HENDERSON INLET WATERSHED CHARACTERIZATION REPORT

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Thurston County
GeoData Center
Water and Waste Management

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Acknowledgments

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List of Acronyms and abbreviations

303(d)	List of impaired water bodies specified in the Clean Water Act, Section 303(d)
Basin	1000 to 10000 acres
B-IBI	Benthic – Index of Biological Integrity
Catchment	32 to 320 acres
DAU	Drainage Analysis Unit
DBH	Diameter breast height
DEM	Digital Elevation Model
Ecology	Washington State Department of Ecology
EIA	Effective Impervious Area
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESB	Engrossed Senate Bill
FEMA	Federal Emergency Management Agency
FRAGSTATS	FRAGSTATS is a computer software program designed to compute a wide variety of landscape metrics

GeoData	Thurston County's GeoData Center
GIS	Geographical Information System
GLO	General Land Office
LiDAR	Light Detecting and Ranging
LWD	Large Woody Debris
NEPA	National Environmental Policy Act
PHS	Priority Habitats and Species
SEPA	State Environmental Policy Act
SSHIAP	Salmon and Steelhead Habitat Inventory and Assessment Program
Sub-basin	100 to 1000 acres
Sub-watershed	320 to 19200 acres
TIA	Total Impervious Area
TMDL	Total Maximum Daily Load
TRPC	Thurston County Regional Planning
USDA	US Department of Agriculture
USGS	US Geological Survey
WAC	Washington Administrative Code
WADNR	Washington Department of Natural Resources
Watershed	19,200 to 320,000 acres
WDFW	Washington State Department of Fish and Wildlife
WRIA	Water Resource Inventory Area as defined in Chapter 173-500 WAC

Executive Summary

This project was initiated to address a top priority in the Puget Sound Action Team's (now the Puget Sound Partnership) *Puget Sound Conservation and Recovery Plan* priority to reduce the environmental damage from stormwater runoff, This includes preventing nutrient and pathogen pollution by assessing the feasibility of a watershed-based National Pollutant Discharge Elimination System (NPDES) permit. This report includes a watershed characterization of landscape conditions in the Henderson Watershed that identified preservation, restoration, and mitigation sites at the watershed scale rather than smaller jurisdictional boundaries used in traditional permit approaches.

There are multiple jurisdictions in the Henderson Inlet basin that have applied for their National Pollutant Discharge Elimination System (NPDES) Phase II and Phase I permits. Thurston County, in addition to the cities of Olympia, Lacey, and Tumwater are designated Phase II permittees. The Washington State Department of Transportation (WSDOT) is a NPDES Phase I permittee in Thurston County.

Each jurisdiction has applied for their respective permit separately. Separate permits could lead to duplicative efforts in planning, assessment, and monitoring as each jurisdiction addresses the six core Clean Water Act (CWA) programs and other requirements under the Safe Drinking Water Act (SDWA). These permits are managed by the Washington State Department of Ecology (WDOE) individually.

Watershed based methods will be most effective when the approach is driven by broader landscape needs and conditions rather than an individual site needs. The result is to refine and collect new data for CWA, SDWA, Endangered Species Act (ESA), Shoreline Management Act (SMA), and Critical Area Ordinance updates. This method represents a transition from a site-driven to a more holistic *landscape-driven* approach towards assessing ecosystem function and current ecological processes within a watershed.

This report includes Steps Two and Three of a six step process detailed in Watershed-Based NPDES Permitting Implementation Guidance, EPA 2003 to assess the feasibility of developing a watershed-based permit based on a watershed scale for the Henderson Inlet basin. These steps are as follows:

- <u>Step One:</u> Select a Watershed and Determine the Boundaries
- <u>Step Two:</u> Identify and facilitate multiple jurisdictions to participate in a watershed-based NPDES permit or permit compliance approach using the EPA's guidance;
- <u>Step Three:</u> Collect and analyze data through a watershed characterization for permit development or permit compliance;
- <u>Step Four:</u> Develop watershed-based permit or permit compliance conditions and documentation.
- <u>Step Five:</u> Issue Watershed-Based NPDES Permit
- <u>Step Six:</u> Measure and Report Progress

Steps four, five and six have not been initiated as proposed, but it is anticipated that work will be completed during the first NPDES Phase I permit period (2007 to 2012).

This document presents the work of the technical team using Gersib et al. (2004) methods. In addition, it is a culmination of refinements made by our technical team to meet the needs of Thurston County. The report provides a scientific approach to analyzing the ecological and biological processes that maintain a healthy watershed. The central goal of the watershed characterization work is to identify natural resource areas that could serve as stormwater retrofit sites to mitigate existing urban development in the Henderson Inlet watershed.

At a landscape scale, we subdivided the Henderson Inlet study area into 64 drainage analysis units (DAU) or catchments and used landscape attributes to characterize the condition of key ecological processes (movement of water, sediment, large wood debris, pollutants, and heat) and biological processes (aquatic integrity and upland habitat connectivity) that have been affected by past urban development. We do this by interpreting existing land cover and natural resource data and by developing databases that identify the location and condition of wetland, riparian, and floodplain resources. We then identify targeted landscape areas having the potential to optimize environmental benefits if restored.

At the site scale, we identify all possible candidate wetland, riparian, and floodplain restoration sites through photo and Geographical Information System (GIS) interpretation of the study area. In addition to creating these natural resource datasets, we developed a stormwater retrofit database to provide additional options for treating stormwater in urban areas where few viable natural resource options exist.

The stormwater retrofit priority list is intended specifically for identifying potential wetland, riparian, and floodplain restoration sites that have potential to mitigate stormwater quality and quantity impacts of past urban development. The natural resource restoration priority list is intended to identify sites that maximize overall ecosystem function. Finally, the fish habitat priority list ranks sites that have the potential to maximize habitat benefits to anadromous and resident fish species.

At the landscape scale, we determined that the Woodland Creek Sub-watershed was mostly altered by development. The total impervious area (TIA) value is 28% of the total watershed, with the once historic prairie uplands being covered almost entirely by urban development. These areas include the Cities of Lacey and Olympia, as well as unincorporated Thurston County. Woodard Creek Sub-watershed had the second highest value for TIA at 16% (mainly in the City of Olympia). East and West Henderson were in the best condition with 6% and 4% TIA.

To identify and evaluate potential restoration opportunities, we used watershed characterization to identify the ecological and biological processes of each DAU. We also identified altered wetland, floodplain, and riparian resources. We then used our understanding of landscape condition to place each potential restoration site in a landscape context. We evaluated and prioritized restoration sites in this context. In the study area, we evaluated 172 riparian areas, over 262 wetland areas, and 26 floodplain areas for a total of 460 potential sites. Those sites were further evaluated for potential stormwater retrofit and fish habitat restoration potential.

Of these sites, 207 potential wetland, floodplain and riparian restoration sites met our minimum criteria for potential use for restoration. We prioritized those sites for optimizing overall ecosystem function within the DAU.

Introduction

This report summarizes a scientific framework for watershed characterization and describes a set of methods developed at the watershed scale to assist in better land use decisions. As a conceptual framework, this document serves as the key deliverable to Thurston County summarizing watershed characterization methods and developing key recommendations that other County departments, local jurisdictions, and other entities can use to help meet current and future environmental assessment and planning needs.

Watershed based methods will be most effective when the approach is driven by landscape need and condition rather than an individual site needs. The results will help to refine and provide new data to meet the needs of the Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Endangered Species Act (ESA), Shoreline Management Act (SMA), and Critical Area Ordinance updates. It represents a transition from a site-driven to landscape-driven approach to assessing current ecological processes of the watershed.

Despite dramatic increases in effort, legal mandates, and expenditures for environmental protection and restoration over the past 20 years, the overall condition of natural ecosystems continues to decline (Karr 1995, Montgomery et al. 1995). A growing body of work indicates that declines in ecosystem integrity are perpetuated by existing policies and traditional techniques that tend to treat local symptoms of resource degradation and fail to address the root biological and physical causes of ecosystem degradation and population decline. These policy and traditional techniques perpetuate a narrow “site” review and analysis that often results in restoration that treat symptoms of localized habitat/resource degradation rather than addressing the systemic causes of ecosystem degradation (Frissell 1996, Angermeier and Schlosser 1995, Montgomery et al. 1995, Reeves et al. 1995, Ebersole et al. 1997).

Thurston County was designated a National Pollutant Discharge Elimination (NPDES) Phase II jurisdiction in the 2000 census. Thurston County submitted a NPDES Phase II permit to Ecology in March 2003. With the issuance of the NPDES Permit for Phase II communities in February 2007, Thurston County determined that a more holistic approach was needed to incorporate all the required regulations at the watershed level to promote efficiency in monitoring, analyzing, and reporting on the health of our water bodies. Current government efforts are segmented and have not proven to provide protection to Thurston County's streams and the Puget Sound.

This study provides substantial opportunity to blend developing watershed approaches with new modeling and assessment tools to develop outcome-based approaches that Thurston County Water and Waste Management, Long Range Planning, Roads and Transportation Services, can use to make better land use decisions and management.

What is in this document?

This document presents the work of the technical team using Gersib et al. (2004) landscape characterization methods and our refinements made by our technical team to meet the needs of Thurston County, a local government. The report provides a scientific approach to analyzing the ecological and biological processes that maintain a healthy watershed. The goal of the watershed characterization work was to identify natural resource areas that could serve as stormwater retrofit sites to mitigate past urban development in the Henderson Inlet watershed.

At the landscape scale, we characterize the condition of key ecological processes (movement of water, sediment, large wood, pollutants, and heat) and biological processes (aquatic integrity and upland habitat connectivity) that have been affected by past urban development. We do this by interpreting existing land cover and natural resource data and by developing databases that identify the location and condition of wetland, riparian, and floodplain resources. We then identify targeted landscape areas having the potential to optimize environmental benefits if restored.

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What are the general findings of this study?

At the landscape scale, it was determined that the Woodland Creek Sub-watershed was the most altered by urban development, with a total impervious area (TIA) value of 28%. Specifically, the once historic prairies have been covered with urban development. These areas include the Cities of Lacey and Olympia, as well as unincorporated Thurston County. Following the Woodland Creek Sub-watershed, Woodard Creek Sub-watershed had the second highest value for TIA at 16%, mainly in the City of Olympia. East and West Henderson were in the best condition with 6% and 4% TIA, respectfully.

To identify and evaluate potential restoration opportunities, we used watershed characterization to identify the ecological and biological processes of each drainage analysis units (DAU). We also identified altered wetland, floodplain, and riparian resources. We then used our understanding of landscape condition to place each potential restoration site in a landscape context. We evaluated and prioritized restoration sites in this context. In the study area, we evaluated 172 riparian areas, over 262 wetland areas, and 26 floodplain areas for a total of 460 potential sites. Those sites were further evaluated for potential stormwater retrofit and fish habitat potential.

Of these sites, 207 potential wetland, floodplain and riparian restoration sites met our minimum criteria for potential use for restoration. We prioritized those sites for optimizing overall ecosystem function within the DAU.

I. Introduction to Watershed Characterization

What is watershed characterization?

Watershed characterization is a series of steps that identify, screen, and prioritize hundreds of potential wetland, riparian, and floodplain restoration sites. These steps focus on gathering ecological and biological watershed data needed toidentify where landscapes are and are not functioning properly, where degraded natural resources exist, and where to target restoration to maximize environmental benefits. In the end, this analysis will allow Thurston County to choose restoration sites that will provide the greatest function, have a high probability of being successful, and ensure that we get the highest value for our investments.

Through watershed characterization, the technical team seeks to integrate the restoration of wetland, riparian, floodplain, and stormwater impacts by restoring the landscape's capacity to function. We do this by assessing the condition of ecological processes, such as the movement of water, sediment, pollutants, large wood, and heat and aquatic integrity and upland habitat connectivity. We then target restoration to degraded natural wetlands, riparian areas, and floodplains having the greatest potential to mitigate past development impacts and result in measurable environmental benefits.

How do we conduct a watershed characterization?

Watershed characterization consists of four key steps.

In Part I, we analyzed the condition of landscape-scale ecological processes and the extent of human alteration to these systems. Key physical processes include the movement of water, sediment, pollutants, large wood, and heat through stream systems within the study area. Key biological processes include aquatic integrity and upland habitat connectivity.

At a landscape scale, we subdivided the Henderson Inlet study area into 64 drainage analysis units (DAU) catchments and used landscape attributes to characterize how land use change has altered the natural movement of water, sediment, pollutants, and large wood, along with aquatic integrity and upland habitat connectivity. We use this information to target restoration efforts within landscapes that have the greatest potential to restore and maintain environmental benefits over the long-term.

In Part II, we identified potential natural resource sites (wetlands, riparian, and floodplain) that have the potential to mitigate past development if restored.

We created potential restoration site datasets for wetlands, riparian areas, and floodplains which we used to identify potential restoration sites. We also identified where stormwater retrofit projects could address existing stormwater runoff problems. We used available data and extensive photo interpretation to develop wetland, riparian, and floodplain datasets. These datasets differ significantly from existing natural resource data, such as local and state agencies might develop, in that we seek to identify potential restoration sites rather than inventorying existing wetlands, riparian areas, and floodplains.

These potential restoration sites include intact existing wetlands and degraded or destroyed wetlands that have potential, if restored, to meet mitigation needs. The technical team established both site and landscape criteria to evaluate and rank potential floodplain, wetland, and riparian restoration and stormwater retrofit sites. In addition, we used the natural resource sites to identify potential fish habitat sites.

This process results in three prioritized restoration site lists; one for potential natural resource restoration sites (with potential floodplain, wetland, and riparian restoration sites); one for potential stormwater retrofit sites, and fish habitat restoration sites.

In Part III, we determine the ecological benefit of each DAU and the environmental benefit of each resource site.

In Part IV, we identify and rank potential restoration sites.

More details on methods used in watershed characterization can be found in the Appendix A of this report.

As we applied the Gersib et al., 2004 methods it was determined that the methodology needed to be updated and refined because of the watershed we were studying and the goals of our characterization. In summary, we modified or clarified the following:

- We did not use the indicator "percent change in drainage network" in the Matrix. This was necessary because we did not have sufficient stormwater infrastructure data.

- Further defined "mature forest" to mean "hydrologically mature forest" (Doug fir 25 years old).

- We added "prairie landscape" to the matrix (some studies indicate that the addition of impervious surface over outwash soils has a larger hydrological effect than covering till soils (Brascher, 2006).

- We discussed the need to develop better indicators for the "movement of sediment". The original use of the matrix was for forestry activities. In an urban environment, with required stormwater best management practices (BMP), cleared earth is typically paved within a limited amount of time, thus no bare soils in the DAU. The exception would be agricultural activities, but they are also temporarily exposed prior to replanting.

