Volunteer Geographic Information Reporting System: A Cross-Case Comparison

Mu-Ning Wang

A Dissertation
Submitted In Partial Fulfillment Of The
Requirements For The Degree Of

Doctor Of Philosophy

University of Washington
2015

Reading Committee:
Peter Schiess, Chair
Timothy Nyerges
Yu-Fai Leung

Program Authorized To Offer Degree:
School of Environmental and Forest Sciences

University of Washington

Abstract

Volunteer Geographic Information Reporting System: A Cross-Case Comparison

Mu-Ning Wang

Chair of the Supervisory Committee:
Peter Schiess
School of Environmental and Forest Sciences

Collaborating with volunteers to collect spatial information for environmental monitoring has been thought to be a socially-oriented mechanism for improving public participation and environmental decision-making when lacking sufficient managerial resources. Unlike general volunteer geographic information that initiates from citizen or interest groups, this research focuses on exploring projects or programs that are designed to help public land managers ease their monitoring costs. Existing research observed that a new program or management process change is most likely facing institutional and management resistance of different degrees. A conceptual framework (Volunteer Geographic Information Reporting Assessment Framework (VGI-RAF)) has been developed to assess and explore why resistance exists. To enhance management acceptance, this research structured volunteer reports based on spatial decision units

(SDUs) and structured forms.

A number of comparisons were performed, which included (a) information process efficiency, (b) database structure quality, and (c) user interface usability. To empirically analyze and compare cases, this research used a cross-case comparison research method to cultivate knowledge from existing cases due to limited research on the same topic. Results showed that VGI-RAF can depict institutional constraints, stakeholder interactions, and information needs. It provides key information for volunteer reporting system design and/or modification. Different scales (coverage) of reporting systems would require proper institutional arrangements to incorporate collected information. A data collection design should match managerial purposes with volunteer or stakeholder’s expectation. Mismatching may cause waste of managerial resources. To increase management acceptance, structuring volunteer reports based on SDUs and structured forms will ensure increased processing and search efficiency. However, because SDUs make a seamless connection between management and reports, SDUs can be used to monitor management performance and therefore may create tensions between volunteers and managers. Choice of SDUs should be well-considered in addition to information processing and political and/or managerial aspects of the VGI reporting circumstances.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Every research starts from a small idea of existing observations. This doctoral research starts from observation of failure cases and would like to contribute small but significant efforts pointing out where the obstacles are and finding a way to enhance data processing process. I was lucky to meet people from Lord Hill Park in Snohomish County that provides me the beginning of research design. Followed by Lord Hill experiences, I was lucky to meet a group of invasive reporting and trail monitoring people from the King County and the Department of Natural Resources, Washington State. Mark Boyar, Tom Cowper, Sasha Shaw, and other friends that helped to implement or test this project with me are much appreciated. In addition to field support, Professor Tim Nyerges provides physical supports to new knowledge production; Professor Tomas Hinckley is also generous to read and provide guidance whenever I need; Professor Yu-Fai Leung is always willing to provide any emergent support for research or dissertation editing; Professor Donald Miller provides critical outsider eyes to make this dissertation into better quality products. Finally, my supervisor and long-term mentor, Professor Peter Schiess, provides me a chance to discover opportunities to my personal research interests at the first. Further than that, he provides unconditional support in research obstacles, writing, and even final revising stage supports. Without numerous help from different friends, I would not be able to provide and finish this research topic myself. To all friends that help in this research, your support is the biggest effort to make this research published and finished.

Chapter 1: Introduction

An ideal situation for public land managers is to have the *best available* information for decision-making. However, defining *best available* information encounters barriers in various empirical situations. First, in a limited managerial resource situation, it is hard to provide a high quality monitoring program tracking dynamic changes in the environment, which enhances the difficulty of decision-making. Second, engaging public stakeholders for participating in environmental decision-making and day-to-day management is an emerging trend in recent decades (Hansen and Reinau 2006; Jude, Jones, Andrews, and Bateman 2006; McNie 2007; Wright, Duncan, and Lach 2010). Integrating stakeholders' input(s) (e.g., ideas, experiences, and monitoring records) with existing information broadens the diversity of inputs but is hard to implement.

To soften these barriers, utilizing voluntary crowd-sourced data entries with spatial locations provides a robust alternative to monitor environmental changes and incidents. Voluntary reports made from public stakeholders are expected to help public land managers track environmental changes (McNie 2007) and assist decision-making with limited managerial resources (Johnson and Sieber 2013). The research presented herein assesses management and institutional acceptance of using volunteer geographic information reporting (VGI-R) to assist environmental decision-making. The use of the term 'Stakeholder' within research about environmental management and decision-making refers to public stakeholder groups. Such stakeholders are impacted by environmental decisions, but are often given little opportunity to voice concerns within decision processes as described in a long lineage of research about analytic-deliberative decision making (NRC 1996). Researchers also noticed that not only has public participation sometimes been in conflict with existing bureaucratic structures, but any new paradigm (such as adaptive management, ecosystem management, volunteer geographic information, etc.) has commonly involved resistance because of fears of change (Stringer et al. 2006), risks and costs of implementation, and large conflicts with existing institutional arrangements (Walters 1997; Imperial 1999; Lee 1999; Stankey et al. 2005; Wright, Duncan, and Lach 2009).

Two approaches will be explored here. The first approach is to assess institutional resistance from government agencies. Besides the management acceptance, it is also important to increase values for information generated by public stakeholders. Hence, our second approach of this research is examining usability of structured participation inputs in (1) data collecting process, (2) database structure, and (3) interfaces.

1.1 Challenges of acquiring *best available* information

Applying *best available* information to make daily-based decisions is a challenge to all land managers who manage public lands. Acquiring *best available* information helps lands managers avoid becoming embroiled in arbitrary, capricious, or abusive lawsuits (sic) (5 U.S.C.S. § 706(2)(A)). One way to define *best available* information is to increase the degree of completeness. From this perspective, scientific information alone is not enough (Leschine et al. 2003). Practitioners' experience (Fazey et al. 2006), understandable scientific result interpretations (Wyk et al. 2008), and observations of the public are also critical information to be acquired. To process different types of input(s) (scientifically collected, experience-based, or contextual local knowledge), an information system to represent and process these shared understandings is essential (Wyk et al. 2008) in environmental management (Smith 1982; Reed 2008).

Beyond participation challenges and institutional constraints, managers in environmental agencies face a dynamic environment that changes at various spatial and temporal scales. Complex systems are used to depict such dynamic environments especially when they contain unexpected surprises, non-linear cause-effect relationships, and multiple standards within different natural regimes (Holling 1973; Holling 1978; Gunderson et al. 2008). Even with dedicated management, inappropriate temporal and spatial scales may cause irreversible changes within the current state (Steffen et al. 2006; Cash et al. 2006). Furthermore, Wyk et al. (2008) found that the decision-makers often felt overwhelmed and lacking adequate technologies to analyze and adequately organize available information. In addition to data integration, extending participation space into existing administrative process is required but not yet well-organized (Smith 1982).

1.2 Existing approaches to cope with decision-making challenges

Multi-stakeholder participation has been facilitated using a spatial-referenced interface since the early 1990's, and participatory geographic information systems (PGIS) have evolved from academic tools into empirical applications in which participatory methods are embedded into GISs to facilitate spatial decision making (Obermeyer 1998; Schlossberg and Shuford 2005; Dunn 2007) in both governmental and non-governmental organizations (NGOs) (Nyerges et. al. 1997; Obermeyer 1998). In addition, PGIS has become a tool for collecting and processing values, opinions, or observations from a diverse array of stakeholders (Jankowski and Nyerges 2001). In order to bridge the gap between public participants and professionals, Nyerges et al. (2006) suggested using structured participation to implement PGIS while softening the potential gap between professionals and the general public. Further, Nyerges et al. (2013) pointed out that the structured participation is a foundation of high-performance collaboration in spatial problem solving.

To track dynamic environments, Adaptive Management (AM) by its nature recognizes that there is no single optimal decision. Early scholars (Holling 1978; Walters 1986) suggested land managers use “experimental” strategies in the decision-making. The AM approach uses an iterative cycle to track decision performance and modify decision contents as the environment changes (Stankey et al. 2005). The most critical stage of AM is getting feedback from management decisions through monitoring (tracking) and evaluating when to modify management plans (Gibbs et al. 1999). To receive comparable tracking results, meaningful measurements and cause-effect relationships between management and the monitoring process are needed when tracking changes caused by original management decision as well as other exogenous factors.

Utilizing crowd-sourced data entries received from voluntary reporting mechanisms, called volunteer geographic information (VGI) (Goodchild 2007), have provided more robust alternatives to monitor and detect environmental changes and incidents. Using public stakeholder as “*sensors*” to capture field status should help managers track the latest environmental situations for their decision-making. At the same time, this stakeholder-generated input creates a pragmatic participation space through knowledge contribution as information for decision-making. Since the 1990s, some researchers began to extend the research field to include public participation, government setting, and environmental fields (Lee 2004; Larsen and Milakovich 2005).

Compared to traditional VGI that carries a broader definition with respect to any user-generated information such as OpenStreetMap (OSM) (Feick and Roche 2013; Goodchild 2007), this research focuses on investigating public land managers’ responses to use voluntary reports made from public stakeholders, a key component of information for their decision-making. To be more specific, this study will use *voluntary reports* to distinguish all other VGI practices. Chapter 2 provides a comprehensive review of PGIS and AM in the first two subsections (2-1 and 2-2) to foster understanding about how PGIS and AM have been utilized in environmental management.

1.3 Management resistance of new interventions

Although potential values and needs of VGI and voluntary reports are well-recognized within the existing literature (Feick and Roche 2013; Goodchild 2007; Johnson and Sieber 2013), management and institutional acceptance of using new interventions to collect useful and quality information is still questionable. Typical barriers include: (a) cost of implementation, (b) jurisdiction challenges and resource sharing, and (c) usage of non-expert data for decision-making (Johnson and Sieber 2013). These barriers point out usability issues for voluntary reports: hard to collect, use, and share voluntary inputs with information quality control. Similar resistance(s) are also found in public participation GIS literature. Ganapati (2011) found that even though over 70% of local governments use GIS to share governmental information with citizens in 2004, higher levels of participation in decision-making between a government and public stakeholders was rarely found. Sieber (2006) found that GIS with public participation purposes were used to provide great communication platforms instead of being treated as a mechanism to improve "shared rights and responsibility" with stakeholders. It appears that public participation practices have a long history of institutional resistance since the 1980s (Smith 1982).

Not only for public participation, it seems any new management or intervention, such as adaptive management and ecosystem management, face institutional resistance as well (Stringer et al. 2006). Inflexible bureaucratic structures and linear decision-making processes have been treated as obvious issues (Halbart 1993; Stankey et al. 2005). Other factors that trigger resistance include fears of change, risks and costs of success, and large conflicts with existing institutional arrangements (Walters 1997; Imperial 1999; Lee 1999; Stankey et al. 2005; Wright, Duncan, and Lach 2009). Finally, from a managerial perspective, Olsson, Folke, and Berkes (2004) pointed out that if managers did not receive direct benefits from new mechanisms or management approaches, they often do not understand a value for change.

From extant literature, it is found that institutional resistance(s) occur in diverse situations. Even though insights have been provided in various research that guide future VGI-R implementations, a conceptual framework that can help land managers inspect their VGI-R design with holistic considerations is still lacking. A conceptual framework with general dimensions is required that offers a way to unpack complex relationships between public stakeholders, voluntary reports, decision-making process, and public land managers. To further accumulate insights and findings for better generality, a conceptual framework that offers foundational dimensions for case comparison is required (Poteete and Ostrom 2008). Using this conceptual framework as a foundation, insights cultivated from existing VGI implementations can be compared and contrasted. Common patterns found from cases will increase evidence for establishing valid insights, and eventually lead to a best practice approach. Several general dimensions must be identified to construct an effective conceptual framework for this work. Our study reviews existing frameworks that focus on institution and actor (i.e., particularly stakeholder) dynamics when implementing new programs using advanced information technology (AIT) within existing institutional settings to identify a collection of general dimensions.

To provide sufficient information to develop a proper framework, subsection 2-3 of Chapter 2 reviews frameworks that characterize dynamic and complex relationships among/between actors, existing institutional decision-making processes, and information collection within the decision processes. A second criterion focuses on frameworks that treat new technology or management mechanisms as drivers to trigger social interactions (DeSanctis and Poole 1994; Campbell 1996), and bring about potential changes to existing institutions. Frameworks that include these two criteria are reviewed as a way to address fears about adopting new participatory information mechanisms (Shindler, Cheek, and Stankey 1999; Stankey et al. 2005).

1.4 Structured Participation

To increase the value of voluntary reports, this research aims to increase the formalization of voluntary reports through structuring them. It is found that structuring decision-making processes within environmental management has been used to explore and refine insights about decision-making processes (NRC 1983) in dynamic and complex environmental decision problems. Previous research has shown that humans can structure decision tasks (Simon 1979) and clarify objectives (March 1978) to enhance their ability to understand complex questions. Hence, Gregory and Keeney (2002) developed a structured decision-making methodology to split a complex decision into several elements to enable managers to avoid arbitrary decisions. This decision-making process has been applied to policy decisions and to repeat management decisions made by managers on a routine basis (Gregory et al. 2011). Structured decision-making encourages managers to decompose a complex decision into several elements to search for information and make decisions on a routine basis.

Since this research focuses on voluntary reports that provide spatial decision support for environmental decision-making, it is important to understand how to structure these reports so managers can see the value and utilize this information. Subsection 2-4 of Chapter 2 will review concepts of structuring decision-making process or data inputs. From the data perspective, subsection 2-5 of Chapter 2 will focus on enhancing data quality in data processing, , which include spatial decision units, data collection forms, database model for queries, and user interface for data collection and geo-visualization of collected information.

Chapter 3 covers the research objectives, approaches, and cases descriptions of this research. This research aims to consider one situation: *limited managerial resources to acquire updated information within the management area*. Because of limited information, incorporating voluntary reports becomes crucial to land managers in their routine decision-making. To understand management resistance of VGI-R implementations, this search builds a conceptual framework and conducts comparisons of four cases to explore the commonalities and differences among cases in Chapter 4. Following this comparison methodology, the research also explores structured participation usability from data collection, database structure, and interfaces in subsection 5-1 to 5-4 of Chapter 5. Chapter 6 discusses the results in light of the research objectives and suggests extra findings within the research process. Finally, Chapter 7 offers conclusions, provides recommended procedures to such empirical cases and notes the contributions and limitations of this research.

Chapter 2: Literature Review

2.1 Participatory Geographic Information Systems

Since mid-1990s, participatory geographic information system (PGIS) has evolved from academic practice into empirical applications that embed participatory methods into GIS for spatial decision-making (Nyerges et. al. 1997; Obermeyer 1998; Schlossberg and Shuford 2005; Dunn 2007) and participatory planning (Craig et al. 2002). Diverse PGIS applications are considered based on different degrees of participation (Arnstein 1969), duration period, and purposes (roles). Typologies of PGIS implementations are explored in the following subsection (2.1.1). Following the typologies, the second subsection (2.1.2) will compare existing empirical results based on different degrees of participation.

2.1.1 Typology of PGIS

One typology of PGIS is about the degree of participation. All PGIS projects can be grouped into three degrees of participation:

1. the lowest level from government information access,
2. the medium level of participation involves information exchange, and
3. the highest level of participation being interactive design of decision-making between public and land managers.

The lowest level of participation involves sharing government information with the public. This participation design focuses on building enhanced citizen-government relationships. The medium level of participation is information exchange. In this type of participation with PGIS, stakeholder knowledge, opinions, and/or values are collected through mapping in GIS and interpreted by researchers or experts. The ultimate goal of the highest level of participation is to create an interactive design for land managers to communicate with stakeholders. The interactive design needs to consider various aspects (Talen 2000; Nyerges and Patrick 2007), which may include the nature of information management and what mechanisms[1] are used to handle group interactions.

A second typology is the role of PGIS in the decision-making process. PGIS can be treated as a visual assistance for projects or as a decision-support aid for routine decisions. Most results from project-based PGIS are “snapshot” records. With a fixed timeframe, PGIS projects should be defined as task-oriented, with a predefined boundary, and having expected products following

[11] The corresponded system should consider the easy-to-share information, a sophisticated information processing mechanism from data collection to representation, and a facilitation and navigation process to lead people into proper decision- making process.

project completion (Green 2010; Bailey and Grossardt 2010). Such projects are typically accompanied with a grant or other funding sources. Alternatively, if PGIS would serve as a decision-support aid, embedding PGIS into existing decision-making process or management workflow would be required. However, situating a new information system (e.g., PGIS) within existing institutional arrangements may raise discomfort and resistance (Imperial 1999; Stankey et al. 2005; Wright, Duncan, and Lach 2009). Hence, it is required to consider a design with proper institutional considerations to assure sustainable operations when using PGIS as official information collection tools for decision-making (Johnson and Sieber 2013).

The third typology is about the mechanism of PGIS implementation. Two main mechanisms have been used for PGIS implementation: Human-driven PGIS (HPGIS) and Technology-driven PGIS (TPGIS). Both approaches consider facilitation as a key element of PGIS implementation[2] but in different ways. HPGIS has been implemented through traditional participatory activities (workshop, focus group, etc.) that use facilitators (Talen 2000) to coordinate and control the process. On the other hand, TPGIS simulates any possible interaction through computer systems (Jankowski et al, 2006) such as the Human-Computer-Human-Interaction (HCHI) focuses (Peng 2001; Nyerges and Patrick 2007) to interact with stakeholders. Further, structuring participation processes is suggested in Nyerges, Wilson and Ramsey (2006) with various well-known methods, such as nominal group technique, Delphi process, Technology of Participation, and citizen panel/jury. Combined with E-Government initiative, TPGIS has burgeoned in recent years (Johnson and Sieber 2013) and the use of the stakeholders' reports to fill in the gap of insufficient information resources has been thought as one way to increase the participation and decision-making performance at the same time (Goodchild 2007). These three typologies illustrate how diverse PGIS project can be. The next section will analyze the pros and cons of various empirical PGIS designs.

2.1.2. Empirical PGIS comparison

The first level of participation uses PGIS to deliver pre-defined knowledge (Wright, Duncan, and Lach 2009[3]), represent experts' planning (Jude et al. 2005), or highlight existing information (Anderson, Beazley, and Boxall 2009) for public and stakeholders. GIS has been treated as an interface and participatory method as a mechanism to serve representation purposes. Further, the second level of participation uses PGIS as a one-way interface for data collection and

[2] This design includes the ability to navigate participants with structuralize discussion content and well-prepared materials (information) to trigger expected communications for specific issues and create shared- understanding products.

[3] These researchers analyzed the cases from western Oregon in the Coastal Landscape Analysis and Modeling Study (CLAMS), which is led by scientist for professional spatial analysis and scientific findings.

information exchange. In empirical implementations, historical livelihood (Martin, Peter, and Corbett 2012), perceptions (Alagan and Aladuwaka 2012), values (landscape value mapping) (Brown and Reed 2009; Brown 2012), or stakeholders' planning projects were delineated by PGIS. In the first (shared government information) and second (information exchange) levels of participation, most PGIS implementations are project-based activities and either implementation mechanisms (HPGIS and TPGIS) are selected depending on the nature of projects[4]. Based on reviewed materials in this research, most of these PGIS projects were carried out by researchers and experts. In other words, land managers use the reports generated from experts and researchers as another source of information for decision supports rather than embedded stakeholder-generated inputs directly in their decision-making process.

To apply interactive design and achieve a higher level of participation, Jankowski et al. (2006) started their research with public information needs and issues of concerns. They built a decision support system with sufficient information for the public to participate, as well as to add the space for alternative policy contents within an urbanizing watershed using a TPGIS mechanism. The TPGIS, containing an interactive design and serving embedded decision-support aid needs, must have a robust design to serve a variety of practical needs. Recently, acquiring an enormous amount of data entries from volunteers (public stakeholders) and letting them serve as a sensor (Goodchild 2007) becomes a possible way to deal with a dynamic environment, especially when there is a lack of managerial resources (Johnson and Sieber 2013). Enabling and enhancing voluntary reporting using interactive web technology (Web 2.0) with map-embedded services is a well-documented development approach (Jankowski and Nyerges 2001; Goodchild 2007; Michanowicz et al. 2012; Johnson and Sieber 2013). For example, ParkScan[5] uses a customized web navigation design and incorporates Google Map for park incident reporting and, for practical application, connected park management with the reporting. Furthermore, a voluntary reporting mechanism based on TPGIS implementation that is capable of capturing environment dynamics in management needs (section 2.2.1) and increasing the degree of participation at the same time (section 2.2.2) will be discussed in the following sections.

[4] Lefer et al. (2008) found that using existing map services (Google Earth) provides a sophisticated map interface with less technology barriers for simple collecting tasks.

[5] ParkScan (http://parkscan.org) is a "website that allows San Franciscans to submit park observations directly to City staff". Based on the descriptions from the website, this website is designed for reporting functions for all the parks within the City of San Francisco. The website is built up from the Neighborhood Parks Council (NPC) and the City Parks Department. The NPC is a nonprofit organization that is working to increase park stewardship, accountability for park management, and securing capital investment funding.

2.2 Implement Adaptive Management through Participatory GIS

2.2.1. Adaptive management: theory to empirical studies

To facilitate efficient decision-making in a complex environment, adaptive management (AM) has undergone continual development since its inception in the 1980s. Holling (1978) and Walters (1986) have recommended applying an experimental and iterative approach in decision-making process to enhance the decision content and the ability to make adaptive modifications when needed. The system works in an iterative way: a decision is made and that decision generates feedback which is then used to either modify the decision or to leave it alone and so forth (Figure 2-1). The feedback is the key (Gibbs et al. 1999) to trigger any modification and learn-by-doing effects (Uychioco et al. 2005; Stankey et al. 2005) through the monitor, evaluate, and adjust steps (Lyons et al. 2008) mentioned in Figure 2-1.

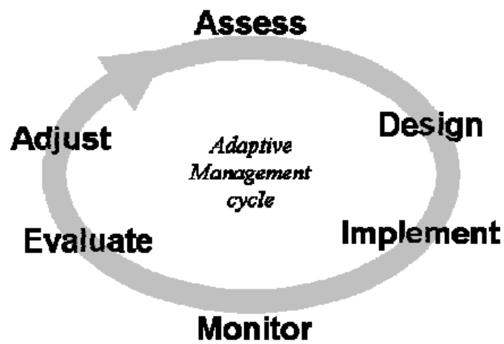


Figure 2-1 Adaptive Management (AM) cycle aims to use the iterative process to modify the decision content to enhance the management effectiveness (Marmorek et al. 2006: 6). The cycle includes Assess, Design, Implement, Monitor, Evaluate, and Adjust steps. Within the cycle, feedback is received from monitor and evaluate stages so decisions can be adjusted and enhanced

Monitoring is an essential component to create feedback for better decision-making, while being considered one of the weakest steps of the entire cycle (Moir and Block 2001) lacking consistent measurement and traceability of data over time. A poorly designed monitoring system could result in inefficient managerial decisions based on misrepresentations of monitoring results (Bearlin et al. 2002). For empirical lessons, monitored objects should be designed based on management needs with clear and measurable variables. However, the pragmatic framework and information system (databases and interfaces) for multiple stakeholder decision-making are still missing.

In addition, the current administrative process and institutions of decision-making agencies are still not well-connected (Walters 1997; Lee 1999; Stankey et al. 2005[6]). As to the conflicts

[6] These empirical studies have listed the following barriers to AM implementation: (a) well-connected information flow; (b) shared understanding and clearly defined problem; (c) ongoing awareness of and flexibility regarding the institutional and working rules compared to a conventional management approach; (d) ability to integrate social and

between experimental approach versus rigid institutions, Halbart (1993) and Stankey et al. (2005) indicate that there is a challenge to twist a current linear decision-making process into the iterative AM cycle. Second, the AM approach may shake an existing power structure (Graham and Kruger 2002; Stringer et al. 2006). Third, the fear (discomfort) of adapting a new approach (Stringer et al. 2006) needs to be minimized (Shindler et al. 1999; Stankey et al. 2005) with enhanced technology aids (Johnson 1999). Last, Olsson, Folke, and Berkes (2004) indicated that it is necessary to connect management tasks, responsible staffs (or managers) and needed information together to shorten the time between information searches to decisions (actions).

In summary, the majority of previous obstacles occurred because most information systems were implemented to collect, analyze, represent, track, and share information on

1. current socio-institutional conditions of administration and management and
2. decision-making in multiple stakeholders groups.

By integrating a participatory approach into GIS (PGIS), the majority of obstacles associated with AM should be alleviated by employing a customized participatory mechanism and the functionalities of GIS.

2.2.2. Feasibility and barriers of merging PGIS and AM

The first section (2-1) of this Chapter revealed that PGIS provides excellent capabilities for visualizing results (Talen 2000) with various purposes[7] (Abbot et al. 1998) and increases the degree of participation (Dunn 2007; Jankowski and Nyerges 2001). In addition, it may provide a possible social learning environment that increases participants from marginalized groups (Aberley and Sieber 2002). In addition to PGIS, AM also provides a consolidated framework to track information in dynamic and changing environments, and generate new knowledge (Graham and Kruger 2002) based on on-going reflections (Cundill and Fabricius 2009). Decisions and feedback from the environment should be housed in traceable records. This tracking mechanism design with an iterative process framework can increase the completeness of information for decision-making needs. Given the above, merging PGIS and AM should provide a possible solution for managers to receive best available information collected from public stakeholders.

However, PGIS is not a panacea in every situation, as there can be considerable costs to implement PGIS. Even though more than 70% of local governments use spatial information and GIS in their decision-making process, there are still difficulties with higher levels of participation

---

natural system considerations into management; and (e) awareness political influence.

[7] These aspects include such as physical volunteer inputs (labor input), local and experiential knowledge (new information feed), or providing alternative policy content design with public needs for decision-makers.

or achieving a satisfactory power sharing balance between a government and its citizens (Ganapati 2011). Also, the motivation for land managers to use PGIS is still limited due to potential power structure shifts and risks of changing institutional arrangements. Wright, Duncan, and Lach (2009) identified several barriers to adapting PGIS into conventional administration process; among the barriers are

1. fear of change,
2. lacking resources and training, and
3. social-institutional barriers.[8]

Since neither PGIS nor AM is being utilized by institutions or agencies in traditional decision-making, a framework to evaluate impacts of incorporating such new approaches is needed before their adoption.

2.3 Assessing Frameworks of Institutional Resistance and Change

As mentioned in Chapter One, a conceptual framework that can assess and inspect institutional resistance is important especially for case-by-case implementations. This section starts to review widely used and well known frameworks so common aspects of assessing institutional resistance of implementing voluntary geographic information and reports can be captured.

The Decision Situation Assessment (DSA) framework has been used to assess decision situations through a multiple granularity approach, focusing mainly on participatory group decision-making problems using GIS information (Nyerges and Jankowski 2010). Because the DSA framework has focused on similar issues like this research, it will be reviewed first. To examine if the DSA framework has included possible general aspects to systematically depict complex relationships among information, actors, and decision-making process, our second step is to discover the compatibility of DSA framework with other widely-used frameworks. In the second step, we compare the original Adaptive Structuration Theory (AST) (DeSanctis and Poole 1994) to consider whether the DSA framework can be modified or enhanced to fit this research purpose better. Following that, we use the same comparison process to examine two other well-known frameworks, the Institutional Analysis and Development (IAD) framework and the Actor-Network Theory (ANT). The IAD framework has been widely used to identify shocks and

[8] Based on North's (1990) theory, institutional changes only happen when the conditions of "changing relative price or preferences" through an "overwhelmingly incremental" process since the institution has its original "buffer" to absorb the impacts of change. Even though Stinchocombe (1990) thinks the technological innovations will bring the changes and people will seek an efficient way to use information, the public bureaucracy (government) is not like the private sector that can alter their department based on best information usage and lacks flexibility to adapt the change. Due to the difficulty of governmental implementation, Smith (1982) and Brown and Reed (2009) have suggested that understanding the current institutional space for participation is a key to success.

barriers of widely accepted management approaches that involve multiple organizations (Ostrom, Gardner, and Walker 1994). Since our research treats PGIS implementations as a new approach to enhance decision-making, unpacking barriers of acceptance from existing institutions, as treated in IAD, is critical. Finally, ANT uses non-human actors (such as technology) to understand interactions between society and technology (Martin 2000; Palmer and Kraushaar 2013). Due to the fact that the ANT has no general framework or dimensions, this research will compare the ANT as the last framework.

2.3.1 Decision Situation Assessment Framework

The decision situation assessment (DSA) framework (Nyerges and Jankowski 2010) evolved from the Enhanced AST (EAST) (Nyerges and Jankowski 1997; Jankowski and Nyerges 2001), originating from AST. The DSA framework uses a three-tier system to characterize the use of participatory GIS (PGIS) in complex decision-making processes. The first tier of DSA framework has three major decision-making components, which are convening (arrangement of participation mechanism), process, and outcome components. The second tier of DSA framework has eight constructs distributed relatively evenly among the three components, and thus further explicating each component. Three major constructs are included in the convening component: “social-institutional influence”, “group participant influence”, and “participatory GIS influence”. These three constructs unpack the participation mechanism based on institution arrangement, actors, and technology focuses. In the process component, “appropriation”, “group-process”, and “emergent influence” are three separate constructs to assess how PGIS has been embedded within group-based decision-making in technical, managerial, and social (process) interaction perspectives. Finally, the outcome construct includes: “social outcome” and “task outcome” separately to characterize social changes and effectiveness of task outcomes of using PGIS. The third tier of DSA framework has twenty-five aspects to depict finer dynamics of decision-making convening, process and outcomes components and the respective constructs. The DSA framework constituted of three tiers is presented in Fig 2-2.

