 2045 to 2085 decreases abundance.
- Historical abundance for LCM is driven primarily by setting wood, shade, floodplain, and fine sediment to historical conditions, and the increased historical abundance is close to the sum of those individual increases. (Not sure what changes in EDT to get such a high abundance).

SUPPLEMENTAL INFORMATION ADDED AFTER REVIEW BY C. MCCONNAHA AND T. BEECHIE:

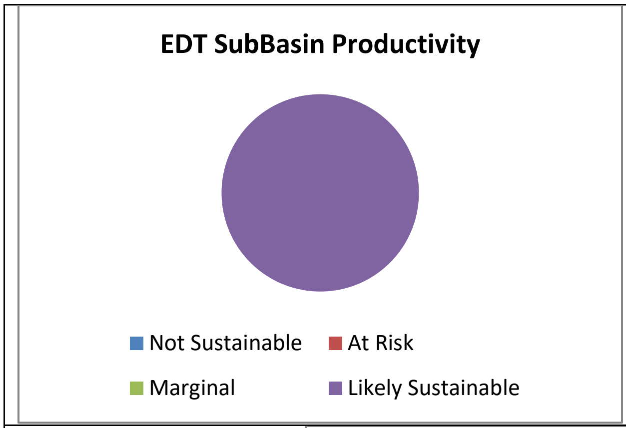
Four sets of pie graphs present EDT and LCM results depicted in paired graphs for Historical, Current, No Action (at late century), and ASRP (at late century with Scenario 3 actions) scenarios. Each pie graph represents the proportional distributions for either productivity or diversity of the modeled subbasins.

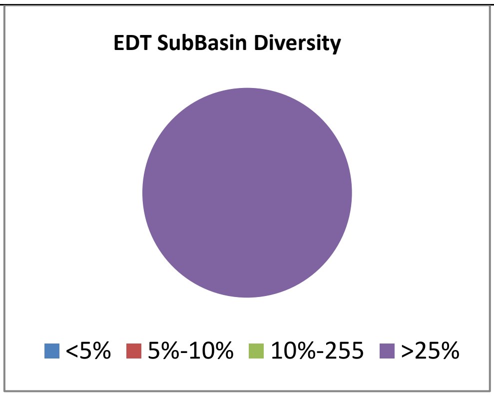
The top two graphs present results from EDT in terms of Productivity and Diversity. These graphs should be viewed as pairs. Productivity represents the productivities of trajectories originating within each subbasin weighted by Neq values (standard weighting procedure used in EDT as described earlier). The diversity values are the metric produced by EDT to report the percentage of modeled trajectories for each population (subbasin scale) for each scenario that are >1, i.e., the percentage of trajectories that are sustainable (exceeding replacement). In this sense, diversity here is a measure of resilience to the population in addition to what productivity provides. Both metrics when considered together provide information about resilience and risk of extinction. Diversity pies represent within population diversity, i.e., the proportion of trajectories within each subbasin that fall within certain ranges of values. Since all trajectories are represented, the pie slices represent proportions of a consistent set of trajectories that does not change across all scenarios.

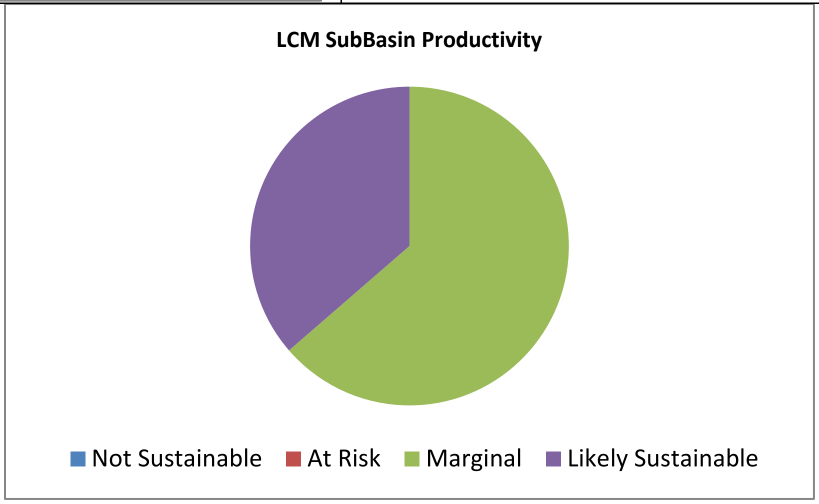
Only one pie chart is presented for LCM results; because there are no sub-populations modeled within each subbasin, the productivity value reflects both Productivity and Diversity. The size of the pie slices represent the proportions of all LCM subbasin populations that fall within the productivity categories.

