

Geodesign for Water Quality Management

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Abstract

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Water quality poses a serious challenge to a community's well-being, whether that of natural or human ecosystem communities. Nonpoint source pollution is the main cause of water quality problems in the USA since point sources have been remediated after the Clean Water Act was instituted in 1972. Land use policies play an important role to guide land development and subsequently influencing water quality. Diverse water use groups, including interested and affected parties (residents in specialist groups and residents in general), technical specialists (planners and scientists), and executive decision makers (water managers and elected officials) all have stakes at risk and roles to play concerning water quality improvement. A comprehensive set of tools to predict the impact of nonpoint source pollution are needed to inform about the relationship between land use policies and water quality. Stakeholder involvement is needed in watershed management to foster credible decision making in land use policy development and water quality improvement as part of watershed management. The research goal focuses on how land use affects nonpoint source pollution and how nonpoint source pollution affects water quality in the Green-Duwamish Watershed of Puget Sound basin, while considering the potential for stakeholder involvement in water quality management. The research achieves a goal for developing a Geodesign Framework for Water Quality Improvement (GeoFWQI). The

framework makes use of a nonpoint source pollution model called OpenNSPECT to simulate total nitrogen in the Green-Duwamish Watershed. A land use change modeling software called ENVISION is used to investigate the impact of total nitrogen from three land use policy scenarios: Status Quo (SQ), Managed Growth (MG), and Unconstrained Growth (UG) for the year 2040. The results of simulating pollution runoff in the OpenNSPECT model revealed that the MG scenario has the least contribution of total nitrogen and the UG scenario has the most contribution of total nitrogen across the watershed. Agriculture areas contribute the most to total nitrogen concentration which are mostly located in the middle elevations of the WRIA9; while forest areas contribute the least to total nitrogen concentration which are mostly located in the upper elevations of the watershed.

The GeoFWQI was tested by implementing a role play modeling activity in the GEOG 514 GIS Problem Solving course within the Master of Geographic Information Systems for Sustainability Management program at the University of Washington. The results from the role play modeling activity produced several findings. Public participation is perhaps not appropriate for all stages of decision making. Public involvement requires time and money that might or might not be available. There appears to be conflict between land owners and policy makers. Research about color map design related to stakeholder interpretations is needed to better understand how water quality is understood. The GeoFWQI that organizes how stakeholders can contribute in every phase of the water quality modeling requires further investigation. This research contributes to using a land-use/cover model together with results from a nonpoint source pollution model to create a social-ecological system for improving water quality management decision making. The application to the Green-Duwamish watershed in Puget Sound provided a complex context for evaluation. The GeoFWQI offers a vehicle to drive the integration of the biophysical and social

sciences to better understand policy makers and public stakeholders in what is occurring at the watershed scale.

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DEDICATION

To my beloved parents

CHAPTER 1: Introduction

1.1 Significance of Water Quality Problems

Water is one of the most important natural resources for sustaining life; both fresh water and marine waters are threatened by human and natural hazards, in different places and at different times. Consequently, water quality is a serious concern to community well-being, be these natural or human ecosystem communities. Nonpoint source pollution is a main cause of water quality problems (Ongley, 2010; Thornton, 1999; US Environmental Protection Agency - USEPA, 1994; Young, 1989). Diverse water use groups, including interested and affected parties (citizens in specialist groups and citizens in general, hereafter referred to as public stakeholders), technical specialists (planners and scientists), and executive decision makers (water managers and elected officials) all have stakes at risk and roles to play concerning water quality (National Research Council 1996, 2005). Therefore, it is very important for public stakeholders to have a voice and engage in the process of water quality management. Local people participate as volunteers in water monitoring programs, water conservation efforts, and act as advisors to decision makers. People can modify their behaviors to safeguard water resources perhaps if they better understand their influence on water quality. The importance of public participation seems to be increasingly recognized by researchers and decision-makers (Luchette and Crawford, 2008; Korfmacher, 2001; Clark, 1996). The expertise, value, and concern of stakeholder groups and preferences of citizens could be integrated to generate consensual decision making (Renn, et.al, 1993, Webler, et.at., 1955)

Nonpoint source pollution is the main cause of water quality problem in the States (USEPA, 2013). Water body collects oil and grease, pesticides, industrial chemical, and other things from roads and land that contribute to reduce the water quality in Puget Sound (DOE, 2014). The USEPA has established nonpoint source pollution as a priority. The pollution stems from land use/covers that either naturally or technologically emit contaminants such as nitrogen, phosphorus, zinc, mercury, and erosion sedimentation (DOE 2009a). Interest in understanding impacts of land use/cover on nonpoint source pollution has existed for years, but extensive examination is a significant challenge. Examining connections between land use/cover and water quality impacts through the use of geographic information systems (GIS) and water quality modeling– based technology has not be undertaken until recently because of recent improvements in software.

A geographic information system (GIS) can integrate data from diverse measurements across the world and facilitate knowledge production through analysis and synthesis. Integrating GIS with water quality modeling is one way to extend the analysis, investigating situations with water quality problems in watershed areas. Local knowledge/voice-based observations and reflections may be a significant source of data, information, and/or evidence included in the process of constructing knowledge via both GIS and water quality modeling.

Puget Sound is surrounded by almost 2,500 miles of shoreline and is famous for its abundant resources. The diversity of mountain ranges, forests, shoreline, deltas, bluffs, mudflats, tideflats, and wetlands supports webs of species ranging from impressive orcas to microscopic algae. The great promise and potential of Puget Sound is based on its natural resources and industries, including tourism and recreation. The growth and development in Puget Sound are stressing the

health of the ecosystem. Pollution from the past and present sources flowing into Puget Sound poses a threat that can spread through the food web initiating a decrease in the health of marine and fresh water species and finally affecting humans as well. Puget Sound has faced significant challenges, from water pollution and sediments burdened with toxic pollutants to noticeable declines in populations of salmon, orcas, marine birds and fish. The threat of habitat loss steadily increases as growth of urbanization, agriculture, and other uses results in conversion of landscape from natural species cover to a human-altered landscape (PSAT, 2007). Consequently, many natural resources in Puget Sound have been reduced. The decline of some fish and wildlife populations are signs that Puget Sound is threatened.

Threats to water quality have been emerging in the Puget Sound Basin for decades. Since the Puget Sound is the second largest estuary in the US by way of surface area of the water, and largest by volume of water, watersheds in the Puget Sound basin are prime candidates for study about how water quality modeling and GIS can be integrated to support water quality management.

1.2 Research Goal and Research Questions

The general goal of this research is to investigate how to enhance water quality management by combining water quality modeling, land use/ land cover modeling, and public participation GIS (PPGIS). This research focuses on nonpoint source (NPS) pollution effects on water quality in Puget Sound, how land use/land cover contributes to NPS pollution, and how public stakeholders can get involved and support NPS pollution management. The following two research questions focus the effort.

Question 1: How can a nonpoint source pollution model and a land use/cover model support decision makers in water quality management, providing a picture of quantity/quality and spatial distribution of water pollution in Puget Sound? Since we are using a modeling process, databases for both models need to be developed to support the modeling. Washington State has delineated watershed areas— Water Resource Inventory Areas (WRIAs)—to support watershed management for improvement of salmon habitat restoration. This research has selected the Water Resource Inventory Area 9 (WRIA9): Green-Duwamish Watershed as the study area.

Question 2: How can PPGIS be a vehicle to drive the integration of the biophysical and social sciences data in order to better inform policy makers and public stakeholders on water quality management? Linking the above two models with PPGIS would enable public stakeholders to get involved in nonpoint source pollution management. In order to get stakeholders involved, water quality modeling for nonpoint source pollution shall be developed in WRIA9 using the OpenNSPECT model developed by Coastal Services Center personnel of the National Oceanic and Atmospheric Administration (NOAA) (Eslinger, et.al, 2012). A conceptual framework characterizing the stakeholder involvement in water quality modeling process has been created in order to contextualize the processes. The framework and the models were used to create a role-play scenario used in a class-room setting to better understand the role of modeling and participation in water quality management.

1.3 Structure of the dissertation

This dissertation is organized into seven chapters. Chapter 1 presents an introduction to the research background, research goal, and research questions. Chapter 2 reviews relevant literatures on nonpoint source pollution, watershed modeling, land use/land cover modeling,

public participation GIS, roles for stakeholder involvement in watershed management, and contributions of stakeholder involvement in watershed modeling. In Chapter 3, the conceptual base of the geodesign framework and conceptual framework for nonpoint source pollution, watershed modeling, and stakeholder involvement integrative system are presented. Chapter 4 describes the Geodesign Framework for Water Quality Improvement (GeoFWQI) in representation and process modeling phases including the model (OpenNSPECT) set up, the application to the WRIA9 and the model calibration and validation. Chapter 5 examines the GeoFWQI in evaluation, change, impact, and decision modeling phases. In Chapter 6, role play modeling activities for WRIA9 are examined in the context of a classroom setting. Chapter 7 concludes the dissertation with a description of how the study presented answers for the research questions and presents the contributions that this research makes to technology and social science. This chapter also includes the limitation of the research and recommendations for further study. Appendices are provided at the end of this dissertation to give related information used in this study.

Chapter 2: Literature Review

Water plays a significant role in diverse realms of life, including but not limited to farming, mining, industry, recreation, and maintaining a healthy ecosystem. Water quality is a serious concern (Luchette and Crawford, 2008) for which citizens and other water users all have roles to play concerning water quality, both passively and actively. Healthy water is necessary for all plants and animals that live in watersheds and coastal areas. Healthy water has a balanced quantity of nutrients and has normal fluctuations in salinity and temperature. Healthy water has an abundance of dissolved oxygen so aquatic animals can breathe with little suspended sediment so underwater plants receive enough sunlight to grow (Clark, 1996). Since water quality is an important aspect of water as a public commodity for domestic life, it is essential to engage stakeholder public groups in the process of water quality management. Understanding a water quality situation and what causes water quality problems in a watershed is a fundamental aspect of addressing water quality management (DEWHA, 2009). Once decision makers, technical specialists, and public stakeholders understand a situation of a water quality problem in an area, and can assess environmental value, they can then design plans, implement those plans through programs, and establish monitoring programs that implement projects on the ground. Those monitoring projects feedback to enhance understanding of situations and the process starts over again.

2.1 Nonpoint Source Pollution

The Clean Water Act (CWA) was enacted in 1972 to serve as the foundation for water quality regulation in the United States. The main objective of the CWA is to “restore and maintain the

chemical, physical, and biological integrity of the Nation's waters."¹ That law focused on the control of point source pollution. A point source of pollution is "any discernible, confined and discrete conveyance... from which pollutions are discharged."² Water quality in the United States has improved dramatically since the adoption of the CWA (Byrne, 2007). Although water quality has been improved greatly from point source control, there is still much remaining water pollution from nonpoint pollution sources (Byrne, 2007; Karigomba, 2009) such as runoff from urbanized areas, as well as agriculture, mining, and logging activities. As a result, the CWA was amended in 1987 to address nonpoint sources of pollution with section 319 of the amended Act. According to section 319, each state must develop and implement a management program for nonpoint source pollution to improve water quality of state waters.³ Although the CWA is a US Federal act, states have much of the authority for implementing it, with the assistance from USEPA including funding and technical support.

Sources of nonpoint source (NPS) pollution include "land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification" (USEPA, 1994). NPS pollution was defined to mean "any source of water pollution that does not meet the legal definition of *point source* in section 502(14) of the CWA" (USEPA, 1994). Examples of pollutants from NPS include sediment from construction sites and farms; fertilizers from agriculture fields; nutrient from livestock and pet waste, heavy metals from industrial and residential areas, and oil and grease from urban runoff and manufacturing (USEPA, 1994; McClenahan, 2007).

Understanding the hydrological cycle is very important for investigating NPS pollution. The factors that define the water movement include precipitation, evaporation, infiltration,

¹ CWA § 101(a), 33 U.S.C. § 1251 (a).

² CWA § 502(14), 33 U.S.C § 1362(14).

³ CWA § 319, 33 U.S.C § 1329(b)(1).

transpiration, surface runoff, and sub-surface runoff (Thornton, 1999). These factors have influence on the amount of NPS pollution. NPS pollution causes water quality degradation and contamination in aquatic ecosystems, which affects drinking water and aquatic wildlife (Ongley, 2010; Thornton, 1999; USEPA, 1994; Young, 1989). Unlike point source pollution, NPS is caused by the movement of rainfall or snowmelt over or through land surfaces, transporting natural and anthropogenic pollutants, eventually to the receiving water downslope such as lakes, rivers, wetlands, and finally coastal waters.

As the US Federal government later recognized greater environmental impacts, particularly in coastal areas, the Congress and U.S. EPA set additional and more stringent management requirements by creating the “Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters” (USEPA, 1993) under the section 6217 of the Coastal Zone Act Reauthorization Amendments. Section 6217 indicates that states and tribes are required to develop coastal zone management programs including coastal nonpoint source control program administered with U.S. EPA and the National Oceanic and Atmospheric Agency (NOAA). The Guidance document indicates the appropriate management guidelines to control NPS pollution in the coastal zone including agriculture, urban area, forestry, marinas, recreational boating, and hydromodification (USEPA, 1993). In 1976 Washington was the first state with a federally approved state Coastal Zone Management (CZM) Program. Washington’s Water Quality Management Plan to Control Nonpoint Source of Pollution was developed in 2000 and updated in 2005 through a collaborative effort involving several agencies. The main agency responsible is the Washington Department of Ecology (Ecology). The plan aims to identify nonpoint sources of pollution, set strategy for protecting and improving water quality

from nonpoint source pollution, and outline methods for evaluating the progress in each watershed (DOE, 2009b).

The U.S. EPA identifies watershed management requirements in the *Handbook for Developing Watershed Plans to Restore and Protect Our Water*, including both technical and implementation parts (McClenahan, 2007). The technical part involves identification, measurement, and monitoring. The implementation part includes policy making and implementation of those policies (USEPA, 2008). State and local watershed managers must address these technical and implementation parts when developing a NPS plan in a specific drainage basin. Identification, estimation, and monitoring of NPS pollution are the main components in the technical part. To meet the technical requirements, watershed modeling can support decision makers, technical specialists, and citizen stakeholders to address the complex spatial and temporal relationship within a watershed.

2.2 Water Quality Modeling

Water quality models are being used more often now than ever before. However, because this research is about how public stakeholders can make use of models, it is important to start with a simple question: What is a model? A model is “an idealized and structured representation of the real” (Johnston *et al.*, 2000 p. 508). Models are a type of tool, and are used in combination with many other assessment techniques. Models can be physically-based, mathematically-based, or other-based. In general, models are representations of systems and/or processes (Okano, 2009). Actual miniature physical representations of natural systems were some of the oldest forms of models. Mathematical models are also representations of systems in a series of mathematical equations. These equations in a model containing the number, form, and interconnections can

range from very simple to highly sophisticated (Butcher *et al.*, 2008). Models provide for efficiency in representing the real world.

Water quality modeling is one among many types of assessments used in watershed management and planning. Replicating the movement of water through a watershed is the key objective of water quality modeling. Water affects many important aspects of a watershed, especially water quality (Arnold *et al.*, 1998). Water affects the types of plants that grow, which is based on the amount of water available. It affects how pollutants in the system get transported, either down into the groundwater or overland into the surface water. Many water quality models have been developed to reflect an understanding of watershed systems. They aim to represent aspects of complex hydrological processes in watersheds to serve water quality managers, enable decision makers to better understand watershed systems, and to support suitable and sustainable decisions regarding pollution control and prevention that maintain and preserve watershed ecosystems (Krysanova *et al.*).

A nonpoint source model (NPS model) is a model that uses estimates of the amount of water, sediment, and pollutants in a watershed. It can be rather complex and require knowledge of several continuing processes (Butcher *et al.*, 2008). The aim of the model is to estimate pollutant load to a receiving water body by analyzing various characteristics of the waters' contributing areas. There are many factors that can affect surface water quality in a watershed, and a NPS model supports decision-making with identifying what these factors are and how they are interacting with other factors, natural or anthropogenic. Topography and surface geology defined as natural characteristic of the watershed can affect surface water quality.

A NPS model starts with representing water movement using precipitation and snow melt data. In this process, the model includes the factors of water evaporation, surface runoff, and/or infiltration. Water does not infiltrate through impervious (land cover) surfaces within areas, e.g. paved parking lots, therefore, only evaporation and surface runoff are considered in these areas. Next, the model calculates pollutant movement by simulating the movement of particles, e.g., soil sediment, whereby such particles commonly carry pollutants. Finally, the movement of nonpoint source pollutants is represented in association with water flow and particulate matter (Anand *et al.*, 2007). Examples of NPS models include N-SPECT (NOAA, 2010), OpenNSPECT (EMBTN, 2010; Eslinger *et al.*, 2012), BASIN (Tong and Chen, 2002; EPA, 2011a), SWAT (Arnold *et al.*, 1998; Gosain and Rao, 2004; TAMU, 2011; USEPA, 2011b), AVSWAT (Di Luzio *et al.*, 2004), ArcSWAT, and SWIM (Krysanova *et al.*, 1998).

N-SPECT (Nonpoint Source Pollution and Erosion Comparison Tool) is a NPS model created by the NOAA Coastal Services Center. It is an Esri ArcGIS extension (requiring Esri ArcMap and Spatial Analyst for operation in ArcGIS 9.3) that helps analysts estimate the impacts to water quality from nonpoint source pollution, including organic compounds and erosion. The aim of this model is to investigate the relationship between land cover, soil characteristics, topography, and precipitation in order to examine geographic distribution of water runoff, nonpoint source pollution, and erosion (National Oceanic and Atmospheric Administration, 2004c). The results of N-SPECT can support water resource managers with making informed decisions about water quality, including the areas to identify impacts of management decisions on water quality and compare current land cover to proposed changes in land cover and land use, as well as help improve decisions about those issues (National Oceanic and Atmospheric Administration, 2004b).

OpenNSPECT is an open-source version of N-SPECT. Instead of using the Esri ArcGIS platform, OpenNSPECT uses MapWindow as a platform to process the model (EMBTN, 2010). MapWindow is a free open-source GIS program implemented for desktop GIS, used to distribute data to others, and used to develop and distribute custom spatial data analysis tools (Corft, 2007). OpenNSPECT supports coastal managers and local officials with examining water pollution impacts to water bodies including rivers, streams, and coastal water from land use/cover change and climate change.

The conceptual underpinnings of the working processes of OpenNSPECT are similar to those of N-SPECT. First, users are required to input data, including land use/cover, elevation, precipitation, and soil characteristics, to create the base data layer. After that users can add different land cover scenarios in order to obtain information about the variations in surface water runoff and nonpoint source pollution (including nitrogen, phosphorus, and erosion particles).

The BASINS (Better Assessment Science Integrating Point and Nonpoint Source) model is a multipurpose environmental analysis system to perform watershed and water quality-based studies developed by the Environmental Protection Agency (EPA) in 1996 (EPA, 2011a). It is also a process-based model that assesses water quality in terms of nitrogen, phosphorus, and fecal coliform in watersheds (Tong and Chen, 2002). BASINS version 4.1 (as the latest version) was developed in 2013 and is integrated with the open-source GIS program MapWindow. There are several modeling tools in the BASINS suite including in-stream models (QUAL2E, AQUATOX, WASP), watershed models (WinHSPF, SWAT, SWMM), and loading models (PLOAD, DFLOW) (USEPA, 2011b). These modeling tools in BASINS provide a way to study watershed and water quality topics by gathering key data and analytical components within a software suite.

The Soil and Water Assessment Tool (SWAT) is a NPS model developed by the United States Department of Agriculture (USDA). The model aims to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management condition over long periods of time. The specific data required for SWAT include weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. SWAT is a continuous time model, for example a long-term yield model (TAMU, 2011). It simulates the hydrologic cycle by providing outputs of the water balance components at each sub-watershed (Gosain and Rao, 2004).

ArcView SWAT (AVSWAT) was developed to work on the ArcView3.0 GIS platform, including watershed tools for “the watershed delineation, definition and editing of the hydrological and agricultural management in puts, running and calibration of the model” (TAMU, 2011; Di Luzio *et.al*, 2004). Another model integrated with ESRI ArcGIS is ArcSWAT. ArcSWAT is an ArcGIS extension and an input interface for the SWAT model as well (SWAT, 2011; Arnold, 1998). Both AVSWAT and ArcSWAT were developed to assist users who often have difficulty within the SWAT native mode, simplifying some steps for easier workflow.

Finally, the Soil and Water Integrated Model (SWIM) was developed based on two models: SWAT and MATSALU. The purpose of SWIM is to provide hydrologic and water quality modeling in big watershed with scales of 100 km² to 10,000 km² (Krysanova *et al.*, 1998). SWIM analyzes the impacts of climate change and land use on water quality.

2.3 Land use / land cover modeling: ENVISION

Land use / land cover influences the quantity and quality of NPS pollution (Schiff, 2007; Tong, 2002; Basnyat, 2000). The relative impacts of different types of land use on surface water need to be examined to investigate impacts. Changes in land use often affect water quality and ecological resources (Basnyat, 2000). This assumes that various land use policies have influence on types of land uses that develop and thus subsequent impacts on water quality. It is very important to understand how land use changes might occur within different future scenarios. We can use such information to estimate future nonpoint source pollution based on different land use policies.

An agent-based land use modeling package called ENVISION can be used to estimate land use change between alternative future scenarios. ENVISION is “a GIS-based tool for scenario-based community and regional planning and environmental assessments” (Bolte, 2010). It is an integrated application used to represent land use policy information and generate future land use scenarios. The conceptual structure of ENVISION represents landscape through change in Actors, Policies, Landscape, Autonomous Change Process, and Landscape Evaluations. Various specific tasks are required to develop an ENVISION application for a specific location that meet alternative future needs, including: 1) defining goals, 2) defining policies, 3) defining scenarios, 4) generating and populating coverage with relevant attributes, 5) creating landscape evaluation and autonomous process model, 6) running scenarios, and 7) analyzing results (Bolte, 2009). A multiagent-based modeling approach is used in ENVISION that contains a robust capacity for determining alternative management strategies and scenarios, integrating a variety of landscape change processes, and developing maps of alternative landscape trajectories (Bolte and Vache, 2010).

The NPS model tools alone could not accomplish sustainable water quality management. All people who live in watersheds are involved in the impacts of nonpoint source pollution on sustainable water quality. Despite the fact that much of the argument of water quality causes and effects occur in the realms of science, there is a lack of readily accessible tools for public and policy-maker use that can assist with improving understanding of the hydrological system and how land use/ land cover impact water quality and society (Falkenmark *et al.*, 2004). Access to geospatial information by non-technical users has been researched using public participation GIS (PPGIS). PPGIS tools have been used to engage public stakeholder and watershed managers to better understand what is occurring in watersheds (Gosian and Rao, 2004) and to get people involved in the process of water quality management as an essential practice. Problems must be addressed by more than policy makers, elected officials, administrators or managers if we are to address the problems broadly. Consequently, stakeholder publics have a potential role to play in addressing and understanding nonpoint source contamination problems.

2.4 Public Participation GIS

PPGIS became a topic of study during the mid-1990s, having been recognized by a workshop hosted by the National Center for Geographic Information and Analysis's (NCGIA) Varenus Project in response to the rising awareness that spatial data and tools were gradually being utilized in social and environmental community participation efforts (Nyerges, Barndt, and Brooks, 1997; Craig *et al.* 2002; Sieber 2006). PPGIS exists in various forms. There are many grass roots organizations using maps and geographic information to facilitate improving effective communication with policy makers (Craig and Elwood, 1998). GIS can be an efficient tool in promoting community awareness, mobilization and conflict resolution (Sieber, 2003).

Sieber (2006) illustrates that representation of knowledge in PPGIS sometimes is critical, but especially where the knowledge from public stakeholders is integrated. Researchers are challenged to incorporate their knowledge (Craig and Elwood 1998; Jankowski *et al.*, 2006; Goldman 2007) into the process of building a GIS database. These methods support local resident efforts to have greater access to the decision-making process. Talen (2000) shows that the exploration of residents' perceptions using GIS helps to better understand residents' perception of issues related to the local planning process. This encouraged geographers, planners, and many others to build some of the ideas and methodology that was readily incorporated local knowledge into the language and structure of GIS.

Public participation has increasingly become a means to get the public involved in community planning and decision-making processes owing to a convergence of new legislative requirements, growing citizen activism, and changing professional values. To recognize the impacts of humans on watersheds, it is essential to integrate biophysical and social sciences to better inform policy makers and public stakeholders about what is occurring in watersheds. This kind of collaboration brings public stakeholders into the nonpoint source pollution management arena. Integrating public participation into the management of nonpoint source pollution problems should be a significant part in the identification of problems and the search for solutions. There are many studies about collaborative issues concerning scientific and stakeholder knowledge for resource management (Nazarea, 1995; Grenier, 1998; Bicker *et al.*, 2004; Chuenpagdee *et al.*, 2004; Habron *et al.*, 2004; Puri and Sundeep, 2004; Gosain and Rao, 2005; Menzies, 2006; Sillitoe, 2007), but few that have incorporated data, information and knowledge development through PPGIS. Nyerges and Jankowski (2010) describe data as a basic level of knowledge that we use to represent aspects of our world in GIS processes. Information is

derived from data through the discovery of relationships, as we select data to use for a specific purpose and add significance to data. Before information is developed into knowledge that people can use for decision situations, we corroborate information to become evidence, which means create valid information, making sense to the people who will use the information.

Evidence derives from different perspectives on information, bolstered by agreement among those perspectives. Once we create evidence, we can claim validity of information to be used as knowledge by decision makers for solving a problem.

Puri and Sundeep (2004) used GIS as a gateway to connect local knowledge to assess water supply resources in India. They found that using GIS to incorporate local knowledge is more useful than the information gained from government information. Their study showed that combining knowledge from local residents and using GIS helped to prioritize areas for intervention. Chuenpagdee *et al.* (2004) conducted a study of using community participation for supporting management of coastal resources in Mexico. Stakeholders created the marine habitat maps through GIS. The study also allowed stakeholders to rate hypothetical resource degradation scenarios, and provided several management options. Habron, Kaplowitz and Levine (2004) integrated biophysical aspects of watershed management with elements of human social systems using hydrological models and GIS to assess concerns about pollutants to university personnel at Michigan State University. A limited number of studies using a watershed model with PPGIS were found. Gosain and Rao (2005) used the SWAT watershed model and incorporated stakeholder perspectives on delineating watershed boundaries to allocate financial resources and design the location of water harvesting structures.

The above described findings from studies about PPGIS have similar basic components. First, they used GIS to show local resource information. Second, they obtained comments from

stakeholders on the quality of the information and converted that information into a spatially-referenced format. Finally, they agree about how the information can support resource managers in decision-making processes. One of the objectives of research herein is exploring how public stakeholders can be engaged within the process of water quality modeling. This could bridge a gap between scientific and local knowledge helping to broaden and deepen water quality management. Workflow processes focusing on steps in stakeholder public engagement is an important aspect of the participatory process. How models are adopted at each phase of a knowledge construction/production process provides insight about the outcomes of each step (Nyerges and Jankowski, 2010).

2.5 Roles for stakeholder participation in watershed management

Public stakeholders can get involved in watershed management through various roles and at different levels of participation, including getting involved in a decision-making process in watershed management policies by providing information about what is at stake; through water monitoring as volunteers to sample water; designing land use practices; reducing pollution; protecting watershed; and exchanging knowledge between public stakeholders and watershed management experts. France (2002) states that it is important to educate all people about how their lives and activities in a watershed affect water conditions. Watershed management involves decisions related to land use, farming practices, habitat restoration, water reserve, and allocations of costs and benefits among all users of water resource (Korfmacher, 2001).

A conceptual framework of watershed management workflow developed for research herein includes *understanding the situation, vision, planning, implementation, monitoring and evaluation*, as adapted from a water quality management framework from DEWHA (2009). This

framework shows that public participation could play different roles in each process. For example, some stakeholder public groups might be involved in volunteer programs for water monitoring. Moreover, the watershed system is affected by land use decisions made by landowners and public agencies. Therefore, watershed management integrally involves the cooperation of landowners and public agencies (Cockerill, 2006). Public involvement is significantly influenced by prior experience with participation, cultural, and institutional contexts (Tippett, *et al.*, 2005). Nyerges and Patrick (2007) describe public participation as a process for GIS in terms of the five levels articulated by the International Association of Public Participation: 1) *inform*, 2) *consult*, 3) *involve*, 4) *collaborate* and 5) *empower*. This spectrum of involvement increases the public impact from *inform* to *empower* on the overall process. This level shows that public stakeholders might be engaged in different degrees of participation for different activities. For example, if public stakeholders participate in the *understanding the situation* process and only want to know what is the current situation of water quality in their watershed, this means that their participation is at the *inform* level (Smith *et al.*, 2000) and has less impact in the watershed management program. With the concepts of various processes of watershed management and different participation levels, it would allow public stakeholders to play different roles and degrees of influence in the participatory process.

GIS and Internet technology are also tools that enhance capacity and influence roles of stakeholder participation in watershed management (Smith *et al.*, 2000). GIS has become a significant tool to engage both stakeholders and governmental agencies, wherein stakeholders can become more interactive and collaborative in the development and implementation of watershed management programs (Harrison and Haklay, 2002). Several GIS tools exist for involving public stakeholders, e.g., web mapping, public meeting, workshop, and interviews

(Smith, 2000; Korfmacher, 2001; Harrison and Haklay, 2002; Gosain and Rao, 2004; Nyerges *et al.*, 2006; Luchette and Crawford, 2008; Danielsen, 2009; Johnson, 2009).

The most important factors that influence the roles of stakeholder participation in watershed management are the government regulations and policies. The Washington State Watershed Management Act highlights participating citizens, water resource users, and interest groups in water resources. One objective of the law, as stated by the Legislature (WA, 1999), is:

“...to provide local citizens with the maximum possible input concerning their goals and objectives for water resource management and development...”
“...planning units established under this chapter shall develop a process to assure that water resource user interests and directly involved interest groups at the local level have the opportunity, in a fair and equitable manner, to give input and direction to the process. (RCW 90.82.030)...”

According to the Watershed Management Act, public participation is required as part of the watershed planning and management process, and is an important part in the development of an effective, robust watershed management program. Public participation is also a significant part of the State Environmental Policy Act (SEPA) and the National Environmental Policy Act (NEPA). In addition, public education is necessary in the implementation and for the accomplishment of the watershed plans and represents an important aspect of public participation (WA, 1999).

Support from the community is necessary for success of watershed management strategies. People who have an impact on watersheds as users and polluters should be supported in the watershed management processes: namely, *understanding the situation, vision, planning, implementation, and monitoring and evaluation* as shown below. Each of these steps has a potential to use GIS as a tool to involve public stakeholders in improving watershed ecosystem.

Figure 1 shows the five steps of the watershed management processes (DEWHA, 2009) and

introduces concepts from the geodesign decision framework presented by Nyerges and Jankowski (2010, Figure 8.1). Encouraging the public to develop, use, and evaluate GIS in order to better represent characterize problems would lead to more effective decision support systems. PPGIS could be employed in the processes to articulate watershed knowledge and it can foster consensus building and decision making. As described below, stakeholders play different roles in watershed management processes, and thus influence how GIS could become a tool to facilitate both public stakeholders and watershed managers in public involvement, consensus building, and decision making.

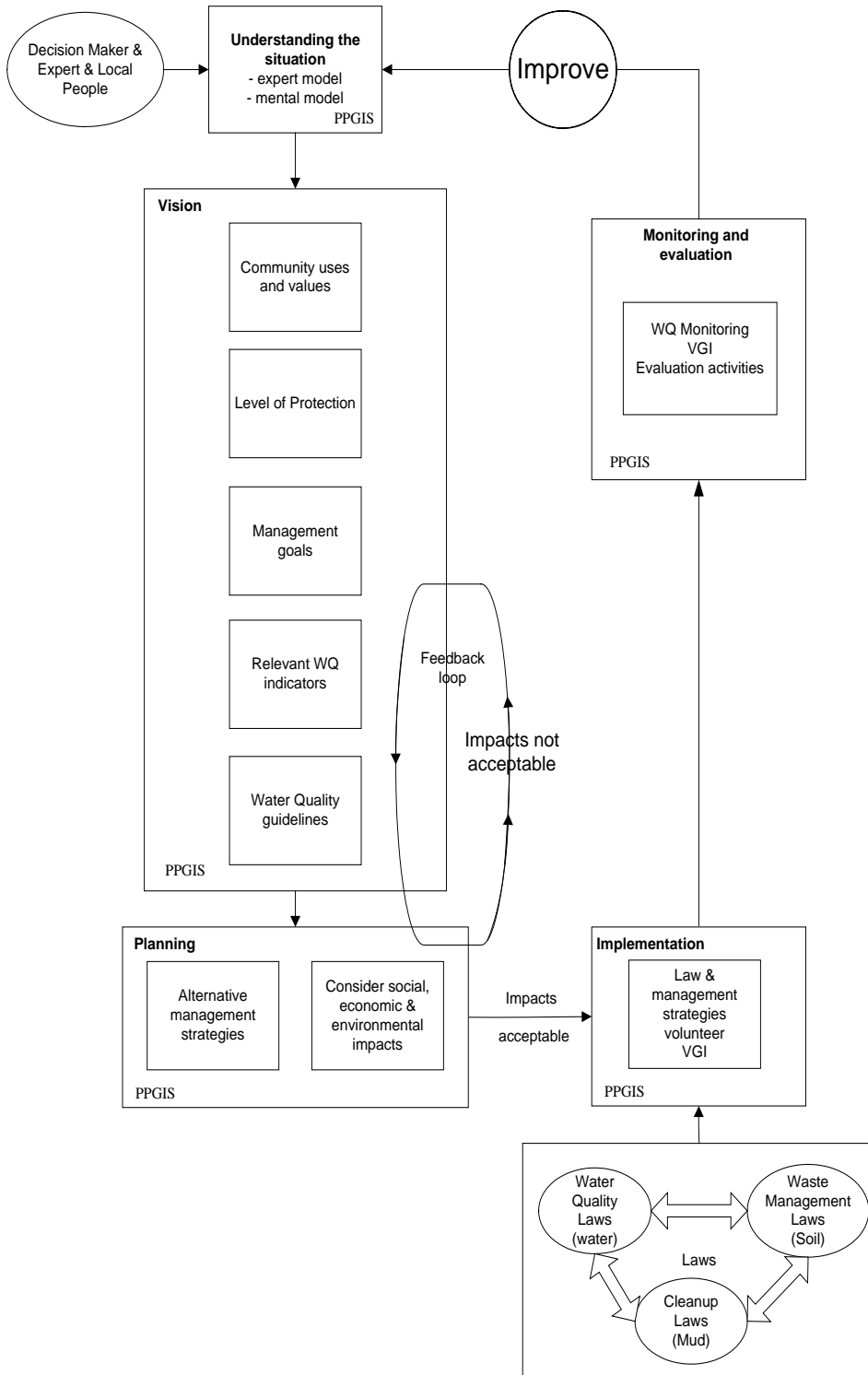


Figure 1. Conceptual Model of Water Quality Management

First, *understanding the situation* of water quality, geology, topography, and climate is fundamental to all processes within the water quality management framework. The information from stakeholders and experts/scientists who are engaged within on-going research clarifies scientific and local knowledge. This assists in describing the broader circumstance of the problem or planning opportunity. PPGIS can support the process by identifying locations for which stakeholders are concerned about water quality and habitat degradation. Public education is very important in this step as well. Public education can assist in preparing public stakeholders with the knowledge base to become involved in making sound decisions on watershed management issues (WA, 1999). The participation level of this process could be at the *inform* and *consult* levels. Smith (2002), for example, applies web-based GIS called Gunpowder Watershed Clearinghouse to disseminate information and thus inform the public about the most relevant environmental concerns and watershed management. The public can get involved in the process of designing a database model of water pollution problems and solutions by using a web-based Internet as a medium to communicate among stakeholders such an example as the methodology in the *Voicing Climate Concerns* (Nyerges, Wright, and Aguirre, 2010) approach. This is a way to educate and engage stakeholder publics and facilitate public involvement in preserving and restoring watershed. This knowledge is repeatedly updated by new information. For example, the results from the planning, implementation, and monitoring and evaluation processes will ultimately develop into new understanding of the situation in time $t+1$.

Second, the *vision* step identifies a forward outlook for water quality based on the stakeholders' perspectives. This supports the identification of specific watershed management objectives, targets, and levels of protection using the inspirational values and uses of water. PPGIS could support this step by locating valuable habitats or locations suggested to be reserved for local

common use. Stakeholders can use GIS to draw and locate the areas that are most valuable for them with different reasons related to their interests. Gosain and Rao (2004) developed Integrated Watershed Management (IWM) tools to involve stakeholders in selecting a suitable site for planning for IWM. The participation level of this process could range from *inform*, to *consult*, and *involve* levels. It actually depends on the activities that they are involved in. Knowing community uses and values will help in the protection and management of water resources and attainment of ideal levels of water quality, which will eventually translate into better and more suitable water quality guidelines.

Third, the *planning step* involves devising management actions that address the causes of pollution and evaluate social, economic as well as ecological impacts in order to negotiate and identify a preferred strategy. A variety of impact assessment techniques are used to evaluate impact and prioritize solutions. In this process, public stakeholders could play significant roles in the planning process through articulation of values as criteria since the Watershed Management Act requires citizens to participate in such a process to ensure that all their interests in land use and water resource are managed in a fair and equitable manner. For example, the watershed planning and management guideline of Washington State indicates the roles and activities of citizen in the public involvement program including: citizen and interest groups representation on the planning unit; public meeting; opportunities for writing input; creation of advisory groups; speaking at meeting of local organizations; opportunities to receive and interact with newsletters; surveys and internet sites; and opportunities for inclusion of volunteers in appropriate activities (WA, 1999). With this policy, PPGIS will help by facilitating public participation in the watershed modeling part of the planning process (Smith, 2002; Luchette, 2008; Korfmacher,

2001). In this iterative management process, actors return to the vision process to rethink the expectations for water quality if the impact identified during planning is not acceptable.

Fourth, the *implementation process* focuses on deciding necessary actions with an assignment of agreed roles and responsibilities. Bennet and Moss (2005) reveal that community actors play various roles in this process, including: 1) determining the roles and responsibilities for management actions; 2) agreeing to institutional changes and improved governance for initiating changes to management actions, based on stakeholders' expectations and responsibilities; 3) establishment or reinterpretation of relevant legislation, policies, guidelines, codes of practice, licenses, and permits; 4) establishment of relevant economic instruments; and 5) implementation of agreed management actions with the established allocation of resources and reporting requirements for the actions in the preferred strategy. For example, People for Puget Sound had volunteer programs for pulling weeds, mulching planting areas, planting native vegetation, and picking up debris and trash in the sites along the Duwamish River (PPS, 2009). Puget Soundkeeper Alliance enforces the Clean Water Act of 1972 through citizen lawsuits against serious violators. The goal of this program is to achieve negotiated settlements that bring polluters either into compliance with the law or into the permitting system. Moreover, there is a Puget Soundkeeper volunteer program that acts as a watchdog to help prevent pollution in Puget Sound. The Puget Soundkeeper acts as the eyes and ears of the public out on the water, monitoring Puget Sound waterways several times a week. The Puget Soundkeeper conducts regular on-the-water pollution patrols using its boat and a network of trained Citizen Soundkeepers, looking for illegal discharges and other evidence of pollution (PSKA, 2009).

Finally, *monitoring and evaluation* is an essential process for water quality management. This process monitors and reviews the effects of the strategy of water quality management objectives

and the results of the vision and plan. For example, the Puget Sound Action Team in the recent past had ongoing research activities associated with the Puget Sound Assessment and Monitoring Program (PSAMP). That activity is now part of the Puget Sound Partnership. The effort is conducted by local governments, research institutions, Tribes, state and federal agencies, and citizen monitoring groups. The scope of the program is focusing on water quality, toxic contamination, near shore habitat and marine species (PSAT, 2007). This process can make use of PPGIS and Internet technology as part of a monitoring program (Danielsen, 2009) such as PPGIS for Citizen-based Watershed Monitoring Program in Pamlico-Tar River in North Carolina (Luchette and Crawford, 2008) or public participation watershed modeling dealing with evaluating water quality problem in the watershed (Korfmacher, 2001). Another example is the Water Action Volunteers program in Wisconsin's streams and rivers, which is a user-friendly web mapping programs (Newman et.al., 2010) including citizen stream monitoring, storm drain stenciling, and river clean ups. The GIS based information—Gunpowder Watershed Clearinghouse—(Smith, 2002) also provides a huge opportunity for tree planting and neighborhood stream monitoring volunteers. The monitoring and evaluation steps bring about an adjustment of the current understanding about water quality and water quality management.

Public stakeholders play various roles in watershed management from only receiving information about watershed situations and providing knowledge about the watershed to getting involved in planning and implementing watershed management programs. Smith (2002) states that “progressive watershed management must operate in a grassroots level to be effective”.

PPGIS and Internet technology facilitate the communication and dissemination of the essential information in the watershed management program such as the Water Action Volunteers program and the Gunpowder Watershed Clearinghouse. Based on the above review of literature,

major benefits and challenges for public participation in watershed management can be synthesized as described in the next section.

2.6 Benefits and Challenges in Stakeholder Participation using GIS in Watershed Management

Research shows the benefits of stakeholder participation using GIS in watershed management that include consensus building, knowledge building, knowledge transferring, creating awareness of watershed protection, involvement, collaboration, and empowerment (Luchette and Crawford, 2008; Goasin and Rao, 2004; Smith, 2002; Burroughs, 1999; Duane, 1997). These major benefits occur in various ways.

Goasin and Rao (2004) reveal that public involvement in watershed management planning process can use a GIS-based modeling framework to identify priorities within a watershed to study. With spatial analysis and representation capabilities, GIS-based modeling facilitates public stakeholders to share and gain knowledge in the area and get involved in selecting suitable sites for planning processes and help build consensus for allocation of financial resources within watershed boundaries. Nyerges et al. (2006) show how collaborative decision processes involve various groups of stakeholders, expanding their knowledge in water resource management. Additionally, this study develops a better understanding of the integration needs among GIS, decision models, and group support systems.