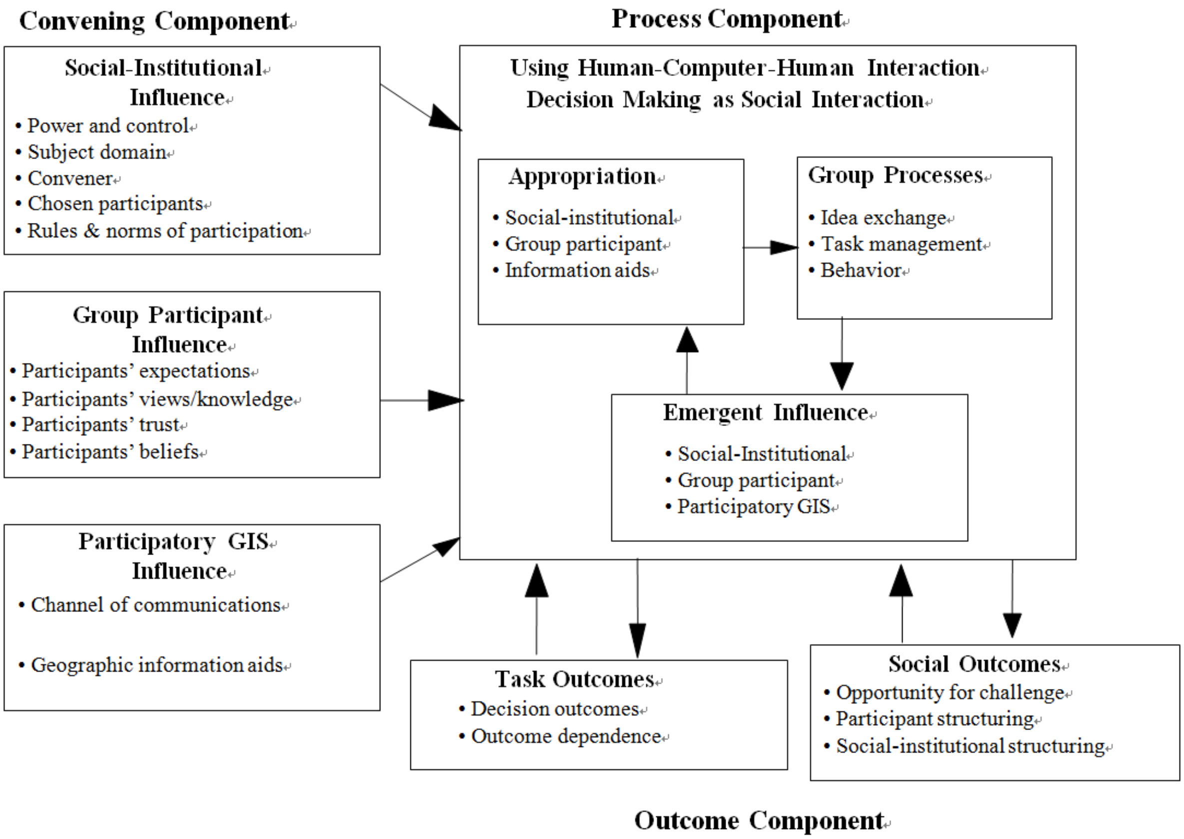


Figure 2-2. The DSA framework is composed of three tiers (three components, eight constructs, and 25 aspects) to characterize group-based GIS use in complex decision situations (Nyerges and Jankowski 2010: 83). The convening component includes influences from institutional arrangements, group interactions, and participatory GIS constructs with 11 aspects. The process component includes appropriation and emergent elements of previous constructs, as well as group process construct. There are nine aspects within these constructs. The outcome component includes task and social outcomes constructs with five aspects.

2.3.2 Compatibility of DSA to Other Frameworks

The DSA framework adopts, but extends and modifies a significant portion of AST in line with spatial-temporal decision problems. AST was proposed by DeSanctis and Poole (1994) and has been recognized as one of the earliest frameworks for observing changes when situating a new information technology into decision making activities in organizations. The AST framework focuses on how AIT is used within small-group decision-making contexts. The DSA framework shares the same purpose of using AIT within group decision-making setting (see detail comparison in table 2-1), but evolved into large group (more than 100 people) decision situations. As such, compared to the DSA framework, AST does not address public participation issues. Thus, the DSA framework summarized existing participation literature and developed another seven aspects to arrive at twenty-five aspects (Jankowski and Nyerges 2001)[9]. The additional seven aspects include (1) Power and Control, (2) Convener (person who facilitate and lead participation), (3) Participants' Trust, (4) Participants' Beliefs, (5) Channel of Communications, (6) Outcome Dependence (stability of outcome), and (7) Opportunities for Challenges.

The DSA framework has incorporated institutional considerations. To inspect whether these considerations are covered by all possible dimensions, this research compares the widely-used IAD framework with the institutional aspects found within the DSA framework. As mentioned earlier, the IAD framework provides comprehensive considerations for examining interactions among groups situated within organizations. Eleven variables are used in the IAD framework to characterize elements that affect institutional arrangements and stakeholder involvement of elements that affects actors' behavior in participation (Ostrom, Gardner, and Walker 1994: 29). All variables listed within IAD are found in similar aspects characterized by the DSA framework. The detailed comparison is presented in table 2-1.

Finally, ANT uses non-human actors (such as technology) to understand interactions between society and technology (Martin 2000; Palmer and Kraushaar 2013). Real actions and relationships among actors are key aspects of ANT (Van, Johannesson, and Ren 2012). Various studies have used ANT to examine interactions between spatial technology and organizations that use these technologies (Martin 2000; Palmer and Kraushaar 2013). Since there is no unified conceptual framework about how analysis should be carried out, various units of analysis are developed, such as "boundary object" (Star and Griesemer 1989: 393), "center of calculation" (Latour 1987), or "obligatory point of passage" (Law and Collon 1992: 46). The comparison found that there is no general framework or variables between ANT and DSA framework. These two frameworks share similar purposes and interests, but use different analysis approaches to arrive at element to element interactions.

In sum, this analysis of frameworks finds that institutional responses to either new program implementation (IAD), AIT implementation (AST), or PGIS implementation (DSA) should incorporate the following elements: (a) institutional arrangement, (b) actor relationships, (c) subject domain, and (d) technology addressing information for the participatory mechanism arrangement (convening) component. Investigating arrangements of participation mechanisms is a key of assessing institutional resistance to (new) voluntary reporting programs. To undertake case comparisons, general comparable aspects will be selected from the convening stage of the DSA framework. The detail of this VGI-RAF is described in the Chapter Four.

---

[9] DSA framework has multiple revisions since 1997. Initial framework is to draw seven other aspects and select 14 aspects from AST to make that into 21 aspects (also called Enhanced AST, EAST). Second revision adds another four useful aspects in 2001 (also called 2nd EAST, EAST2).

Table 2-1. Comparison of the commonalities of the AST and IAD frameworks with the DSA framework. DSA was compared with AST to reveal the seven new elements generated for participatory GIS usage. On the other hand, elements developed from IAD frameworks have be compared with aspects in DSA framework to evaluate the compatibility of DSA framework.

AST	DSA[10]	IAD
AIT Influences on...	Convening Components	
• Institution • Subject Domain	• Social-Institutional Influence	
	▪ *Power and Control*	Actors & Positions
	▪ Subject Domain	Actions
	▪ *Convener*	
	• Group Participants Influence	
	▪ Participants' Expectation	Potential outcome Resources delegation
	▪ *Participant's Trust*	Participants' preference
	▪ *Participant's Belief*	
	▪ Participants' view/knowledge	Capacity of Information processing & Criteria of action decision
• Existing Technology	• Participatory GIS Influence	
	▪ *Channel of Communications* ▪ Geographic Information Aid	Information
Appropriation of using AIT at...	Process Components	
• Existing institutional rules	• Appropriation	
• Group decision actions	• Group Process	
	▪ Task Management	Process of actions to outcomes
• Existing Tech. Integration	• Emergent Influences	
Outcome of using AIT	Outcome Components	
• Task outcome	• Task Outcomes	Costs and benefits related to action outcomes
	▪ *Outcome dependence*	
• Organizational changes	• Social Outcomes	
	▪ *Opportunities for Challenges*	

2.4 Structuring Decision-Making Process and Structured Participation

To handle dynamic and complex environmental decision problems, the National Research Council has worked to unpack the decision-making process since 1983. Public environmental managers were trained to use precise environmental analysis understanding the environment status but research found that few decision-making techniques and decision-relevant contents were used in environmental decision-making (Gregory and Keeney 2002; Brewer and Stern 2005). Making a decision involves not only environmental conditions but values and judgments as well. To incorporate values and judgments within existing environmental analysis, NRC (1996)

[10] Italic fonts in DSA are new developed aspects as compared to the original AST.

suggested using the two concepts, “deliberation” and “analysis”, to “forming understandings on the basis of knowledge, and reaching agreement among people, and thought this analytic-deliberative approach can help the manager make reliable decisions.” In addition, Gregory and Keeney (2002) further elaborate on the analytic-deliberative approach into structured decision making (SDM) methodology. SDM attempts to split a complex decision into several elements so managers can avoid arbitrary decisions because of limited ability to structure decision tasks (Simon 1990) and clarify objectives (March 1978). The decision-making process mentioned here is not only applied to policy decisions but applied to repeated management decisions made by managers on a routine base (Gregory et al. 2011).

Beyond SDM, incorporating stakeholder participation with spatial concerns is another focus in existing research. Developing since the mid-1990’s, participatory geographic information system (PGIS) has evolved from academic practice into empirical applications that embed participatory methods into GIS for spatial decision-making (Nyerges et al. 1997; Obermeyer 1998; Schlossberg and Shuford 2005; Dunn 2007). Although diverse PGIS applications were found based on different degrees of participation (Arnstein 1969), most data collection activities were implemented by researchers of collecting stakeholders' historical livelihood (Martin et al. 2012), perceptions (Alagan and Aladuwaka 2012), and values (landscape value mapping) (Brown and Reed 2009; Brown 2012). On the other hand, citizen-driven data collection activities are more common in citizen science and volunteered geographic information (VGI) projects. One of the earliest citizen science projects (since 1990) is the Christmas Bird Counts that brought citizen-based monitoring and voluntary data collection activities to environmental research (Silvertown 2009). Benefiting from the Web 2.0 technology, VGI projects enable citizens to generate various contents on different geographic features through web-based mapping interfaces (Elwood et al. 2012). Although citizens have the potential of becoming the largest sensor network on earth (Goodchild 2007), unfortunately, VGI does not typically include traditional measures of accuracy (Elwood et al. 2012), and the credibility of data is not judged by experts (Grira et al. 2010; John and Sieber 2013).

Using a broad definition, this research focused on programs that involve voluntary reports that provide spatial-decision support for environmental management. Conceptually, Olsson, Folke, and Berkes (2004) suggested that connecting management tasks, responsible person(s), and needed information can increase efficiency in decision-making processes. Grira et al. (2010) indicated that data collection quality is another main element affecting the functionality and quality of voluntary reports. Practically, Nyerges et al. (1997) suggested that group-based geographic information support should include information management (storage, retrieval, and organization), visual aids (analysis and representation), and group-collaboration support techniques. Since many local agencies in the United States use GIS (Ganapati 2011) for visual aids; this study focuses on structuring voluntary reports to improve information quality and usability in environmental management. The next section will focus on structured participation considerations in data collection, database structure, and visual aids.

2.5 Information system architecture: database and user interfaces

The information system design for current environmental management should apply key concepts of AM and PGIS. To incorporate a tracking function that is inherent in an AM approach, a well-designed database needs to trace any information with query functionality (Shindler et al. 1999; Stankey et al. 2005). Based on Jankowski and Nyerges (2001:1), common principles of information from group decision-making meetings should be able to:

1. formulate, frame, or assess the decision situation,
2. provide the possible impacts of different alternatives when facing multiple choice situations, and
3. enhance the ability to connect these impacts to management objectives or purposes (Sage 1991).

Based on these three listed principles, a clear physical object with spatial information should be defined to connect

1. existing GIS information,
2. voluntary reports, and
3. management task content.

This object, named spatial decision units (SDUs), can organize all types of stakeholder inputs and existing information within a fixed spatial extent based on management tasks for decision-making. In the following sections, the SDU needs to be defined and explored as a fundamental first design construct. Second, the design and connection of a database system should be addressed; making sure the traceability function (ability to query and trace stakeholder inputs and management tasks) is prepared in the information system.

2.5.1 Spatial decision unit: definition and functions

To group collected information based on managerial uses, a fundamental unit should be explored and defined. This spatial decision unit (SDU) should include a clear spatial extent and serve as a fundamental (smallest) unit for management content. Depending on the nature of management focus, the unit for management tasks might be a polygon, a line, or a point that has been extracted from physical objects into a GIS feature class.[11]

Since the SDU has a clear spatial extent, GIS will be the interface to visualize the information attached with SDUs. In addition, other existing scientific information of GIS format can interact and overlay with SDUs. Further, SDUs can be used as a common target for stakeholder to report their observations. Because stakeholders' inputs are grouped by SDUs, it helps managers to connect these inputs with their management tasks. Finally, using SDUs has structured stakeholders inputs over time with same spatial extent. Since the decisions of management tasks and monitoring information (collected from stakeholders) are organized into SDUs, it enhances the traceability (requirements of AM) and increases the efficiency of data (stakeholder inputs) processing.

To keep track how information is changed within the same SDU, a database system design will be applied to track all types of information (scientific, stakeholder inputs, decisions of management tasks, etc.) for further analyses. How to design and implement the design of the database, structurally generate the stakeholder inputs, and set up clear spatial extent for each SDU will be discussed in the next subsection.

2.5.2 Database systems and configurations

Database systems have the capability to track and query information across different records (Yeung and Hall 2007). Relational database is designed to connect different datasheets (tables) that have predefined relationships from one to another. Also, unlike the production database that only records transactions; relational decision support system (RDSS) database articulates the needs of decision questions and collect information based on management needs. A geodatabase is designed for spatial information integration (Law 2007) and should support various formats (file-based data, spatial database data, and format from map web services[12]). Besides that, a geodatabase should also provide a connection to most relational databases (Arctur and Zeiler 2004: 15).

Since most governmental agencies have their own GIS and geodatabases (Ganapati 2011), any VGI-R project needs to use another database to collect stakeholder inputs through the web. The web-based database system needs to connect a geodatabase to visualized inputs collected from

[11] Feature class is a collection of geographic features with the same geometry type (such as point, line, or polygon), the same attributes, and the same spatial reference in ArcGIS that can be stored in geodatabase or other formats (GIS dictionary of ESRI Support, http://support.esri.com/en/knowledgebase/GISDictionary/term/feature%20class)

[12] All types of feasible formats are listed in ArcGIS website: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/About_geographic_data_formats/00r90000006r000000/

the web-based database through GIS. With web-based consideration, Yeung and Hall (2007: 45) have listed all possible web-based database system configurations. These configurations included various relationships between clients (use by stakeholder users) and server (control by data managers) in regard to the data processing (input/output, I/O) arrangements. Within these configurations, the easiest design for users to understand is a database associated with projects that can minimize technological gaps for users. Both databases use a relationship to connect one table to another within or across various databases.

To envision which table is connected to another, a relationship schema needs to be mapped out. To link one table to another, an attribute is used to establish a link to other tables, the link being called a Foreign Key (FK) (Rob and Semaan 2004: 9-10). A FK in both tables that contains identical content are essential for this relationship to be formed. The types of relationships include "1:1 (one-to-one)", "1: M (one-to-many)", and "M: N (many-to-many)" relationship types. A one-to-one relationship regulates one record in a table that can be linked to only one record of another table. This relationship is rarely found in any practical database. A one -to-many relationships is the most common one within these three possible types of relationships. In this type, one table can connect to other tables, and one record from this table may be associated with many records from the other tables. For example, a trail has been defined as a SDU and may be associated with condition of trails (e.g., slope, elevation), land managers that are associated with custodianship (e.g., contact information, land ownership), or recent work orders about this trail. Lastly, a many-to-many relationship can occur when one record (value) will be used and both tables to which it connects have more than one relationship (Rob and Semaan 2004: 19-22). For example, one SDU may have different types of public inputs, and these types of public inputs can happen in many other SDUs as well. Through different types of relationships and records, the relational database can be used to connect information differently.

As to the database connection, as mentioned earlier, most cases tend to build up a web-based interface with free web-based database (such as MySQL) to collect public inputs and connect their information with in-house geodatabase based on the same unique record feature identifier (a SDU, called FID in the feature class). With this configuration, every report will have its record ID (TID) and be able to connect with a geodatabase through existing tools such as those in ArcGIS[13] (Figure 2-3).

[13] To connect any table (data sheet) from traditional database to geodatabase, temporary connection includes join

Web database tables			
TID	User ID	Group	Comments
01	wang_v1	Volunteer	…….

Relationship Class in Geodatabase			
FID	TID	Type	Note
01	01	Hike	Closed in winter

Trail Class in Geodatabase			
FID	Name	Type	Modification
01	Main Trail	Hike	Closed in winter

Figure 2-3. In order to connect web database (collected stakeholder inputs) into geodatabase, Trail ID (TID) should be used as a *management unit* from the web database so that it can connect Trail feature class (Feature_ID) in the geodatabase through a 1: M relationship.

2.5.3 User interfaces

Finally, because a user interface facilitates navigation for participants (using client software such as a browser), the interface plays a key role within this process of a VGI-R implementation. Generally speaking, the user interface is the first element of the system that interacts with users (stakeholders) (JoAnn and Hackos 1998). Clear design of interface navigation is required, and it only happens when the user behavior is well understood by designers and developers. Hence, the usability of user interfaces is the key to enhance the website credibility and user acceptance through reducing error and training efforts (Maguire 2001).

Unfortunately, usability of user interfaces has not received much attention as compared to the transparency and participation capacity evaluation in VGI-R projects (Zhao and Coleman 2007; Rinner and Malczewski 2002; Anderson et al. 2009). Consequently, usability in this research should be further discussed and defined. First, a user interface should provide assistance to navigation while public stakeholders generate their observations. Second, it is required to build a straightforward connection between database and interface to visualize different result for various users (including land managers). Finally, a user interface should provide options for data sharing services. Designing a proper sharing network that can be used by different stakeholders to access the information they need is a critical aspect of information in volunteer reporting.

and related tools. As to the permanent connection, the relationship in the geodatabase can be created.

Chapter 3: Research Objectives, Approaches, and Cases

The first two chapters in this research cover the hardship for a public land manager to acquire best available information. It seems that merging the Adaptive Management (AM) concept of tracking changes through crowd-sourced voluntary reports with spatial information is a feasible option from a theoretical perspective. However, empirical case studies found institutional and management resistance to this new intervention (embedding voluntary reporting as one of their key information for decision making). These resistances include jurisdiction constraints (Imperial 1999; Johnson and Sieber 2013), non-traditional linear decision-making process (Halbart 1993; Stankey et al. 2005), power shift potential (Graham and Kruger 2002; Stringer et al. 2006), insufficient technology supports (Johnson 1999; Stankey et al. 2005), and insufficient benefits to managers (Olsson, Folke, and Berkes 2004).

Since management and institutional acceptance is the primary consideration in this research, assessing institutional resistances and looking for possible solutions to increase the acceptance are the two major foci. Structured participation (Nyerges et al. 2013) creates one option to formalize participation process, and this research proposed that the inputs generated from participation should be structured simultaneously. Accompanied with structured inputs, having a common unit to organize discussions and track all possible changes is suggested in the integration of PGIS with AM. Projects can use the combination of SDUs (spatial decision units) and structured voluntary reports to enhance the usability of structured participation.

The following section (section 3.1) will describe research objectives and assumptions in detail. Since resistance to new information was found in most of the empirical cases, this research will use cross-case comparison as the research approach. Detailed methodology and comparison design will be described in section 3.2. Finally, since cultivating insights from empirical cases is an important part of this research, section 3.3 will cover selections of cases in detail. In short, four empirical cases will be compared. Since each case has particular institutional arrangements, a subsection in section 3.3 will cover a brief description of each case.

3.1 Research Objectives

Opening paragraphs of this chapter point out that management and institutional acceptance is the primary consideration in this research. Two research foci will be (1) assessing institutional acceptance of VGI implementations and (2) structuring reporting information to increase management acceptance. The first research focus identifies institutional resistances from various cases based on a conceptual framework so common findings can be synthesized. Second, structuring reporting information through SDU and structured forms should increase processing efficiency compared through cases. The design of SDU organized by management actions serves as a fundamental entity to increase the ability of data tracking, retrieval, and integration in database models. In addition, the precise spatial feature in SDU provides a delineated unit to assemble structured voluntary inputs and visualized through web-based map interfaces.

In sum, the two research objectives are:

1. develop an assessment framework (considering institution, stakeholder, and techonology perspectives) to assess if the voluntary reports design considers institution (include management needs), stakeholder, and techonology perspectives;
2. compare usability of structured participation intervention (SDU and structured voluntary reports) in VGI-R. This research will compare few technical considerations among the cases, which include data collection process, database structure, and the user interfaces.

To exclude some possible practical uncertainties, some assumptions are listed below.

1. This research does not consider modifying existing governance structures to improve participation. The assessment framework is used to clarify land managers' information needs and existing limiations for VGI-R projects.
2. SDUs should be the smallest working element for management, but still can be characterized as features within a GIS layer. Each SDU should not have any overlapping area and are to be individual and unique. After the SDU has been defined, almost every existing information can find possible relationships to it, even though completeness may differ.
3. All inputs generated from public stakeholders are treated as credible information sources. Formal engagement of stakeholders as sensors should benefit managers. Based on various needs, different structured inputs may be regulated or designed case by case.
4. With highly structured public engagement and participation, there should be less insitutional and management resistance to such a formal engagement.

3.2 Research Approach: Cross-Case Comparison

The cross-case comparison aims to systematically compare detailed observations and construct general patterns across cases, thereby increasing external validity (Yin 1994; Cook and Campbell 1979) to inform policy, generate knowledge, and support theoretical interface verification (Rudel 2008; Poteete and Ostrom 2008; Bilotta 2014). Validity has been defined as "the best available approximation to the truth or falsity of proposition" (Cook and Campbell 1979:37), and thus external validity suggests that findings can be generalized (Yin 1994) into patterns that apply to real-world situations. To further explore the meaning of general patterns, Brinberg and McGrath (1985) use three levels of processes to build patterns and increase validity. These three levels of processes are (a) discovering different valuable elements, (b) creating correspondence among these valuable elements, and (c) evaluating robustness of the findings to create interpretations. This exploratory study focuses on finding insights from various cases. However, limited cases may not allow this research to draw substantially generalized patterns in this research yet, and therefore foster high external validity. Thus, the first level of building patterns (discovering valuable elements and identifying important relationships among them) is the primary goal in this research.

Finding new patterns and matching observations with theoretical interfaces are two ways to construct a thorough understanding (Trochim 1985). Poteete and Ostrom (2008) extended and deepened these ideas by constructing a case database, called a meta-database. They used the database to perform cross-case studies and create findings of collected actions in common pool resources. Ample cases helped them build 'strong evidence' against the theory of tragedy of the commons (Hardin 1968). After comparing various research methods (e.g., systematic review, meta-analysis, and comparative studies) that have been used to conduct cross-case comparison at various scales, it appears that all comparison methods followed similar workflows, which include data collection, data organization, and analysis stages.

To compose a robust research question, almost every method suggests using shared or common meta-categories (some call them features) to form a comparable standard across different comparisons. Most methods start with pre-defined questions to support or challenge existing theories. However, some researchers suggest that observed patterns can be derived from cases without a thoroughly predefined question as part of case study methods (Yin 1994; Leslie 2005; Crossan and Apaydin 2010). Since this research focuses on exploratory discovery of institutional resistance and possible alternatives to soften the resistance, finding observed patterns from cases drives the investigation.

Second, although data collection processes are varied in other methods[14], a coding framework is used within all methods to organize data collected from cases. Researchers may decide to use existing coding frameworks made from specific cases or combine frameworks to generalize across cases (Leverington et al. 2010). A simple tabulation of cases into structured frameworks might not be enough for complex situations. Poteete and Ostrom (2008) use a meta-database to

[14] One use is by forming randomized controlled trail (RCT) results, as in meta-analysis that aims to use a statistical procedure to synthesize findings (Wolf 1986). Unlike RCT results, both systematic review and case study use different types of data.

organize data collected from cases thereby potentially broadening investigations. To deepen investigations, such as investigating causal relationships with multiple variables, a chain of evidence can be used to organize related information using meta-analyses (Ades 2003) and/or case studies (Yin 1994).

This research combines existing frameworks to compose a coding framework to assess institutional resistance of voluntary reports. As mentioned in opening paragraphs and research objectives, this framework is going to unpack complex relationships among institutions, stakeholder, and techonology barriers. The first section of Chapter 4 (section 4.1) discusses elements of this assessment framework for institutional resistances. The second portion of this research explores the effectiveness of structured participation through cases used in the first portion of this research. Various structured participation arrangements are compared through data collection, database model, and user interfaces. Three subsections within Chapter 5, section 5.1 discuss the framework and variables used in the comparisons. Unlike the institutioanl resistance assessment, the usability assessment of structured participation has no existing framework as a foundation. Hence, all variables and comparisons are based on my observations, related references, and personal experiences. Hence, the results of comparison are not replicable without further conceptualization and examination.

3.3 Subject and Case Selection

In this research, two environmental management subjects, recreation and invasive species monitoring, were chosen because they have similar programmatic needs to adopt volunteer reporting. Furthermore, both interact with considerable numbers of volunteers to complete management tasks because very limited managerial resources exist for monitoring status and management. The limited managerial resource situation makes voluntary reporting one of the more critical resource issues for assisting decision-making.

Recreation can be treated as one type of ecosystem services or a non-consumptive use of natural resources. Because the staff-management area ratio is disproportional, volunteers represent a crucial work force (Brudney 1999) for parks. Land managers rely heavily on volunteers for various environmental protection activities (Propst et al. 2003). In comparison, involving citizens in tracking and reporting invasive species is a critical part of environmental management because threats from invasive species (i.e., plants, pests, and animals) to current agriculture and ecosystem are substantial. Increasing the number of observations can help with early detection and rapid response (EDRR[15]) of invasive species spread. Four cases (two each for the above

[15] Early detection and rapid response (EDRR) and control and management (CM) are two main strategic goals out of four that were set up from The National Invasive Species Council (NISC) by Executive Order 13112 in 1999

topics) were selected based on opportunistic circumstances, but aim to provide an interesting diversity of institutional missions, resources, and scales. The following subsection briefly introduces each case, providing additional information to establish insights and shared understanding using cross-case comparison.

3.3.1 Case I: Lord Hill Regional Park

Lord Hill Regional Park (LHRP) is a mid-sized county park (approximately 1400 acres) in Snohomish County, Washington. LHRP has various types of trails and habitats managed by the Snohomish Park and Recreation Department (Snohomish PRD). Due to limited managerial resources, LHRP and nine other parks are managed by one of the ranger groups[16]. Like most existing bureaucratic structures, Snohomish PRD has a hierarchical structure and rangers are at the lowest level of decision-making. Luckily, because the LHRP attracts a variety of users, different volunteer groups or regional non-profit organizations have become stewards of LHRP seeking active involvement in decision-making. Because LHRP is managed with nine other parks, insights from related incident reports[17] are difficult to share among responsible staffs and rangers. Furthermore, even when there are incident reports, these reports would only be transferred to upper decision-making level when they exceed a rangers' decision power. Park users tend to report incidents to volunteers instead and seek immediate help from them. Even though LHRP has actively involved volunteers, there is no formal setting for public participation for LHRP. All government-public interactions are heavily dependent on managers' attitudes. Also, volunteer reports might be undervalued because of a lack of organization.

3.3.2 Case II: Department of Natural Resources, Washington State Government

To incorporate volunteer efforts for recreation management, Washington State Department of Natural Resources (WA-DNR) has initiated a volunteer program, called "Forest Watch Program". Our case study was conducted in one of the regions, the Puget Sound Region. Since each region has fewer staff resources than county park departments, it is very critical to work with volunteers and non-profit organizations for trail and park maintenance. For example, there are only 40-50 employees whose responsibility is related to recreation affairs in WA-DNR. The management area for these employees includes 1.8 million acres of public lands and about 1,100 miles of trail with daily management needs (Jordan Reeves, personal communication, November13, 2012). Each region has its own coordinator to handle volunteer reports and coordinate volunteers for

---

(National Invasive Species Council 2005). To generate better performance for EDRR and CM, volunteers in collaboration with environmental NGO/NPOs become a requirement for invasive species control and management.

[16] One ranger group (2-3 rangers) accompanied by other 10-20 parks in the Snohomish County.

[17] These incidents include enforcement, coordinating volunteer activities, estimating park usage, and handling emergencies.

other park maintenance affairs. The program sets a clear agenda for training, tasks for volunteers to participate, and rewards. Finally, even with limited resources, both managers and coordinators have knowledge and skills related to GIS so more incident reports can be transferred and visualized.

3.3.3 Case III: King County, Washington Weed Watcher Program

The King County Weed Watcher Program (KC-WWP) was initiated in 2006, moving all volunteer reports into digital collection in 2012[18]. Similar to WA-DNR's Forest Watch program, KC-WWP aims to collaborate with volunteers so more invasive species can be located and controlled. Similar to WA-DNR, there is one coordinator who is responsible for handling volunteer reports (collected from web interfaces) and provides volunteer trainings and the program has been formally set up with grants to support routine operations. Beyond reporting invasive species, KC-WWP also encourages volunteers to control invasive species listed by KC-WWP. In comparison, KC-WWP has very strong GIS support. The coordinator has one GIS specialist to help her build web interfaces, organize the information, and visualize all reports through GIS in-house.