- The Henderson Inlet does not include the typical altered floodplain as regulated under the Federal Emergency Management Agency (FEMA). Thus, the methods were modified to reflect the watershed (Park 2006).

- We defaulted to an "at risk" for the condition process "movement of pollutants" because under current Total Maximum Daily Load (TMDL) regulations we are required to restore the water quality to support all beneficial uses, thus all areas are eligible for restoration.

- We used 67 meter buffers throughout the analysis vs. 33 meter, as stated in the matrix for the movement of heat. The 67 meter buffer reflects the standard aquatic buffer that Thurston County currently has in effect.

- We further defined the rules and assumptions used in the analysis.

- We modified the stormwater retrofit ranking criteria.

- We modified the fish habitat ranking criteria.

Further work is required to improve the methods for future watershed characterizations.

- While estuarine and marine landscape indicators exist in various forms (Appendix H), we did not find them complete enough to use in this analysis.

- Thurston County's FEMA maps are outdated and incomplete. Future goals include updating the Federal Insurance Rate Maps (FIRM) using LiDAR.

- Thurston County's stormwater infrastructure maps are incomplete. This data is essential to fully understand the delivery and routing of water. Future goals include collecting stormwater infrastructure data to better analyze the movement of water.

- Aquatic integrity and habitat connectivity indicators could be further defined and improved. Based on this work, Thurston County plans to investigate additional Benthic Indicator Biotic Indicators (BIBI) sites.

- Add and standardize criteria for initial natural resource site identification and condition descriptions.

How was local information and expertise acquired and used?

An important part of the watershed characterization efforts is coordination with local and regional governmental entities and watershed groups. Our reasons for doing this are:

- To ensure that local natural resources managers and interest groups are aware of what we are doing within their area, what watershed characterization is, and how it works.

- To gain insight into local permitting criteria and policies.

- To ensure that information developed through watershed characterization is compatible with existing planning efforts by local, tribal, or regional governments, whenever possible.

- To acquire locally developed datasets of relevance to watershed characterization.

- To identify and acquire local watershed recovery plans, priorities, and locally identified restoration opportunities.

An integral part of watershed characterization is the identification and use of locally identified themes. These themes are used, in part, to establish criteria for prioritizing potential restoration sites. We consulted draft and final reports containing watershed priorities for habitat restoration, salmonid recovery, water quantity and base flow improvements, and water quality improvements. Besides containing much valuable background, these were reviewed for lists of local restoration priorities. Later in the watershed characterization process, we matched these lists to our own restoration site lists, affording higher priority to sites that were also local priorities.

Each of these documents contains locally defined projects or targeted stream reaches for water quality enhancement, runoff control, ecosystem recovery, salmon recovery, sediment control, flood amelioration, or similar benefits. We matched locally identified recovery sites to sites identified through watershed characterization and used this information to help prioritize our candidate restoration sites found in Appendices C through F.

What are the project deliverables?

Watershed characterization deliverables for the Henderson Inlet Study are:

- Extensive documentation of technical methods, assumptions, and results of watershed characterization in a manner that is comprehensive and understandable.

- Extensive information on the landscape condition of key ecological processes.

- Potential wetland, floodplain, riparian, stormwater retrofit, and fish habitat data layers with all site-specific data.

- A prioritized list of potential natural resource restoration sites for overall ecosystem function in the study area.

Our goal is to make this report clear and understandable to the average person, while still providing all of the technical documentation necessary to support science-based decision-making. To do this, we have chosen a multi-level presentation:

- In the main report body we use a format that seeks to "tell the story" of the study area and of our results
- We provide our detailed step-by-step results in the appendices
- We keep technical methods in a separate methods document
- Our GIS data, modeling assumptions, and other technical details are available on a CD as requested

We are hopeful that this format will be more understandable for the non-technical reader and yet ensure that all methods, data, assumptions, and results are readily accessible to technical and regulatory reviewers.

What are the limitations?

The most significant limitation of the results is the data used in the analysis. While we used the relatively recent satellite data (SPOT imagery August 2005 and LiDAR 2001), other coverages used include 2003/2005 aerials and other state data. The landscape has probably significantly changed, and thus all sites should be verified as still viable.

Thurston County has recently acquired 2006 aerial photos, and we will use that data to verify sites identified in the study. Another caveat is the Department of Natural Resources (DNR) stream hydro layer used in the analysis. When the DNR hydro layer was compared to LiDAR data, it was obvious that the stream layer is not accurate in some reaches. To compensate for the errors we applied a 67 meter buffer vs. a 33 meter buffer as detailed in the original methods.

II. The Study Area

What is the study area and how was it defined and subdivided for analysis?

The Henderson Inlet Study Area is shown in Figure 1. Henderson Inlet Study Area. The study area was delineated using LiDAR data. Multiple scales were established including 0.1 sq mile DAUs, 0.25 sq mile DAUs, four sub-watersheds, and the study area watershed. These scales were based on the Center for Watershed Protection definitions and the goal of the study to develop stormwater retrofit sites (Zielinski, 2002). The analysis used the 0.25 sq mile DAUs, sub-watersheds, and the watershed (Figure 2. Study Area Drainage Analysis Units). The delineation excluded all direct discharges to the Inlet because they did not drain into the freshwater streams. Thurston County staffs are working on developing additional watershed characterization methods for those marine areas.

III. Potential Restoration Opportunities

Potential natural resource restoration sites were determined by assessing several ecological and biological landscape indicators that were then used to assess the ecological and biological processes at the DAU scale.

Step One: Follow the Matrix of Landscape Indicators to assess biological and ecological processes at the DAU scale.

Step Two: Identify potential natural resource sites using aerial photos and other GIS data in the study area.

Step Three: Determine current state of all ecological and biological processes at the DAU scale to determine their ecological benefit to maintain sites if restored.

Step Four: Rank natural resource sites for their environmental benefit if restored.

How were preservation and restoration sites identified?

The goal of this study was to determine natural resource sites that can be restored to provide greater function in the DAU to mitigate past disturbances, specifically the movement of water. The exception is the wetlands dataset which also contains sites for avoidance and preservation. Thus, by default, all wetland sites not ranked high for restoration can be assumed to be of high ecological value for avoidance and preservation.

There are two essential steps to identify and assess natural resource sites; Determine the ecological and biological processes at the DAU scale using the Matrix of Pathways and Indicators (Matrix); and identify all degraded natural resource sites in the study area. These two data sets are the foundation of the watershed characterization.

The matrix was used to identify DAUs that are “properly functioning” (PF), “at risk” (AR) or “not properly functioning” (NPF) for the five ecological processes (movement of water, wood, sediment, pollutants, and heat, and the two biological processes (aquatic integrity and habitat connectivity).

The natural resource site (potential wetland, riparian, and floodplain restoration sites) datasets were determined primarily through aerial photo and LiDAR interpretation of the study area and supplemented by existing natural resource inventories, and locally identified natural resource recovery areas. See the revised watershed characterization methods document (Appendix A) for detailed descriptions of the methods specific to the development of each natural resource database.

How were preservation and restoration sites prioritized?

The focus of the restoration sites are water quality (including water quantity) and aquatic habitat improvement. Thus, only riparian and floodplain sites having restoration potential were identified. All intact and properly functioning riparian and floodplain sites were not included in the natural resource lists. Further work is needed to evaluate a priority list of preservation sites for riparian and floodplain sites. Conversely, all wetland sites were evaluated for restoration, avoidance, and preservation based on their attributes. All wetland sites having a low restoration value are assumed to have a high avoidance and preservation value.

Based on the needs within the study area, three priority restoration site lists were developed. The first, a natural resource restoration priority list, identifies and prioritizes potential wetland, riparian, and floodplain restoration sites having potential to maximize environmental benefit within the study area. The second, a stormwater quality and quantity restoration priority list, identifies and prioritizes potential wetland, riparian, and floodplain restoration sites having potential to provide stormwater water quality improvement within the study area. The third is a list of restoration sites that are prioritized for benefit to anadromous fish habitat restoration.

Data on the following key environmental attributes were compiled on each candidate restoration site:

- All ecological and biological process condition rankings
- Anticipated environmental benefits gained if the resource is restored
- Type of natural resource
- Site targeted for restoration in a local or regional recovery plan
- Site on or adjacent to publicly owned land
- The size of the candidate restoration site

Detailed methods for prioritizing natural resource restoration sites are described in Appendix A and detailed data and results are presented in Appendices C through F.

When developing the priority list for natural resource restoration, all potential riparian, wetland, and floodplain restoration sites were initially considered candidates for natural resource restoration. Attributes of each candidate site were then compared to criteria established for all landscape attributes. These sites were further evaluated based on the DAU ecological rank of PF, AR, or NPF. This process eliminated sites from further consideration and, at the same time, ranked remaining sites. The resulting potential natural resource sites environmental benefit lists are presented in Table 1.

The potential natural resource restoration site database consists of 460 polygons, including:

- 262 unique wetland polygons
- 172 unique riparian polygons
- 26 unique floodplains polygons

Table 1. Potential Natural Resource Restoration Sites

All Potential Resource Sites				
	Wetland	Riparian	Floodplain	Total
Woodland	133	101	14	248
Woodard	74	44	11	129
East	44	15	0	59
West	11	12	1	24
Total	262	172	26	460

We initially considered all potential riparian, wetland, and floodplain restoration sites when developing the priority list. Attributes of each candidate site were then evaluated using established criteria. This process eliminated sites from further consideration and, at the same time, ranked remaining sites.

After criteria were applied to the initial site database, a total of 207 sites were further evaluated to determine if they could be viable as stormwater retrofit sites.

What are the preservation and restoration opportunities within the study area?

Based on the site's environmental ranking and ecological process rank of the DAU that it resides in, a total of 207 potential wetland, riparian, and floodplain restoration sites met minimum ranking criteria and were prioritized. These sites were further evaluated for stormwater retrofit sites and fish habitat sites. These prioritized lists and data used in the prioritization process are presented in Appendices C through F.

Were any of the sites given closer examination?

Thurston County will have 2006 aerial photography by November 2007. Upon availability of the more recent aerial photography, the sites will be verified as still existing. If sites are still available (haven't been developed), then an economical analysis will be completed to determine which sites are viable and practicable to pursue further for restoration opportunities.

How should this information be used?

The information in this report should be used as the first screening tool to evaluate restoration opportunities at the landscape scale. These sites have been evaluated to provide the greatest ecological benefit if restored.

IV. Conditions of Natural Resources in the Study Area

We have analyzed all the candidate floodplain, wetland, and riparian restoration sites using aerial photo interpretation, but only a limited number have had preliminary field verification. The potential restoration site priority lists developed through watershed characterization should be considered as the starting point for a more extensive site assessment effort by project environmental staff or their consultant support. This is, in reality, recognition that the selection of the best potential restoration sites requires both a landscape-scale assessment and a detailed site-specific analysis.

Watershed characterization products are limited by the number, location, and extent of potential wetland, floodplain, and riparian restoration sites within the study area to mitigate past development. The goal of a watershed characterization is to eliminate or reduce the need for hard stormwater infrastructures, such as a conveyance system to engineered ponds, etc.

What conditions did we find in the Henderson Inlet study area?

Our Henderson Inlet study area drains 25,539 acres (40 sq miles), including Woodland Creek and its tributaries, Woodard Creek, and other wall base tributaries that drain to the inlet, as defined by LiDAR (see Figure 3. Study Area Sub-Watersheds). In this study, Hicks and Pattison lakes were excluded while other areas were included (Little McAllister) in the analysis based on the delineation using elevations derived from LiDAR.

Henderson Inlet, located in Thurston County, is one of five inlets that form the southern terminus of Puget Sound. It is located between Budd Inlet on the west and Nisqually Reach on the east. The five-mile long inlet ranges from one-fourth to three-fourths miles in width, averaging about 25 feet in depth. A large portion of the lower inlet is exposed mudflats at low tide. Since the 1980s, commercial shellfish harvesting in the lower third of Henderson Inlet has been prohibited or restricted due to high fecal coliform bacteria levels in the water. Tidal elevations in this area (South Puget Sound) range from +16 to -4 feet (Cleland, 2000).

The Henderson Inlet watershed is the second largest watershed in Water Resource Inventory Area (WRIA) 13. Woodland and Woodard Creeks are the largest of the main tributaries to Henderson Inlet, draining 80% of the watershed. The other streams in the watershed, Dobbs Creek, (East Henderson), Meyer Creek (Inlet), and Sleepy Creek (West Henderson), drain small areas of the Dickerson Point and Johnson Point peninsulas (Thurston County WWM, 1995).

Henderson Inlet and several of its tributaries are on the 303(d) list of water bodies not meeting water quality standards for at least one water quality parameter. Some waterbodies listed in Table 2 are not currently on the 303(d) list, but they do not meet water quality standards. The parameters of concern include fecal coliform bacteria, dissolved oxygen, pH, and temperature.

Woodland Creek, the largest creek draining to Henderson Inlet with an area of approximately 30 square miles, flows through northeast Olympia and central Lacey before emptying into Henderson Inlet. Three lakes connected by extensive wetlands form a horseshoe-shaped chain which makes up the headwaters of Woodland Creek. Hicks Lake flows into Pattison Lake and then Long Lake; all three lie between 152 and 157 feet above sea level (USGS, 1999). From Long Lake to Martin Way, Woodland Creek includes one mile of perennial stream to Lake Lois. From Lake Lois to Martin Way, Woodland Creek is an intermittent channel that often dries during the summer. Downstream of Martin Way, several springs provide perennial flow to lower Woodland Creek. Woodland Creek tributaries include; College, Eagle, Palm, Fox, Jorgenson, and Quail creeks.

The Woodland Creek basin is one of the fastest growing areas in the county (Thurston County WWM, 1995). Ninety percent of the Woodland Creek watershed lies within an Urban Growth Area (UGA), primarily Lacey but also Olympia. The basin still contains substantial areas of undeveloped forests though the dominant land use is suburban-density, residential development. Residential subdivisions are spreading rapidly in the area around the headwater lakes and near the mouth of the stream sub-watershed. Residential development is most dense in the southern (upper) portion of the basin.

A complete description of Woodland and Woodard Creek basin geology, soils, hydrology, vegetation, fish habitat, and critical areas can be found in the Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1995) and the Current Conditions Report Woodland Creek Pollutant Load Reduction Project, (Pacific Groundwater Group and Brown and Caldwell, 2007).

Pre-development land cover

Prior to European settlement, the landscape was predominately young coniferous and deciduous forest, with open prairies. The area was subject to relatively frequent fire disturbance, to maintain prairies that were used by Native Americans to maintain their food sources, such as game and bulbs.

South Puget Sound prairies developed during the hot and dry Hypsithermal period, about 10-9,000 to 7,000 b.p. (Ames and Maschner 1999). Under the subsequent cooler and moister climates, the open structure and diversity of the vegetation was enhanced and maintained by regular fire. The extent of the landscape maintained as open prairie for thousands of years likely fluctuated with varying climates and resources for Native Peoples, and varying population densities (Easterly, R.T, et al. 2005).