Duane (1997) describes benefits of public participation in ecosystem management including: 1) environmentalists are as much representatives of the public community as are the state or nation; 2) there is consistency in the agreements and plans with existing state and federal environmental laws wherein participation can help clarify those inconsistencies; and 3) there is an opportunity to increase influences from experiments affecting fairly small areas. Moreover, GIS web-based

Internet provides a more effective way to communicate/interact and disseminate large volumes of information about watershed areas to many public groups at the same time.

Smith (2002) found that GIS and Internet technology produce huge benefits by providing watershed-based data and information to citizens on a large-scale drainage basin at almost “no cost”. He reveals that the advantages of sharing that information are 1) an online survey to help watershed managers know the public’s priorities concerning issues in the watershed; 2) demystification of watershed management; 3) establishment of concrete volunteer opportunities; and 4) plentiful opportunities for sharing data and information between environmental professionals and general publics.

Luchette and Crawford (2008) show that public stakeholders are empowered to design a network of potential locations for monitoring water quality in an area of concern to the Citizen Watershed Monitoring Project (CWMP). With the ability of web-based GIS, CWMP provides an easy and effective tool as well as a way to make the information accessible. Volunteers can go online and investigate what they are monitoring. This could lead public stakeholders to awareness about watershed protection. Knowledge transfer is one of the main benefits of public participation because public stakeholders are both consumers and providers of information (Burroughs, 1999).

The more knowledge the public has about watershed management, the more they can get involved in it. The more they get involved in watershed management, the more likely that land and water usage will become fair and equitable.

The major challenges for stakeholder participation in watershed management include social conflict and dissensus, marginalization, motivation in participation, limited knowledge, integration of knowledge (between local and scientific knowledge), technology constraints, lack

of trust in public participation, high budget cost, and high time consumption (Duane 1997; Korfmacher, 2001; Harrison and Haklay, 2002; Weiner and Harris, 2003; Schuurman, 2006; Elwood, 2008).

Duane (1997) identifies several main issues about social conflict in watershed management, including: *cognitive conflict*—people have different understanding or judgment; *value conflict*—argument over goals, whether an action or outcome is desirable; *interest conflict*—costs and benefits are not distributed equally; *relationship conflict*—emotional motivations leads to conflict on grounds other than facts, values, or interests. Such conflicts are often ignored in discussions about watershed management processes.

Some research shows the challenges of PPGIS in terms of data access, integration, and analysis (Korfmacher, 2001; Weiner and Harris, 2003; Elwood, 2008). Some public groups might have difficulty in the data access to geospatial data because they have less experience or training using GIS and do not know where the available data sources are located (Elwood, 2008). Some public groups are marginalized from the use of web-based GIS in watershed management processes because they have difficulty in accessing the Internet especially those within rural areas of developing countries. Preventing the public from getting involved is an essential and critical problem. While this could empower one group, it can marginalize other people who have not been involved. Another challenge of using Internet technology to engage the public is how to persuade the public to use a program/website once they are in front of the computer. Motivation and engagement are very important in public involvement as in any other kind of activities. Therefore, the challenge is how administrators could motivate the public to get involved, then subsequently learn and share their resources. At the same time, administrators, themselves, should be motivated and willing to share their knowledge and power (Burroughs, 1999).

Another challenge of public involvement in watershed management is the lack of trust in public participation. With the bias administrators have about the limited knowledge of public groups, they will be skeptical, lack of awareness, and suspicious about the efficiency of public participation and bring to a high degree of disbelief and separation in the impact of public participation in the decision results (Korfmacher, 2001; Harrison and Haklay, 2002).

High cost and time consumption are among the main challenges of public involvement in watershed management. Additional cost and time are required for public involvement programs (WA, 1999), particularly because administrators need to create the program to involve and educate public stakeholders, requiring implementation of techniques such as workshops, meetings, newsletters, and interviews. These processes take time and money to be accomplished. Moreover, if the process makes use of GIS and Internet technology, then the process might need more time and money in developing and maintaining a database, as well as training public stakeholders to make use of these geospatial technologies.

Although public participation in watershed management has many benefits, it also has many challenges. Empowering one group of people often means disempowering other groups. Sharing knowledge between local people and administrators could bring about the consensus of objectives and solutions of the watershed management; however, sometimes there is difficulty in the integration between local knowledge and official knowledge. Collaboration could bring a consensus decision with balance of benefits; however, dissensus always happens during the processes of watershed management and sometimes it is difficult to find the best solutions. Consensus building in any process of watershed management costs a lot of time and money. GIS and Internet technology facilitate public stakeholders to receive, share, and understand the spatial relationship in the watershed so that they can have more awareness in the watershed protection

and become willing to be involved in any kinds of activities that can help protect their watershed. However, there are a lot of difficulties with technology barriers. Without motivating public involvement in watershed management, it would be difficult for the public to get involved.

2.7 Contributions of Public Stakeholders Integrated into Water Quality Models

As mentioned earlier, water quality modeling is about physical and chemical processes, which is often performed by hydrologists and environmental scientists (Johnson, 2009). Therefore, it has been seen as a technical activity and has been performed only by technical experts (Arnold *et al.*, 1999). Water quality models are used to support complex decisions about watershed problems. For an efficient use of water quality models, the consensus about the appropriateness of their assumptions and results should be built among parties interested in or affected by the decisions on watershed management. Public stakeholder contributions that could be incorporated into water quality modeling processes include: determining objectives; developing a conceptual model of the system; constructing the mathematical model; calibrating the model; confirming the model; and applying the model (Korfmacher, 2001).

In the step involving the objective, public stakeholders could contribute to characterizing the determination about what the model is to predict. Some watershed models might not have the capability to predict what the public desires, i.e., focus on particular values of interest to the public. However, this reveals the importance of public values, which provide the idea of what should be considered in the outcome, and the selection of models that are suitable for what is to be predicted. The technical experts and/or modelers should clarify the differences between desired and feasible outcomes. Moreover, public stakeholders could contribute to the pre-discussion about the level of accuracy required for decision making.

For the development of a conceptual model, public stakeholders could be involved in making decisions about the scope, more than the cost and accuracy, of the conceptual framework for watershed management. The watershed modeling aims to represent the complex hydrology system and to predict water quality and natural phenomena. Due to the complex system, especially for nonpoint source pollution analysis, there are many factors and data to be considered and put in the model such as elevation, rainfall, land use, soil type, evaporation, infiltration, snow melt, and ground water (Arnold *et al.*, 1999; Johnson, 2009). The more complexity of required data for the model, the more amounts of expense increases and accuracy often decreases. Consequently, public stakeholders can contribute to the decision about the scope of cost and level of accuracy of the model (Korfmacher, 2001).

Due to the uncertainty of the model prediction, in the construction of the watershed model process, (Arnold *et al.*, 1999), public stakeholders, as for other users as well, should be educated about the uncertainties involved in watershed modeling. This educates public stakeholders to expect accuracy in line with the funding used to derive results. In this process, a simulation model requires technical skills and professional judgments for characterizing uncertainty about variables in the model such as coefficients of pollution. The values of this variable vary depending on the type of land use, soil, and topography, and the level of empirical data to characterize those. The uncertainty about data used for the variables leads to uncertain results from the model. Thus, it might be too complicated for public stakeholders to contribute to a simulation model; although this position would make an interesting hypothesis to test.

A watershed model needs to be calibrated because of the uncertainty of input data. Observed data are needed in this step to compare with simulated (predicted) data results from the model. If the observed and predicted data do not match and are noticeably different, the modelers will adjust

the parameter input such as the coefficients of pollution or defined new boundary of sub-watershed (Okano, 2009). There are many ways to adjust the model until the prediction can fit with the observed data. In this process, public stakeholders could offer ideas about which parameter should be adjusted to fit both the observed and predicted data, because they have more experience with the watershed (on the ground) landscape and phenomena than modelers. They might have more insight from their experience to determine which variable should be adjusted in the model to better fit with the observation data. The public stakeholders should be involved in decisions when the fit of observed to predicted data should be acceptable (Korfmacher, 2001).

The step of confirming the model involves validating the predicted data by using it within the model to examine the new adjusted parameters, and then compare them to the observed data (Arnold *et al.*, 1999; Okano, 2009). Public participation could contribute in deciding if the results of the confirmed model are satisfactory enough to be used in decision making (Korfmacher, 2001; Johnson, 2009).

Apply the model as intended: Once the model is calibrated and validated and consensus is built between the stakeholders and modelers from previous processes, the model is ready to run alternative scenarios with different hypotheses (Arnold *et al.*, 1999; Johnson, 2009; Okano, 2009). Public stakeholders play a significant role in this step by contributing their interests and concerns about the assumptions for defining scenarios. They can create various scenarios such as the industrial discharge, comparing pollution from different types of land uses and agriculture practices. Scenarios add to option formulation that broaden consensus building in the decision process for watershed management. Assumptions ground the scenarios for realistic consideration.

2.8 Discussion

Public stakeholders could contribute in every step of watershed modeling. They help determine objectives, develop a conceptual model of the system, construct the mathematical model, calibrate the model, and confirm the model. They contribute to the pre-discussion about the level of accuracy of the model and deciding which parameter(s) should be adjusted to fit the model. Finally, they play important roles by contributing their interest and concerns in the assumptions for defining scenarios. However, to make it easy for public stakeholders, the model should be transparent and user-friendly. The facilitators should be well-organized to get the public actively involved in the participation with the model and open the opportunities for the public to share their value and knowledge with the ultimate decision makers (Johnson, 2009; Korfmacher, 2001).

Chapter 3: Conceptual Framework for Water Quality Management

Communication among local people, experts/scientists, and decision makers help build the knowledge among stakeholders, and provides options leading toward a solution based on water quality management that is to be scoped, designed, and implemented. Community support is necessary for the success of water quality management strategies. Those who have direct impact on water quality as a user and polluter should participate in the water quality management process. To illustrate the relationship between people and water quality management, a schematic diagram is provided below that identifies and links the processes, namely activities that involve *understanding the situation, vision, planning, implementation, and monitoring and evaluation* (Figure 2) (DEAHR, 2009). PPGIS can assist in all phases of the process to articulate and exchange water quality knowledge with all stakeholders and link them to a decision making component. Thus, a system should utilize these processes by establishing a relationship for integrating public participation and GIS with NPS pollution modeling.

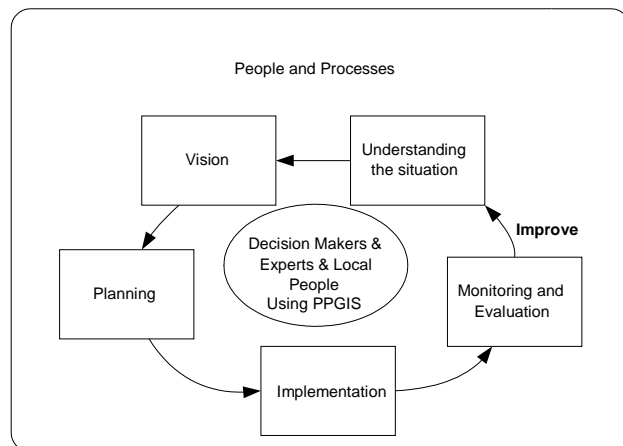


Figure 2. People and Process for Water Quality Management

3.1 Conceptual base: Geodesign framework workflow analysis

Nyerges and Jankowski (2010) describe how Steinitz’s geodesign workflow framework can integrate regional planning and GIS through plan-making processes and iterative tasks. The GIS use is evident in the components of the workflow analysis. The geodesign framework (Steinitz, 2012 and 1990) consists of six key questions to be answered by six models. The questions are asked through three passes as described below (Figure 3).

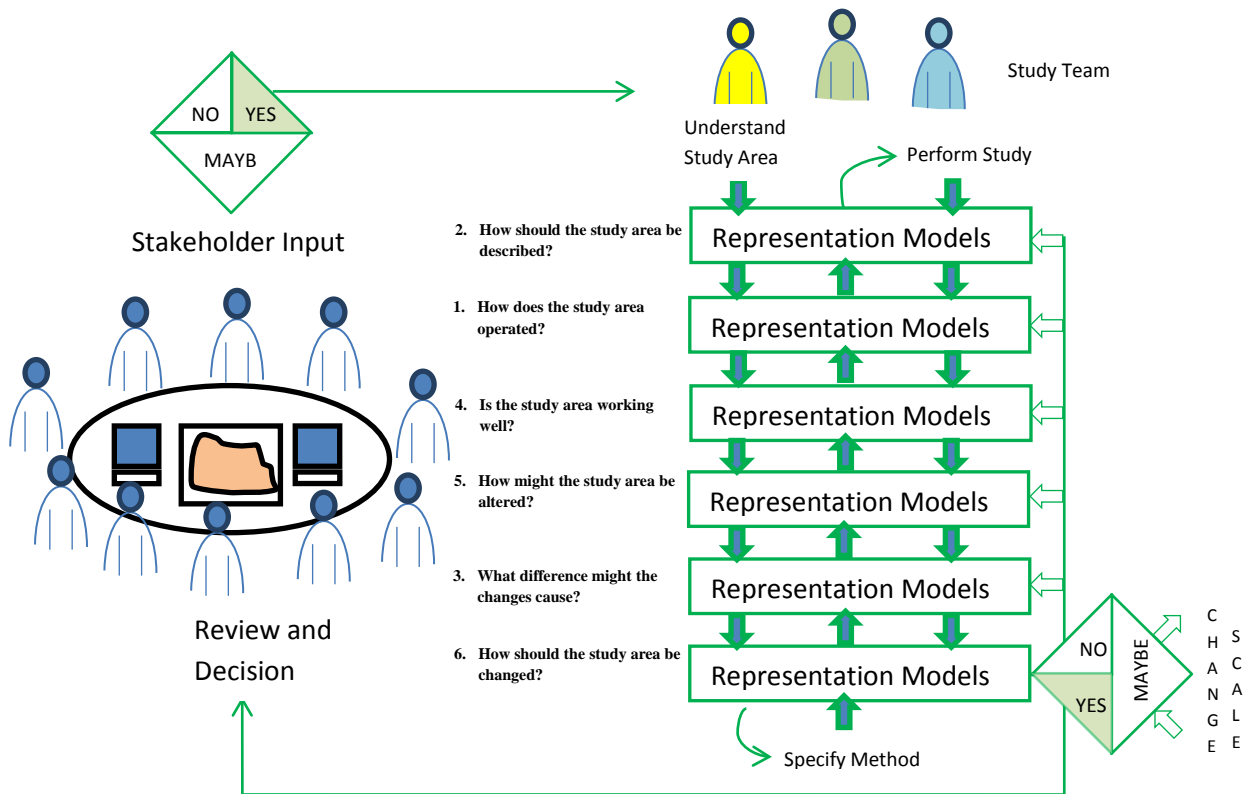


Figure 3. Stakeholders, study team, and framework for geodesign from Carl Steinitz (2012)

The six key questions of the framework are the following.

1. How should the study area be described? This question is answered by *representation models*.
2. How does the study area operate? This question is answered by *process models*.
3. How is the current study area working? This question is answered by *evaluation models*.
4. How might the study area be altered? This question is answered by *change models*.
5. What differences might the changes cause? This question is answered by *impact models*.
6. How should the study area be changed? This question is answered by *decision models*.

Questions 1, 2 and 3 refer mainly to past and current conditions of the study area. Questions 4, 5, and 6 refer to future conditions more than the past and present. These questions (and their subsidiary questions) are asked three times in each of three iterations using six models of the framework. The first iteration, called “understand study area”, is treated as the WHY questions, or WHY the study is to open. The six questions are asked in order from 1 to 6 through each model. This first iteration provides a study team with an understanding of the study area, problems, issues, and constraints of the place and the objective of the geodesign application. The example questions for this iteration are shown in Table 1 below.

Table 1. First Iteration Questions through Six Models of the Geodesign Framework
(Steinitz, 2012 p. 27)

First Iteration (Top to Bottom)	Example Questions
1. Representation models	Where is the study area? How should it be defined? What are its physical, ecological, economic, and social geographies in present and histories?
2. Process models	What are the area’s major physical, ecological, economic, and social processes? How are they linked to each other?
3. Evaluation models	Is the area seen as attractive? Is the area developing or declining? Are there any environmental or other problems in the area?
4. Change models	What major changes are foreseen for the region? Are they related to growth or decline?
5. Impact models	Are anticipated changes seen as beneficial or harmful? To whom? Are they seen as serious? As irreversible?
6. Decision models	What is the main purpose of the geodesign study? Public action? Economic profit? Scientific advancement? Who are the major stakeholders? Are they public or private? Are they in conflict? Are there legal and implementation-related aspects that must be considered?

The **second iteration**, called “specify method”, is treated as the *HOW* questions. In this iteration, the questions are asked in reverse order of the framework from 6 to 1. The purpose of this iteration is to choose and clearly define the methods of the study, and is decision-driven rather than data-driven. The example questions for this iteration are shown in Table 2.

Table 2. Second Iteration Questions through Six Models of the Geodesign Framework (Steinitz, 2012 p. 28)

Second Iteration (Bottom to Top)	Example Questions
6.Decision models	How will decision be made? By Whom? What do the decision makers need to know? What are their based of evaluation? Scientific evaluations? Cultural norms? Legal standards? Are there issues of implementation such as cost, phasing, and choice of technology?
5.Impact models	Which impacts of possible changes are most important? Which complex must assessed by law or regulation? How complex must the impact assessment be? How much, where, when, and to whom are these seen as good or bad?
4.Change models	Who defines the assumptions and requirements for change? How? Which scenarios for change are selected? Toward which time horizon(s)? At what scale(s)? Which issues are beyond the capabilities of the geodesign team and study models? Which change model(s) are to be applied? Are the outcomes to be designed, or simulated, or both?
3.Evaluation models	What are the measures of evaluation? In ecology? In economics? In politics? In peoples' visual preferences?
2.Process models	Which process model should be included? How complex should the models be? At what scale(s) should they operate? At what time horizon(s)?
1.Representation models	Where exactly is the study area? How is it bounded? Which data are needed? For which geography? At what scale? At which classification? For what times? From what sources? At what cost? In which mode of representation?

The **third iteration**, called “perform study”, includes the *WHAT, WHERE, and WHEN* questions. This last iteration is again asked from the top to bottom, 1 to 6, through the framework. Questions from this iteration help to implement processes of the methodology designed from the second iteration. The example questions for this iteration are shown in Table 3 below.

Table 3. Third Iteration Questions through Six Models of the Geodesign Framework (Steinitz, 2012 p. 30)

Third Iteration (Top to Bottom)	Question/Activity Examples (need to be accomplished during this stage)
1. Representation models	Obtain the needed data, organize them in an appropriate technology, visualize the data over space and time
2. Process models	Implement, Calibrate, and test the process models, Link them to each other as appropriate, Link them to the expected change models
3. Evaluation models	Evaluate past and present conditions, visualize and communicate the results
4. Change models	Propose and/or simulate future changes, Represent them as data
5. Impact models	Assess and compare the impacts of each change model via the process models, visualize and communicate the results.
6. Decision models	Compare the impacts of the change models and decide: <i>No</i> , which requires feedback, or <i>Maybe</i> , which may require further study at a different size or scale, or <i>Yes</i> , which leads to presentation to the stakeholders for their decision and possible implementation.

In the last decision models, if the study team says *NO* with the decision, this means that the project needs to be redesigned, improved, or find better data and work through all of the six steps again. If the team says *MAYBE*, the project may need to change in scale, size, or time frame of the study. However, the project still needs to work through the six questions of the framework until we get to a *YES* decision. Finally, if the project reaches the *YES* decision, the resulting study and proposed project will be presented to stakeholders for review and implementation. Steinitz mentions that agreement upon implementation is not necessary automatic or immediate, particularly for large and long term project. With time changing, the geography may change and lead to a new representation model.

As seen from the geodesign framework, stakeholders are involved in the first iteration and definitely in the review and decision phases. They are potentially not involved in the second and third iteration (specify methods and perform study). Involving stakeholders in specifying methods and performing the study may increase consensus among the team and stakeholders and

enhance efficiency of the results. With this reasoning, engagement among agents is very important to provide credibility in the project.

3.2 Conceptual Framework for nonpoint source pollution, watershed modeling and PPGIS integrative system

In the following section, the conceptual framework from Steinitz (1990 and 2012) is adapted for nonpoint source pollution, watershed modeling, and PPGIS integrative system. With the concepts of geodesign, social-ecological systems (SESs), the framework for nonpoint source pollution, watershed modeling and PPGIS integrative system are designed to engage public stakeholders as much as possible through three iterations. When stakeholders and study teams share knowledge of the SES among others, it will perceive lower cost of organizing and increase consensus of the results and decisions (Ostrom, 2009).

The questions and translations below follow Steinitz's questions (2012 p. 37 and 1990 p. 137) in the geodesign framework.

1. How should the state of the landscape be described in terms of content, boundaries, space, and time? This level of inquiry leads to *representation models*. This question could be adapted to NPS pollution modeling as: *How should NPS pollution be described in terms of content, boundaries, space, and time?*

2. How does the landscape work? What are the functional and structural relationships among its element? This level of inquiry leads to *process models*. This question could be adapted to NPS pollution modeling as: *How does nonpoint source pollution operate? What are the functional and structural relationships among its elements?* Once the relevant components of the

nonpoint source pollution have been identified and defined, relationships between constituents can be established.

3. How does one judge whether the current state of the landscape is working well? This level leads to *evaluation models*. This question could be adapted to NPS pollution modeling as: *Is the water quality in good condition when comparing empirical data and a standard threshold?* An initial evaluation of water quality is made by operating process models on the data that represents a baseline state of water quality in association with landscape conditions.

4. By what actions might the current representation of the landscape be altered: what, where, and when? This level of inquiry leads to *change models*. This question could be adapted to NPS pollution modeling as: *By what actions might the current representation of the NPS pollution be altered: what, where, and when?*

5. What predictable differences might the changes cause? This level of inquiry shapes *impact models*. This question could be adapted to NPS pollution modeling as: *What predictable differences might the changes of land use/ land cover cause for NPS pollution impacts?* This level of inquiry question leads to *impact models*, in which the process models are used to estimate the change leading to a difference referred to as an impact.

6. How will a decision change (or conserve) the landscape conditions? This level of inquiry leads to *decision models*. This question could be adapted to NPS pollution modeling as: *How is a decision to be made to mitigate the NPS pollution problems with regard to results from impact models?*

The sequence of questions and model runs can iterate until stakeholders, modelers and decision makers arrive at a consensus decision for NPS pollution management goals. The public stakeholders, modelers, and decision makers can make a decision together for adjusting the input parameters, calibration and validation values, or land use scenarios that alter the system until they find the best solution to meet their goals.

Table 4. Three Iterations of Questions through Six Models for Nonpoint Source Pollution, Watershed Modeling and PPGIS Integrative System Adapted from the Geodesign Framework (Steinitz, 2012 p. 27)

First Iteration (Top to Bottom)	Example Questions
1. Representation models	<i>Where is the study area? What is its physical, ecological, economic, and social geography in present and histories?</i>
2. Process models	<i>What are the area's major physical, ecological, economic, and social processes? How are they linked to each other?</i>
3. Evaluation models	<i>Is the area seen as attractive? Is the area developing or declining? Are there any nonpoint source pollution problems in the area?</i>
4. Change models	<i>What major changes are foreseen for the region caused by nonpoint source pollution? Are they related to growth or decline? Are they related with land use change?</i>
5. Impact models	<i>Are anticipated changes seen as beneficial or harmful? To whom? Are they seen as serious?</i>
6. Decision models	<i>What is the main purpose of the nonpoint source pollution study? Public action? Economic profit? Scientific advancement? Who are the major stakeholders?</i>
Second Iteration (Bottom to Top)	Example Questions
6. Decision models	<i>How is a decision to be made to mitigate the NPS pollution problems with regard to results from impact models?</i>
5. Impact models	<i>What predictable differences might the changes of land use/ land cover cause NPS pollution impacts?</i>
4. Change models	<i>By what actions might the current representation of the NPS pollution be altered: what, where, and when?</i>
3. Evaluation models	<i>Is the water quality is in good condition comparing with real data and standard?</i>
2. Process models	<i>How does the nonpoint source operate? What are the functional and structural relationships among its elements?</i>
1. Representation models	<i>How should the NPS pollution be described in terms of content, boundaries, space, and time? Which data are needed at what scale at which classification and from what sources?</i>

Third Iteration (Top to Bottom)	Question/Activity Examples (need to be accomplished during this stage)
1. Representation models	<i>Obtain the needed data for nonpoint source pollution modeling</i>
2. Process models	<i>Run, calibrate, and test water quality model, Link them to the expected change models (land use/land cover change model)</i>
3. Evaluation models	<i>Evaluate past and present conditions of water quality, and compare results with water quality standard and show the results of evaluations</i>
4. Change models	<i>Propose simulate future changes of land use change model and represent results</i>
5. Impact models	<i>Process results from change model with water quality modeling in order to access and compare the impacts of each change model, visualize and communicate the results.</i>
6. Decision models	<i>Compare the impacts of the change models and decide which land use policy is the most situations for the area. How is a decision to be made to mitigate the NPS pollution problems with regard to results from impact models? No—redesign, improve, or find better data MAYBE—change scale, size, or time YES—Implement it</i>

These questions flow from the first iteration (understand study area) to the second iteration (design of the model), and finally to the third iteration (perform study) until stakeholders, modelers and decision makers meet the consensus decision for NPS pollution management.

Public stakeholders, modelers, and decision makers can make a decision together for adjusting the input parameters, calibration and validation values, or land use scenarios that alter the system until they find the best solution to meet their goals.

Explicitly using the questions raised by Steinitz in his workflow analysis as a guide, the Geodesign Framework for Water Quality Improvement (GeoFWQI) (Figure 4) was developed by integrating public participation and GIS with a water quality modeling as it pertains to NPS pollution management.

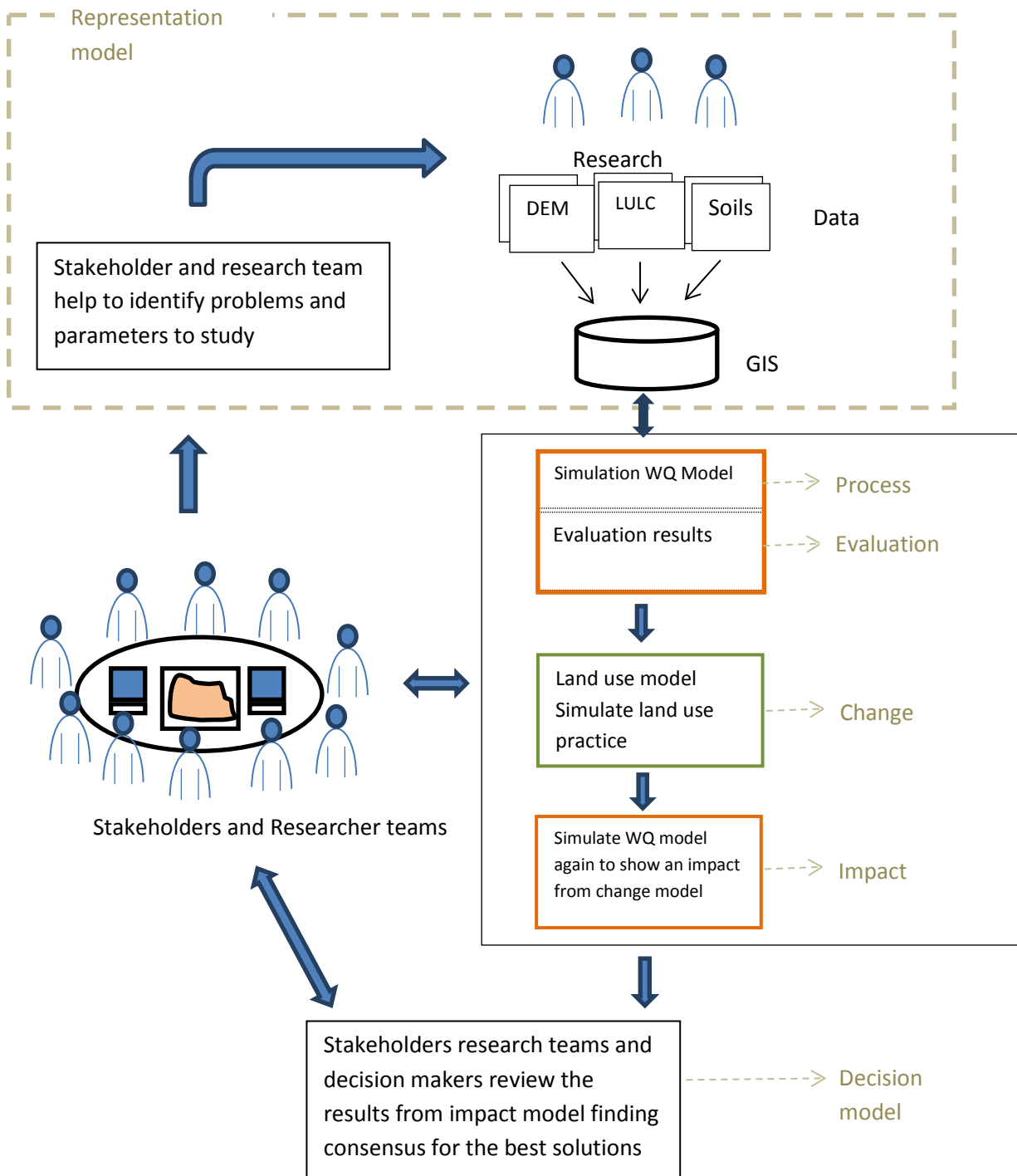


Figure 4. Geodesign Framework for Water Quality Improvement (GeoFWQI)

The following section describes the GeoFWQI in terms of the six-step modeling process, which is separated into two parts including the water quality modeling and the public involvement in the modeling process.

Water Quality Simulation Modeling

1. Database design (Representation modeling)

In this phase of inquiry, we scope the concept of NPS pollution, characteristics of NPS pollution, type and source of pollution, which basically involves database design. GIS, as a tool used to organize the spatially explicit data related to NPS pollution, will contribute to an understanding of data on land use/ land cover, soil type, rainfall, elevation, roads, surface runoff, sub-surface runoff evaporation, and infiltration (Thornton, 1999). By constructing a database model and by representing the process in maps, charts, and diagrams we further add to that understanding. The geodatabase model for nonpoint source pollution modeling will be created using ArcGIS software from ESRI.

2. Water quality modeling (Process modeling)

Understanding a hydrological cycle is important for investigating the processes of nonpoint source pollution (Liebscher, 2009). The factors that define the water movement including precipitation, evaporation, infiltration, transpiration, surface runoff, and sub-surface runoff (Thornton, 1999) influence the amount of NPS pollution loading. Another important factor influencing the quantity and quality of NPS pollution is land use/ land cover. Once the relevant components of NPS pollution have been identified, the relationship between each component can be established. For example, runoff can be determined by soil characteristics, land cover and

precipitation, and pollution loading is determined by runoff, land cover, and pollution coefficients (Thornton, 1999; Leibscher, 2009; NOAA, 2010). Due to the amount of time and high cost of monitoring the watershed in order to investigate NPS pollution loading, water quality modeling is introduced in this level to simulate hydrological cycle in order to investigate water runoff and quality/quantity of NPS pollution. Using water quality modeling consumes less time and cost to operate (Arnold, 1998; Di Luzio *et al.*, 2004). Moreover, selecting a suitable water quality model is important in this phase. We need to select a suitable tool for certain areas. Once the water quality model is designed, the data identified from phase 1 will be used. Monitoring data are used to confirm the result of runoff loading and quality/quantity of NPS pollution loading for calibrating and validating the model (Vieux, 2001).

3. Evaluation results (Evaluation modeling)

The qualified “working well” question introduces evaluation (Steinitz, 1996) of the result from water quality modeling. Results from WQ modeling will be evaluated with the water quality standard of Washington State. This process includes the evaluation of situations of water quality, helping decision makers and public stakeholders to understand how their watershed health and how their land use plan is going to affect water quality in the area.

4. Change of land use (Change modeling)

For NPS pollution, an important type of change to be considered is how the amendments of policies alter land use/ land cover. The land use transformation could result in obvious changes in surface conditions, which could cause noticeable changes in NPS pollution load flow (Shen *et al.*, 2010). In this phase of inquiry, the alternative scenarios for future urbanization shall be designed to see the change of land use/ land cover with a different scenario. To investigate the

change of land use/ land cover in different scenarios, a land use scenario model is brought to the front to support the simulation of the change. The changed land use data from land use modeling (ex. ENVISION) will be created or will be brought from other resource data.

5. Simulate the impact of WQ model from the change of land use (Impact modeling)

Once land use has been predicted from step 4, these results will be simulated in the water quality model (e.g. using NSPECT) again to reveal the impact of NPS pollution from the different scenario policies. This will show the relationship between land use policies and NPS pollution.

6. Making decision (Decision modeling)

Each of the impact assessments reveals one aspect of how the alternative scenarios of land use practices are predicted to change NPS pollution impacts. The alternative scenario and criteria by which choices are assessed will vary among individuals and groups who hold different interests (Steinitz, 1996). The results from simulating the impact of WQ model will be input to the decision model to weight alternative scenarios of land use practices one against another.

Public involvement in modeling process

There are many ways for the public to get involved in the modeling process.

1. Database design

In this process, public stakeholders could examine the situation of NPS pollution problems that currently occur. They also help to identify the parameters to be investigated. Moreover, public stakeholders could provide the preliminary discussion of the level of accuracy of the model

required for decision makers (Korfmacher, 2001). In this state, the design database for NPS pollution is established at this level of inquiry.

2. Simulation WQ model

In this process, public stakeholders who can get involved in this process should be educated until they have sophisticated knowledge enough to work in this step. The public stakeholders also should be educated about uncertainty predictions involved in water quality modeling to help maintain public stakeholders' expectations about water quality modeling (Korfmacher, 2001). Additionally, public involvement in this process would influence selecting suitable models or even create a new one that should have user-friendly functions and should not be too complicated for public stakeholders to understand and get involved. With the ability of spatial representation of GIS, watershed model linking with GIS would be transparent and easily explained to decision makers and stakeholders in the watershed areas.

3. Evaluation results

Another important way to evaluate models is bringing public stakeholders and watershed managers together to investigate the resultant changes in pollution loading from the models, and brainstorm among concerns, and then provide feedback. For example, stakeholders could provide insights about which parameters have the most concern and how the land use plan could be adjusted to enhance the health of the watershed. This could be possible because public stakeholders live in the area and might have more accurate estimate than modeler (Korfmacher, 2001). The results from this evaluation model phase set up the opportunity to explore change in the next phase of the GeoFWQI.

4. Change land use scenarios

In this process, public stakeholders can provide insights about alternative land use policies and practices from experience and knowledge through land use model. Public stakeholders can provide the specifications of different land use scenarios, including boundary and management options, for use in the next phase.

5. Simulating impacts from the change of land use scenario

Public stakeholders could get involved in decisions about land use practices. They could share their knowledge and concern in their location in response to land use policies. An impact model characterizes the direction of a change in land use policies that subsequently leads to different characteristics of NPS pollution impacts. If a land use policy focuses on urban growth pattern by emphasizing commercial and industrial areas, this might create more heavy metal pollutants in the area, than if residential areas were the land use. Once the decision makers and public stakeholders have the impacts of alternative scenarios, they can use them in decision making in the next phase.

6. Making decisions about change in land use policy

In a decision model, public stakeholders could get involved by expressing their concern about directions for land use practice and of NPS pollution control. Public stakeholder groups, technical specialists, and decision makers review the results from the impact model and work through consensus development for the best decision. Recommending the best alternative scenarios of land use practices is the responsibility of public stakeholders and policy makers that

will be influenced by future development (Steinitz, 1996). Results from the decision model derive from the knowledge of all actor groups.

3.3 Discussion

Nonpoint source pollution problem is not a single problem facing a single person. It is created from many factors and many groups of people such as framers, vehicle drivers, etc. Bringing groups of people together in the management process would be a sustainable way to mitigate problems related to nonpoint source pollution. The GeoFWQI has been created to better understand how to integrate the concepts of nonpoint source pollution, watershed modeling and PPGIS. Six main inquiry questions of six models flowing through three iterations among the study team and stakeholders form the GeoFWQI. The GeoFWQI identifies and links ideas, activities, collaboration, and tasks that need be undertaken to accomplish the goal of a complex project requiring agreement and consensus.

Chapter 4: Representation and Process Model

From the Geodesign Framework for Water Quality Improvement (GeoFWQI) in Chapter 3, the representation model is the phase of inquiry that establishes the need for data for the nonpoint source pollution modeling. The process model is important for investigating the processes of nonpoint source pollution by running and calibrating the water quality model to better understand water quality conditions in the Water Resource Inventory Area 9 (WRIA9). This chapter describes the representation and the process model used. Total nitrogen was used as an example of a pollutant flow simulated with the water quality model. The results for process model will then be used as input for the change and impact models in the next chapter.

4.1 Study Area

This research has selected the Water Resource Inventory Area 9 (WRIA9): Green-Duwamish Watershed as the study area. The size of the drainage area of WRIA9 is approximately 125,400 hectares, including the Puget Lowland and Cascade regions (Figure 5). The annual average precipitation in the Green-Duwamish watershed is about 59 inches. The watershed spans an area from the ridge of the Cascade Mountains at the headwater of the Green River westward to the mouth of the Duwamish River, where the river drains into Elliott Bay in the City of Seattle (King County, 2007).

WRIA9 is an area that has a variety of land use and land cover and where salmon habitat is substantially degraded. This area has been under active salmon habitat protection and restoration for many years. Nonpoint source pollution is the main concern for water quality in this area. The

impacts from impervious surfaces are typically due to vehicle loads, runoff from suburban lawn maintenance chemicals, agriculture fertilizers and pesticides, and industrial wastes.

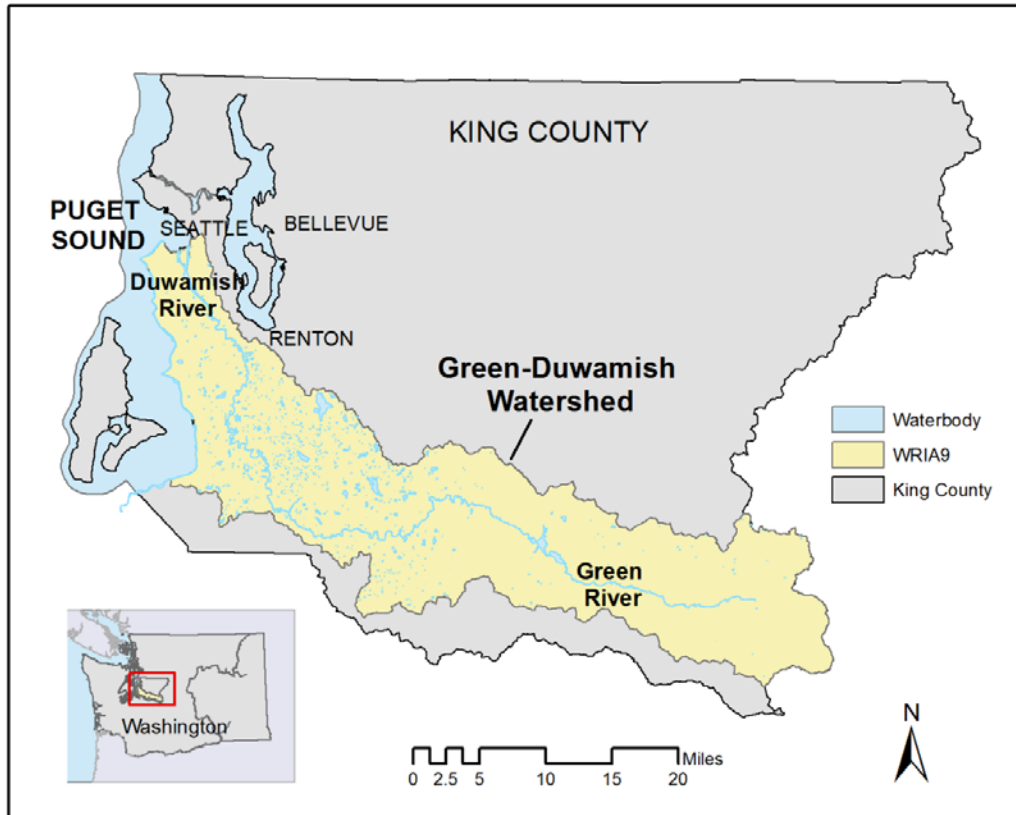


Figure 5. Water Resource Inventory Area 9 (WRIA9): Green-Duwamish Watershed

4.2 Model Description

OpenNSPECT is an open-source version of N-SPECT that facilitates an estimation of the pollution impacts on water quality from nonpoint source pollution and erosion. The model was designed as a water quality screening tool by NOAA. OpenNSPECT uses MapWindow as a platform to host the model (EMBTN, 2010). MapWindow is a free open-source GIS program that can be used as an open-source desktop GIS (Corft, 2007). OpenNSPECT examines water

pollution and soil erosion impacts to rivers, streams, and coastal water. Three main functions of OpenNSPECT include a rainfall-runoff model, a pollution model and a sediment-yield model.

This research uses only rainfall-runoff model and pollution model.

4.3 OpenNSPECT Model Setup

OpenNSPECT comes with default datasets to the Wai'anae region of O'ahu, Hawai'i. This study applies this tool in WRIA9, requiring the following datasets.

- Topography data (Digital Elevation Model, DEM)
- Land cover data (raster format)
- Rainfall data (raster format)
- Soil data (shapefile format)
- R-factor data (raster format)
- Local pollution coefficients (table format)
- Water quality standards (table format)

OpenNSPECT automatically sets the raster analysis environment to the parameters of the DEM file. This is a significant step to make sure that all raster grids developed from the model have the same cell size, spatial reference, and extent. Without this automatic setting, the input and output raster grids might not register correctly.

4.4 Application to the Water Resource Inventory Area 9—Duwamish-Green Watershed

Before running the model, several datasets need pre-processing. The following section describes the data and how to perform data input. The details of data input are in Appendix A. How to run the model is in Appendix C.