3.3.4 Case IV: Early Detection and Distribution Map System

The Early Detection and Distribution Map System (EDDMapS) was developed by the Center for Invasive Species and Ecosystem Health at the University of Georgia in 2005 to monitor invasive species distribution. Unlike KC-WWP, EDDMapS focuses on collecting complete records of invasive species distribution so it can provide a database for researchers and land managers to use. To collect the most complete information, EDDMapS also provides various data collection interfaces[19]. Since the EDDMapS focuses on a nationwide scale, most reports have to be collected and processed through web-based interfaces. Participants are allowed to report only, since controlling invasive species population is not the main focus on EDDMapS. Compared to other cases, EDDMapS has a web-based map system to visualize species distribution. EDDMapS also built an information review and sharing network with related nonprofit organizations and land managers. Voluntary reports are verified or corrected by land managers or local experts to ensure quality information.

---

[18] The Weed Watcher program provides education and outreach as part of the King County Noxious Weed Control Program. This program began in 2006 with a specific area (Middle Fork Snoqualmie Valley) and expanded to the Snoqualmie Pass Area and other closer wilderness in 2010. Beginning with 22.5 miles of surveyed trail, this program has grown to over 100 miles in 2010 in a single year with more than 200 volunteers throughout the King County.

[19] In addition to that, to maximize the efforts of public reporting, EDDMapS received the data from more than 10 mobile applications launched by their partners.

Chapter 4: Assessing Institutional Resistances

Based on research objectives, approach, and assumptions mentioned in Chapter 3, a coding framework of assessing instituional resistance of volunteer geographic information reporting will be developed and is discussed in section 4.1. The cross-case comparison results based on this coding framework will be presented within section 4.2 and the respective subsections.

4.1 Volunteer Geographic Information Reporting Assessment Framework (VGI-RAF)

Within the DSA framework, the convening components (consisting of three constructs) use eleven aspects (Figure 2-2, pp.14) to depict the situational arrangement for participation. In this VGI-RAF, some aspects from the DSA framework are not feasible when implemented within a web-based VGI-R systems. First, the *Convener* aspect within the *Social-Institutional Influence* construct is mainly considered to be a person within an organization who initiates and sets ground rules for participatory activity. In this research, volunteer activities are already initiated, which is voluntary reporting. In addition to ground rule setting, the participation formats and fundamental rule setting takes the form of human-computer interfaces. Second, since this research focus on voluntary reports contributed by public stakeholders, any stakeholder who does not hold trust or belief in this system may not be allowed to report. Hence, Stakeholder*s' Belief* and *Stakeholders' Trust* aspects are assumed to be positive and thus eliminated from the VGI-RAF. In sum, three of eleven aspects have been eliminated, leaving eight to constitute the VGI-RAF.

The first aspect, *Power and Control,* frames various *actors* who hold various powers (*positions*) within governmental agencies, and establish a relationship of actors under power to voluntary reporting system. The second aspect, *Subject Domain*, characterizes information needs from governmental agencies and points toward the need to ask questions about what information should be provided by a voluntary reporting system, and whether such an approach is an efficient and effective way to gather information. Gathering information from these two aspects helps institutions clarify their information needs within their current institutional arrangement. The third and fourth aspects, *Chosen Participants* and *Rules and Norms of Participation* characterize the appropriate space (participants), clear rules, and norms for participation in the existing management workflows. These rules and interactive patterns become the action element within the IAD framework, and each interaction should be documented. From the group participant focus, the *Stakeholders' Expectations* aspect depicts the needs and motivations for voluntary reporting behaviors from public stakeholders. To ensure that reporting content meets accuracy standards, it is important to examine a gap between *Stakeholders' Knowledge* and data quality needs. The last two aspects in this framework aim to depict a programmatic setting within an existing decision-making process. The *Channels of Communications* aspect characterizes decision-making and the information handling processes therein. This process can clarify the information needs and flows, and points out a weak link (i.e., gap in information and resource sharing). Lastly, the *Geographic Information Aids* aspect should be used to investigate current technology capacity in regards to information needs, institutional arrangements, stakeholders' needs, and decision-making processes (Table 4-1).

Table 4-1. The *Volunteer Geographic Information Reporting Assessment Framework (VGI-RAF)* contains 8 aspects to assess a decision situation and resistance while implementing a stakeholder reporting system. These foci include institution, contents, stakeholder interaces, communication channel, and techonology focuses. Each aspect includes its characteriziation focus and associated construct from DSA framework.

Aspects	Characterization Foci	Constructs
Power and Control	Intent and attitudes of public participation in the current decision-making structure	Social-Institutional Influence
Subject Subject	Needs of public reporting for management situation	
Chosen Participants	Who is selected/enabled to participate	
Rule and Norms of Participation	The design of the structured pariticipation method	
Participants' Views/ Knowledge	Member expertise with subject subject, methods, and technology	Group Participation Influence
Participants' Expectations	Categorized stakeholders with various interactive patterns with decisionmakers.	
Channels of Communications	Reporting and information workflow within the decision-making process	PGIS Influence
Geographic Information Aids	Technology capabilities	

4.2 Results of Cross-Case Comparison

Based on VGI-RAF, there are eight common aspects that serve as a coding framework to conduct a cross-case comparison. The following subsections provide a cross-case comparison based on each of the eight aspects.

4.2.1 Power and Control

Three types of formal program settings are found within these four cases. First, as to LHRP, there is no responsible staff in charge of voluntary reports. Daily incident reports are carried out by the rangers and no formal setting has been set. Unlike LHRP, the Puget Sound Region of the WA-DNR officially created the Forest Watch program with one volunteer coordinator to obtain all incident reports from volunteers. Furthermore, the WA-DNR also collaborated with environmental NPOs (E-NPOs) for trail maintenance through grants. Like WA-DNR, WC-WWP also has one education (outreach) coordinator to become the experts in this program to receive and process all reports. Finally, since EDDMapS focuses on collecting information at a nationwide scale, all of the voluntary reporting interactions are predefined and arranged through web-based interfaces.

4.2.2 Subject Domain

Receiving trail incident reports from voluntary reporting exists for both LHRP and WA-DNR. These two cases also support processing of these reports automatically without having to read through each of these voluntary reports. Time invested in processing becomes a major consideration whether they would use voluntary reports or not. Having a list of structured information based on managerial needs[20] would be ideal. Compared to trail incident reporting, invasive species control and monitoring tends to add web-based mapping systems to present the current status of invasive species distribution of animals and plants. However, EDDMapS appears to contain the most complete reported information versus KC-WWP that arranges information based on management content (e.g., trail and lakes) with a list of target invasive species to control.

4.2.3 Chosen Participants

Three common roles can be found in all cases even though each role may contain different actors. These roles are data collectors, data users, and decision-makers. Decision-makers are normally land managers. In the EDDMapS, the decision-maker becomes the person who decides the data collection mechanism, content, and resulting visualization. In contrast to the first data users of ranger groups in the LHRP, the volunteer coordinators in both WA-DNR and KC-WWP programs and the web-based interfaces of EDDMapS are the first groups for handling voluntary reports. These first data users might decide to pass the information to higher level of management (in LHRP case) or share with other partners (such as environmental nonprofit organization). The EDDMapS interface collects information and passes reports to partners so local experts can help verify voluntary reports.

4.2.4 Rules and Norms of Participation

The rule of participation has been found to provide a close connection to the formalized setting of VGI implementation. The LHRP has no formal institutional arrangement for stakeholder participation. It is found that fluctuation of participation occurs during work rotation of managers since managers are given the power to decide when and how to participate. In contrast, VGI programs in both WA-DNR and KC-WWP set a clear expectation for volunteer training (mandatory for WA-DNR), responsible staffs, volunteer appreciation, and information sharing

[20] To create an accurate and precise report for managers to use, the WA-DNR spent extra time to lay out various categories (i.e., maintenance, enforcement, invasive plant) of reporting needs based on their daily needs. For example, the maintenance form includes downed trees that are blocking paths, drainage and surface issues, etc.

arrangements. Besides volunteers, both programs have a grant relationship with their partners (environmental nonprofit organizations) for better collaboration. In comparison to WA-DNR and WC-WWP efforts, the EDDMapS activity is limited to only collecting voluntary reports. However, the participants of EDDMapS can visualize their reports from the map system immediately after reporting. As for other partners (land managers or local nonprofit organizations), EDDMapS participants collaborate and share information with these other partners and also ask for their help with report verification.

4.2.5 Participants' Expectations

In the LHRP, since there is a loose connection between the LHRP and the Snohomish PRD, local volunteer leaders and stakeholders expect to be actively involved in LHRP management. Both regional programs (WA-DNR and KC-WWP) listed clear expectations and possible activities for volunteers to decide whether they would like to participate. As compared to LHRP, volunteers of these two programs will have proper expectations when participating. Finally, even though the EDDMapS program provides passive participation only, participants are very clear about their efforts.

4.2.6 Participants' Knowledge

Among four cases, participants' in LHRP generally have a better understanding of their park situation than the decision-makers of Snohomish PRD. However, our records also showed that managers might still see less value if the stakeholder knowledge is not properly aligned with management activities. Unlike LHRP, decision-makers of the other programs tend to hold more knowledge and control more power than do the participants in these cases. Hence, training has been provided to fill gaps in volunteer reporting. To some participants with expert knowledge, these programs tend to collaborate with them and use their knowledge to improve the quality of collected information.

4.2.7 Communication Channel

In the LHRP case, trail incident reporting was transmitted through a variety of formats (i.e., e-mail, phone message, or in person) without regular communication channels. However, incident reports have not fully been transferred to intermediate and high-level decision-makers, who are usually allocating and prioritizing tasks and resources. Rangers will receive orders and make decisions based on the summaries. This workflow creates a massive amount of failed reports because of mismatching tasks and responsible personnel, or unclear descriptions without precise locations. Unlike the LHRP, the WA-DNR established a responsible single process and one person (regional coordinator) to coordinate all possible tasks, process them, and distribute the information (See Fig. 4-1). The invasive species reporting is relatively formal and regular. The information and reporting workflows start with volunteer training about the reporting process. Verification reports are provided by education and outreach coordinators (agencies technicians) who then distribute the processed information to E-NGOs and land managers (Figure 4-2). When reports are initated, volunteers may choose to use a handheld GPS to capture their spatial location and fill out a form (from paper or mobile applications) about infested areas.

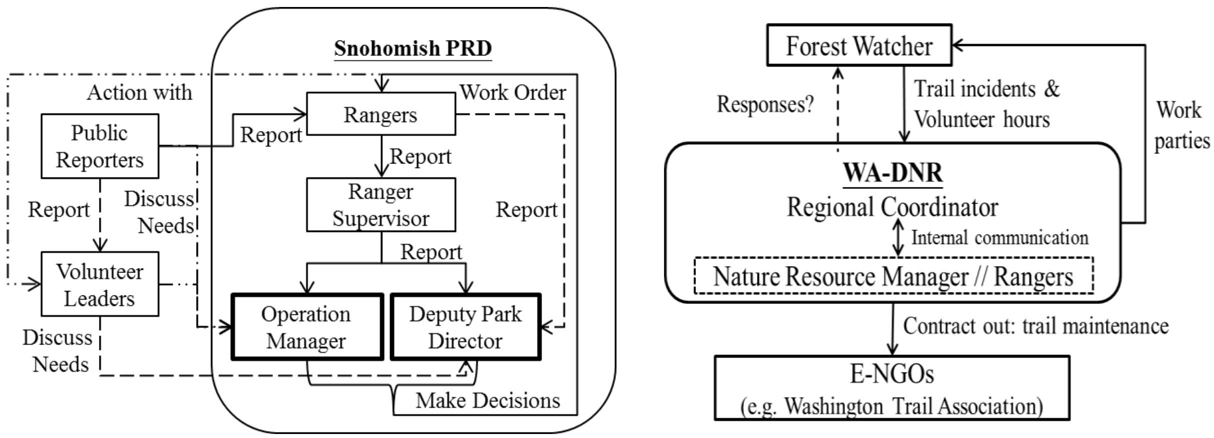


Figure 4- 1. The comparisons of trail incident reporting process between the LHRP (left) and the WA-DNR (right): The LHRP has complex reporting channels that cause reports to be wasted. The WA-DNR uses a single channel with one responible person to process information precisely.

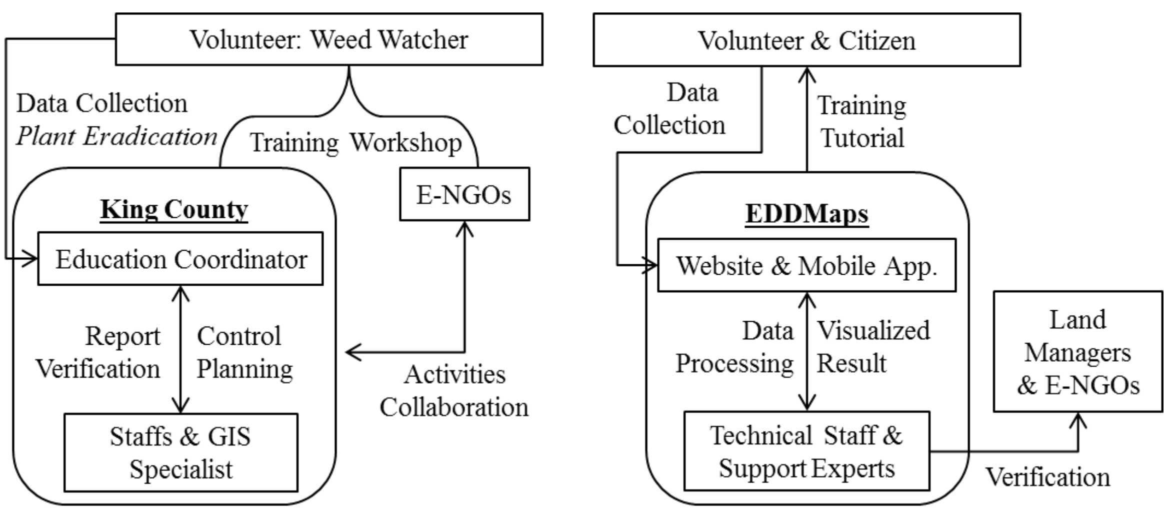


Figure 4- 2. The comparisons of invasive species reporting and control process between the King County Weed Watcher Progrgam (left) and the EDDMapS (right): The information flow starts from education training, report processing, reporting content verification, modification, and archived reports.

4.2.8 GIS Information Aid

GIS and information aids differ on a case-by-case basis. The LHRP case includes very limited

GIS knowledge and resources. Data collectors only felt comfortable to use official park trail map (printed map) to report trail incidents. Data users and decision-makers have limited access to GIS support from the county government. Thus, it is necessary to create a simple web interface to process trail incidents with existing trail maps. Unlike LHRP, the other three implementations found that reporters felt comfortable to use GPS (Global Position System) to record their locations. EDDMapS also utilized GPS capability from smart phone to support people who have difficulty using GPS. The data-users, staffs and managers of these cases have GIS skills and experiences. Both the King County and EDDMapS developed their own platforms for data collection and visualization. To enhance the efficiency, each case used a structured reporting form to help with data collection efficiency.

Chapter 5: Structured Participation: Cross-Case Comparisons

5.1 Comparison Design and Variables

Based on the second research objective, this research compares usability of structured participation interventions (SDU and structured voluntary inputs) of voluntary reports in data collection processes (comparison A), database structures (comparison B), and user interfaces (comparison C). The following subsections will describe each comparison in detail.

5.1.1 Comparison A: SDUs and structured reports in data collection

To compare structured participation in data collection processes, four comparisons are made to observe if the efficiency of information processing can be imporved. The first comparison of this section is to examine if voluntarty reports can be better structured after using SDU to organize the content. Voluntary reports collected by LHRP (Lord Hill Regional Park) are traditional meeting minutes between stakeholders and park managers. Two measurements used in this comparsion are:

1. percentage of content that can be transferred to tables and
2. number of extra steps for land managers to use organized information versus non-structured volunteer inputs

The second comparison is to test if reports organized by SDUs can increase the search efficiency. In this comparison, two invasive species monitoring programs, KCWW and EDDMapS, are compared. Both programs collect structured voluntary reports with different organizing strategies. The KCWW program uses trail/lake as their SDU and EDDMapS uses GPS coordinates to organize their voluntary reports. The objective of this search should provide a land manager with enough information to plan proactive actions. Three measurements used in this comparison are :

1. search interface capability: time to search and download the needed information,
2. retrieval efficiency: time to process all downloaded information into one single spreadsheet, and
3. abundance of information: species diversity, number of records, reporter divsersity.

The third comparison compares the benefits and drawbacks of various degree of structured inputs. Three different degress of structured inputs are compared. With no structured inputs, we use the meeting minutes from LHRP as the data. The semi-structured inputs are non-structured LHRP's meeting minutes organized by SDUs and a few management categories. The highly structured inputs structure all required information from management into one form for public stakeholder to fill in. The data of this highly structured input collects from WA-DNR's forest watch program. To evaluate the performance of various structured reporting forms, the comparsion focuses on:

1. the correctness of matching reporting contents with right personnel or departments,
2. the efficiency (fewer processing steps) of connecting reporting content to management activites (i.e, management tasks and actions), and
3. the integratity of transferring textual content into tabular data with numerical values.

Final comparison for the data collection process is to test if using multiple forms for different users will be better. Same as the second comparison, this comparison will compare the KCWW that uses one form versus EDDMapS that uses multiples forms and devices for data collection. These four comparison will be presented in section 5.2.2 of Chapter 5.

5.1.2 Comparison B: Quality assessment of database models

If using SDUs and structured inputs to organize stakeholder inputs can organize non-structured information, then the next step in the comparison examines if SDUs and structured inputs can also increase the quality of database model (content and structure of a database). Quality of a database model can affect different aspects of the system, such as results of search ability, connectivity to other systems, correctness and efficiency of inputs for data processing. To assess the quality of the database model, Moody (1998) developed eight factors (e.g., completeness, correctness, integrity, simplicity, integration, flexibility, implementability, and understandability) based on multiple stakeholders' perspectives (e.g., data user, data analyst, data administrator, and application developer). This experiment used the *integration*, *completeness*, and *correctness* quality factors in Moody's (1998) research to examine the capacity of using SDUs to:

1. connect other systems,
2. search capacity for users, and
3. maintain correct and complete records in the database.

This research will compare the two invasive species cases since their databases have been built and used for years. Comparsions will be presented in section 5.3. The *integration* factor evaluates the consistency between each database and other systems. It is necessary to find the relationship between one database and another with the least amount of data duplication. The measurements used to assess *integration* are:

1. how many connections between reporting database and GIS are incomplete and
2. if there is a gap for connecting existing records to the GIS.

The *completeness* factor assesses if a database model contains all information required by users. It is the most essential requirement because it affects the effectiveness of the whole system. Three measurements to assess *completeness* factor are:

1. the percentage of fields that can be used to query needed results,
2. the number of summarizable fields, and
3. how many purposes can be served through the search mechanism.

The *correctness* factor assesses the credibility of each record and assures that records were properly arranged. Enhancing the correctness of a database is required to set up data input rules so null-value records can be minimized. The measurements of this factor include:

1. if clear rules were defined for data inputs and
2. the percentage of null values stored in the database.

5.1.3 Comparison C: Interface usability: website and mobile applications

Finally, since a user interface interacts with users, providing better navigation for a user to input data or better visualization design to view results are important. Usability, by definition (ISO, 1998), is a way to understand the effectiveness, efficiency, and satisfaction of the information object. Since various devices are developed and used in the EDDMapS, this research conducted two usability evaluations: one for websites accessed from a desktop and one for mobile application interfaces.

Within various evaluation methods available (Maguire 2001), a first evaluation is a heuristic (expert) evaluation (Nielsen 1993) using an inspection approach (Banati et al. 2006). In this evaluation, the researcher is the only person who served as in the expert's role to evaluate various websites. Thirty minutes were spent for one website as a first time user who wants to report observations. Based on this purpose, usability was evaluated based on the evaluation framework and criteria listed in Table 5-1. This evaluation framework includes map services, query capacity, and navigation design with eight different criteria and 18 associated measurements. Each measurement takes a score from one to five based on defined thresholds. Detail thresholds and score relationships are shown in Appendix A. Since the EDDMapS is the only case that has a complete website among all cases in this research, this evaluation compares the EDDMapS with other two similar websites (ParkScan and What's Invasive[21]). Detail evaluation results are provided in section 5.4.1 of Chapter 5.

A second comparison aims to assess interface usability of mobile devices from general users' perspectives. The method combined *evaluation walkthrough* (Nielsen 1993) and the *controlled user testing* (Dumas and Redish 1993; Bevan and Macleod 1994) that invited specific stakeholder groups to test usability of invasive species reporting mobile applications. A

[21] For brief introduction of ParkScan and What's Invasive systems, please see the Appendix B.

notification was sent to several groups, including:

1. students enrolled in introductory GIS course taught in the School of Environmental and Forest Science, University of Washington with GIS and environment knowledge; and
2. volunteers, E-NPOs coordinators, County coordinators, and students who had experiences on invasive species detection and control.

A questionnaire with textual suggestions was recorded anonymously. Except for the questionnaire, textual feedback was provided by participants after physically testing two mobile applications. The online survey was hosted for one month. Fourteen participants filled out the survey (reply rate 17.5%) after sending out around 80 notifications (45 emails and 35 by oral announcements through classes). The summarized results are shown in subsection 5.4.2 of Chapter 5.

Table 5- 1. Heuristic (expert) evaluation for website interface includes map services, query capacity, and report navigation categories. Each category has 2-3 criteria, and each criterion includes two to three measurements. To compare each case with precise definition, the measurement thresholds and score relationships have been provided in Appendix A.

Category	Criterion	Measurements
Map services	1. Cartography: legend, symbol, and extra information usage	1.1 Clear legend & reasonable breakdown 1.2 Extra information to explain map usage
	2. Map proportion, accessibility, and connection to website content.	2.1 Map proportions 2.2 Map functionality 2.3 Maps & website content connection
Query capacity	3. Search capacity: diverse commands and speed of searching	3.1 Theme/Location search 3.2 # of clicks to results 3.3 Connectivity between Input Data and Result Query (%)
	4. Extension capacity	4.1 Ability to customize and modify existing map capacity 4.2 Static/Dynamic Maps
	5. Data distribution capacity	5.1 Web distribution 5.2 Download content (raw data, fixed results, etc.)
Reporting navigation	6. Navigation designs	6.1 Clear navigation 6.2 Easy to use
	7 Tutorial Guide for First-Time User	7.1 User instruction 7.2 Media of education
	8 Q & A Sections	8.1 Q & A section 8.2 Channels of trouble shooting

In general, mobile applications are the latest gadget that use embedded GPS, photo taking, and Internet to transmit all information at the same time. Two significant mobile applications

(PlantTracker and PNEDN[22]) for invasive species reporting were evaluated in this research. The two were selected from a collection of nine similar mobile applications; see comparison in Appendix C. Ten questions (criteria) were developed to focus on:

1. user management,
2. reporting navigation and measurement, and
3. map service and result representation.

The complete questionnaire can be found in Appendix D.

5.2 Result A: Capacity of Structured Participation in Data Collection Process

A new intervention (SDUs and structured inputs) is used to structure reports based on management needs. To unpack their individual effectiveness, SDUs and structured inputs were separated in the test. Subsection 5.2.1 describes the comparison results of testing SDU capacity alone (the first and second comparison of subsection 5.1.1) to organize existing information into attribute tables[23] with SDUs. Following the first comparison, subsection 5.2.2 examines various ways of structuring reports and compares the capacity of reporting (the third and fourth comparison of subsection 5.1.1).

5.2.1 SDU and data organization capacity

Traditionally, meeting minutes and agendas are grouped by various themes (see full scan records in Appendix E). A six-step process is used to process stakeholder meeting minutes into useful information in LHRP's case. To analyze the meeting minutes and formulate possible management activities and visualize results from maps, a Snohomish PRD manager must:

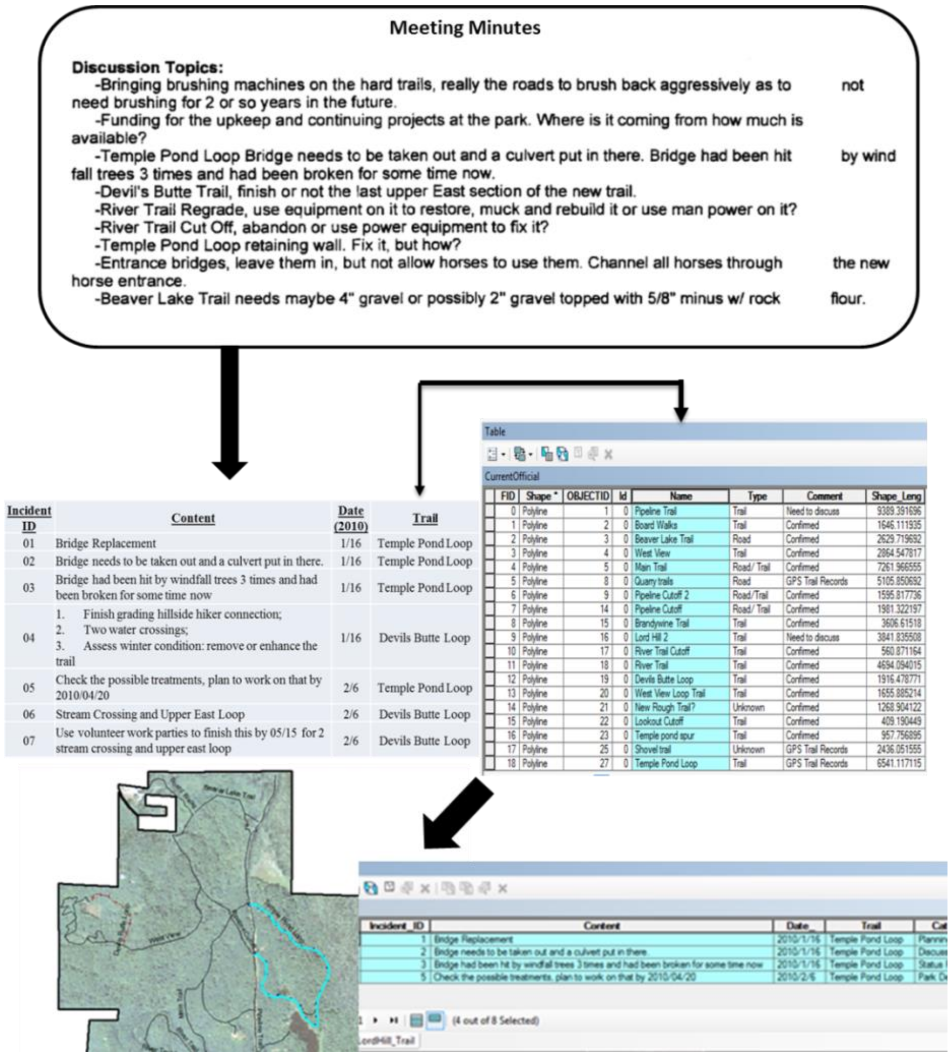
1. browse all meeting minutes,
2. clip the related text pieces,
3. match these text pieces with focused trail, parks, or other facilities,
4. group these text pieces with themes and order these contents chronologically,
5. summarize these contents into numerical values, and
6. connect these values into GIS layer based on the summarized tables.

During this information assessment process, the percentage of original information used and stored are varied based on the manager or staff who is responsible for processing these meeting minutes.

After arranging these meeting minutes of trail maintenance based on SDU (trail segement),

[22] PNEDN is the abbreviation of the Pacific Northwest Early Detection Network.
[23] Attribute tables is a tabular file that attached with a GIS vector layer (a set of geographic features). Usually one geographic feature attached one row and different attached data is recorded into various columns.

LHRP's meeting minutes have been transferred into tabular records that are arranged by each trail (Appendix F). It seems that over 90% of the records can be transferred, besides for the records that do not have any location information for identifying trails. Since the trail is the spatial object that can be delineated into GIS information, the tabular organized meeting minutes can be connected to GIS through a trail segment GIS layer.[24] After using SDUs to organize the meeting minutes, this arrangement saved the first three steps of processing original meeting minutes and increase the efficiency of report processing. Figure 5-1 shows the process of transferring meeting minutes into GIS-connected records.



Meeting Minutes

Discussion Topics:
-Bringing brushing machines on the hard trails, really the roads to brush back aggressively as to not need brushing for 2 or so years in the future.
-Funding for the upkeep and continuing projects at the park. Where is it coming from how much is available?
-Temple Pond Loop Bridge needs to be taken out and a culvert put in there. Bridge had been hit by wind fall trees 3 times and had been broken for some time now.
-Devil's Butte Trail, finish or not the last upper East section of the new trail.
-River Trail Regrade, use equipment on it to restore, muck and rebuild it or use man power on it?
-River Trail Cut Off, abandon or use power equipment to fix it?
-Temple Pond Loop retaining wall. Fix it, but how?
-Entrance bridges, leave them in, but not allow horses to use them. Channel all horses through the new horse entrance.
-Beaver Lake Trail needs maybe 4" gravel or possibly 2" gravel topped with 5/8" minus w/ rock flour.