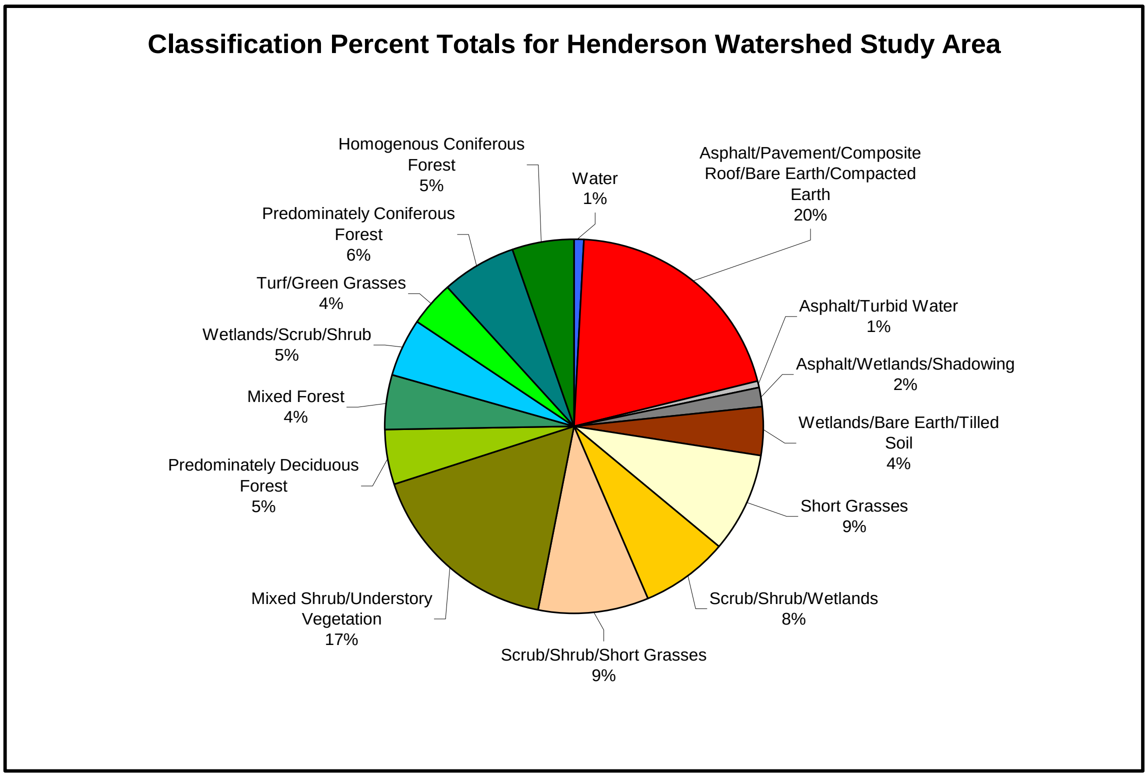
By the time European settlers arrived in the South Puget Sound and began providing written records of the landscape, populations of Native Peoples were reduced to a fraction of their former levels by devastating disease epidemics that swept through the region during the preceding century, or even earlier (Ames and Maschner 1999; White 1980). Correspondingly, the managed prairie landscape was undoubtedly already reduced from its former extent (Easterly, R.T, et al. 2005).

Qualitative information about the extent and composition of the prairie landscape in the Puget Sound in the mid-18th century was provided by early Europeans, some of whom were skilled observers (Easterly, R.T, et al. 2005). Another dataset providing information about the post-contact landscape was the General Land Office (GLO) surveys, done between 1853 and 1876 in the study area (Figure 4. General Land Office Survey). For that project, surveyors traversed Washington's lowland landscape to establish a grid of Section corners. Information recorded in the field notes included prairie and wetland margins. This study reviewed all GLO notes and summarized the data for this report (see Appendix B for a list of vegetation recorded by the GLO).

Current conditions

Twenty percent of the Henderson Inlet is covered by urban land uses (see Figure 5 and 5a, Classification Percent Totals for Henderson Watershed Study Area).

Figure 5a.   Classification Percent Totals for Henderson Watershed Study Area



Land cover data derived from 2005 SPOT imagery.

In addition to classifying land cover in the study area, 14 landscape indicators were evaluated (see Figure 6, Landscape Indicators). We analyzed the condition of each of the following indicators within each DAU:

1. Forest Land Cover
2. Prairie Resources
3. Wetland Resources
4. Total Impervious Surface (TIA)
5. Riparian Zones
6. Steep Slopes
7. Habitat Connectivity
8. Impaired Water Bodies
9. Benthic Indices of Biotic Indicators (BIBI)
10. Road Density
11. Stream Crossings
12. Stream Channel Straightening
13. Floodplain Decoupling
14. Bare Soils

The current condition of each DAU was determined to be "properly functioning", "at risk" or "properly functioning" based on methods detailed in the Matrix (see Appendix A for complete methods).

Future conditions

Currently, Thurston County is updating zoning in the rural areas, and within the Urban Growth Areas (UGA). Because it is unknown what the outcome of that work will be, this study did not project future conditions.

However, Thurston Regional Planning Council's report "Estimates of Future Impervious Area Conditions, Thurston County" projects that Henderson Inlet will increase total impervious surface to an estimated 24% impervious cover by the year 2030.

Hydrogeology and groundwater recharge

The Henderson Inlet watershed study area is composed of glacially derived sediments overlying tertiary sedimentary rock (Figure 7, Surficial Geology in Henderson Inlet). The area is located close to the southernmost extent of recent glacial advances. The geologic description for the study site is based on Drost et al. (1998) and Pacific Groundwater Group (1998 and 2000).

The unconsolidated material in the study area can be divided into six units. The most recent material is alluvial and deltaic sand deposited in the bottom of the Nisqually Valley. Below the alluvial and deltaic material lies the uppermost glacial unit in the area, the Vashon recessional outwash (Qvr), which is made up of sand and gravel. The Qvr covers much of the study area and, where saturated, forms unconfined or perched aquifers. A thick layer of Vashon till underlies the recessional outwash in most areas. This "hardpan" layer consists of poorly sorted sand, gravel, and boulders that are held in a mixture of silt and clay. The till forms a confining layer that typically restricts upward flow from the underlying Vashon advance outwash (Qva) aquifer except in the McAllister Springs corridor. The Qva aquifer underlying the till consists of gravel in a matrix of sand and is a major water source for the area. A non-glacial silt and clay layer underlies the Vashon outwash and forms a second confining layer.

Below the non-glacial silt and clay is a second aquifer composed of undifferentiated Pre-Vashon deposits including the Salmon Springs Drift (?) and materials older and younger than Salmon Springs Drift (?). The aquifer is also referred to as the sea level (Qc) aquifer system (Pacific Groundwater Group, 2000). The Qc aquifer is composed of coarse sand and gravel and is confined in most places except in the McAllister Springs area. Groundwater flow direction and model simulations indicate that the Qc aquifer underlying the Woodland Creek watershed flows toward McAllister Springs rather than north as the topography would indicate (USGS, 1998 and 1999). AquaTerra (1994) suggests that most of the recharge occurring in the upper Woodland Creek Basin flows to McAllister Creek or Puget Sound, completely skirting Woodland Creek.

Water quality

Henderson Inlet and its associated tributaries currently do not meet state water quality standards for fecal coliform (FC), dissolved oxygen (DO), temperature, and pH. Several of the sub-watersheds have been placed on the 303(d) list and are subject to a Total Maximum Daily Load (TMDL), and are undergoing the development of a water clean-up plan (Table 2. Water Quality in Henderson Inlet (Sargent, D., et al., 2006))

Table 2. Water Quality in Henderson Inlet

Waterbody	Parameter	2004 303(d) list	1998 303(d) list	1996 303(d) list
Marine Water				
Henderson Inlet	FC, DO	y	y	y
Freshwater				
Woodland Creek	FC, DO, Temp	y	y	y
College Creek	FC	*	**	**
Eagle Creek	FC	*	**	**
Palm Creek	FC	*	**	**
Fox Creek	FC	*	**	**
Jorgenson Creek	FC	*	**	**
Quail Creek	FC	*	**	**
Woodard Creek	FC, DO, pH	y	y	y
Dobbs Creek	FC, pH	y	y	y
Sleepy Creek	FC, DO, pH	y	y	y
Meyer Creek	FC, pH	*	**	**
Goose Creek	FC	*	**	**

* does not meet water quality standards, but not on 2004 303(d) list
** does not meet water quality standards, but not on the 1998 or 1996 303(d) lists
FC – fecal coliform
DO – dissolved oxygen
Temp - temperature

Fish Resources

The Washington State Conservation Commission report on Habitat Limiting Factors for WRIA 13 (Haring and Konovsky, 1999), reported salmon and steelhead distribution information for Henderson Inlet streams (Table 3). The City of Lacey staff also reported chum salmon spawning in Eagle Creek, a tributary of Woodland Creek in the fall of 2001 (Rector, 2002).

Table 3. Salmon and Winter Steelhead Distribution for Henderson Inlet Streams.

Stream Name	***Species***	***Uppermost Distribution River Mile (RM)***
Woodland Creek	Chinook salmon Coho salmon Chum salmon Winter steelhead Sockeye salmon	RM 3.10 RM 5.10 RM 5.00 RM 5.10 RM 4.40
Woodland Creek (tributaries) Fox Hollow Creek Jorgenson Creek Fox Creek Eagle Creek	 Coho salmon Coho salmon Chum salmon Coho salmon	 RM 0.40 RM 0.40 RM 0.30 RM 1.10
Woodard Creek	Coho salmon Chum salmon Winter steelhead	RM 7.00 RM 3.60 RM 7.00
Sleepy Creek	Coho salmon	RM 1.00
Dobbs Creek	Coho salmon Chum salmon	RM 1.50 RM 1.50

Washington State Conservation Commission report on Habitat Limiting Factors for WRIA 13 (Haring and Konovsky, 1999)

Shellfish Resources

Henderson Inlet is one of Puget Sound's most productive shellfish harvesting areas. In 1986, more that 250,000 pounds of oysters were harvested. In 1984, the Washington State Department of Health (DOH) changed the classification of 180 acres of shellfish growing area in Henderson Inlet from *Approved* to *Conditionally Approved*, citing contamination from rural nonpoint sources. At that time, the designated area was closed to shellfish harvest for five days following a rainfall of greater than one inch in a 24-hour period. In 1985, 120 acres in the southern portion of the *Conditionally Approved* area was reclassified to *Prohibited*.

In 1999, in response to declining water quality, DOH adjusted the criterion for the *Conditionally Approved* classification to the more restrictive 0.5" of rain in 24 hours. Based on the results of water samples collected between September 1996 and December 1999, DOH downgraded an additional eight acres of the *Conditionally Approved* area to *Prohibited* in November 2000 (Puget Sound Action Team, 2001). In 2001, an additional 300 acres of *Approved* shellfish growing area was downgraded to *Conditional Approved*.

In May 2005, DOH an additional 49 acres were reclassified from *Conditionally Approved* to *Prohibited*, moving the closure line north (Sargeant, D. et al., 2006).

What conditions did we find in the Woodland Creek Sub-watershed?

Woodland Creek drains 13,489 acres (21 sq miles) (see Figure 8, Woodland Creek Sub-watershed). Woodland Creek, the largest creek draining to Henderson Inlet flows through northeast Olympia and central Lacey before emptying into Henderson Inlet. Three lakes connected by extensive wetlands form a horseshoe-shaped chain which makes up the headwaters of Woodland Creek. Hicks Lake flows into Pattison Lake and then Long Lake; all three lie between 152 and 157 feet above sea level (USGS, 1999). From Long Lake to Martin Way, Woodland Creek includes one mile of perennial stream to Lake Lois. From Lake Lois to Martin Way, Woodland Creek is an intermittent channel that often dries during the summer. Downstream of Martin Way, several springs provide perennial flow to lower Woodland Creek. Woodland Creek tributaries include; College, Eagle, Palm, Fox, Jorgenson, and Quail creeks.

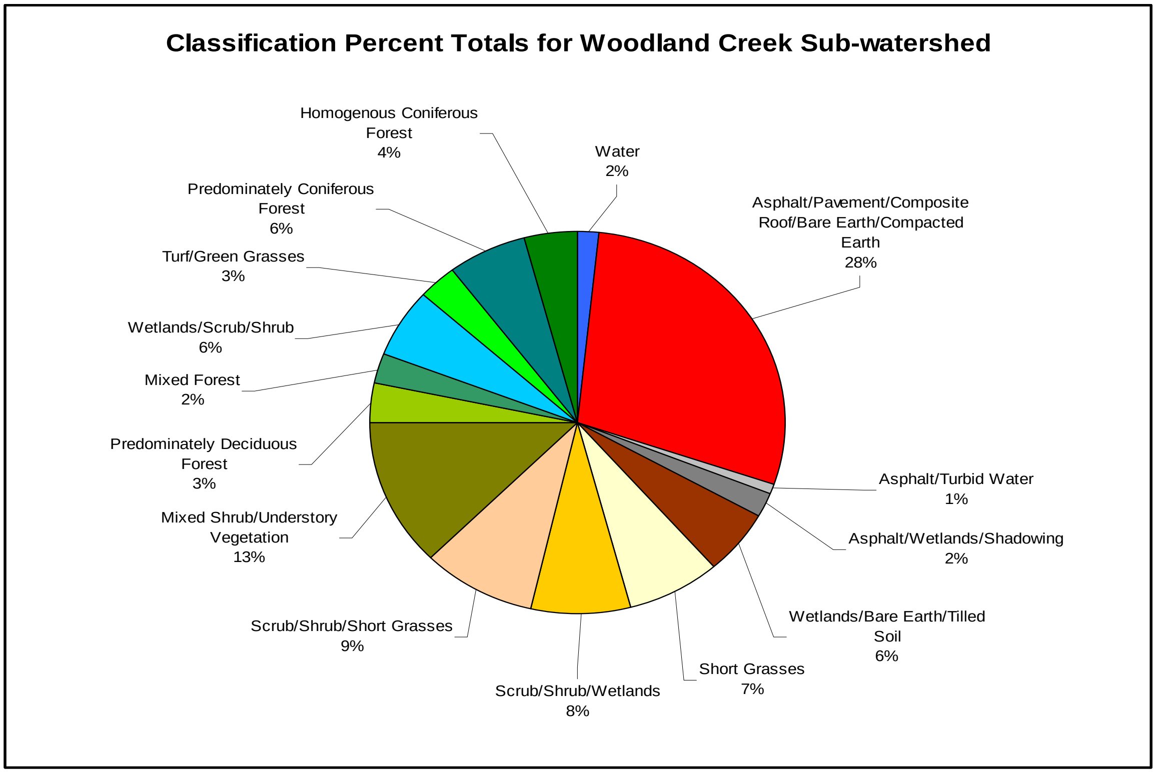
The Woodland Creek basin is one of the fastest growing areas in the county (Thurston County WWM, 1995; TRPC, 2006)). Ninety percent of the Woodland Creek watershed lies within an Urban Growth Area (UGA), primarily the City of Lacey, but also the City of Olympia. The basin still contains substantial areas of undeveloped forests though the dominant land use is suburban-density, residential development. Residential subdivisions are spreading rapidly in the area around the headwater lakes and near the mouth of the stream basin. Residential development is most dense in the southern (upper) portion of the basin. In 1987, approximately 80% of the lake shorelines and 16% of the creek shorelines in the Henderson Basin were developed (Thurston County WWM, 1995). Due to the rapid growth in this area, those percentages are higher today.