4.4.1 Data Input

Data sets used for OpenNSPECT are displayed in Table 5.

Table 5. Input Database for OpenNSPECT

Data Type	Data Source	Data Description
Elevation	USGS 2006	30 Meter Digital Elevation Model (DEM)
Land Cover	NOAA 2006	CCAP (Costal Change Analysis Program)
Precipitation (Rainfall data)	The National Climate Center (NCDC)	Parameter-elevation Regressions on Independent Slopes Model (PRISM)
Soils and erosional characteristic	NRCS 2005	Soil Survey Geographic (SSURGO) database
R-Factor	NRCS 2005	Rainfall/Runoff erosivity factor, number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.
Pollution Coefficient	EPA and King County	The value represents the ratio of pollution of a given type generated from a given land cover.

4.4.1.1 Topographic Data

The 30-meter Digital Elevation Model (DEM) for WRIA9 was obtained through the United States Geological Survey (USGS) via Washington Geospatial Data Archive (WAGDA University of Washington), and clipped to the WRIA9 boundary. The data were downloaded in the ASCII format for twenty-six areas (Appendix B) to cover WRIA9. After downloading all twenty-six areas within WRIA9, they were converted to a raster file using the tool “ASCII to Raster” in ArcToolbox. Then, all twenty-six areas were merged into one area and clipped to WRIA9.

4.4.1.2 Land Cover Data

The land cover data were obtained from the Coastal Change Analysis Program (CCAP) land cover data set developed by NOAA in 2006. This data set is a nationally standardized land cover and land change analysis for coastal regions of the United States. Once the data were downloaded from the NOAA (2006), the data was clipped to the WRIA9 boundary.

4.4.1.3 Rainfall Data

Parameter-elevation Regressions on Independent Slopes Model (PRISM) provided annual precipitation at a resolution of a 800-meter grid. This dataset was clipped to the WRIA9 boundary. The National Climate Center (NCDC, 2012) provides precipitation data by stations in the federal network. The precipitation data from NCDC website were obtained in the .csv format and then converted to point shape file and interpolated with kriging method to raster grid at 30-meter resolution, and the units were converted to centimeters. Kriging is one method of interpolation and is often recommended for precipitation data (Haberlandt, 2007; Di Piazza *et al.*, 2011). The seasonal precipitation data were converted to raster file with the same process as the annual precipitation. After finishing the conversion process, all of the precipitation data were clipped to WRIA9 boundary.

4.4.1.4 Soil Data

The soil data was obtained from the U.S Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database. Once the selected data was downloaded, two tables from the dataset, component and chorison data tables needed to be joined with the soil polygon shape file. The component table contains the hydrologic soil

group attributes (Table 6). The chorison table includes the kfactor values (Eslinger, 2012). Once the tables were joined, the soil polygon shapefile was exported and cleaned to eliminate the unnecessary fields contained in the attribute table.

Table 6. Hydrological Soil Group Definitions (Eslinger, 2012)

Hydrologic Soil Group	Soil Texture	Soil Group Characteristics
A	Sand, loamy sand, or sandy loam	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well- to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Silt loam or loam	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, and moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Sandy clay loam	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

4.4.1.5 R-factor (Rainfall Erosivity Factor)

The R-factor is a representation value of erosivity of the climate at a particular location. Its average annual value is calculated from historical weather records and the average annual sum of the erosivity of individual storms (USDA, 2012) and its individual storm is determined as the product of the storm’s total energy and the storm’s maximum 30 minute intensity. The range of erosivity is from less than 10 inches the western US to greater than 600 inches in Louisiana (USDA, 2012). In this study, R-factor was downloaded from the Natural Capital Project (NCEAS); the data values being digitized from USDA Isoerodent maps of the United States. The data was clipped to the WRIA9 boundary.

4.4.1.6 Pollution Coefficient

The value of pollution coefficient represents the ratio of pollution of a given type generated from a given land cover. The pollution coefficient used in this model was based on those values represented in Hawaii and was adjusted by the pollution coefficient obtained from the Washington State Department of Ecology. The new coefficient of total nitrogen was adapted from the Puget Sound Watershed Characterization Project (Stanley *et al.*, 2011).

4.4.2 Model Calculation Process

4.3.2.1 Runoff Estimation Process

The basic method to estimate runoff value in OpenNSPECT is SCS Curve Number method from the Natural Resources Conservation Service's *Urban Hydrology Small Watersheds: Technical Release 55*, utilized by NRCS. Runoff is determined using the following equations.

$$(1) \dots\dots\dots Q = \frac{(P-I_a)^2}{(P-I_a)+S}$$

$$(2) \dots\dots\dots I_a = 0.2 \times S$$

$$(3) \dots\dots\dots S = \left(\frac{1000}{CN}\right) - 10$$

Where:

Q = runoff (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

I_a = initial abstraction (inches)

CN = runoff curve number

If the initial abstraction at a given cell is greater than the rainfall at that cell, OpenNSPECT sets runoff depth to zero: $(P - I_a) \leq 0$, then $Q = 0$. Runoff estimation process is shown in Figure 6.

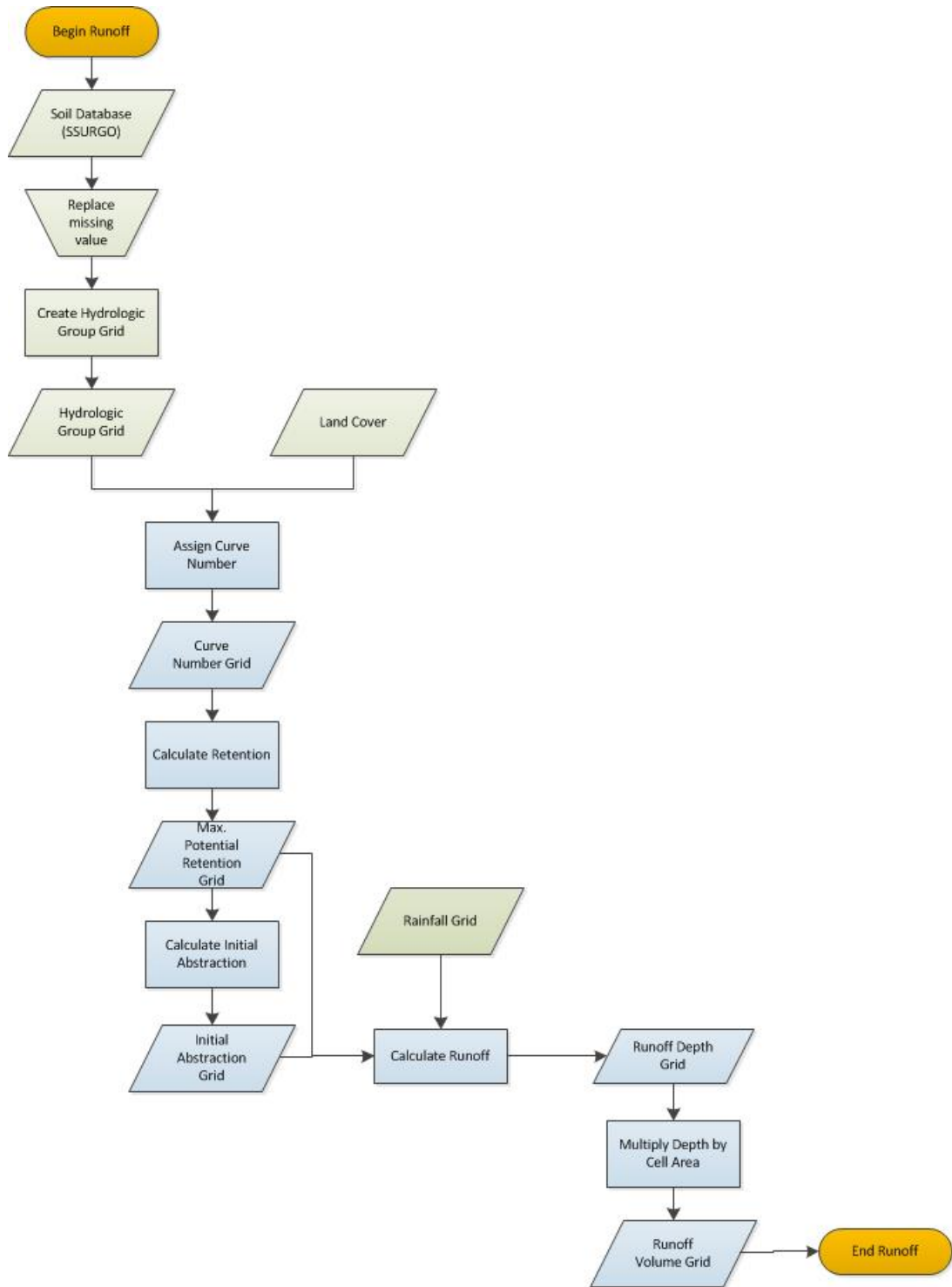


Figure 6. Runoff Estimation Process (Eslinger *et al.*, 2012)

There are six steps from technical guide of OpenNSPECT showing the runoff calculating process behind the scenes (showing in blue in Figure 6).

First step creates the Curve Number Grid. The Curve Number (CN) represents the infiltration capacity of soil developed by NRCS based on soil properties. CN varies from 0 to 100, which 0 indicates no runoff and 100 indicates no infiltration. OpenNSPECT uses this number to derive a curve number for each grid cell based on the land cover and hydrologic soil group for that cell.

Second step calculates maximum potential retention. Retention is the ability of the soil to absorb water or moisture. This means the areas that have high retention have less runoff. The retention value is calculated using below equation in OpenNSPECT:

$$\text{Retention (inches)} = (1000 / \text{Curve Number}) - 10$$

Third step calculates initial abstraction. The abstraction value represents the losses of water occurring before runoff begins including water stored by surface depressions and water interacted by vegetation, evaporation, and infiltration. The abstraction value is calculated in OpenNSPECT with the equation below:

$$\text{Abstraction (inches)} = (0.2 \times \text{Retention})$$

Fourth step composes precipitation grid. The detail of obtaining precipitation grid is in Appendix A. For estimating water runoff the unit of precipitation must be inches. However, the precipitation measured in centimeter units can be used in OpenNSPECT. The model will convert the unit from centimeters to inches automatically.

Fifth step calculates runoff. The event-based runoff depth is estimated using the below equation in OpenNSPECT.

$$\text{Runoff Depth} = (\text{Rainfall} - \text{Abstraction})^2 / (\text{Rainfall} - \text{Abstraction}) + \text{Retention}$$

The annual runoff depth is calculated by the following equation:

$$\text{Runoff depth} = \frac{(\text{Rainfall} \times (\text{Abstraction} \times \text{RainDays}))^2}{[(\text{Rainfall} \times (\text{Abstraction} \times \text{RainDays})) + (\text{Retention} \times \text{RainDays})]}$$

The runoff value will be set to zero when the abstraction is greater than rainfall.

Sixth step converts units. This step converts the runoff depth grid to runoff volume and to other units that will be used as inputs to subsequent processing.

Summarizing, data preparation involves calculating runoff values, using data for rainfall, elevation, land cover, and soil. The output data set of this process is runoff volume (L).

4.3.2.2 Pollution Loading Process

The pollution loading process of OpenNSPECT is driven by the Pollution Coefficients Method (NOAA, 2004a). The pollution variable of this model is estimated using land cover data of various types, each type contributing a level of pollution. The equation is in following.

$$(4) \text{ OPL (Observed Pollution Load)} \dots\dots\dots = (C_0 \times LC_0) + (C_1 \times LC_1) + (C_2 \times LC_2) + \dots\dots\dots + (C_N \times LC_N)$$

Where:

OPL = a pollutant measurement (ex: nitrogen)

LC = the percentage of the total upstream contributing area by a given land cover class where $i = 0, 1, \dots, N$

C = the coefficient value associated with this land cover class for this pollutant where $i = 0, 1, \dots, N$

i = the number representing C-CAP land cover classes (See Table 7)

Table 7. C-CAP Land Cover Classes in WRIA9 (NOAA, 2012)

i	C-CAP land cover classes description
0	Background – areas within the image file but containing no data value
1	No Data – areas in which land cover cannot be determined including clouds and deep shadow
2	High Intensity Developed – heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses. Vegetation occupies < 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover.
3	Medium Intensity Developed – this class commonly includes multi-and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use. Constructed materials account for 50 to 79 percent of total area.
4	Low Intensity Developed – this subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use. Constructed materials account for 21 to 49 percent of total area.
5	Developed Open Space – contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. Constructed surfaces account for less than 20 percent of total land cover.
6	Cultivated Land – contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
7	Pasture/Hay – contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
8	Grassland – contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
9	Deciduous Forest – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
10	Evergreen Forest – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
11	Mixed Forest – contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
12	Scrub/Shrub – contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
13	Palustrine Forested Wetland – include tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
14	Palustrine Scrub/Shrub Wetland – includes tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

i	C-CAP land cover classes description
15	Palustrine Emergent Wetland – includes tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent.
16	Estuarine Forested Wetland – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
17	Estuarine Scrub/Shrub Wetland – includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
18	Estuarine Emergent Wetland – includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent.
19	Unconsolidated Shore – includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
20	Bare Land – contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.
21	Water – include areas of open water, generally with less than 25 percent cover of vegetation or soil.
22	Palustrine Aquatic Bed – includes tidal and non-tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.
23	Estuarine Aquatic Bed – includes tidal wetlands and deep water habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.
25	Snow/Ice – includes areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.

OpenNSPECT estimates pollutant concentrations by using land cover as a proxy. The estimation is accomplished by applying pollutant contribution coefficients (similar to event mean concentrations) to land cover classes and introducing a runoff volume grid. There are 7 steps for estimating pollutant loading.

1. The runoff volume grid is converted to liters by multiplying each cell by a conversion factor (Figure 7-8).

2. The accumulated runoff grid is created from the flow direction grid and the new runoff volume grid. Each cell in the accumulated runoff grid represents the total amount of water that passes through that cell, including contributions from upstream cells.
3. A pollutant concentration grid is then created from either the default pollutant coefficients or a new set derived from local sampling data where each cell is assigned a value based on its land cover classification.
4. The pollutant coefficient value represents an average concentration (mg/L) for a given land cover classification. When the pollutant concentration grid is multiplied by the runoff volume grid, the result is a new grid that indicates the mass of the pollutant produced by each individual cell. This grid does not take into account upstream contributions.
5. The pollutant mass grid is accumulated using the flow direction grid. The result is an accumulated pollutant mass grid in which the value of each cell represents the total mass of pollutant that passes through that cell, including contributions from upstream cells.
6. An accumulated pollutant concentration grid is derived by dividing the accumulated pollutant mass grid by the accumulated runoff grid. However, this grid does not include the pollutant mass and runoff volume generated at the current cell, instead including only the total value of all upstream cells that flow through the current cell.
7. The final pollutant concentration grid is created by adding the pollutant mass grid and accumulated pollutant mass grid, then dividing this quantity by the sum of the runoff volume grid and the accumulated runoff grid.

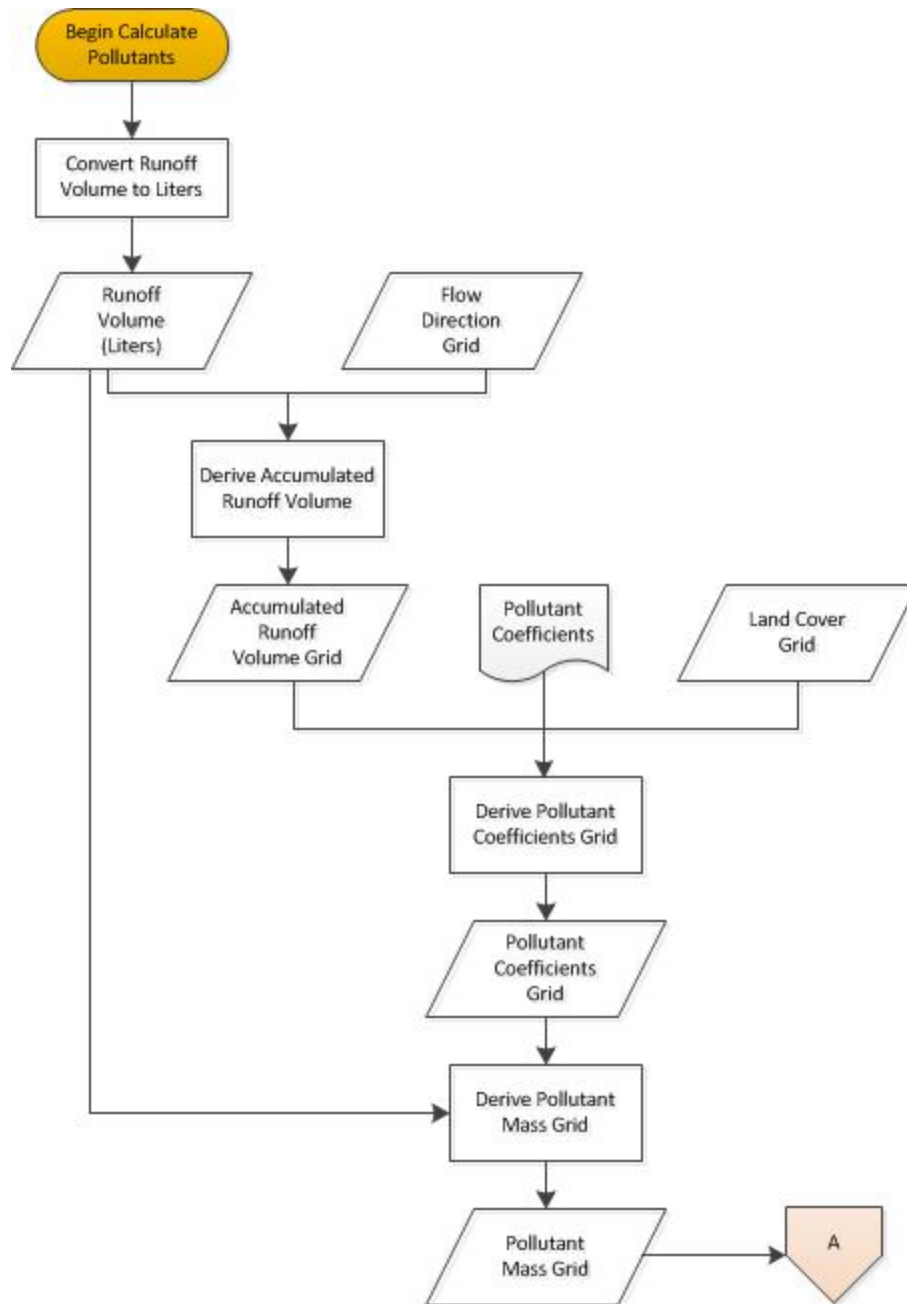


Figure 7. Estimation process of pollutant concentration (cont'd.)

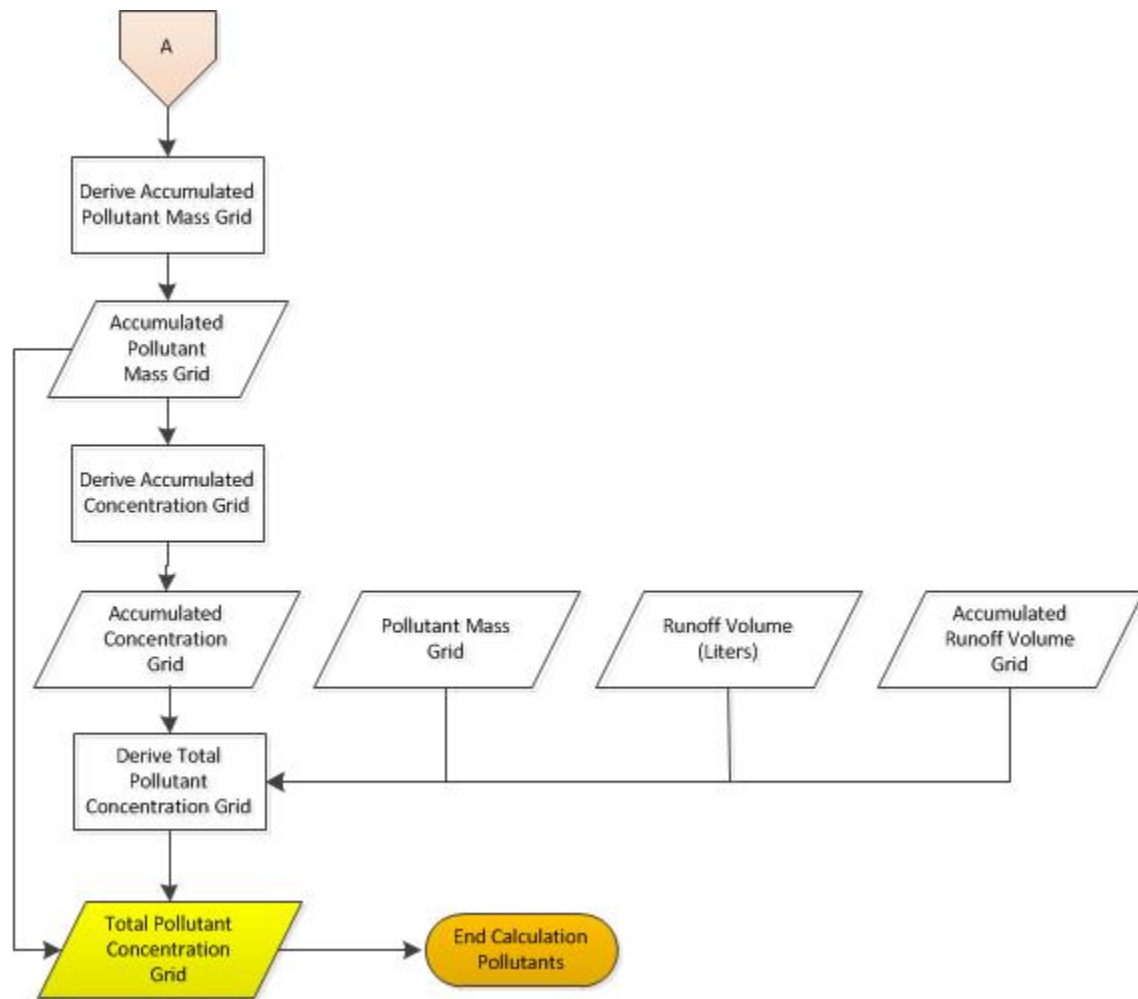


Figure 8. Estimation process of pollutant concentration (Eslinger *et al.*, 2012)

In summary, the input data sets used in this process are rainfall, elevation, land cover, and soil data. The output data sets of this process are accumulated pollutant (kg), pollutant concentration (mg/L).

4.5 Model Calibration

4.5.1 Model Calibration for Runoff

Runoff accumulation that is simulated from the model is the first essential information to be evaluated when performing a calibration of a model. Because water is a driving force of the runoff process and hence the model, when determining how well the model functions, we need to establish how well the model predicts runoff accumulation. To calibrate the model, all input parameters were derived and imported into the model and compared with data from USGS gauge stations in WRIA9.

The runoff amount from OpenNSPECT represents only storm runoff and does not include baseflow in a stream. For this reason, the streamflow data from USGS could not compare directly with the output runoff from the model. The streamflow data had to go through a baseflow separation using the sliding-interval method formulated by Pettyjohn and Henning (1979), which is the method used by the USGS for its water resource investigations (Sloto and Crouse, 1996).

The sliding-interval method equations are as follows.

$$(5) \text{ Lowest Stream discharge} = [0.5 \times (2N - 1) \text{ days}]$$

$$(6) N = A^{0.2},$$

where N is the number of days after runoff ceases and A is the drainage area in square miles, and 2N is the odd integer between 3 and 11 nearest to 2N (Sloto and Crouse, 1996).

The mean daily streamflow data from USGS were used for the baseflow separation method described above. Before performing the baseflow separation, the unit of streamflow data was

changed from “cubic feet per second” to “liters per year”, creating a commensurate unit with the OpenNSPECT model. Subsequent to baseflow separation, the baseflow was subtracted from the total streamflow to obtain storm runoff, which was compared with the runoff output from OpenNSPECT. The streamflow data were downloaded from the USGS National Water Information System website (USGS, 2013). Four stations were used for calibration, including USGS station numbers 12113349 (Mill Creek near Mt. at Orillia), 12113000 (Green River near Auburn), 12106700 (Green River at Purification Plant near Palmer), and 12105900 (Green River below Howard Hanson Dam).

Calculating percent difference between the recorded storm runoff and simulated runoff from the model was the next step. The simulated runoff data from the model were taken at the locations of the USGS stations. This comparison was calculated using equation (7) below. If the percent difference is between $\pm 10\%$, the model’s ability to predict is considered ‘good’. If the model prediction is between $\pm 10\%$ - 20% , the model ability is acceptable, and thus the calibration is deemed reasonable (Tong and Chen, 2002).

$$(7) \text{ \% difference} = \left(\frac{\textit{simulated-measured}}{\textit{measured}} \right) \times 100$$

Table 8 shows the percent difference of simulated runoff data from USGS measured storm runoff data, which represents the present error of simulation data. It shows that all of the percent differences from stations are outside of the $\pm 10\%$ good error margin. There is only one station (12113349) that has -14.40% , which is in the range of acceptable error margin.

Table 8. Percent Error of Simulated Runoff from USGS Measured Storm Runoff

Station Number	Percent (%) Error of Simulation data
12113349	-14.40
12113000	-34.05
12106700	-18.01
12105900	-21.47

The raining day factor is a sensitive factor for OpenNSPECT and it influences overall runoff accumulation (Gaut, 2009). To calibrate the runoff data from this model, the raining day value was adjusted within the model. After adjusting raining day factor, it was discovered that testing raining day at the number 23 provides a most representative amount of runoff value indicated by the percent error of simulated data within the $\pm 10\%$ good error margin as shown in Table 9.

Table 9. Calibrated Percent Error of Simulated Runoff from USGS Measured Storm Runoff Adjusting Raining Days

Station Number	Percent (%) Error of Simulation data
12113349	-1.82
12113000	-16.15
12106700	5.22
12105900	1.10

As per the data shown in the Table 9, when the raining day factor within the model was adjusted from 27 to 23, there were three stations (12113349, 12106700, and 12105900) that had the percent error within the range of $\pm 10\%$ good error margin (-1.82%, 5.22%, and 1.1%, respectively). There was one station that had the percent error out of the range of $\pm 10\%$, however it was still within the range of $\pm 10\%$ -20% (-16.15%), which is within the range of an acceptable error.

Another step taken for calibrating simulated runoff within the model is to adjust the curve numbers (CN) to reduce the percent error of simulated runoff. The curve numbers for land cover

and soil hydrologic groups varies depending on the hydrologic condition of the area. In this research, CN adopted by the Department of Ecology (Ecology) in Puget Sound Watershed Characterization (Stanly *et al.*, 2011) was used to adjust the CN for the OpenNSPECT model runs (Details in Appendix D). After adjusting the CN, the most representative runoff value was based on 20 raining days as shown in Table 10.

Table 10. Calibrated Percent Error of Simulated Runoff from USGS Measured Storm Runoff Adjusting CN

Station Number	Percent (%) Error of Simulation data
12113349	8.02
12113000	-19.22
12106700	-3.49
12105900	-7.04

Comparing the percent error in Table 10 with Table 8, only one station (12106700) achieved a reduced percent error, from 5.22 % to 3.49%. The other three stations gain in percent error from Table 9 to 10 to a level of 8.02%, 19.22% and 7.04%, respectively. These results show that using CN from Ecology has more percent error of simulation runoff than using default CN from OpenNSPECT. However, the percent errors of those four stations are still within the range of good and expectable error ranges.

4.5.2 Model Calibration for Pollutants

In the next step, pollution amounts were calibrated for the model. The simulated total nitrogen from the model was compared with the measured total nitrogen from Ecology. Total nitrogen is a major contributor to eutrophication of surface water, resulting in an increase in algal biomass and photosynthesis that cause water eutrophication. Eutrophication interrupts the ecology leading to toxic algal blooms, loss of oxygen, and loss of aquatic species including species that are

important in this area such as salmon. Eutrophication can also affect the quality of water used for drinking, industry, agriculture, recreation, and other purposes. The sources of total nitrogen are from fertilizers, animal manure, domestic effluents, atmospheric deposition, and soil nitrogen. Total nitrogen concentration has a trend of increasing as a consequence of residential, industrial, and agricultural development (Anne and Gerard, 2009; Preston and Brakebill, 2012; Xu *et al.*, 2014; MPCA, 2013).

There were four water quality stations in WRIA9 including station 09A080 (Green River at Tukwila), 09A190 (Green River at Kanaskat), 09N050 (Mullen Slough at Frager Rd), and 09Q060 (Redondo Cr above Marine View Dr S). There are only two stations used in this research: 09A080 and 09A190. The data from 09N050 and 09Q060 were not used because Ecology had stopped monitoring these stations in September 2011 for the reasons that the overall water quality at these stations consistently did not provide useful information to the Department (DOE, 2013).

Table 11 shows the baseline percent error of the model simulation for total nitrogen concentration (mg/L), to total nitrogen from Ecology. The percent error of total nitrogen from station 09A080 is 233.18 % and from station 09A190 is 894.24%. This shows a very high percent error.

Table 11. Baseline Percent Error of the Model Simulation for the Total Nitrogen Concentration

Station Number	Percent (%) Error of Simulated Total Nitrogen
09A080	233.18
09A190	894.24

With this high percent error, this model should be adjusted so the coefficient of total nitrogen is within a more reasonable range. The pollutant coefficient value represents an average concentration (mg/L) for a given land cover classification. The new coefficient of nitrogen was adapted from the Puget Sound Watershed Characterization Project (Stanley *et al.*, 2011) as shown in Appendix E. Table 12 shows the calibrated percent error of the model simulation for total nitrogen concentration as compared to total nitrogen estimated by Ecology.

Table 12. Calibrated Percent Error of the Model Simulation for the Total Nitrogen Concentration

Station Number	Calibrated Percent (%) Error of Simulated Total Nitrogen
09A080	-26.33
09A190	95.25

Comparing the percent error in Table 12 with those in Table 11, the calibrated percent error was reduced from 233.18% to 26.33% at station 09A080 and from 894.24% to 95.25% at station 09A190. The percent error was reduced substantially; however, they are still out of the acceptable margin of error.

4.6 Discussion

Adjusting the raining day and CN reduced the percent error of model simulated runoff as shown in Tables 9 and 10. However, there are challenges with finding a suitable CN that helps adjust the simulated runoff value to fit with the measured runoff for all stations. The most suitable calibration uses 23 raining days with the base CN number. For calibrating total nitrogen, the percent error was very high when using base nitrogen coefficient (Table 11). When calibrating with the new nitrogen coefficient, the percent errors were reduced on both stations, but they were still not within the acceptable margin of error (Table 12). This encourages a change about how to

present the magnitudes showing the absolute magnitudes of total nitrogen to show relative level of total nitrogen change within the Change and Impact Models.

Chapter 5: Evaluation, Change, Impact, and Decision Modeling

Based on the GeoFWQI, once the database (Representation Modeling) and the WQ Simulation Model (Process Modeling) were developed and run (Chapter 4), then evaluation, change, impact and decision modeling can be performed. Those tasks require implementing a water quality comparison (Evaluation Modeling), developing a change of land use (Change Modeling), creating a simulation of the impact of water quality model, exploring impacts from change of land use (Impact Modeling), and decision modeling. Those tasks are discussed as follows.

5.1 Water Quality Comparison (Evaluation Modeling)

The process of evaluation modeling is the way to investigate whether the water quality (result from the process model, concentration of total nitrogen) is in good condition compared with the water quality standards. Results from WQ modeling (process modeling) are evaluated against the water quality standard from the U.S. EPA (USEPA, 2000).

The U.S. EPA developed the National Strategy for the Development of Regional Nutrient Criteria (National Strategy), which was created for four types of waters including 1) lakes and reservoirs, 2) rivers and streams, 3) estuaries and coastal waters, and 4) wetlands. Those criteria include total phosphorus, total nitrogen, chlorophyll *a*, and turbidity. For this research, the EPA's nutrient criteria for "Rivers and Streams in Nutrient Ecoregion II" have been used. Ecoregion II is called "Western Forested Mountains" and it includes most of the large mountain ranges that are located in the Western US. The total nitrogen from the sub-ecoregion # 2 (Puget Lowland) was used for the areas of WRIA9. The range of the standard of total nitrogen in Puget lowland is 0.0 – 0.53 mg/L. This criterion is to represent conditions of surface water that is minimally

impacted by human activities and thus protected against the adverse effects of nutrients that cause eutrophication (USEPA, 2000). Eutrophication results in excessive oxygen depletion in water.

The result estimating total nitrogen concentration in year 2010 from the last chapter was evaluated against the range standard of total nitrogen concentration in Puget lowland from the U.S. EPA using ArcGIS 10.2 as shown in the Figure 9 below.

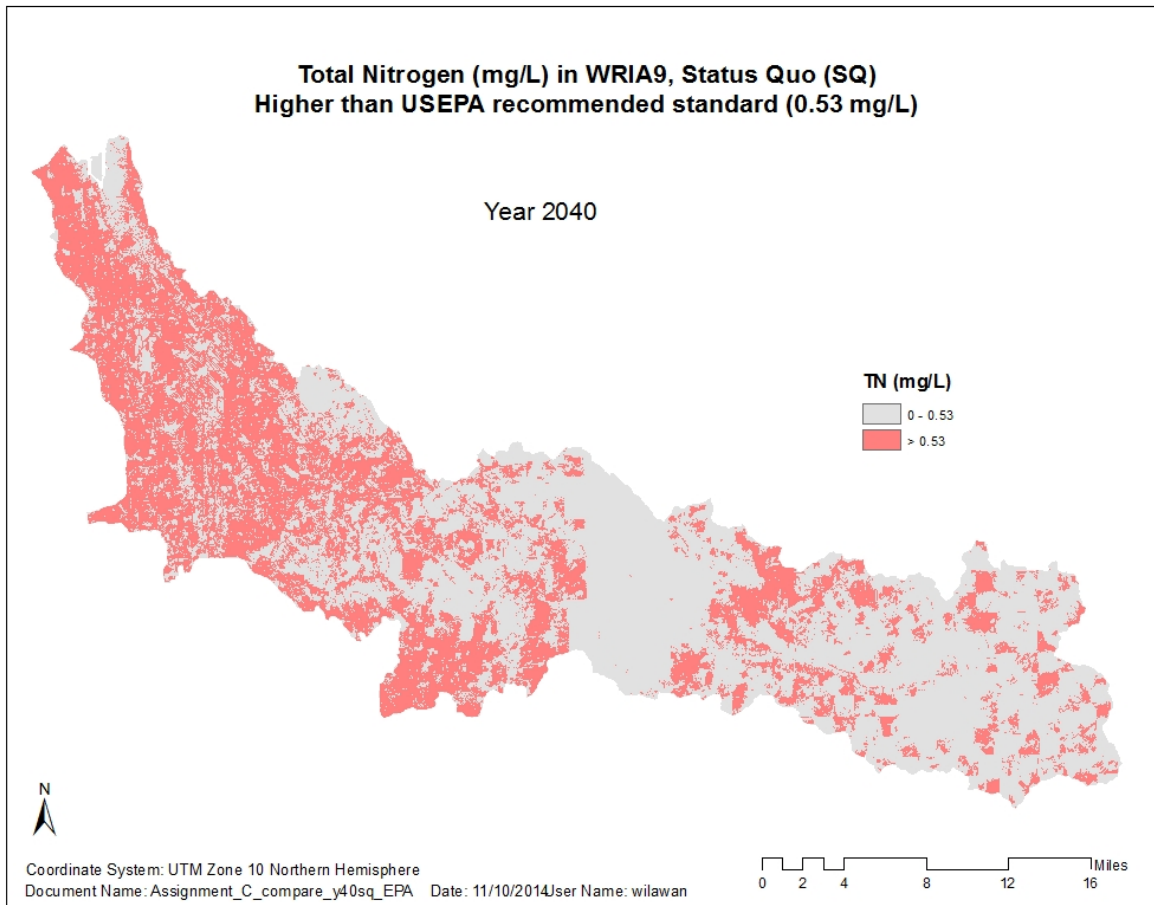


Figure 9. Total nitrogen concentration (mg/L) in WRIA9, higher than USEPA recommended standard

Evaluation modeling is used by public stakeholders and decision makers to select criterion for comparison of total nitrogen concentration (mg/L) based on differences in land use/cover results. Thus, working groups would be able to explore scenarios for water quality (total nitrogen) in WRIA9 under different land use conditions. That information can be used by the working group to consider what should be changed (what kinds of interventions are needed) to improve water quality. As such, scenarios provide a way for stakeholders and decision makers to consider “what if” situations. Establishing the evaluation model sets up the input for the change model described in the next section.

5.2 Change of land use (Change modeling)

Land use transformation can result in obvious changes to a surface, thereby leading to noticeable changes in NPS pollution load flow (Shen *et al.*, 2010). In this chapter, the results from the alternative scenarios leading to the changes of land uses for alternative future urbanizations from the ENVISION model runs will be used as input to OpenNSPECT. Consequently, output information from the ENVISION land use change scenario model is processed by OpenNSPECT as input data to investigate total nitrogen load in WRIA9.

5.2.1 ENVISION model

As mentioned in section 2.3, there are seven steps required to develop an ENVISION application, which include: 1) define goals, 2) define policies, 3) define scenarios, 4) generate and populate coverage with relevant attributes, 5) create landscape evaluation and autonomous process model, 6) run scenarios, and 7) analyze results. Each step requires specific tasks as shown in Table 13. The input data needed for those steps are shown in Table 14.

Table 13. ENVISION Application Development Workflow (Bolte, 2009)

Processes	Tasks
Define Goals	Establish benchmarks for landscape performance.
Define Policies	Specify alternative management strategies considered in the analysis.
Define Scenarios	Define the alternative policy sets and management strategies considered in the analysis.
Generate and Populate IDU Coverage with Relevant Attributes	Generate IDU coverage as a polygon-based GIS database that stores the spatial representation of the landscape and contains attributes required for policies and models used in the analysis
Create/Assemble Landscape Evaluation and Autonomous Process Models	Use model plug-ins that conform to ENVISION’s interface requirements.
Run Scenarios	Use ENVISION to run multiple scenarios, generate outputs for analyses
Analyze Results	Use ENVISION’s built-in tools or export data to other analysis tools to interpret scenario results.

Table 14. ENVISION Data Sets for Input (Bolte, 2009)

Data	Source
Integrated Decision Unit (IDUs) polygons	Developed using below data
Land Cover	NOAA C-CAP (Coastal Change Analysis Program), GAP Analysis
Watershed boundaries	King County
Urban Growth Area (UGA)	King County
Census200 block groups	King County

Data	Source
County zoning data	Washington State Office of Financial Management
Protected lands	Puget Sound Nearshore Ecosystem Restoration Program (PSNERP) Project
FEMA 100yr floodplain	Washington State Department of Ecology
Landslide hazard	Washington State Department of Ecology
Stream network	USGS
Road network	King County
Inactive railroads	PSNERP
Impervious area	PSNERP
Wetland	Washington State Department of Ecology
Herring spawning areas	PSNERP

ENVISION engages a spatially-explicit representation of the landscape, containing a set of polygons, termed Integrated Decision Units (IDUs) that contain multiple attributes describing polygonal areas. These IDUs form the fundamental spatial unit for actor decision-making in Envision. The IDU coverage for this analysis was created by intersecting several primary data sources including NLCD land cover data, watershed boundaries, and Urban Growth Area (UGA) boundaries (Bolte and Vache, 2010).

The ENVISION model was never successfully run for this research study because of the complicated instructions despite trying for several months to run the model. The developer of the model was never receptive to providing clarification of the instructions. Fortunately, this study

was able to obtain land use change analysis output consisting of decadal change 2010-2060 created as part of the ‘alternative futures’ study conducted by John Bolte (software developer) at Oregon State University for the PSNERP (Puget Sound Nearshore Ecosystem Restoration Project) activity and funded by the Washington Department of Fish and Wildlife (Bolte and Vache, 2010). That output was used for the impact modeling. The study created three scenarios of land use change policies: 1) Status Quo (SQ), 2) Managed Growth (MG), and 3) Unmanaged Growth (UG). Status Quo refers to the land use policy to continue current trends in the region. Managed Growth adopts an aggressive set of land use policies focusing on protecting and restoring ecosystem along with concentrating growth within the urban growth area (UGA). Unmanaged Growth represents the land use policy with no land use development restrictions, and limited protection using ecosystem policy. Detailed characteristics of these three land use scenarios are provided in Table 15.

Table 15. Land Use Scenario Description (Bolte and Vache, 2010)

Scenario Quality	Status Quo (SQ)	Managed Growth (MG)	Unconstrained Growth (UG)
Population Allocation	Maintain exiting allocation distributions	Greater allocation to UGA's; greater emphasis on concentrating growth around Regional Growth Centers	Greater allocation to areas outside UGA's through explicit preferences and relaxed development standards; less emphasis on concentrating growth around Regional Growth Centers
Urban Growth Pattern	Maintain existing development pattern, mix of densities, uses	Emphasize higher densities; mix of residential/commercial/industrial; primarily urban form in residential development; floodplain avoidance	Emphasize commercial/ industrial; lower residential densities, primarily suburban form in residential development
Rural Growth Pattern	Maintain existing development pattern, mix of densities, uses	Resource lands protected: Where conversion occurs, growth concentrated near existing density, away from resource uses, sensitive habitats, viewsheds	Distribute growth relatively uniformly, without consideration of resource uses, sensitive habitats
Nearshore /Coastline Development	Maintain existing development pattern, mix of uses	Restrict development in nearshore areas, particularly in areas near sensitive lands,	Unrestricted development in nearshore areas

Scenario Quality	Status Quo (SQ)	Managed Growth (MG)	Unconstrained Growth (UG)
		certain shoreform types, away from wetlands, sensitive lands, unstable areas, viewsheds	
Shoreline Modifications	Maintain existing relationship between modification amounts/densities, population densities	Reduce amounts/densities of nearshore modifications relative to existing conditions	Increase amounts/densities of nearshore modifications relative to existing conditions
Sensitive Areas/Open Space	Maintain moderate level of protection of wetlands, some restoration of historic wetlands; Moderate level of new park/open spaces	High level of protection of existing, undeveloped historic wetlands; aggressive restoration of historic wetlands, protections of sites with high conservation/restoration potential; Aggressive levels of park/open space acquisition, both within and outside UGA's	Low level of wetlands protection; no restoration of historic wetlands; no new parks/open space

The ENVISION model was used to run the three land use scenarios to create land use changes for decadal time points 2010-2060. The output files (shapefile) from the ENVISION model for a subbasin were processed, extracting the land use/cover data for the WRIA9 project area (Figure 10 for 2040). Comparing these three land use scenarios, the map representing the land use scenario UG has more urban area and less green space than SQ and MG land use scenarios. These show that the results of the land use change scenarios reflect how the land use policies contribute to the trend of land use in the future. These data were used as the input to the OpenNSPECT model for computing impacts to water quality.