Incident ID	Content	Date (2010)	Trail
01	Bridge Replacement	1/16	Temple Pond Loop
02	Bridge needs to be taken out and a culvert put in there.	1/16	Temple Pond Loop
03	Bridge had been hit by windfall trees 3 times and had been broken for some time now	1/16	Temple Pond Loop
04	1. Finish grading hillside hiker connection; 2. Two water crossings; 3. Assess winter condition: remove or enhance the trail	1/16	Devils Butte Loop
05	Check the possible treatments, plan to work on that by 2010/04/20	2/6	Temple Pond Loop
06	Stream Crossing and Upper East Loop	2/6	Devils Butte Loop
07	Use volunteer work parties to finish this by 05/15 for 2 stream crossing and upper east loop	2/6	Devils Butte Loop

Table

CurrentOfficial

FID	Shape *	OBJECTID	Id	Name	Type	Comment	Shape_Leng
0	Polyline	1	0	Pipeline Trail	Trail	Need to discuss	9389.391696
1	Polyline	2	0	Board Walks	Trail	Confirmed	1646.111935
2	Polyline	3	0	Beaver Lake Trail	Road	Confirmed	2629.719692
3	Polyline	4	0	West View	Trail	Confirmed	2864.547817
4	Polyline	5	0	Main Trail	Road/ Trail	Confirmed	7261.966555
5	Polyline	8	0	Quarry trails	Road	GPS Trail Records	5105.850692
6	Polyline	9	0	Pipeline Cutoff 2	Road/Trail	Confirmed	1595.817736
7	Polyline	14	0	Pipeline Cutoff	Road/ Trail	Confirmed	1981.322197
8	Polyline	15	0	Brandywine Trail	Trail	Confirmed	3606.61518
9	Polyline	16	0	Lord Hill 2	Trail	Need to discuss	3841.835508
10	Polyline	17	0	River Trail Cutoff	Trail	Confirmed	560.871164
11	Polyline	18	0	River Trail	Trail	Confirmed	4694.094015
12	Polyline	19	0	Devils Butte Loop	Trail	Confirmed	1916.478771
13	Polyline	20	0	West View Loop Trail	Trail	Confirmed	1655.885214
14	Polyline	21	0	New Rough Trail?	Unknown	Confirmed	1268.904122
15	Polyline	22	0	Lookout Cutoff	Trail	Confirmed	409.190449
16	Polyline	23	0	Temple pond spur	Trail	Confirmed	957.756895
17	Polyline	25	0	Shovel trail	Unknown	GPS Trail Records	2436.051555
18	Polyline	27	0	Temple Pond Loop	Trail	GPS Trail Records	6541.117115

Incident_ID	Content	Date_	Trail	Cat
1	Bridge Replacement	2010/1/16	Temple Pond Loop	Plannin
2	Bridge needs to be taken out and a culvert put in there.	2010/1/16	Temple Pond Loop	Discuss
3	Bridge had been hit by windfall trees 3 times and had been broken for some time now	2010/1/16	Temple Pond Loop	Status
5	Check the possible treatments, plan to work on that by 2010/04/20	2010/2/6	Temple Pond Loop	Park De

(4 out of 8 Selected)

LordHill_Trail

Figure 5-1. The process of turning original textual meeting minutes into a GIS-ready table includes: 1) group textual records based on trail (SDU), 2) saved into tabular format (e.g., Excel spreadsheet), and 3) relate (build cross-reference from) the report table to layer attribute table and 4) display these records in ArcGIS.

---

[24] The table will be connected to trail GIS layer based on the trail name. Use the "Relate" function in the GIS can help to bridge their table information and GIS layer.

Beyond the meeting minutes, the SDU can also be used to form the connection between decision-making and human-driven PGIS (HPGIS) project. The Snohomish PRD started a HPGIS project[25] in 2010, and I was the coordinator who conducted it as a UW capstone project[26] with Snohomish PRD needs. The project started to simulate possible trails (Figure 5-2 Simulated Trail Map(b)) by using the digital elevation model (DEM) with 3-foot resolution.

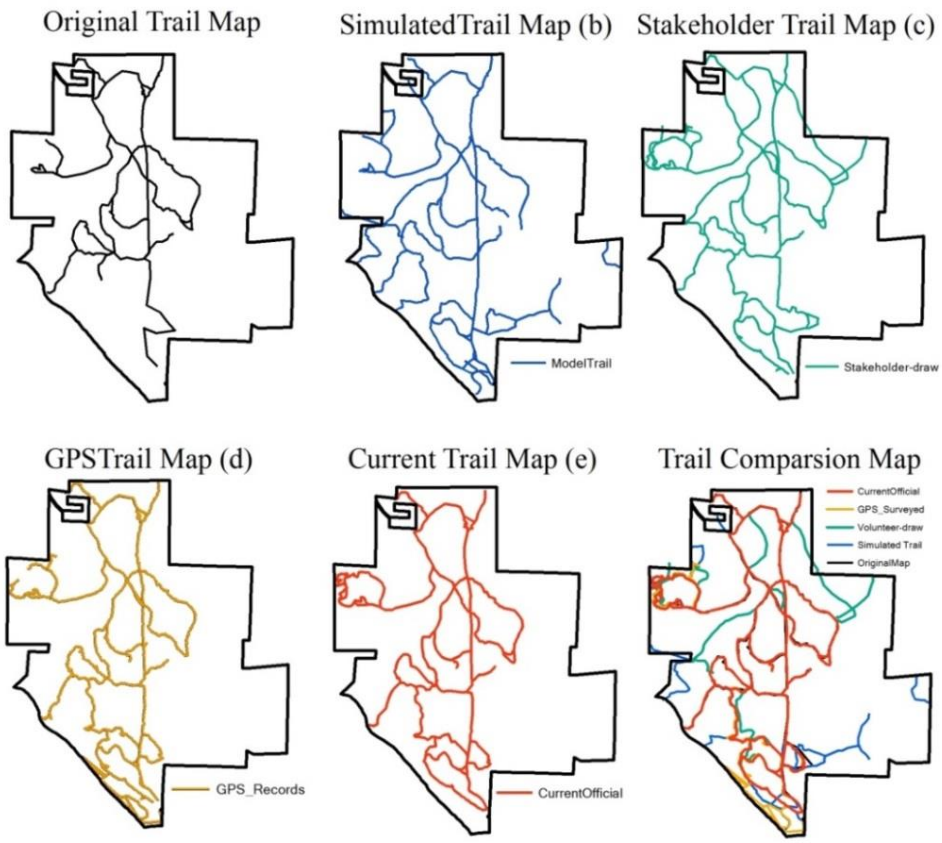


Figure 5- 2. Using trail as the SDU to integrate different types of results: (a) orginal hard copy delineated from Snohomish PRD; (b) scientific simulated results from high resolutation DEM , (c) stakeholder drawing from Face to Face PGIS results, (d) GPS records collected from ranger , (e) final offical map delinated from Snohomish PRD, and (f) the comparsion among these trail map records. Using trail segments as SDUs bridge different types of data with same comparable interface (maps).

25 This situation is because the Lord Hill Regional Park (LHRP) was commercial forestland before it was turned into a park; many of the roads here were developed for logging usage in the past. Depending on different purposes, the road width in the LHRP ranges from 6 to 12 feet and some of these roads are not treated as trails for public use. When there is a transition of a manager, a planner, or even a ranger position, the new administrative levels may be unfamiliar with the LHRP roads and trails, since some trails are not shown in the park trail map.

26 UW capstone project hosted in the Geography Department is a quarter-based course (GEOG469/569 GIS Workshop). This course invites real-case proposals from local government, non-profit organizations, and other research institutes who have a short-term GIS project to achieve. I was the client representative to Snohomish PRD in 2010 and also collaborate with three undergraduate students in Geography Department to conduct this FPGIS project for three months (April to June).

After that, main stakeholders were invited to verify and correct the map in two workshops. In the workshops, the participants were asked to draw and correct simulated results (Figure 5-2 (c)). Adding content for each trail (e.g., surface [paved/unpaved], width, slope) was encouraged. Because all records and drawings are based on the same SDUs (trail segments), the Snohomish PRD can easily organize the information and survey these new trails on their own (Figure 5-2 (d)) without organizing stakholder meeting minutes again. A second version of the LHRP official trail map was made (Figure 5-2 (e)). Although the updated official map has eliminated some trails[27] (around 10-15%) that are close to the neighborhood residents or unofficial trails, called social trails (Figure 5-2 (f)). Using trail segments can integrate various types of information (e.g., hand-draw maps, GPS records, modeled results, and original maps) and store that in the system. Beyond that, the new map creates a direct connection between management tasks (e.g., obtain precise GPS routes) and the updated information. Besides the capacity of using a common unit to reorganize all types of information, this research case enabled examination of the difference between using SDUs and GPS points. To make the comparison, the Weed Watcher program's interface (i.e., using trail and lake as SDUs) was compared with the interface of EDDMapS (i.e., using species as the unit and record GPS coordinates when connecting to GIS).

The second test of SDU compares the search ability of two invasive reporting systems. The search used in this comparison is to find all invasive species reports within King County with spatial information (e.g., GPS, trails, parks, ownership boundaries). The search results can help managers plan control treatment for invasive species in their jurisdiction. Based on the search range, records of both systems were downloaded. Search interface capability, time spent for information retrieval process and, results were compared based on the three measurements described in section 5.1.1.

The spatial decision units used in the KCWW program are trails. By contrast, EDDMapS uses GPS coordinates and county boundaries (no spatial decision units) to categorize VGD. Although the KCWW program uses only a textual filter that categorizes data according to trail (lake), trail group, and land manager as their web search interface, users can locate the trail and land managers and submit a query in approximately 0.5 to 5 minutes, depending on the familiarity of the area. The retrieval results arranged according to query are downloadable to an Excel spreadsheet. Because the records are attached to the closest trails, the content can be visualized based on trails. A search of the entire King County database yielded 766 records, over half of which contained GPS coordinates for exact locations. A search of the abundance of information

[27] The second workshop was held to clarify the information usage and the relationship with decision making. From the discussion, it was found that some of these trails may affect privacy and security issues with the residents. The Snohomish PRD decided not to list these trails to the official trail maps.

revealed 490 species. Finally, the records were collected by 33 volunteers. Data search, retrieval, and use were estimated to require less than one hour in the KCWW program system.

The EDDMapS system offers a map-based interface that enables users to easily search for information. For the same search area, the system provided a list of 416 species, but each species had a different webpage and information had to be retrieved separately. I spent 3 hours reviewing each web page to download data for my needs. To resolve this problem, I requested an advanced query tool from the EDDMapS technition; this tool is similar to the KCWW program interface and enables searches to be completed in 0.5 minutes to 3 hours, depending on the user's familiarity with the interface. Furthermore, the records in EDDMapS are grouped and stored according to species. In some records, county was used as the spatial reference, whereas GPS coordinates were used in other records. I spent one-half hour reorganizing these materials. County boundary was the finest scale among all records, and no finer resolution was provided for management activities or routine decisions. Finally, regarding the abundance of information (although EDDMapS contained 1,207 records, of which 156 included GPS coordinates), only 4% of the species (20/455) can be located using GPS records. Finally, only 12 reporters provided information, and nearly all GPS records (94.87%) were collected from a single reporter, the United States Geological Survery (USGS) Nonindigenous Invasive Species Database. Data search, retrieval, and use were estimated to require approximately a few hours to a few days in the EDDMapS system. As to the KCWW program, all reports are generated through 33 volunteers (weed watchers) and GPS records are contributed from 30 volunteers. In sum, with the same time spent, using SDUs can connect these records to the GIS and enhance search results with the same searching process.

5.2.2 Capacity of various structured inputs

The various degrees of structured stakeholder inputs can be categorized into three types of structured inputs (pp.27). The LHRP meeting minutes organized by SDUs (freeform), trail reporting form for the LHRP (semistructured), and trail reporting form for the WA-DNR's Forest Watcher program (highlystructured) were compared. Using the free-form format, no limitations are imposed on nonstructured meeting minutes (grouped according to trail); thus, they adequately represent participant needs. However, free-form meeting minutes do not enable managers (or other data users) to make decisions easily. The stakeholder inputs that managers received must be assigned to responsible people to define necessary tasks and to denote their own needs. In addition to a long processing workflow, these reports are easily mistransferred if they are not managed carefully. Compared with the other structured inputs, the free-form meeting minutes exhibit poor accuracy in matching stakeholder inputs with the needs of staff and managers for management activities and decisions. The diversity of stakeholder inputs prevents them from being transformed into a summary of numerical values, although integrity can be maintained in transferring textual content.

In cooperation with volunteer leaders and Snohomish PRD rangers I designed, implemented, and deployed the semi-structured form that was subsequently approved by upper-level managers. The semi-structured form categorizes stakeholder inputs based on management tasks and provides a first level organization so users can evaluate and plan future actions. To segregate different functions of reports, several categories[28] are used in this report form to increase the efficiency and accuracy of reports transferred. These categories can typically be grouped into routine management, scheduled events, or status reports. Regarding the description of trail status, the LHRP semistructured form provides textual space in which volunteers can describe observations (the left side of Figure 5-3). Because the semistructured form must be read individually, it cannot achieve efficient processing measurements. Although the semistructured form can be used to transfer information to staff members or managers and retain trail status descriptions, it fails to provide an efficient method for processing information.

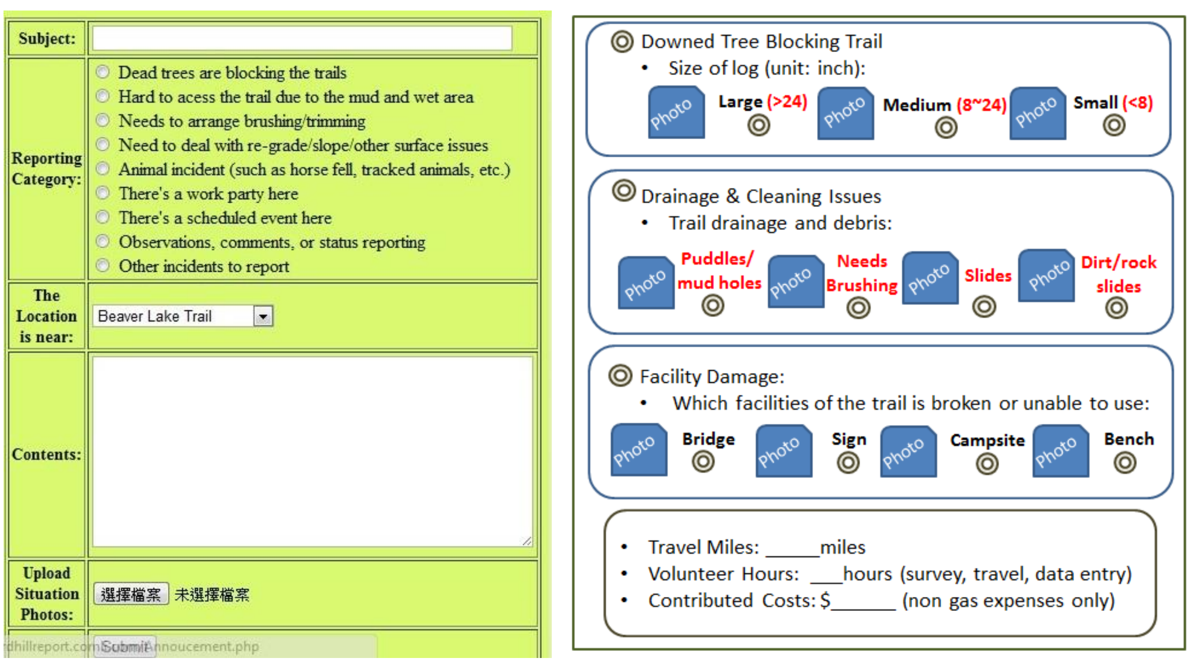


Figure 5- 3. LHRP semi-structured form includes reporting categories but uses a blank content area for reporters to describe incident in detail (left). Compared to that, WA-DNR Forest Watch's form breaks down work tasks into detail selections for a reporter to select (right).

[28] These categories can be grouped into (a) routine management (e.g., dead tree blocking, trail surface cleaning, and animal incident), (b) scheduled announcements (e.g., work parties or park events) for public to participate, and (c) status reports for integrating existing records for future uses.

With fewer staff, the WA-DNR was interested in the LHRP reporting form, but asked for a more cooperative design to process reports without reading individual report. Ideally, they expected that all of the reports can be summarized and structured into a table, and can be turned directly into to-do lists. Based on this request, I developed the highly-structured reporting forms with the WA-DNR's cooperation. Finally, the highly structured form (in the WA-DNR case) categorizes all possible decisions or management activities into selectable options that volunteers can select. The highly structured form enables stakeholder inputs to be transformed into numerical values directly because all possible reporting categories are selectable options, and enables stakeholder inputs to be processed and transferred to appropriate staff members or managers efficiently and accurately. For example, the tree-block trail reporting section in the trail maintenance reporting form (the right side of Figure 5-3) listed various size logs (with photos) for a reporter to select. Different log sizes will require different treatments so WA-DNR staffs can arrange proper management actions. However, because all options are predefined, volunteers can only report their observations based on limited selections. When the status is complex or a combined incident requires more then one selection, it may create biases and affect the credibility of the stakeholder inputs .

The first portion of the case focused on comparing the efficiency and participation space of various structured forms, but each agency has a unified reporting form. Compared to one unified form for reporters to report, the EDDMapS uses two reporting forms in different interfaces. The first form (the left side of Figure 5-4) is used in the website reporting with detailed data entries in a file-based format (called *Bulk Data Entry*[29]). This type of form is mostly made by land managers, agencies, or research institutes that can collect detailed information for each report. The second form (the right side of Figure 5-4) is developed within the mobile application for their volunteers or public reporters. This form includes species, GPS locations, photo, time stamp, and infested area estimation.

The report form for public reporters used in the mobile application version is easy to operate. Any reporter without experience can still report their observations by taking photos and submitting to the EDDMapS. Easy-to-operate strategy can eliminate the knowledge gap of participants and increase the number of reports. However, the EDDMapS webpage showed some inconsistencies. For example, the Japanese Knotweed search page showed at least three different reporting contents. The first reporting content is collected from existing scientific records (Herbarium/Literature). The second reporting content comes from the detail reporting form. The

[29] Based on the EDDMapS website, the bulk data entry has been used for multiple record reports. It is easy for a reporter (or organizations) that collect hundreds or thousands of data points to format the data and sent to the EDDMapS directly.

third record is collected using a mobile application. Compared to these three types of records, existing records (Herbarium/Literature) do not have any GPS location, and the mobile reports did not have detailed description of plant and status. To organize these different types of information, restricted rules or a well-defined database system is needed. However, all of them are compiled into one file, and thus various inputs may limit the ability of further analyses.

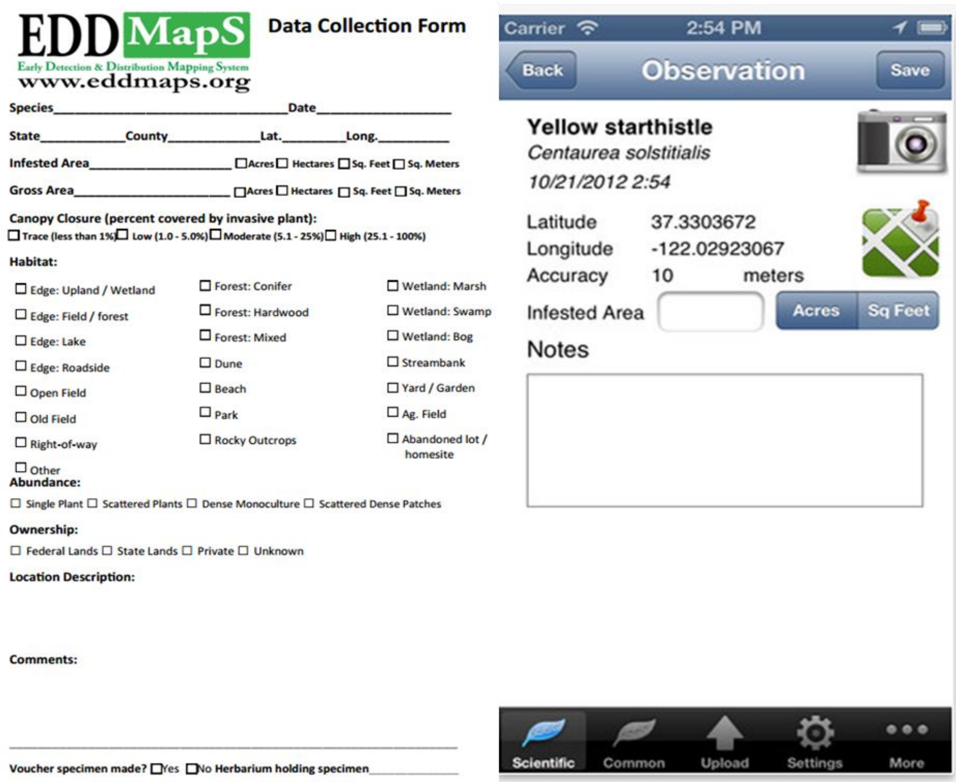


Figure 5-4. Two EDDMapS reporting forms: (left) expert with (right) public versions. Expert version of reporting form has growth area, habitat, ownership, and various fields to fill. The public version of mobile applications only reports the infested area and blank notes.

5.3 Result B: Capacity of Database Models

Database models (schema content and structure) organize inputs from data collection and structure searches (queries). Testing if information arranged with SDUs increases effiency of queries, this effort compares KCWW program (using SDUs as their data collection) to EDDMapS (without using SDUs). To conduct possible database model comparisons, this effort uses front-end search results and data collection forms to delineate possible data model. After that, an Entity-Relationship Diagram (ERD) is used to depict the relationship among each entity (Figure 5-5 and Figure 5-6). After the database model has been delineated, assessment results are carried out based on the ERD analysis.

A registered user can choose either to use Excel spreadsheets (bulk data entry) or mobile application to generate their reports in EDDMapS system. However, it appears that the reporting forms from these two collections are different. Instead of using a better data organization to merge forms, EDDMapS just arranges these two forms together and leaves many blanks in the data sheets. Seven different search results can be generated through the “Distribution Map” of their website for various uses. In the distribution map, if an invasive species is found, it will been marked based on county or state level for existing records without GPS coordinates. Newer data collections that have GPS coordiantes can be transferred into a GML layer, and use Google Map to visualize. The Excel spreadsheet is generated based on each species with each record regardless the county or state. Finally, detail records (called list) are based on the species but can be filtered by county, but there is no other summarized results generated through the EDDMapS (Figure 5-5).

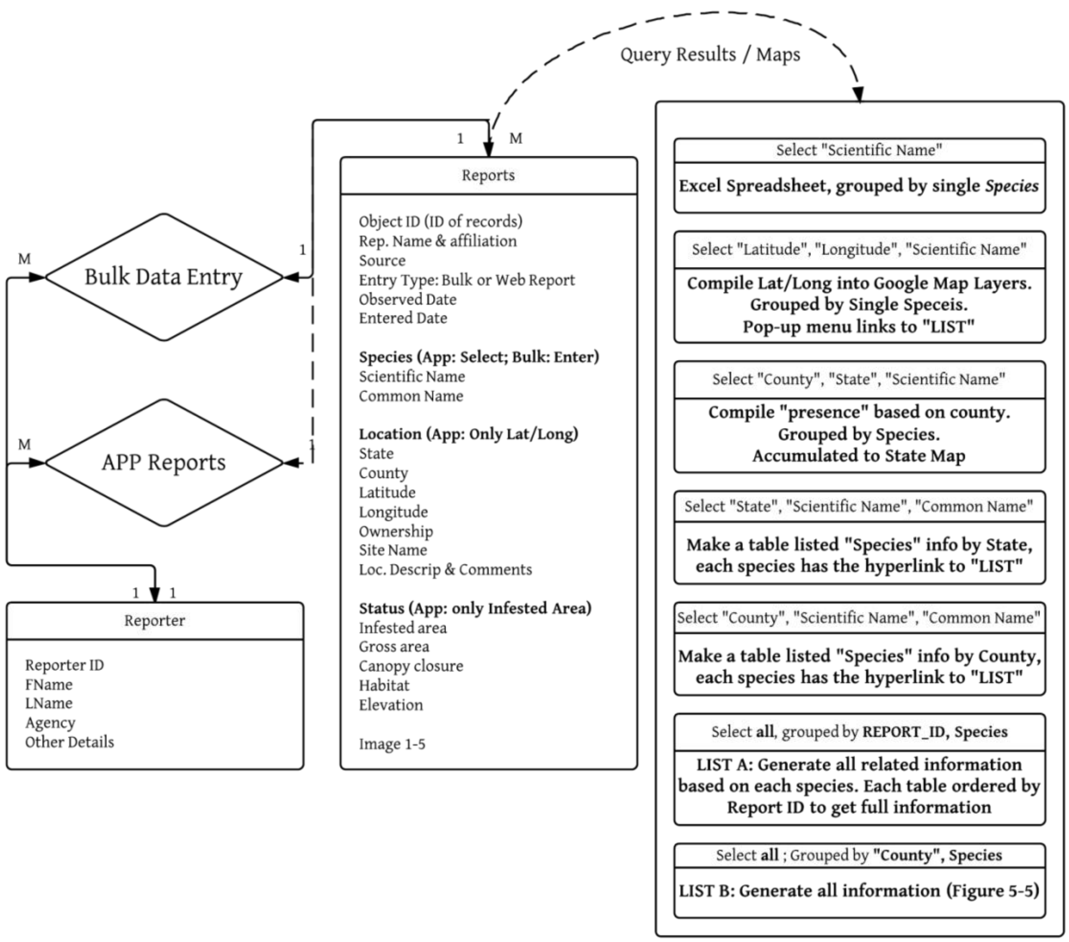


Figure 5-5. The EDDMapS Entity Relationship Diagram (ERD). The diagram includes data entry (application reports and bulk data entry) to tables of records, as well as possible queries/maps generated from these records. There is no SDU used in the EDDMapS.

Trail ("Trail List") has been used as SDUs in KCWW system to organize data inputs. Each trail also has a specified ownership so it is easy to connect reports to land managers. Unlike the EDDMapS with maps, the KCWW program did not provide any map as their representation, but maps could be easily connected to this database. These tables can include summarized values (Summmary Reports) or individual records (Trail Detail Report, Survey Data, and Trail List). Four types of records can be generated that serve clear purposes (Figure 5-6), which include volunteer annual efforts, detail reports, invasive survey data, and trail lists[30]. A finer query allows a user to customize a search with precise results.

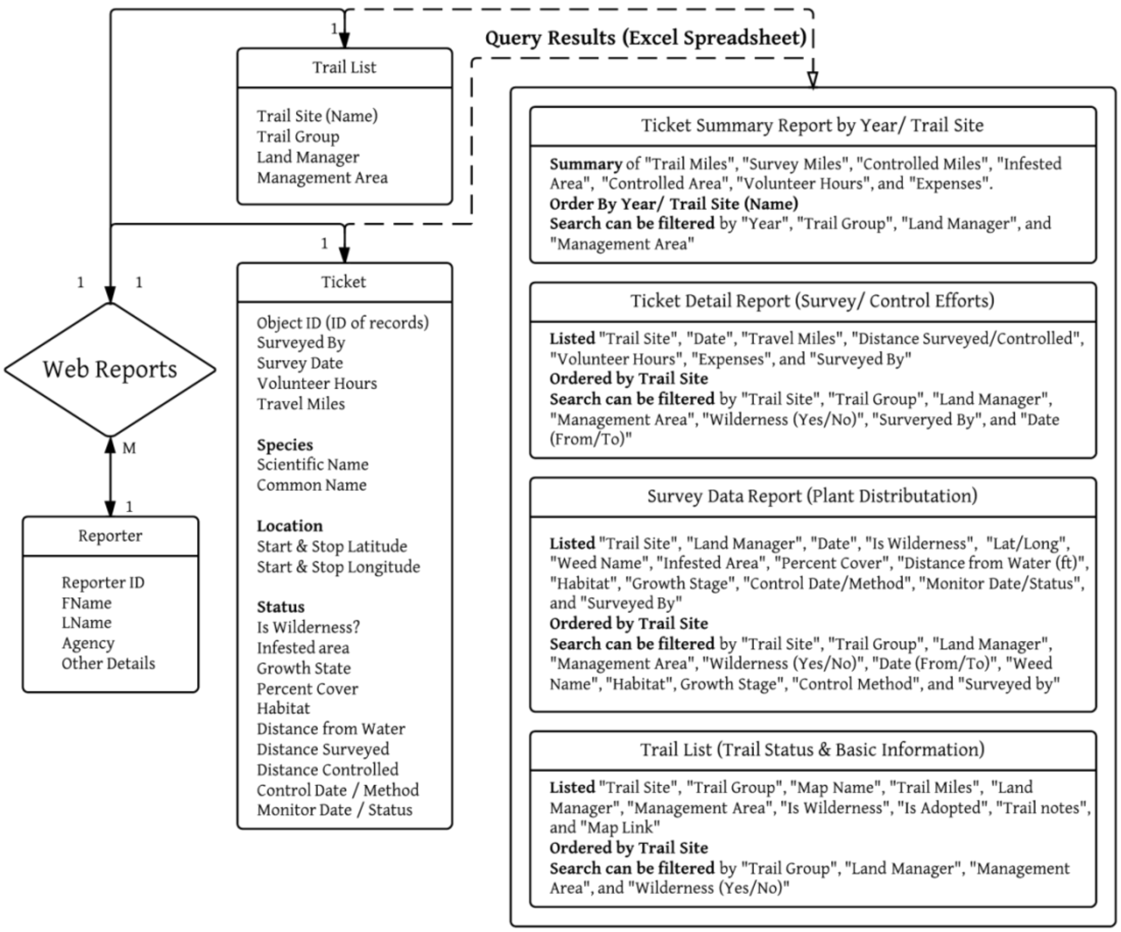


Figure 5-6. The Weed Watcher ERD. It has one data input (web reporters) only and the trail list has been used to assist the reporting and data processing mechanism. Each report is called a ticket. More possible queries and maps can be generated when compared to the EDDMapS.