For both EDT and LCM, Productivity values re: Non Sustainable (productivity <1); At Risk (productivity between 1 and 2); Marginal (productivities 2-5); Likely Sustainable (productivities >5).

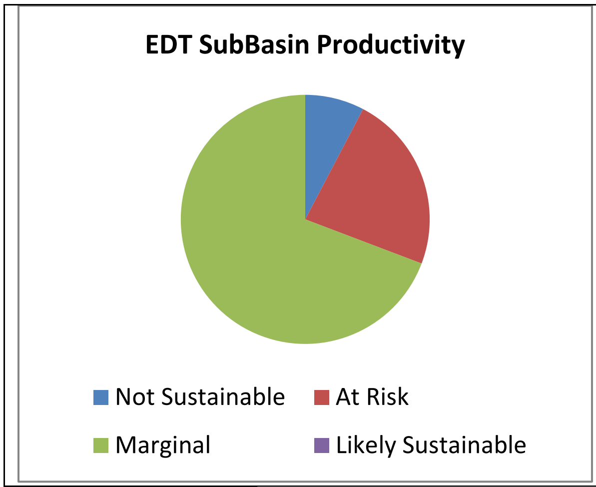
Historical Conditions

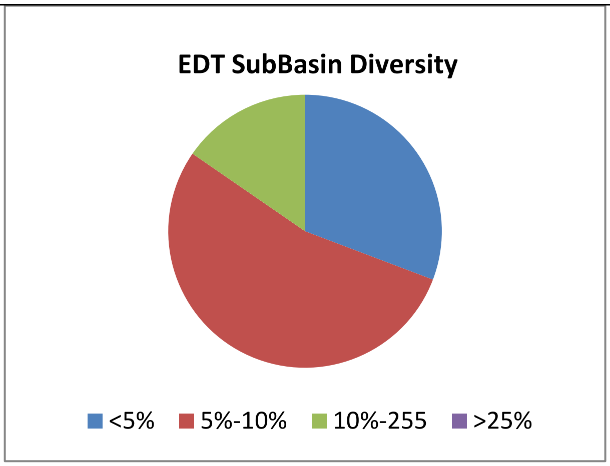


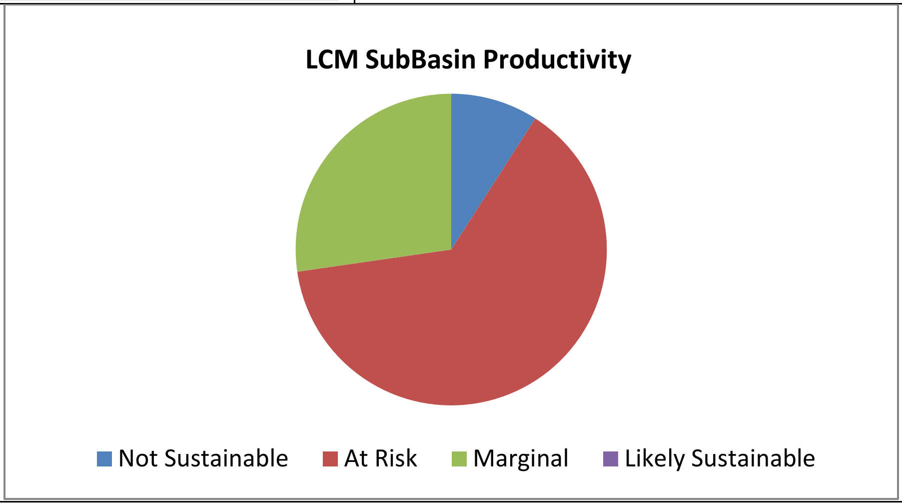




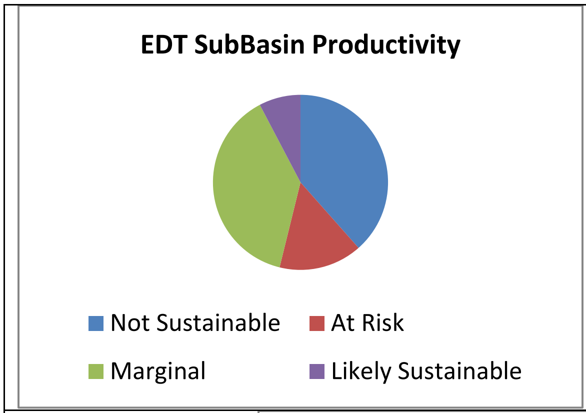