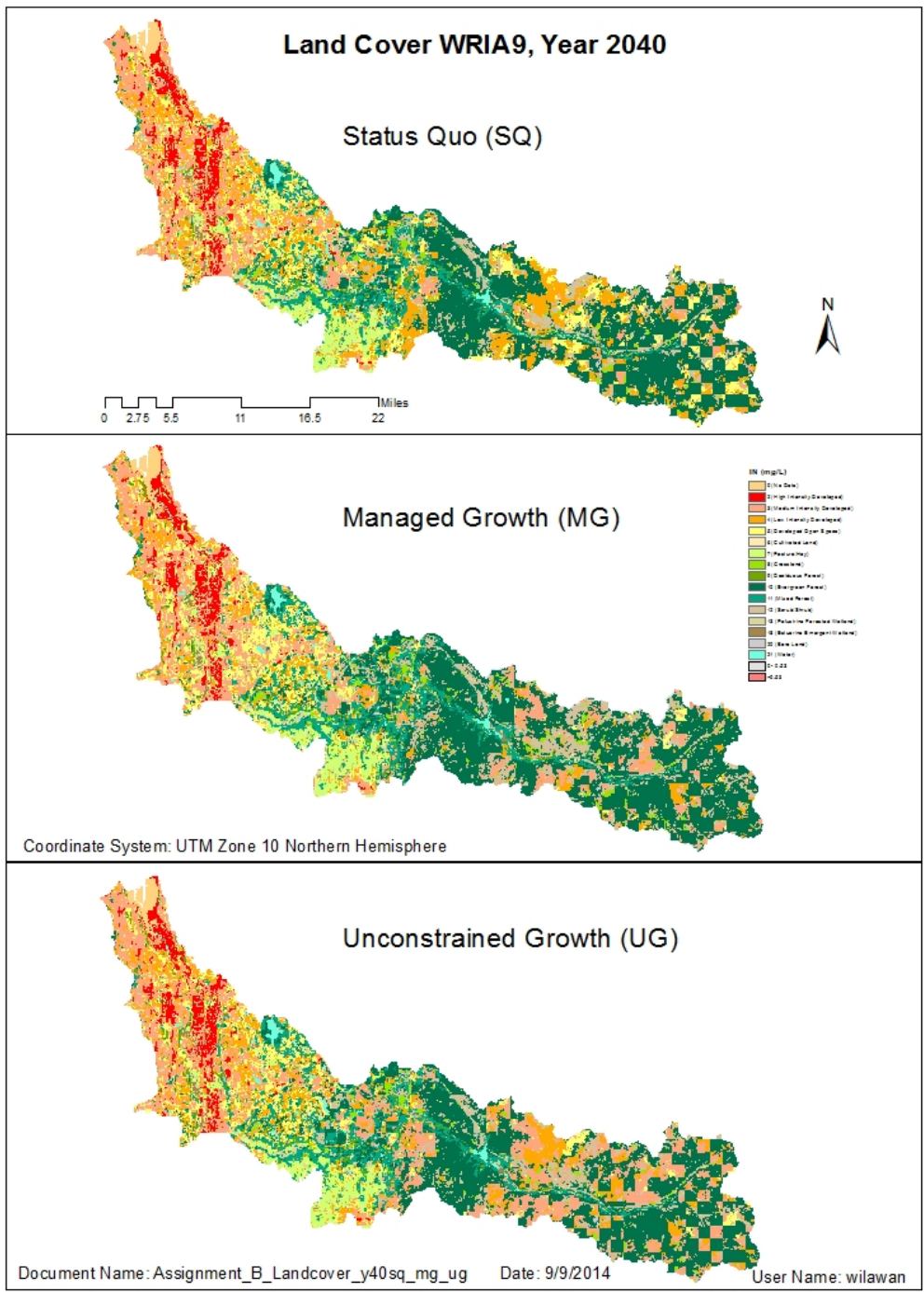


Figure 10. SQ, MG, and UG land use/cover scenarios in year 2040 simulated by ENVISION model

5.3 Simulate the impact on WQ from changes in land use (Impact model)

Changes in land uses contribute to surface water runoff, and subsequently nonpoint source pollution, which eventually affects water quality and water-based ecological resources. Once land use was predicted in the change modeling process by ENVISION, the results were used to simulate water quality changes in the (OpenNSPECT) model to reveal the impact of NPS pollution from the different land use policy scenarios. This showed the influence of land use policies on NPS pollution runoff, and hence water quality.

Four output land use shapefiles from ENVISION were exported to raster files (*wria9LC10mg*, *wria9LC10ug*, *wria9LC40mg*, and *wria9LC40ug*). They were used as the input files for OpenNSPECT to calculate the total nitrogen concentration (mg/L) loading for each of those four comparison scenarios. The results show the different distribution of total nitrogen concentration in WRIA9 year for 2040 according to the SQ, MG, and UG scenarios as shown in Figures 11 - 14.

The results of total nitrogen concentration from OpenNSPECT in Figures 11 - 13 show how land use policies contribute to the concentration of total nitrogen in WRIA9 year 2040. The results show that with the SQ land use scenario policy, the concentration of nitrogen year 2040 is much higher than those of SQ year 2010 (Figure 10). For the MG land use scenario policy, the concentration of total nitrogen year 2040 is only a bit higher than those of SQ year 2010 (Figure 12). For the UG land use scenario policy, the concentration of total nitrogen year 2040 is much higher than those of SQ year 2010, SQ year 2040 and MG year 2040 (Figures 13 and 14). These show that the unconstrained growth land use policy induces the most impact to increase total nitrogen in WRIA9, as one might expect.

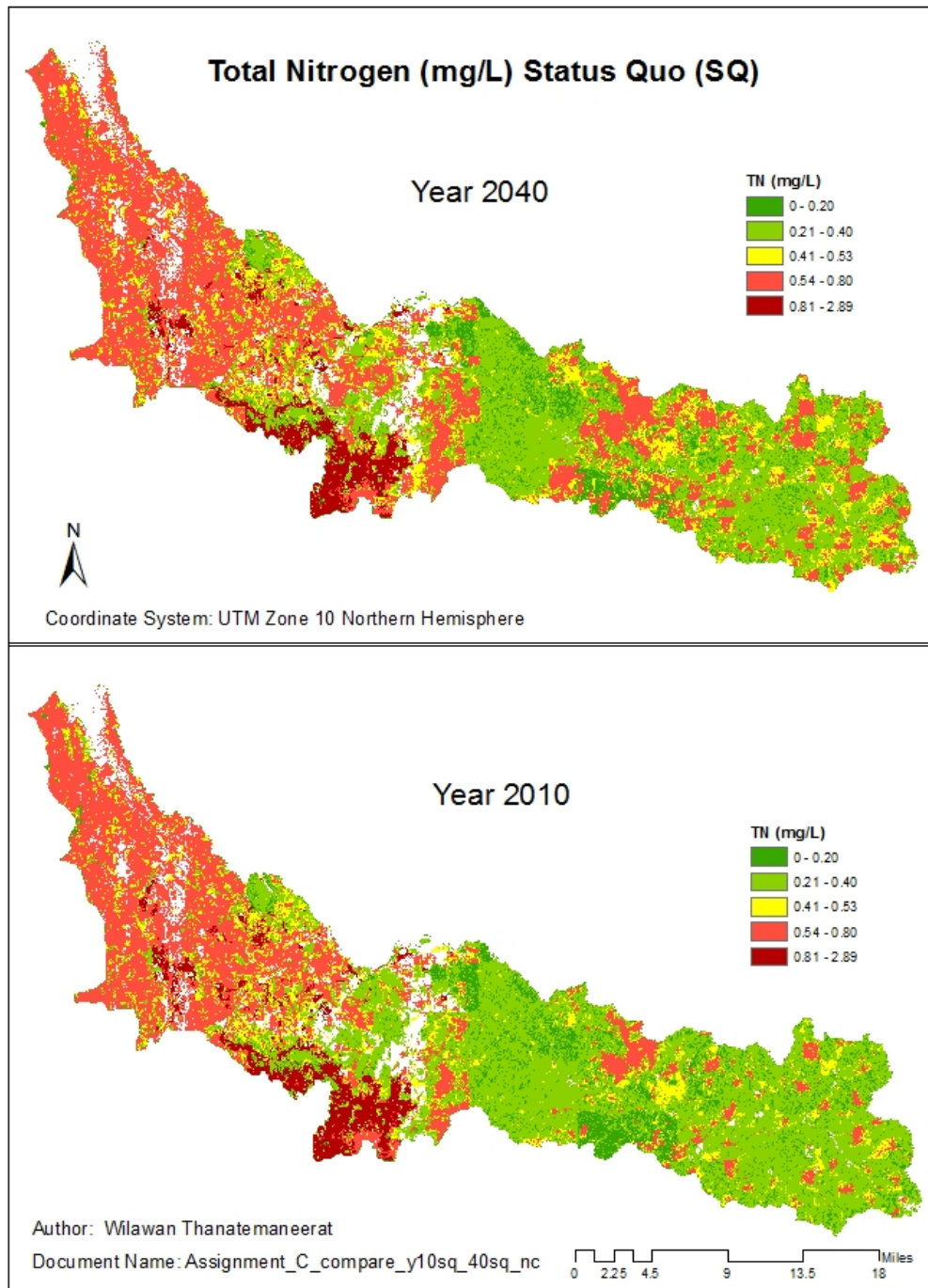


Figure 11. Total nitrogen (mg/L) from Status Quo land use scenario year 2010 and 2040

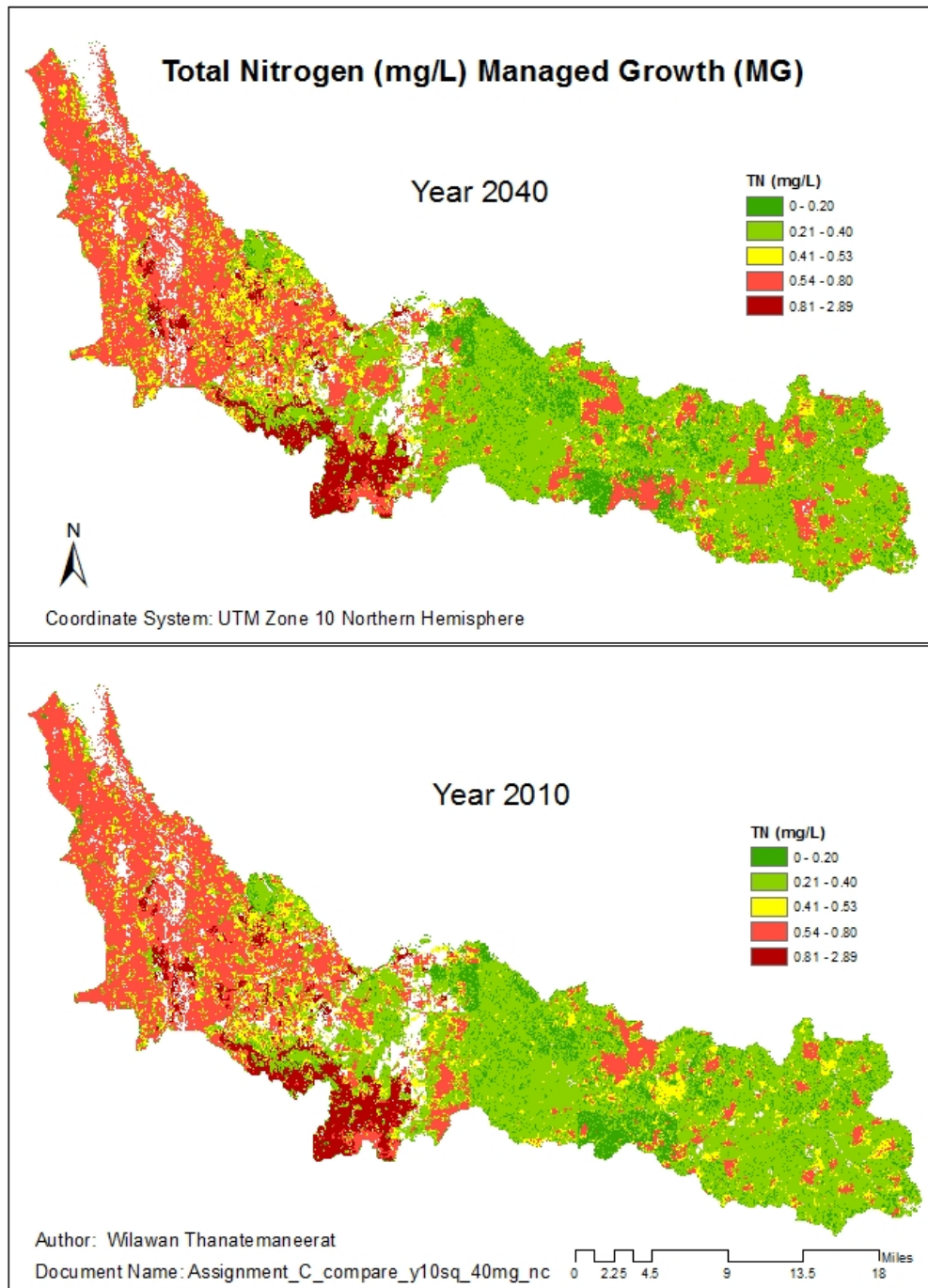


Figure 12. Total nitrogen (mg/L) from Managed Growth land use scenario year 2010 and 2040

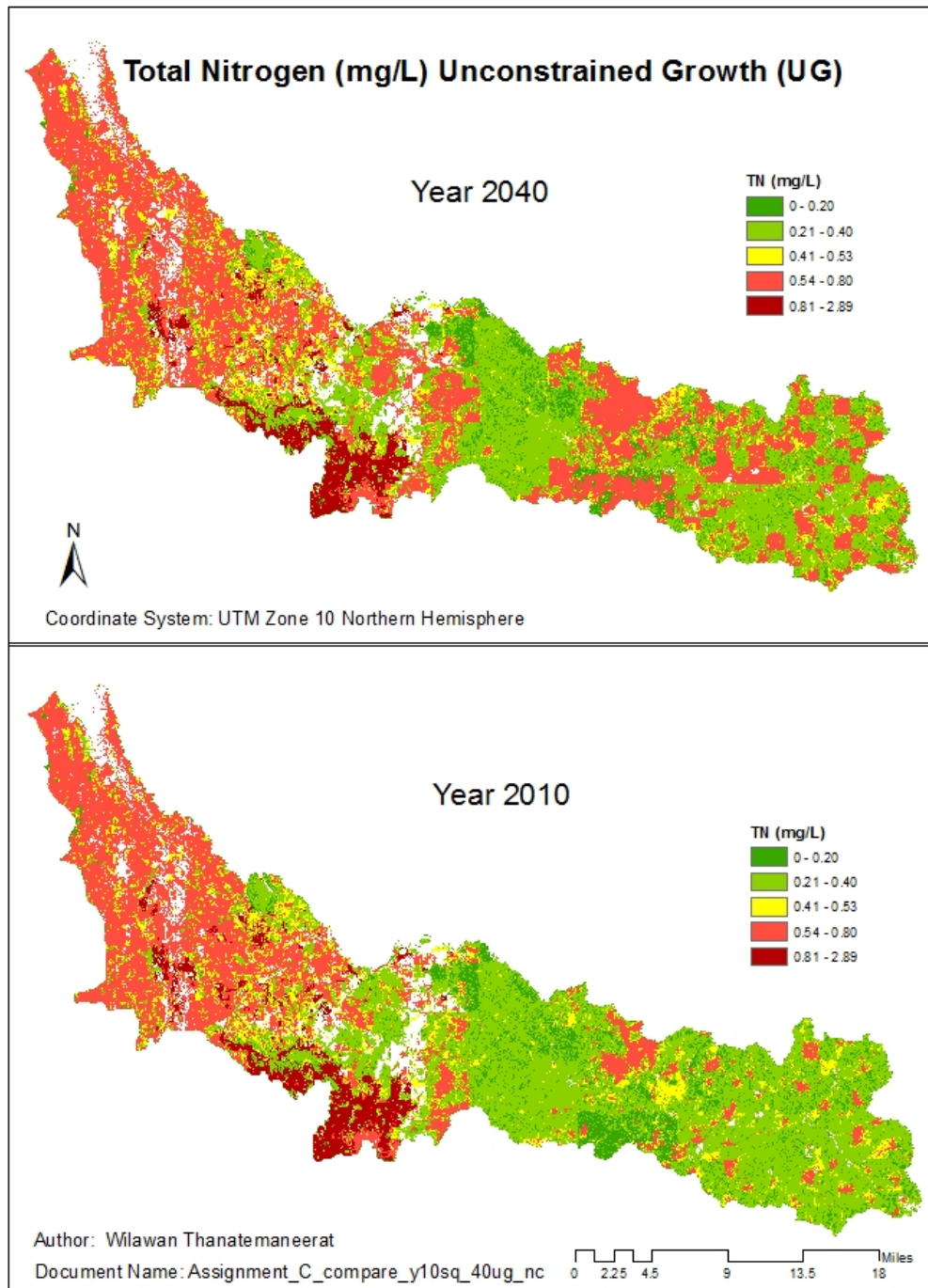


Figure 13. Total nitrogen (mg/L) from Unconstrained Growth land use scenario year 2010 and 2040

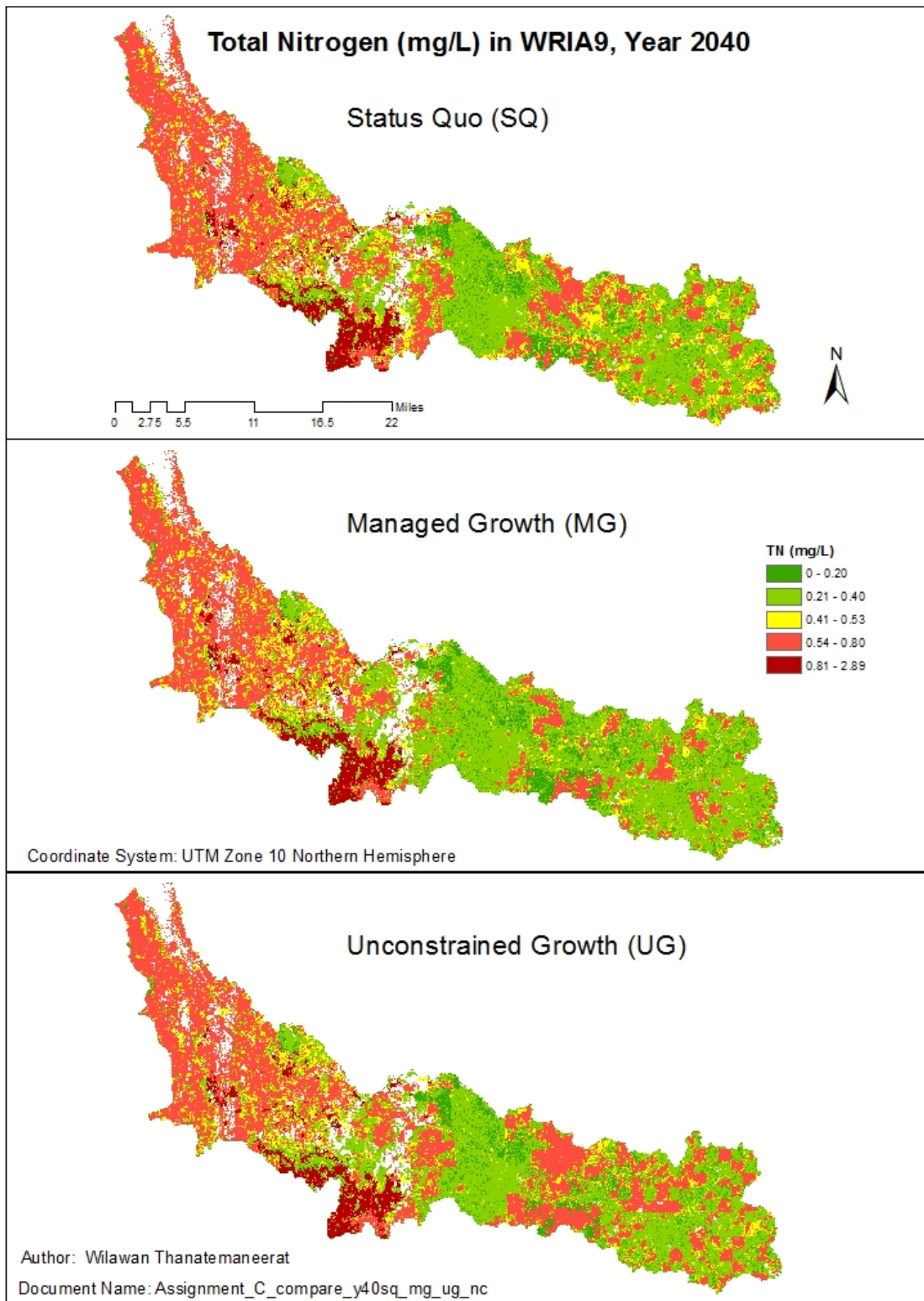


Figure 14. Total nitrogen (mg/L) from SQ, MG, and UG land use scenarios year 2040

To gain a sense of the total nitrogen concentration impact in the WRIA9 area, the results of total nitrogen concentration of SQ, MG, and UG year 2040 were compared with the EPA’s nutrient criteria for “Rivers and Streams in Nutrient Ecoregion II”. The results of comparison are shown in Figure 15. The total nitrogen concentration from MG land use scenario has less impact than other scenarios. The total nitrogen concentration from UG land use scenario has the most impact in WRIA9.

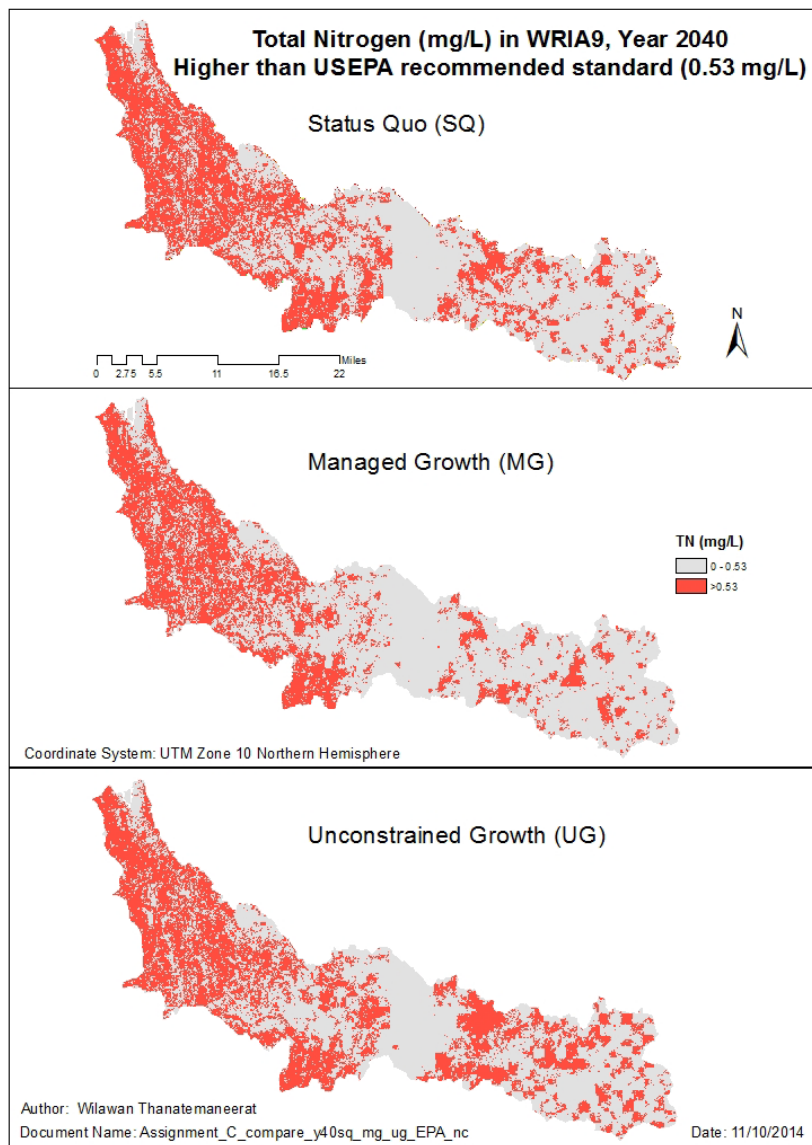


Figure 15. Total nitrogen (mg/L) from SQ, MG, and UG land use scenarios year 2040 showing higher than USEPA recommended standard.

5.4 Decision modeling

In the fifth phase of modeling (previous section) we explored the distribution of impacts from the total nitrogen to WRIA9 which can be used for input to a decision model. In the decision modeling (6th) phase, we explore how a decision model can be used to mitigate the NPS pollution problems. Each of the impact assessments reveals one aspect of how alternative scenarios result in nonpoint source pollution impacts. The alternative scenarios, the impacts associated with them, and the criteria by which choices are assessed based on those impacts will vary among individuals and groups who hold different interests, and thus stakeholder perspectives.

To accomplish decision modeling, we explore how to develop and use a decision model based on multi-criteria analysis (Nyerges and Jankowski, 2010). We use the multi-criteria analysis to simulate a watershed improvement program decision environment that prioritizes how decision makers might address subwatershed cleanup for total nitrogen load. This is an exploratory decision situation for watershed improvement similar to what the watershed council for WRIA9 might explore as part of a watershed investment district (Earth Economics, 2010). There are three aspects to decision modeling, including 1) scoring decision criteria, 2) weighting criteria, and 3) calculating rank, weight, and total scores.

5.4.1 Scoring Decision Criteria

Four criteria including ***total nitrogen concentration*** (*milligrams/liter*), ***eroded sediment*** (*kilogram*), ***habitat*** (*square meters*), and ***cost*** (*dollar*) were used to rank and weigh the scores for each subwatershed to identify suitable locations for implementing a watershed management program. Those criteria were normalized for their data values by assigning a rank across the range from 1

to 10, and inserting these into the rank column, and then storing them in Tables (See Tables 16 and 17). The criteria data values were rank ordered in a consistent manner with regard to the problem interpretation, the nature of the data, what we prefer less of or more of in regards to criteria. For example, from Table 16, in regard to total nitrogen data, a rank number 1 was assigned to the lowest category of data values, and 10 was assigned to the maximum category of data values for the amount of the total nitrogen concentration. However, if we prefer solving a big pollution problem as higher priority, then the ranking would be the inverse, as we prefer to tackle large concentrations before we tackle lower concentrations. For the cost criterion (Table 19), the lower costs would be preferred more than the higher costs, and thus the rank for cost criteria would be 10 for the lowest range of cost and 1 for the highest range of costs because less expensive problems (holding all other criteria the same) would be the higher priority.

Table 16. Ranking Total Nitrogen Concentration Criteria

Total Nitrogen concentration (TN_mgL)	Rank (TNmgL_Rank)
0.00 – 0.10	1
0.11 – 0.20	2
0.21 – 0.30	3
0.31 – 0.40	4
0.41 – 0.50	5
0.51 – 0.60	6
0.61 – 0.70	7
0.71 – 0.80	8
0.81 – 0.90	9
0.91 – 1.00	10

Table 17. Ranking Eroded Soil Criteria

Eroded Soil (SoiAc_kg)	Rank (SoiAc_rank)
0.0 – 3,000,000,000	1
3,000,000,001 – 5,000,000,000	2
5,000,000,001 – 7,000,000,000	3

Eroded Soil (SoiAc_kg)	Rank (SoiAc_rank)
7,000,000,001 – 10,000,000,000	4
10,000,000,001 – 12,000,000,000	5
12,000,000,001 – 15,000,000,000	6
15,000,000,001 – 18,000,000,000	7
18,000,000,001 – 20,000,000,000	8
20,000,000,001 – 23,000,000,000	9
20,000,000,001 – 26,000,000,000	10

Table 18. Ranking Habitat Criteria

Habitat (Habi_raito)	Rank (Habi_Rank)
0 – 0.1	1
0.11 – 0.2	2
0.21 – 0.3	3
0.31 – 0.4	4
0.41 – 0.5	5
0.51 – 0.6	6
0.61 – 0.7	7
0.71 – 0.8	8
0.81 – 0.9	9
0.91 – 1.0	10

Table 19. Ranking Cost Criteria

Cost (Cost_dol)	Rank (Cost_rank)
0 – 100,000,000	10
100,000,001 – 140,000,000	9
140,000,001 – 190,000,000	8
190,000,001 – 230,000,000	7
230,000,001 – 270,000,000	6
270,000,001 – 320,000,000	5
320,000,001 – 360,000,000	4
360,000,001 – 400,000,000	3
400,000,001 – 450,000,000	2
450,000,001 – 490,000,000	1

5.4.2 Weighting Criteria

Some decision criteria are often more important than others within a decision problem. Therefore, after normalizing the criteria data values, criteria were weighted to establish preference of criteria contribution in the overall score. Public stakeholders and decision makers may get involved in weighting criteria, depending on what stakes are held by whom. The weight number was also normalized so that the number should sum to a convenient ‘cognitive anchor’ number, e.g. 100 (Nyerges and Jankowski, 2010). Whichever criterion is weighted more indicates that the criterion is more important for a project. For example, we may distribute our weightings as in the example below (Table 20). This research study used this example set of weights to calculate total score with the perspective that habitat criterion is the most important and eroded soil is the least important (Table 20), as a single example of a weighting scheme.

Table 20. Criteria Weight Scores

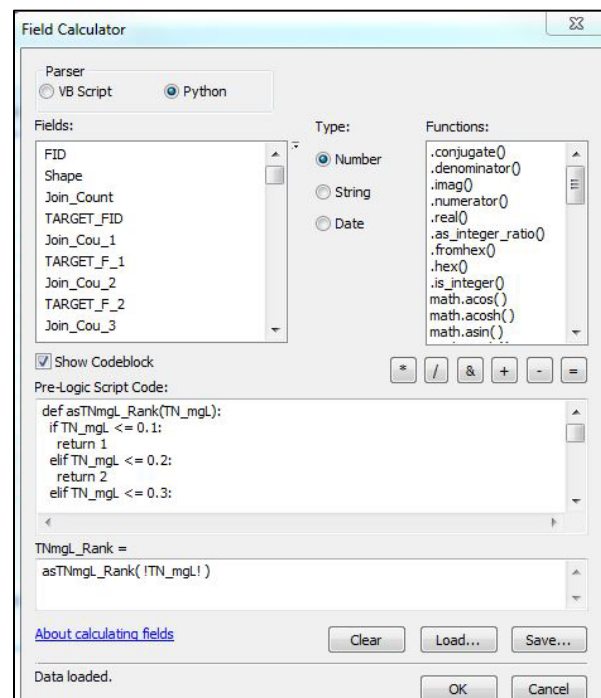
Criteria	Field name	Weight score
Total Nitrogen (mg/L)	TNmngL_Weig	25
Eroded Soil (kg)	SoiAc_Weig	15
Habitat (m ³)	Habi_Weig	35
Cost (\$)	Cost_Weig	25

5.4.3 Calculating Rank, Weight, and Total Scores

The rank and weighted values for those criteria were used in calculating the sum of the total scores for each subwatershed to characterize watershed clean up that could lead to priorities for a management strategy recommendation. ArcGIS 10.2 was used for this calculation. The values of those four criteria were imported to the WRIA9’s subwatershed shapefile. Four new fields including “TNmgL_Rank”, “SoiAc_Rank”, “Habi_Rank”, and “Cost_Rank” were added to the

subwatershed attribute table to represent rank scores. To calculate the rank score, the Field Calculator was used with Python script code, with an example of the “*TNmgl_Rank*” script below. When applying the ranking with other criteria with different ranges, one must assign different ranks than those provided in the script. The script was changed in the *if*, *elif*, and *return* statements to correspond to the numbers assigned in Tables 17 – 19.

```
def TNmgl_Rank(TN_mgl):
    if TN_mgl <= 0.1:
        return
        1
    elif TN_mgl <= 0.2:
        return
        2
    elif TN_mgl <= 0.3:
        return
        3
    elif TN_mgl <= 0.4:
        return
        4
    elif TN_mgl <= 0.5:
        return
        5
    elif TN_mgl <= 0.6:
        return
        6
    elif TN_mgl <= 0.7:
        return
        7
    elif TN_mgl <= 0.8:
        return 8
    elif TN_mgl <= 0.9:
        return
        9
    else:
        return 10
```



```
SoiAc_Rank = asTNmgl_Rank(!TN_mgl!)
```

To calculate the weight value for those four criteria, we first need to create new fields called “TNmgL_Weig”, “SoiAc_Weig”, “Habi_Weig”, and “Cost_Weig” and simply use “Field Calculator” to calculate each weight value in Table 20 for each criterion.

After calculating rank and weight scores for those criteria, it was then appropriate to calculate the total score for each of the subwatersheds to identify the details of an evaluation strategy for watershed improvement program. The field called “Scor_Sum” was created. Rank and weighted scores of those four criteria were summed to compute a total score for each subwatershed in this field. The “Field Calculator” was used with VBscript formula below in the expression box:

$$([TNmgL_Rank] * [TNmgL_Weig]) + ([SoiAc_Rank] * [SoiAc_Weig]) + ([Habi_Rank] * [Habi_Weig]) + ([Cost_Rank] * [Cost_Weig])$$

The results of total score in *Scor_Sum* field shows distribution scores in all subwatersheds. These results created distribution maps that illustrated spatial distribution of those scores (Figure 16). Figure 17 shows the spatial distribution of the top five of total scores across all subwatersheds in WRIA9.

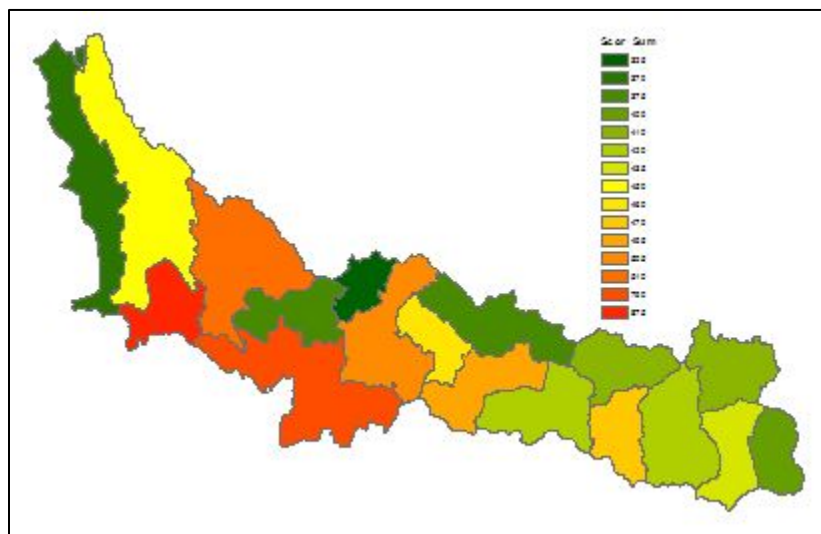


Figure 16. Spatial distribution of total score across subwatersheds in WRIA9

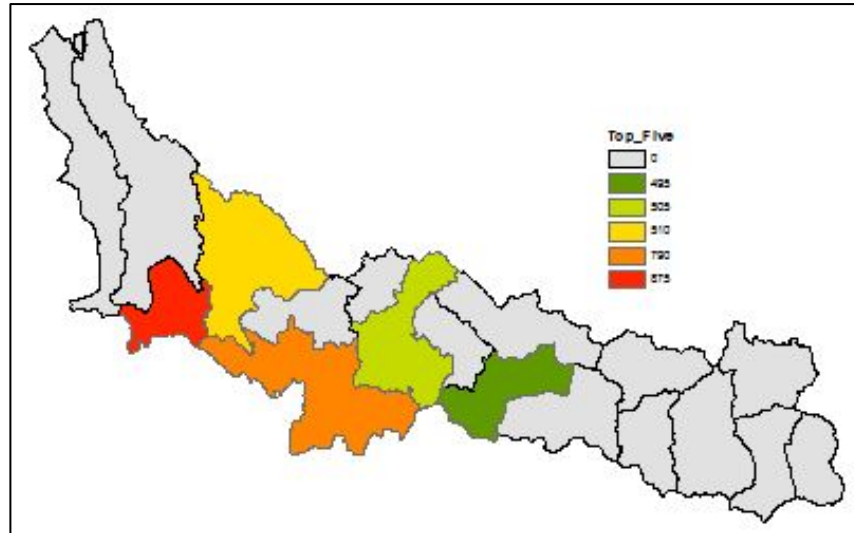


Figure 17. Top-five total scores across subwatersheds in WRIA9

These results provide information for decision makers and public stakeholders to help identify the location of a subwatershed to implement the water quality improvement program.

5.5 Discussion

Based on the conceptual framework (Figure 4, Chapter 3), and using the results from the process modeling in Chapter 4, Chapter 5 used those results as input to *evaluation, change, impact, and decision modeling*. The *evaluation modeling* shows where the total nitrogen exceeds the recommended standard set by US EPA across WRIA9. This process would help the working group to better understand the overall situation of water quality (total nitrogen) in WRIA9. The *change modeling* is a next step to see how the different land use policy scenarios induce the change of land use in the future. The results from the ENVISION model were investigated using SQ, MG, and UG land use policy scenarios. The results show that the land use scenario UG encourages development of hardened urban area and less green spaces than SQ and MG land use scenarios reflecting how the land use policies contribute to the trend of future land use. The

impact modeling shows how the changes of different land use policies contribute to different distributions of total nitrogen in WRIA9. The results from the impact modeling process show that the total nitrogen concentration from MG land use scenario has less impact than other scenarios. The total nitrogen concentration from UG land use scenario has the most impact in WRIA9. Finally, *decision modeling* used the results from the impact modeling as input to multi-criteria analysis as a component of watershed improvement programming. The results show the top-five priority subwatersheds including Mill Creek-Green River, Newaukum Creek-Green River, Big Soos Creek, Coal Creek-Green River, and Howard Hansen Dam-Green River to be proposed for implementing habitat restoration through watershed clean up. The four modeling phases play an important role in decision support for prioritizing the target areas of a watershed improvement program.

Chapter 6: Role Play Modeling Activities for WRIA9

6.1 Design of the Role Play

Based on the Geodesign Framework for Water Quality Improve (GeoFWQI) (Figure 4) in Chapter 3, public stakeholders, modelers, and decision makers convene for collaborative work that involves adjusting input parameters, calibrate and validate values, and/or define land use scenarios that characterize the watershed system until they identify a reasonable solution to meet their goals (Korfmacher, 2001). To test the GeoFWQI in light of a stakeholder involvement process in WRIA9, considering a lack of funds to implement this framework with the real local public stakeholders in WRIA9, we used a classroom setting as a role play to be performed in the GEOG 514 GIS Problem Solving (Professor Timothy Nyerges) within the Master of Geographic Information Systems (MGIS) for Sustainability Management program at the University of Washington (UW).

Expectations of the classroom role play are rather different from those of a public role play. In terms of the location, the public role play is suitable to implement in a local area where it is convenient for local stakeholders to participate. A classroom role play is suitable to implement at a school because students are a 'learning-engaged' group. When materials are prepared, a public role play commonly requires specific and sophisticated materials. The public role play would also likely involve more time than the classroom role play, because of the expected realistic nature of a public decision.

The participants of the classroom role play in this study are students within the UW MGIS. The students have background and knowledge in GIS and sustainability management, and thus more

easily engage in these role play activities with computers than participants within a public role play. However, we conclude that participants within a public role play will know more about the study area as well as perhaps the roles to be played. The most important challenge of public role play is funding. All activities of a public role play would require funds to facilitate processes; while classroom role play can be hosted without funding as part of the classroom learning experience.

The classroom role play has three steps in an initial plan for implementing a role play modeling process for WRIA9 following the GeoFWQI. First, it starts with creating lab assignments for students to work together as groups with different stakeholder perspectives for water quality improvement. There are four lab assignments including lab assignment A: Representation and Process Modeling, lab assignment B: Evaluation and Change Modeling, lab assignment C: Impact Modeling, and lab assignment D: Decision Modeling. These four lab assignments follow the GeoFWQI process. The details of these lab assignments are in Appendix F.

Second, the modeling activities were planned to implement as a role play with 22 students in GEOG 514. The online Master Professional Program focuses on sustainability management and GIS technologies to develop sustainable solution to a variety of complex problems from housing development to land use impacts on water quality improvement, which is an appropriate context for the topic of this research. Most of students are working full time, some of them have experiences using GIS in their careers and some of them do not. The GEOG 514: GIS Problem Solving class focuses on a geodesign workflow method using geospatial information technologies, including data management, geospatial analysis and geovisualization, for addressing complex geospatial problems. Although GEOG 514 is an online class, there are three days of on-site instruction on the UW campus in which students work on the topic of a

Geodesign Modeling Approach. The role play was planned for the last day at the morning session (September 10, 2014, 8:30 AM – 12:00 PM at Savery Hall, UW). Details of the schedule appear in Appendix G.