A description of Woodland and Woodard Creek basin geology, soils, hydrology, vegetation, fish habitat, and critical areas can be found in the Woodland and Woodard Creek Comprehensive Drainage Basin Plan (Thurston County WWM, 1995).

Current conditions

Twenty-eight percent of the Woodland Creek Sub-watershed is covered by urban land uses (see Figure 9 and 9a, Classification Percent Totals for Woodland Creek Sub-watershed). Residential uses are concentrated in the southern portion of the basin in the City of Lacey. Commercial and residential development has been increasing the past few years, and is expected to continue in the near future within the urban growth area (UGA) boundaries.

Figure 9a. Classification Percent Totals for Woodland Creek Sub-watershed



Land cover data from 2005 SPOT imagery.

Future conditions

Estimates provided by TRPC state that Woodland Creek Sub-watershed would increase to 28% in 2030. Their estimates include the area of Hicks and Pattison Lakes, which are excluded from this study, thus the discrepancy with the current 28% determined through land use classification completed in this study.

Hydrogeology and groundwater recharge

The headwaters of Woodland Creek begin in a series of three lakes; Hicks, Pattison, and Long lakes. In this study, only Long Lake was included based on the delineation using LiDAR.

Human alteration to the movement of water

The effects of human land use on the natural delivery of water to the Woodland Creek and its tributaries in the Woodland Creek Sub-watershed were characterized using the following landscape attributes: percent TIA, percent forest land, and percent wetland cover at the DAU scale. Results indicate that the Woodland Creek Sub-watershed is in a "not properly functioning" and "at risk" condition for the delivery of water (Figure 10, Condition of the Movement of Water.

Human alteration to the natural movement of sediment

The effects of human land use on the natural delivery of sediment to the Woodland Creek and its tributaries in the Woodland Creek Sub-watershed were characterized using the following landscape attributes: percent bare soils, road density, and percent unstable slopes at the DAU scale. However, because there are no forestry activities or unstable slopes in the sub-watershed, road density was the only applicable indicator. The result was an "at risk" for all but two DAUs located in the northern sub-watershed that are considered "properly functioning" (Figure 11, Condition of the Movement of Sediment).

Human alteration to the natural movement of large wood

The effects of human land use on the natural delivery and routing of large wood in the Woodland Creek and its tributaries were characterized using the following landscape attributes: percent forested riparian and average number of stream crossings per kilometer of stream at the DAU scale. Results indicate that the Woodland Creek Sub-watershed is primarily in an "at risk" condition for the delivery and routing of large wood. Exceptions include eight DAUs that are conditioned to be in "not properly functioning" and one DAU that is "properly functioning" (Figure 12, Condition of the Movement of Large Wood).

Human alteration to the natural movement of pollutants

The effects of human land use on the natural delivery and routing of pollutants in the Woodland Creek and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria and condition and extent of wetlands at the DAU scale. Results indicate that the Woodland Creek Sub-watershed is in an "at risk" condition for the delivery and routing of pollutants (Figure 13, Condition of the Movement of Pollutants). This was a default designation based on the regulatory requirement to restore the beneficial uses of the water body.

Human alteration to the natural movement of heat

The effects of human land use on the natural delivery and routing of heat in the Woodland Creek and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria, percent 67 meter riparian zone with mature canopy, road density, and percent TIA at the DAU scale. Results indicate that the Woodland Creek Sub-watershed is primarily in an "at risk" condition for the delivery and routing of large wood. The exception is two DAUs that are conditioned to be in "not properly functioning (Figure 14, Condition of the Movement of Heat).

Aquatic integrity

The effects of human land use on aquatic integrity in the Woodland Creek and its tributaries in the Woodland Creek Sub-watershed were characterized using the following landscape attributes: percent riparian forest, percent TIA, and available B-IBI scores at the DAU scale. Results indicate that the Woodland Creek Sub-watershed is in an “at risk” condition for aquatic integrity (Figure 15, Condition Map for Aquatic Integrity).

Habitat Connectivity

Forest covers only 15 percent of the Woodland Creek Sub-watershed, concentrated in northern sub-watershed. Most of the remaining forest is in rural residential areas and the sub-watershed’s primary land cover is composed of increasingly dense urban, agricultural and commercial areas. The Woodland Creek Sub-watershed is considered “not properly functioning” and “at risk”, with only one DAU considered “properly functioning” for habitat connectivity and has a very low probability of supporting habitat connectivity for organisms that rely upon the predevelopment condition of the landscape (Figure 16, Condition Map for Habitat Connectivity).

Ecological Benefit

All DAUs within the study area having ecological and biological processes that are considered “at risk” under current land use conditions were identified for further consideration. DAUs in the “at risk” category for multiple key ecological and biological processes are assumed to provide the greatest potential to maximize environmental benefits when restored. The process scores are then ranked according to the weight criteria, and converted to a high, medium, or low process rank. Woodland Creek has primarily high and moderate ecological benefit, with only four DAUs ranked as low (Figure 17, Woodland Creek Sub-watershed Weighted Processes).

Environmental Benefit

Once all the DAUs were ranked for their ecological benefit, all natural resource sites were ranked for their environmental benefit. Only the high and medium scoring sites were used in further evaluation to develop natural resource, fish habitat, and stormwater preservation and restoration sites.

Table 4. Environmental Benefit Ranking of Natural Resource Sites

Woodland Creek Potential Restoration Sites				
Rank	Wetland	Riparian	Floodplain	Total
High	1	4	0	5
Medium	30	67	4	101
Low	102	30	10	142

The following wetlands, riparian and floodplain sections describe the environmental benefit ranking of the natural resource sites.

Wetlands

Prior to human alteration, wetlands in the Woodland Creek Sub-watershed totaled approximately 1080 acres and represented eight percent of the 13,490 acres sub-watershed. We estimate that approximately 263 acres, or twenty-four percent of the sub-watershed, are currently wetlands or degraded/destroyed wetlands with some restoration potential.

Based on photo interpretation, we estimate that approximately 817 acres of wetlands in the Woodland Creek Sub-watershed are considered properly functioning (having little or no hydrologic or vegetative alteration). Less than eight percent (83 acres) of the 1080 acres of current or potential wetlands have evidence of hydrologic alteration, while thirty-six percent (386 acres) have some level of vegetative alteration. When both hydrologic and vegetative alterations are considered together, 390 acres (thirty-six percent) of the 1080 current or potential wetland acres in the Woodland Creek Sub-watershed are considered altered.

Of the 1080 acres of current or potential wetland acres, dominant hydrogeomorphic wetland classes in the Woodland Creek Sub-watershed include 784 acres of depressional wetlands (seventy-three percent) and 127 acres of riverine wetlands (twelve percent). Anadromous fish are estimated to have access to seven percent (78 acres) of the 1080 acres of the current or potential wetlands in this sub-watershed (Figure 18, Wetlands Condition).

Riparian condition

Urban development has encroached on approximately 322 acres of the 67-meter wide riparian corridors in the Woodland Creek basin. Of the 322 acres, approximately 260 acres have some restoration potential (Figure 19, Riparian Areas Condition).

Floodplain Condition

Urban development has encroached on approximately 328 acres of the 67-meter wide riparian corridors in the Woodland Creek basin. Of the 328 acres, approximately 153 acres have some restoration potential (Figure 20, Floodplain Areas Condition).

Natural Resource Sites

All potential natural resource sites were evaluated for their environmental benefit and ranked high, medium, or low. Following evaluation, a total of 31 wetland (521 acres), 71 riparian (248 acres), and four floodplain (70 acres) sites were of high or medium environmental benefit (Figure 21. Woodland Creek Ecological Processes and Resource Site Scoring).

Fish Habitat

There were 170 sites evaluated for habitat value to salmonid fish species. These sites were then used to evaluate potential natural resource sites that have the potential to be stormwater retrofits sites. While the goal is to use natural resource sites as stormwater retrofit sites, we don't want to compromise high quality fish habitat sites (Figure 22. Woodland Creek Condition of Fish Habitat).

Stormwater Retrofit

All the natural resource sites were evaluated for stormwater retrofit sites (Figure 23. Woodland Creek Potential Stormwater Restoration Sites).

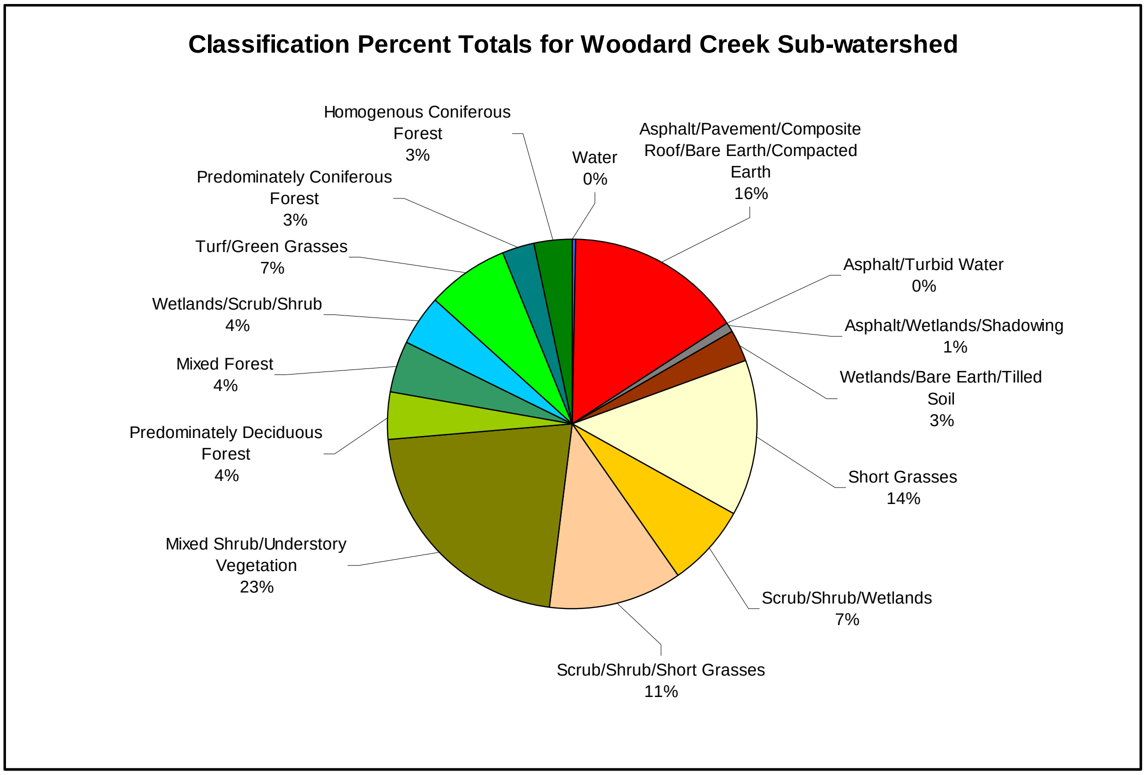
What conditions did we find in the Woodard Creek Sub-watershed?

Woodard Creek drains 5537 acres (8.7 sq miles) (see Figure 24, Woodard Creek Sub-watershed). Woodard Creek, the second largest creek, is 7.5 miles in length and drains a basin of 5090 acres (Thurston County PHSS and WWM, 2000). Ground water feeds a large wetland at the headwaters of Woodard Creek just south of I-5 at the Pacific Avenue interchange. Industrial and commercial development on Fones Road surrounds the wetland at the creek's headwaters. Large portions of high-density commercial areas in Lacey and Olympia, including the South Sound Mall and Olympia Square, drain into the wetland through the Fones Road ditch. The mouth of Woodard Creek is an estuarine wetland that is currently protected as a natural area by the Washington Department of Natural Resources.

Current conditions

Sixteen percent of the Woodard Creek Sub-watershed is covered by urban land uses (see Figure 25, Current Land Use in the Woodard Creek Sub-watershed). Residential uses are concentrated in the southern portion of the basin, mainly in the City of Olympia.

Figure 25a. Classification Percent Totals in the Woodard Creek Sub-watershed.



Land cover data from 2005 SPOT imagery.

Human alteration to the movement of water

The effects of human land use on the natural delivery of water to the Woodard Creek and its tributaries in the Woodard Creek Sub-watershed were characterized using the following landscape attributes: percent TIA, percent forest land, and wetlands cover at the DAU scale. Results indicate that the entire Woodard Creek Sub-watershed is in a “at risk” condition for the delivery of water (Figure 26, Condition of the Movement of Water).

Human alteration to the natural movement of sediment

The effects of human land use on the natural delivery of sediment to the Woodard Creek and its tributaries in the Woodard Creek Sub-watershed were characterized using the following landscape attributes: percent bare soils, road density, and percent unstable slopes at the DAU scale. However, because there are no forestry activities or unstable slopes in the sub-watershed, only road density is applicable to characterize sediment movement. The result was that all DAUs were considered “at risk” for the movement of sediment (Figure 27, Condition of the Movement of Sediment).

Human alteration to the natural movement of large wood

The effects of human land use on the natural delivery and routing of large wood to the Woodard Creek and its tributaries in the Woodard Creek Sub-watershed were characterized using the following landscape attributes: percent forested riparian and average number of stream crossings per kilometer of stream at the DAU scale. Results indicate that the Woodard Creek Sub-watershed is primarily in an "at risk" condition for the delivery and routing of large wood. Exceptions include three DAUs that are conditioned to be in "not properly functioning" and two DAUs "properly functioning". (Figure 28, Condition of the Movement of Large Wood).

Human alteration to the natural movement of pollutants

The effects of human land use on the natural delivery and routing of pollutants in the Woodard Creek and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria and condition and extent of wetlands at the DAU scale. Results indicate that the Woodard Creek Sub-watershed is in an "at risk" condition for the delivery and routing of pollutants (Figure 29, Condition of the Movement of Pollutants). This was a default designation based on the regulatory requirement to restore the beneficial uses on the water body.