[30] As to summary reports by year or trail site, the manager can understand annual efforts that have been invested by volunteers. With the individual record table, the ticket detail report is designed for reporters to modify existing reports. Most related to KCWW program is the survey data report. The survey data report includes evey detail information of invasive plants and it includes more information than the EDDMapS. The last report called trail list report is to show the status of trails of volunteer adoption and stewardship status.

To compare the database model quality between these two cases, three categories of quality assessments has been applied (section 5-1-2). In the *intergration* category, a measurement can be made by counting how many connections are incomplete or whether there is a gap with connecting existing records to the GIS. Three different types of maps of EDDMapS represent information that can be connected to GIS, but none of these maps contains complete information because there is no unified geographical scale for data collection. Further than that, because there is no connection between management (ownership) and these geographic scales (such as GPS, county, and state boundary), it is hard to make decisions based on these geographic scales. The KCWW program uses trail as SDUs to provide unified geographic scales for data collection. Also, SDUs can be stored as a GIS feature class and linked to geodatabase seamlessly. With this connection, the user can visualize various summarized results based on different trails. More easy-to-use interfaces can be constructed based on this seamless connection. Since the GPS coordinates are only required for some species, the points layer can be generated and coordinated with the trail from the GIS interface.

The second category of this comparison is *completeness* factor with three measurments. The first measurement compares how much collected data can be queried and generate results. In the EDDMapS system, four of 179 fields (2%) are used to generate query results. Even in the advanced query tool, only nine fields out of 179 fields (5%) are used to generate queries. The KCWW program, however, thirteen of twnety-eight fields (46%) can be used to generate queries. The second measurement measures how many different types of summarized table can be generated through searches. The EDDMapS can only summarize by two fields (the number of records and registered reporters) and produce two summarized tables. The KCWW program, however, can summarize seven different types tables (see trail summary report in Figure 5-7). The third measurment measures how many purposes can be generated from information. The EDDMapS can provide species presense/absence information only. The KCWW program provides four purposes, whick include trail status (being steward or not), plant distribution (presense/absence), control efforts tracking, and summary of survey efforts. Both systems provide an information sharing (downloadable Excel spreadsheet) service.

The last category compares the *correctness* of a database model and records. To avoid “null” values in a record, it is suggested that data inputs should be unified and the blanks are expected to be as few as possible. In the EDDMapS, since there are two different data inputs, fields that have different standards (required or optional) triggers incomplete records. On the other hand, the KCWW program web form designed in the website has the same rules of required fields so incomplete records will not be stored. The data model quality comparison between EDDMapS and KCWW program showed that using SDUs not only unified geographical scales but also link these scales to management directly. Regardless, the amount of data collection, maximize the uses of information and enhance the quality of data completeness will be key to similar data collection practices.

5.4 Result C: Interface usability assessment results

5.4.1 Public reporting website usability evaluation

EDDMapS was compared with the other two existing websites (i.e., What's Invasive and ParkScan) using the comparison framework mention in Table 5-1 (pp.37-38) because EDDMapS is the only case in this research that provides a map service on their website. The first comparison in this section is conducted by me as an expert perspective. Three different categories have been used to examine the capability of the EDDMapS. Three categories of comparisons are: query capacity, map services, and reporting navigation.

EDDMapS appears to have the highest score in the query capacity category (three criteria with seven measurements, see Table 5-1 for detail) through providing great download services. However, two major drawbacks were found in EDDMapS. First, searching in EDDMapS (more than four clicks) takes double the clicks rather than the two of other websites (e.g.,, ParkScan). Second, incomplete records will be received from EDDMapS although it collects a huge amount of reports. Generally speaking, all map-based searches should be enhanced because every website serves less than five types of searches. In terms of map uses (map services category, two criteria with five measurements), it appears that EDDMapS incorporated less than 40% maps throughout their overall web pages compared to ParkScan's website. As to the cartographical design, maps in these three websites have a clear legend, but the EDDMapS did not explain the completeness of data records from their maps.

Finally, the reporting navigation comparison (three criteria with six measurements) showed that although EDDMapS creates multiple ways (online form, web application, excel spreadsheet, etc.) for users to collect information, all data collections forms are not the same and require specific knowledge to complete. ParkScan only uses one form but keeps the reporting process simple and easy. To deal with knowledge gap issue, EDDMapS provides a large amount of education materials and useful Q&A section to direct a lost user back to a right direction. The assessment summary is listed in Table 5-2 with the scores, and full assessment report is in Appendix G. Compared with the "ParkScan" and the "What's Invasive" websites, the usability of the EDDMapS is right at the middle, receiving lower scores than ParkScan website. The ParkScan website defines its purpose very clearly: only park incident reporting, responding, and status checking. Although EDDMapS tends to provide more functions than the ParkScan, their data collection with different forms causes poor search capacity and data collection quality. Despite having a poor search capacity due to lack of data collection, EDDMapS did provide a robust data-sharing mechanism.

Table 5- 2. Heuristic (expert) evaluation result for website interface usability includes map services, query capacity, and report navigation categories. ParkScan, EDDMapS, and What's Invasive cases were compared and evaluated. The EDDMapS has a 78% score, which is between ParkScan (84%) and What's Invasive (68%).

	ParkScan	**EDDMapS**	**What's Invasive**
Map Service	**98%** (24.5/25)	**74%** (18.5/25)	**64%** (16/25)
● Cartography	10/10	8/10	10/10
Clear legend & reasonable theme maps	5	5	5
Explanation of map use	5	3	5
● Map Functions & Proportion	14.5 / 15	10.5/15	6/15
Map proportion (%) of website	4.5	4.5	4
Functionality of maps	5	3	1
Connections between maps and website	5	3	1
Query Capacity	**71%** (25/35)	**80%** (28/35)	**60%** (21/35)
● Search Capacity	13/15	10/15	11/15
Theme/Location search	5	5	3
Number of clicks to results	5	4	3
Connection between Inputs & Results	3	1	5
● Extension and Existing Capacity	10/10	8/10	8/10
Extension to map system architecture	5	3	3
Static/Interactive Maps	5	5	5
● Data distribution capacity	2/10	10/10	2/10
Downloadable Content	1	5	1
Data distribution (to other sources)	1	5	1
Reporting navigation	**82%** (24.5/30)	**80%** (24/30)	**80%** (24/30)
● Navigation Design	10/10	6/10	8/10
Clear Navigation	5	3	5
Easy to use	5	3	3
● Education & Training	7.5/10	9/10	6/10
User instructions	4.5	4	3
Media of educations	3	5	3
● Q & A Sections	7/10	9/10	10/10
Q & A Sections	4	5	5
Channels of trouble shooting	3	4	5
Average percentage	**84%**	**78%**	**68%**

5.4.2 Invasive species reporting applications

Compared to websites, mobile applications require a more delicate design because there are less movement options (e.g., click and slide) and interface spaces than on websites. To understand if similar mobile applications for invasive species reporting have similar designs, nine mobile applications (Appendix C) were compared and the two most significant were chosen for assessment. The possible user actions of these two mobile applications were depicted by an UML behavior model (Figure 5-7). This behavior model captures how users use web applications to report their sightings for invasive species. These behaviors include (a) downloading and login, (b) reporting, and (c) visualizing real-time invasive distribution from map services.

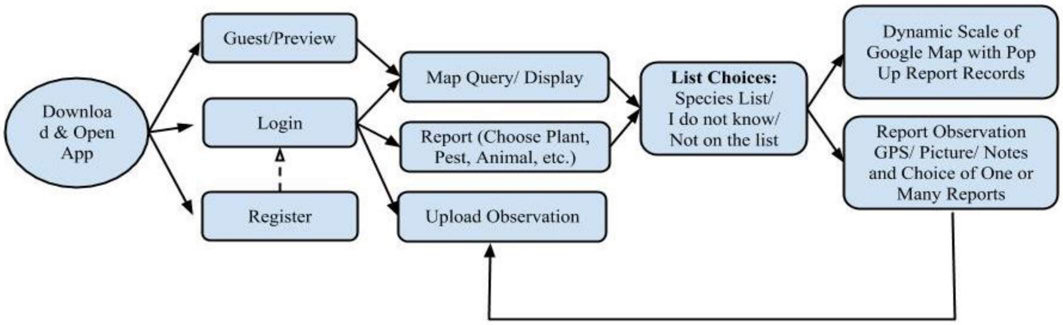


Figure 5- 7. UML behavior model is to characterize the possible behaviors in invasive reporting mobile applications. Overall, behaviors of these applications include user login, map display, generating reports with species navigation, and the upload option to submit reports.

After user behavior with the web application was characterized, a usability comparison was developed with four categories (e.g., user management, reporting navigation, and map services) and turned into ten questions through online questionnaire. This questionnaire was available for one month, wherein fourteen stakeholders participated (out of thirty invitations). Every stakeholder was tasked to download and test PNEDN and PlantTracker web applications (see 5.1.3, pp.38) and answered questions that compare designs (see detail assessment result in Appendix H).

In regards to comparison of user management, stakeholders expressed preference for a login system (57.1%, see Table 5-2). Although it might take time for a user to register, this registration enabled data manager tracking about who is reporting what information. Almost thirty percent of the responses prefer the no login arrangement and they believe that this arrangement helps to attract more people to contribute in invasive plant reporting activities. To reduce the knowledge gap of plants identification, even though having plant picture is useful for users, over two-thirds of participants (71%) felt more information is needed to help them identify plant species. When using photos as an aid, not only a photo about the plant was needed, users asked for the land cover (26%) and immediate surroundings as well as bodies of water (24%), are two extra photos that should be provided. To search species, better navigation is required. Submitting a long list of several easy-to-use lists based on different classifications was also desired. These classifications can be taxonomy, nature habitats, or existing physical boundaries (e.g., lake, county, trail, park boundary). Visualizing results is preferred (86%), and over fifty percent of respondents think current mapping services (map species distribution by species) is good enough. However, some responses (29%) suggest mapping infestation area by invasive species (coverage) could be useful. To enhance map representation, over eighty percent responses suggest to use different theme maps (see detail in Appendix H). Finally, a map should either zoom in/out based on full extent of query content (35.7%) or based on the exact location of reports (35.7%). The summary of usability evaluation results is shown in Table 5-3.

Table 5- 3. Mobile application (PNEDN and PlantTracker) interface's usability evaluation result includes user management, report navigation, and map services criteria. This summary provides numerical statistics about the counts and percentage of total counts. Detail evaluation results are in the Appendix H.

<table>
<tr><td colspan="12">User Management: Is the user login required?</td></tr>
<tr><td colspan="4">Login-PNEDN</td><td colspan="4">No Login-PlantTracker</td><td colspan="4">Others</td></tr>
<tr><td colspan="4">8 (57.1%)</td><td colspan="4">4 (28.6%)</td><td colspan="4">2 (14.3%)</td></tr>
<tr><td colspan="12">User Management: Motivation to keep user reporting</td></tr>
<tr><td colspan="6">See reports has been updated to the results</td><td colspan="6">Top 10 Reporters will be listed to the website</td></tr>
<tr><td colspan="6">11 (78.6%)</td><td colspan="6">3 (21.4%)</td></tr>
<tr><td colspan="12">Report Navigation: If current application is good for selecting species of reporting?</td></tr>
<tr><td colspan="3">EDDMapS is enough</td><td colspan="3">PlantTracker is enough</td><td colspan="3">Extra species information</td><td colspan="3">Extra location information</td></tr>
<tr><td colspan="3">0 (0.0%)</td><td colspan="3">4 (28.6%)</td><td colspan="3">6 (42.9%)</td><td colspan="3">4 (28.6%)</td></tr>
<tr><td colspan="12">Report Navigation:</td></tr>
<tr><td colspan="2">Growing land cover (Grassland)</td><td colspan="2">Immediate surroundings (Water)</td><td colspan="2">Non-invasive species at same habitat</td><td colspan="2">Approximate growth from last reporting</td><td colspan="2">Near to roads (pathway)?</td><td colspan="2">Current plant stage (is it seeding?)</td></tr>
<tr><td colspan="2">10 (26.3%)</td><td colspan="2">9 (23.7%)</td><td colspan="2">6 (15.8%)</td><td colspan="2">5 (13.2%)</td><td colspan="2">5 (13.2%)</td><td colspan="2">3 (7.9%)</td></tr>
<tr><td colspan="12">Report Navigation: Reporting measurements</td></tr>
<tr><td colspan="6">Real-life Unit (1 cubic = xx pizza boxes)</td><td colspan="6">Regular Unit (Acre/Sq. Feet)</td></tr>
<tr><td colspan="6">6 (42.9%)</td><td colspan="6">8 (57.1%)</td></tr>
<tr><td colspan="12">Map Services: Is map required for reports representation?</td></tr>
<tr><td colspan="6">PNEDN: Maps to show # of reports</td><td colspan="6">PlantTracker: No MAP services</td></tr>
<tr><td colspan="6">12 (85.7%)</td><td colspan="6">2 (14.3%)</td></tr>
<tr><td colspan="12">Map Services: Where to put maps in the mobile application?</td></tr>
<tr><td colspan="4">Accompany with species list</td><td colspan="4">Accompany with management purposes</td><td colspan="4">Beginning, showed the area of infestation (by category)</td></tr>
<tr><td colspan="4">8 (57.1%)</td><td colspan="4">2 (14.3%)</td><td colspan="4">4 (28.6%)</td></tr>
<tr><td colspan="12">Map Services: What is the best extent for maps?</td></tr>
<tr><td colspan="4">Area from your location</td><td colspan="4">Area by legal boundaries</td><td colspan="4">Full extent of query content</td></tr>
<tr><td colspan="4">5 (35.7%)</td><td colspan="4">3 (21.4%)</td><td colspan="4">5 (35.7%)</td></tr>
</table>

Chapter 6: Discussion

Chapter Six is structured into five sections. Section 6.1 discusses findings from cross-case comparisons. Section 6.2 discusses SDU capacities, limitations, and concerns. Section 6.3 discusses different uses of structured inputs. Section 6.4 highlights the connection between SDUs and database structure. The final section discusses findings from interface navigations.

6.1 Cross-case comparisons: four cases and further implication

Four subsections below constitute our discussion of results about cross-case comparison. The discussion starts with the usability of the coding framework. After that, the research is grouped according to findings from cross-case comparisons based on institution, stakeholder, and technology considerations.

6.1.1 Usability of the VGI-RAF

The VGI-RAF aims to provide a way to better situate voluntary reporting within government institutions. Eight aspects from the DSA framework are related to each other. Within the *Social-Institutional Influence* construct (Table 4-1), the *Power and Control* aspect lays out actors in the government and stakeholder groups, with clear responsibilities and power. The *Subject Domain* aspect clarifies the management needs from the government agencies of voluntary reporting system. The *Chosen Participants* and *Rules and Norms of Participation* aspects characterize participation mechanisms because most voluntary reporting systems in this research are initiated from the government with predefined participation arrangement. The two aspects from *Group Participation Influence* construct characterize the behavior of information reporters. *Participants' Expectation* aspect is affected by the settings of voluntary reporting; wherein this aspect affects volunteers' awareness about continuing their contribution. If *participants' expectation* cannot be achieved by voluntary reporting systems, participants might choose their own strategies to participate. Furthermore, *Participants' Knowledge* aspect might influence the credibility and accuracy of the reports. The last two aspects from the *PGIS/VGI Influence* construct reveal pragmatic connections between volunteer reports and existing decision-making. The *Communication channel* aspect defines current information flow within the decision-making process. *Geographic information aids* aspect characterizes the technical capacity of incorporating volunteer reports into existing decision-making process. The following discussions elaborate on these three constructs by considering commonalities and differences when implementing a voluntary reporting system within government agencies.

6.1.2 Institutional features of voluntary reporting system

From the *Power and Control* aspect, it shows that a trade-off exists between participation flexibility versus stability. The LHRP's case is the only case without a formal institutional arrangement. No responsible personnel exist, which creates ample opportunities for stakeholders to participate. However, the participation within the LHRP case is not stable because the Snohomish PRD holds the decision-making power to choose participation mechanisms. Comparing that to the regional stewardship program, the KC-WWP and WA-DNR Forest Watch programs have responsible personnel and official institutional arrangements for participation. Because of the formal setting, the power and responsibilities of government officials and other stakeholders are stable and clearly stated. When expanding the scale from regional to national (e.g., EDDMapS), passive responses will likely replace active interactions within regional programs.

The *Subject domain* of each case shows similar patterns, but the needs for information content are different. An automatically generated summary of all volunteer reports is expected in all four cases. However, this list is useful only when government agencies spend considerable time laying out what information is critical to them. To incorporate this information into the decision-making process, management workflow should be aligned with easy information access. Otherwise, the government may ignore the value of voluntary information.

The other two aspects are similar among the cases. Three different behaviors can commonly be characterized. Data collectors are contributing their knowledge and observations. Rangers and volunteer coordinators are primary data users. Voluntary reports are used to identify management priorities for decision-makers and decide about collaboration plans with partnered nonprofit organizations and/or volunteers. The EDDMapS case has an official agreement with partners to verify volunteer reports. Some unofficial, but face-to-face collaborative activities also exist within the regional programs. The KC-WWP has built an effective information sharing network through sharing GIS reporting interfaces with partner organizations.

6.1.3 Group participants' setting of voluntary reporting system

Within the *Participants' Expectation* aspect, three different patterns have been observed. LHRP's case shows that the local stakeholders become main stewards and provide some passionate involvement to steward the park. However, mismatched expectations between land managers and public stakeholders may spread resources of park management thin and thus waste resources. The regional scale programs become a proper scale to implement voluntary reporting settings. The formalized participation process organized within these programs sets common expectations of the land managers. The stakeholders who share the same expectations will participate. However, at the regional scale, cross-jurisdiction collaboration challenge (Johnson and Sieber, 2013) still exists. Lastly, the EDDMapS case includes limited actions by participants, but uses mobile applications attracting general participation from the public.

Participants' Knowledge aspect is related to the willingness of participation and affects the accuracy and completeness of reports contributed by stakeholders. To make sure the participant's knowledge is qualified, almost all voluntary reporting settings incorporate training materials and some require training. Usability evaluation of training materials and reporting forms are essential in the voluntary reporting system implementation. In the LHRP case, however, we observe that public stakeholders have more knowledge and experiences than managers. However, like the expectation mismatch wherein public stakeholders have enough knowledge, it may not be sufficient for land managers' needs, and thus potentially causes a waste of resources.

6.1.4 Technical impacts on voluntary reporting system

PGIS/VGI Influence construct is used to understand technical impacts of voluntary reporting system implementation based on the communication channels and technical capability. Three of the cases in this research show a direct and regular data processing process for handling stakeholder reports, LHRP case is the only one that is not. Processing reports should be well-planned. No responsible personnel or complex communication mechanism can cause many errors when transferring these voluntary reports. It is necessary to transfer these reports to proper personnel that need this information.

The reporting behavior requires that training involve spatial location plus profession knowledge to generate credible reports. To lower the professional knowledge need, it is possible to use a clickable checklist with easy-to-understand options. The use of GPS can be accomplished through existing mobile applications. However, invasive species reporting requires professional knowledge of plant identification, and knowledge requirement may limit the number of participants. The EDDMapS, however, tends to use mobile applications to reduce the knowledge of operating GPS and simplifies the reporting form by taking photos with simple estimation only. Although the simplified form might reduce the knowledge gap, it might increase the data processing load by requiring integration of different inputs. As to the technical situation, the LHRP case is the only one that lacks the GIS skill training and knowledge. Consequently, it requires an easy user interface that does not require specialized GIS skills. The King County and WA-DNR have GIS skills or a strong GIS center to provide enough support. Only the EDDMapS visualizes their partial reports with Google Earth map service.

6.2 Capacity, limitation, and concerns of using SDUs

Capabilities of using SDU (spatial decision units) for data organization and collection have been examined in the section 5.2.1 of Chapter 5. Using an unified geographical scale to organize information is not a completely new concept. Soil survey uses "map unit" to organize complex soil information through entire United States and the census survey uses "tracts", "block groups", and “blocks” to aggregate demographic and social economic measurements. From another angle, using an unified unit with attached management tasks or program activities helps manager to track the performance of management or program implementation (Kelly 1985). Combining both ideas, SDU within a GIS can be represented as point, line, or polygon based on the objects of management or decision-making to track management performances (Gibbs et al. 1999).

SDU capacity in information processing

Using SDU to organize and visualize textual stakeholder inputs through mapping can update management status and ideally help manager to prioritize their management tasks. It also shows the contribution made from the stakeholders. Choosing SDUs should also consider what might be a noticeable object for a stakeholder to easily report an incident. Using trail as a SDU for park trail maintenance (LHRP case) and invasive species reporting (King County Weed Watcher, KCWW) satisfy both managerial needs and clearness object for users to report. When trails are used as an index, stakeholder inputs can be transferred to the land manager who is responsible for an area. Even within a single park (the LHRP case), categorizing stakeholder inputs based on trails assists managers with filtering information, particularly when they were unfamiliar with the park details. Arranging stakeholder inputs according to SDUs resulted in a substantial increase in data management efficiency, thereby creating an incentive for managers to use this information to improve communication with volunteers.

A second examination tested search capabilities between SDUs and normal geographic features (i.e., GPS coordinates and county boundaries. Two sophsicated stakeholder reporting systems, KCWW program and EDDMapS, were tested with various measurements. It is found that EDDMapS uses different geographic scales (county for historial records and GPS for stakeholder input reports). Different geographic scales within EDDMapS suggests that personnel can only use county boundaries to organize information. Using county boundaries to aggregate information may cause more information processing tasks for land management[31] (Gibbs et al. 1999; Lyons et al. 2008). In addition, the EDDMapS does not provide the transformation between GPS points and county records, users can only have partial information to use even though they can download both records.

Using SDUs to organize stakeholder inputs shortens the data-cleaning process by unifying the spatial information before and after stakeholder inputs collection. The results indicated that using SDUs enabled qualitative results to be connected to GIS, therefore enhancing visualization. Because SDUs are based on management tasks, they shorten data processing and enable

[31] Gibbs, Snell, and Causton (1999) stated, “Monitoring must be done to satisfy some desired state of an appropriate indicator that management is intended to meet.”

information to be matched to associated management tasks.

Concerns: potential costs and pressures

Based on the assumption and hypothesis from Chapter 3, the SDU was proven to bridge qualitative results, management tasks or workflows, and GIS-based scientific information.In addition to bridging the gaps between stakeholder inputs and information needs for decision making, SDUs were associated with several potential costs and pressures. Although SDUs shortens the data-cleaning process, they may exert a negative/possitive influnces on the public image of the government agencies. A manager mentioned that more stakeholder reports means more problems in the area, which leads to a poor performance image to the public in trail maintenance practices. In contrast, in invasive species reporting case, additional stakeholder inputs can create a positive public image for land managers since more reports means land managers understand and control invasive species well. A land manager who collects additional stakeholder inputs on invasive plant species is proactive in eliminating this threat and attempts to gain an understanding of how invasive species can be controlled. Hence, creating SDUs should be considered from a data processing perspective as well as a means of improving a manager's public image.

Second, SDUs may trigger complex administrative workflows pertaining to responses and liability. In the LHRP and WA-DNR cases, if the stakeholder inputs cannot be properly managed, then the land manger may face unexpected law suits because managers failed to handle incidents that happened in the park.[32] Another concern is authority sharing. Certain land managers do not treat stakeholders as equal partners. The manager of the Snohomish PRD (LHRP case) treats stakeholder's trail knowledge as a reference. He orders the rangers to resurvey trails and decides how trails are officially treated within the county park trail. There is no communication with stakeholders who provide their knowledge (pp. 42). One-way data collection may result in staff shortage (in the LHRP case) or scale limitations (nationwide EDDMapS); however, this setting limits communication between land managers and volunteers.

Regarding the regional scales of cases (i.e., the KCWW Program and the WA-DNR Forest Watch Program), managers tend to share responsibilty and authority with volunteers to ensure that the stakeholders are motivated and willing to continue participation in activities. The above results reflect the importance of using decision-making assessment. The assessment process helps a manager to understand how to delineate a proper SDU, and thus avoid overwhelming responses

[32] At a WA-DNR meeting on 2012-11-06, the volunteer coordinator and nature resource managers from the WA-DNR mentioned that, without careful planning regarding liability concerns, stakeholders reporting trail incidents may trigger unexpected risk.

or pressures.

Finally, for most cases, SDU information is not fully complete or is not appropriately updated. When trails are used as SDUs, it is assumed that the existing GIS trail layer or map is completely updated. However, this assumption may not be practical. A complete trail layer may not be applicable in most cases (i.e., LHRP, the WA-DNR, and KCWW programs) because land managers do not want to be responsible for certain social trails that they have not built, thereby creating the jurisdictional barriers mentioned in Johnson and Sieber (2013). This concern should be addressed by building a consortium GIS (i.e., a GIS center in which all agencies collaborate) to maintain a complete trail information set because trail data clearing should be a one-time effort, regardless of the land manager and situation.

6.3 Structured stakeholder inputs: pros and cons

The first test of structured stakeholder inputs reported in subsection 5.2.2 of Chapter 5 revealed that tradeoffs must be made because each structured reporting form features different functions. The free-form meeting minutes provides great flexiblity in enabling participants to describe their focus, regardless of land manager needs. However, reading and reprocessing free-form meeting minutes is a time-consuming drawback, and the risk of mistransferring data is high. The semi-structured form (LHRP enhanced form) uses functional categories to clarify and identify possible incidents that occur on trails. Because the categories are predefined, this form reduces the risk of mistransfer because these categories are associated with the decision-making process. However, this form does not satisfy the most crucial needs of the manager: time saving. Reading each report separately provides few incentives for land managers to adopt this form.

The highly structured form developed for the WA-DNR provides the highest efficiency of processing stakeholder inputs. Because all management activities are seamlessly connected to selectable options in a reporting form, this form connects task orders with stakeholder inputs. In addition, all records can be summarized and land managers do not need to read individual reports. However, creating this form relies on a one-time, massive time investment of characterizing management activities into various selections. The WA-DNR considered the semistructured form to be applicable only if reporters are trained in accurately describing incidents properly (WA-DNR coordinator meeting minutes, 2012). However, processing high numbers of stakeholder inputs requires a tradeoff between data processing efficiency and the integrity of stakeholder inputs. Various levels of structured forms might be selected to fit diverse purposes of stakeholder input collection. The structured form reveals the pattern of interaction between volunteers and land managers, and land managers may need to prioritize and choose structured forms to fit the purposes of their volunteer programs.

The second test reported in section 5.2.2 of Chapter 5 has examined the integration of various types of reports in the same system. The EDDMapS tends to create another reporting form with few fields within the mobile applications for the general public. At the same time, the EDDMapS also has a detailed form (*bulk data* entry) on the website for agencies or partners to complete. The two different types of reports create a successful segregation between public- versus agency-generated information. Because of few fields and no professional knowledge required to fill in the fields, the EDDMapS thought this form may cause less chaos for inexperienced reporters. In addition, the verification mechanism within EDDMapS can easily tackle these reports because it has a different content than the bulk data entry. In the EDDMapS, different structured reporting mechanism helps segregate reports made from different professional knowledge. Keeping two different reporting forms in the EDDMapS system may provide another way to lower participation requirements and knowledge. However, having multiple reporting forms for the same task did not increase the information processing efficiency. Because of the two different reporting contents, it may cause difficulty in future data integration, and leads to possible errors in the reports when lacking well-organized database arrangement.

6.4 SDU connectivity to the database structure

A quality assessment of a database model makes use of "*integration*", "*completeness*", and "*correctness*" factors as criteria for comparing the database model qualities of the EDDMapS and the KCWW programs (subsection 5.3 of Chapter 5). The *integration* factor helps examine whether using SDU provides a direct connection between stakeholder reports and information that can be visualized and stored in GIS. Since the EDDMapS uses multiple geographic scales for their data collection, records will become incomplete since geographic scale differences (i.e., stakeholder reports only include GPS and historical records only include county or state information). This leads to limited queries[33] in their system. The KCWW program uses trail as their SDUs to bridge stakeholder reports in the existing workflows[34]. Based on this arrangement, records can be summarized and traced after control actions were implemented. When reports and activities are organized based on various trails, it is easy to track the connection between reports, management activities, and volunteer efforts. In sum, using a SDU as an entity of a database for organizing information can achieve two results at the same time:

1. integrate with other GIS information, and
2. build a connection between management information needs and collected reports.

[33] Records with county information can only visualize the presence/absence result of species within the county. The GPS records face similar issues of failing to organize these point records within a feasible management scale for analysis.

[34] In the section 5-3 of Chapter 5 (pp.48-49), the KCWW program uses trails as SDUs to organize all three elements so each trail contains land managers' information, E-NGO partners' (if applicable), road condition, etc.

The *completeness* factor examines whether the database model can support the information needs for various users (Moody 1998). Results showed that the EDDMapS collected many fields for reports, but many of them (98%) are not accessible for searches or use. In the EDDMapS, only presence/absence of maps and files with full records can be generated. On the other hand, the Weed Watcher database uses around 46% of the fields collected from the reports arranged by trails. Four types of reports can be generated, and around 10 finer filters can be applied to narrow the results. One reason to explain the poor performance of the EDDMapS database model is the inconsistent inputs. The EDDMapS collects various kinds of records, and many of them have different ways to record the spatial reference and other information. Consequently, that type of data collection causes poor quality for the database model storage and thus poor search results.

Lastly, as to a *correctness* factor, having multiple reporting forms should be accompanied with separate designs in the database model. The EDDMapS merged all possible fields into one giant table, and the records are collected from different forms, and create huge amounts of null values (blanks) throughout the records (see detail in section 5.3 in Chapter 5). Two enhancements need to be made in the EDDMapS. First, unifying existing information into same spatial reference so records can be summarized based on same units. Second, normalization process of records should be implemented to reduce the redundancy and missing data value issues.