Third, the Geodesign Role Play was planned to start with introducing the GeoFWQI to students and asking them to form student groups. Members in each group needed to adopt roles to play. This study proposed five stakeholder perspectives for water quality improvement for students to role play including 1) Regulatory/Resource Agency Perspective, 2) Elected Official Perspective, 3) Engineering Consulting/Academic Perspective, 4) Environmental Group Perspective, and 5) Business/Community Leader Perspective. Detail about these stakeholder perspectives appear in Appendix H. Once students formed groups and their stakeholder perspectives, each lab assignments was planned to demonstrate to students and students work together at the same time. In the end of each lab assignment, there are discussion questions for student to fill in (Appendix F). The discussion part for those questions was planned to discuss at the end of the session of modeling process.

6.2 Results of the Role Play

Having arrived that morning, it was discovered that many students needed more time to do their lab assignments from the class; there was only one hour for the whole session of the modeling process. The initial plan was adjusted to undertake a demonstration of the GeoFWQI with lab assignment A, B, C, and D without students to work together. Lab assignment A was demonstrated. The OpenNSPECT model was run using land use status quo scenario year 2010. The run was successful in demonstrating how a sophisticated software can provide more insightful results, than the software in ArcGIS. After that lab assignments B, C, and D were

demonstrated by presenting the Power Point that was prepared with results from lab assignments B, C, and D.

We explained to students how the lab assignments related to the GeoFWQI, as a review and discussion of the results. Lab assignment A (representation and process modeling using OpenNSPECT) showed the data that are used to run the model and also how to set up and run the OpenNSPECT model. Lab assignment B (evaluation and change modeling) demonstrated how to evaluate the results from the model from lab assignment A to explore the water quality situation by comparing with the U.S. EPA recommended standard (USEPA, 2000). Then, the results from the land use change model, ENVISION, were shown to demonstrate the change of the spatial distributions for each land use policy scenarios (SQ, MG, and UG). Lab assignment C (impact modeling) showed how to use the OpenNSPECT to run the results from ENVISION model to see the impact of water quality from different land use scenarios. Lab assignment D (decision modeling) showed students the components of a decision model to prioritize how we might address subwatershed management by implementing a prioritization of subwatershed clean-up to contribute to a habitat restoration program for WRIA9.

The four lab assignments were demonstrated with discussion questions at the end of each lab assignment. Because of the limited time, the questions were not used. However, several discussion questions were used by Professor Nyerges, who was leading the session, and from students in class. Those discussion questions are summarized in the next paragraphs.

6.3 Discussion of Role Play

The discussion part of the role-play was digitally recorded to provide a record of what was said.

No students are identified in the recount of the discussion below, because IRB was not sought for this activity.

In the beginning of the session, Professor Nyerges asked students to consider how the five stakeholder perspectives related to the nature of each of the six models in the GeoFWQI. There was no particular response to this question at this time. However, a student offered a perspective about land owners and which group of the land owner should be part of a public process. The discussion considered whether a land owner was in the elected official or business community perspective group or another group? He made the point that when talking about changes in land uses, stakeholders often voice concerns near the end of a process, and those concerns develop into conflict. The student also mentioned that he liked the idea of the GeoFWQI because it fosters interaction with stakeholders for evaluating results and gets them involved in the different steps of the framework. From his experience, more participation occurs at the beginning and at the end; wherein participation is missing in between. Professor Nyerges responded to his comments by saying that many frameworks often involve ‘decide and defend’ kind of participation, which does not really embrace the concerns of all involved. Decision makers make the decision and defend the decision rather than talking it through from the beginning.

Continuing with the discussion about lack of participation from residents in every phase of a project, another student shared a point about residents who do not get represented because they do not have money and/or power. She also mentioned that the ‘decide and defend’ approach usually does not work very well. Starting with a bottom-up approach where in everyone can

participate in the beginning would be preferred. However, it would take considerable time for stakeholders to understand details about water quality, for example, trying to get all groups to understand in the same way. In her experience, her agency does not want to do that. Professor Nyerges added to this point that participation is complex, expensive and detailed. Technology trends are moving toward more participation rather than less, and technology development is at the beginning of these issues. There are organizations that are looking for input in the way that they can help manage the process because there is no single organization that has the view of what the world should be like. Professor Nyerges also pointed out that GIS is an integrating technology, and it is very important recognize that there are many technological developments underway including database management technology, analysis technology, communication technology, and decision analysis technology, all within the context of social media developments.

There was only one question from a student asking about the model. He asked how to prepare the land use data type and land use coefficient tables to put in the OpenNSPECT model. Since the author worked on this model, I answered the question. Default data about land use types and land use coefficient values (which represent those values in Hawaii) exported from the model using a .txt file. The parameters were changed so that the numbers represented the land use types and coefficient values of the Puget Sound area. After that, they were then imported into the model. .

During the demonstration of the OpenNSPECT model, a model error occurred and could not finish running. The computer lab permissions did not allow creation of subfolders. Thus, the run needed to change to the computer that created the output. That development leads to a discussion about commercial versus open source software. A question was asked of students “how many of you use open source software and commercial software, either one and/or the other for a single

task?” A student responded to this question that his agency used commercial software because of the capabilities, however he also mentioned there is a problem with the budget to maintain commercial software. Another student mentioned that using open source software required less money up front, but requires more software knowledge of computer languages to access the full ability of the software. Professor Nyerges added to this point that open source software is not always easy solution. He also mentioned that people use different products because of the different capabilities. Furthermore, a big reason for using commercial software is the maintenance that is provided. He mentioned that many agencies of the State of Washington, for example, use ESRI software because of the availability of maintenance.

The discussion then returned to the first question of the session “about the five stakeholder perspectives and how they relate to the six modeling phases of the GeoFWQI”. Professor Nyerges mentioned that all stakeholder groups might not follow the entire processes through, because everyone does not have the same knowledge. Some groups have more relevant knowledge at points in the processes; while other groups have more relevant at the other points in the process. Therefore, it came to the question that “in term of the input data such as land use coefficient or soil data, which one of these stakeholder groups here are capable of understanding those environment?” “*The Engineer Groups*” was an answer from a student. Professor Nyerges responded to this answer that the engineers who work as consultants (even if they are from an academic background) could be the one who measure the soil and land use coefficients.

There are also other perspectives in terms of other datasets used in this model, such as the land cover dataset, and this lead to two other questions. Which of these stakeholder groups should be involved in the land cover dataset? Where would the land owner fit in the entire of the processes in each of the six phases? There were no students responding to these questions. Professor

Nyerges offered his opinion for the answers to the questions that the land owner group may have a significant input in what happens and what the impact is on the ground, e.g., in regards to changes in water and land use. Land owners are one of the parties that are more affected by change in land and water use. Land owners are one of the principal stakeholder groups of *representation modeling*. Taking the diversity of knowledge about what are the nature problems of their land, what are their concerns, and what is cause of their concern? This information can translate into feature classes and feature class use through every process of the framework. This issue is at the core of the first steps of conceptual modeling in database design (Nyerges and Jankowski, 2010) including addressing the identified information products and research questions, identify and detailing the keys feature classes and thematic layers, and grouping representation into datasets. The other phase that the land owner or the general public is most connected to is the decision modeling phase. This phase can capture the diversity of concerns from the various groups. Other processes might need more technical expertise to identify the character of the impacts as part of impact modeling.

After showing the results of total nitrogen concentration for impact modeling, the session participants discussed the spatial distribution of the concentrations across WRIA9. The upper headlands of WRIA9 contain more forested areas, and the lower portion is more industrialized and impermeable surfaces. The total nitrogen is showing up more in the lower portion of WRIA9. One student asked a question “Is this the result of stormwater flowing down river?” Professor Nyerges responded to this question by saying that there is no integrated water system, i.e., the piping infrastructure and nonpoint system are often represented separately, not in a single database. No database system contains both in this region.

The last topic to be discussed in the session involved the color ramp for total nitrogen on the maps, which was using a green to red ramp. The green color represents the low value and the red color represents the high value. Professor Nyerges mentioned that in the cartography literatures, the green to yellow to red ramp is one of the best saturation ramps because it provides the widest range of different saturations distinguishable to the human eye. Given the nature of diverse groups of people interpreting the maps, a question was posed to students “What would be one way to interpret these maps?” A student who played a role as a land owner revealed a different perspective that the red color will signify a different message which will lead to more controversy. Professor Nyerges added that another good approach to representation would be to use a color saturation ramp that ranges from yellow to brown. Figure 18 shows the play role modeling session about WRIA9.

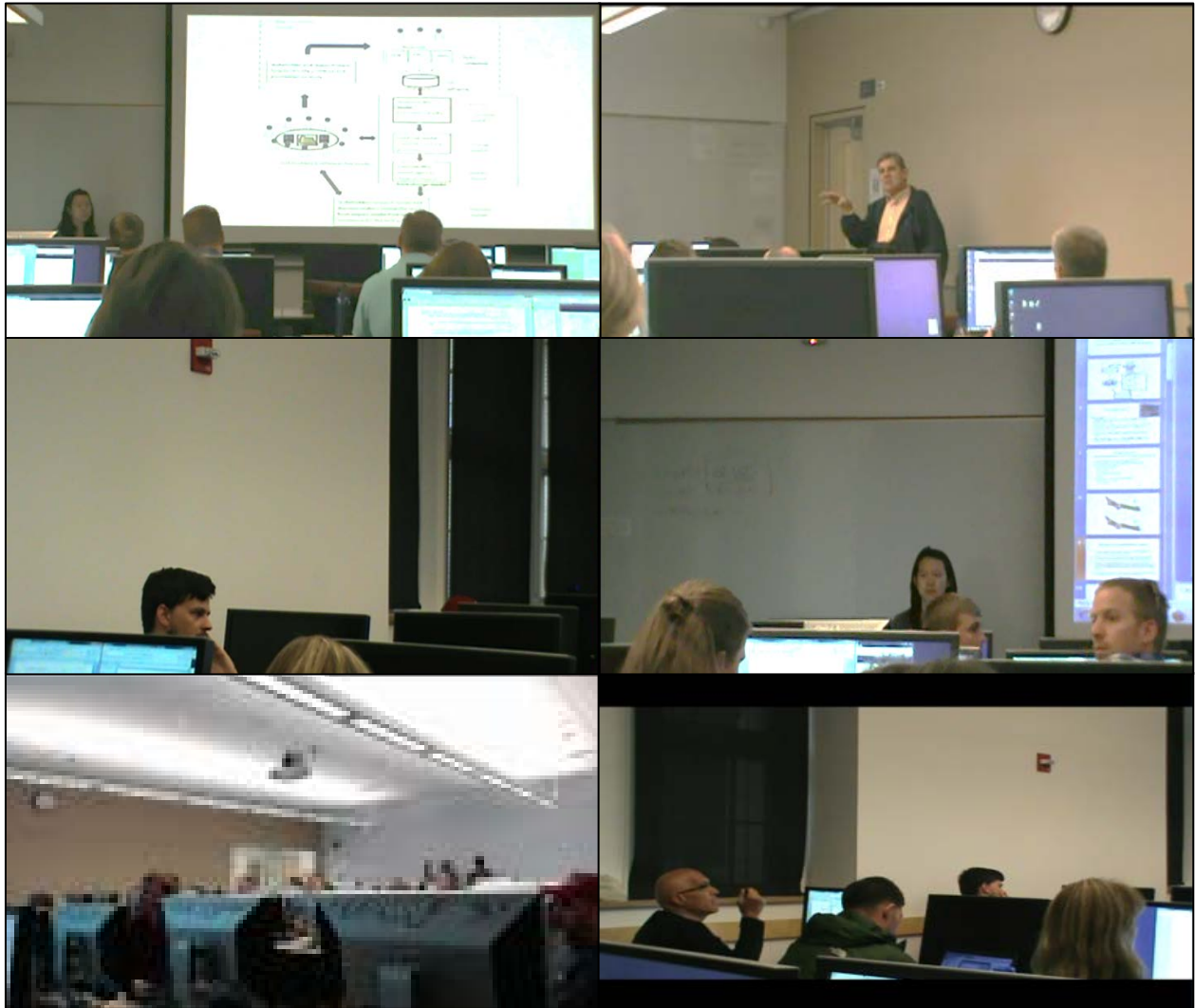


Figure 18. The session of public involvement in modeling process for WRIA9 at UW

6.4 Findings

There were many points of interest about the stakeholder involvement process arising in the session. One of the discussion points showed that there is a real conflict out here about the land owner and the policy makers from student experiences (remembering these are professional graduate students with many having considerable experience in the work world). The GeoFWQI could be one among several methods that lead to the consensus decisions and less conflict if all phases are pursued. However, this would be the beginning stage of this kind of work that

involves the stakeholders in the modeling process for water quality management. There is not a lot of research work that has reported on stakeholder processes in this research area, but see Arnold *et al.* (1999), Korfmacher (2001), Gosain and Rao (2004), Johnson (2009), and Okano (2009) for participatory modeling examples. Involving citizens as stakeholders in producing scientific information is one of the controversial issues and requires a lot of time and money (Korfmacher, 2001). This leads to a good discussion point in the session that the US EPA, at least at the federal level, is the main agency that is responsible for the participation processes in environmental issues and encourages the state and local agencies to implement more public involvement processes. One last finding about the discussion in the session shows that there were only a few students who participated in the discussion, although all are mature graduate students who hold stakes. There was only one student who played their role as a land owner in the session. It reveals that it is quite difficult to structure a session and expect people to role play in a way that is meaningful. This might have come about because of the limited time and/or the familiarity with the roles.

The classroom role play revealed that organizing diverse views on water quality management especially for water quality modeling was rather difficult. Some of the challenges included lack of knowledge of the problem and unfamiliarity with the process. Much of that challenge centered on students not knowing about water quality and modeling. Therefore, it was quite difficult for them to engage in the activities. A solution might be allotting more time to articulate background information, therefore providing participants with more time to engage, even in a class with students having GIS background. However, the biggest challenge was with absence of background about water quality, clearly a topic in need of tutorial information.

6.5 Chapter Summary

Stakeholder involvement in modeling process in WRIA9 aims to test the GeoFWQI adapted from Steinitz's geodesign framework. Students from GEOG 514 class in the Master of GIS for Sustainability Management program at UW played roles as public stakeholders in the session. Instead of students working as groups and doing all the lab assignments provided, students discussed the lab assignments A, B, C, and D which follow the concept of the GeoFWQI, because students had recently undertaken the assignments as part of their course activity. There were several interesting points discussed as part of the session, including, descriptions of different types of land owners, formation of stakeholder groups, lack of public involvement in various stages of decision making, conflicts between land owners and policy makers, issues of time and money for public involvement, less voices from the residents that have less money and power, and land owner or general citizen suitability of involvement in representation and decision modeling activities that provide diverse knowledge to database designers and decision makers.

Chapter 7: Conclusion and Recommendation

To discuss and conclude this study, we return to the beginning of this research to examine the objectives and research questions that drive this study. This dissertation aimed to investigate an effective way to support water quality management by combining watershed modeling, land use/land cover modeling, GIS, and public participation. The research focuses on nonpoint source pollution effects on water quality in Puget Sound, how land use/land cover contributes to nonpoint source pollution, and how public stakeholders can get involved in support of nonpoint source pollution management. This chapter lays out how the study addressed answers to the research questions, makes a contribution to knowledge, and offers recommendations for future research.

7.1 Addressing the Research Questions

Two principal research questions are stated in Chapter 1 as the motivation for this study.

Question 1: How can a nonpoint source pollution model and a land use/cover model support decision makers in water quality management, providing a picture of quantity/quality and spatial distribution of water pollution in Puget Sound?

The OpenNSPECT software is used to develop a model for estimating nonpoint source pollution in WRIA9. The data required for this software model include elevation, land use/cover, rainfall, soil, and pollution coefficients. Once those data were gathered, they were clipped into WRIA9 and transformed into the format that is compatible with the model. After that, they were loaded into the model as the input data. The details of this process are in Appendix A. There were errors when loading the input data into the software because of the format of the data was not

compatible with the software. We contacted NOAA Coastal Services Center, who developed the software and shared the data with them to ask the cause of the errors. The back and forth between researcher and the model working group team from NOAA took quite a long time to resolve the issues. This helped the researcher to understand more about the model than was available by reading the online documentation prepared for the model. The detail of the error is in Appendix A. Once the model had all the input data, it was ready to run. The model was tested with the land use data from Coastal Change Analysis Program (CCAP) year 2006. The first model run was not successful. The researcher tried to find the problem and finally discovered that the soil data loaded into the model was not in the appropriate format for the model to run. We edited the soil data and then reran the model again and it was successful. The detail of this error is in Appendix C.

Results from the model, including runoff and total nitrogen concentration, were calibrated to reduce model error. The runoff results were calculated for the percent difference with the USGS measured runoff from four stations in WRIA9. As with prior research, OpenNSPECT results were very sensitive to the number of raining days and runoff curve number (CN) parameters, which mainly effect the runoff results (Gaut, 2009). The raining day and CN values were adjusted, iteratively until they provided a representative amount of runoff indicated by percent errors of simulated data within the $\pm 10\%$ (good) margin of error (Tong and Chen, 2002). The total nitrogen value was calibrated in the same way as the runoff value by adjusting the pollutant coefficient value. The percent errors were reduced, but they were still outside of the $\pm 10\%$ (good) margin of error, but sufficient for continuing the research.

The results from ENVISION, land use change model, were then used as the input data for running OpenNSPECT. Four land use scenarios were used to run the model including Status Quo

(SQ) year 2010, SQ year 2040, Managed Growth (MG) year 2040, and Unmanaged Growth (UG) year 2040. The results show that the total nitrogen from land use scenario SQ year 2010 has less total nitrogen than the SQ, MG, and UG scenarios for year 2040. In terms of comparing different land use scenarios, the results show that the MQ scenario has the least contribution of total nitrogen in WRIA9 and UG scenario has the most contribution of total nitrogen in WRIA9.

Those three scenarios have similar spatial distribution patterns. High concentrations of total nitrogen are located in the lower elevations of the watershed connecting with Puget Sound within the City of Seattle. This might be because there are more industrial and residential areas in the lower part of WRIA9. For the middle part of WRIA9, the north of the middle part has lower level of total nitrogen concentration. This might be because this area is mostly forested area. The south of the middle part has the highest level of total nitrogen concentration including Krain, Enumclaw, and Osceola. This might be because these areas are less forested and most of them are pasture and hay areas such as dairy farms. For the upper elevations of WRIA9, it has less total nitrogen concentration than other parts. This might be because this part is more mountain and forest area. However, there are some areas that have higher levels of total nitrogen concentration perhaps because they are affected by logging land use activity, bare areas and the areas that have roads. These information show that residential and industrial land uses/covers contribute more total nitrogen than forested land use/covers; while agriculture land use/covers contribute the most to total nitrogen concentration. All these processes show how a land use/cover model such as Envision coupled to a nonpoint source pollution model such as OpenNSPECT can support decision makers in water quality management and provide information for understanding the quantity/quality and spatial distribution of water pollution flowing into Puget Sound.

Question 2: How can PPGIS be a vehicle to drive the integration of the biophysical and social sciences in order to better inform policy makers and public stakeholders on water quality management?

The GeoFWQI (Chapter 3, Figure 4) has been developed in this research to integrate the biophysical and social sciences through a social-ecological systems perspective, and in turn uses PPGIS to better inform policy makers and public stakeholders about water quality management. There are six phases in the GeoFWQI including: 1) representation modeling, 2) process modeling, 3) evaluation modeling, 4) change modeling, 5) impact modeling, and 6) decision modeling. The framework is designed to work with the land use change model and the nonpoint source pollution model together with stakeholder involvement in every phase of the modeling framework. The GeoFWQI was tested using role-play modeling activities for WRIA9 in the GEOG 514 GIS Problem Solving course (Professor Timothy Nyerges) within the Master of Geographic Information Systems (GIS) for Sustainability Management program at the University of Washington (UW). Four lab assignments were created and used in the role play including lab assignment A: Representation and Process Modeling, lab assignment B: Evaluation and Change Modeling, lab assignment C: Impact Modeling, and lab assignment D: Decision Modeling. This research proposed five stakeholder perspectives about water quality improvement with which students were to role play, including: 1) Regulatory/Resource Agency Perspective, 2) Elected Official Perspective, 3) Engineering Consulting/Academic Perspective, 4) Environmental Group Perspective, and 5) Business/Community Leader Perspective.

In the final lab assignment (decision modeling), the results of total nitrogen concentration from SQ scenario year 2010 were used in multi-criteria analysis as a case study in WRIA9 to prioritize how decision makers might address subwatershed cleanup for total nitrogen load. Four criteria

including total nitrogen concentration (milligrams/liter), eroded sediment (kilogram), habitat (square meters), and cost (dollar) were used to rank and weigh the scores for each subwatershed. The results show the top five priority subwatersheds including Mill Creek-Green River, Newaukum Creek-Green River, Big Soos Creek, Coal Creek-Green River, and Howard Hansen Dam-Green River to be proposed for implementing watershed clean up. These results provide information for decision makers and public stakeholders to help identify the location of a subwatershed to implement the habitat restoration and cleanup program.

The result of the role play activities shows many interesting points. First, public participation is perhaps not appropriate for all stages of decision making. Second, there appears to be conflict between land owners and policy makers. Third, public involvement requires time and money that might or might not be available. Fourth, it is likely that some residents, e.g. those with less money and power, are likely to have less voice. Fifth, research about color map design related to stakeholder interpretations is needed. Sixth, few students participated in the discussion, revealing that it is rather difficult to structure a session and expect people to role play in a meaningful way without them having deeper knowledge of the topic. Seventh, the GeoFWQI that organizes how stakeholders can contribute in every phase of the framework needs investigation.

For this research, the conceptual knowledge within a PPGIS context about water quality management opens an opportunity for public stakeholders to get involved in water quality management by using GIS integrated with water quality modeling. This research detailed a step-by-step approach called GeoFWQI for engaging stakeholders within a PPGIS approach. Stakeholders could easily engage in each step of the GeoFWQI. Following this framework makes it easier to identify how stakeholders can contribute in each step and help stakeholders to understand scientific concepts. The concepts include data for the model, hydrological processes,

what is happening in a watershed, and other general concepts that are part of water quality management. The framework can be one among several methods that leads to a better decision with less conflict.

7.2 Contributions to Knowledge

There are two main contributions to knowledge in this research. The first contribution is based on the technical knowledge gained by using a land use/cover model together results from a nonpoint source pollution model to create a social-ecological systems model for improving water quality management decision making with particular application to Puget Sound. Part of that technical contribution is a prototype database design (database model) and database to feed the linked social-ecological systems model. This database model of nonpoint source pollution for WRIA9 provides the picture about how water runoff contributes to water pollution in the area. The immediate results from the model will be useful for educating students about social-ecological systems modeling. The database (input and output data) and lab assignments from Chapter 6 used for the role play session can be useful material for GIS classes at the UW Department of Geography. Furthermore, the development is expected to contribute to the design of a program for scientific investigation of salmon habitat restoration in WRIA9, and act as a template for other watershed areas. Moreover, the results will be of interest to watershed and water quality management teams in the Washington Department of Ecology (Ecology), Department of Natural Resources (DNR), Puget Sound Partnership, Department of Fish and Wildlife, and the Puget Sound Nearshore Ecosystem Restoration Project with interest in connecting habitat restoration and land use policy. The results also support Ecology for water quality monitoring program, for example, using the spatial distribution of pollutants to design water quality monitoring areas.

Second, conceptual knowledge about public participation GIS in water quality modeling is developed using the GeoFWQI. This knowledge offers a vehicle to drive an integration of biophysical and social sciences information to better understand policy makers and public stakeholders in what is occurring in the watershed. The results of testing this conceptual knowledge will lead to knowledge about how public stakeholders can get involved in nonpoint source pollution management. The research will bring public stakeholders with direct and indirect knowledge of runoff pollution together in water quality management. This will lead to public information sharing, knowledge creation, and consensus building among stakeholder groups as an approach to sustainable watershed management. This knowledge can support work within organizations that convene stakeholder involvement. For example, the Ecology is the main agency that manages Washington's Water Quality Management Plan to control NPS pollution developed in 2000 and updated in 2005 through a collaborative effort involving several agencies (DOE, 2009b). The Ecology could adapt the GeoFWQI to support watershed managers in setting plans for mitigation of NPS pollution. Academic organizations could also adapt this system for research about PPGIS or water quality modeling. This could be a system that provides the processes of building knowledge for students and/or stakeholders located in research areas.

7.3 Recommendations for Further Work

For the ENVISION model part of this research, there were challenges to setting up the software and simulating the land cover change with the model. Lack of documentation and example data for testing the model created difficulty to successfully implementing the model. Working through technical issues when implementing ENVISION requires more attention. Moreover, future work about outputs from ENVISION as inputs to the simulated erosion tool implemented in OpenNSPECT is recommended. That kind of effort with 'coupling' the models could have

major benefits. Such coupling will make it easier to show how different land use policies contribute to erosion in a targeted area; model iteration would be crucial for such work.

Other recommendations for the model part of this research would involve work on other pollutants such as phosphorus or heavy metal and continue to work on other WRIA until all WRIsAs in the Puget Sound are addressed. These outcomes would improve multi-criteria analysis in decision modeling, and thereby obtain better information to target watershed cleanup for implementing habitat restoration. Lastly with regard to the modeling part, to increase the accuracy of the model, more research on runoff CNs and pollutant coefficients in Puget Sound area are needed to reduce uncertainty about the NPS information.

For the participation portion of this research, further work on testing the GeoFWQI with real people in the area is needed. A strategy to get real contributions from the public to enhance the efficient use of the GeoFWQI will be important for effective information. Once the framework is used with real local people, it can be evaluated and adjusted to be suitable for each area.

Moreover, public stakeholders and decision makers can also implement sensitivity analysis to rank and weight criteria to explore different results of target locations based on their respective perspectives, which will likely enhance consensus among parties. This will lead to better decisions with less conflict for improving water quality management about nonpoint source pollution in the future.

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Appendix A: Preparing Input Data for OpenNSPECT

Preparing DEM and WRIA9 boundary

1. Download DEM from USGS (seamless.usgs.gov). The data can be downloaded directly from the website; it does not have to be requested. DEMs for 26 areas (26 files) were downloaded from USGS. The lists of areas and file names are in Appendix B.
2. Files were unzipped and converted from USGS DEMs to raster files (ArcToolBox→Conversion Tool→To Raster →DEM to Raster).
3. Raster files were merged (ArcToolBox→Data Management Tool→General→Merge).
4. Download WRIA boundary (*WRIA_boundary.zip*) from King County from WAGDA website which leads to King County webpage (<http://www5.kingcounty.gov/gisdataportal/Default.aspx>). Then, unzipped it (*WRIA_boundary.shp*)
5. Select by attribute only WRIA09 area (*WRIA9_boundary.shp*)
6. WRIA9 boundary was adjusted to make boundary smoother when it was used to be the boundary for DEM raster by using “Editor” tool.
7. Clipped DEM raster file (from step #3) using *WRIA9_boundary.shp* as a clipped boundary (ArcToolBox→Analysis Tools →Extract →Clip).
8. Result is a raster DEM file of WRIA9 area for using in the watershed delineation step.
9. Final step, convert raster DEM to .tif file by exporting raster data and change type file to .tif. Changed to .tif file format as requirement of MapWindow and OpenNSPECT
10. Work with OpenNSPECT and MapWindow requires a .prj of raster data. Created a projection file (.prj) from *wria9_dem30.tif* (ArcCatalog→Properties of that file→Coordinate System→ Save as projection file)

Challenges: Checking and editing WRIA9 boundary took considerable time

Prepare Watershed Delineation Data

1. The OpenNSPECT tool has an Advanced Settings tool “Watershed Delineation”. What we need for creating watershed delineation is DEM raster file (wria9_dem30.tif) (OpenNSPECT→Advanced Settings→Watershed Delineations).
2. Once the “Watershed Delineations” window show up, select Options→ Create from a DEM
3. Once the “Create New Watershed Delineation” window show up,
 - a. wrote down the delineation name (wria9ws_LA), LA represents large subwatershed
 - b. put in DEM grid (wria9_dem30.tif)
 - c. unchecked the box next to DEM is hydrologically correct (filled)
 - d. set DEM Units (meters)
 - e. set Subwatershed Size (Large), select OK
4. Created other two watershed delineations with subwatershed size medium and small and named them wria9wa_ME and wria9wa_SM, respectively.
5. Now, the Run Analysis window of OpenNSPECT has “wria9wa_LA”, “wria9wa_ME”, and “wria9wa_SM” in the Watershed Delineation dropped down menu.

Challenges:

- a. Every time raster files need to be exported to .tif file for working with OpenNSPECT and MapWindow.
- b. During the watershed delineation process using WRIA9DEM, there was an error message stated that the WRIA9DEM had not been projected even though it had projected. This is because the way of MapWindow working with raster data is different from that with ArcGIS. For MapWindow, it requires a projection file separately. Therefore, the projection file (.prj) of WRIA9DEM was created (ArcCatalog→Properties of that file→Coordinate System→ Save as projection file). As this result, a projection file needs to be created from raster data to be used every time.

Preparing Land Cover data

1. Download data from Coastal Change Analysis Program (C-CAP) data sets are produced by the NOAA Coastal Services Center (<http://www.csc.noaa.gov/digitalcoast/data/ccapregional/>). The land cover data had been requested covering the study area from NOAA (above website). The data were sent via email within a couple days. These data were in a zip file.
2. Check the coordinate system, it should be the same as the coordinate system in the DEM file (Special Reference: NAD27_UTM_zone_10N; Datum: D_North_American_1972; Unit: Meter)
3. The spatial reference of land cover data was changes to be the same as DEM raster file. (ArcToolBox→Data Management Tools→Projections and Transformations→Raster→Project Raster).
4. Before going to mask land cover data into WRIA9 area. Geoprocessing→ Environments needed to be set:
 - a. Output Coordinates: to be the same as *wria9_dem30.tif*
 - b. Processing Extent
 - i. Extent: to be the same as *wria9_dem30.tif*
 - ii. Snap Raster: *wria9_dem30.tif* ****(this is very import step, it needs to set the Snap Raster with DEM file to make the clipped file to have the exactly same boundary as Dem file, which it is very important for OpenNSPECT to RUN, otherwise there will have an error when you run OpenNSPECT.)****
 - c. Raster Analysis
 - i. Cell Size: 30
 - ii. Mask: *wria9_dem30.tif*
5. Once the Geoprocessing Environments had been set, the land cover was masked to wria9 area by using *wria9_dem30.tif as a mask* boundary (ArcToolBox→Data Spatial Analyst Tools→Extraction→ Extract by Mask), and then export it to .tif file (*wria9_LU.tif*)
6. Created a projection file (.prj) from *wria9_LU.tif* (ArcCatalog→Properties of that file→Coordinate System→ Save as projection file)

Adding a new Land Cover Type table into OpenNSPECT

1. Checked the attribute table of *wria9_LU* to see how many land cover types in WRIA9.
2. In MapWindow, click on the OpenNSPECT → Advanced Setting → Land Cover Types, once the Land Cover Types window show up, clicked on the Options → New
3. In the New Land Cover Type window, put the information as in the following:
 - a. Land Cover Type: CCAP_wria9 (name of the land cover type table)
 - b. Description: CCAP Land cover (2001 Classification Scheme)
 - c. Put the classification, SCS Curve Number and RUSLE as in the figure below.

Classification		SCS Curve Numbers				RUSLE	
Value	Name	CN-A	CN-B	CN-C	CN-D	Cover-Factor	Wet
0	Background	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
1	No Data	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
2	High Intensity Developed	0.8900	0.9200	0.9400	0.9500	0.000	<input type="checkbox"/>
3	Medium Intensity Developed	0.7700	0.8500	0.9000	0.9200	0.010	<input type="checkbox"/>
4	Low Intensity Developed	0.6100	0.7500	0.8300	0.8700	0.030	<input type="checkbox"/>
5	Developed Open Space	0.4900	0.6900	0.7900	0.8400	0.005	<input type="checkbox"/>
6	Cultivated Land	0.6700	0.7800	0.8500	0.8900	0.240	<input type="checkbox"/>
7	Pasture/Hay	0.3900	0.6100	0.7400	0.8000	0.050	<input type="checkbox"/>
8	Grassland	0.3000	0.5800	0.7100	0.7800	0.120	<input type="checkbox"/>
9	Deciduous Forest	0.3000	0.5500	0.7000	0.7700	0.009	<input type="checkbox"/>
10	Evergreen Forest	0.3000	0.5500	0.7000	0.7700	0.004	<input type="checkbox"/>
11	Mixed Forest	0.3000	0.5500	0.7000	0.7700	0.007	<input type="checkbox"/>
12	Scrub/Shrub	0.3000	0.4800	0.6500	0.7300	0.014	<input type="checkbox"/>
13	Palustrine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
14	Palustrine Scrub/Shrub W...	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
15	Palustrine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
16	Estuarine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
17	Estuarine Scrub/Shrub We...	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
18	Estuarine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
19	Unconsolidated Shore	0.0000	0.0000	0.0000	0.0000	0.500	<input type="checkbox"/>
20	Bare Land	0.7700	0.8600	0.9100	0.9400	0.700	<input type="checkbox"/>
21	Water	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>
22	Palustrine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>
23	Estuarine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>
25	Snow/Ice	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>

- d. After done with this step, the Run Analysis window of OpenNSPECT has “CCAP_wria9” in the Land Cover Type dropped down box.

Preparing Rainfall data

1. Download Rainfall data (precipevents.zip) from WADOT (<http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm>), and then unzipped that file.
2. The estimated 24 hour average annual precipitation was used (*w24hman.tif*).
3. Before going to mask rainfall data into WRIA9 area. Set Geoprocessing → Environments to be the same as:
 - a. Output Coordinates: to be the same as *wria9_dem30.tif*
 - b. Processing Extent
 - i. Extent: to be the same as *wria9_dem30.tif*
 - ii. Snap Raster: *wria9_dem30.tif*
 - c. Raster Analysis
 - i. Cell Size: 30
 - ii. Mask: *wria9_dem30.tif*
4. Rainfall data (*w24hman.tif*) was masked into wria9 area by *wria9_dem30.tif* (ArcToolBox → Data Spatial Analyst Tools → Extraction → Extract by Mask), and then export it to .tif file (*wria9_w24hmam.tif*)
5. Created a projection file (.prj) from *wria9_w24hmam.tif* (ArcCatalog → Properties of that file → Coordinate System → Save as projection file)

Adding Precipitation Scenario to OpenNSPECT

1. The default precipitation scenario is precipitation in Wai'anae region in Oahu, Hawaii. The precipitation in WRIA9 area is needed to be added to OpenNSPECT tool.
2. In MapWindow, click on the OpenNSPECT → Advanced Setting → Precipitation Scenarios, once the Precipitation Scenario window popped up, clicked on the Options → New
3. In the Precipitation Scenarios window, I put the information as in the following:
 - a. Scenario: Annual Precipitation WRIA9
 - b. Description: Annual Precipitation for WRIA9
 - c. Precipitation Grid: *wria9_w24hmam.tif*
 - d. Spatial Units: Meters

- e. Precipitation Units: centimeters
 - f. Time Period: Annual
 - g. Raining: 100
 - h. Type: Type I
4. After done with creating a new precipitation scenario, now the Run Analysis window of OpenNSPECT has “Annual Precipitation WRIA9” in the Precipitation Scenario dropped down box.

Preparing Soil data and Challenges

1. Download soil data from the U.S. Department of Agriculture’s (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (soils.usda.gov/survey/geography/ssurgo/). The data were requested in the study area. Once the data had been requested, NRCS sent those data via email (waiting for a couple of days). There were three files needed in order to cover WRAI9 area: soil_wa633, soil_wa634, and soil_wa775. Then, the data were downloaded and unzipped.
2. SSURGO database has both spatial and tabular data including the detail soil properties. More detail about this look at <http://soils.usda.gov/survey/geography/ssurgo/description.html>
3. Once the data were unzipped, three shape files (soilmu_a_wa633.shp, soilmu_a_wa634.shp, soilmu_a_wa775.shp) needed to be merged (ArcToolBox → Data Management Tool → General → Merge) (*633_634_775merged.shp*).
4. Next step is joining “component” and “chorizon” tables (located in soildb_WA_2003.mdb) with the merged soil data (*633_634_775merged.shp*), using *mukey* and *cokey* fields as fields used for joining with component and chorizon table, respectively (*633_634_775joined.shp*).
 - a. The component table provides “Hydrologic Soil Group (HSG)” data (field name “hydgrp”).
 - b. The chorizon table provides “k-factor” data (field name “kffact”).
5. Now, the joined shape file (*633_634_775joined.shp*) needed to be clipped into WRIA9 area. (*633_634_775Cliped.shp*)

6. Before, the soil shape file will be converted to raster grid file; a new field called “Hydgroup” was created with a data type of long integer. Next process was using ‘select by attribute’ tool to select the features that have “hydgrp” = ‘A’, and used “Field calculator” to calculate those records of “Hydgroup” = 1, and worked on the same step with “hydgrp” = ‘B’, “hydgrp” = ‘C’, “hydgrp” = ‘D’, and calculated them to “2”, “3”, “4”, respectively. A new field was created to show hydrologic soil group in number 1, 2, 3, and 4 (instead of A, B, C, and D). For the features that were water area the records did not contain kfactor and hydrologic soil group data. Those features must be populated to conservative data (Eslinger, 2012). In this case, water areas were set kfactor to 0 and the hydrologic soil group to D.
7. Now, the clipped shape file (*633_634_775Cliped.shp*) was converted to raster file (ArcToolBox→Conversion Tool→To Raster →Polygon to Raster) using “hydgrp” as a field value.
8. Then, I converted the clipped shape file (*633_634_775Cliped.shp*) to raster file again using “k-factor” as a field value.
9. With the aim of having the same exactly boundary for all raster data, step 7 and 8 was needed to be accomplished again by using *wria9_dem30.tif* as a mask file again (ArcToolBox→Data Spatial Analyst Tools→Extraction→ Extract by Mask) and set the Environment to be the same as:
 - a. Output Coordinates: to be the same as *wria9_dem30.tif*
 - b. Processing Extent
 - i. Extent: to be the same as *wria9_dem30.tif*
 - ii. Snap Raster: *wria9_dem30.tif*
 - c. Raster Analysis
 - i. Cell Size: 30
 - ii. Mask: *wria9_dem30.tif*
10. The dataset that will be used in the OpenNSPECT are *633_634_775Cliped.shp* and the raster files.

Adding Hydrologic Soils Data Set to OpenNSPECT

1. In MapWindow, click on the OpenNSPECT →Advanced Setting→Soils, once the Soils window popped up, clicked on the Options→New
2. In the Soils Setup window, put the information as in the following:
 - a. Name: Soils WRIA9
 - b. DEM GRID: *wria9_dem30.tif*
 - c. Soils Data Set: *633_634_775Cliped.shp*
 - d. Hydrologic Soil Group Attribute: HydGroup
 - e. K Factor Attribute: K-factor
3. After done with adding soil data to OpenNSPECT, now the Run Analysis window of OpenNSPECT has “Soils WRIA9” in the Hydrologic Soils Data Set dropped down box.

Appendix B: USGS DEM files associated with areas WRIA9

Filenames of downloaded USGS DEM files associated with areas of WRIA9.