Human alteration to the natural movement of heat

The effects of human land use on the natural delivery and routing of heat in the Woodard Creek and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria, percent 67 meter riparian zone with mature canopy, road density, and percent TIA at the DAU scale. Results indicate that the Woodard Creek Sub-watershed is primarily in an "at risk" condition for the delivery and routing of large wood. The exception is three DAUs that are conditioned to be in "not properly functioning (Figure 30, Condition of the Movement of Heat).

Aquatic integrity

The effects of human land use on aquatic integrity in the Woodard Creek and its tributaries in the Woodard Creek Sub-watershed were characterized using the following landscape attributes: percent riparian forest, percent TIA, and available B-IBI scores at the DAU scale. There is only one sample site in the Woodard Creek Sub-watershed. Results indicate that the Woodard Creek Sub-watershed is predominantly in an "at risk" condition for aquatic integrity (Figure 31, Condition Map for Aquatic Integrity).

Habitat Connectivity

Forest covers only 36 percent (2020 forested acres) of the Woodard Creek Sub-watershed, concentrated along the riparian corridor. The sub-watershed's primary land cover is composed of increasingly dense urban, agricultural and commercial areas. The

Woodard Creek Sub-watershed is considered "at risk", with the exception three DAUs "not properly functioning" and one DAU "properly functioning" for Habitat Connectivity and has some probability of supporting habitat connectivity for organisms that rely upon the predevelopment condition of the landscape (Figure 32, Woodard Creek Sub-watershed Habitat Connectivity).

Ecological Benefit

All DAUs within the study area having ecological and biological processes that are considered "at risk" under current land use conditions were identified for further consideration. DAUs in the "at risk" category for multiple key ecological and biological processes are assumed to provide the greatest potential to maximize environmental benefits when restored. The process scores are then ranked according to the weight criteria, and converted to ranking a high, medium, or low process rank. All DAUs in the Woodard Creek Sub-watershed are rated high ecological benefit (Figure 33, Woodard Creek Sub-watershed Weighted Processes)

Environmental Benefit

Once all the DAUs were ranked for their ecological benefit, all natural resource sites were ranked for their environmental benefit. Only the high and medium scoring sites were used in further evaluation to develop natural resource, fish habitat, and stormwater preservation and restoration sites.

Table 5. Environmental Benefit Ranking of Natural Resource Sites

Woodard Creek Potential Restoration Sites				
Rank	Wetland	Riparian	Floodplain	Total
High	2	0	0	2
Medium	27	33	6	66
Low	45	11	5	61

The following wetlands, riparian and floodplain sections describe the environmental benefit ranking of the natural resource sites.

Wetlands

Prior to human alteration, wetlands in the Woodard Creek Sub-watershed totaled approximately 1036 acres and represented nineteen percent of the 5,537 acres sub-watershed. We estimate that approximately 537 acres, or fifty-two percent of the sub-watershed, are currently wetlands or degraded/destroyed wetlands with some restoration potential.

Based on photo interpretation, we estimate that approximately 565 acres of wetlands in the Woodard Creek Sub-watershed are considered properly functioning (having little or no hydrologic or vegetative alteration). Approximately thirty-seven percent (385 acres) of the 1036 acres of current or potential wetlands have evidence of hydrologic alteration, while forty-four percent (452 acres) have some level of vegetative alteration. When both hydrologic and vegetative alterations are considered together, 470 acres (forty-five percent) of the 1036 current or potential wetland acres in the Woodard Creek Sub-watershed are considered altered.

Of the 1036 acres of current or potential wetland acres, dominant hydrogeomorphic wetland classes in the Woodard Creek Sub-watershed include 619 acres of depressional wetlands (sixty percent) and 401 acres of riverine wetlands (thirty-nine percent). Anadromous fish are estimated to have access to thirty-seven percent (381 acres) of the 1036 acres of the current or potential wetlands in this sub-watershed (Figure 34, Wetlands Condition).

Riparian condition

Urban development has encroached on approximately 122 acres of the 67-meter wide riparian corridors in the Woodard Creek basin. Of the 122 acres, approximately 107 acres have some restoration potential (Figure 35, Riparian Areas Condition).

Floodplain Condition

Urban development has encroached on approximately 305 acres of the 67-meter wide riparian corridors in the Woodard Creek basin. Of the 305 acres, approximately 152 acres have some restoration potential (Figure 36, Floodplain Areas Condition).

Natural Resource Sites

All potential natural resource sites were evaluated for their environmental benefit and ranked high, medium, or low. Following evaluation, a total of 29 wetland (521 acres), 33 riparian (100 acres), and six floodplain (135 acres) sites were of high or medium environmental benefit (Figure 37 Woodard Creek Ecological Processes and Resource Site Scoring).

Fish Habitat Sites

There were 107 sites evaluated for habitat value to salmonid fish species. Of these, a total of 87 sites were ranked high or moderate. These sites were then used to evaluate potential natural resource sites that have the potential to be stormwater retrofits sites. While the goal is to use natural resource sites as stormwater retrofit sites, we want to avoid high quality fish habitat sites (Figure 38 Condition of Fish Habitat).

Stormwater Retrofit Sites

All the natural resource sites were evaluated for stormwater retrofit sites (Figure 39, Woodard Creek Potential Stormwater Restoration Sites).

What conditions did we find in the East Henderson Sub-watershed?

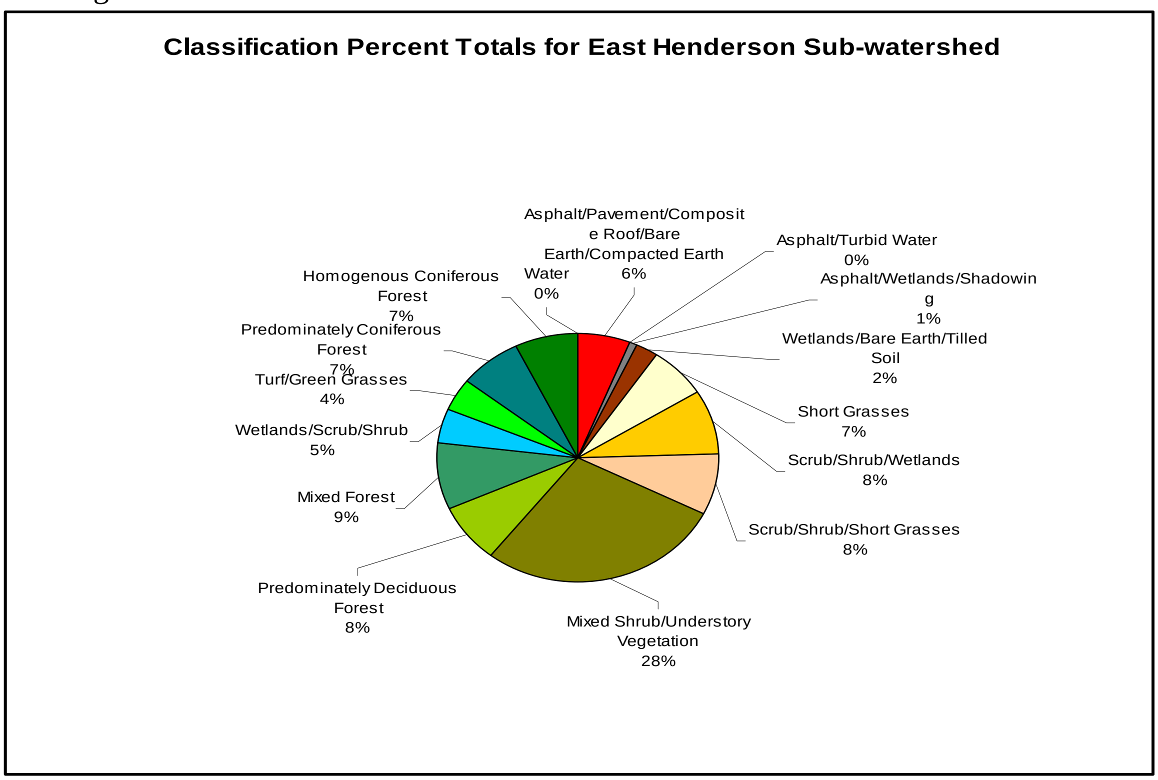
East Henderson Sub-watershed drains 2432 acres (3.8 sq miles) and contains four drainages; Dobbs Creek, Swayne Creek, and two unnamed tributaries (see Figure 40, East Henderson Creek Sub-watershed).

Dobbs Creek is 1.5 miles in length, with primary land uses being rural, residential, and agricultural. The creek flows through wooded terrain as well as open pastures near the headwaters (Thurston County PHSS and WWM, 1999). Pleasant Forest Campground, a large recreational vehicle park, is located along the mid-stem of the creek. Near the mouth of the creek, 1983-98 flows ranged from 0.3 to 16.2 cfs averaging 3.3 cfs (Thurston County PHSS and WWM, 2001). Coho and chum salmon use Dobbs Creek (Thurston County WWM, 1997).

Current conditions

Seven percent of the East Henderson Creek Sub-watershed is covered by urban land uses (see Figure 41 and 41a, Classification Percent Totals for East Henderson Sub-watershed). Residential uses are scattered throughout the Sub-watershed in unicorporated Thurston County.

Figure 41a. Classification Percent Totals for East Henderson Sub-watershed



Land cover data from 2005 SPOT imagery.

Human alteration to the movement of water

The effects of human land use on the natural delivery of water to the East Henderson and its tributaries in the East Henderson Sub-watershed were characterized using the following landscape attributes: percent TIA, percent forest land, and wetlands cover at the DAU scale. Results indicate that the entire East Henderson Sub-watershed is in an "at risk" condition for the delivery of water (Figure 42, Condition of the Movement of Water).

Human alteration to the natural movement of sediment

The effects of human land use on the natural delivery of sediment to the East Henderson tributaries and Inlet were characterized using the following landscape attributes: percent bare soils, road density, and percent unstable slopes at the DAU scale. However, because there are no forestry activities or unstable slopes in the sub-watershed, only road density was used as an indicator to characterize sediment movement. All the DAUs are "at risk", with the exception of one DAU that is "properly functioning" which contains the headwaters of Dobbs Creek for the movement of sediment (Figure 43, Condition of the Movement of Sediment).

Human alteration to the natural movement of large wood

The effects of human land use on the natural delivery and routing of large wood to the East Henderson and its tributaries in the East Henderson Sub-watershed were characterized using the following landscape attributes: percent forested riparian and average number of stream crossings per kilometer of stream at the DAU scale. Results indicate that the East Henderson Sub-watershed is primarily in a "at risk" condition for the delivery and routing of large wood, with the exception of one DAU that is conditioned to be in a "not properly functioning" (Figure 44, Condition of the Movement of Large Wood).

Human alteration to the natural movement of pollutants

The effects of human land use on the natural delivery and routing of pollutants in the East Henderson and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria and condition and extent of wetlands at the DAU scale. Results indicate that the East Henderson Sub-watershed is in an "at risk" condition for the delivery and routing of pollutants (Figure 45, Condition of the Movement of Pollutants). This was a default designation based on the regulatory requirement to restore the beneficial uses on the water body.

Human alteration to the natural movement of heat

The effects of human land use on the natural delivery and routing of heat in the East Henderson and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria, percent 67 meter riparian zone with mature canopy, road density, and percent TIA at the DAU scale. Results indicate that the East Henderson Sub-watershed is primarily in an “at risk” condition for the delivery and routing of large wood. The exception is one DAU that is conditioned to be in a “not properly functioning” condition (Figure 46, Condition of the Movement of Heat).

Aquatic integrity

The effects of human land use on aquatic integrity in the East Henderson and its tributaries in the East Henderson Sub-watershed were characterized using the following landscape attributes: percent riparian forest, percent TIA, and available B-IBI scores at the DAU scale. However, there are no sample sites in the Sub-watershed. (Figure 47, Condition Map for Aquatic Integrity).

Habitat Connectivity

Forest covers fifty-nine percent (1433 acres) of the East Henderson Sub-watershed, concentrated in small, scattered patches throughout the Sub-watershed. The East Henderson Sub-watershed is considered “at risk” for Habitat Connectivity and has the potential of supporting habitat connectivity for organisms that rely upon the predevelopment condition of the landscape (Figure 48, Condition of Habitat Connectivity).

Ecological Benefit

All DAUs within the study area having ecological and biological processes that are considered “at risk” under current land use conditions were identified for further consideration. DAUs in the “at risk” category for multiple key ecological and biological processes are assumed to provide the greatest potential to maximize environmental benefits when restored. The process scores are then ranked according to the weight criteria, and converted to ranking a high, medium, or low process rank. The East Henderson Sub-watershed has a high ecological benefit (Figure 49, East Henderson Sub-watershed Ecological Benefits).

Environmental Benefit

Once all the DAUs were ranked for their ecological benefit, all natural resource sites were ranked for their environmental benefit. Only the high and medium scoring sites were used in further evaluation to develop natural resource, fish habitat, and stormwater preservation and restoration sites.

Table 6. Environmental Benefit Ranking of Natural Resource Sites

East Henderson Potential Restoration Sites				
Rank	Wetland	Riparian	Floodplain	Total
High	2	0	na	2
Medium	5	10	na	15
Low	37	5	na	42

The following wetlands, riparian and floodplain sections describe the environmental benefit ranking of the natural resource sites.

Wetlands

Prior to human alteration, wetlands in the East Henderson Sub-watershed totaled approximately 342 acres and represented nineteen percent of the 2,433 acres sub-watershed. We estimate that approximately 95 acres, or twenty-eight percent of the sub-watershed, are currently wetlands or degraded/destroyed wetlands with some restoration potential.

Based on photo interpretation, we estimate that approximately 246 acres of wetlands in the East Henderson Sub-watershed are considered properly functioning (having little or no hydrologic or vegetative alteration). Approximately twenty-five percent (84 acres) of the 342 acres of current or potential wetlands have evidence of hydrologic alteration, while twenty-eight percent (96 acres) have some level of vegetative alteration. When both hydrologic and vegetative alterations are considered together, 96 acres (twenty-eight percent) of the 342 current or potential wetland acres in the East Henderson Sub-watershed are considered altered.

Of the 342 acres of current or potential wetland acres, dominant hydrogeomorphic wetland classes in the East Henderson Sub-watershed include 222 acres of depressional wetlands (sixty-five percent) and 114 acres of riverine wetlands (thirty-three percent). Anadromous fish are estimated to have access to two percent (six acres) of the 342 acres of the current or potential wetlands in this sub-watershed (Figure 50, Wetlands Condition).

Riparian condition

Urban development has encroached on approximately 66 acres of the 67-meter wide riparian corridors in the East Henderson Sub-watershed. Of the 66 acres, approximately 59 acres have some restoration potential (Figure 51, Riparian Areas Condition).

Floodplain Condition

There are no identified floodplain areas in the East Henderson Sub-watershed.