Overall, SDUs bridge management acitivities with spatial reference. It provides a basis for initiating collaboration among stakeholders. Beyond that, it provides the traceability of management performances. The users of KCWW program can compare volunteer efforts (e.g., survey, control, and monitor efforts) of different years based on the same trails of interest. Besides that, having a unified reporting form or well-organized database models to process multiple reporting forms is required in this stakeholder reporting system. The poor search ability of the EDDMapS results in (a) multiple forms with no well-designed arrangement, and (b) multiple spatial references in the same system.

With these two improvements, the majority of records collected from the EDDMapS can provide better information rather than raw data sharing and appearance maps.

6.5 Role of navigation in interfaces

The last effort examined user interface usability of stakeholder reporting systems. Since the EDDMapS is the only system that incorporates map-based designs in their web interface, this effort compared the EDDMapS with the other two cases (the ParkScan website and the What's Invasive website) to assess the usability of the EDDMapS. EDDMapS received acceptable performance from both evaluations (see detail in section 5.4 of Chapter 5). The EDDMapS has several basic elements (e.g., reporting navigation, map-based search options, education materials, invasive species distribution results[35], and user management control/reward) for navigation and data sharing strategy (downloadable customized spreadsheets). The information retrieval performance in the EDDMapS needs better database management. The map-based interface did not provide much information[36]. It is suggested that color-coded theme maps for various purposes should be incorporated based on the second assessment results[37] (see detail in section 5.4.2 in Chapter 5). The map services seem to have huge potential for improving existing web interfaces.

If results are related to management activities, using a SDU helps to track interactions between stakeholders and land managers. The ParkScan case is the example that uses a park as their SDUs so reports generated by stakeholders will be addressed by managers and each record is traceable. Compared to that, the EDDMapS provides information of invasive species distribution only; it does not connect to management activities (i.e., plant eradication). Although the EDDMapS may have different purposes than the ParkScan, it still requires the use of SDU to provide better search capabilities. In addition, using the time-stamp records to track each report and lay out the temporal dynamics of species distribution and control actions increase traceability of invasive species monitoring. Finally, map services may be customized based on the users' needs or expectations. In the ParkScan website, government responses were recorded and updated periodically. The EDDMapS chose a seamless approach for updating reporters' reports into the map system so other users can view their reports right away.

[35] The mobile applications only incorporate GPS records (part of records) in the Google Map system

[36] The search process starts with clicking geographic objects (e.g., park point, county) and links to the report records. However, because of poor structure in its database model, the EDDMapS has poor performance on the single measurement (e.g., rate between collected fields and types of query report) that is associated with the database model.

[37] Besides map services, the second assessment results also suggest to (a) document or address inconsistent dataset; (b) add the customized zoom in/out based on various purposes, and (c) enhance navigation system in terms of plant identification process.

Chapter 7: Conclusions, Limitations, and Further Research

Chapter Seven provides research conclusions, limitations, and further research in three subsections. Four subsections in section 7.1 describe conclusions from findings of volunteer reporting systems, capacity of SDUs and structured inputs, practial considerations of implementation, and research contributions. Section 7.2 covers limiations of this research. The final section describess possible future research.

7.1 Conclusions

7.1.1 Volunteer Reporting System: Commonality or Case Specific?

Four cases were assessed using the *assessment framework,* from which several common patterns about volunteer reporting systems were observed. The assessment framework used in this research depicted institutional constraints, stakeholder interactions, and information needs. It provides key information when planning a new stakeholder reporting system in a current decision-making process.

In the institutional arrangement (*social-institutional influence* construct), three scales of implementation were found[38], including a single park scale (LHRP), a regional scale (KCWW program and Forest Watch programs), and a nationwide scale (EDDMapS). Only the single park scale lacked a formal institutional arrangement for participation. At all three scales, managers seek efficient ways to process information. They typically allowed a fixed duration to process stakeholder inputs despite the number of reports. With the limited duration, managers prefer to receive a single summarized report for that scale instead of reading all reports. In addition, three common *roles of participants* are found at all three scales, data reporters, data users, and decision makers. Any stakeholder may hold one to multiple roles, and one role can be played by one to multiple stakeholders.

To trigger a functional interaction with the reporting system, a *stakeholder's expectation* should reach sharable concerns with *participation norms and rules* defined by managers. A common understanding of participation will more likley result in efficient and effective participation efforts. However, *stakeholders' knowledge* is highly related to reporting credibility, but hard to predict and estimate. Finally, even though technical arrangement (*Participatory GIS Influence* construct) may vary, it still should consider *stakeholder's knowledge* and *communication channels* aspects. An implementation strategy for fostering collection of best available information should consider details for:

---

[38] Because of difficulties with cross-boundary collaboration (Johnson and Sieber 2013), a consortium (cross-jurisdictional) scale was not observed in this research.

1. proper education materials,
2. easy-to-complete reporting form,
3. clear navigation on the interface, and
4. appropriateness of current decision-making process and corresponding database models.

7.1.2 Overall capacity of SDUs and structured inputs

The second part of the comparisons compare the capacity of using a SDU (spatial decision unit) and structured inputs across all four stages of the information systems for stakeholder reporting, including data collection, integration, storage, and representation stages. Three principal issues were addressed:

1. data integration and collection process (section 5.2 of Chapter 5),
2. database structure (database model) arrangement (section 5.3 of Chapter 5), and
3. interface design and development for result representation (section 5.4 of Chapter 5).

In section 5.2.1 of Chapter 5, a SDU is used to test as a common unit for data integration. Results show that when a SDU is used, it reorganizes stakeholder reports into summary records based on routine management activities or tasks. After this reorganization, stakeholder reports become one type of information that matches an information need for managers. In addition, because each SDU is one geospatial information type, the information arranged by SDU does include spatial variability (Steffen et al. 2006; Cash et al. 2006) consideration in the decision-making. Furthermore, since stakeholder reports are connected to GIS, those inputs can be categorized into one format[39] and therefore be more easily incorporated into management activities planning. Using GIS as an interface allows a manager to visualize stakeholder's contribution.

Structured inputs can be treated as part of structured participation (Nyerges et al. 2013) with data focus (see detail in subsection 5.2.2 of Chapter 5). Structured inputs define what information is required. Three structured inputs (i.e., free-form, semi-structured, and highly structured) are used to observe tradeoffs between gaining efficiency of processing reports and increasing constraints of describing stakeholders' observations in detail. Highly structured forms (e.g., invasive species reporting form in the KCWW program and Forest Watch program of trail incident reporting) appear to increase processing efficiency by using selections to replace textual descriptions. This design enables the processing of reports to be automatic and supports summarizing report contents (e.g., counts and numerical measurements), eliminating the requirement to read all reports. However, limiting a reporters' capability for describing nuances about their observations might reduce volunteers' reporting motivation, especially if these volunteers are proactive and

[39] Based on Masser (1998), GIS data has been treated as one of formal format for government information.

want to be involved in management activities.

Receiving large amounts of inputs collected from stakeholders requires enhanced processing efficiency and likely leads to increased costs of information search. First, use of a highly structured form should seek to match participants' knowledge with managers' information needs. When there is a gap between a participants' knowledge and manager information needs, we find that systems typically provide learning materials to assist participants on how to complete reports. However, as an optional supplement, learning material achieves partial credibility only with an uncertain outcome. To motivate proactive stakeholders, shared management activities and decisions (i.e., giving volunteers the power to eradicate invasive species or patrol trails) provides greater incentives for continued participation. In addition to using case study learning materials in EDDMapS, using various reporting forms to segregate different types of reporters were used in EDDMapS. The EDDMapS uses two types of reporting forms and navigation interfaces (section 5.4 of Chapter 5) to match different users' knowledge and needs (e.g., mobile application, bulk data entry). The intent of the reporting mechanism design was effective, but fails to integrate various report forms into a database model. The lack of integration affects the ability to search on databases, and few results can be generated based on inconsistent reporting inputs.

When comparing two database models using entity-relationship diagrams (ERD) in section 5.3 of Chapter 5, a SDU links management content (e.g., work tasks, action plans) spatially rather than solely using general spatial object (e.g., GPS points, county). The SDU helps to unify the spatial reference and uses that spatial reference to connect with management activities. The linkage of management workflow saves extra effort to filter stakeholder inputs by different management districts or areas. Since over half of local governments and public agencies have prepared basic GIS layers and their own geodatabase, the extra information that comes from stakeholder inputs should minimize the changes to existing database system and avoid altering privilege or security settings. Using a SDU as a direct connection between web databases (stored stakeholder generated inputs) and geodatabases (stored GIS layers) provides for a flexible design to attach or detach stakeholder generated information when needed.

The final effort (section 5.4 of Chapter 5) examined the role of interfaces as a reporting assistance and an interface for report visualization. Compared to other cases (e.g., ParkScan, What's Invasive), the EDDMapS interfaces include reporting navigation, education materials, and map-based system for information search and invasive species distribution results[40]. However, the map is used for location search only. More theme maps should be generated based

[40] The mobile applications only incorporate GPS records (part of records) in the Google Map system

on reports so more meaningful results can be presented. In addition, the reporting navigation in the mobile application could be enhanced by providing search ability for professional knowledge (e.g., plant information). However, none of the current interfaces incorporate an ability to visualize stakeholder reports across various time periods.

It is suggested that the *institutional resistance assessment framework* should be used to assess participation arrangement in stakeholder reporting systems, such as stewardship programs for environmental monitoring or similar citizen science projects. The SDUs and structured inputs in the reporting system achieved excellent performance in information management with well-considered design. The seamless connection (between managers' information needs and stakeholder inputs) created from SDUs and structured inputs include:

1. historical data integration,
2. data organization,
3. database integration,
4. information retrieval enhancement, and
5. report visualization.

Overall, a SDU has an excellent capability to integrate information (both qualitative and quantitative) and ability to visualize stakeholder reports in GIS. With a well-designed database (i.e., clear and simple entity relationship arrangements), all records can be stored in a geodatabase or non-spatial database for better traceability.

7.1.3 Design consideration and procedures for stakeholder reporting system

To utilize the arrangement (SDUs and structured inputs) in a stakeholder reporting system, having a best practice as a guideline to assess, design, and develop a stakeholder reporting system in the government helps managers to integrate their volunteer or citizen science program and management activities together. This research suggests using *institutional resistance assessment framework* (see detail in Table 4-1) to assess the workflow of developing stakeholder reporting system.

The *power and control* aspect of the framework should specify a scale (e.g. from the four scales[41]) be applied in the current situation. After choosing a scale, a formal institutional arrangement[42] (e.g., existing volunteer program, responsible coordinator) is required. After that,

[41] The four scales were mentioned in section 6-1 of Chapter 6, including Case Scale, Regional (Jurisdiction) Scale, Consortium Scale, and Nationwide Scale.
[42] The case scale which may only have informal institutional arrangements needs to match the expectation between the land managers and stakeholders.

a *subject domain* aspect of the framework defines management focuses, potential information needs, and government expectations for a stakeholder reporting system. With information needs being clarified, participants should be arranged by three major roles (i.e., reporters, data users, and decision makers) of the reporting system (defined in subsection 7.1.1 of Chapter 7, pp.63). The interaction mechanism (*norms and rules of participation*) should be customized and could vary case by case. The first four aspects (*Social-Institutional* construct) of the framework complete a conceptual design for reporting content and SDU selection, as well as define which level of structured input is needed based on government perspectives. Choosing a SDU requires careful inspections. The reporting content should provide positive public images to managers and increase the efficiency of report processing. The case studies showed significant differences (pp.58) between the trail incident reporting (negative public image) and invasive species detection (positive public image) subjects. Turning a negative image into a positive one without requiring more report processing should consider automatic response mechanisms. This conceptual design should be verified between participants and decision-makers (i.e., agencies or land managers) in the following two aspects.

The *participants' expectation* aspect should match the *norms and rules of participation aspect* and create a common vision and delegated activities or tasks among land managers, E-NGOs, and local stakeholders who may have different expectations about a stakeholder reporting system. To secure a commitment between collaboration partners (e.g., E-NGOs, other land managers), main decision-makers (responsible agency) could use a formal agreement or share the technology to construct a sustainable collaboration. A SDU should be easy-to-distinguish for reporters. For example, a physical trail with names is a clearer object than an invisible jurisdiction boundary. Considering participants' expectations, including shared management activities (e.g., trail patrol, trail adoption, and invasive species eradication) could be a way to implement proactive participations. Alternatively, other participants may seek an easy way to contribute. However, using multiple reporting forms could create inconsistency (e.g., too many null values and make query results become incomplete) of report inputs except than the well-developed database and interfaces are prepared. In sum, *participants' expectation* aspect creates a balancing act after the participation program has been delineated by decision-makers (i.e., agencies or land managers). Information needs from various participants should be considered and incorporated into database and interface designs, as well as maximizing the usage of reporting contents.

The *participants' knowledge* aspect affects many other aspects in a stakeholder reporting system in regards to reports' structure and content. If a knowledge gap exists between managers' needs and participants' knowledge, managers (i.e., trail incident reporting of WA-DNR and invasive species reporting of King County and the EDDMapS) usually provide voluntary supplements (e.g., learning materials and training workshops) for use. Incorporating report navigation in the interface or using multiple forms for various reporters is another way to fill the knowledge gap. When adding navigation to an interface, periodically usability assessment is required to assess the navigation utility for current reporters. Using multiple forms should ensure that different inputs can be fully integrated into a database. The design of a database model will affect the productivity of query and possible results that can be provided to participants.

Finally, *communication channel* and *PGIS technology* aspects create empirical arrangement (a SDU and structured inputs) in the stakeholder reporting system. The empirical arrangement should be located in current communication channels. Based on that, managers can estimate how much time is needed for incorporating stakeholder reports into their decision-making process. In the *technology* aspect, system configuration and architecture should be delineated based on previous needs and existing constraints. Based on current technological capacity, managers can decide and estimate potential costs when implementing or enhancing a stakeholder reporting system. Since over 70% government agencies have GIS platforms, it is possible to use a separate web-based database system to collect stakeholder reports and connect these reports to GIS for better visualization. Having a real-time mapping system (such as the EDDMapS) to update reporters' observation or an automatic design to generate acknowledgements when reporters submit their observations are examples. This research suggested using a SDU as a core element for connecting spatial references, management needs, and stakeholder reports. Management needs should be incorporated into database developments and interfaces for result representation. The checklist between aspects in the VGI-RAF and associated system design elements are incorporated into Appendix I.

7.1.4 Contribution

This research lays out a practical roadmap for environmental managers incorporating stakeholder generated information into their decision-making while enhancing stakeholder participation at the same time. Unlike other research focused on power-sharing in the decision-making process, this research seeks programmatic cooperation between public stakeholders and managers. The power-sharing collaboration versus volunteered input for cooperation is the main focus and difference between research domains about decision support in PGIS and user generated input in VGI, respectively. The research reported herein combines those two GIS research domains through yet a third research domain called adaptive management. An *institutional resistance assessment framework* organizes a way to assess stakeholder reporting systems pulls appropriate concepts from all three domains to assess management practice. Several contributions are made. First, the *institutional resistance assessment framework* inspects the institution setting. Without proper preparation, there arise resistances to incorporating new mechanisms that have caused many failed experiences as shown in the Adaptive Management research literature[43] (Walters 1997; Imperial 1999; Lee 1999; Stankey et al. 2005; Stringer et al. 2006; Wright et al. 2009). Second, the structuring processes (i.e. using SDUs and structured inputs) consolidate the foci and discussions with precise location, time stamp records, and structured contents. Using the concept of SDUs built a channel for data integration so that all the existing information can be incorporated. Structured inputs should match management needs in the design stage, which provides direct incentives to managers. Third, database schema as a model of a database and interfaces are two critical elements to store and represent values and respective data of stakeholder generated information.

Directed at knowledge generation, this research uses a sequence of programmatic steps to test suggestions from research literature within empirical cases. These steps include *institutional resistance assessment framework*, SDUs (Spatial Decision Units), structured inputs, and whole system coordination. As to the *rapid assessment framework*, this research first develops an eight-aspect framework incorporating theoretical suggestions that is easy for managers to use. Second, to solve the poor connection between management and monitoring information (Bearlin et al., 2002. see detail in pp.8), this research develops a SDU and structured inputs so management needs can be structured. Beyond that, highly structured inputs can be processed without reading each post. This increases the efficiency of information processing and reduces the drawback of time-consuming participation processes. The development of database models and interfaces further tested usability and values of stakeholder generated information. Much current research is focused on enhancing the credibility of non-expert information. Alternatively, this research, considers the usability of stakeholder generated information and how to incorporate them in the existing information system used for decision making and management.

7.2 Limitations of the research

Some unexpected results were observed during case studies and field tests. First, a potential power shift was found when using SDUs to connect management needs and stakeholder inputs. Even though sharing management activities with proactive stakeholders is suggested, managers may still resist any decision power sharing (i.e., having suggested actions in the reporting forms).

[43] Any new paradigm (such as adaptive management, ecosystem management, volunteer geographic information, etc.) has commonly involved resistance because of fears (Stringer et al., 2006), risks and costs of success, and large conflicts with existing institutional arrangements (Walters, 1997; Imperial, 1999; Lee, 1999; Stankey et al., 2005; Wright et al, 2009).

Second, a new information system (stakeholder reporting system) is not strong enough to bring institutional change, which contradicts the finding about structuration of information developed by DeSanctis & Poole (1994) (see detail in pp. 10). This research found that the *Volunteer Geographic Information Reporting Assessment Framework*, SDUs, and structured inputs only prepared foundations for managers to trigger possible institutional changes. Lastly, tradeoff between free-form participation and participation security is an unexpected result. Free-form participation may have the highest flexibility for stakeholders to deliver their observation or opinions; however, it can be jeopardized if there is no official arrangement of participation (such as the LHRP case). Some scholars may argue that collected information which only meets managers' needs is an unbalanced power relationship between public stakeholders and managers. However, articulating clear goals for institutional arrangements helps public stakeholders to decide if they want to participate. A stakeholder can easily walk away if there is not enough motivation for stakeholders to participate; we thus wonder about 'who is really holding stakes'. Managers, on the other hand, may face risks of getting no report for the system, if the system is not properly designed to elicit valued input.

7.3 Further Research

Our research focus on finding the bridge/channel for stakeholder inputs may be treated as one of many useful information avenues in decision-making through structured arrangements (SDUs and structured inputs), database model, and through interfaces. Further research should explore the usability of stakeholder generated information to capture and visualize the environment dynamics. Values of these reports to decision-making should be tested in the future. A second research direction is the resistance to potential power shift. As mentioned in the research limitation, further research should focus on uncovering the power relationship and dynamics of stakeholders and managers when implementing volunteer reporting systems besides institutional considerations. In addition to enhancing information processing process in decision-making, how to enhance examination through all similar or related processes is important. This research uses case comparison approach to compare four empirical cases. How to modify this approach so more cases can be incorporate and ground up evidence from existing evidence should be focused in the future. Finally, usability assessment for user interface tailored for volunteer reporting system or similar VGI practices should be examined to have an idea about design great navigation for VGI practices.

References

5 U.S.C.S. § 706(2)(A)

Abbot, J., Chambers, R., Dunn, C., Harris, T., de Merode, E., Porter, G., and Weiner, D. (1998). Participatory GIS: opportunity or oxymoron? *PLA Notes 33*, 27–34.

Aberley, D., & Sieber, R. (2002). Public Participation GIS (PPGIS) Guiding Principles. *First International PPGIS Conference*: 20–22. New Brunswick, NJ, July 20-22, 2002.

Ades, A. E. (2003). A chain of evidence with mixed comparisons: models for multi-parameter synthesis and consistency of evidence. *Statistics in medicine*, *22*(19), 2995-3016.

Alagan, R., & Aladuwaka, S. (2012). Innovative public participatory GIS methodologies adopted to deal with the social impact assessment process challenges: A Sri Lankan experience. *Urisa Journal*, *24*(2), 19-32.

Anderson, C., Beazley, K., & Boxall, J. (2009). Lessons for PPGIS from the application of a decision-support tool in the Nova Forest Alliance of Nova Scotia, Canada. *Journal of environmental management*, *90*(6), 2081-2089.

Arctur, D., & Zeiler, M. (2004). *Designing geodatabases: case studies in GIS data modeling*. Redlands, CA: ESRI Press.

Arnstein, S. (1969). A Ladder of Citizen Participation. *Journal of the American Institute of Planners, 35*(4), 216-224.

Bailey, K., & Grossardt, T. (2010). Toward Structured Public Involvement: Justice, Geography and Collaborative Geospatial/Geovisual Decision Support Systems. *Annals of the Association of American Geographers, 100* (1), 57-86.

Banati, H., Bedi, P., & Grover, P. S. (2006). Evaluating Web Usability from the User's Perspective, *Journal of Computer Science*, *2*(4), 314-317

Bearlin, A. R., Schreiber, E. S. G., Nicol, S. J., Starfield, A. M., & Todd, C. R. (2002). Identifying the weakest link: simulating adaptive management of the reintroduction of a threatened fish. *Canadian Journal of Fisheries & Aquatic Sciences*, *59,* 1709-1716.

Bevan, N., & Macleod, M. (1994). Usability measurement in context. *Behaviour & Information Technology, 13*, 132-145.

Bilotta, G.S., Milner, A.M., and Boyd, I. (2014). On the use of systematic reviews to inform environmental policies. *Environmental Science and Policy* 42, 67-77.

Brinberg, D., & McGrath, J. E. (1985). *Validity and the research process*. Beverly Hills, CA: Sage Publications.

Stern, P. C., & Brewer, G. D. (Eds.). (2005). *Decision Making for the Environment:: Social and Behavioral Science Research Priorities*. National Academies Press.

Brown, G. (2012). Public participation GIS (PPGIS) for regional and environmental planning: Reflections on a decade of empirical research. *URISA Journal, 24*(2), 7-18.

Brown, G. G., & Reed, P. (2009). Public participation GIS: A new method for use in national forest planning. *Forest Science*, *55*(2), 166-182.

Brudney, J. L. (1999). The Effective Use of Volunteers: Best Practices for the Public Sector. *Law and Contemporary Problems* 62, 219–255.

Cash, D. W., Adger, W. N., Berkes, F., Garden, P., Lebel, L., Olsson, P., …, and Young, O. (2006). Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World. *Ecology & Society, 11*(2). Retrieved from http://www.ecologyandsociety.org/vol11/iss2/art8/

Craig, W. J., Harris, T. M., & Weiner, D. (2002). *Community participation and geographic information systems*. London, UK: Taylor & Francis.

Crossan, M. M., & Apaydin, M. (2010). A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature. *Journal of Management Studies* 47, 1154-1191.

Cook, T. D., & Campbell, D.T. (1979). *Quasi-experimentation: Design & analysis issues for field settings*. Boston: Houghton Mifflin.

Cundill, G., & Fabricius, C. (2009). Monitoring in adaptive co-management: Toward a learning based approach. *Journal of Environmental Management, 90* (11), 3205-3211.

DeSanctis, G., & Poole, M. S. (1994). Capturing the Complexity in Advanced Technology Use : Adaptive Structuration Theory. *Organization Science*, *5*(2), 121–147.

Dumas, J. S., & Redish, J. (1999). *A practical guide to usability testing*. Exeter, England: Intellect Books.

Dunn, C. E. (2007). Participatory GIS a people's GIS? *Progress in Human Geography, 31*(5), 616-637.

Elwood, S., Goodchild, M. F., & Sui, D. Z. (2012). Researching volunteered geographic information: Spatial data, geographic research, and new social practice. *Annals of the association of American geographers*, *102*(3), 571-590.

Fazey, I., Fazey, J. A., Salisbury, J. G., Lindnmayer, D. B., & Dovers, S. (2006). The nature and role of experiential knowledge for environmental conservation. *Environmental Conservation, 33*(1), 1-10.

Feick R. & Roche, S. (2013). Understanding the value VGI. In: Sui D, Elwood S, Goodchild M (ed) *Crowdsourcing Geographic Knowledge*. Springer, London, pp.15-30.

Ganapati, S. (2011). Uses of Public Participation Geographic Information Systems Applications in E-Government. *Public Administration Review, 71*(3), 425-434.

Gibbs, J. P., Snell, H. L., & Causton, C. E. (1999). Effective Monitoring for Adaptive Wildlife

Management: Lessons from the Galápagos Islands. *The Journal of Wildlife Management*, *63*(4), 1055-1065.

Goodchild, M. F. (2007). Citizens as sensors: the world of volunteered geography. *GeoJournal*, *69*(4), 211–221.

Graham, A. C., & Kruger, L. E. (2002). *Research in adaptive management: Working relations and the research process* (General Technical Report 538). Pacific Northwest Research Station: United States Department of Agriculture Forest Service.

Green, D. R. (2010). The role of Public Participatory Geographical Information Systems (PPGIS) in coastal decision-making processes: An example from Scotland, UK. *Ocean & Coastal Management*, *53*(12), 816-821.

Gregory, R. S. & Keeney, R. L. (2002). Making smarter environmental management decisions. *Journal of the American Water Resources Association*, *38*(6), 1601-1612.

Gregory, R.S., Failing, L. Harstone, M. Long, G. McDaniels, T. and Ohlson, D. (2011). *Structured decision making: a practical guide to environmental management choices*. Chichester, West Sussex: Wiley-Blackwell.

Grira, J., Bedard. Y, and Roche, S. (2010). Spatial data uncertainty in the VGI world: Going from consumer to producer. *Geomatica, 64* (1), 61–72.

Gunderson, L., Peterson, G., & Holling, C. S. (2008). Practicing adaptive management in complex social-ecological systems. In Norberg, J., & Cumming, G. S. (Eds.). *Complexity theory for a sustainable future* (pp.223-245). New York, NY: Columbia University Press.

Halbart, C. L. (1993). How adaptive is adaptive management? Implementing adaptive management in Washington State and British Columbia. *Reviews in Fisheries Science, 1*(3), 261-283.

Hansen, H. S., & Reinau, K. H. (2006). Who are the citizens in public participation GIS. In E. Fendel, & M. Rumor (Eds.), *Proceedings of UDMS '06: 25th Urban Data Management Symposium.* (pp. 10.25-10.36). Urban Data Management Society.

Hardin, G. (1968). The tragedy of the commons. *Science 162*: 1243–1248.

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1-23.

Holling, C. S. (1978). Adaptive environmental assessment and management. *International series on applied systems analysis, 3.* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Imperial, M. (1999). Institutional Analysis and Ecosystem-Based Management: The Institutional Analysis and Development Framework. *Environmental management*, *24*(4), 449–465.

ISO/IEC. (1998), ISO/IEC 9241-11 Ergonomic requirements for office work with visual display terminals (VDT)s - Part 11 Guidance on usability.

Jankowski, P., & Nyerges, T. (2001). *Geographic Information Systems for Group Decision Making: Toward a Participatory, Geographic Information Science*. London, UK: Taylor & Francis.

Jankowski, P., Robischon, S., Tuthill, D., Nyerges, T., & Ramsey, K. (2006). Design Considerations and Evaluation of a Collaborative, Spatio-Temporal Decision Support System. *Transactions in GIS, 10*(3), 335-354.

JoAnn, T. H., & Hackos, J. T. (1998). *User and task analysis for interface design*. New York, NY: Wiley.

Johnson, B. L. (1999). The role of adaptive management as an operational approach for resource management agencies. *Conservation Ecology, 3*(2). Retrieved from http://www.consecol.org/vol3/iss2/art8/

Johnson, P. A., & Sieber, R. E. (2013). Situating the adoption of VGI by Government in Crowdsourcing Geographic Knowledge. In Sui, D., Elwood, S., Goodchild, M. (Eds.). *Crowdsourcing Geographic Knowledge: Volunteered Geographical Information (VGI) in Theory and Practice* (pp.65-83). London, UK: Springer.

Jude, S., Jones, A. P., Andrews, J. E., & Bateman, I. J. (2006). Visualisation for Participatory Coastal Zone Management: A Case Study of the Norfolk Coast, England. *Journal of Coastal Research, 226,* 1527-1538.

Kelly, L. (1985). Budgeting in Nonprofit Organizations. *Drexel Library Quarterly, 21*(3), 3-18.

Larsen, B., & Milakovich, M. (2005). *Citizen Relationship Management and E-Government*. *Lecture Notes in Computer Science, 3591*, 57-68.

Law, D. (2007). Many Choices: Many Geodatabase types available with ArcGIS 9.2. *ArcUser, 10*(1). Retrieved from http://www.esri.com/library/reprints/pdfs/arcuser_geodatabase.pdf

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Law, J., & Callon, M. (1992). The life and death of an aircraft: A network analysis of technical change. In Bijker, W. E. & Law J. (Eds). *Shaping Technology/Building Society: Studies in Sociotechnical Change* (pp. 21–52). Cambridge, MA: MIT Press.

Lee, K. N. (1999). Appraising adaptive management. *Conservation Ecology, 3*(2). Retrieved from http://www.consecol.org/vol3/iss2/art3/

Lee, M. (2004). *E-Reporting: Strengthening Democratic Accountability*. Washington, DC: IBM Center for the Business of Government.

Lefer, T. B., Anderson, M. R., Fornari, A., Lambert, A., Fletcher, J., & Baquero, M. (2008). Using google earth as an innovative tool for community mapping. *Public Health Reports, 123*(4), 474-480.

Leschine, T. M., Ferriss, B. E., Bell, K. P., Bartz, K.K., Macwilliams, S., Pico, M., & Bennetts, A.

K. (2003). Challenges and Strategies for Better Use of Scientific Information in the Management of Coastal Estuaries. *Eatuaries, 26*, 1189-1204.

Leslie, H. (2005). A Synthesis of Marine Conservation Planning Approaches. *Conservation Biology 19*, 1701-1713.

Leverington. F., Costa, K. L., Pavese, H., Lisle, A., and Hockings, M. (2010). A global analysis of protected area management effectiveness. *Environmental Management 46*, 685-98.