File Names	Area Names
q1221	Duwamish Head
q1222	Seattle South
q1223	Mercer Island
q1321	Vashon
q1322	Des Moines
q1323	Renton
q1324	Maple Valley
q1325	Hobart
q1422	Poverty Bay
q1326	North Bend
q1423	Auburn
q1424	Black Diamond
q1425	Cumberland
q1426	Eagle Garge
q1427	Cougar Mountain
q1428	Findley Lake
q1429	Lost Lake
q1430	Stampede Pass
q1524	Buckley
q1525	Enumclaw
q1526	Cyclone Creek
q1527	Greenwater
q1528	Nagram
q1529	Laster
q1530	Blowout Mountain
q1629	Nable Knab

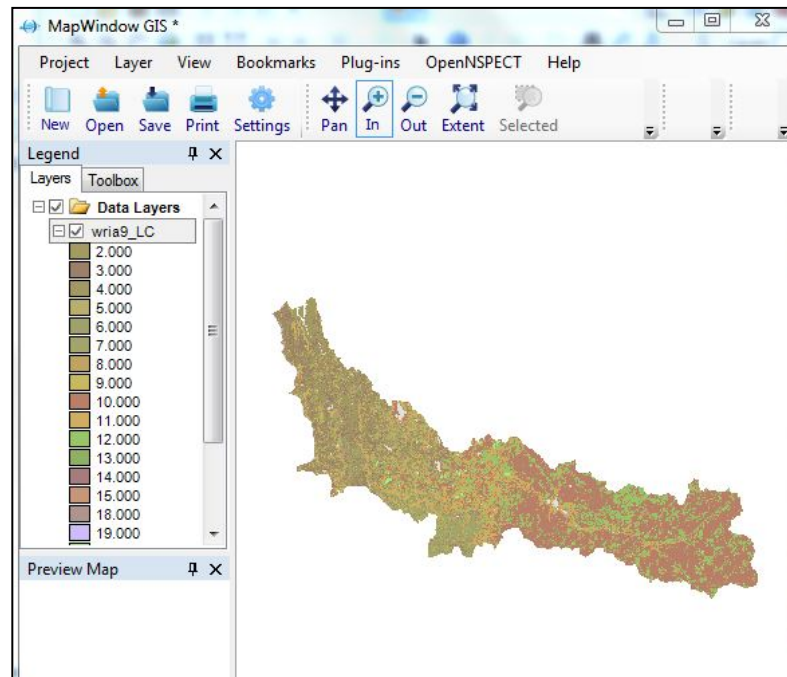
Source: USGS (Downloaded from WAGDA, University of Washington)

(<http://gis.ess.washington.edu/data/raster/tenmeter/byquad/seattle/index.html>)

(<http://gis.ess.washington.edu/data/raster/tenmeter/byquad/wenatchee/index.html>)

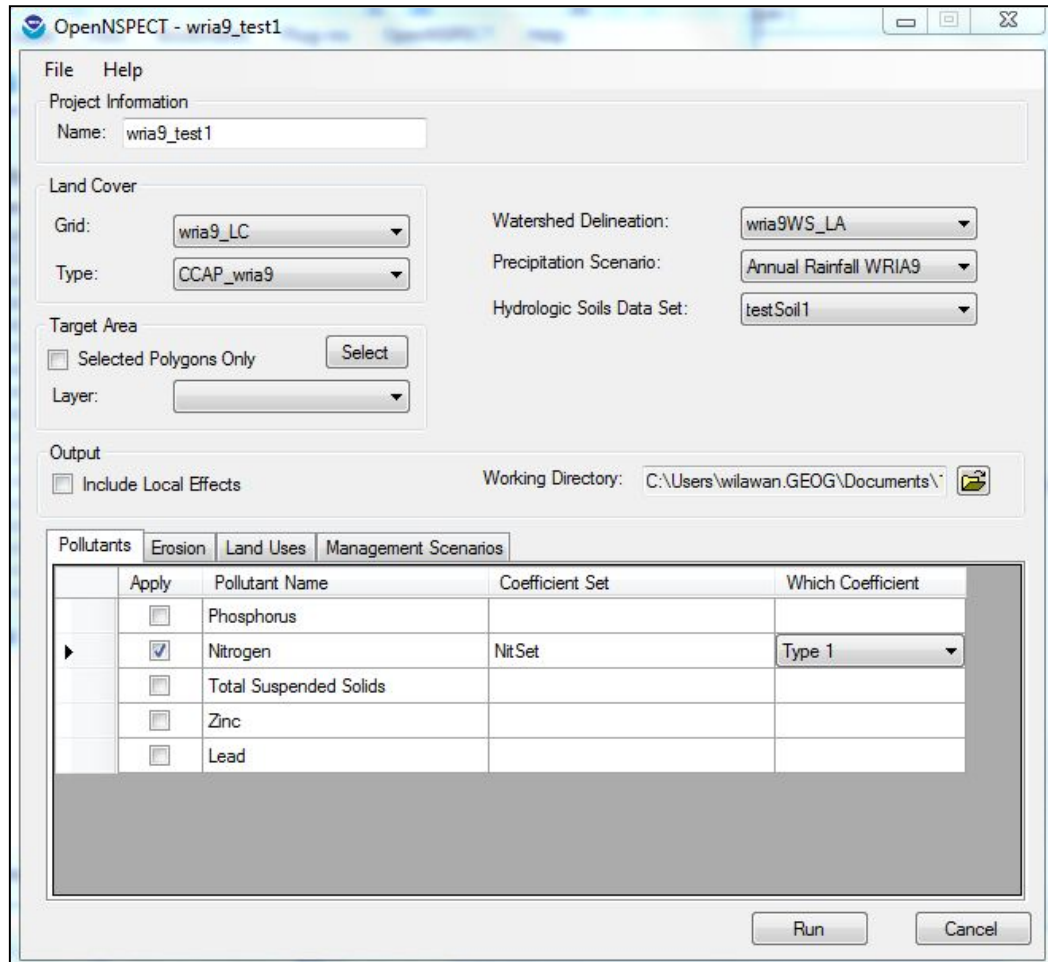
Appendix C: Running Analysis OpenNSPECT process

1. In MapWindow, add Land Cover data (*wria9_LC.tif*) to the table of content.

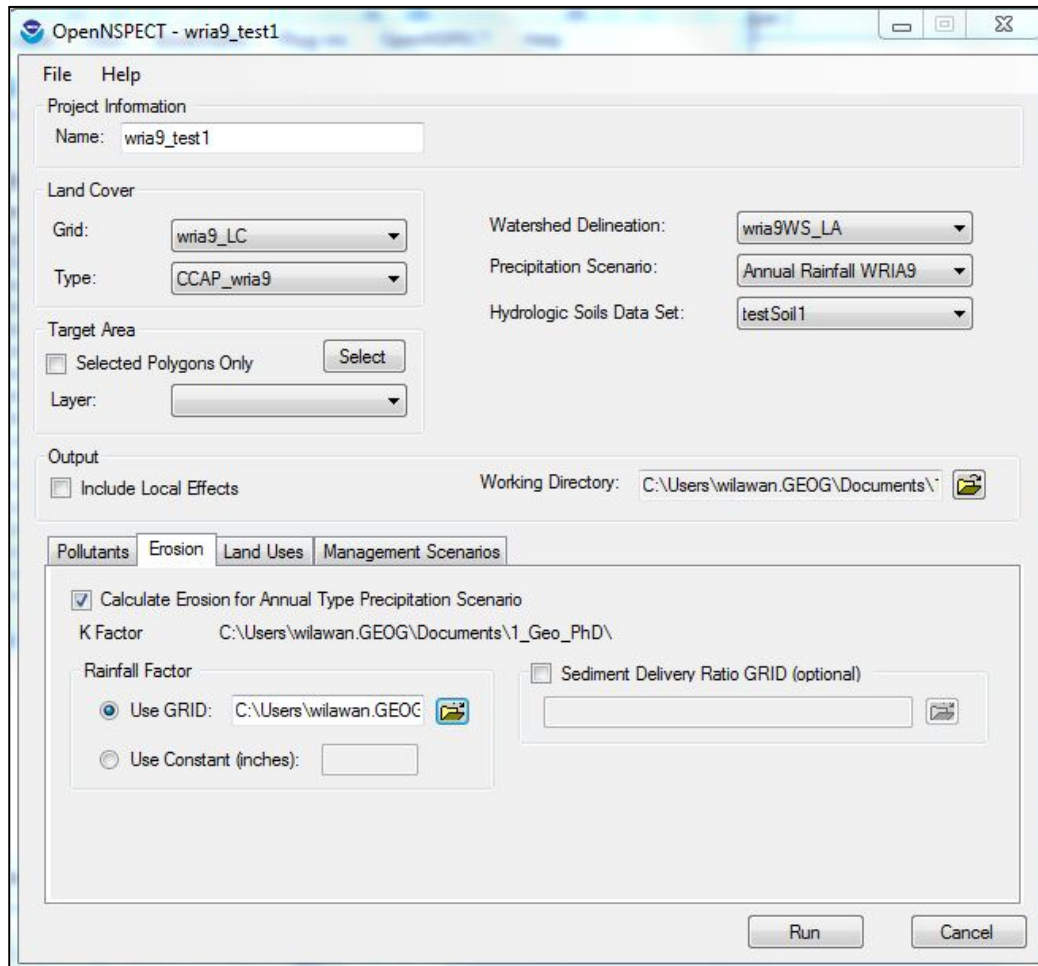


2. Clicked the OpenNSPECT →Running Analysis, the window of OpenNSPECT shown up all the needed input data for running OpenNSPECT have been put in the program. The program is ready to run.
3. The Running Analysis was set as the following:
 - a. Project Information Name: *wria9_test1*
 - b. Land Cover
 - i. Grid: *wria9_LC*
 - ii. Type: CCAP
 - c. Watershed Delineation: *wria9ws_LA*
 - d. Precipitation Scenario: Annual Precipitation WRIA9
 - e. Hydrologic Soils Data Set: *testSoil1*
 - f. Target Area: Uncheck
 - g. Output: Uncheck
 - h. Working Directory: Output Folder
 - i. Pollutants Tab:

- i. Apply: checked Nitrogen
- ii. Coefficient Set: NitSet
- iii. Which Coefficient: Type 1



- j. Erosion Tab:
 - i. Calculate Erosion for Annual Type Precipitation Scenario: Checked
 - ii. Rainfall Factor: Use GRID "Soilk1.tif"



4. Then, Clicked Run.

ERROEs during Running OpenNSPECT

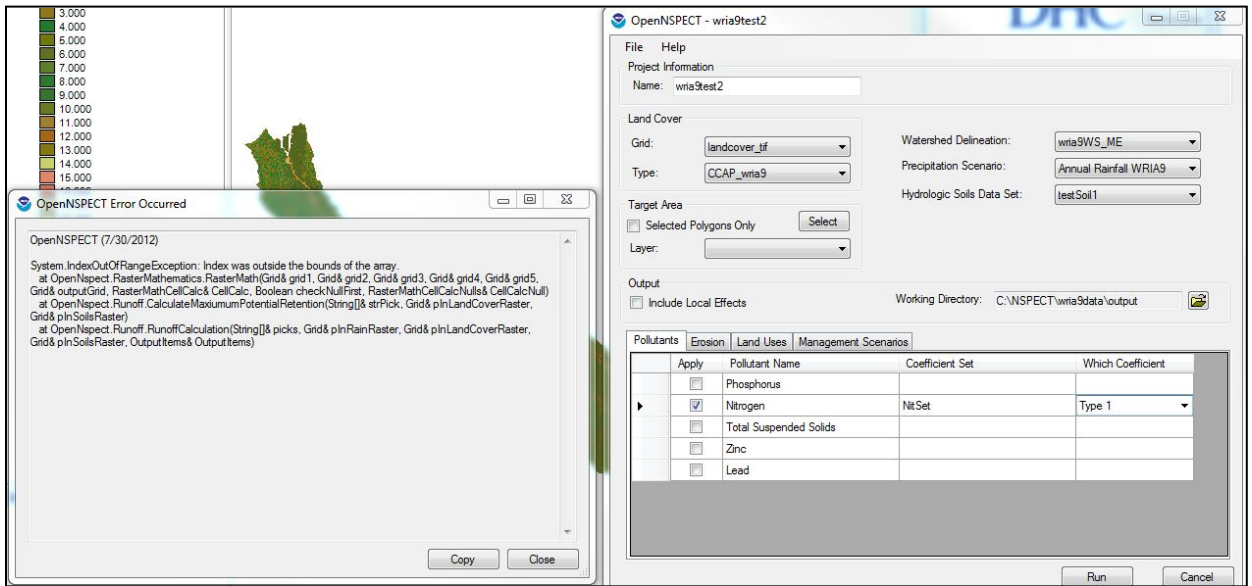
1. The first error that occurred when first running OpenNSPECT was Error:

“Your OpenNSPECT Land Class Table is missing values found in your landcover GRID dataset.”

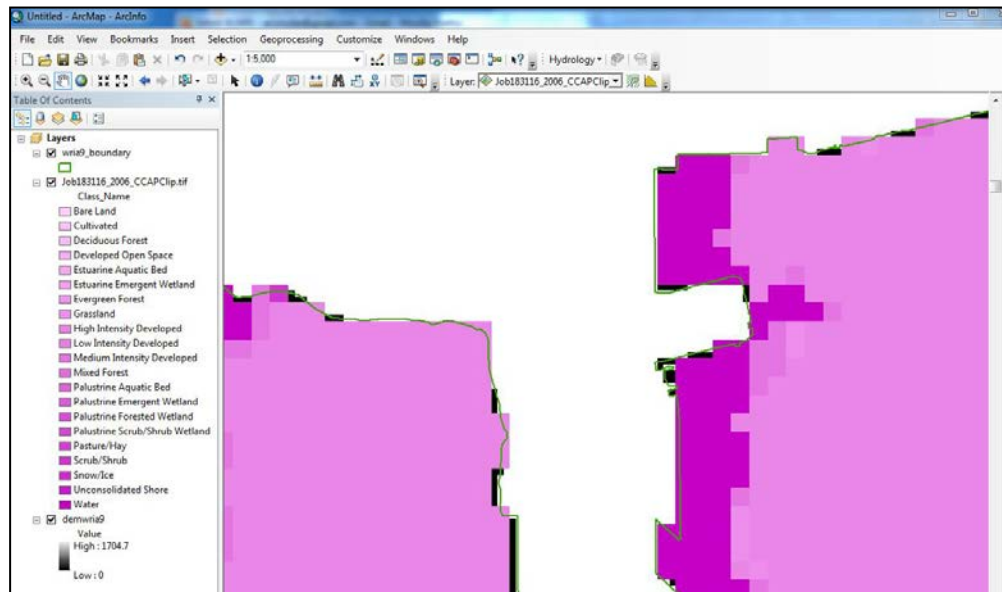
With the communication with a NOAA staff who working with OpenNSPECT about this error, it might because the Land Class Table in OpenNSPECT did not match with the value in attribute table of land cove data. With this reason, the attribute table of *wria_LC.tif* was checked and was found that the value of land cover did not match with the Land Class Table in the OpenNSPECT. Therefore, a new Land Class Table covering all the land cover type in *wria9_LC* was created and added into OpenNSPECT. After that

the OpenNSPECT was run again and this error had gone. However, there was second error shown up.

2. The second error was “...Index was outside the bounds of the array at OpenNSPECT...”

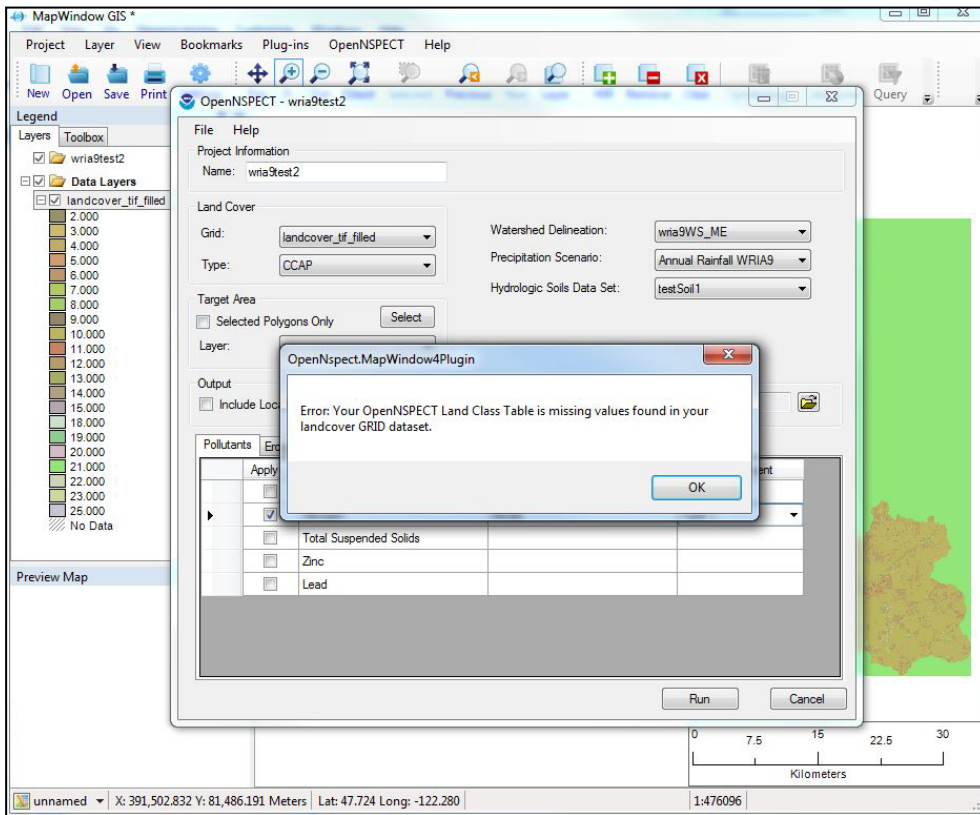


After communicating with NOAA officers responding for this model, it found that this error occurred because of the missed match of each input data boundary.



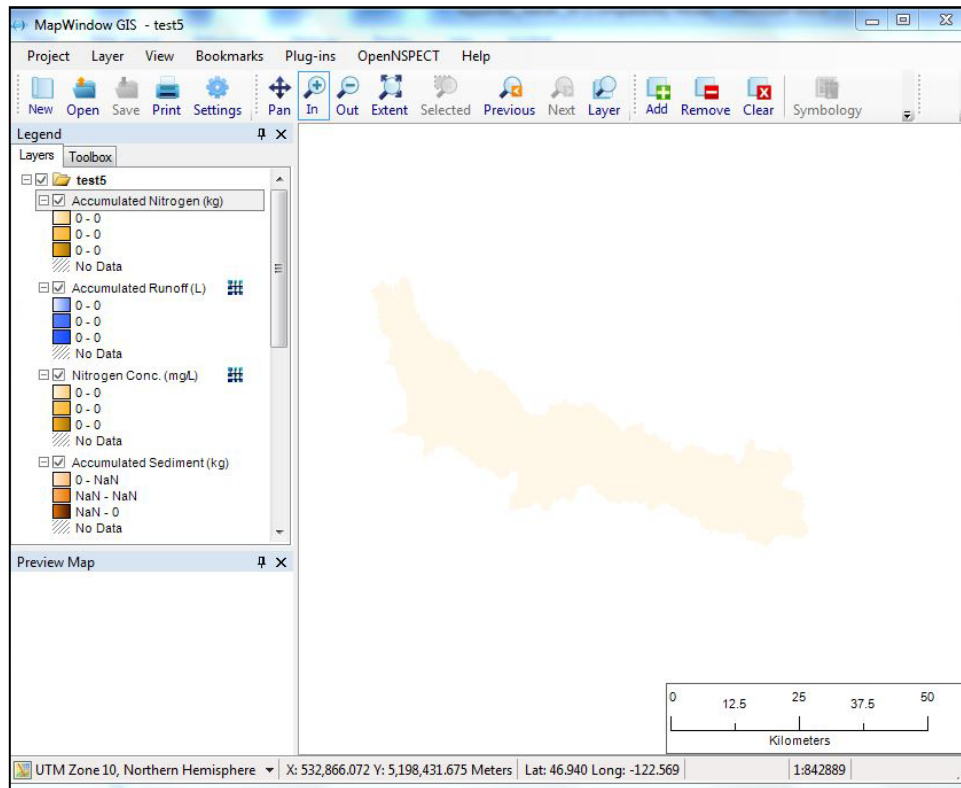
After playing around to solve the boundary problem, found out that each input data that was masked, it needed to set ‘Snap Raster’ at the geoprocessing environment.

3. After all grid files have snapped and added to OpenNSPECT, the model was run again and shown up the same error as the first error.



After checking the error, it was found out that the pollutant coefficient table needed to be updated to have the land cover type as same the land class table.

4. After the pollutant coefficient table has been updated, the model was successful run, there was no error show up. However, the grid files have no result values in those grids.



Without responding back with this issue from NOAA stuff, the model was tried to run again with changing the precipitation data and soil data but still got the same result error.

5. After got feedback from NOAA, we found that the reason that the model could not run because of the soil characteristic in soil data was not assigned to model. Therefore, we adjusted the table of soil data and then the model can run.

Appendix D: Curve Number Adjustments: Baseline and Calibrated Tables

1.) Baseline CN

Land Cover Types

Options Edit Help

Land Cover: CCAP

Description: CCAP Landcover (2001 Classification Scheme)

Classification			SCS Curve Numbers				RUSLE	
Value	Name	CN-A	CN-B	CN-C	CN-D	Cover-Factor	Wet	
0	Background	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>	
1	No Data	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>	
2	High Intensity Developed	0.8900	0.9200	0.9400	0.9500	0.000	<input type="checkbox"/>	
3	Medium Intensity Developed	0.7700	0.8500	0.9000	0.9200	0.010	<input type="checkbox"/>	
4	Low Intensity Developed	0.6100	0.7500	0.8300	0.8700	0.030	<input type="checkbox"/>	
5	Developed Open Space	0.4900	0.6900	0.7900	0.8400	0.005	<input type="checkbox"/>	
6	Cultivated Land	0.6700	0.7800	0.8500	0.8900	0.240	<input type="checkbox"/>	
7	Pasture/Hay	0.3900	0.6100	0.7400	0.8000	0.050	<input type="checkbox"/>	
8	Grassland	0.3000	0.5800	0.7100	0.7800	0.120	<input type="checkbox"/>	
9	Deciduous Forest	0.3000	0.5500	0.7000	0.7700	0.009	<input type="checkbox"/>	
10	Evergreen Forest	0.3000	0.5500	0.7000	0.7700	0.004	<input type="checkbox"/>	
11	Mixed Forest	0.3000	0.5500	0.7000	0.7700	0.007	<input type="checkbox"/>	
12	Scrub/Shrub	0.3000	0.4800	0.6500	0.7300	0.014	<input type="checkbox"/>	
13	Palustrine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
14	Palustrine Scrub/Shrub W...	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
15	Palustrine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
16	Estuarine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
17	Estuarine Scrub/Shrub We...	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
18	Estuarine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input checked="" type="checkbox"/>	
19	Unconsolidated Shore	0.0000	0.0000	0.0000	0.0000	0.500	<input type="checkbox"/>	
20	Bare Land	0.7700	0.8600	0.9100	0.9400	0.700	<input type="checkbox"/>	
21	Water	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>	
22	Palustrine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>	
23	Estuarine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>	
24	Tundra	0.3000	0.4800	0.6500	0.7300	0.014	<input type="checkbox"/>	
25	Snow/Ice	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>	

Restore Defaults OK Cancel

2.) Calibrated CN

Land Cover Types

Options Edit Help

Land Cover: CCAP_WRIA9_DOE

Description: CCAP Landcover (2001 Classification Scheme)

Classification		SCS Curve Numbers				RUSLE	
Value	Name	CN-A	CN-B	CN-C	CN-D	Cover-Factor	Wet
0	Background	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
1	No Data	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>
2	High Intensity Developed	0.8900	0.9200	0.9400	0.9500	0.005	<input type="checkbox"/>
3	Medium Intensity Developed	0.7700	0.8500	0.9000	0.9200	0.006	<input type="checkbox"/>
4	Low Intensity Developed	0.6100	0.7500	0.8300	0.8700	0.030	<input type="checkbox"/>
5	Developed Open Space	0.4900	0.6900	0.7900	0.8400	0.005	<input type="checkbox"/>
6	Cultivated Land	0.6700	0.7800	0.8500	0.8900	0.240	<input type="checkbox"/>
7	Pasture/Hay	0.4900	0.6900	0.7900	0.8400	0.240	<input type="checkbox"/>
8	Grassland	0.3000	0.5800	0.7100	0.7800	0.050	<input type="checkbox"/>
9	Deciduous Forest	0.3000	0.4800	0.6500	0.7300	0.004	<input type="checkbox"/>
10	Evergreen Forest	0.3000	0.4800	0.6500	0.7300	0.004	<input type="checkbox"/>
11	Mixed Forest	0.3000	0.4800	0.6500	0.7300	0.004	<input type="checkbox"/>
12	Scrub/Shrub	0.3000	0.4800	0.6500	0.7300	0.014	<input type="checkbox"/>
13	Palustrine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
14	Palustrine Scrub/Shrub W...	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
15	Palustrine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
16	Estuarine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
17	Estuarine Scrub/Shrub We...	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
18	Estuarine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	<input type="checkbox"/>
19	Unconsolidated Shore	0.0000	0.0000	0.0000	0.0000	0.500	<input type="checkbox"/>
20	Bare Land	0.7700	0.8600	0.9100	0.9400	0.700	<input type="checkbox"/>
21	Water	0.0000	0.0000	0.0000	0.0000	0.000	<input checked="" type="checkbox"/>
22	Palustrine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.500	<input checked="" type="checkbox"/>
23	Estuarine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.500	<input checked="" type="checkbox"/>
25	Snow/Ice	0.0000	0.0000	0.0000	0.0000	0.000	<input type="checkbox"/>

Restore Defaults OK Cancel

Appedix E: Pollution Coefficient Adjustments: Baseline and Calibrated

1.) Baseline nitrogen coefficient

Pollutants Coefficients Help

Pollutant Name: Nitrogen

Coefficients Water Quality Standards

Coefficient Set: Nitrogen_NLCD Land Cover Type: NLCD2001_2006

Description: Nitrogen runoff coefficients for full NLCD 2001 and 2006 classifications

	Class		Coefficients (mg/L)			
	Value	Name	Type 1	Type 2	Type 3	Type 4
▶	11	Water	0.0000	0.0000	0.0000	0.0000
	12	Perennial Ice / Snow	0.0000	0.0000	0.0000	0.0000
	21	Developed Open Space	1.2500	0.0000	0.0000	0.0000
	22	Low Intensity Developed	1.7700	0.0000	0.0000	0.0000
	23	Medium Intensity Developed	1.2500	0.0000	0.0000	0.0000
	24	High Intensity Developed	2.2200	0.0000	0.0000	0.0000
	31	Bare Land	0.9700	0.0000	0.0000	0.0000
	41	Deciduous Forest	1.2500	0.0000	0.0000	0.0000
	42	Evergreen Forest	1.2500	0.0000	0.0000	0.0000
	43	Mixed Forest	1.2500	0.0000	0.0000	0.0000
	51	Dwarf Shrub	0.0000	0.0000	0.0000	0.0000
	52	Scrub/Shrub	1.2500	0.0000	0.0000	0.0000
	71	Grassland	1.2500	0.0000	0.0000	0.0000
	72	Sedge Herbaceous	0.0000	0.0000	0.0000	0.0000
	74	Moss	0.0000	0.0000	0.0000	0.0000
	81	Pasture/Hay	2.4800	0.0000	0.0000	0.0000
	82	Cultivated Land	2.6800	0.0000	0.0000	0.0000
	90	Woody Wetland	1.1000	0.0000	0.0000	0.0000
	95	Emergent Wetland	1.1000	0.0000	0.0000	0.0000

OK Cancel

2.) Calibrated nitrogen coefficient

Pollutants

Pollutants Coefficients Help

Pollutant Name: Nitrogen

Coefficients Water Quality Standards

Coefficient Set: wria9_NitSet_DOE Land Cover Type: CCAP_WRIA9_DOE

Description:

Class		Coefficients (mg/L)			
Value	Name	Type 1	Type 2	Type 3	Type 4
0	Background	0.0000	0.0000	0.0000	0.0000
1	No Data	0.0000	0.0000	0.0000	0.0000
2	High Intensity Developed	0.6300	0.0000	0.0000	0.0000
3	Medium Intensity Developed	0.6000	0.0000	0.0000	0.0000
4	Low Intensity Developed	0.5300	0.0000	0.0000	0.0000
5	Developed Open Space	0.3400	0.0000	0.0000	0.0000
6	Cultivated Land	2.8900	0.0000	0.0000	0.0000
7	Pasture/Hay	0.4000	0.0000	0.0000	0.0000
8	Grassland	0.3400	0.0000	0.0000	0.0000
9	Deciduous Forest	0.2000	0.0000	0.0000	0.0000
10	Evergreen Forest	0.2000	0.0000	0.0000	0.0000
11	Mixed Forest	0.2000	0.0000	0.0000	0.0000
12	Scrub/Shrub	0.3400	0.0000	0.0000	0.0000
13	Palustrine Forested Wetland	0.3000	0.0000	0.0000	0.0000
14	Palustrine Scrub/Shrub Wetland	0.3000	0.0000	0.0000	0.0000
15	Palustrine Emergent Wetland	0.3000	0.0000	0.0000	0.0000
16	Estuarine Forested Wetland	0.3000	0.0000	0.0000	0.0000
17	Estuarine Scrub/Shrub Wetland	0.3000	0.0000	0.0000	0.0000
18	Estuarine Emergent Wetland	0.3000	0.0000	0.0000	0.0000
19	Unconsolidated Shore	0.2800	0.0000	0.0000	0.0000
20	Bare Land	0.2800	0.0000	0.0000	0.0000

OK Cancel

Appendix F: Lab Assignments for a Role Play Modeling Activities for WRIA9

Representation and Process Modeling

Assignment Data: Assignment A Data folder on Canvas

Deliverables: Please see detailed instructions at the end of this assignment.

Learning Objectives:

- **Understand and practice representation and process modeling within the geodesign framework**
- Exposure to watershed modeling and nonpoint source pollution

Introduction: Open-Source Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT)

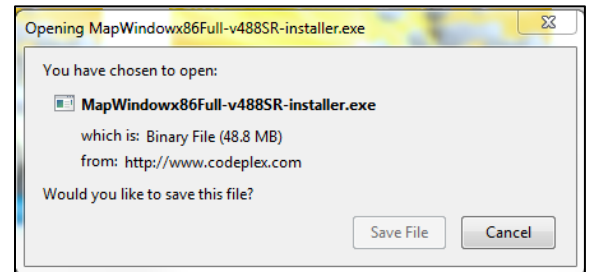
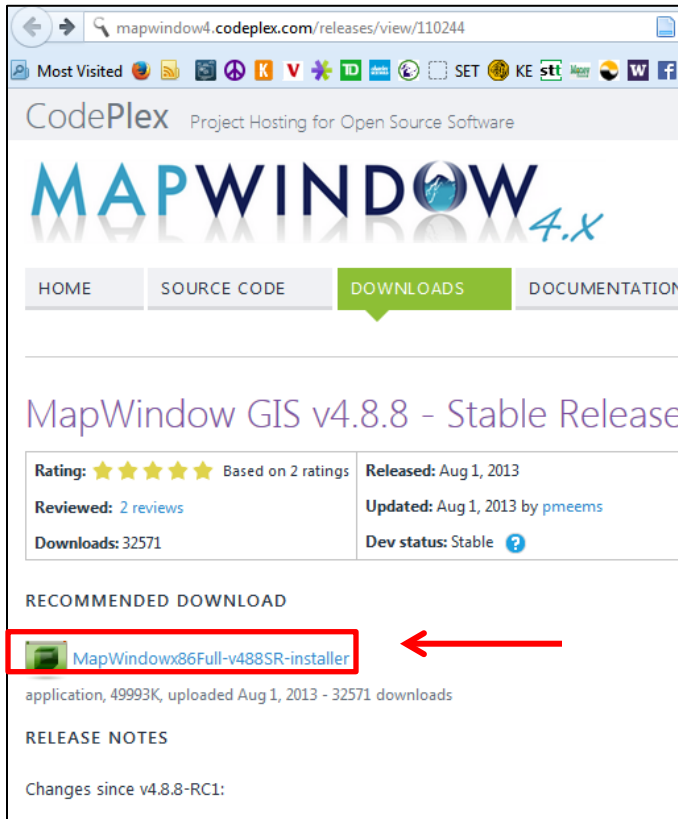
In this assignment, we examine a representation and process model of nonpoint source pollution flow and its relations to receiving water bodies such as streams, rivers, lakes, and coastal water for the Water Resource Inventory Area 9 (WRIA9). We use OpenNSPECT to estimate the volume and location of nonpoint source pollution and its potential impacts on water quality. To understand water runoff and toxic pollutants in runoff, we must characterize topographic information for the study area. In addition, land use/cover type and precipitation have significant influences on the course of runoff with toxic pollutants.

OpenNSPECT, an open-source version of N-SPECT software, estimates impacts on water quality from nonpoint source pollution and erosion. The model was designed as a water quality screening tool by NOAA. Due to changes in ArcGIS .Net technology, instead of using Esri ArcGIS product to host, OpenNSPECT uses MapWindow as a platform to host the model. MapWindow is a free and open-source GIS program that can be used as an open-source alternative desktop GIS, to distribute data to others, and to develop and distribute custom spatial data analysis tools. OpenNSPECT supports coastal managers and local officials with examining the relationship between land cover, nonpoint source pollution, and erosion to understand water pollution impacts to water bodies including rivers, streams, and coastal water from the increasing of development, land use change, and climate change. OpenNSPECT has ability to work on water quality screening tool, spatially distributed pollutant and sediment model, and compares the effects of different land cover and land use scenarios on total yields. There are three main functions in OpenNSPECT including rainfall-runoff model, pollutant model and sediment yield model. For our assignments, we will use OpenNSPECT rainfall-runoff and pollutant models to understand the characteristic of total nitrogen in WRIA9 for this assignment. More detail about OpenNSPECT is available at: <http://www.csc.noaa.gov/digitalcoast/tools/opennspect>.

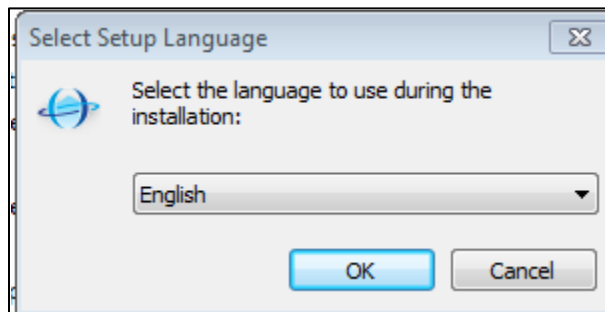
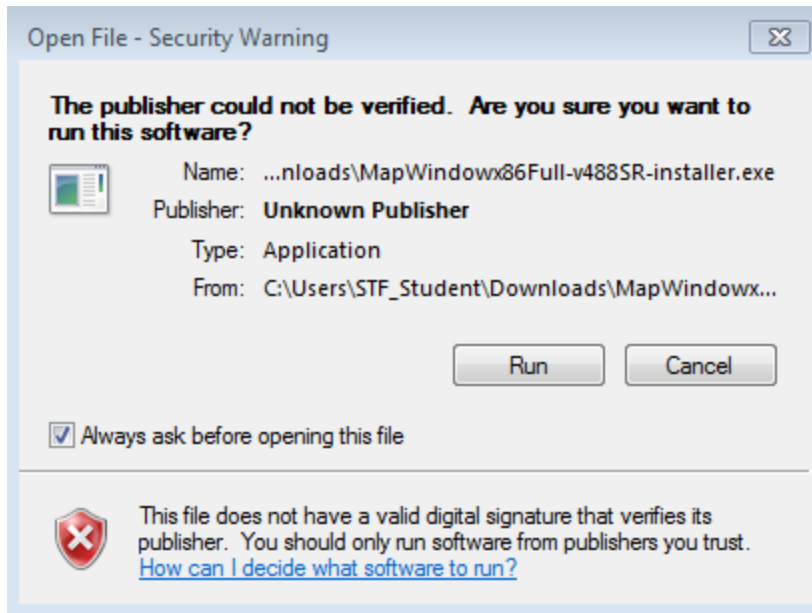
1. Installing MapWindow GIS

Download the MapWindow desktop software at <http://mapwindow4.codeplex.com/releases/view/110244>

(**MapWindowx86Full-v488SR-installer.exe**). MapWindow is a native Windows application that requires installation of the Microsoft .NET framework. It runs on XP, Vista, and Windows 7.



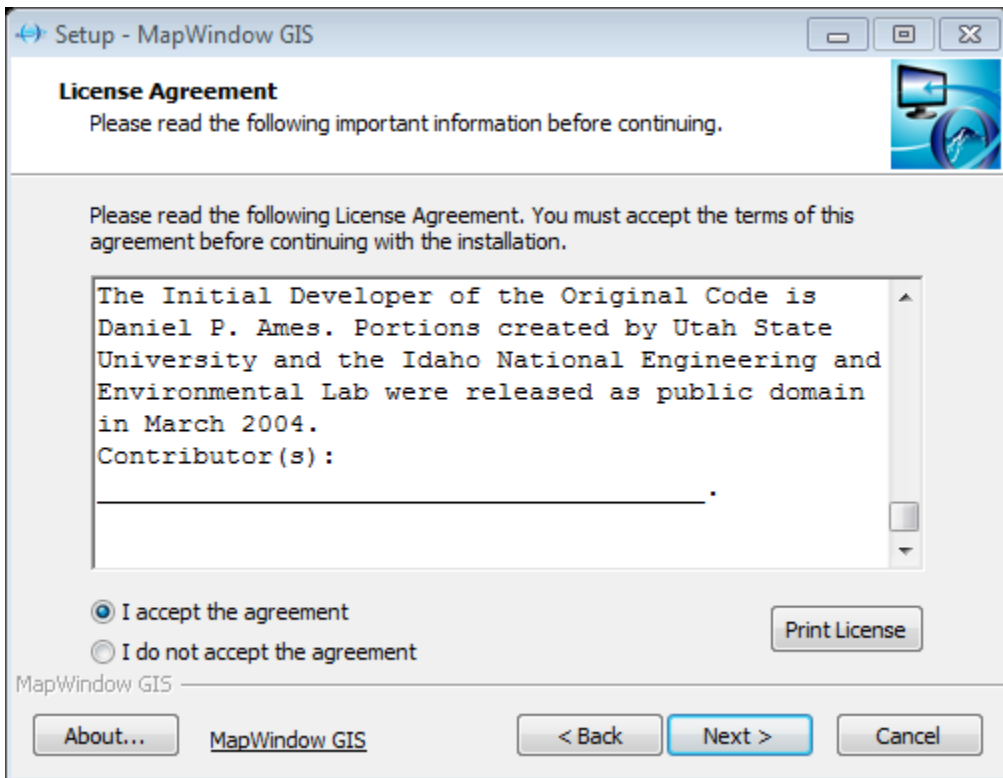
Save “MapWindowx86Full-v488SR-installer.exe” on your computer, after that double click on this file, and click RUN to install the program.



Select English on Select Setup Language window, and then click OK.

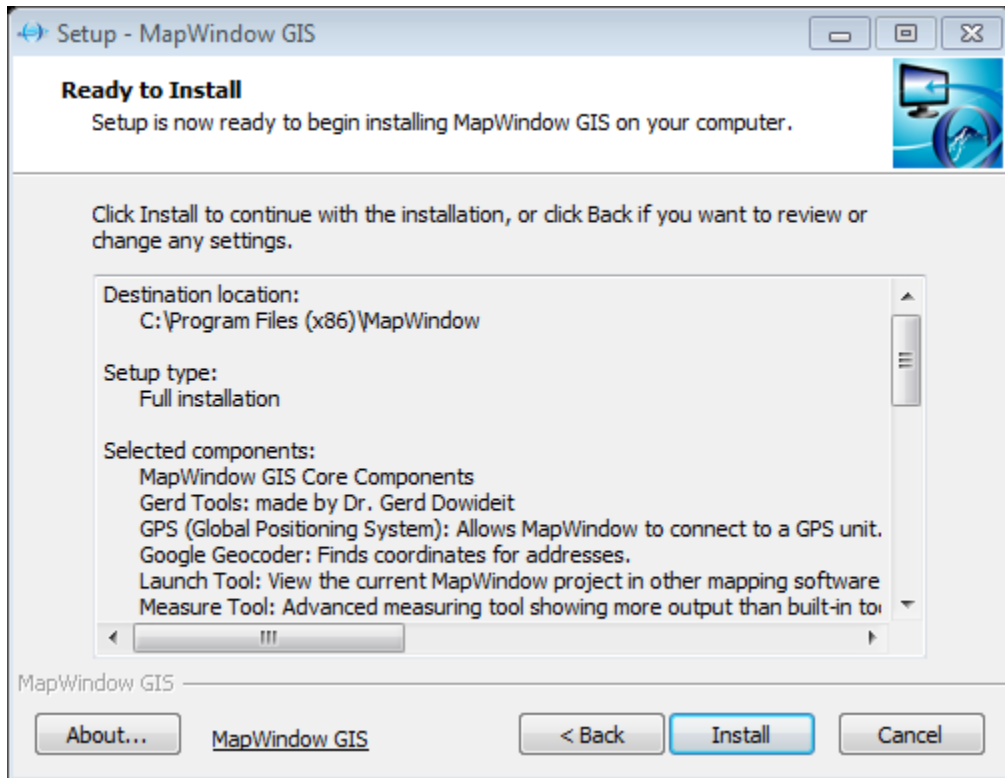


Click Next on Setup – MapWindow GIS window,



Select “I accept the agreement”, and then click Next.

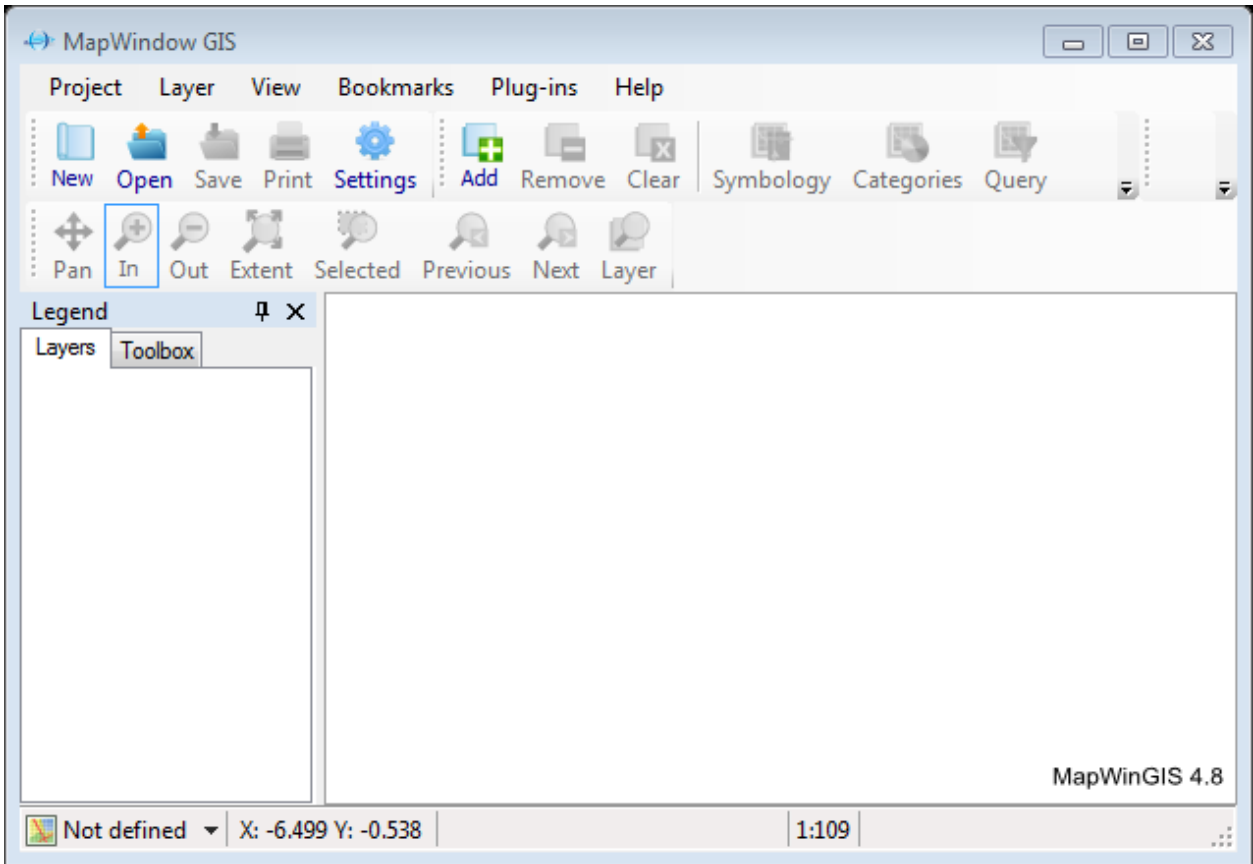
After this, you will click “Next” until you got this below page, and then you click “Install”





Click Finish.