Natural Resource Sites

All potential natural resource sites were evaluated for their environmental benefit and ranked high, medium, or low. Following evaluation, a total of seven wetland (79 acres), 10 riparian (59 acres) were of high or medium environmental benefit. There were no floodplain sites in East Henderson to evaluate (Figure 52, East Henderson Ecological Processes and Resource Site Scoring).

Fish Habitat Sites

There were 58 sites evaluated for habitat value to salmonid fish species. Of these, a total of 14 sites were ranked high or moderate. These sites were then used to evaluate potential natural resource sites that have the potential to be stormwater retrofits sites. While the goal is to use natural resource sites as stormwater retrofit sites, we want to avoid high quality fish habitat sites (Figure 53 Condition of Fish Habitat).

Stormwater Retrofit Sites

All the natural resource sites were evaluated for stormwater retrofit sites (Figure 54, East Henderson Potential Stormwater Restoration Sites).

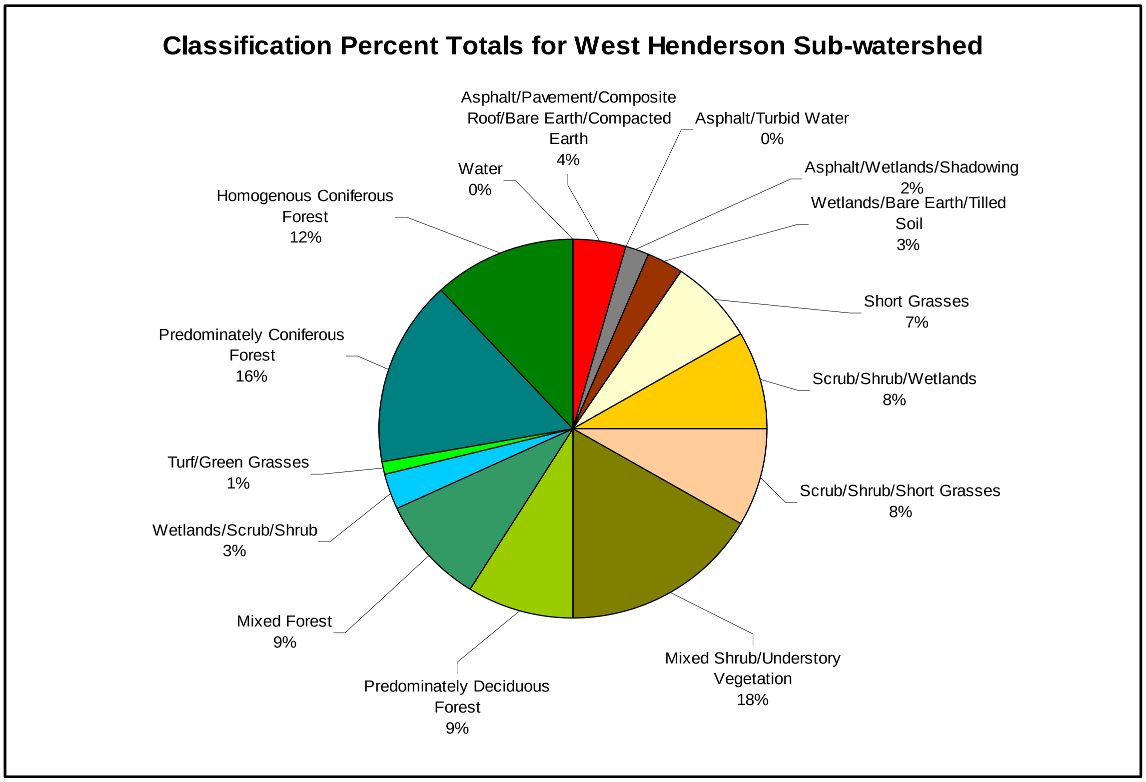
What conditions did we find in the West Henderson Sub-watershed?

West Henderson drains 1340 acres (2.1 sq miles) and comprises 5% of the study area (see Figure 55, West Henderson Sub-watershed). It includes Sleepy Creek and an unnamed tributary. Sleepy Creek is 1.1 miles in length, with primary land uses of rural, residential, and agricultural. This creek originates in a wetland, flows through a series of gullies and wooded ravines, and enters Henderson Inlet at Chapman Bay (Thurston County PHSS and WWM, 1999). Coho and Chum salmon use Sleepy Creek (Thurston County WWM, 1997). Near the mouth of the creek, 1987-98 flows ranged from no flow to 64 cfs averaging 5.0 cfs (Thurston County PHSS and WWM, 2001).

Current conditions

Four percent of the West Henderson Sub-watershed is covered by urban land uses (see Figure 56, Classification Percent Totals for West Henderson Sub-watershed). The primary land uses are rural, residential, and agricultural.

Figure 56a. Classification Percent Totals for West Henderson Sub-watershed



Land cover data from 2005 SPOT imagery.

Human alteration to the movement of water

The effects of human land use on the natural delivery of water to the West Henderson and its tributaries in the West Henderson Sub-watershed were characterized using the following landscape attributes: percent TIA, percent forest land cover, and wetland cover at the DAU scale. Results indicate that the entire West Henderson Sub-watershed is in an "at risk" condition for the delivery of water, with the exception of one DAU that contains the unnamed creek which is "not properly functioning (Figure 57, Condition of the Movement of Water).

Human alteration to the natural movement of sediment

The effects of human land use on the natural delivery of sediment to the West Henderson and its tributaries in the West Henderson Sub-watershed were characterized using the following landscape attributes: percent bare soils, road density, and percent unstable slopes at the DAU scale. However, because there are no forestry activities or unstable slopes in the sub-watershed, the results indicate that the Sub-watershed is "at risk", with the exception of one DAU. Interestingly, the one DAU properly functioning contains Libby Road and all the associated development (Figure 58, Condition of the Movement of Sediment).

Human alteration to the natural movement of large wood

The effects of human land use on the natural delivery and routing of large wood to the West Henderson and its tributaries in the West Henderson Sub-watershed were characterized using the following landscape attributes: percent forested riparian and average number of stream crossings per kilometer of stream at the DAU scale. Results indicate that the West Henderson Sub-watershed is primarily in a "at risk" condition for the movement of large (Figure 59, Condition of the Movement of Large Wood).

Human alteration to the natural movement of pollutants

The effects of human land use on the natural delivery and routing of pollutants in the West Henderson and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria and condition and extent of wetlands at the DAU scale. Results indicate that the West Henderson Sub-watershed is in an "at risk" condition for the delivery and routing of pollutants (Figure 60, Condition of the Movement of Pollutants). This was a default designation based on the regulatory requirement to restore the beneficial uses on the water body.

Human alteration to the natural movement of heat

The effects of human land use on the natural delivery and routing of heat in the West Henderson and its tributaries were characterized using the following landscape attributes: Extent of 303(d) listed water bodies for nutrients, toxicants, and bacteria, percent 67 meter riparian zone with mature canopy, road density, and percent TIA at the DAU scale. Results indicate that the West Henderson Sub-watershed is primarily in an "at risk" condition for the delivery and routing of heat (Figure 61, Condition of the Movement of Heat).

Aquatic integrity

The effects of human land use on aquatic integrity in the West Henderson and its tributaries in the West Henderson Sub-watershed were characterized using the following landscape attributes: percent riparian forest, percent TIA, and available B-IBI scores at the DAU scale. There is no BIBI data for this sub-watershed (Figure 62, Condition Map for Aquatic Integrity).

Habitat Connectivity

Forest covers sixty-two percent (834 total forested acres) of the West Henderson Sub-watershed, concentrated. The West Henderson Sub-watershed is primarily in an "at risk" condition for Habitat Connectivity, with the exception of one DAU that is "properly functioning". This sub-watershed has the potential of supporting organisms that rely upon the predevelopment condition of the landscape (Figure 63, Condition Map for Habitat Connectivity).

Ecological Benefit

All DAUs within the study area having ecological and biological processes that are considered “at risk” under current land use conditions were identified for further consideration. DAUs in the “at risk” category for multiple key ecological and biological processes are assumed to provide the greatest potential to maximize environmental benefits when restored. The process scores are then ranked according to the weight criteria, and converted to ranking a high, medium, or low process rank. West Henderson has high ecological benefit (Figure 64, West Henderson Sub-watershed Ecological Benefit).

Environmental Benefit

Once all the DAUs were ranked for their ecological benefit, all natural resource sites were ranked for their environmental benefit. Only the high and medium scoring sites were used in further evaluation to develop natural resource, fish habitat, and stormwater preservation and restoration sites.

Table 7. Environmental Benefit Ranking of Natural Resource Sites

West Henderson Potential Restoration Sites				
Rank	Wetland	Riparian	Floodplain	Total
High	0	0	0	0
Medium	3	12	1	16
Low	8	0	0	8

The following wetlands, riparian and floodplain sections describe the environmental benefit ranking of the natural resource sites.

Wetlands

Prior to human alteration, wetlands in the West Henderson Sub-watershed totaled approximately 289 acres and represented nineteen percent of the 1,349 acres sub-watershed. We estimate that approximately 12 acres, or four percent of the sub-watershed, are currently wetlands or degraded/destroyed wetlands with some restoration potential.

Based on photo interpretation, we estimate that approximately 274 acres of wetlands in the West Henderson Sub-watershed are considered properly functioning (having little or no hydrologic or vegetative alteration). Approximately two percent (five acres) of the 289 acres of current or potential wetlands have evidence of hydrologic alteration, while five percent (15 acres) have some level of vegetative alteration. When both hydrologic and vegetative alterations are considered together, 15 acres (five percent) of the 289 current or potential wetland acres in the West Henderson Sub-watershed are considered altered.

Of the 289 acres of current or potential wetland acres, dominant hydrogeomorphic wetland classes in the West Henderson Sub-watershed include 280 acres of depressional wetlands (ninety-seven percent) and nine acres of slope wetlands (three percent). Anadromous fish are estimated to have access to zero percent of the 289 acres of the current or potential wetlands in this sub-watershed (Figure 65, Wetlands Condition).

Riparian condition

Urban development has encroached on approximately 61 acres of the 67-meter wide riparian corridors in the West Henderson Sub-watershed. All 61 acres have some restoration potential (Figure 66, Riparian Areas Condition)

Floodplain Condition

Urban development has encroached on approximately 80 acres of floodplain in the West Henderson Sub-watershed. All 80 acres have some restoration potential (Figure 67, Floodplain Areas Condition).

Natural Resource Sites

All potential natural resource sites were evaluated for their environmental benefit and ranked high, medium, or low. Following evaluation, a total of three wetland (11 acres), 12 riparian (61 acres), and one floodplain (80 acres) sites were of high or medium environmental benefit (Figure 68, West Henderson Ecological Processes and Resource Site Scoring).

Fish Habitat Sites

There were 12 sites evaluated for habitat value to salmonid fish species. Of these, a total of seven sites were ranked high or moderate. These sites were then used to evaluate potential natural resource sites that have the potential to be stormwater retrofits sites. While the goal is to use natural resource sites as stormwater retrofit sites, we want to avoid high quality fish habitat sites (Figure 69, Condition of Fish Habitat).

Stormwater Retrofit Sites

All the natural resource sites were evaluated for stormwater retrofit sites (Figure 70, West Henderson Potential Stormwater Restoration Sites).

References

Aqua Terra, 1994. Woodland and Woodard future conditions, Thurston County, Washington, Final Results.

Ames and Maschner 1999

Angermeier, P. L. and I. Schlosser. 1995. Conserving aquatic biodiversity: beyond species and populations. In: Evolution and the Aquatic Ecosystem: Defining Unique Units in Population Conservation. Nielsen, J. L. (ed.) American Fisheries Society Symposium 17:402-414

Brascher, J. 2006. Personal Communication

Cleland, Bill, 2000. Sanitary Survey of the Nisqually Reach Conditionally Approved Commercial Shellfish Growing Area. Washington State Department of Health, Office of Shellfish Programs.

Derek B. Booth, James R. Karr, Sally Schauman, Christopher P. Konrad, Sarah A. Morley, Marit G. Larson, Stephen J. Burges (2004) Reviving Urban Streams: Land Use, Hydrology, Biology, And Human Behavior. Journal of the American Water Resources Association 40 (5), 1351–1364.

Dinicola, R. S. 2001. Validation of a Numerical Modeling Method for Simulating Rainfall-Runoff Relations for Headwater Basins in Western King and Snohomish Counties, Washington. U.S. Geological Survey Water Supply Paper 2495.

Drost, B.W., G.L. Turney, N.P. Dion, and M.A. Jones, 1998. Hydrology and quality of ground water in Northern Thurston County, Washington. U.S. Geological Survey Water-Resources Investigation Report 92-4109, 230 p. + 5 plates.

Easterly, R.T, et al. 2005. Wet Prairie Swales of the South Puget Sound, Washington. The Nature Conservancy, Olympia WA 98501

Ebersole, J. L., W. Liss, and C. Frissell. 1997. Restoration of stream habitats in the Western United States: restoration as re-expression of habitat capacity. Environmental Management 21(1):1-14

Frissell, C. A. 1996. A new strategy for watershed restoration and recovery of Pacific salmon in the Pacific Northwest. In: Watershed and Salmon Habitat Restoration Projects: Guidelines for Managers of State Trust Lands. Dominguez, L. (ed.). Washington Department of Natural Resources. Olympia, WA 90 pp.

Gersib, R., B. Aberle, L. Driscoll, J. Franklin, B. Haddaway, T. Hilliard, K. Lautz, J. Neugebauer-Rex, J. Park, A. Perex, R. Schanz, L. Van Natta, A. Wald, and B. Wood., 2004. Enhancing Transportation Project Delivery through Watershed Characterization Operational Draft Methods Document. Washington State Department of Transportation, Washington State.

Haring, D. and J. Konovsky, 1999. *Washington State Conservation Commission Salmon Habitat Limiting Factors Final Report Water Resource Inventory Area 13*. Washington State Conservation Commission, Olympia, WA.

Karr, J. R. 1995. Clean water is not enough. Illahee 11(1-2):51-59.

Montgomery, D. R., G. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Bulletin 31(3):369-386.

Pacific Groundwater Group, 1998. McAllister Springs Wellfield-Phase II supplemental analysis of pumping effects and proposed mitigation for the City of Olympia. September.

Pacific Groundwater Group, 2000. City of Lacey McAllister Creek Seepage Inflow Study. 10 p. October.

Pacific Groundwater Group and Brown and Caldwell, 2007. Current Conditions Report Woodland Creek Pollutant Load Reduction Project

Park, J., 2007. Personal Communication

Rector, Julie, 2002. Memorandum to Debby Sargeant Dated September 26, 2002. City of Lacey, Lacey, WA.