Lyons, J. E., Runge, M. C., Laskowski, H.P., & Kendall, W. L. (2008). Monitoring in the Context of Structured Decision-Making and Adaptive Management. *The Journal of Wildlife Management, 72* (8), 1683-92.

Maguire, M. (2001). Methods to support human-centred design. *International Journal of Human-Computer Studies*, *55*(4), 587–634

March, J. G. (1978). Bounded rationality, ambiguity, and the engineering of choice. *Bell Journal of Economics, 9*(2), 587-608.

Marmorek, D. R., Robinson, D.C.E., Murray, C & Greig L. (2006). *Enabling Adaptive Forest Management – Final Report*. Prepared for the National Commission on Science for Sustainable Forestry by ESSA Technologies Ltd., Vancouver, B.C. 94 pp.

Martin, E. (2000). Actor-networks and implementation: examples from conservation GIS in Ecuador. *International Journal of Geographical Information Science, 14*(8), 715-738.

Martin, M., Peters, B., & Corbett, J. (2012). Participatory Asset Mapping in the Lake Victoria Basin of Kenya. *Urisa Journal, 24*(2), 45-56.

McNie, E. C. (2007). Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environmental science & policy, 10* (1),17-38.

Michanowicz, D., Malone, S., Kelso, M., Ferrar, K., Christen, C., & Volz, C. D. (2012). A Participatory Geographic Information System (PGIS) Utilizing the GeoWeb 2.0: Filling the Gaps of the Marcellus Shale Natural Gas Industry. *Journal of Systemics, Cybernetics & Informatics, 10*(3), 45-53.

Moir, W. H., & Block, W. M. (2001). Adaptive management on public lands in the United States: commitment or rhetoric? *Environmental Management, 28*(2), 141-148.

Moody, D. L. (1998). Metrics for Evaluating the Quality of Entity Relationship Models. In Ling, T. W., Ram, S., & Lee, M. L. (Eds.).(1998) *International Conference on Conceptual Modeling*. Paper presented at Conceptual modeling - ER '98: 17th International Conference on Conceptual Modeling, Singapore (pp. 211-225). Berlin, Germany: Springer.

National Research Council (NRC) (U.S.). Committee on the Institutional Means for Assessment of Risks to Public Health, 1983, Risk assessment in the federal government: Managing the process (Washington, D.C.: National Academy Press.)

National Research Council (NRC) (U.S.). (1996). *Understanding risk: Informing decisions in a democratic society*. National Academy Press, Washington, D.C:

Nielsen, J. (1993). *Usability engineering*. Boston, MA: Academic Press.

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge university press.

Nyerges, T., Barndt, M. & Brooks, K. (1997). Public Participation Geographic Information Systems, *Proceedings*, Auto-Carto 13, Seattle, WA, American Congress on Surveying and Mapping, Bethesda, MD, pp. 224-233.

Nyerges, T. L., & Jankowski, P. (1997). Enhanced adaptive structuration theory: A theory of GIS-supported collaborative decision making. *Geographical Systems, 4*(3), 225-259.

Nyerges, T. L., & Jankowski, P. (2010). *Regional and urban GIS: A decision support approach*. New York, NY: Guilford Press.

Nyerges, T., & Patrick, M. (2007). Rethinking Public Participation as Instant Access to Virtual Meetings. In Miller, H. (Eds.) *Societies and Cities in the Age of Instant Access*. Dordrecht, Netherlands: Springer, 331-342.

Nyerges, T. L., Roderick, M. J., & Avraam, M. (2013). CyberGIS design considerations for structured participation in collaborative problem solving. *International Journal of Geographical Information Science, 27*(11), 2146-2159.

Nyerges,T. Ramsey, K., & Wilson, M. (2006). Design Considerations for an Internet Portal to Support Public Participation in Transportation Improvement Decision Making, in Shivanand Balram and Suzana Dragicevic (eds.) *Collaborative Geographic Information Systems*, Idea Publishing, Hershey PA, pp. 208-230.

Obermeyer, N. (1998). The evolution of public participation GIS. *Cartography and Geographic Information Systems, 25*, 65-66.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75-90.

Ostrom, E., Gardner, R., & Walker, J. (1994). *Rules, games, & common-pool resources*. Ann Arbor, MI: University of Michigan Press.

Palmer, M. H., & Kraushaar, S. (2013). Volunteered Geographic Information, Actor-Network Theory, and Severe-Storm Reports. In Sui, D., Elwood, S., Goodchild, M. (Eds.). *Crowdsourcing Geographic Knowledge: Volunteered Geographical Information (VGI) in Theory and Practice* (pp.287-307). London, UK: Springer.

Peng, Z.-R. (2001). Internet GIS for public participation. *Environment and Planning B: Planning and Design*, *28*(6), 889–905.

Propst, D.B., Jackson D. L., and McDonough, M. H. (2003). Public Participation, Volunteerism and Resource-Based Recreation Management in the U.S.: What Do Citizens Expect? *Society and Leisure, 26*(2), 389-415.

Poteete, A. & Ostrom, E. (2008). Fifteen Years of Empirical Research on Collective Action in Natural Resource Management: Struggling to Build Large-N Databases Based on Qualitative Research. *World Development 36*, 176-195.

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation, 141*(10), 2417-2431.

Rinner, C., & Malczewski, J. (2002). Web-Enabled Spatial Decision Analysis Using Ordered Weighted Averaging (OWA). *Journal of Geographical Systems, 4*(4), 385-403.

Rob, P., & Semaan, E. (2004). *Databases: Design, development & deployment*. Boston, MA: McGraw-Hill.

Sage, A. P. (1991). An Overview of Group and Organizational Decision Support Systems. *IEEE Control Systems Magazine, 11*(5), 29-33.

Schlossberg, M., & Shuford, E. (2005). Delineating "Public" and "Participation" in PPGIS. *URISA, 16*(2), 15-26.

Shindler, B., Cheek, K. A., & Stankey, G. H. (1999). *Monitoring and Evaluating Citizen-Agency Interactions: A Framework Developed for Adaptive Management* (General Technical Report 452). Pacific Northwest Research Station: United States Department of Agriculture Forest Service.

Sieber, R. (2006). Public participation geographic information systems: A literature review and framework. *Annals of the Association of American Geographers 96*, 491-507.

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution, 24* (9), 467-471.

Simon, H. A. (1979). Rational Decision Making in Business Organizations. The American *Economic Review, 69* (4), 493-513.

Smith, L.G. (1982). Alternative mechanisms for public participation in environmental policy-making. *Environments, 14*(3), 21-34.

Stankey, G. H., Clark, R. N., & Bormann, B. T. (2005). *Adaptive management of natural resources: Theory, concepts, and management institutions* (General Technical Report 654). Pacific Northwest Research Station: United States Department of Agriculture Forest Service.

Star, S. L., & Griesemer, J. R. (1989). Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science, 19*(3), 387-420.

Steffen, W., Sanderson, A., Tyson, P. D., Jäger, J., Matson, P. A., Moore III, B.,…Wasson, R. J. (2006). *Global change and the Earth system: A planet under pressure*. Berlin, Germany:

Springer.

Stinchocombe, A. L. (1990). *Information and Organizations*. Berkeley, CA: University of California Press

Stringer, L. C., Dougill, A. J., Fraser, E., Hubacek, K., Prell, C., & Reed, M. S. (2006). Unpacking "Participation" in the Adaptive Management of Social--ecological Systems: a Critical Review. *Ecology and Society, 11(*2). Retrieved from http://www.ecologyandsociety.org/vol11/iss2/art39/

Talen, E. (2000). Bottom-Up GIS: A New Tool for Individual and Group Expression in Participatory Planning. *Journal of American Planning Association, 66,* 279-294.

Trochim, W. M. (1985). Pattern matching, validity, and conceptualization in program evaluation. *Evaluation Review*, *9*(5), 575-604.

Uychiaoco, A.J., Arceo, H.O., Green, S.J., Cruz, M.T., Gaite, P.A., & Aliño, P.M. (2005). Monitoring and Evaluation of Reef Protected Areas by Local Fishers in the Philippines: Tightening the Adaptive Management Cycle. *Biodiversity and Conservation*, *14* (11), 2775-2794.

Van, D. D. R., Johannesson, G. T., & Ren, C. (2012). *Actor-Network Theory and Tourism: Ordering, Materiality and Multiplicity*. Hoboken, NJ: Taylor & Francis.

Walters, C. J. (1986). *Adaptive management of renewable resources*. New York, NY: Macmillan.

Walters, C. J. (1997). Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology*, 1(2). Retrieved from http://www.consecol.org/vol1/iss2/art1/

Wright, D., Duncan, S., & Lach, D. (2009). Social Power and GIS Technology: A Review and Assessment of Approaches for Natural Resource Management. *Annals of the Association of American Geographers*, *99*(2), 254-272.

Wyk, E., Roux, D., Drackner, M., & McCool, S. (2008). The Impact of Scientific Information on Ecosystem Management: Making Sense of the Contextual Gap Between Information Providers and Decision Makers. *Environmental Management, 41*(5), 779-791.

Wolf, F. M. (1986). *Meta-analysis: Quantitative methods for research synthesis* (Vol. 59). Sage.

Yeung, A. K. W., & Hall, G.B. (2007).*Spatial database systems: design, implementation and project management. GeoJournal library, v. 87*. Dordrecht, Netherlands: Springer.

Yin, R. K. (1994). *Case study research: Design and methods*. Sage publications.

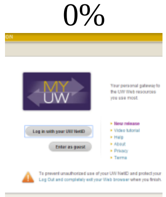
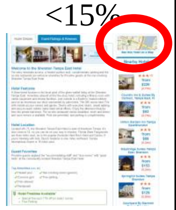
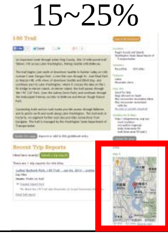
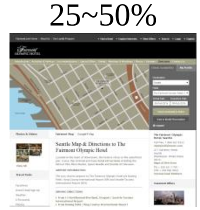
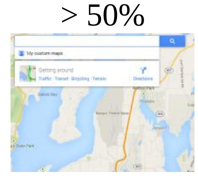
Zhao, J., & Coleman, D. J. (2007). An Empirical Assessment of a Web-based PPGIS Prototype. *Annual Conference of the Urban and Regional Information Systems Association*. Washington, DC. [Internet] Available from http://www.urisa.org/files/JZhao.pdf

Appendix A. Website Interface Comparison: Thresholds and Scores

Heuristic evaluation is an expert-oriented evaluation. Table 5-1 (pp. 36) from this manuscript lists eight criteria and their associated measurements. This appendix lists each criterion (C1~C8) and its measurements (1.1~8.2). Each measurement includes a definition, scores, and thresholds. The thresholds provide a better reference assigning proper score in comparison. Detail evaluation result will be shown in Appendix G.

Table A-1 Detailed measurements of each listed criterions for heuristic evaluation.

C1. Cartography: legend, symbol, and extra information usage			
1.1 Clear legend/symbol and reasonable breakdown			
Content: The legend within the map should provide a clear distinguished function. Theoretically, the color ramp with 3-8 categories makes it easier for users to distinguish one from the other. Same as the legend, the font size should be between 8-12 pts.			
Score	1	3	5
Threshold	Too many categories in the map, hard to tell one from another.	Confusions exist with different categories due to the miss use of colors or fonts	Clear use of color ramp and legend to get information from the map
1.2 Extra information to explain map use			
Content: In order to facilitate the communication process, some websites provide the fundamental information to assist their user to use the map			
Score	1	3	5
Threshold	Only map	The website includes basic directions about how to start	The website provides useful and detailed information

C2. Map proportion, accessibility, and connection to website content						
2.1 Map proportion						
Content: a. How many percentage of maps are covered in a single webpage b. In this website, how many web pages are using the maps? (%) Averaging scores received in a. & b. is the final score of this map.						
Score		1	2	3	4	5
Threshold	a	0% 	<15% 	15~25% 	25~50% 	> 50% 
	b	0%	<10%	10~20%	20~30%	>30%
2.2 Map Functionality						
Content: How many functions (e.g., search interface, results representation, reporting navigation) use map or spatial information within the website?						

Score	1	3	5
Threshold	Just for reference, few interactions	Has 1-2 functions, such as visualization, search, or others	Has > 3 different functions

2.3 Maps & website content connection

<u>Content:</u> The linkage between a map item and its narrative information

Score	1	3	5
Threshold	Disconnected	Partially connected	Well connected

C3. Query capacity: diverse commands and speed of searching

3.1 Theme/Location Search

<u>Content:</u> A map query can retrieve the most complete information for users based on the contents within its associated table.

Score	1	2	3	4	5
Threshold	The map is only for display, with no data query function	The map has its categories and showed in the legend	The map only provide either location or theme search	The map only provide both search but not within same search level	The map only provide both search in same search level

3.2. Number of clicks to search results

<u>Content:</u> How many clicks are needed from the search page to the results? A theme and location search will be performed and the accumulation of the clicks will be evaluated and scored based on threshold

Score	1	3	5
Threshold	more than 10 clicks	5-10 clicks	<5 clicks

3.3 Connectivity between Input Data and Result Query (%)

<u>Content:</u> Calculate the percentage of public input fields that can be used and represented in the results.

Score	1	3	5
Threshold	<20% inputs are used in result query	20~50% inputs are used in result query	>50% inputs are used in result query

C4. Existing and extension capacity

4.1 Existing limitation due to the map system architecture

<u>Content:</u> The map systems used in current website is meeting the needs and has extension ability for future uses.

Score	1	3	5
Threshold	Current map system meets <30% needs of website, and needs higher technical skills to enhance	Current map system meets 30~50% needs of website and have some capacity to extend map system	Current map system meets >50% needs and a flexible arrangement were made for extension

4.2 Static/Interactive Maps

Content: Does the website use interactive maps for communication?

Score	1	3	5
Threshold	Static Paper Map	Static Digital Maps	Interactive Maps

C5. Data distribution capacity

5.1 Downloadable Content

Content: Users can download the information of the map from the website

Score	1	3	5
Threshold	The maps cannot be downloaded	Alternative formats can be downloaded (JPG, PDF, etc.)	All raw information or analysis results are downloadable

5.2 Information distribution (to other website)

Content: Users can insert some html syntax to move the map content into their own website or webpage as well

Score	1	3	5
Threshold	Only used in this website	Can use and open in specific software	Be able to insert into your website

C6. Navigation Designs

6.1 Clear Navigation

Content: The reporting interface should design a step-by-step navigation to help users choose or fill in the right information

Score	1	3	5
Threshold	Lack of enough information or knowledge to start	Some blanks are hard to fill with lack of knowledge	All information that needs to be filled are clearly stated and easy to fill

6.2 Easy to use interface

Content: The reporting interface should be designed as easy as possible, using less click or spend less time to think before clicks

Score	1	3	5
Threshold	Users do not know where to start	Users feel lost sometimes with new/updated designs	Users can easy to click without thinking and spend <2 minutes to finish a report

C7. Tutorial Guide for First-Time User

7.1 Instruction or Tutorial for first-time user

Content: This website includes the instruction or tutorial contents to guide the first-time user to use this information.

Score	1	2	3	4	5
Threshold	No	The instruction is hard to understand	Need to do trial-and-error several times	Most operations are told from instructions	Easy to operate followed by instructions

7.2 Education materials or training design

Content: This website includes materials to explain and tell users where to start.

Score	1	2	3	4	5
Threshold	No	Textual and brief information only	Slides or step-by-step instructions	With video to guide a step-by-step process	A complete setting with video and a training kit

C8. Q&A and trouble shooting			
8.1 Q & A section			
Content: This website has Q & A section, by which some technical issues or operation barriers for the users can be solved.			
Score	1	3	5
Threshold	No Q& A section	Only includes first time user problems and solutions	Includes both technical issues & purpose statements
8.2 Communication Channel for trouble shooting			
Content: The communication channel to help user for trouble shooting			
Score	1	3	5
Threshold	No place to contact the system administrators	Having email and “Contact us” option from the website	Having a complete form of different types trouble shooting

Appendix B. *Park Scan* and *What's Invasive*

To evaluate the interface usability of the EDDMapS, two other similar websites, *ParkScan* and *What's Invasive* are compared with the EDDMapS. Because the *ParkScan* and *What's Invasive* are not included in this research, the background and key elements are described in the following paragraphs.

The *ParkScan* website (http://parkscan.org) is a "*website that allows San Franciscans to submit park observations directly to City staff*". The website is built up from Neighborhood Parks Council (NPC)[44] and City Parks Department. Unlike complex map system, ParkScan use Google map to place each park point. Each point has the connection to 1) park info and 2) reporting and processing updates. Since the website is designed for stewardship for encouraging voluntary reporting to increase the effectiveness of park management, the website simply provides the linear reporting mechanism for any city resident to steward their neighborhood park or open spaces. The design of this reporting mechanism starts from users reporting the concerns (or called the observation at the website) and then passing that information through the City's work order system (311 system). The work order will be transferred to the staff and the processing status will be shown in the website. After the issue is solved, each record will be turned into "closed" status but it is available to track and output the report for any interested user to use.

What's Invasive (http://whatsinvasive.com) uses mobile applications to report and to represent the results on the website. Users can download the applications and report the invasive species they saw from anywhere. Once you have registered, you can login and report the invasive species by using your smartphone for precise GPS location. Once you submit a report from the application, the website will receive the data and generate result based on the region or park you reported. The navigation is not organized well. Any user needs to select the park before accessing all major sections, such as "Top Invasive", "Data & Photos", and "Maps" in the global menu. However, once you choose the park, each major section can provide some critical information, such as the plants situation, the location of these plants that are invasive, and the statistics of the plant population and observation contribution. Overall, the website creates a sophisticated interaction mechanism between users and website managers, but it is more focused on one-sided communication (user to website managers/experts) instead of two-sided communication (work together for specific actions).

[44] NPC is a nonprofit organization that is working to increase park stewardship, accountability for park management, and securing capital investment funding

Appendix C. Invasive Species Reporting Mobile Applications Comparison

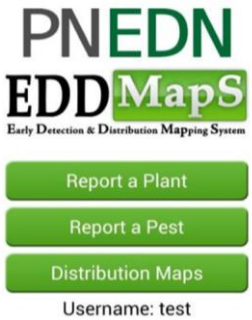
To select the two most different interfaces of invasive species reporting mobile application, this appendix surveyed nine mobile applications and compared their host organizations, map server, user management (login), map coverage, invasive species information (species list), reporting content, unit of measurement, and map services (Table C-1). Compared all mobile applications hosted by EDDMapS, this research uses the *PNEDN* that focused on Pacific Northwest region invasive species. On the other hand, *PlantTracker* has been selected based on different interface arrangements. The second table (Table C-2) illustrates differences between *PNDEN* and *PlantTracker*.

Table C-1. Comparisons user interfaces of existing nine invasive reporting mobile applications.

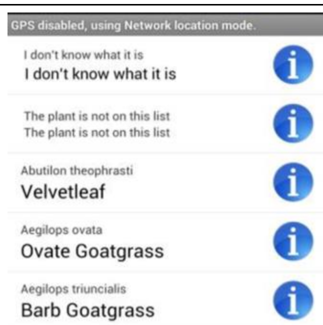
	Plant Tracker	PNEDN	IveGot1	What's Invasive	SEEDN	MAEDN	Outsmart Invasive Species	IPANE	GLEDN
Host Organization	EA[45]	EDDMapS							
Map Server	Google Map								
Login System	No Login	Login is required for reports. Guest or Preview design has been made as the trial section							
Coverage	UK	Pacific Northwest	FL State	Whole USA	Southeast USA	Mid Atlantic USA	MA State	New England	Great Lakes
Species List	Only 15 species	Weed/Pest/Animal. Arranged By Taxonomy, Habitats, or Regions (What's Invasive) More than 20 species in most categories							
Report Navigation	Click Photos	Use keywords, common name, and scientific name. Some of them accompanied with smaller photo to select reporting species. Has "unknown" species selection							
Species Info.	Image Gallery, Textual Info, and Confusion Species (only *PlantTracker*)								
Reporting Content	Photos, Location, Amount (Infested Area), Note, and Email (only *PlantTracker*)								
Unit	Pizza Boxes	Acre & Sq. Feet							
Map Service	N/A	Using Google Map to display all records into geo-tag points. Each point has the link to complete records							

[45] The Plant Tracker project is the collaboration between the Environment Agency, the Nature Locator team at the University of Bristol and the Centre for Ecology and Hydrology.

Table C-2. The Comparison Snapshots between PNEDN and PlantTracker

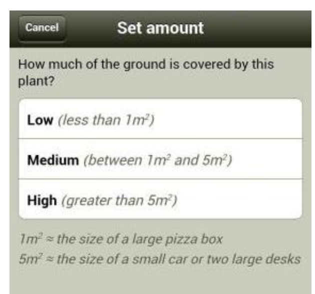
<table>
<tr><th>PNEDN</th><th>PlantTracker</th></tr>
<tr><td colspan="2">Login Page // Homepage</td></tr>
<tr><td>


</td><td>

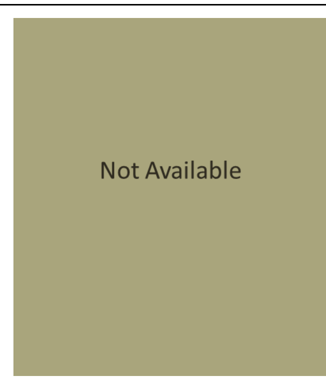

</td></tr>
<tr><td colspan="2">The Interface of Species Selection for User Reporting</td></tr>
<tr><td>


</td><td>


</td></tr>
<tr><td colspan="2">Reporting Form and Measurements</td></tr>
<tr><td>


</td><td>


</td></tr>
<tr><td colspan="2">Mapping the Reporting Results (mobile interface)</td></tr>
<tr><td>


</td><td>


</td></tr>
</table>

Appendix D. Invasive Reporting Mobile Application Usability Questionnaire

The *PNEDN* and *PlantTracker* are the two mobile applications used in the evaluation based on comparison results from Appendix C. This questionnaire examines usability of mobile applications interface. As mentioned in chapter 5-1-3 (pp.38), this questionnaire includes user management (Q1, Q8, and Q10), reporting navigation and measurement (Q2~Q4), and map service and result representation (Q5~Q7 and Q9) categories in the evaluation. A full questionnaire is provided on following snapshots. We emailed to all interest groups and persons (e.g., weed watcher volunteers). This questionnaire is created from Google website with an open URL link:
https://docs.google.com/forms/d/1M_o9X8opkQ8I1P2__4R0dFbquZqCpj_lNygR7vwP65M/viewform

Table D-1 heading

GeoWeb for Invasive Species

PNEDN (hosted by EDDMaps, https://itunes.apple.com/us/app/pacific-northwest-early-detection/id535512357?mt=8&ls=1) and PlantTracker (https://itunes.apple.com/us/app/planttracker/id528236850?mt=8) are two different invasive species reporting mobile apps that have some critical and classic design features regrades to the map using, data distribution, and collections. Please help us evaluate these two Invasive Species reporting apps and let us know what kind of elements (designs) needed to be incorporated.

* Required

Which user log-in (welcome) page makes you want to report the observation? *

If the log-in page will scare off the reporters or can actually block out some "noises" (fake reporting)

- ○ PNEDN Design: Both Login & Trial/Demo/Guest
- ○ PlantTracker: No Login
- ○ Key user groups will have different features after login

How to select the right species to report? *

How to show the reasonable number of species

- ○ PlantTracker: With the photo and common name of the species only
- ○ PNEDN: Leave the full name for the species
- ○ Add a segregation based on legal boundary (park, county, zip, etc.)
- ○ Add extra information since Name & Picture is not enough

Extra Information to Identify Species

If you choose extra information for the previous question, please choose what kind of information you need

- ☐ Photos of growing land cover (Grassland, Forests, Wetland, etc.)
- ☐ Non invasive species that grew next to this species
- ☐ Immediate surroundings such as, bodies of water
- ☐ Approximate growth since lastest reporting
- ☐ Current invasive plant stage i.e. is it seeding?
- ☐ Location based on major pathways (imminent disturbance possible?)

The measurement of the reporting form *

When reporting your observation, some measurement is not hard to estimate, how can it be enhanced

- ○ PlantTracker: 1 cubic = xx pizza boxes
- ○ PNEDN: Acre/Sq. Feet (Regular Unit)

Reviewing Current Report through Map Interfaces *

To have a place to review and visualizing the reporting is important, what kind of design is the better fit for user to use

- ○ PNEDN: Search/Display by Species List with # of reporting
- ○ PlantTracker: No MAP on Mobile App, maybe somewhere (website) you can see them

Navigation Design of Map Dynamic Scale Setting

If you choose PNEDN and want to make a map from the mobile app, what should be the right scale

- ○ Zoom In to the biggest extent of Query Content
- ○ Show anything from your current location
- ○ Show some specific area by legal boundaries

Color coded your reporting records *

Current PNEDN map only showed # of records by species. Do you think we can add more value to it by color coded these records?

- ○ Yes, it can add some color to show different group of reporters, the status of reports, etc.
- ○ No, this map is good/complex enough.

Keep contributing your reports *

We want to have your reports regularly not just one time event, what options may helps you to

- ☐ See your reports has been uploaded into the map
- ☐ Like a game, you can upgrade your reporting content by verifying with other reports
- ☐ Appreciation and Top 10 Reporters will be shown to the website even one page of the APP

When and where you want a MAP not a TEXT *

Sometimes MAP can deliver better than words, if you are having an app, where should we have a MAP?

- [ ] Beginning, showed the area of infestation (by category)
- [ ] Accompany with species list
- [ ] Accompany with other management purposes (volunteer adapted area, work parties, etc.)

Identify your relationship with invasive species reporting *

Understand your organization and role for the invasive species reporting

- ○ A staff/manager in Environmental NGOs
- ○ A volunteer coordinator in governmental agencies
- ○ A volunteer that works in different industry
- ○ A staff/land manager in governmental agencies
- ○ A park/trail user would like to contribute something to our earth
- ○ A data manager/IT person in governmental agencies
- ○ A volunteer that works in environmental related jobs
- ○ A volunteer coordinator in Environmental NGOs
- ○ Researchers/ Education Institute

Extra Suggestion for future design

Do you find something is missing in current reporting app? Share your idea with us

Appendix E. LHRP Meeting Agenda and Minutes

Traditional stakeholder meeting records are agenda and meeting minutes. In the LHRP case, one of the most valuable stakeholder inputs is meeting minutes based on agenda and specific themes. Since the meeting minutes are captured from stakeholders' observation and suggestion, it is the best representation format for stakeholder but not for managers. It takes six steps to process information for LHRP management, as mentioned in dissertation manuscript pp.38.

Table E-1. Summary of stakeholder meeting agenda, minutes, and notes (scanned). Three meetings were held in 2010 to 2010 and there were 5 records were collected during this period.

The first stakeholder meeting is called by volunteer leaders from E-NGOs and rangers. This non-official meeting has been emailed to interested persons but welcome to any person to participate. The following agenda was provideed on the meeting day only.

Lord Hill Trails Meeting Agenda
01/16/2010
8 am to 11:30 am

Introductions:

Work Party Dates: 10 minutes
1. March TBA: Friends of Lord Hill
2. April 24: Friends of Lord Hill
3. May 1: Friends of Lord Hill
4. June 5: Everett Mountaineers National Trails Day
5. Washington Trails Association: TBA
6. Everett Mountaineers: TBA

Trail Projects: 30 minutes
1. Temple Pond Loop Bridge Replacement-
2. Devils Butte Loop- Finish grading hillside hiker connection. Two water crossings. Assess winter condition use to remove or enhance trail.
3. River Trail- Re-grade trail surface
4. River Trail cut-off: Determine abandonment or reroute of trail
5. Temple Pond Loop Retaining Wall-
6. Entrance Bridges- Assess condition and determine future repair
7. Beaver Lake Trail- repair water damage, drainage and brush trimming(Mid-March, FLHRP)
8. General Trail Maintenance- Work Parties for brushing and tread maintenance

Trail

New Trails: 15 minutes
1. Rail Road Grade- Grade runs ¾ of a mile from Cutter's road to Main Trail
2. Connector Trail- Locate and flag connector trial from River Trail to the Quarry Trails.
3. LH 2 Bridge: New bridge to cross culvert pond outflow to finish trail connection

Equipment Needs: 10 minutes
1. Trail Machine- Power wheel dump bucket for moving material
2. Track hoe/blade
3. Chainsaw pulley

Resources

Grant Agencies: 10 minutes
1. American Hiking Association- ASA
2. Snohomish Sportsman Club
3. Mountaineers Foundation
4. Washington IAC
5. REI Coop
6. Cabela's Outdoor

Field Trip: 9:30 to 11:30 am. We have limited time and can not possibly see every thing on our agenda and will have to prioritize visits in the field.

This meeting minute is finished by one park ranger (Tom). The director and managers in Snohomish PRD were participated. 10 other interested volunteers joined this meeting. There is no map or other information for the park trails trails, so this meeting is only for experienced park user or volunteer to join. The meeting minute was organized with discussion topic and contents. However, the lack of structured content was hard to use and time-consuming.

MINUTES

L H Stewardship Planners Meeting

@ L H Barn Upper Room

January 16 2010 8:00 AM

Call to Order @ 8:18 AM by Tom Cowper

The meeting was held in the upper room in the LH barn near the main entrance to the park. It was a cool day and the meeting was as well. By the time the meeting had started Temps had risen to about 52 degrees in the room. It was quite cool and many attendees sat very closer to each other to stay warmer. Coats, hats and gloves were the standard attire for this meeting.

Opening talk and greeting-Tom Teigen & Hal Gausman

Attendees: We had 13 at this meeting.