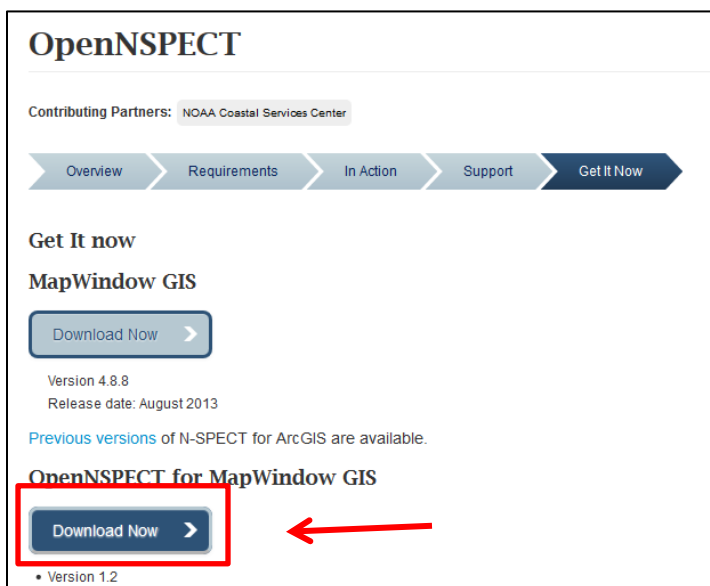
Then, MapWindow will pop up, look like this.

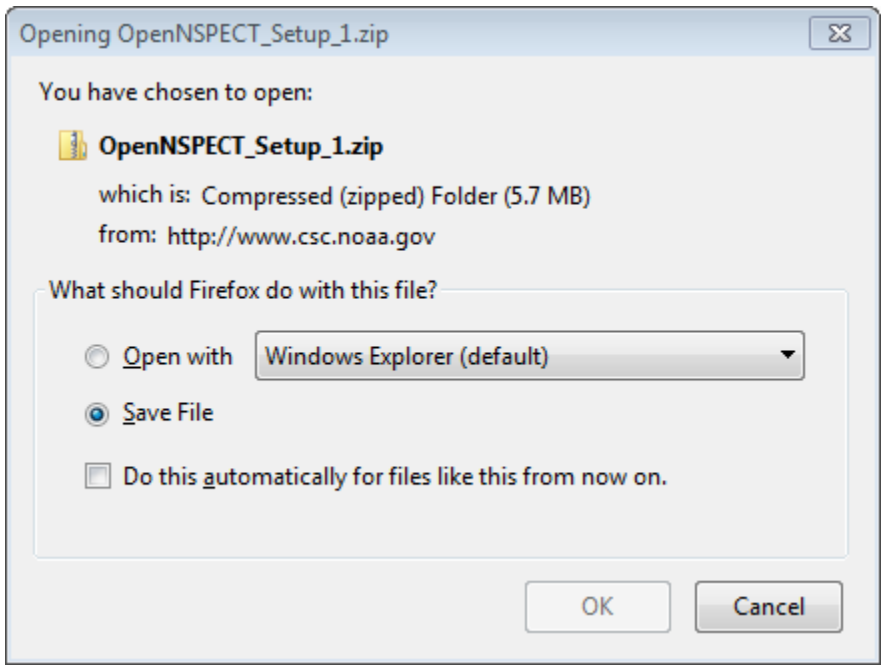


Now, you finished installing MapWindow program. A MapWindow GIS icon will be added to your desktop. A quick start guide is available on the MapWindow website.

2. Installing OpenNSPECT

Download OpenNSPECT plug-in extension for MapWindow GIS at <http://www.csc.noaa.gov/digitalcoast/tools/opensnspect>

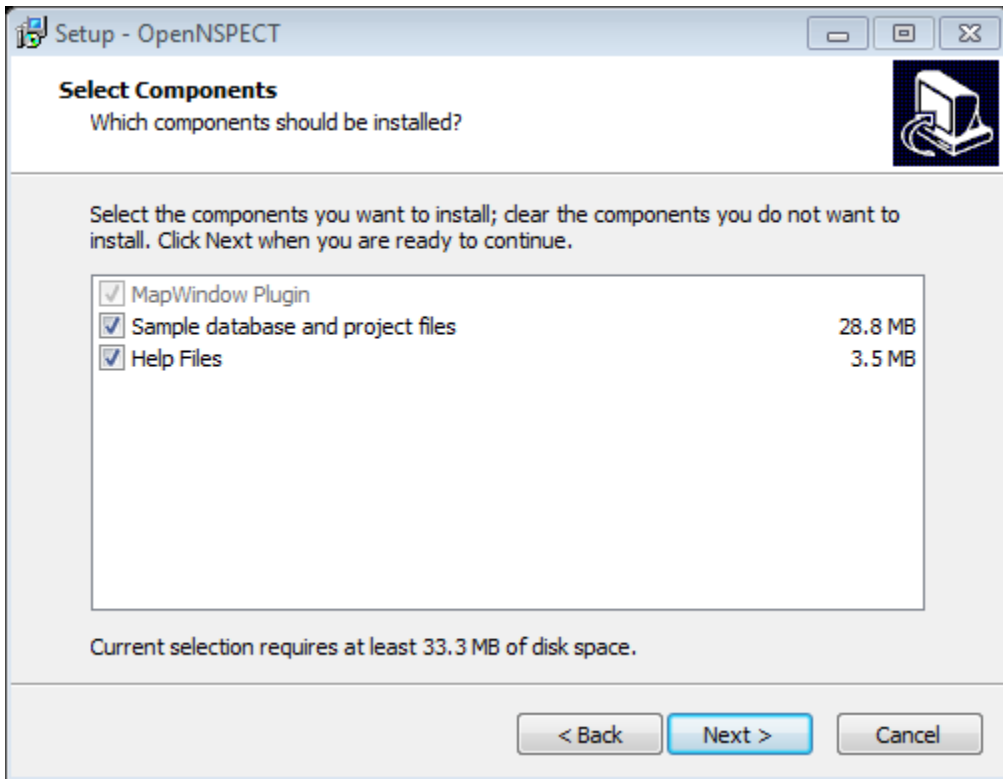




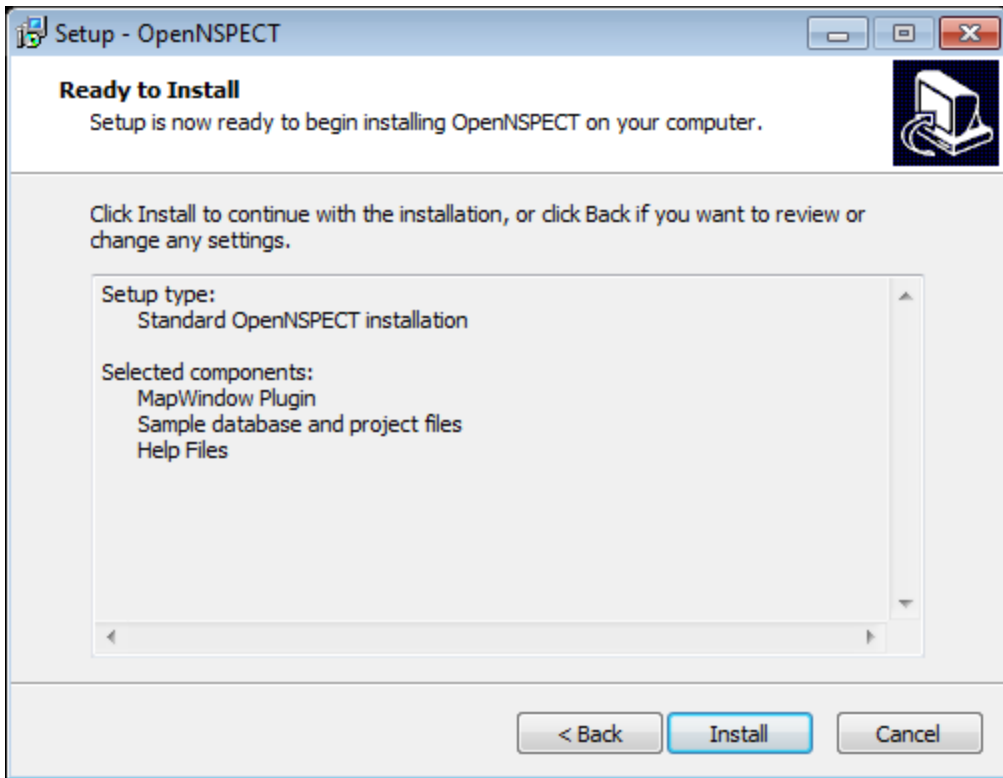
Save OpenNSPECT_Setup_1.zip file on your computer and then unzip it. Make sure that the MapWindow program is not running. After this double click on OpenNSPECT_Setup_1_2.exe to run setup software to installed OpenNSPECT.



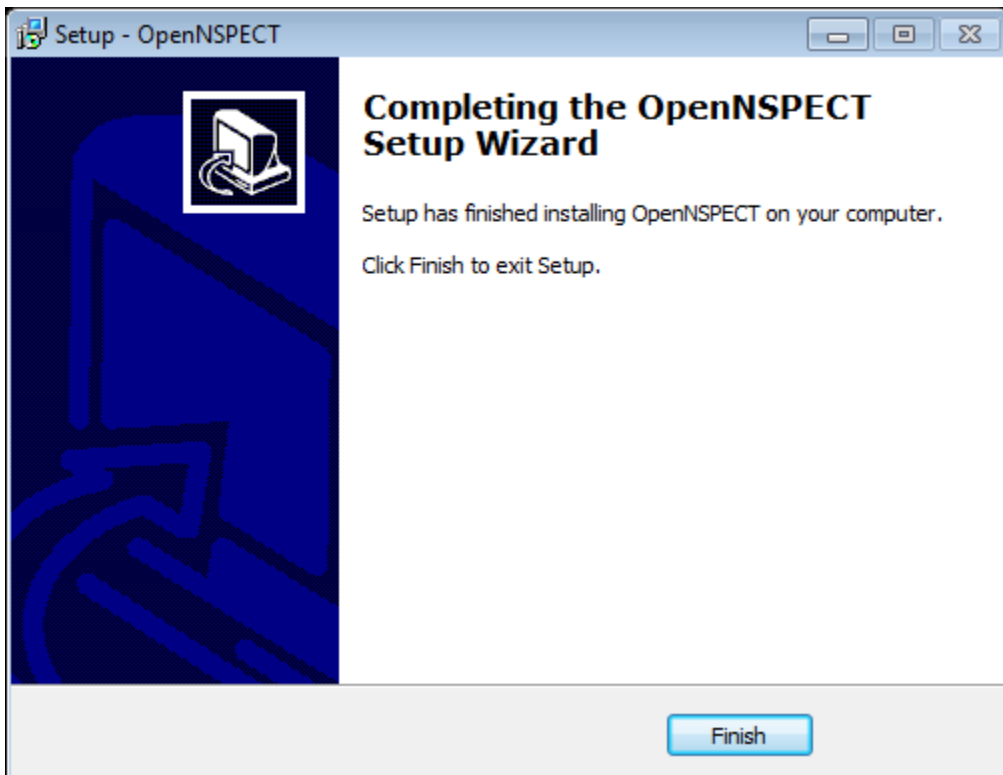
Click Next



Leave the Select Components as default, click Next



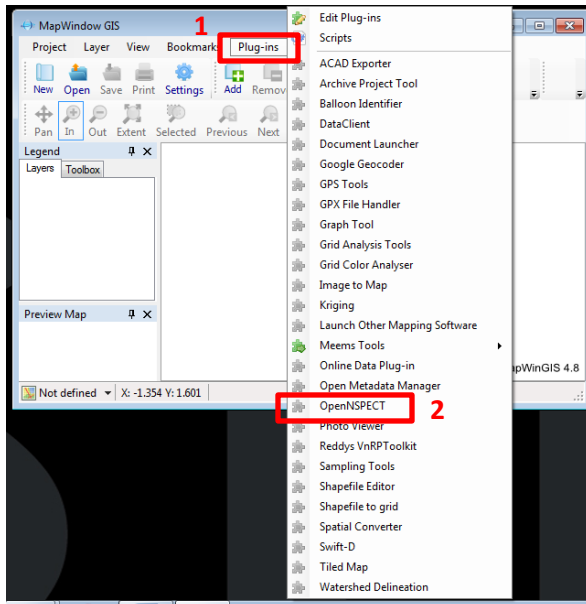
Click "Install"



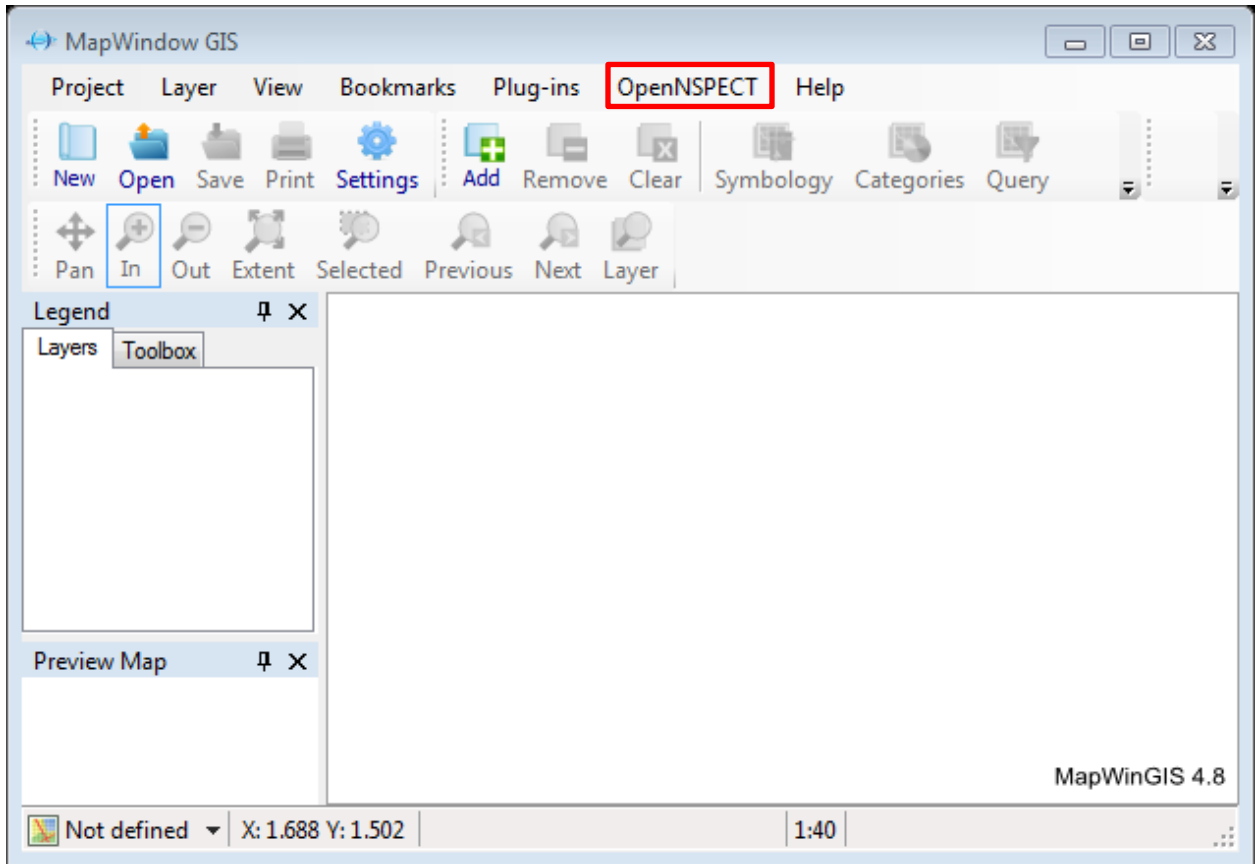
When it is done, click “Finish”. Now, you already installed OpenNSPECT plugin-in extension for MapWindow GIS.

3. Loading OpenNSPECT

Double click on MapWindow GIS icon on your desktop to open it. You will see “Welcome to MapWindow” dialog box showing up; click “Close” to dismiss the box.



Click on “Plug-ins”, and then select “OpenNSPECT”. Now you added OpenNSPECT to the main pull-down menu.



Now, you already have OpenNSPECT in the MapWindow GIS program. You are ready to work on OpenNSPECT

4. Preparing Input data

The input data that the model need to generate runoff and pollutant models include DEM, rainfall, land cover, and soil. The table below shows you the sources of the data. For this assignment, we have already prepared those data for WRIA9 for you. You can download from Canvas website.

Data Type	Data Source	Data Description
Topology	USGS 2006 http://viewer.nationalmap.gov/viewer/	30 Meter Digital Elevation Model (DEM)
Land Cover	NOAA 2006 http://www.csc.noaa.gov/dataviewer/index.html#	CCAP (Costal Change Analysis Program)
Precipitation (Rainfall data)	PRISM Climate Group http://www.prism.oregonstate.edu/	Parameter-elevation Regressions on Independent Slopes Model (PRISM)
Soils	NRCS 2005 http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx	SSURGO (Soil Survey Geographic)

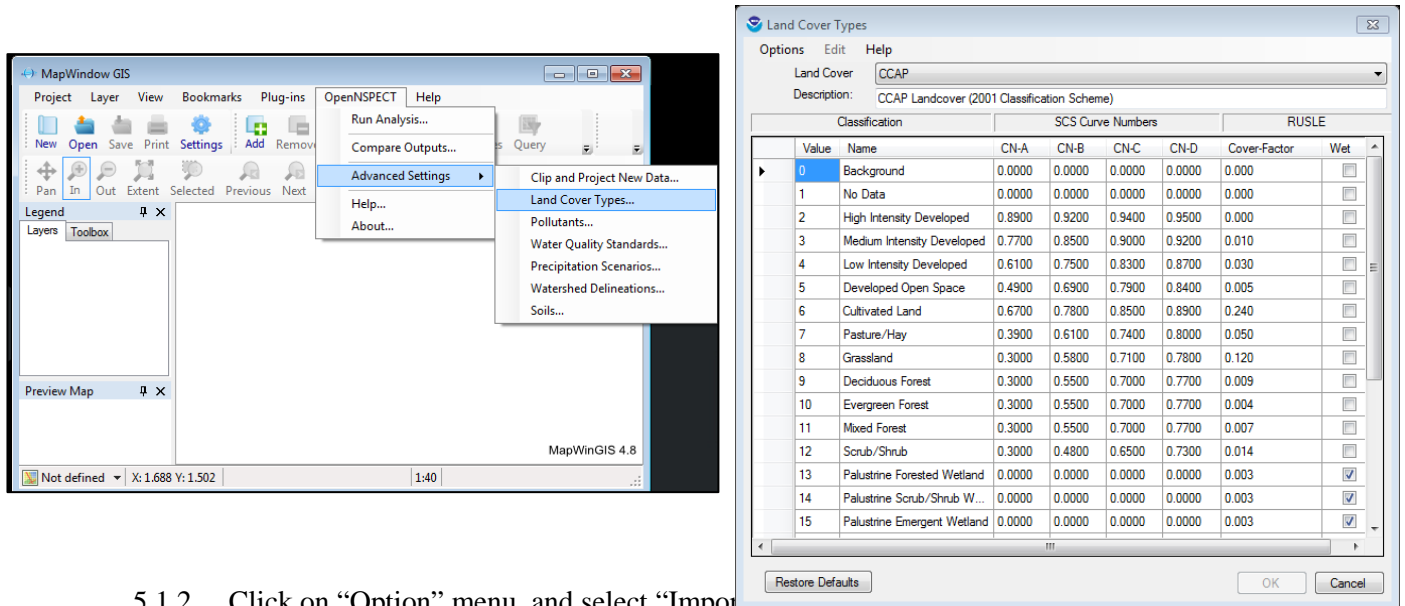
5. Generate OpenNSPECT Derivative information from the Input Data

Before we can run the model, we need to generate the derivative information for the input data.

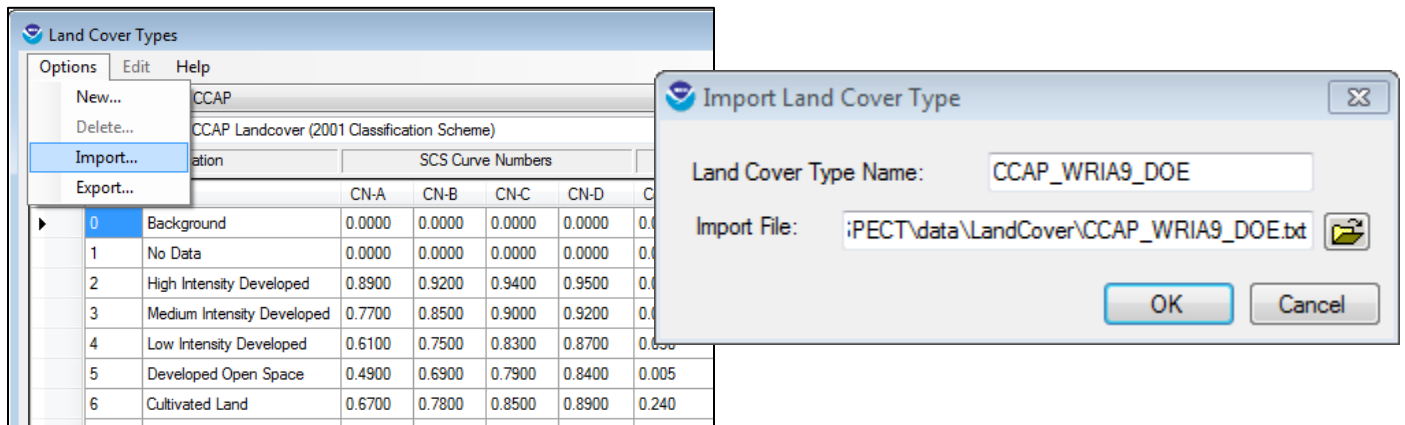
5.1. Land Cover Types

The land cover data is the basis data of OpenNSPECT's functionality. It is used to estimate pollutant values by applying coefficients of each land cover class for each pollutant. OpenNSPECT already defined land cover types for CCAP 2001 and NLCD2001_2006 using in NOAA project in Hawaii. We already prepared the land cover type table for WRIA9 in the Canvas (CCAP_WRIA9_DOE.txt). Now, we will import a land cover type txt file of WRIA9 for using in this assignment.

5.1.1. Click on OpenNSPECT menu → Advanced Setting → Land Cover Types



5.1.2. Click on “Option” menu, and select “Import...” the Land Cover Type Name and browse to select “CCAP_WRIA9_DOE.txt” (on Assignment A Data folder on Moodle) to be your import file. Click “OK”.



5.1.3. After you finished importing land cover type, at Land Cover Type window, click on “Land Cover:” pulled down menu; you will see “CCAP_WRIA9_DOE” has been added to be one of land cover type of OpenNSPECT. Then, close the Land Cover Types window.

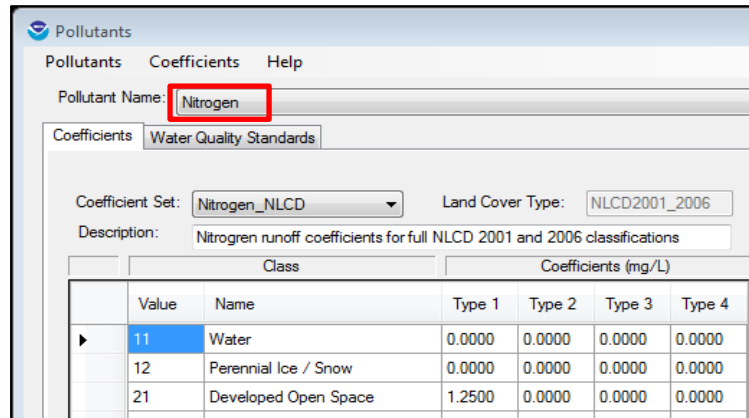
5.2. Pollutants

We will import a new coefficient set of total nitrogen for land cover types of WRIA9.

The coefficient table provides you the average concentration of the selected pollutant that is released by the identified land cover.

5.2.1. Click on “OpenNSPECT” main menu → Advanced Setting → Pollutants

5.2.2. “Pollutants” will show up, then at the “Pollutant Name:” change from “Lead” to “Nitrogen”



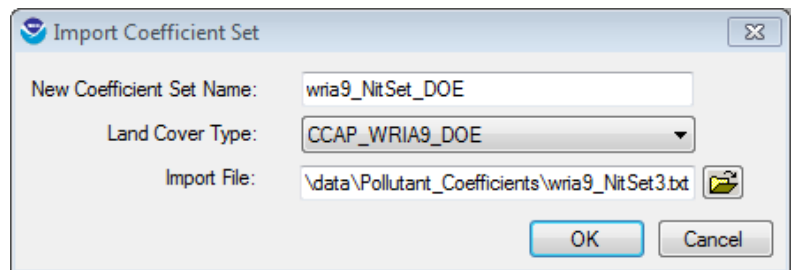
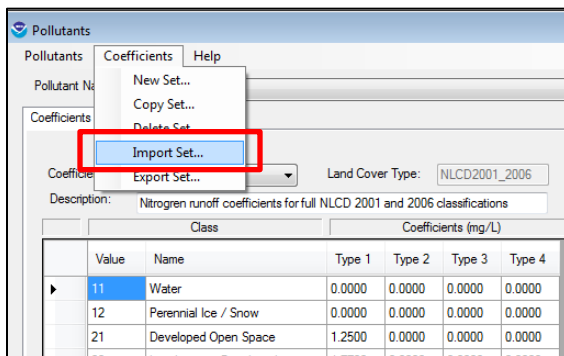
5.2.3. Click on “Coefficients” on the menu bar of the Pollutants window and select “Import Set”

5.2.4. On the “Import Coefficient Set” window, set it as the following:

New Coefficient Set Name: **wria9_NitSet_DOE**

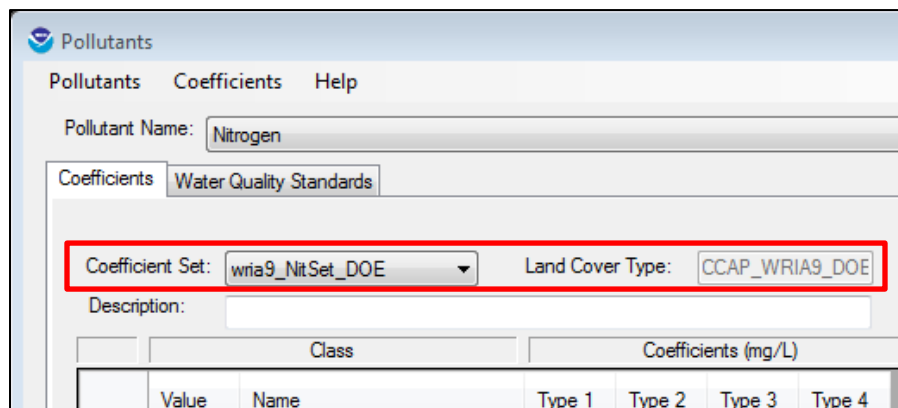
Land Cover Type: select **CCAP_WRIA9_DOE**

Import file: brown to file **wria9_nitSet3.txt** (from Canvas)



5.2.5. Then, click “OK”

5.2.6. Now you will see that, the **wria9_NitSet_DOE** has been added to be one of the Coefficient Set of Nitrogen as you can see from the figure below. The, close the “Pollutants” window



5.3. Precipitation Scenarios

The precipitation or rainfall data is used for runoff component of OpenNSPECT. For this assignment we will use average annual rainfall year 2011 in WRIA9. The data is on the assignment A folder on the Canvas website. Now, we will add this rainfall data to OpenNSPECT.

5.3.1. Click on “OpenNSPECT” main menu → Advanced Setting → Precipitation Scenarios

5.3.2. On the “Precipitation Scenarios”, click on “Option” → “New”

5.3.3. Set the “New Precipitation Scenario” window as the following:

Scenario: **Annual Rainfall WRIA9**

Description: **Annual Rainfall WRIA9**

Precipitation Grid: brown to file “wria9_ppt_bg_cenNAD1983.tif”

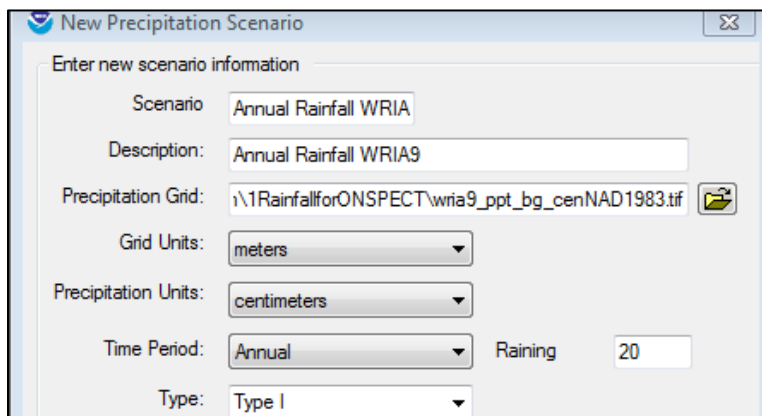
(from assignment A folder on the Canvas website)

Grid Units: **meters**

Precipitation Units: **centimeters**

Time Period: **Annual** Raining: **20**

Type: **Type I**



5.3.4. Click “OK”. Then, there is a “Record Added” window pop up, this shows that you have successfully added rainfall data on OpenNSPECT, click OK. You can see that “Annual Rainfall WRIA9” has been added to Precipitation Scenario window. Now, close this window.

5.4. Watershed Delineations

OpenNSPECT will use DEM data to generate flow direction and flow accumulation grids and delineate watershed area. The DEM data is on the Canvas website.

5.4.1. Click on “OpenNSPECT” main menu → Advanced Setting → Watershed Delineations

5.4.2. Now click on “Option” → “Create from a DEM”

5.4.3. Set the “Create New Watershed Delineation” window as the following:

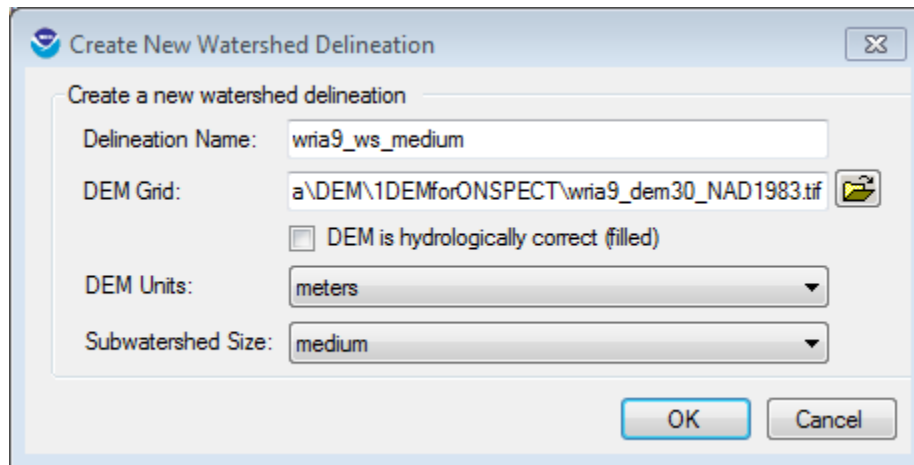
Delineation Name: **wria9_ws_medium**

DEM Grid: brown to **wria9_dem30_NAD1983.tif** (from assignment A folder data from Canvas website)

Unchecked at “DEM is hydrologically correct (filled)”

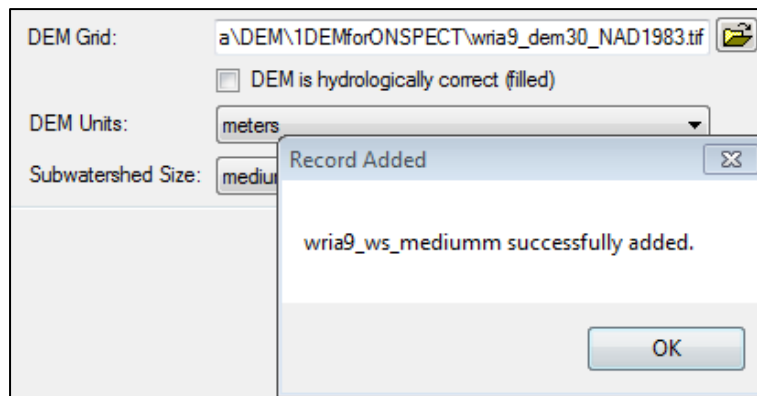
DEM Units: **meters**

Subwatershed Size: **medium**



5.4.4. Click “OK”.

5.4.5. After it done, this dialog box will show up to indicate that you have successfully generated wria9_ws_medium to OpenNSPECT.



5.4.6. Click “OK” and then close the “Watershed Delineations” window.

5.5. Soils

Soils data are used to estimate runoff and sediment loads. Soils data will provide parameters hydrologic soils group, which is a measure of how permeable the soils are. Soil data also provide K-factor parameter, which is a measure of how erodible the soils are. The soils data is on the assignment A folder on the Canvas website.

5.5.1. Click on “OpenNSPECT” main menu → Advanced Setting → Soils

5.5.2. Now click on “Option” → “New”

5.5.3. Set the “Soils Setup” window as the following:

Name: **wria9_soils**

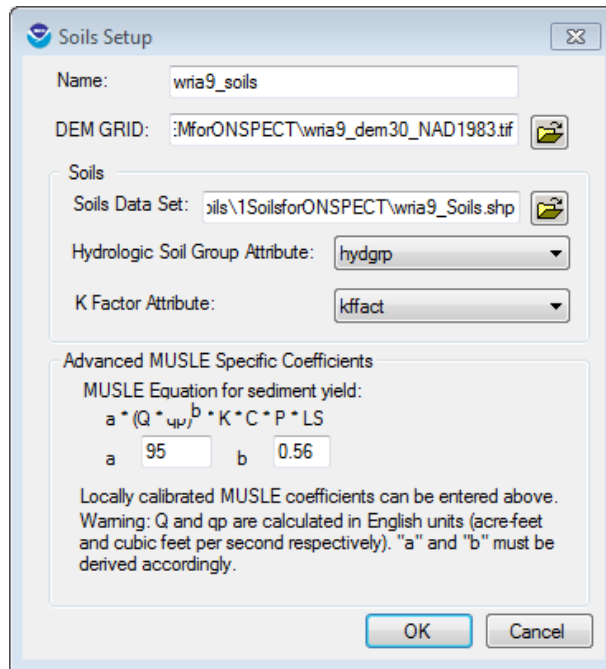
DEM GRIS: brown to “**wria9_dem30_NAD1983.tif** (from assignment A folder data from Canvas website)

Soils Data Set: brown to “**wria9_Soils_NAD1983.shp**” (from assignment a folder data from Canvas website)

Hydrological Soil Group Attribute: **hydgp**

K Factor Attribute: kffact

*leave “Advanced MUSLE specific Coefficients” as default, and then click “OK”. It will take a bit of time to finish this process.



5.5.4. Once it done, you will see that “wria9_soils” is added to the “Soils” window. Click “OK” to close “Soils” window.

Now, we finished the process of Generate OpenNSPECT Derivative information from the Input Data. Next, we will work on running OpenNSPECT.

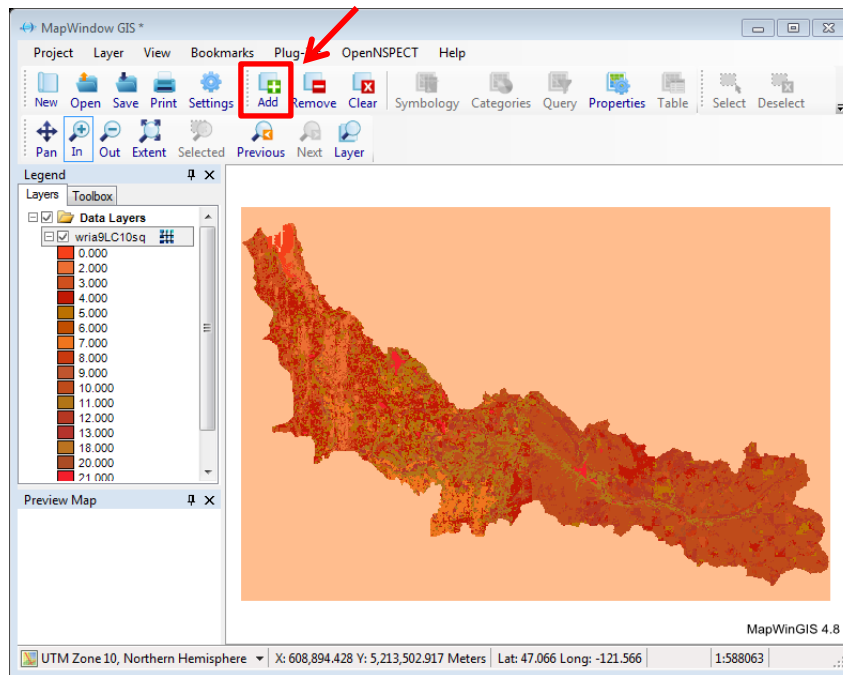
6. Running an Analysis with OpenNSPECT

We have set all preprocessing data for OpenNSPECT. Now we will use those data to run the model to estimate runoff volume, pollutant loads, and concentrations. OpenNSPECT uses DEM to calculate flow direction and flow accumulation throughout WRIA9. Land cover, precipitation, soils data area processed to estimate runoff volume. Pollutant concentrations are estimated using coefficients that characterize the contribution of each land cover class to the generally pollutants load.

6.1. Setting up a Project

Before you will run analysis model, you should create a folder named “output” and in the “output” folder create four subfolders named “y10sq”, “y40sq”, “y40mg”, and “y40ug”. You will put your results from running the model in these folders based on your results. In this assignment, you will put your result analysis in the output subfolder “y10sq”. Now we will start to set up a project and run the model.

6.1.1. At the MapWindow GIS program, click button “Add Layer” , navigate to select and open land cover file “wria9LC10sq.tif” (from Canvas).



6.1.2. Click on “OpenNSPECT” main menu bar and select “Run Analysis”.

6.1.3. Set the “OpenNSPECT” run analysis window as the following:

Name: **wria9_y10sq**

Grid: **wria9LC10sq**

Type: **CCAP_WRIA9_DOE**

Watershed Delineation: **wria9_ws_medium**

Precipitation Scenario: **Annual Rainfall WRIA9**

Hydrologic Soils Data Set: **wria9_soils**

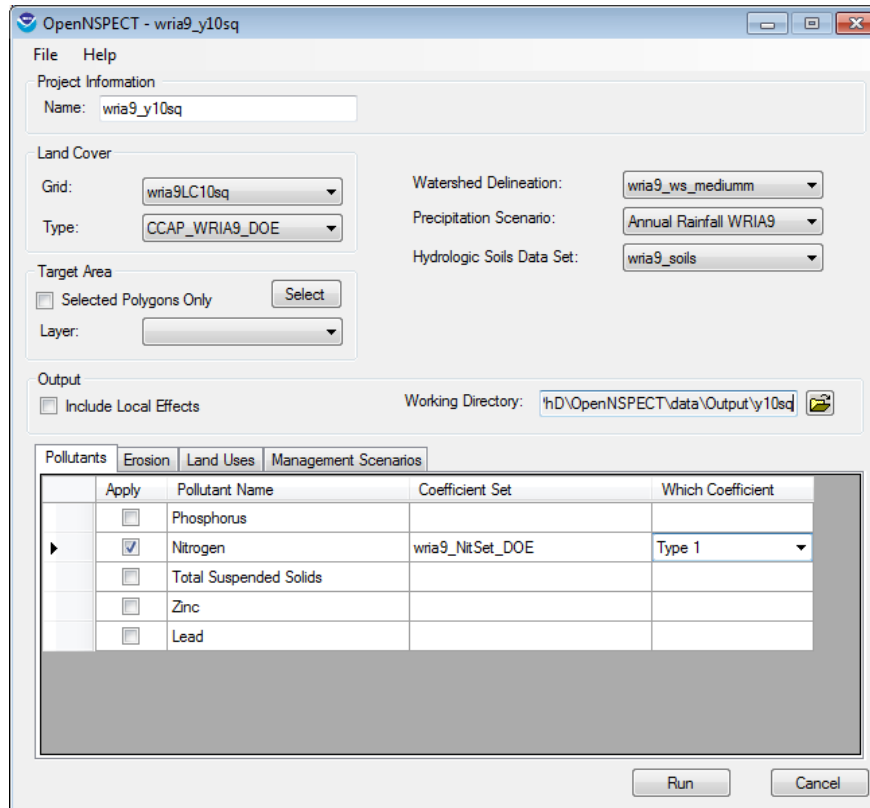
Working Directory: (navigate to your output subfolder) “**y10sq**”

Target Area: leave as default (don’t put anything in it)

Output: leave as default (unchecked Include Local Effects)

Pollutant tab:

- on the Apply column, check on a box next to Nitrogen,
- on the Nitrogen row and *Coefficient* column, click on the table box and select “wria9_NitSet_DOE”
- on the Nitrogen row and *Which Coefficient* column, click on the table box and select “Type 1”



6.1.4. Click “Run”. Then, it will ask you to save a project file name “wria9_y10sq”, click “Save”, and then the model will run analysis. It will take a little bit of time. After running analysis done, all the result will be added to MapWindowGIS window.

6.1.5. Do the same step 6.1.1, but change the land use file to “wria9LC40sq”. Do the same step 6.1.2 and change name to **wria9_y40sq**, change Grid to: **wria9LC40sq**, and change Working Directory to: (navigate to your output subfolder) “**y40sq**”.

Deliverables:

1. Adopt a stakeholder perspective. What is your stakeholder perspective (role)?

Answer:

2. Describe the differences between results of total nitrogen concentration of year 2010 and 2040.

Answer:

3. From your perspective, if you have a chance to improve OpenNSPECT, what is (are) the other input parameter(s) that should be included in this model? Why?

Answer:

4. What do you think the level of accuracy of the model should be when used by decision makers?

Answer:

Evaluation and Change Modeling

Assignment Data: Assignment B Data folder on Canvas

Deliverables: Please see detailed instructions at the end of this assignment.