Reeves, G. H., L. Benda, K. Burnett, P. Bisson, and J. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. In: Evolution and the Aquatic Ecosystem: Defining Unique Units in Population Conservation. Nielsen, J. L. (ed.). American Fisheries Society Symposium 17:334-349.

Sargent, D., et al., 2006. Henderson Inlet Watershed Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Temperature Total Maximum Daily Load Study)

Thurston County Department of Water and Waste Management, 1995. Woodland and Woodard Creek Comprehensive Drainage Basin Plan. Storm and Surface Water Program, Olympia, WA.

Thurston Regional Planning Council, 2006. South Puget Sound Indicators Report.

Thurston County Public Health and Social Services and Water and Waste Management Departments, 2000. Thurston County Water Resources Monitoring Report: 1998-1999 Water Year.

Thurston County Public Health and Social Services and Water and Waste Management Departments, 2001. Historic Water Quality Data Provided in Electronic Form by Thurston County Water Resources: 1988-2001 Water Years.

Thurston County Department of Water and Waste Management, 1997. Henderson Inlet Drainage Management System Final Report, CCWF Grant Project TAX90209, Thurston County, Olympia, WA.

USGS, 1998. Hydrology and quality of ground water in Northern Thurston County, Washington. U.S. Geological Survey. Water Resources Investigations Report 92-9104 (Revised), 230 p. + 5 plates.

USGS, 1999. Conceptual model and numerical simulation of the ground-water-flow system in the unconsolidated sediments of Thurston County, Washington. U.S. Geological Survey. Water Resources Investigations Report 99-4165, 254 p.

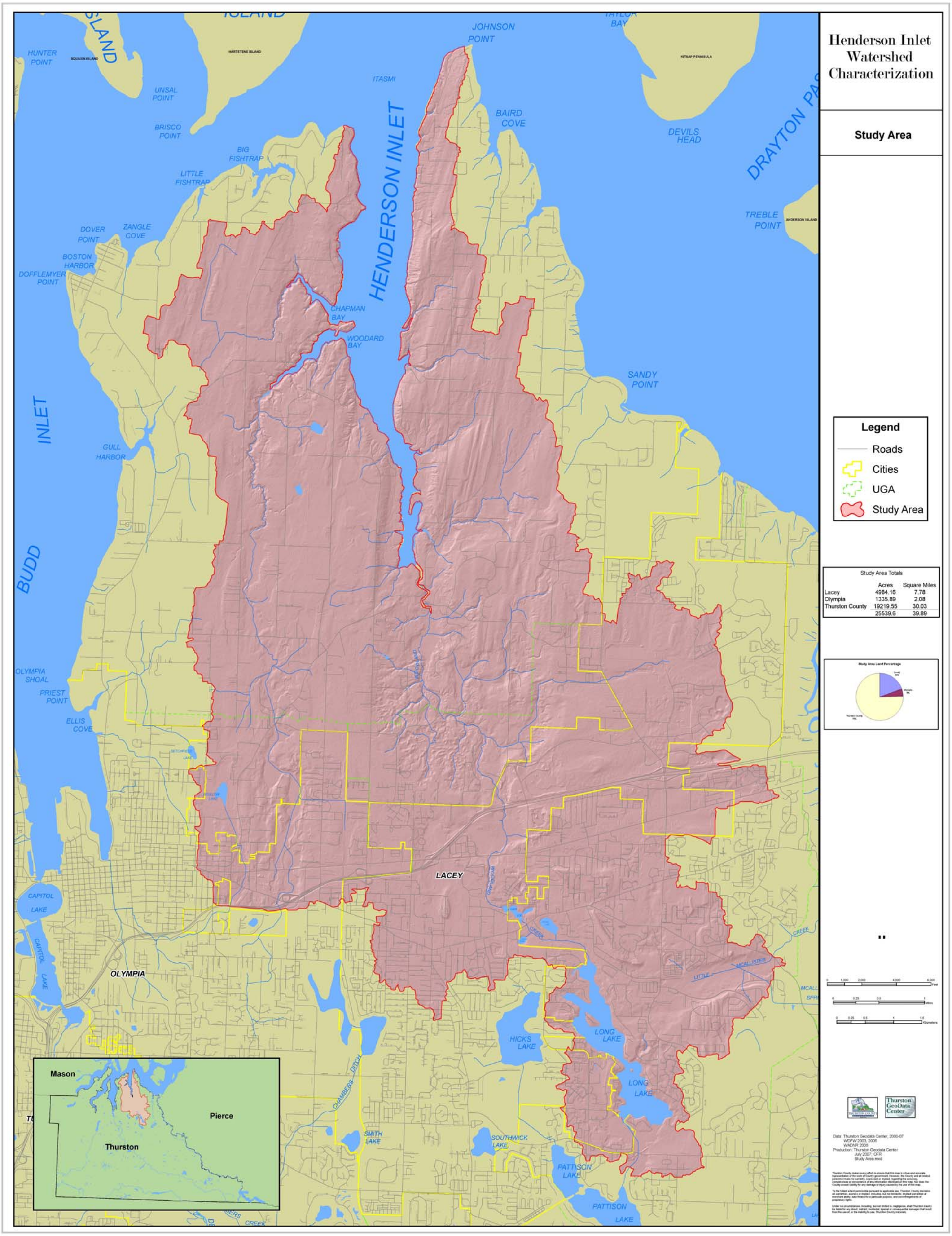
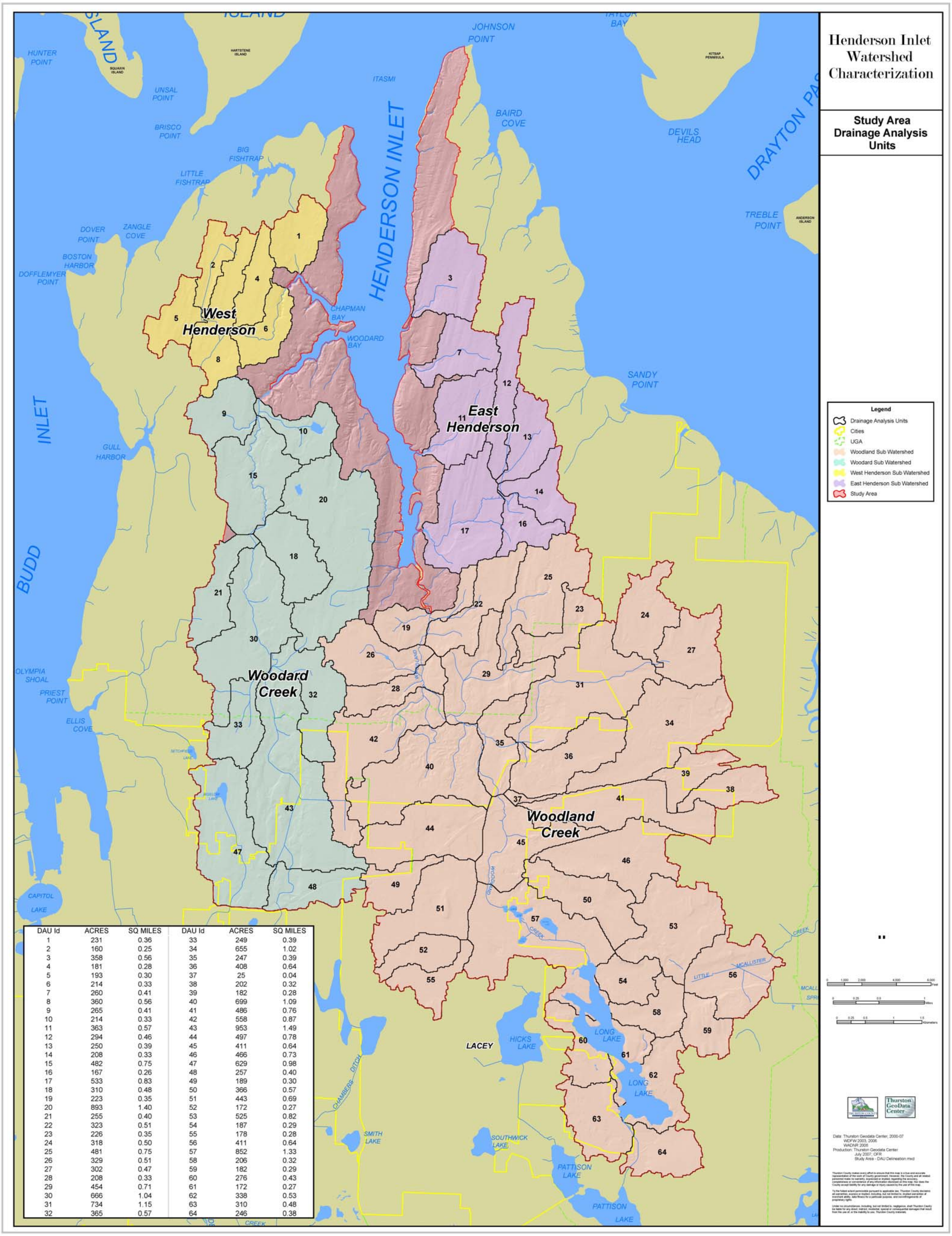


Figure 1 Henderson Inlet Study Area



DAU Id	ACRES	SQ MILES	DAU Id	ACRES	SQ MILES
1	231	0.36	33	249	0.39
2	160	0.25	34	655	1.02
3	358	0.56	35	247	0.39
4	181	0.28	36	408	0.64
5	193	0.30	37	25	0.04
6	214	0.33	38	202	0.32
7	260	0.41	39	182	0.28
8	360	0.56	40	699	1.09
9	265	0.41	41	486	0.76
10	214	0.33	42	558	0.87
11	363	0.57	43	953	1.49
12	294	0.46	44	497	0.78
13	250	0.39	45	411	0.64
14	208	0.33	46	466	0.73
15	482	0.75	47	629	0.98
16	167	0.26	48	257	0.40
17	533	0.83	49	189	0.30
18	310	0.48	50	366	0.57
19	223	0.35	51	443	0.69
20	893	1.40	52	172	0.27
21	255	0.40	53	525	0.82
22	323	0.51	54	187	0.29
23	226	0.35	55	178	0.28
24	318	0.50	56	411	0.64
25	481	0.75	57	852	1.33
26	329	0.51	58	206	0.32
27	302	0.47	59	182	0.29
28	208	0.33	60	276	0.43
29	454	0.71	61	172	0.27
30	666	1.04	62	338	0.53
31	734	1.15	63	310	0.48
32	365	0.57	64	246	0.38