Don Heirman	Tom Teigen	Hal Gausman	Tom Cowper
Forrest Clark	Charlene Feetham	Dan Hall	Rich Guthrie
Louise Guthrie	Adam Clark	Laura Bunker	Joan Deutche
Mike Kovak			

Discussion Topics:

-Bringing brushing machines on the hard trails, really the roads to brush back aggressively as to not need brushing for 2 or so years in the future.

-Funding for the upkeep and continuing projects at the park. Where is it coming from how much is available?

-Temple Pond Loop Bridge needs to be taken out and a culvert put in there. Bridge had been hit by wind fall trees 3 times and had been broken for some time now.

-Devil's Butte Trail, finish or not the last upper East section of the new trail.

-River Trail Regrade, use equipment on it to restore, muck and rebuild it or use man power on it?

-River Trail Cut Off, abandon or use power equipment to fix it?

-Temple Pond Loop retaining wall. Fix it, but how?

-Entrance bridges, leave them in, but not allow horses to use them. Channel all horses through the new horse entrance.

-Beaver Lake Trail needs maybe 4" gravel or possibly 2" gravel topped with 5/8" minus w/ rock flour.

NEW TRAILS:

-R R Grade Trail

-River Trail/Quarry Connector Trail

-LH2 Bridge

EQUIPMENT NEEDED:

-Trail Machine

-Small Track Hoe

-Chain Saw

-Grip Hoist and/or Winch

POSSIBLE FUNDING SOURCES:

-American Hiking Society (AHA)

-Snohomish Sportsman Club

-The Mountaineers Foundation

-The old WA State IAC which is now the new WA State ROC

-R.E.I.

-Cabela's

-Community Outreach, Private Donations, large or small

Meeting adjourned @ 10:40 AM

A small group of attendees went out on a field trip into LH park to look at some problems areas that needed attention. The River Cut Off Trail was looked at, as was the River Trail itself.

The 2nd stakeholder meeting was called and facilitated by one volunteer leader. This is the 2nd and also the last meeting for this year because this "stewardship planners meeting" did not include some degree of institutional arrangements. The data sharing plan was poor from the first meeting (agenda is only provided on the meeting day). There is no meeting minute after this meeting.

LORD HILL REGIONAL PARK

Stewardship Planners Meeting

Saturday, February 6th, 8:30 AM to 10:30 AM

Willis Tucker Park Headquarters Conference Room

Call to Order @
Entry talk/Greeting
Ground Rules for the meeting (Large scratch pad for items of concern)
Intros by full name
Why you're spending Saturday morning with us here?

Updates on past meeting items:
-Brushing machine in the park on main accesses
-Funding for materials and equipment (purchases), grant sources, private funds, etc.
-Risk management items being discussed and looked into
Parks is drafting power tool use guidelines for volunteer workers.
It first goes to risk management to be looked at and then to the volunteer sector for comments. It is being considered that parks may use of power tools after a training course and providing insurance
-Repairs and equipment use on trails is undecided at present. A tour with maintenance staff is planned for Feb. 9th to review areas within the park.

Opportunities for benevolence and education:
-Saturday, March 20th (2 hour) North Pipeline Trail, Beaver Loop, White Gate, Temple Loop
-Saturday, March 27th (2 hour)
-Saturday, April 24th (8 hour) Rock Candy bypass, LH2 connector, Devils Butte stream crossing
-Saturday, May 1st (8 hour)
-National Trails Day, Saturday, June 5th, 8AM (8 hour)
-Trail Maintenance Workshop
-Crew Leader Workshop
-3-5 Other Trail Maintenance opportunities

Sequencing of existing and continued projects:
-Devil's Butte Trails, stream crossing and upper East loop
-Redo River Trail for muck out, drainage and slope
-Start up on RR grade trail (2 year run for completion, 2011)
-Start up on River Trail to Quarry Trail (2-3 year run for completion, 2012)
-Temple Pond Loop retaining wall

Other Items of interest:
-Tool Count
-Bridges at Beaver Pond vs. New Culverts
-North beaver Pond Trail is on private land! What shall we do, block off, what?
-Fires at LH2 are continuing, concern about the dry summer season & wildfire
-Most trail damage occurs between Nov. 1 - April 30 due to high level of rains, shall access be limited during that time for users on softer trails within the park?
-All trails should be marked better, Non-Horse, Hiker only, Horse-Hiker and Bike-Hiker.
-Is proper dog and horse waste etiquette the same, FYI

Time allowing, additional topics

Next LH stewardship planning meeting?

First *stewardship planners* meeting of 2011 was held on Feb. 12th. The agenda showed a simple "to-do" list without other detail information about this or previous meeting (e.g., follow up actions, conclusion). The other volunteer was the note taker and responible for the meeting minutes. However, more participants joined include residents who live near LHRP because the major trail construction was revealed and presented by Snohomish RPD.

Tom Teigen
⇒ Recreation.

AGENDA
LORD HILL
STEWARDSHIP PLANNERS MEETING

SATURDAY, February 12th, 2011
9 till 11 AM
@ Lord Hill Barn

David. Energineer.

Timing: early season construction.

Call to Order

permits 3months more

Welcome

June PDF

Introductions

The end of this month. ← Final

Report Topics:
- Bridge Updates
- Update on maps/website
- 2010 Work completed
- 2011 Work projects TBD

*Sign-up

Schedules for 2011
- 2011 Schedules for Lord Hill
- 2011 Schedules for other group sponsored projects

Alarm *.

New Business
- Volunteer appreciation event/dinner for Sno Co Parks
    - Date, time, place
    - Potluck, OK?
    - Beverages
    - Awards (ie plaques, certificates, picture plaques etc.)

→ emergency day (tag).

CONTECA.

Old Business – None

* Concern: wash-out the colverts?

Next Meeting

* Emergency → ~~Template~~ pond loop.

Widen Area

Park Users.

low maintence. low risk.

metrial: woods fence.

<14 feet, ? 12feet trail crossing

* non-jeopotyl * Zero - Wetland impacts,

* Temple ponds

This meeting minutes has prepared by another volunteer leader from local friends' group. Since there is no regular format of structuring records, the meeting minute arrangement has altered based on note takers' perference. After this meeting, there is one meeting in the Snohomish PRD conference room but no minutes were found or recorded

MINUTES
LORD HILL
STEWARDSHIP PLANNERS MEETING

SATURDAY, February 12th, 2011
9-11 AM @ Lord Hill Barn

Meeting was called to order by Forrest Clark @ 9:03 AM and a warm welcome was given to all.

Location of restrooms, availability of coffee and tea as well as location of the sign in sheet for the meeting were given. Also the location of name tags, copies of the agenda for the meeting and current maps of the park.

A round robin of introductions included everyone in the room and late arrivals too. There were 31 in attendance.

First topic of the meeting was the presentation of the research and planning of the water crossings in the park in need of upgrade and repairs. This was done by the consultants/engineers already procured by parks. Sites discussed were North Pipeline, North Temple Pond Loop and Quarry Trail.

It was decided by a vote of the attendees to go with a 14' wide structure with 48-54" high rub rails and bottom curb rails. An open bottom culvert, bridged by a steel structure over the top of the culvert will be used to span the water courses. The new structures will go in the existing locations except for the Temple Pond site which will be moved about 80' laterally from the existing site to give a better site line on the trail and to shorten the span of the new structure.

Second topic was the presentation from Mu-Ning Wang in regards to a web site for Lord Hill Park. The web site might be used for listing event schedules as well as for communication of closed areas of the park and "trees down" reports to the ranger staff. When in place this web site has the likelihood of making communication between all much easier.

Reports were given by all groups and individuals present who ran projects or worked within the park in calendar year 2010. Reporting were Joan Deutch, Rich Guthrie, Ralph Cutter, Forrest Clark and Don Heirman. Much work had been completed and a round of applause was given for the much appreciated work. Forrest Clark announced that 276,600 pounds of rock had been moved into the park and placed at several different work sites in the last 3 months of 2011. Much of it with either wheel barrows or horses with panniers. Thanks to the Back Country Horsemen. The muddy trails are being drained and dried up. Many of the worst muddy trails within the park are now dry and usable again due to the placement of this material being used.

Appendix F. LHRP Meeting Minutes Organized by Trail Management Unit

All LHRP meeting agenda and minutes (3 times[46] throughout 2010 to 2011, see appendix E for detail) have been transferred into tabular records and arranged by trails in LHRP. This table provides a start-up point to structure textual records into one single file with same arrangements. In addition, trail incident reports were grouped by task categories so it is easy to process and transfer to responsible personnel. Based on this arrangement, all content can be connected and stored into GIS.

Table F-1. Reorganized meeting minutes and agenda content into tabular format listed by trails.

Incident ID	Content	Date	Trail	Category
01	Bridge Replacement	2010/1/16	Temple Pond Loop	Planning
02	Bridge needs to be taken out and a culvert put in there.	2010/1/16	Temple Pond Loop	Discussion
03	Bridge had been hit by windfall trees 3 times and had been broken for some time now	2010/1/16	Temple Pond Loop	Status Report
04	Retaining Wall	2010/1/16	Temple Pond Loop	Planning
05	Fix it, but how?	2010/1/16	Temple Pond Loop	Discussion
06	1. Finish grading hillside hiker connection; 2. Two water crossings; 3. Assess winter condition: remove or enhance the trail	2010/1/16	Devils Butte Loop	Planning
07	Finish or not the last upper East section of the new trail?	2010/1/16	Devils Butte Loop	Discussion
08	Brushing and tread maintenance	2010/1/16	ALL	Planning
09	Re-grade trail surface	2010/1/16	River Trail	Planning
10	Use equipment on it to restore, much and rebuild it or use man power on it?	2010/1/16	River Trail	Discussion
11	Determine abandonment or reroute of trail	2010/1/16	River Trail Cut-off	Planning
12	Abandon or use power equipment to fix it	2010/1/16	River Trail Cut-off	Discussion
13	Entrance Bridges - Assess condition and determine future repair	2010/1/16	Board Walks	Planning
14	Leave them in, but not allow horses	2010/1/16	Board Walks	Discussion

[46] There were four stakeholder meetings (2010/1/16; 2010/02/06; 2011/02/06; and 2011/02/27) during 2010 to 2011. However, not each meeting has the agenda and meeting minutes (there was no meeting minutes for 2010/02/06; there was no meeting agenda and minute for 2011/02/27). The information sharing mechanism was poor, there was no interface to share or reuse this information. Besides that, this meeting has no official arrangement; it has been terminated at the end of 2011 because the manager has been changed. Last, there is no specific arrangement about who the facilitator, note takers, and other roles are.

	to use them.			
15	Repair water damage, drainage and brush trimming	2010/1/16	Beaver Lake Trail	Planning
16	Needs maybe 4" gravel or possibly 2" gravel topped with 5/8" minus with rock	2010/1/16	Beaver Lake Trail	Discussion
17	New trail - grade runs 3/4 of a mile from Cutter's Road to Main Trail	2010/1/16	Rail Road Grade Trail	Planning
18	New trail - Locate and flag connector trail from River Trail to the Quarry Trial	2010/1/16	Connector Trail	Planning
19	New trail - New bridge to cross culvert pond outflow to finish trail connection	2010/1/16	LH 2	Planning
20	Channel all horses through the new horse entrance	2010/1/16	Board Walks	Discussion
21	Check the possible treatments, plan to work on that by 2010/04/20	2010/2/6	Temple Pond Loop	Park Decision
22	Stream Crossing and Upper East Loop	2010/2/6	Devils Butte Loop	Planning
23	Use volunteer work parties to finish this by 05/15 for 2 stream crossing and upper east loop	2010/2/6	Devils Butte Loop	Work Party
24	Trail damage occurs. Nov.1-April 30 with high amount of rain.	2010/2/6	ALL	Status Report
25	It was asked if the softer trails should be closed to certain users during that time period. No decision has made.	2010/2/6	ALL	Discussion
26	All trails needs be marked better: No Horse, Hiker Only, Horse/Hiker, or Hiker/Biker.	2010/2/6	ALL	Discussion
27	Accessing issue to Todd's Property	2010/2/6	ALL	Status Report
28	276,000 pounds of rocks has been removed in the last 3 month of 2010	2010/2/6	ALL	Work Party
29	Is a culvert better? No firm decision was made, but a discussion took place regarding the replacement	2010/2/6	Temple Pond Loop	Discussion
30	Sweep the loop by March 13th	2010/2/6	Temple Pond Loop	Discussion
31	2nd priority - Use work parties to finish this by volunteer groups by 05/15 for 2 stream crossing + upper east loop	2010/2/6	Devils Butte Loop	Discussion
32	muck-out, drainage and slope redo	2010/2/6	River Trail	Planning
33	Plan to coordinate with WTA for further work (await)	2010/2/6	River Trail	Park Decision

34	Needed to be looked at to determine if repairs are needed to them or if they should be tore out or closed	2010/2/6	Board Walks	Discussion
35	Beaver Pond Loop needs a small bridge or culvert for water-crossing	2010/2/6	Beaver Lake Trail	Planning
36	Worked on the culvert for Beaver Pond Loop by 05/01	2010/2/6	Beaver Lake Trail	Park Decision
37	North portion is muddle and block the trail accessing, needs to be maintaining	2010/2/6	Pipeline Trail	Planning
38	Fencing for the beaver pond	2010/2/6	Pipeline Trail	Discussion
39	Start-up the trail building (2 year run for completion, 2011)	2010/2/6	Rail Road Grade Trail	Planning
40	Volunteer Group's 3rd priority to work -Work with several people for this trail layout, basically for multiple uses	2010/2/6	Rail Road Grade Trail	Discussion
41	4th priority	2010/2/6	Rail Road Grade Trail	Park Decision
42	Start-up the trail building (2-3 year run for completion, 2012)	2010/2/6	Connector Trail	Planning
43	Volunteer Group's 4th priority to work	2010/2/6	Connector Trail	Discussion
44	3rd Priority -Wait in the future	2010/2/6	Connector Trail	Park Decision
45	Fire! There was concern about the safety of the trees and hillside uphill from the area the kids have been using for their party area	2010/2/6	LH 2	Status Report
46	Work with Water Crossing Bridge and Hire the engineer to make a consolidate plan	2011/2/12	Temple Pond Loop	Park Action
47	In 2010, remove stumps in the middle of the trail and topping the trail with crushed rock in areas where it is needed due to mud issue	2011/2/12	Temple Pond Loop	Work Party
48	Work with high school students (Friends of Lord Hill) on 04/23	2011/2/12	Temple Pond Loop	Work Party
49	Work with Back Country Horsemen for Gravel Haul on 05/21	2011/2/12	Temple Pond Loop	Work Party
50	In 2010, 2 culverts has been implanted	2011/2/12	Devils Butte Loop	Work Party
51	Implanted 2 access control gates in 2010	2011/2/12	Beaver Lake Trail	Work Party
52	Work with Water Crossing Bridge and Hire the engineer to make a consolidate plan	2011/2/12	Pipeline Trail	Park Action

53	In 2010, 4 turnpikes, 2 water bars, and 2 drain dips installed there	2011/2/12	Pipeline Cut-Off	Work Party
54	Work with Water Crossing Bridge and Hire the engineer to make a consolidate plan	2011/2/12	Quarry Trail	Park Action

Appendix G. Interface Heuristic Evaluation of the Website: Full Version Result

This appendix includes results of website interface evaluation (heuristic evaluation) that used evaluation criteria and scoring thresholds developed from Appendix A. As mentioned in Appendix A, this evaluation includes eight criteria and their associated measurements. The interface usability of *ParkScan*, EDDMapS, and *What's Invasive* websites were assessed. In this evaluation, I spent 30 minutes for a website as a first time user who wants to report observations. The scores and textual judgments are provided so that more detail information can be adjusted. Summary results have been listed in table 5-2 of the manuscript (pp.49)

Table G-1. Detailed comparison results

ParkScan	EDDMapS	What's Invasive
C1. Map Proportion		
5, 5 10/10	5, 3 8/10	5, 5 10/10
1.1 Clear legend & reasonable theme maps		
There are no different classes or meanings except the mark of locations (one class)	There are no different classes or meanings except the mark of locations or appearance of species distribution	Using different color of symbol to represent the different species distributions
1.2 Explanation of map use		
Each park (points) has two functions for click, easy to use.	The website includes basic directions about how to start	The website provides summarized records of maps
C2. Map proportion, accessibility, and connection to website content		
4.5, 5, 5 14.5/15	4.5, 3, 3 10.5/15	4, 1, 1 6/15
2.1 Map proportion		
> 40% of contents are tight with for any specific park. Also, when a webpage has map, it occupies around 35-50% of webpage	Around 30-40% contents contain maps, mostly maps is using for search. Around 25-50% map was incorporated in the webpage	Maps only occupies 1/7 (15%) of the website and most webpages are not having maps except its own page with >50% map in that webpage
2.2 Map Functionality		
Serves 4 functions in the same map (location, information, reporting, and search reports)	Having two separate maps but each one search 1 function only. (link to species or points of reports)	Only show the status of species based on select park and no other function
2.3 Connections between maps and website		
Each park location has a link with the content, all contents and maps are well-connected	Some records are not connect to the Google Map but county map is connected	The map system is powered by EDDMapS but create disconnected with website content
C3. Query capacity: diverse commands and speed of searching		
5, 5, 3 13/15	5, 4, 1 10/15	3, 3, 5 11/15

3.1 Theme/Location Search		
Search functions for 1) keyword (theme) and 2) park (location). Different page of search but within same level	Search functions for 1) habitats (theme) and 2) state/county (location). Different page of search but within same level.	Only location search (parks). Map of all species or content will be shown in the second level of search
3.2 Number of clicks to search results		
Either through key word or park search, results will be shown <2 clicks	Both theme and location search takes > 4 clicks to retrieve reports (back and forth map will be seen during the search)	No connection between map and content. It will need to research from other webpage. > 3 clicks to receive results
3.3 Proportion between Data Inputs and Possible Queries		
Use Park to Generate/Summarize Reports. Inputs: 6 fields.	Use Species to Generate/Summarize Reports. Two different inputs: 5~30 fields.	Use Park/County to Generate/Summarize Reports. Inputs: 3 fields.
C4. Existing and extension capacity		
5, 5 10/10	3, 5 8/10	3, 5 8/10
4.1 Existing limitation due to the map system architecture		
Since this website only have simple purpose, almost all of the purposes can be served from existing map system. Partially customized Google map can provide flexible extension	Current maps can only showed distribution and points of reports, more functions are needed but flash map may have limitation to modify	Current maps can only showed records/species on the map, most functions are moved to EDDMapS. Maintenance is low but have limited extension
4.2 Static/Interactive Maps		
Interactive Map	Interactive Map	Interactive Map
C5. Data distribution capacity		
1, 1 2/10	5, 5 10/10	1, 1 2/10
5.1 Downloadable Content		
Whole results are displayed only.	All raw information can be downloaded.	Whole results are displayed only
5.2 Information distribution (to other website)		
Maps or results is not transferrable	The Google map can be used in other website (but data is incomplete)	Maps or results is not transferrable
C6. Navigation Designs		
5, 5 10/10	3, 3 6/10	3, 3 8/10
6.1 Clear Navigation		
Click the park and reports with clear selections of its structured form	Having many ways to reports (data entry, mobile applications) with different forms, may create confusions	Using mobile application to report, provide a short list (narrowed by park) of reporting, easy to report
6.2 Easy to use		
Provide easy directions for	Without training, it may hard to	Without training, it may hard

user to report	fill half of critical information from the data entry form	to distinguish the species and estimate area of infestation
C.7 Tutorial Guide for First-Time User		
4.5, 3 7.5/10	4, 5 9/10	3, 3 6/10
7.1 User instructions		
Even without detail instruction, this website's design have a clear and easy for user to click and report	This website provide a detail information of reporting and some other webpages of mobile applications but not too much with searching	This website have vague interfaces, even though training has been provided, trail-and-error is needed
7.2 Channel of educations		
Having textual information to describe how to report step-by-step	Having detail training materials (video, slides, handbook, etc.) to help reporters to start	Having slides and some snapshots to teach first-time user to report, not much with website using
C8. Q&A and trouble shooting		
4, 3 7/10	5, 4 9/10	5, 5 10/10
8.1 Q & A Sections		
There is FAQ section for more website content, few to cover	Detail information are organized in the about section with both technical or conceptual issues	A help (Q&A) section is included and covered with technical and conceptual issues
8.2 Channel of trouble shooting		
Having email and "Contact us" option from the website	Have email and responsible contact in different issues	Have both email and contact form for trouble shooting

Appendix H. Mobile application interface's usability comparison results

This appendix compares the results of mobile application interface usability. Two mobile applications, PNEDN and PlantTracker, were evaluated by 14 participants with Appendix D's questionnaire (10 questions). The following table includes counts of each selection (#) and percentage of each selection (counts divide by total counts). After the questionnaire, if the participant provides further comments, it will be listed with associated questions. A summary of the result was listed in the table 5-3 of the manuscript (pp. 52).

The user management includes login system (Q1) and reward design (Q7). Over half of the (57.1%) participants were satisfied with the design in PNEDN and think login page is required. Having a better user control setting can let users view or edit their records. In addition to that, some data users can also receive credible information since each reporter needs to register. Another third of the participants (29%) prefer no login arrangement. As to the user rewards, 78% of participants felt satisfied when seeing their reports were used and recorded.

As to the report navigation, over 70% participants (71.5%) suggested to incorporate more information so any citizen user can report the invasive species precisely since current mobile applications are not as good as it should be. 42.9% of all participants suggest to add species information, and 28.6% of all participants suggest to add location information for user to use. As to further information, many items are suggested to be incorporated; the two most important items are

1. Photos of growing land cover (e.g., Grassland, Forests, Wetland) (26%); and
2. Immediate surroundings such as, bodies of water (24%).

Compared with two mobile applications (*PNEDN* and *PlantTracker*), most participants (86%) preferred having map services on the mobile application. For the usage, over half of participants (57.1%) thought the map should be arranged by species. To improve the capacity of map usage, using theme maps can enhance the usability of maps. Lastly, the map should either zoom in/out based on full extent of current query content (35.7%) or the exact location of reports (35.7%).

Table H-1. Summary Result of Usability Questionnaire with Additional Comments from Participants

	#	%
User Management		
Q1 Login System		
PNEDN Design: Both Login & Trial/Demo/Guest	8	57.1%
PlantTracker: No Login	4	28.6%
Key user groups will have different features after login	2	14.3%
Further Comments: ● For the multi-feature designs, it may take many works if the verification is needed to be made by Data Managers. ● Require login with option to save user/password as default for next entry. ● "I like the idea that Key User Groups could have different features they are permitted to access within the app". *Noise* could be limited and minimized by allowing everyday concerned people to make a preliminary report of an invasive plant/species in a given area, which could later be verified by someone who is registered or designated to make a final report which would then be added/recorded to a map. ● Like the login to keep tracking with the reporting content and keep accountability of reports		
Q7 Reporters' Rewards		
See reports has been updated to the results	11	78.6%
Top 10 Reporters will be shown to the website	3	21.4%
Further Comments: ● Do not think the second option is pretty fun, it will be too demanding for the reporters. ● Volunteer design is important, but the education game for Plant ID is also the other one to think about		
Report Navigation		
Q2 Species Selection		
Current EDDMapS is enough	0	0.0%
Current *PlantTracker* is enough	4	28.6%
Extra species information is needed	6	42.9%
Extra location information is needed	4	28.6%
Further Comments: ● Plant Tracker approach is good, i.e. name + photo for quick ID and then Info for more detailed. ● Even though segregation by boundary may be clear, it may still lead the wrong information or did not show right information to the potential invasive plants. ● With overlap the land manager boundary, it is important for reporter to know.		
Q3 What Extra Species Information *(click all that applies, only 11 participants answered)*		
Photos of growing land cover (e.g., Grassland, Forests, Wetland)	10	26.3%
Immediate surroundings such as, bodies of water	9	23.7%
Non-invasive species that grew next to this species	6	15.8%

Approximate growth since latest reporting	5	13.2%
Location based on major pathways	5	13.2%
Current invasive plant stage i.e. is it seeding?	3	7.9%
Further comments: ● Not sure what the main pathway actually means.		
Q4 Reporting Measurements		
1 cubic = xx pizza boxes (Real-life Unit)	6	42.9%
Acre/Sq. Feet (Regular Unit)	8	57.1%
Further comments: ● The Plant Tracker estimate choices are good but should also allow actual unit entry too. ● That is how we teach our volunteer to know Acre/Sq Ft		
Map Services		
Q5 Reports Representation		
PNEDN: Search/Display by Species List with # of reporting	12	85.7%
PlantTracker: No MAP on mobile application	2	14.3%
Further Comments: ● As the manager, I do not have problem see reports on the website, but the crew in the field would need that ● PNEDN is 'missing' the website map where you could verify your reports, see what others are reporting, etc. similar to what PlantTracker has it already on their website. ● Most of our reports were based on trails, how can we get points to trials?		
Q6 Customized Zoom In/Out of Maps		
Show anything from your current location	5	35.7%
Show some specific area by legal boundaries	3	21.4%
Zoom In to the biggest extent of Query Content	5	35.7%
No answer	1	7.1%
Q8 Theme Maps (Color-coded) with content		
Yes, show different contents	12	85.7%
No, current map is good	2	14.3%
Further Comments: ● Adding a color scheme would be useful in distinguishing the types of plants. I think having an option to sign in and be able to report different items or access to different tools would encourage users to provide more input. ● I believe displaying the different types of species by color is a great addition in helping reporting in various locations. If a map displaying the progress could be displayed, I believe it would assist and encourage users like myself in reporting. ● I also think that your idea for color coating the map is brilliant. It would be valuable to color coded, or use different shading to show the growth, or alternately the recession, of species since the last reporting in conjunction with the dates of both reporting. It would give a better idea of high risk areas in comparison to species that are moving in more slowly.		
Q9 Map Locations and Usage		
Accompany with species list	8	57.1%

Accompany with management purposes	2	14.3%
Beginning, showed the area of infestation (by category)	4	28.6%
Further Comments: ● Like both two and three. Think it would be really interesting to see group's efforts as well.		
Roles of Invasive Species Reporting		
Q10 Your relationship with Invasive Species Reporting		
A staff/manager in Environmental NGOs	1	7.1%
A staff/land manager in governmental agencies	1	7.1%
A data manager/IT person in governmental agencies	1	7.1%
Researchers/ Education Institute	3	21.4%
A volunteer coordinator in Environmental NGOs	1	7.1%
A volunteer that works in environmental related jobs	1	7.1%
A volunteer that works in different industry	2	14.3%
A park/trail user would like to contribute something to our earth	4	28.6%

Appendix I. Volunteer Reporting System Development Checklist

Having a handy workflow as a guideline to assess, design, and develop a stakeholder reporting system in the government helps managers to integrate their volunteer-based program and management activities. This checklist uses the VGI-RAF (see detail in table 4-1) as the foundation to incorporate all elements (e.g., *management units*, structured inputs, communication and decision-making process, database, and existing system architecture) of stakeholder reporting system development.

Original VGI-RAF includes eight-aspects but in practical purposes the *Chosen Participants* and *Rules and Norms of Participation* aspects should be combined to *characterize participation mechanisms* designed by governments. First, this checklist lists all aspects. In each aspect, it includes several items to check or decision should be made. Based on the detail description in Chapter 7.2 of the manuscript (pp.70-72), this checklist (Table I-1) provides major items for planner/managers to check when initiating a stakeholder-reporting system on their own. For example, in the *Power and Control* aspect, managers need to choose suitable scale and design institutional arrangement for participation to take place.

Table I-1. An empirical checklist to construct a volunteer reporting system for your organizations/agencies

- *Power and Control* Aspect
  - ✓ Choose right scale (e.g., a single case scale (LHRP), a jurisdictional scale (Weed Watcher and Forest Watch programs), and a nationwide scale (EDDMapS))
  - ✓ Design institutional arrangement (informal/formal) for participation
- *Subject Domain* Aspect
  - ✓ Have clear management focus <u>*to define management unit*</u>
  - ✓ List all potential information needs <u>*to structure the reporting content*</u>
  - ✓ Clarify government expectation <u>*to decide degree of participation*</u>
- *Chosen Participants* and *Rules of Participation* Aspect
  - ✓ Evaluate the chosen scale effectiveness (decide if modification is needed)
  - ✓ Match government expectation with rules of participation
  - ✓ Posit existing stakeholder with three major roles (reporters, data users, and decision maker)
- *Stakeholders' Expectation* Aspect
  - ✓ Match stakeholder expectation with rules of participation <u>*to create the delegation*</u>

and collaboration patterns among all stakeholders (include government agencies)

- ◆ Building substantial partnerships through official agreement, sharing information, or sharing technology.
- ◆ Provide multiple ways (degrees) of participation from reporting to partial management actions.
- ◆ Review reporting content to make sure proper loading of generating each report.

- *Stakeholders' Knowledge* Aspect
  - ✓ Provide enough learning materials and training workshops *to bridge the gap between information needs and stakeholders' knowledge*
  - ✓ Create easy-to-report interface *to shorten the knowledge gap*
  - ✓ Apply usability assessment result to modify the interfaces or reporting content periodically

- *Communication Channel* Aspect
  - ✓ Estimate time and cost of implementing this reporting system in current decision-making process, and find the most efficient or effectiveness ways to use it.
  - ✓ Revisit the structured content and management unit to make sure reporters can easily use it.
  - ✓ Review the connection between database schema, query ability, and government expectation

- *PGIS Information Aid* Aspect
  - ✓ Define available capacity of building a public access map interface and providing the newest updates for general public
  - ✓ Choose minimize cost to connect existing GIS system with this reporting system (e.g., using a separated web-based database system to collect reports)
  - ✓ Estimate how many results can use map service to display and share with various stakeholders from general public, environmental NGOs, and other land managers.