Learning Objectives:

- Understand how to evaluate model results with water quality standard based stakeholder perspectives
- Understand and practice scenario modeling within the geodesign framework using a combination of software tools

Introduction

In this assignment, we will practice evaluation model and change modeling. We will investigate results from OpenNSPECT and brainstorm among concerns then provide feedback. After we evaluate the result from assignment A, we will continue with change modeling. We will create three alternative land use policies for change modeling. Public stakeholder can apply experiences and knowledge through land use modeling.

1. Evaluation Modeling


The results from OpenNSPECT that you just ran from assignment A will be evaluated with the water quality standard. In assignment A, we ran the model to get the value of total nitrogen (mg/L). We will use the result to compare with water quality standard from US EPA.

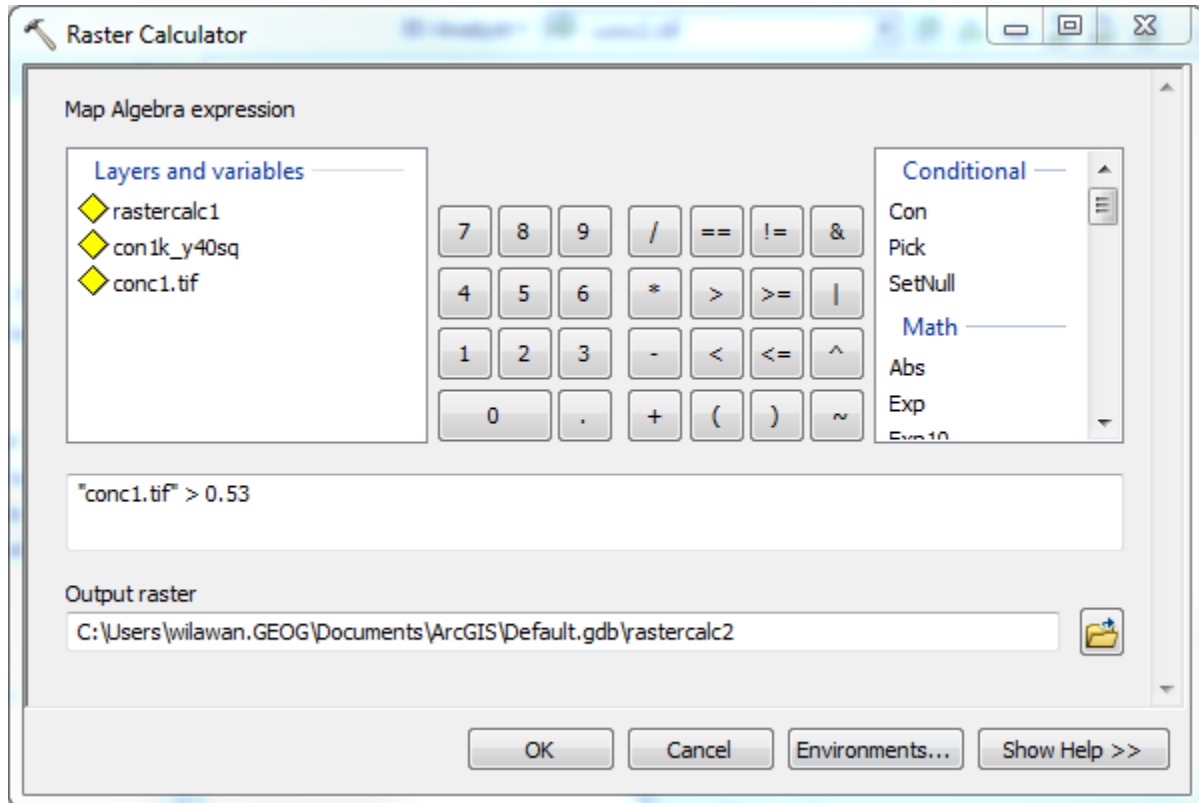
US EPA developed the National Strategy for the Development of Regional Nutrient Criteria (National Strategy), which was created for four types of waters including lakes and reservoirs, rivers and streams, estuaries and coastal waters, and wetlands. Those criteria include total phosphorus, total nitrogen, chlorophyll *a*, and turbidity. For our assignment, we will use EPA's nutrient criteria for "Rivers and Streams in Nutrient Ecoregion II". Ecoregion II is called "Western Forested Mountains" areas including most of the great mountain ranges that are located in the western US. We will use the total nitrogen from the sub-ecoregion # 2 (Puget Lowland) which represents the areas of WRIA9. The range standard of total nitrogen in Puget lowland is 0.0 – 0.53 mg/L. This criterion is to represent conditions of surface water that are minimally impacted by human activities and thus protect against the adverse effects of nutrient to cause eutrophication (<http://www2.epa.gov/sites/production/files/documents/rivers2.pdf>) (<http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm>).

1.1 Compare your result of total nitrogen (mg/L) with the EPA's standard

1.1.1 Open ArcMap and add your result of total nitrogen concentration (mg/L).

This file is named “conc1.tif” and it should be in your subfolder “y10sq” within the output folder that you created for assignment A.

- 1.1.2 Open Arc Toolbox window  and click on Spatial Analyst Tools → Map Algebra → Raster Calculator
- 1.1.3 On the Raster Calculator window, double click on “conc1.tif” and click on “>” and then type “0.53”, then your expression will be like this below picture, and you can save this output to your folder. Then click OK



- 1.1.4 Once Raster Calculator running is completed, the new result will show at your ArcMap. Value 1 represents the areas that have total nitrogen’s concentration more than 0.53 mg/L and value 0 represents the areas that have total nitrogen’s concentration less than or equal 0.53 mg/L.
- 1.1.5 Now you can get an idea of areas that have total nitrogen more than the EPA’s standard are located.
- 1.1.6 Do the same with the Raster Calculator tool for total nitrogen concentration year 2040.

Deliverables 1:

1. Describe the result of your total nitrogen concentration comparing with EPA's standard in both year 2010 and 2040. How are year 2010 and 2040 different comparing with EPA's standard?

Answer:

2. From your stakeholder perspective, what could help you with the evaluation process of total nitrogen concentration? What kind of experience?

Answer:

2. Change Modeling

Land Use/Land Cover Change Modeling with Envision

Land use / land cover is one of the main influences on quantity and quality of nonpoint source (NPS) pollution⁴. Different types of land use/cover and how they contribute to surface water runoff underpins the potential impacts of NPS pollution. Consequently, changes in land use/cover often affect water quality and ecological resources depending on the type of change. This means that land change policies can be designed, whether explicit or not, to influence water quality. In order to understand how current and future land use/cover contribute to and affect NSP, we can employ land use policy and develop scenarios based on those policies as a basis for estimation.

Envision, an agent-based land use model, can be used to estimate land use change by establishing a current and future land use scenarios. As per the Envision website, Envision is a GIS-based tool for scenario-based community and regional planning and environmental assessments. It is a spatially- and temporally-explicit alternative futures analysis model, developed by researchers at the Oregon State University. More information about Envision is available at <http://envision.bioe.orst.edu>. The general structure of Envision uses several elements to compute landscape change, including: Actors, Policies, Landscape, Autonomous Change Process, and Landscape Evaluations (See below Figure 1).

⁴ At US EPA see <http://water.epa.gov/polwaste/nps/index.cfm>

At WA Dept of Ecology see <http://www.ecy.wa.gov/programs/wq/nonpoint/sources.html>

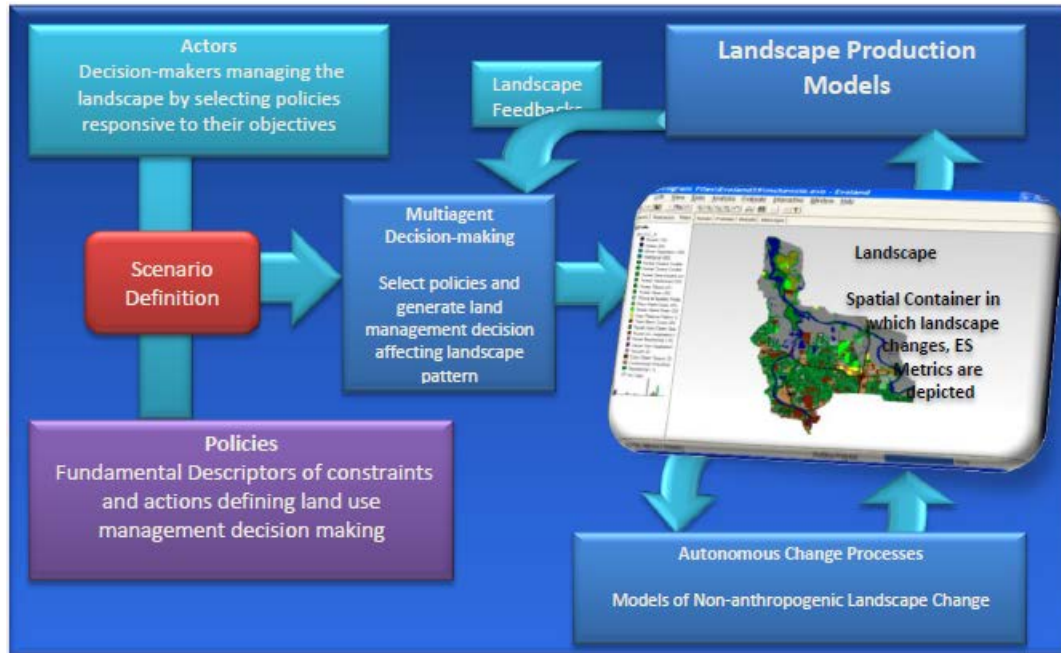


Figure 1: Envision's Conceptual Framework, p. 6 from http://envision.bioe.orst.edu/StudyAreas/PugetSound/PSNERP_Final_Report.pdf

Several specific tasks are required to develop an Envision application for a specific location and to meet alternative future needs, including: 1) define goals, 2) define policies, 3) define scenarios, 4) generate and populate coverage with relevant attributes, 5) run scenarios, and 6) analyze results. A multi-agent-based modeling approach of Envision contains a robust capacity for determining alternative management strategies and scenarios, integrating a variety of landscape change processes, and developing maps of alternative landscape trajectories.

Envisioning Puget Sound Alternative Futures

Oregon State University, with the support from the Washington Department of Fish and Wildlife and in support of the Puget Sound Nearshore Ecosystem Restoration Project, completed an analysis of alternative future regional trajectories of landscape change for the Puget Sound region in 2009. This effort developed three scenarios of change: 1) Status Quo, reflecting a continuation of current trends in the region; 2) Managed Growth, reflecting the adoption of an aggressive set of land use management policies focusing on protecting and restoring ecosystem functions and concentrating growth within Urban Growth Areas (UGA) and near regional growth centers; and 3) Unmanaged Growth, reflecting a relaxation of land use restrictions with limited protection of ecosystem functions.

Analyses assumed a fixed population growth rate across all three scenarios, defined by the Washington Office of Financial Management county level growth estimates. Scenarios were generated using Envision. The model accepts input as a vector-based representation of the landscape and associated datasets describing relevant landscape characteristics, various processes influencing landscape change, and a set of *policies*, or decision alternatives, which reflect

scenario-specific land management alternatives (more information at http://envision.bioe.orst.edu/StudyAreas/PugetSound/PSNERP_Final_Report.pdf).

Three scenarios were developed for the study: 1) **Status Quo** (SQ), 2) **Managed Growth** (SG), and 3) **Unconstrained Growth** (UG). Primary characteristics of each scenario are defined below.

Scenario Quality	Status Quo (SQ)	Managed Growth (MG)	Unconstrained Growth (UG)
Population Allocation	Maintain existing allocation distributions	Greater allocation to UGA's; greater emphasis on concentrating growth around Regional Growth Centers	Greater allocation to areas outside UGA's; less emphasis on concentrating growth around Regional Growth Centers
Urban Growth Pattern	Maintain existing development pattern, mix of densities, uses	Emphasize higher densities; mix of residential/commercial/industrial; primarily urban form in residential development; floodplain avoidance	Emphasize commercial/industrial; lower residential densities, primarily suburban form in residential development
Rural Growth Pattern	Maintain existing development pattern, mix of densities, uses	Resource lands protected: Where conversion occurs, growth concentrated near existing density, away from resource uses, sensitive habitats, viewsheds	Distribute growth relatively uniformly, without consideration of resource uses, sensitive habitats
Nearshore /Coastline Development	Maintain existing development pattern, mix of uses	Restrict development in nearshore areas, particularly in areas near sensitive lands, certain shoreform types, away from wetlands, sensitive lands, unstable areas, viewsheds	Unrestricted development in nearshore areas
Shoreline Modifications	Maintain existing relationship between modification amounts/densities, population densities	Reduce amounts/densities of nearshore modifications relative to existing conditions	Increase amounts/densities of nearshore modifications relative to existing conditions
Sensitive Areas/Open Space	Maintain moderate level of protection of wetlands, some restoration of historic wetlands; Moderate level of new park/open spaces	High level of protection of existing, undeveloped historic wetlands; aggressive restoration of historic wetlands, protections of sites with high conservation/restoration potential; Aggressive levels of park/open space acquisition, both within and outside UGA's	Low level of wetlands protection; no restoration of historic wetlands; no new parks/open space

(Bolte, 2009. Envision Puget Sound Scenarios.

http://envision.bioe.orst.edu/StudyAreas/PugetSound/PSNERP_Final_Report.pdf)

The results from this project are provided in shape files (vector data) in three scenario policies (SQ, MG, and GT) for the years 2010, 2020, 2030, 2040, 2050, and 2060. In this assignment, we will use these shapefiles years **2010** and **2040** as the basis for our scenario analysis.

Analyzing Scenarios

Importing the results from Envision for OpenNSPECT, we extract the data for WRIA9 area and convert them from vector to raster data. These data are prepared and can be downloaded from the Canvas including **wria9LC40mg** and **wria9LC40ug**. These landuse data from Envision model have been divided into several categories. A detailed description of each category used for the field LULC_B can be found at:

http://envision.bioe.orst.edu/StudyAreas/PugetSound/FieldInfo/PS_FieldInfo.html#LULC_B

To use OpenNSPECT to calculate the contribution of each land use to the amount of total nitrogen to WRIA9, we need to reclassify these land use categories to CCAP. A detailed description of CCAP can be founded at: http://www.csc.noaa.gov/digitalcoast/_pdf/ccap_class_scheme.pdf

Now these land use will be reclassified categories from LULC_B to CCAP using “Reclassify” tool form Arc Toolbox. The table below shows land use code that will be changed from LULC_B to CCAP. For example, Barren land has a value of 1 in the LULC_B code, so it should be reclassified to be a new code “20” in the new classification scheme. Because of the limited time that we have for doing these assignments, these two land use files (**wria9LC40mg** and **wria9LC40ug**) have been changed codes for you already. You can download from the Canvas. Add land use data **wria9LC40mg** and **wria9LC40ug** to ArcMap. All these raster data will be used in the next assignment.

ENVISION (shapefile) model's own code		OpenNSPECT (raster) classification follow CCAP	
LULC_B	Label	Value	Class_Name
1	Barren Land	20	Bare Land
2	Cultivated Crops	6	Cultivated Land
3	Deciduous Forest	9	Deciduous Forest
4	Developed, High Intensity	2	High Intensity Developed
5	Developed, LowIntensity	4	Low Intensity Developed
6	Developed, Medium Intensity	3	Medium Intensity Developed
7	Developed, Open Space	5	Developed Open Space
8	Emergent Herbaceous Wetland	18	Estuarine Emergent Wetland
9	Evergreen Forest	10	Evergreen Forest
10	Hay/Pasture	7	Pasture/Hay
11	Herbaceous	8	Grassland
12	Mixed Forest	11	Mixed Forest
13	Open Water	21	Water
14	Snow/Ice	25	Snow/Ice
15	Shrub/Scrub	12	Scrub/Shrub
16	Woody Wetlands	13	Palustrine Forested Wetland

Deliverables:

1. From your perspective, what land use scenarios you will select to represent your land use policy? Why?

Answer:

2. What major changes are foreseen for the study area that should be led to non- point source pollution?

Answer:

3. By what actions might the current representation of the NPS pollution be altered: what, where, and when?

Answer:

4. From your perspective, what are policies that you will alter (add/delete/adjust) from the table of three scenarios land use practice (page 5 of this document), which will support you for water quality management?

Answer:

5. From your perspective, what do you think you could help to accurate land use data?

Answer:

Impact Modeling

Assignment Data: Assignment C Data Folder on Canvas.

Deliverables: Please see detailed instructions at the end of each Part in this assignment.

Learning Objectives:

- Understand and practice Impact modeling within the geodesign framework
- Understand how to compare results from different land use scenario data using OpenNSPECT as the basis of impact modeling
- Calculate the amount of total nitrogen concentration based on different land use types

Introduction: Impact Modeling using OpenNSPECT

Change in land use/ land cover contribute to surface water runoff and Nonpoint Source (NPS) pollution, which eventually affects water quality and ecological resources. In Assignment B, we have examined the three scenarios in land use management: Status Quo (SQ), Managed Growth (MG), and Unconstrained Growth (UG). In this assignment, we will learn how to use the OpenNSPECT tool to investigate the impact of NPS pollution under these three land use scenarios. We will use the four land use raster files (**wria9LC10mg**, **wria9LC10ug**, **wria9LC40mg**, and **wria9LC40ug**) that are provided for this assignment to calculate the total nitrogen concentration (mg/L) loading for each of the four scenarios.

1. Modeling the Impact

Now, we are going to run OpenNSPECT on MapWindow using four land use scenarios: wria9LC40mg and wria9LC40ug. The processes to do this are the same as the one that we did in assignment A.

- 1.1. Open MapWindow, and click button “Add Layer”, navigate to select and open land use file “wria9LC40mg” (from Canvas).
- 1.2. Click on “OpenNSPECT” main menu bar and select “Run Analysis”.
- 1.3. Set the “OpenNSPECT” run analysis window as the following: (same as Assignment A)

Name: **wria9_y40mg**

Grid: **wria9LC40mg**

Type: **CCAP_WRIA9_DOE**

Watershed Delineation: **wria9_ws_medium**

Precipitation Scenario: **Annual Rainfall WRIA9**

Hydrologic Soils Data Set: **wria9_soils**

Working Directory: (navigate to your output subfolder) “**y40mg**”

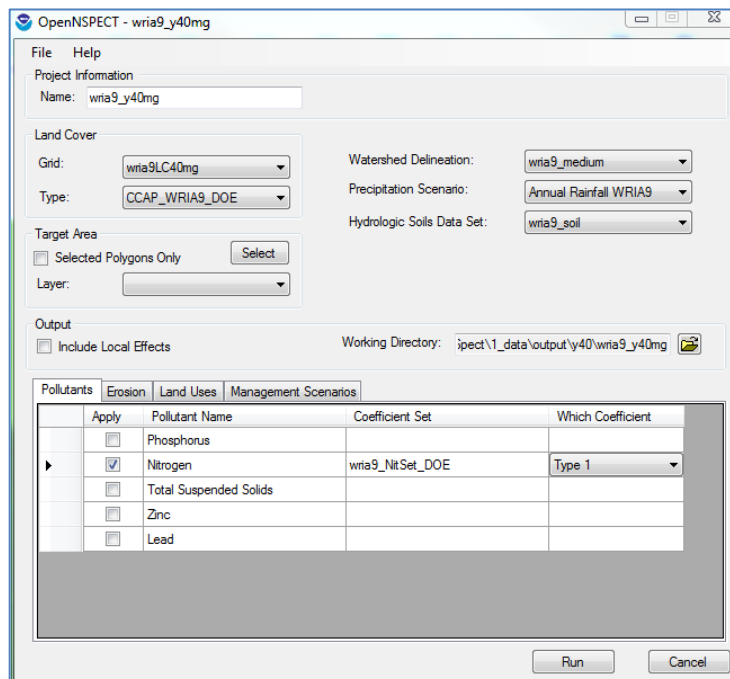
Target Area: leave as default (don't put anything in it)

Output: leave as default (unchecked Include Local Effects)

Pollutant tab:

- on the Apply column, check on a box next to Nitrogen,
- on the Nitrogen row and *Coefficient* column, click on the table box and select “wria9_NitSet_DOE”
- on the Nitrogen row and *Which Coefficient* column, click on the table box and select “Type 1”

- 1.4. Click “Run”. Then, it will ask you to save a project file name “wria9_y40mg”, click “Save”, and then the model will run analysis. It will take a little bit of time. After running analysis done, all the result will be added to MapWindowGIS window.
- 1.5. Do the same run analysis using another land use scenario (wria9LC40ug), and don’t get to change name of the project, grid, and working directory associated with land use scenario names.
- 1.6. Now you will have results of total nitrogen concentration (mg/L) from those four land use scenarios.
- 1.7. Open ArcMap, and add all results of total nitrogen concentration (mg/L) from four different land use scenarios. Those files are named “concl.tif” and they supposed to be in your subfolder “y10sq, y40sq, y40mg, and y40ug” in the output folder that you created in assignment A. At the table of content, you might need to change those names to concl.tif_y10sq, concl.tif_y40sq, concl.tif_y40mg, and concl.tif_y40ug, for example, to indicate the different resulting scenarios.
- 1.8. Now you can compare these results together and investigate the differences of results from different land use scenarios.
- 1.9. Referring to Assignment B, use “Raster Calculator” to see where the areas that have total nitrogen values excess the EPA standard are.



Deliverables:

1. Assess and compare the impacts of each change model and describe below.

Answer:

2. Are anticipated changes seen as beneficial or harmful? To whom? Are they seen as serious? Why or why not?

Answer:

3. What predictable differences might the changes of land use/ land cover cause for NPS pollution impacts on water quality?

Answer:

Decision Modeling

Assignment Data:

- Assignment D Data Folder on Canvas

Deliverables: Please see detailed instructions at the end of this assignment.

Learning Objectives:

- Gain understanding of the components of a decision model within geodesign framework
- Practice with these components in a case study setting employing multi-criteria analysis

Introduction

Each of the impact assessments reveals one aspect of how alternative scenarios result in nonpoint source pollution impacts. The alternative scenarios, the impacts associated with them, and the criteria by which choices are assessed based on those impacts will vary among individuals and groups who hold different interests, and thus stakeholder perspective. Public stakeholder groups could be involved in a decision model evaluation to express their concerns and directions for land-use practices, as well as the direction of nonpoint source pollution management. Selecting the best alternative is the responsibility of a combination of public stakeholder groups, technical specialists who provide information (like you), and policy makers that influence future development.

In assignment C, we explored the distribution and the impacts from total nitrogen the subwatershed drainage areas with impact modeling. A subwatershed is established as a decision option (also called a decision unit). In this assignment, we will learn how to develop a decision model using a multi-criteria approach to watershed improvement programming that prioritizes how we might address subwatershed cleanup of arsenic. This is an exploratory decision situation similar to what the watershed council for WRIA9 has been exploring, called a watershed investment district (WID) that is described [here](#). The WID idea was fostered by the WRIA9 forum that is described [here](#).

In this assignment, we will consider four criteria — ***total nitrogen concentration*** (*milligrams/liter*), ***eroded sediment*** (*kilogram*), ***habitat*** (*square meters*), and ***cost*** (*dollar*) — that will be used to rank and weigh the scores for each subwatershed in order to find suitable locations to implement the watershed management program. The particular decision rule we will use is called “linear weighted average”.

1. Scoring Decision Criteria

We will normalize (value-standardize) the criteria data values by assigning a rank across the range from 1 to 10, and insert this into the rank column, and then store them in tables. Keep in mind that we must rank order data in a consistent manner with regard to our problem interpretation, the nature of the data, and what we prefer less of or more of. For example, in regards to total nitrogen data, we might assign the rank number 1 to the lowest data values, and assign 10 to the maximum value of the amount of total nitrogen concentration. However, if what we want is to prefer solving a big problem, then the ranking would be the inverse, as we prefer to tackle large concentrations before we tackle low concentrations. For the cost criterion, we would prefer low costs over high costs. In this case, we might want to assign 10 to the lowest range of cost, and 1 to the highest costs because less expensive problems (holding all other criteria the same) would be preferred.

Complete the tables below by filling in your rank for each category. Note: these tables just provide a template – you can use them as is or create your own data categories for ranking based on your understanding and interpretation of the problem.

Total Nitrogen concentration (TN_mgL)	Rank (TNmgL_Rank)
0.00 – 0.10	1
0.11 – 0.20	2
0.21 – 0.30	3
0.31 – 0.40	4
0.41 – 0.50	5
0.51 – 0.60	6
0.61 – 0.70	7
0.71 – 0.80	8
0.81 – 0.90	9
0.91 – 1.00	10

Eroded Soil (SoiAc_kg)	Rank (SoiAc_rank)
0.0 – 3,000,000,000	
3,000,000,001 – 5,000,000,000	
5,000,000,001 – 7,000,000,000	
7,000,000,001 – 10,000,000,000	
10,000,000,001 – 12,000,000,000	
12,000,000,001 – 15,000,000,000	
15,000,000,001 – 18,000,000,000	
18,000,000,001 – 20,000,000,000	
20,000,000,001 – 23,000,000,000	
20,000,000,001 – 26,000,000,000	

Habitat (<i>Habi_raito</i>)	Rank (<i>Habi_Rank</i>)
0 – 0.1	
0.11 – 0.2	
0.21 – 0.3	
0.31 – 0.4	
0.41 – 0.5	
0.51 – 0.6	
0.61 – 0.7	
0.71 – 0.8	
0.81 – 0.9	
0.91 – 1.0	

Cost (<i>Cost_dol</i>)	Rank (<i>Cost_rank</i>)
0 – 100,000,000	
100,000,001 – 140,000,000	
140,000,001 – 190,000,000	
190,000,001 – 230,000,000	
230,000,001 – 270,000,000	
270,000,001 – 320,000,000	
320,000,001 – 360,000,000	
360,000,001 – 400,000,000	
400,000,001 – 450,000,000	
450,000,001 – 490,000,000	

2. Weighting Criteria

Some criteria in a decision problem are often more important than others. Therefore, after normalizing the criterion data values, we weigh the criteria to establish preference of criteria. We also normalize the weights, so the weights should sum to a convenient number, e.g. 100. For example, we may distribute our weightings as in the example below:

- Total Nitrogen concentration: 25
- Eroded Soil: 15
- Habitat: 35
- Cost: 25

The total score for these criteria is 100.

3. Assign your weight scores that sum to 100 in the table below.

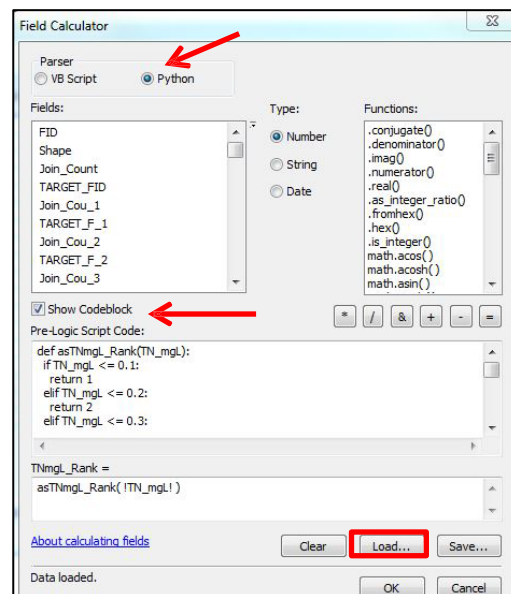
Criteria	Field name	Weight score
Total Nitrogen (mg/L)	TNmgl_Weig	
Eroded Soil (kg)	SoiAc_Weig	
Habitat (m ³)	Habi_Weig	
Cost (\$)	Cost_Weig	

Now, we will use the data provided for this assignment to calculate the total score for each subwatershed. This will help us find suitable locations for a watershed clean up and management strategy recommendation.

4. Add shape file *wria9_criteria* to your map. Open the attribute table and examine the contents. You can see that fields that represent *ranks*, *weights*, and *scores* were already created for you. You will calculate the values for these fields in the following steps.

5. Calculate the rank of total nitrogen concentration (*TNmgl_Rank*).

- On the Editor Tool, you need to click on “Start Editing” first, then open the attribute table of *wria9_criterai*, right click field *TNmgl_rank*, and select Field Calculator.
- Click the button next to Python under Parser, check the box next to Show Codeblock, and click “Load...” button to load the Python expression script named “*TNmgl_Rank.cal*” (in Canvas).



The Pre-logic Script Code looks like the script below:

```
def TNmgl_Rank(TN_mgL):
    if TN_mgL <= 0.1:
```

```

    return 1
elif TN_mgL <= 0.2:
    return 2
elif TN_mgL <= 0.3:
    return 3
elif TN_mgL <= 0.4:
    return 4
elif TN_mgL <= 0.5:
    return 5
elif TN_mgL <= 0.6:
    return 6
elif TN_mgL <= 0.7:
    return 7
elif TN_mgL <= 0.8:
    return 8
elif TN_mgL <= 0.9:
    return 9
else:
    return 10

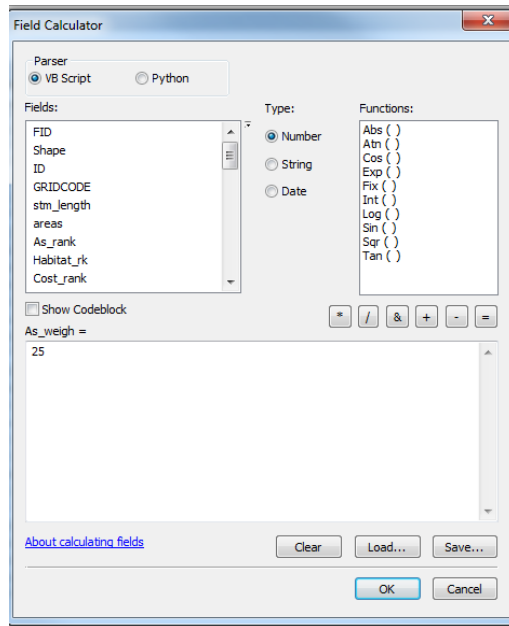
```

6. **IMPORTANT:** If you use different value ranges and assign different ranks to this criterion than those provided in the script, you need to change the values in the *if*, *elif*, and *return* statements in the script to correspond to the numbers assigned in your own tables.

7. Do the same field calculation for *other criteria* on page 2 to get their ranks (*SoiAc_Rank.cal* for *SoiAc_Rank*, *Habi_Rank_from_ratio.cal* for *Habi_Rank*, and *Cost_Rank.cal* for *Cost_Rank*). Again, make sure to adjust the data and rank values according to those in your tables if they are different from the default numbers in the Python script.

8. Calculate the weight value for each criterion.

- a. Right click field *TNmGL_Weig*, then click Field Calculator.
- b. Select VB Script under Parser, uncheck the *Show Codeblock* box, and provide the weight for criterion scores written in the table. For example, if a weight value of 25 is associated with total nitrogen concentration criterion, add 25 in the calculation box.



c. Populate weight scores for the other three criteria by using the same process.

9. Now we will calculate the total scores for all subwatersheds to evaluate a strategy for a watershed management program. Sum the four weighted criteria scores to compute a total score for each subwatershed.

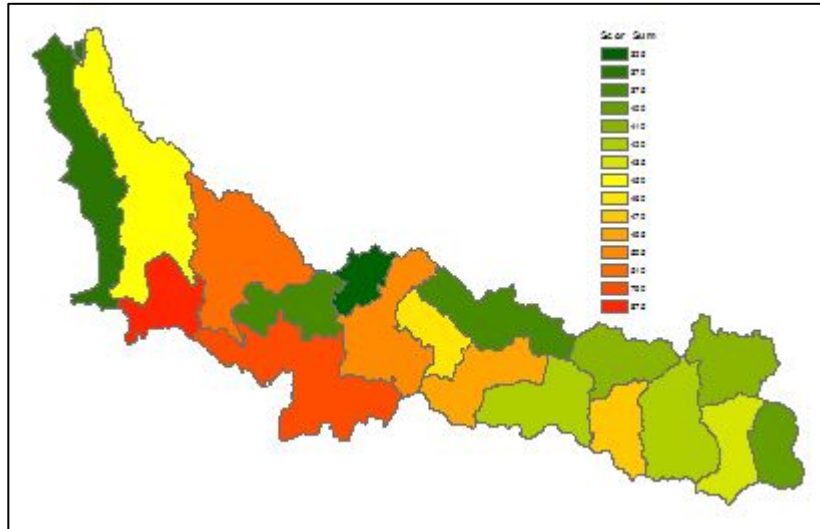
- a. Right click field *Scor_Sum* Field Calculator.
- b. Select VBscript under Parser, and copy and paste the formula below in the expression box:

$$([TNmgL_Rank] * [TNmgL_Weig]) + ([SoiAc_Rank] * [SoiAc_Weig]) + ([Habi_Rank] * [Habi_Weig]) + ([Cost_Rank] * [Cost_Weig])$$

10. Now we will show the distribution of total scores across the subwatersheds.

- a. Right click *wira9_criteria* in the TOC. Select Properties to open the Layer Properties window.
- b. Click Symbology tab. Under Categories, click Unique values.
- c. Choose *Scor_Sum* for the Fields Value, and click “Add All Values”.
- d. At the Color Ramp select color from green to red, or right click on the color ramp and unchecked the “Graphic View” and select “Condition Number”

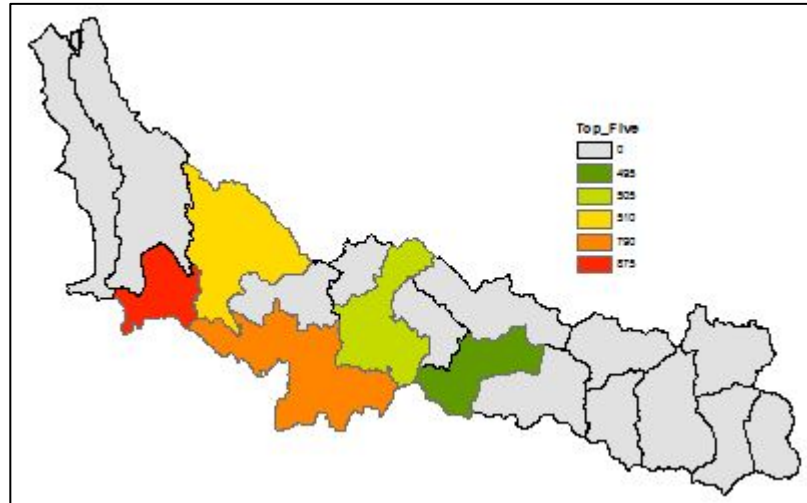
- e. Click OK. The figure below provides an example (Note: your map may be different based on the ranking and weighting scheme used).



11. Now, we want to examine the spatial distribution of the five subwatersheds that have the highest scores (again, the distribution patterns may vary based on your design).

- a. Open the attribute table of *wria9_criteria*.
- b. Add a field to the attribute table, and set up the following:
Name: *top_five*
Type: Short Integer
- c. Select the top five scores under *Scor_Sum* in the attribute table.
- d. Right click the heading of the field *top_five*, select Sort Descending.
- e. Select only top five record, and click to show selected records, then right click on the field *top_five* and select Field Calculator and use the formula in the expression box:
 $top_five = [Scor_Sum]$, then click OK

12. Now we've copied the scores of the top ten subwatersheds. We are ready to make a map showing the spatial distribution of the scores of these five subwatersheds. Choose a map type, classification method, and color ramp that you think would best represent this geographic phenomenon. The map below provides an example.



Deliverables:

1. Briefly describe the spatial patterns of the geographic phenomena represented on the map. Which subwatershed(s) is (are) the ones that are to be used to implement habitat restoration program? Why?

Answer:

2. From your perspective, what are other criteria that you think they should be included in the decision process?

Answer:

3. Sustainability development is a continuing process that encompasses three essential and inseparable dimensions of development: environmental, economic, and social. In our assignments, we have addressed environmental (arsenic concentration) and economic (cost in dollars) dimensions but not the social dimension. How would you address social dimension in the context of nonpoint source pollution as a GIS analyst, e.g., what factors and data would you use to characterize social impacts? In terms of your role, how might a social aspect be involved in nonpoint source pollution management? Please provide a short discussion to address these questions.

Answer:

Appendix G: Geodesign Role Play Plan

8:00 AM Getting Started

Discuss the problem of water quality improvement

Review stakeholder perspective for each group and have students form a small group and adopt a particular stakeholder interest. OK to move to another location in room where stakeholder perspective is shared if that is desirable.

8:30 AM Assignment A. Representation and process modeling using OpenNSPECT

Discussion questions

9:00 AM Assignment B. Evaluation and Change Modeling

Discussion questions

9:45 AM Break

10:00 AM Assignment C. Impact Modeling

Discussion questions

10:30 AM Perform Assignment D. Decision Modeling

Discussion questions

11:00AM Geodesign Modeling Review and Discussion

What was different in the OpenNSPECT versus NPSFlow modeling exercises? When would that difference matter?

What aspects of geodesign methodology seem to be the most challenging within the context of the exercise that we undertook? What if we had different software for each step? What software?

Assignment Questions

Representation and Process Modeling (Assignment A) Questions:

1. Adopt a stakeholder perspective. What is your stakeholder perspective (role)?
2. Describe the differences between results of total nitrogen concentration of year 2010 and 2040.
3. From your perspective, if you have a chance to improve OpenNSPECT, what is (are) the other input parameter(s) that should be included in this model? Why?
4. What do you think the level of accuracy of the model should be when used by decision makers?

Evaluation and Change Modeling (Assignment B) Questions:

1. From your perspective, what land use scenarios you will select to represent your land use policy? Why?

2. What major changes are foreseen for the study area that should be led to non- point source pollution?
3. By what actions might the current representation of the NPS pollution be altered: what, where, and when?
4. From your perspective, what are policies that you will alert (add/delete/adjust) from the table of three scenarios land use practice (page 5 of this document), which will support you for water quality management?
5. From your perspective, what do you think you could help to accurate land use data?

Impact Modeling (Assignment C) Questions:

1. Assess and compare the impacts of each change model and describe below.
2. Are anticipated changes seen as beneficial or harmful? To whom? Are they seen as serious? Why or why not?
3. What predictable differences might the changes of land use/ land cover cause for NPS pollution impacts on water quality?

Decision Modeling (Assignment D) Questions:

1. Briefly describe the spatial patterns of the geographic phenomena represented on the map. Which subwatershed(s) is (are) the ones that are to be used to implement habitat restoration program? Why?
2. From your perspective, what are other criteria that you think they should be included in the decision process?
3. Sustainable development is a continuing process that encompasses three essential and inseparable dimensions of development: environmental, economic, and social. In our assignments, we have addressed environmental (arsenic concentration) and economic (cost in dollars) dimensions but not the social dimension. How would you address social dimension in the context of nonpoint source pollution as a GIS analyst, e.g., what factors and data would you use to characterize social impacts? In terms of your role, how might a social aspect is incorporated into nonpoint source pollution management? Please provide a short discussion to address these questions.

Appendix H: Stakeholder Perspectives for Water Quality Improvement

The following stakeholder perspectives can help identify the connections between values/interests and criteria for water quality improvement.

The decision problem to be addressed involves land use scenario practice for water quality management and identifies a location to implement habitat restoration in WRIA9 by a Nonpoint Source Pollution Management Panel representing diverse stakeholder groups. Members of the Panel hold strong values for environmental protection and stewardship to balance with economic development – a foundational perspective for integrated resource management. Each of the stakeholder groups promotes certain community values. The values are shared by some groups, but other values might be in opposition for other groups. The panel perspective will eventually ‘meld’ a number of perspectives.

Regulatory/Resource Agency Perspective

Representatives of the regulatory/resource agencies generally show a strong concern for protecting the environment and preventing pollution in the river as per their respective agency mandates and missions. A number of the agencies believe that controlling pollution should be the first priority for the panel. Some believe the best approach is to balance among potentially conflicting needs, striving for the best return on investment and using the panel's work as a catalyst for more work later. Two evaluation criteria derive directly from this perspective including minimize nonpoint source pollution from the river, and selecting the suitable sites for habitat restoration to mitigate water quality problem in the area.

Elected Official Perspective

Elected officials show a strong appreciation for the environment and its importance to people and the region's quality of life. Clean water is one of the important values expressed by the elected officials, with one official citing the importance of clean water for children. Correcting environmental problems and the sources of those problems is also an important value as long as doing so doesn't create other problems. In fact, the work of the panel is seen as an opportunity to look for creative solutions, some of which may solve multiple problems. Gaining the most long-term value for the money spent is another strong value of the elected officials. The least expensive parcels are those that are vacant as established by the County assessor. Individual elected officials show interest in developing public safety and clean water.

Engineering Consulting/Academic Perspective

Consulting/academic individuals focus to a great degree on planning ahead, picking priorities and choosing projects that help us understand the externalities caused within the community so that such problems can be avoided in the future if at all possible. Planning for the long-term is very important to avoid unforeseen problems. As a way to set priorities, the group values the use of risk assessment, with a focus on clear risks to people; maintenance of existing resources while looking for other opportunities, and the ability of projects to sustain themselves beyond the panel's work.

Environmental Group Perspective

Representatives of environmental groups feel strongly about preventing nonpoint source pollution and reducing risks to people and the environment, restoring areas to a greatly improved state, and finding ways to involve the public. An important value is pollution prevention and the protection of living things, including people. Generally, priorities should be based on reducing the greatest risks to human and environmental health. Protection of salmon is important, in part, because of its economic contribution to the region's quality of life. A public process will also help the panel establish values to use in making decisions and make implementation less difficult.

Business/Community Leader Perspective

Business and community leaders express a range of values that the panel should use in guiding its decisions. The panel should balance economic values with social values. Reasonableness and an eye to multiple uses may be important to finding a balance between potentially conflicting needs. Yet, efforts to restore the water resources, remediate land use problem areas and eliminate sources of pollution are very important to these leaders. In fact, eliminating sources of pollution is a higher priority for many of the leaders than employment opportunities. Improving public health fosters healthy employees. Public health is also important, particularly as pollution affects the quality of fish, shellfish and other edible fishes. Several leaders use the phrase, "fishable/swimmable," to summarize their definition of clean water. Spending excessive amounts of money to get infinitesimal results is not valued; yet, doing the job right the first time is valued.