Current Conditions

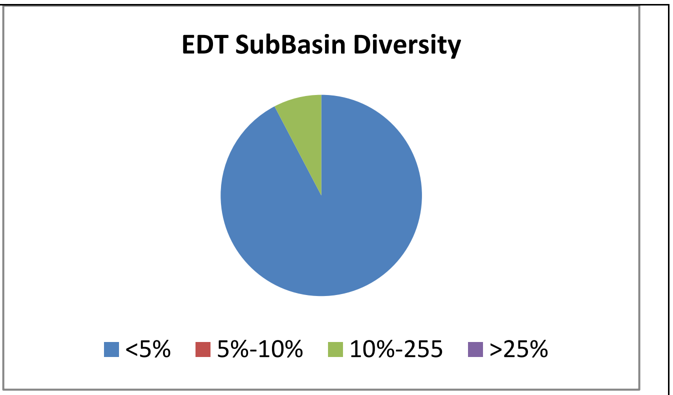


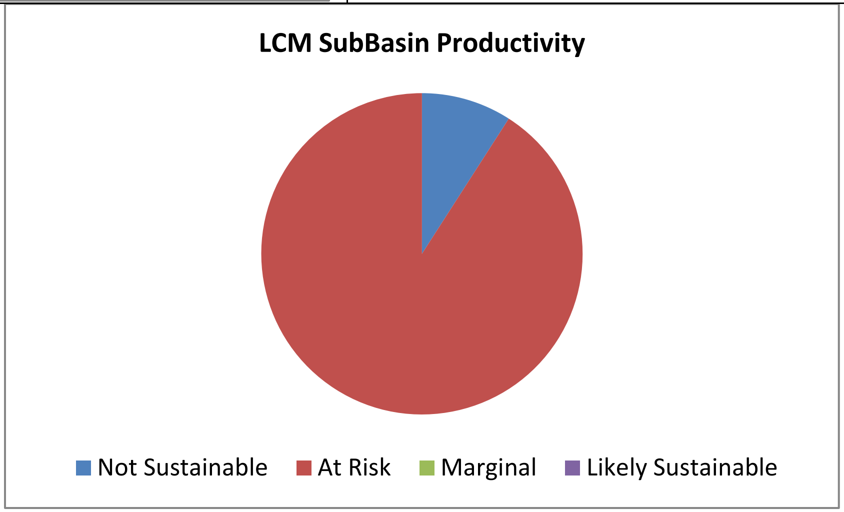




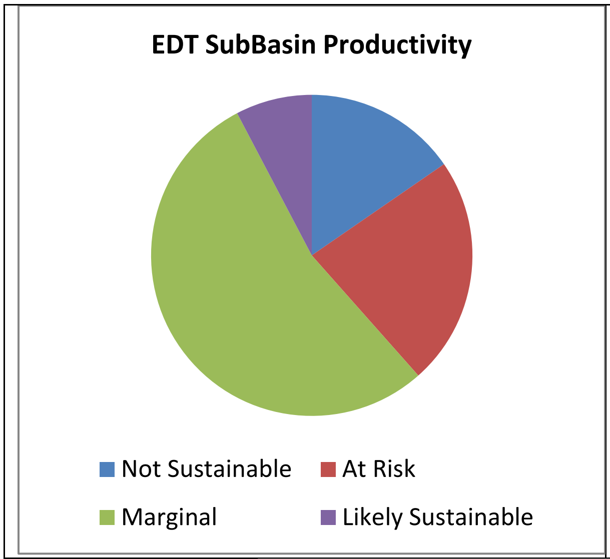
No Action

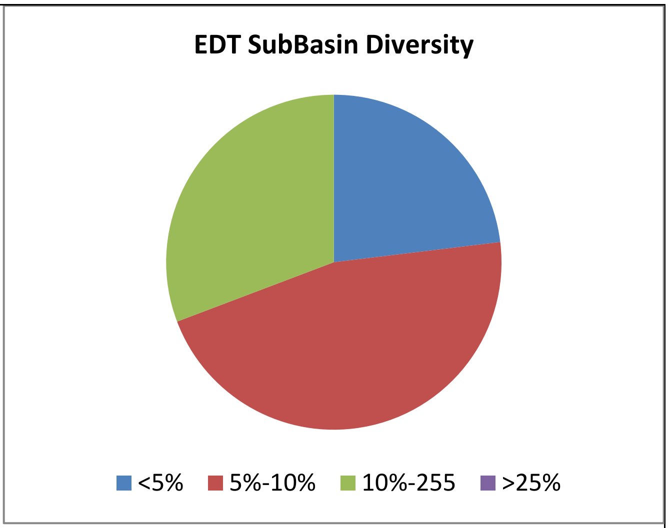

EDT SubBasin Productivity
Not Sustainable
At Risk
Marginal
Likely Sustainable

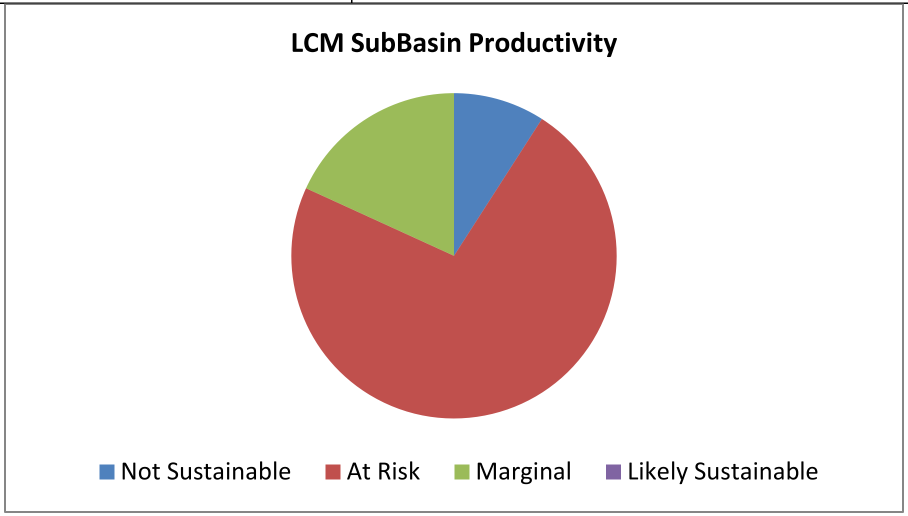

EDT SubBasin Diversity
<5%
5%-10%
10%-255
>25%


LCM SubBasin Productivity
Not Sustainable
At Risk
Marginal
Likely Sustainable

ASRP 3


EDT SubBasin Productivity
Not Sustainable
At Risk
Marginal
Likely Sustainable


EDT SubBasin Diversity
<5%
5%-10%
10%-255
>25%


LCM SubBasin Productivity
Not Sustainable
At Risk
Marginal
Likely Sustainable

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