Figure 2 Henderson Inlet Study Area Drainage Analysis Units

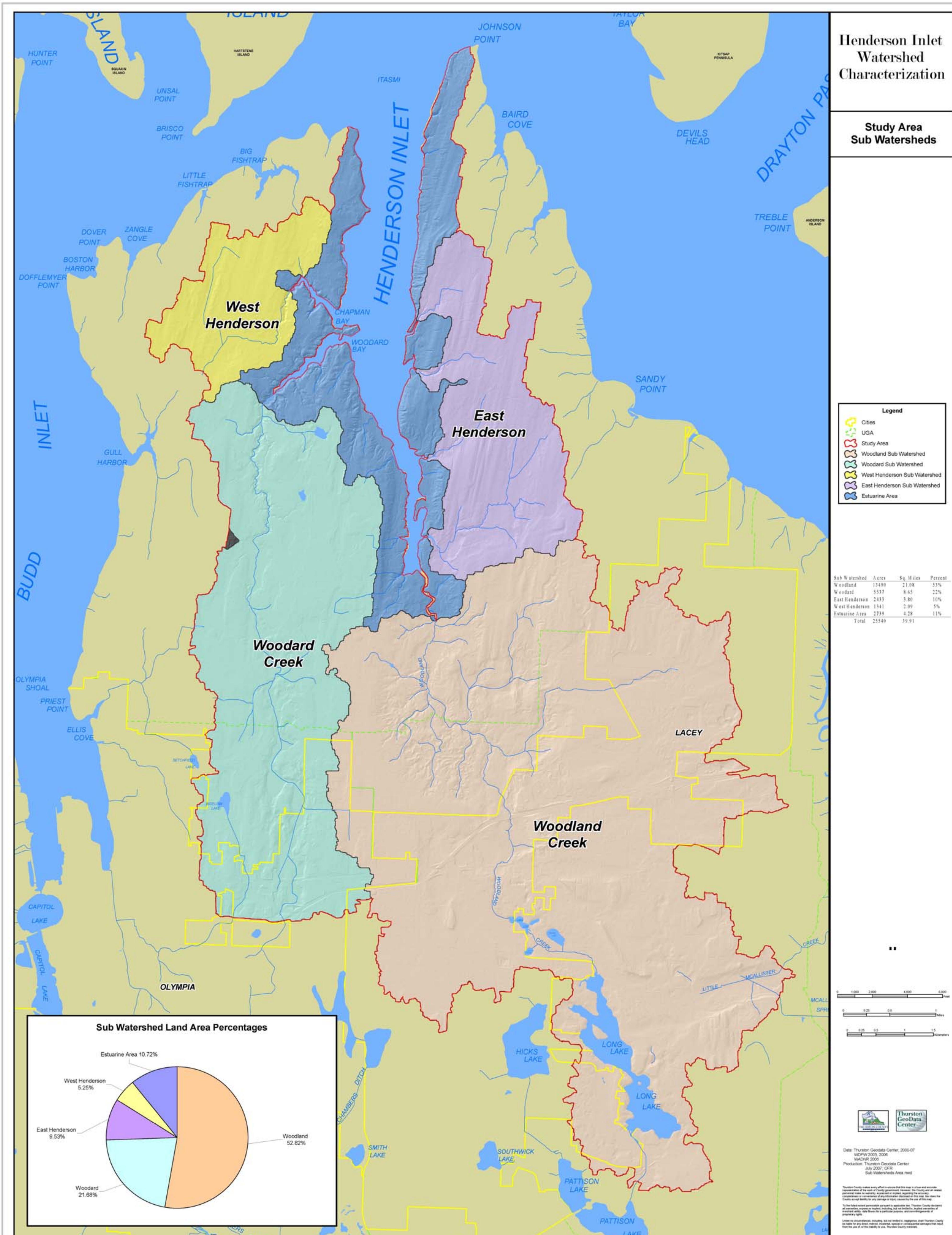


Figure 3 Henderson Inlet Study Area Sub-watersheds

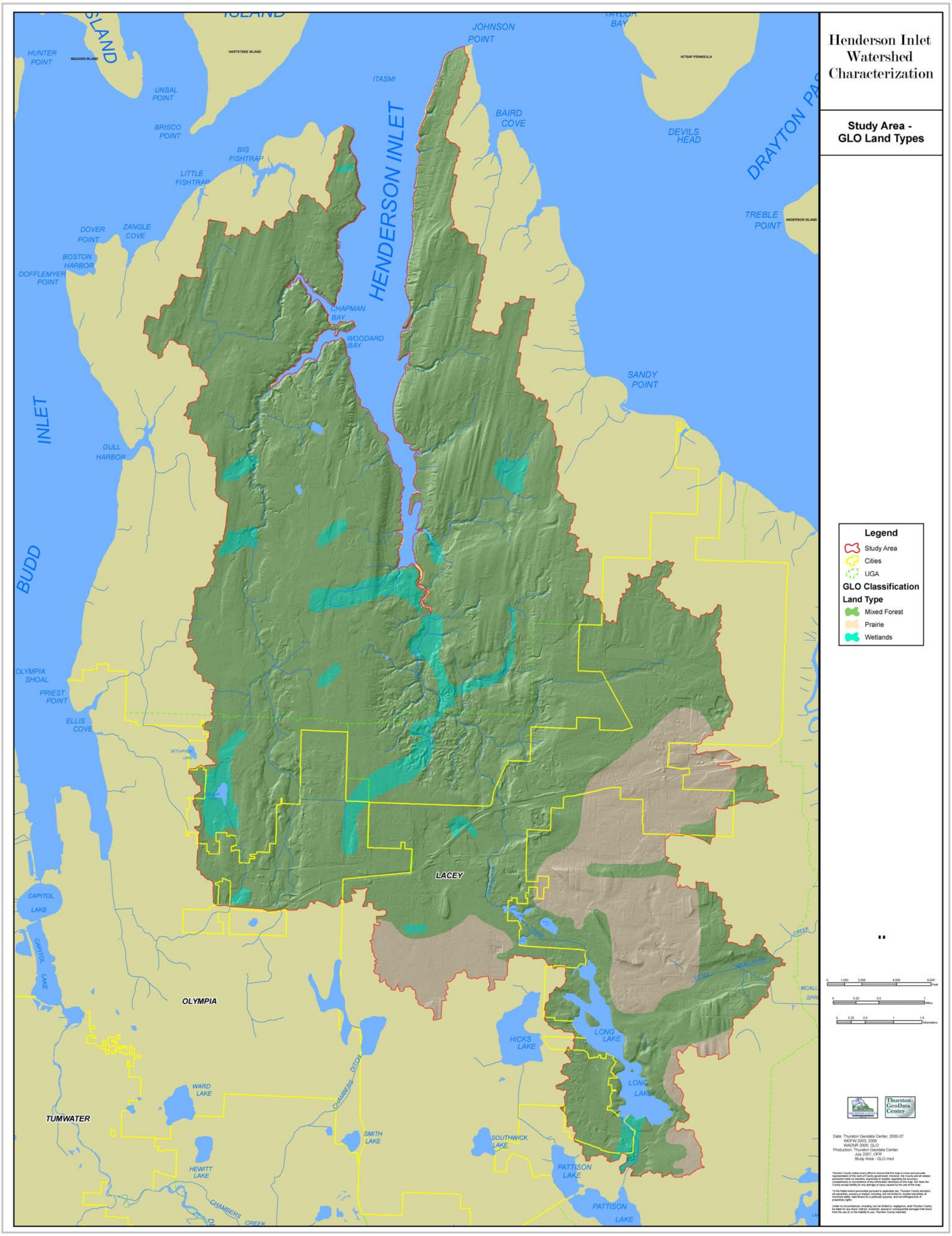


Figure 4 Henderson Inlet General Land Office Survey

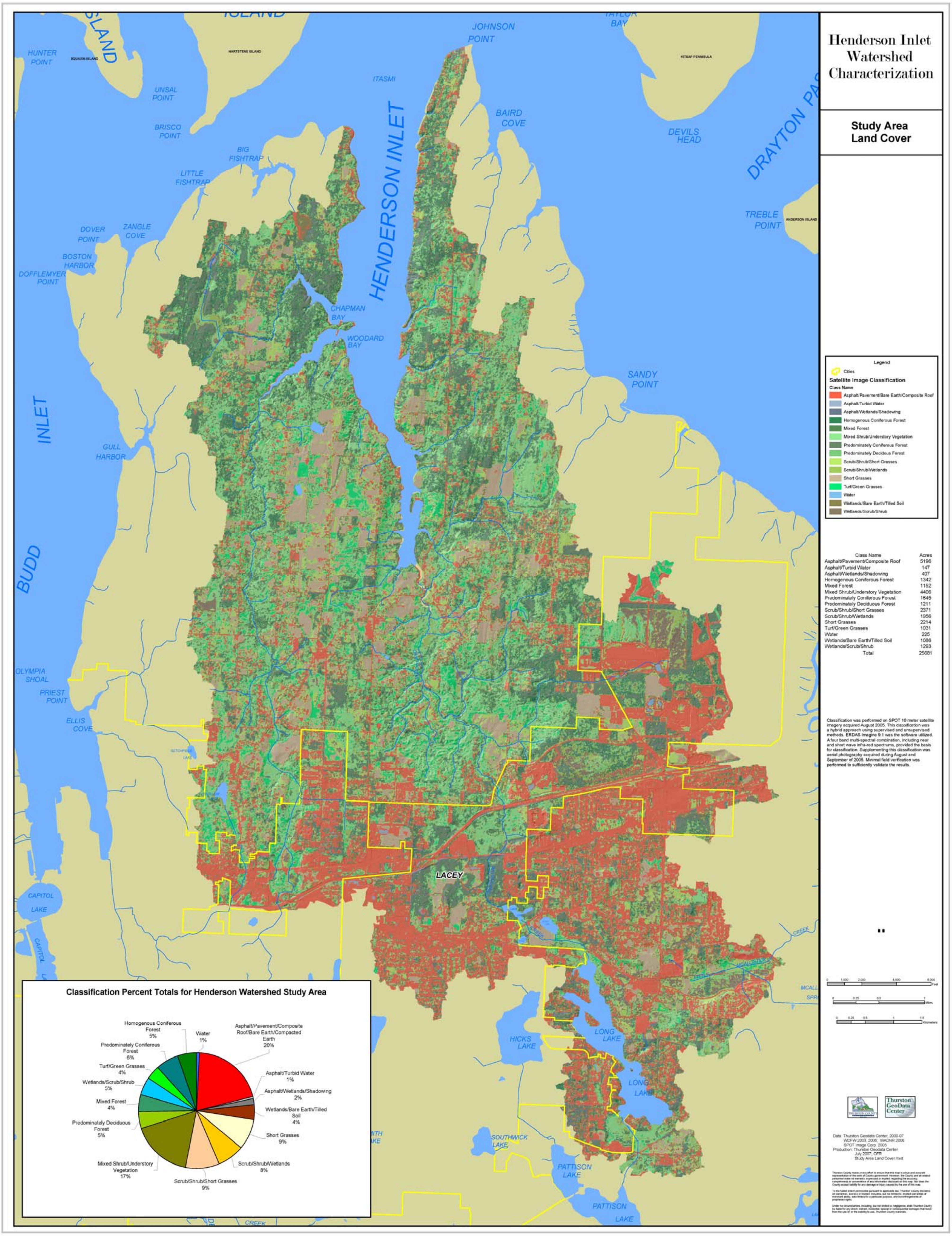


Figure 5 Henderson Inlet Watershed Study Area Land Cover

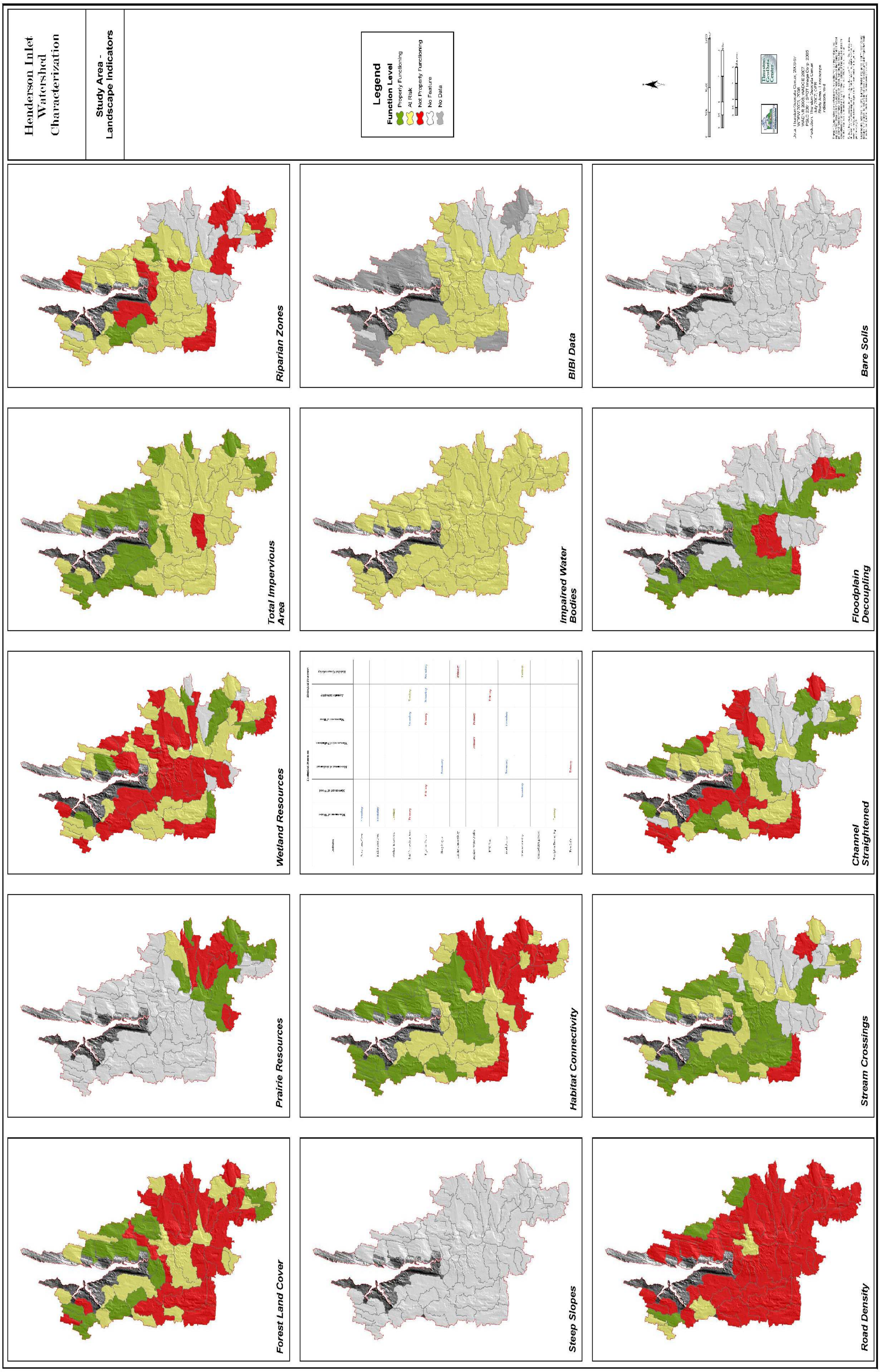


Figure 6 Henderson Inlet Watershed Study Area Landscape Indicators

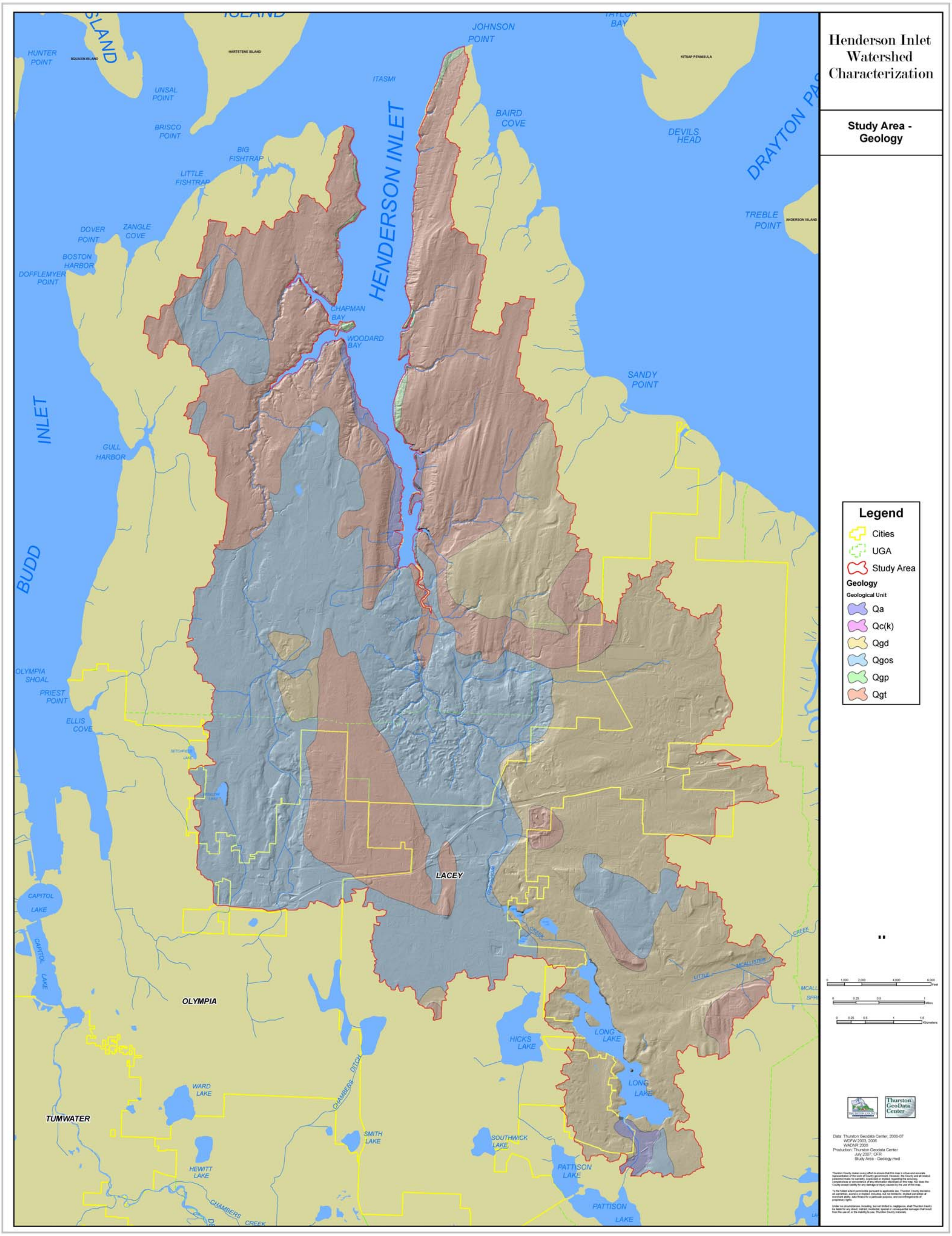


Figure 7 Henderson Inlet Study Area Geology